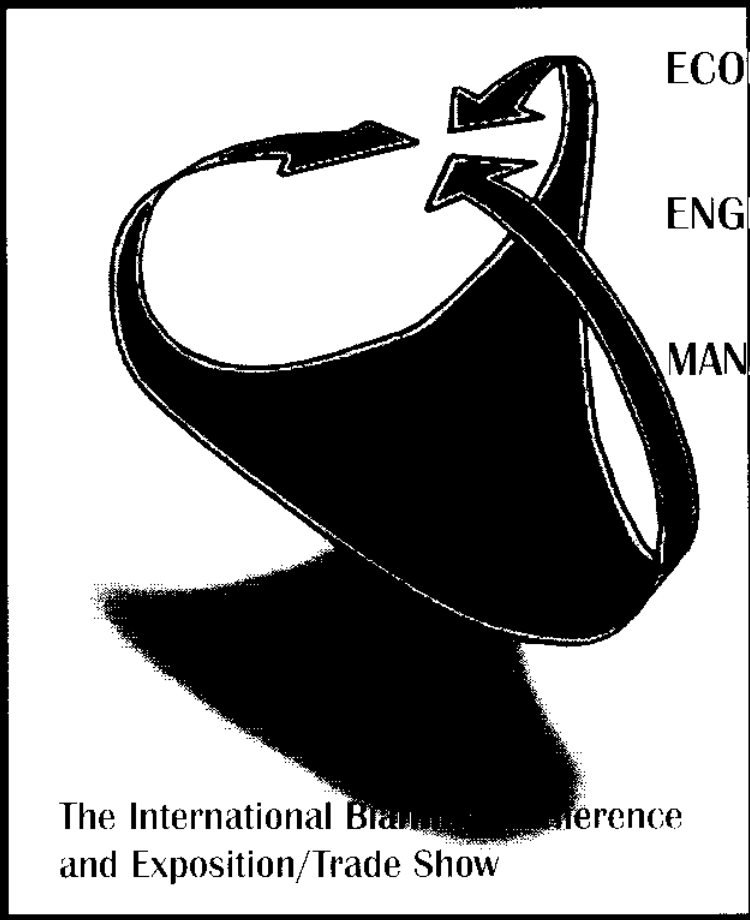
PROCEEDINGS

The Second International Conference on

Recirculating Aquaculture



ECONOMICS

ENGINEERING

MANAGEMENT

The International Bla[illegible]ference
and Exposition/Trade Show

July 16-19, 1998

Acknowledgments

Leadership for this conference was provided by **Dr. George S. Libey**, Associate Professor, Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University.

The planning committee would like to thank the authors for their diligence in submitting their papers early enough so that these proceedings could be distributed at the conference. Speakers were selected based on their experience and practical knowledge in commercial-scale recirculating aquaculture.

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Finally, the Planning Committee expresses their thanks for the firms that provided financial support of the program and those that participated in the trade show. Without their participation, this program would not have been possible.

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Proceedings of The Second International Conference on Recirculating Aquaculture

Hosted by Virginia Polytechnic Institute and State University
Roanoke, Virginia
July 16 - 19, 1998

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Designed by Christopher G. Libey

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Biosecurity: Principles and Practices in the Commercial Poultry Industry

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Preface: Conceptually, the rearing of poultry and fish in a commercial setting have much in common. Both involve the concentration and maintenance of large numbers of animals in a confined space. In fact, the only major difference between the two seems to be the medium of gaseous exchange. Therefore, it is natural to conclude that the principles of biosecurity which have application in the poultry industry may be of value in aquaculture. The purpose of this presentation is to familiarize aquaculturists with these basic principles and demonstrate their practice using poultry as a model. The material contained in this manuscript has been used to educate poultry producers. Thus, a knowledge of aquacultural management and medicine will be required to accurately extrapolate this information.

What is Biosecurity? Simply stated, biosecurity is the means by which you keep infectious disease off your farm or, in the event that you have a disease problem, how you can keep it from spreading to your neighbors!

How Do Diseases Transmit? Disease transmission occurs when infectious material travels from sick or recovered birds to susceptible ones. How this material gets from one place to another is a function of the disease agent itself. Some infectious agents can be passed from infected breeding stock through eggs. Some can be carried by the wind on loose feathers and in dust. Some are transmitted through contaminated water supplies. Most are transmitted by fecal material carried on everything from equipment to shoes and hands. Sometimes vermin like rodents, wild birds, skunks, raccoons, and even cats, and dogs can carry the infectious agents and never show any signs of sickness. Without question, the #1 way in which disease moves from farm to farm is people!

Biosecurity Self-Assessment: The following list may be helpful as you assess the level of biosecurity on your poultry farm. It is suggested that you walk around the premises and do a thorough inspection, responding to the statements as you go. If a statement doesn't

apply to your type of operation don't answer it. Otherwise do the best you can. Most importantly, don't fudge your answers…its your farm and your livelihood! In some cases there may be nothing you can do about your situation. But in other cases, if there's room for improvement, at least you'll know what needs to be done.

Principle # 1: <u>ISOLATION</u> helps you maintain a safe distance between your birds and potential disease threats.

Location

- The next poultry farm is a mile or more away as the crow flies. True False
- The processing plant is a mile or more away as the crow flies. True False
- The main route by which trucks travel to the processing plant is a mile or more away as the crow flies. True False
- My farm is more than a mile from a standing body of water (pond, lake) as the crow flies. True False
- The nearest rendering facility is a mile or more away as the crow flies. True False
- My farm is located outside Rockingham County. True False

Traffic On and Off the Farm

- I do not take farm vehicles off the farm. True False
- I do not lend or borrow equipment from other poultry operations. True False
- I have a gate that restricts vehicle access to the poultry houses. True False
- My poultry houses are surrounded by a fence. True False
- All visitors to the farm must sign a log book. True False
- I permit no visitors on the premises except authorized personnel that is, people who need to be there. True False
- I check vehicles coming onto the farm to see if they are clean. True False
- I ask vehicle operators if they have disinfected their tires prior to coming on the farm. True False
- I ask visitors where they have been prior to coming on the farm. True False
- My poultry houses are locked to discourage unauthorized entry. True False
- I have erected signs indicating that access is restricted. True False
- No one except myself, my employees, service personnel, and veterinarians are permitted in my poultry houses prior to load-out. True False
- Load-out crews are not permitted to go anywhere else on the farm except for house they are assigned to work in. True False
- I never visit other poultry farms. True False
- I never visit the live-side of the processing plant. True False
- Feed truck drivers are not permitted to enter poultry houses. True False
- I have a box for feed tickets on the feed bin so that the driver doesn't have to enter the house. True False
- Fuel truck drivers are not permitted to enter the poultry houses. True False

- I only have one age of birds on the farm during a given production cycle. True False
- When there are multiple ages of birds on the farm, the order of care is youngest to oldest or I have different employees caring for different ages. True False

Pest Management

- I have a rodent control plan. True False
- I regularly check bait boxes and traps to be sure that the bait is fresh and to remove dead rodents. True False
- I regularly check for rodent activity e.g., active holes near the foundations, chewed curtains and insulation, rodent droppings on sills and in ante-rooms. True False
- I do not let trash and junk pile up in my ante-room. True False
- I keep grass and weeds trimmed around the house. True False
- I have no debris, hay bales, or brush piles located within 100 feet of the poultry houses. True False
- I clean up outside feed spills promptly i.e., under the boot. True False
- I remove dead birds promptly and place them in vermin proof containers prior to disposal. True False
- I regularly check and repair the screening in the eaves of my poultry houses to prevent wild bird access. True False
- I regularly check and repair wire screening on the sides of the
- house to prevent wild bird access. True False
- I do not permit the feeding of wild birds on my farm. True False
- I do not leave the gable doors open after the house has been cleaned and disinfected. True False
- I have concrete pads at every entrance to the house. True False
- I regularly spray for insects using an approved insecticide. True False

Other Livestock and Animals

- I do not permit other livestock within 100 ft of my poultry houses. True False
- Livestock are not permitted to congregate near the well head. True False
- Dogs and cats are not permitted in the poultry houses. True False
- I do not own any other birds as pets. True False
- I do not own any other poultry, game birds, or waterfowl. True False

Principle # 2: Good <u>HYGIENE</u> prevents dissemination of infectious agent by reducing their numbers or eliminating them from the environment.

House Cleaning and Disinfection

- I've recently done a total cleanout of my facility. True False
- Litter that is removed from my houses is stored in a covered shed. True False
- I do not store used litter in uncovered piles. True False
- I compost litter in an approved, properly managed composting facility. True False
- Litter is not spread on fields adjacent to my poultry houses or those of my neighbors. True False
- I do not store used litter near clean litter. True False
- When removing litter from my houses I make sure that spills in roadways and entrances to the house are cleaned up. True False
- All equipment used during litter removal is properly cleaned and disinfected after use. True False
- After litter removal the house is thoroughly swept from top to bottom. True False
- All rafters, sills, lighting fixtures, fan blades, motors, louvers, heaters, brooders etc. are blown off or wiped clean. True False
- The entire facility, including curtains (inside and out), ante-rooms, and equipment is washed from top to bottom with a detergent spray. True False
- The entire facility is disinfected using an approved product at the concentration recommended by the manufacturer. True False
- A high pressure sprayer (200 psi) is used for washing and disinfection. True False
- All feed pans, feed lines, and hoppers are emptied prior to cleaning. True False
- All feed pans, cones, hoppers, and waterers are scraped, scrubbed, washed, and disinfected. True False
- The feed bin, boot, and auger are regularly cleaned and disinfected. True False
- I clean, descale, and sanitize water lines between flocks. True False
- Loose feathers and debris are cleaned up outside the house. True False
- I allow at least 2 weeks for the facility to dry out and remain open. True False
- I rebed using clean, dry, litter, which is free of any moldy smell. True False
- I do not use hardwood shavings or shavings containing pine bark. True False
- I use an approved insecticide on top of new litter if insects are a problem. True False
- I clean and disinfect removable equipment like feed trays and jug waters just prior to setting the house up for new birds. True False

Personal Hygiene and Apparel

- I regularly clean vehicles that leave the farm and disinfect the cabs and beds. True False
- I shower before going out to work in the poultry houses. True False
- I do not wear street clothes or shoes in the poultry houses. True False
- I have a separate cap and pair of coveralls for each house and / or each brooder and finisher unit. True False

- I regularly launder my caps and coveralls, especially between flocks. True False
- I have a separate pair of boots for each house and / or brooder and finisher unit. True False
- I clean and disinfect my boots before and after use. True False
- I clean and disinfect my hands between units. True False
- I have disinfectant dip pans at every poultry house entrance. True False
- I change the disinfectant in the pans every 2-3 days. True False
- All visitors who wish to enter my poultry houses must wear
- clean, sanitized caps, coveralls, gloves, and boots. True False
- All soiled, disposable, apparel is disposed of on the farm when visitors leave. True False

Principle # 3: <u>FLOCK HEALTH CARE AND MONITORING</u> are essential for early detection and prevention of disease

- I immediately call my service person when birds appear to be sick. True False
- Sick or dead birds are regularly examined (posted) to determine if infectiousagents may be responsible for the problem. True False
- Birds are routinely bled to determine if any infectious agents may be present on the farm. True False
- Birds are are only vaccinated for agents known to have caused problems on the farm in the past. True False
- When using vaccines, I always follow the manufacturers instructions. True False
- I only use antibiotics when birds are sick. True False
- I always administer antibiotics according to the dosage listed on the label or according to the instructions of a veterinarian. True False
- I always use antibiotics for the full treatment period prescribed on the label or by a veterinarian. True False
- I never use expired vaccines or antibiotics. True False
- I try to stay informed with regard to disease problems that may be going on around me. True False
- I have taken the time to learn more about the types of diseases that affect poultry. True False

Principle # 4: <u>GOOD MANAGEMENT PRACTICES</u> make for a healthy environment

- I follow the temperature guidelines prescribed by the company. True False
- If the birds look chilled, I supply more heat without compromising air quality. True False
- I ventilate according to company recommendations. True False
- I consider the air in my houses to be suitable for human consumption (long term). True False

- I routinely remove caked litter or till according to company recommendations. True False
- I top dress with dry, composted, mold free litter or fresh, clean litter. True False
- I clean and disinfect waterers several times a week. True False
- I use a chlorinator or some other means to reduce bacterial contamination in my water. True False
- I raise feeders and waterers at the appropriate time to reduce wastage and litter contamination. True False

How Biosecure Is My Farm? To obtain a rough assessment of the level of biosecurity on your farm, count the number of "Trues" and "False" that you circled. Divide the number of "Trues" by the total number of "Trues and False" and multiply this answer by 100. Your final answer will be a percent. The closer it is to 100% the better your biosecurity and the lower your risk of disease. If you are close to 100% it doesn't mean you won't have a disease problem, but it does mean you are doing just about everything you can do to prevent a disease outbreak on your farm.

Endnote: A similar type of biosecurity self-assessment may be generated for aquacultural operations. Use this questionnaire as a template. Consider how each principle is addressed by the question; then substitute the various conditions and variables that would make it relevant to aquaculture.

For Additional Information on Biosecurity, see the Poultry Resource Homepage: http://www.apsc.vt.edu/Faculty/Clauer/clauer.html or obtain a copy of *Biosecurity in the Poultry Industry*, American Association of Avian Pathologists, New Bolton Center, 382 W. Street Road, Kennett Square, PA 19348, Tel: 610-444-4282, Fax: 610-444-5387, Email: aaap@vet.upenn.edu.

Common Chemicals for Cleaning and Disinfecting Aquaculture Facilities

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One of the most important biosecurity components of a recirculating aquaculture facility is the establishment of a comprehensive cleaning and sanitizing program. Before pathogenic and undesirable microorganisms in a facility and production system can be eliminated through the application of sanitizing compounds, a thorough cleaning program must first be applied. An effective cleaning program will remove various types of soils that will both: (1) reduce the number of pathogens prior to the sanitation procedure; and (2) provide an opportunity for the sanitizing application to physically contact the pathogens.

Selection of the optimum cleaning and sanitizing program for a recirculating aquaculture system and facility is complex and difficult for many reasons:

1. There are many chemical compounds and physical treatments that are available thereby making selection somewhat complicated.
2. There are no information sources able to provide performance data on the various cleaning and sanitizing compounds currently available. Recirculating aquaculture is a rather new science and biosecurity is a developing technology for this industry.
3. There is no single identified microorganism or virus that can be used as an indicator of cleaning and sanitizing effectiveness. Consequently, the establishment of realistic cleaning and sanitizing schedules combined with a quality control program is difficult, if not impossible, to establish with any degree of certainty.
4. Some of the equipment in a recirculating aquaculture facility is not easily cleaned and sanitized. Unless all equipment can be cleaned and sanitized, the effectiveness of an integrated program is highly questionable and may be ineffective. For example, a rotating biological contactor (RBC) is virtually impossible to clean and sanitize while pumps and pipes lend themselves to a CIP (clean in place) system.
5. Cleaning and sanitizing some equipment may result in the interruption of a production facility. Cleaning a biological filter can reduce the microflora on the filter, thereby severely diminishing or eliminating the filter's capability to remove toxic compounds from the growing waters. Also, cleaning and

sanitizing a filter may require redundant equipment to normalize production schedules.

6. Microorganisms are capable of forming biofilms which provide protection from cleaning and sanitizing chemicals. An effective biosecurity program will depend on the ability to remove biofilms since they may harbor undesirable microorganisms.
7. The type of materials used in the construction of a recirculating aquaculture facility may not lend itself to easy cleaning and sanitizing. Concrete provides a more difficult surface to clean and sanitize than either stainless steel or fiberglass. When designing a recirculating aquaculture facility, equipment and construction material selection should be a major biosecurity consideration.

As recirculating aquaculture becomes a more defined science and technology, advances in biosecurity will continue but in the interim, fish health will continue to be a major production issue with control being a somewhat empirical science.

Microorganisms such as bacteria, molds, and yeasts depend upon soils, feed particles, and other similar materials for their survival in aquaculture facilities. Soil particles protect microorganisms during facility cleanups by neutralizing the germicidal effects of some sanitizing agents and by preventing other sanitizing agents from penetrating to the microorganisms. Consequently, without first thoroughly cleaning tanks, fish handling equipment, floors, walls, etc. with suitable cleaning compounds, followed by flushing away, sanitizing agents alone are of little use. In fact, it has been estimated that effective cleaning is 90 per cent of an entire sanitizing program, while use of sanitizing agents is 10 per cent.

Generally, the function of cleaning compounds is to lower the surface tension of water so that soils can be lifted and flushed away. Cleaning agents are not intended to kill or inactivate microorganisms and viruses; sanitizing agents have that function. However, large numbers of microorganisms and viruses may be removed during the cleaning operation when lifted soils are properly flushed away. After cleaning the surface, sanitizing agents are used to destroy remaining organisms that are exposed as a result of cleaning.

The first requirement for an effective cleaning program is the use of <u>suitable</u> water in conjunction with the cleaning compounds. Next to the selection of a good cleaning compound, water is the most important consideration. Basically, the water should be clear, cool, noncorrosive, and most importantly, free from microorganisms. In addition, the water should be "soft." It has been found that "hard" water (water which contains minerals) may interfere with the action of some cleaning compounds, thus limiting the ability of a cleaning compound to do its job. It should be mentioned, however that some detergents contain certain components designed to counteract the effects of hard water.

Synthetic detergents are the most common cleaning compounds used today. Like soap, the primary function of a detergent in water is to make an insoluble soil water-soluble so it may be easily flushed away.

Selecting a suitable detergent to use may not be simple. To begin with, there are probably dozens of detergent manufacturers and each may have dozens of types of detergents. Moreover, each manufacturing firm has its own brand names and codes making selection even more complex. However, with a basic understanding of the various components which make up cleaning compounds, and with some feel for how cleaning compounds do the job, selecting suitable cleaning agents is not too difficult.

In order to understand the actions of detergents and other cleaning compounds, it is necessary to review the terminology usually associated with the subject.

1. Chelating Agents. Agents which prevent hardness constituents and salts of calcium and magnesium from depositing on equipment surfaces by binding such salts to their molecular structure.
2. Emulsification. The intimate mixing of two normally immiscible liquids. One of the liquids becomes disperse in the other in the form of small droplets.
3. Rinsibility. The ability of a cleaning agent to be easily removed from a surface with little or no residue.
4. Saponification. The hydrolizing of fats by alkali into water soluble components.
5. Suspension. The process by which a detergent lifts and holds soil particles in solution.
6. Water Conditioning (Softening). The process of moving or tying up minerals present in water.
7. Wetting Agent. Chemical agents with the ability to lower the surface tension of water to allow water to better penetrate soils.

A synthetic detergent is composed of a variety of chemical components, each designed to serve a specific function during cleaning. Depending upon the cleaning operation desired, detergents can be tailored to meet very specific cleaning needs. A knowledge of the types and capabilities of the various detergent components is important in understanding how cleaning compounds work.

<u>Inorganic Alkaline Detergent Compounds</u>

These detergent ingredients work primarily by dissolving food solids. They are especially good saponifying agents; however, many times they may be corrosive or irritating to the skin. For this reason, they are normally used only in heavy duty cleaning. The following are some of the more common inorganic alkaline detergents:

1. Sodium Hydroxide (caustic soda) - Caustic soda is an extremely powerful detergent with excellent saponifying capabilities; however, it is also corrosive and a skin irritant. Like other inorganic alkaline detergents, it has little effect on mineral deposits.
2. Silicates (sodium metasilicate, sodium orthosilicate, and sodium sesquisilicate) -

These are good emulsifying and saponifying agents. Like caustic soda, they have excellent capabilities for removing fats. These compounds are not as corrosive as caustic soda; however, they are skin irritants.

3. Trisodium Phosphate - Again, this detergent has excellent emulsifying and saponifying properties. It also has excellent water softening capabilities. It has no value as far as mineral deposit control.
4. Sodium Carbonate - This is one of the oldest alkaline cleaners used. The main function of this component in detergents is to serve as a buffering agent.

Inorganic and Organic Acid Detergent Components

Acid cleaners are especially valuable in removing mineral deposits formed as a result of using alkaline cleaners or other process activities. The organic acids such as citric, tartaric, sulfanic, and gluconic are also excellent water softeners, rinse easily, and are not corrosive or irritating to the skin. Inorganic acids, although excellent for controlling mineral deposits, can be extremely corrosive and irritating to the skin.

Surface Active Detergents (Wetting Agents)

The major components of these detergents serve the same function as soap; that is, emulsifying fats, oil, and greases. They are the components usually responsible for the formation of suds in detergents.

Basically, wetting agents may be divided into three major categories: cationic, anionic, or non-ionic.

1. Cationic Wetting Agents. Actually, detergents in this category are poor wetting agents, however, they do have the property of being strong bacteriocide agents. In fact, cationic wetting agents, like quaternary ammonia, are generally treated more as sanitizers than wetting agents. Chemically, these particular agents give positively charged active ions in aqueous solution.
2. Anionic Wetting Agents. These wetting agents are characterized by a negatively charged active ion when in solution. They are also the most commonly used wetting agents in detergents, since they are combative with alkaline cleaning agents and have good wetting qualities. Unlike cationic wetting agents, there are no bactericidal properties associated with them.
3. Non-Ionic Wetting Agents. Non-ionic wetting agents have no charge associated with them when in aqueous solution; consequently, they are effective under both acid and alkaline conditions. One of the major problems with non-ionic wetting agents, however, is their ability to produce large amounts of foam. Obviously, unnecessary amounts of foam may cause problems in drainage and sewage systems. A detergent does not have to foam to do a good cleaning job. One advantage of non-ionic wetting agents is that they are not affected by water hardness.

In review, wetting agents serve an important function as components in detergents. Most have strong emulsifying, dispersion, and wetting capabilities. They are non-corrosive, non-irritating, and are normally easily rinsed from equipment surfaces. Wetting agents are also responsible for suds formation produced by a detergent.

Phosphates

Phosphates such as sodium tetra-phosphate, sodium tripolyphosphate, sodium hexametaphosphate, and tetrasodium pyrophosphate, are excellent emulsifying, dispersion, suspension, and peptizing agents. In addition, they are easily rinsed away and are non-corrosive and non-irritating to the skin.

Enzymes

In some cases, detergents have enzymes as a component. These prove useful in removing protein buildups; however, because of the extended soak time for effectiveness, they are not usually practical to use in an aquaculture facility.

Components and Capabilities of Detergents

The preceding discussion addresses the basic components and capabilities of selected detergents. By using selected combinations of these components, detergents can be tailored to remove specific soils. The basic types of soils are: (1) fats, oil, and grease: (2) protein materials: (3) carbohydrate materials; and (4) mineral deposits.

1. Fats, Oils, and Grease. Obviously, one of the first requirements necessary to remove these kinds of soils is hot water. Hot water will melt or soften the fat, oil, or grease for easier removal. Coupled with this, a good detergent with saponifying and emulsifying properties should be used, usually one from the alkali group.
2. Protein Materials. Many proteins are soluble in the alkaline pH range; consequently, synthetic detergents with alkaline cleaners are useful in removing protein deposits.
3. Carbohydrate Materials. Since carbohydrate materials are readily soluble in water, nearly any of the synthetic detergents will readily remove these deposits.
4. Mineral Deposits. Mineral deposits may be a problem wherever hard water is used. Acid cleaners are usually the most effective in removing these deposits.

In addition to selecting cleaning compounds, some other basic factors affect the degree of cleaning:

1. The temperature and concentration of the detergent solution.
2. The amount of time the detergent is in contact with soils.
3. The amount of soil material to be removed.

4. The amount of agitation of detergent/soil interface.

Available Sanitizers

Before discussion of specific sanitizers and their use, the properties of an ideal sanitizer should be considered.

1. Should have good microbiological properties.
   a. Uniform, broad spectrum activity against vegetative bacteria, fungi, viruses, and molds.
   b. Produce rapid kill for inactiviation.
2. Should not be adversely affected by environmental factors.
   a. Organic matter (soil load).
   b. Detergent and soap residues.
   c. Water hardness and pH.
3. Should have good cleaning properties.
4. Must not be highly toxic or irritant to user.
5. Should be soluble in water in all proportions.
6. Should have a pleasant odor or no odor.
7. Should be stable in concentrate and use dilution.
8. Should be easy to use, readily available, and inexpensive.
9. Should be easily measured in use solution.

Now that we know the properties that an ideal sanitizer should possess, it can be stated that there is no such product on the market today. Further, there is no such thing as a "best" sanitizer. As we go from facility to facility, equipment, soil loads, cleaning procedures, and water supplies (to name a few factors) are different. This means that the sanitizer of choice will be different. Table I lists some commonly used sanitizers in the seafood industry and some characteristics of each. Table II describes the disadvantages of commonly used sanitizers.

Characteristics of Some Commonly Used Sanitizers

1. Steam. Sanitizing with steam is not a very effective way to do the job. The problem is that people mistake water vapor for steam and thus the equipment does not get the necessary contact time to do the job. Thus, it is very hard to have good control. With the soaring cost of energy, it is also an expensive procedure. Steam is not amenable to continuous sanitation of conveyors. If steam issued in a confined environment the steam flow should be maintained long enough to keep the thermometer reading above 170^{o}F for at least 15 minutes or above 200^{o}F for at least 5 minutes. When steam is used on assembled equipment, the temperature should be maintained at 200^{o}F for at least 5 minutes as checked at the outlet end of the assembled equipment.
2. Active Chlorine. Active chlorine solutions are extremely active sanitizers,

particularly as free chlorine and in slightly acid solutions. Those species are believed to act through protein denaturization and enzyme inactivation. Although effective against Gram-positive and Gram-negative bacteria, as well as some viruses and spores under certain conditions, it is quickly inactivated by organic soil and is corrosive. Active chlorine is economical to use, but is irritating. Concentrations of active chlorine can be easily measured by test kits and dispensed at a desired concentration.

3. Active Iodine. Active iodine solutions, like active chlorine solutions, can be rated as excellent all-around sanitizers. Combined with proper wetting agents to form iodophors, low staining and increased stability is imparted to the iodine. Iodophors are very stable products and therefore have a much longer shelf-life than hypochlorites. Iodophors are not as affected by organic soil as is chlorine, and they are active at a much lower concentration. They are also easily measured and dispensed, and the brown color gives visual control. Iodophors exhibit good penetration qualities, and their acid nature prevents film formation and spotting on equipment. The temperature of the use solution should not be above 120^{o}F, since free iodine will dissipate.
4. Quaternary Ammonium Compounds. The "quats" as they are commonly known, have become widely used on floors, walls, equipment, and furnishings. They are by nature wetting agents and thus have built-in detergency properties. They are good to use on porous surfaces, as they are good pentrants. Quats act against microorganisms in a different manner than chlorine and iodine compounds. They are often quite selective in the destruction of various types of organisms. They form a bacteriostat film when applied to surfaces which inhibits bacterial growth. Quat solutions are also easy to measure and they are more stable in the presence of organic matter than chlorine or iodine solutions.
5. Acid Sanitizers. The use of acid sanitizers combines the third and fourth steps of the cleaning procedure, that is, the rinse and sanitize steps. The acid neutralizes the excess alkalinity left behind by the cleaning procedure, prevents formation of alkaline deposits, and sanitizes. Acid sanitizers show good kill against both Gram-positive and Gram-negative bacteria. The mechanism of kill is believed to be caused by disruption of cell membranes. They are non-staining, odorless, stable, and easily measured in use solutions. They are limited, however, due to their effectiveness only at acid pH, and due to the generation of foam.
6. Dry Heat. Hot air ovens and chambers are not generally used because the method requires longer times and higher temperatures. When such cabinets are used, the temperature must be at least 180^{o}F for a holding period of at least 20 minutes.
7. Hot Water. An effective, non-selective sanitization method for food-contact surfaces, however, spores may remain alive even after an hour of boiling temperatures. The microbial action is thought to be the coagulation of some protein molecules in the cell. Hot water has several advantages: it is readily available, inexpensive, and nontoxic. Sanitizing can be accomplished by either pumping the water through assembled equipment or immersing equipment into the water. When pumping it through equipment, the temperature should be

maintained to at least 170°F for at least 5 minutes as checked at the outlet end of the equipment. When immersing equipment, the water should be maintained at a temperature of at least 170°F for 1-5 minutes depending on the size of the equipment.

8. Ultraviolet Radiation. Low pressure mercury vapor lamps which produce effective bactericidal action by the emission of radiation at a wave length of around 2500 A. have had limited use. Major applications has been with disinfection of air; however, installations of lamps have been reported on selected equipment and over open vats in breweries. Bacterial resistance will highly influence the lethal exposure time. Moreover, the light rays must actually strike the microorganism because the rays are absorbed by dust, thin films of grease and opaque or turbid solutions.
9. Chlorine Dioxide. Chlorine dioxide is becoming more popular as a sanitizing agent. The principal advantages of chlorine dioxide over chlorine are that it retains its antimicrobial activity in the presence of organic matter (as in slime layers) and at pH levels >7.5. In fact, high pH levels enhance the activity of chlorine dioxide. Traditionally, chlorine dioxide has been considered only for use in situations in which heavy organic loads are encountered. The presence of phenolic or nitrogenous compounds also indicate the need for this compound. Chlorine dioxide is corrosive and a skin irritant, therefore adequate control of the concentration must be exercised.
10. Phenols. Phenolic compounds have been in widespread use as a sanitizer, although their popularity has declined due to their potential toxicity and the fact they cannot be used on food contact surfaces. The antimicrobial activity of phenols is dependent on the exact formulation and concentration of the active components, temperature, pH, level of organic matter, and other factors. Higher-substituted phenolics tend to be insoluble and are frequently mixed with soaps to increase solubility. Phenolic compounds can only be used in conjunction with anionic detergents because both catanionic and nonionic surfactants destroy their sanitizing activity. This could lead to practical difficulties if phenolic disinfectants are used on surfaces where residuals from other disinfectants types are still present. Viral pathogens may be more resistant to phenols than the majority of bacteria.
11. Alcohols. Simple aliphatic alcohols are among the most widely studied disinfectant compounds. Alcohols do not appear to be affected by contaminating organic matter, but this may be because they are only effective at high concentrations. If the concentration of an alcoholic disinfectant is dropped below a certain critical level, then they rapidly become ineffective. It has long been known that the bacterial action of the aliphatic alcohols increases in the series: methyl < ethyl < propyl < butyl < amyl. Alcohols may or may not be effective against various viral agents, the effectiveness depends on the alcohol and the particular virus. Alcohols are also included in disinfectant formulations in lower concentrations to potentiate the action of other active components.
12. Aldehydes. The two principal aldehydes used as disinfectants are formaldehyde

and glutaraldehyde. The former is available as an aqueous solution of approximately 37% (w/w). However, the solution is relatively unstable and is usually supplied in a stabilized form containing 10 to 15% methyl alcohol. Formaldehyde gas, generated by heating the solid polymer paraformaldehyde, has been used to successfully disinfect surfaces contaminated with disease virus. Formaldehyde and glutaraldehyde are often considered as chemical sterilants because of their extremely broad spectrum of activity. Glutaraldehyde can achieve a rapid rate of kill against viruses as well as vegetative and spore forms of bacteria and fungi. The presence of organic matter does not appear to markedly interfere with the action of glutaraldehyde at its usual working concentration. Most glutaraldehyde-based disinfectants are used at 2% for high-level disinfection.

13. Bases. Basic compounds are not generally considered to be a disinfectant class on their own, but, rather, are included in disinfectant formulations as a means of modulating pH. In spite of this, many viruses are susceptible to high pH and many disinfectants are strongly basic in reaction. Caustic alkali solutions have also been recommended as disinfectants for particular animal viruses. One basic compound which has been tested against several viruses is sodium metasilicate.
14. Chlorhexidine and Polymeric Biguanides. Chlorhexidine is a cationic biguanide, available as dihydrochloride, diacetate, or gluconate salts. The gluconate salt is freely soluble in water and is the most commonly used in disinfectant formulations. However, contact with inorganic anions such as sulfate, phosphate, carbonate, nitrate, and chloride may result in a reduction of the disinfectant activity due to the precipitation of less soluble salts. These anions are commonly found in hard water and many biological fluids. Chlorhexidine shows a wide spectrum of activity against vegetative cells of Gram-negative and Gram-positive bacteria. It is mainly used as a topical antiseptic in either aqueous (hygienic hand wash) or alcoholic (waterless hand wash) solution because it combines a high rate of kill with persistence on the skin surface. Aqueous solutions are used for general-purpose disinfection and alcoholic solutions (60 - 90% ethanol or isopropanol) are also widely used in more critical areas. Polymeric biguanides are also available for general disinfection and are mainly used in conjunction with quaternary ammonium compounds for general disinfection.

Necessary Conditions for Sanitation

In order for sanitizers to be applied properly, it is critical that they be applied to surfaces free of visible soil. These soils include rust deposits, blood, grease, oil, protein, and mineral buildup. These soils provide areas for growth both below and within the soil, and in most cases hold food and water necessary for the bacteria's growth. Chemical sanitizers that would normally destroy the bacteria cannot adequately penetrate these soil deposits to do the job. That is why it is imperative to clean the equipment before sanitizing, or else the sanitation effort is largely a waste of time.

There are at least four physical/chemical factors affecting the use of sanitizers, including:

1. Time of Exposure. Studies have been shown that the death of a population follows a logarithmic relationship, so that if 90 per cent of a population were killed in a unit of time, the next 90 per cent of the remaining would be killed in the next unit of time, leaving only one per cent of the original number. The required time will not only depend on the preceding factors, but on microorganism populations and the populations of cells having varied susceptibility to the sanitizer due to cell age, spore formation, and other physiological factors of the microorganisms.
2. Temperature. The temperature dependency of the antimicrobial activity of a chemical agent represents a complex situation. Up to a point, the growth rate of the bacteria and the death rate due to application of the chemical will both increase with increasing temperature. However, a higher temperature also generally lowers surface tension, increases pH, decreases viscosity and effects other changes which may enhance its germicidal action. It should be noted that chlorine compounds are more corrosive at high temperatures, and iodine tends to sublime at temperatures above 120^{o}F.
3. Concentration of Sanitizer. In general, the more concentrated a sanitizer, the more rapid and certain its actions. Increases in concentration are usually related to exponential increases in effectiveness until a certain point when it accomplished less noticeable effectiveness.
4. pH. The activity of antimicrobials which occur as different species within a pH range may be profoundly influenced by relatively small changes in the pH of the medium. Quaternary compounds present a varied reaction of pH depending on the type of organism being destroyed. Chlorine and iodophors generally decrease in effectiveness with an increase in pH. These four factors must be kept in mind when applying sanitizers. If not, the sanitizer that is applied may not bring about the desired effect.

Biofilms

In their effort to maintain viability, microorganisms seek solid surfaces conditioned with nutrients for growth. When attached to a surface, microorganisms deposit, attach, and initiate growth. As they grow and multiply, the newly formed cells attach to each other as well as to the surface, forming a confluently growing colony of microorganisms. When this mass of cells becomes sufficiently large that it entraps debris, nutrients, and other microorganisms, a microbial biofilm is established.

Microbial attachment and biofilm formation may be detrimental and thus undesirable in a recirculating system. Potential problems exist, for example, in the attachment of pathogenic microorganisms to surfaces. Many investigators have studies the resistance of attached microbial pathogens to sanitizers. Microorganisms in biofilms were 150 - 3,000 times more resistant to monochloramine than were unattached cells. Biofilm resistance to sanitizers may increase with biofilm age.

In general, acidic quaterinary ammonia, chlorine dioxide, and peracetic acid were the most effective sanitizers on biofilms. Least effective were chlorine, iodophores, and neutral quaterinary ammonium compounds. When cleaning compounds prior to treatment with sanitizers were used, the bacteria in biofilms were inactivated. It has been reported that chemical cleaners were much more effective than sanitizers in eliminating specific pathogens in biofilms on stainless steel and plastic surfaces. A microbial biofilm is covered with deposited soil composed of fats, carbohydrates, proteins, and minerals. When treated with only a sanitizer, the chemical is inactivated by the deposited soil and becomes ineffective in reaching and destroying all the microorganisms. When the soil-covered biofilm is treated first with a detergent, however, the soil is solubilized and rinsed away. The sanitizer then is very effective in killing the exposed microorganisms.

TABLE I

Advantages of Commonly Used Sanitizers

Hypochlorites	Iodophors	Quats
Inexpensive	Stable Long Shelf Life	Stable Long Shelf Life
Active against all microorganisms	Active against all microorganisms except bacterial spores and bacteriophage	Active against many microorganisms, especially the thermoduric types
Unaffected by hard water salts	Unaffected by hard water salts	Form bacteriostatic film
Water treatment	Non-corrosive	Prevent and eliminate odors
Active against spores	Not irritating to skin	Not irritating to skin
Active against bacteriophage	Easily dispensed and controlled	Non-corrosive
Easily dispensed and controlled	Acid nature prevents film formation	Stable in presence of organic matter
Non film forming	Concentration easily measured by convenient field test	Easily dispensed and controlled
Concentration easily measured by convenient field test	Visual Control (color) Good penetration qualities Spot-free drying	Stable to temperature changes Good penetration qualities May be combined with nonionic wetting agents to formulate detergent sanitizers
Use Concentration		
200 ppm C1	25 ppm I	200 ppm quat

TABLE II

Disadvantages of Commonly Used Sanitizers

Hypochlorites (liquid)	Iodophors	Quats
Short shelf life	Not as effective against spores and bacteriophage as hypochlorites	Incompatibility with common detergent compounds
Odor	Expensive	Germicidal efficiency varied and selective
Precipitate in iron	Should not be used at temperatures exceeding 120EF.	Slow in destruction of coliform and Gram-negative psychrophilic bacteria (like Pseudomonas)
Adverse effect on skin	Staining of porous and some plastic surfaces	Not effective in destruction of spores and bacteriophage
Corrosiveness on some metals	Germicidal action adversely affected by highly alkaline water or carryover of highly alkaline detergent solutions	Expensive Slow to dissipate (residual problem) Objectionable film on surfaces treated Foam problem in mechanical application
Use Concentration:		
200 ppm C1	25 ppm I	200 ppm quat

Isolation and Quarantine - Practical Considerations

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Diseases can cause the economic ruin of a business using recirculating aquaculture technology. Among the many reasons this is true are: the lack of approved chemotherapeutics, the problems associated with treating the pathogen without killing the nitrifying bacteria on the biofilter, and the fact that recirculating systems often are very stressful to the fish being grown. The high density, feeding patterns, artificial feeds, and compromised water quality can lead to catastrophic losses if a disease outbreak occurs.

For a disease outbreak to occur three factors must be present:

fish - always present since these are the animals being produced
stress - can be severe at worst, chronic at best
pathogen - try to keep from introduction through quarantine and isolation

There are various methods that a pathogen can find its way into a production facility. Some of these ways include: water, air, feed, fingerlings, equipment, and humans

Some practical aspects to isolation for each of these methods of introduction include:

water
- separate water from production area
- one way flow from isolation area to waste discharge - never from isolation to production area
- gradually acclimate incoming fingerlings to facility water

air
- insure exhaust fan from production area does not feed into inlet for isolation area

feed
- purchase feed from a reputable dealer with a proven track record
- be aware of truck and delivery person interactions with the isolation area

fingerlings
- incoming fish should be isolated for 60 days
- get disease diagnosis and analysis from aquatic veterinarian

- remember what a Adisease free@ fish really is - one from a batch where, in a very small sample, a specific pathogen was not diagnosed
- use prophylactic treatment if recommended by the vet
- buy fingerlings from a reputable dealer

equipment

- keep the equipment in the isolation area separate from production area equipment
- make the isolation area equipment highly visible so there is no confusion

humans

- have company policy in place regarding personnel activity in and around the isolation area that is:
  - well thought out
  - well understood
  - well enforced
- require clothing change before entering
- have a foot bath at the entrance to the isolation area
- minimize traffic into/out of the area
- only authorized personnel permitted in the area

By following these simple suggestions the risk of introducing a disease to your facility will be greatly reduced - not removed. Remember that nothing can replace good husbandry practices. If you keep the fish happy, they will make you happy at the end of the year when you total your annual profit/loss statement.

Biosecurity and Fish Health Monitoring for Aquaculture Facilities

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Biosecurity is the protection of living organisms from any type of infectious organism. Thus, biosecurity in aquaculture is the protection of fish or shellfish from infectious (viral, bacterial, fungal or parasitic) agents. Designing an effective biosecurity program requires an understanding of the aquaculture operation, general principles of disease transmission, and knowledge of the fish or shellfish maintained in the facility.

Mortality due to diseases or decreased feed efficiency and/or decreased growth rates due to infectious processes are major factors for economic loss in aquaculture. In addition, as the density of fish or shellfish in an intensive aquaculture facility becomes more concentrated, the probability of individuals coming into contact with a potential pathogen becomes greater. Thus, safeguards to protect the health of both fish or shellfish in an aquaculture facility becomes very important. While aquaculture has made rapid advances in the past few years in fish and shellfish diagnostics, disease prevention and disease control measures lag significantly behind.

The primary goal of a biosecurity program in aquaculture is to prevent the introduction of any infectious organism into an aquaculture facility. Since this is not always possible, the goal may have to be modified to eliminate or control infectious diseases within the facility.

There are numerous potential sources of entry for an infectious agent into an aquaculture facility. These include additions of new stock (eggs, fry, fingerlings, production fish and broodstock); contaminated water or feed; humans, animals or equipment (fomites), and subclinical (asymptomatic) carriers within the existing stock (production fish or broodstock). Each of these potential sources needs to be evaluated and continuously monitored to prevent the entry of infectious organisms into the facility. Thus, a sound biosecurity program for a fish or shellfish aquaculture facility would incorporate a) disease prevention, b) disease monitoring, c) cleaning and disinfection between production cycles, and d) general security precautions.

Disease prevention includes the methods used to prevent the entrance of all potential pathogens into the aquaculture facility. One of the principle methods used to avoid the introduction of certain pathogens into an aquaculture facility is to purchase fish or shellfish from a producer selling certified specific pathogen-free stock. Though this does not

eliminate all potential pathogens, it does help reduce the risk of introducing the major pathogens of a fish or shellfish. Unfortunately, only a few species of fish (i.e. salmonids) or shellfish are presently sold in this manner. Thus, many producers have established in-house broodstock or spawning facilities to provide stock for their production facilities. In addition to disease avoidance, a rigid quarantine program should be incorporated to isolate any new arrivals at a facility. The time interval required for a quarantine period can vary, but will generally take between 45-60 days. During this time, the fish can be closely monitored for clinical signs of disease, sampled for diagnostic health techniques, and treated if warranted. Vaccination is another means of disease prevention in aquaculture. Though only a small number of bacterins are APHIS approved and commercially licensed for sale in the United States, it is only a matter of time before additional bacterins and vaccines are available to prevent or control a wide variety of bacterial and viral diseases in aquatic animals.

Another important method of disease prevention includes providing a pathogen-free water source. Thus, an "infected" water supply may require modern technology (mechanical filtration, chemical treatment, UV filtration, ozonation, etc) to make the water acceptable for a biosecure facility. Finally, optimal management techniques, including stocking densities, nutrition, and genetics) are essential for all aquacultured species to develop and maintain an optimal health and immunological status to fend off any potential pathogens.

Disease monitoring should be an essential part of any biosecurity program. This consists of regularly scheduled health evaluations of all stock in an aquaculture facility. Depending on the particular situation, this may include either lethal or non-lethal sampling or both. Non-lethal techniques may include gill, skin and fin sampling, blood analysis for hematology, blood chemistries, and immunological assays, while lethal sampling may include bacterial cultures, viral isolation and histopathology. Though none of these assays can completely guarantee that there are no potential pathogens in a fish or shellfish population, they do help reduce the risk of maintaining a pathogen in a population. An initial or pre-purchase health evaluation of new stock will establish baseline information about the fish or shellfish, and can provide valuable information if a disease occurs in a facility. Periodic monitoring can also help determine the number of individuals within a population that are infected, and the level or intensity of infection within that population.

An important area of disease prevention and control that is often overlooked in the aquaculture industry is disinfection. Routine disinfection is used to reduce the pathogen load in a facility, thereby reducing the risk of spreading an infectious organism between groups of fish or shellfish in a single facility. For example, providing an adequate number of containers of appropriate disinfectant for nets and other shared equipment is one method used to inactivate potential pathogenic organism. However, having separate equipment (nets, feed buckets, water sampling jars, etc.) for each production unit would be optimal in helping to eliminate the risk of contamination between production systems. Disinfecting live-haul vehicles after delivery of stock to farms or other facilities also helps to avoid bringing back a potential pathogen from these other sites. In addition, cleaning and disinfection of the aquaculture facility and associated equipment between production

cycles is very important and helps reduce the risk of spreading an infectious agent from one production group to the next.

Finally, general security precautions need to be established for each facility to help support the activities of both disease prevention and disease control. A manual of standard operating procedures (SOPs) should be assembled to provide a set of standard rules for biosecurity measures and disease monitoring. This should include such things as facility design, facility flow for both personnel and stock, rules for limited or restricted access to facility, required visitor log book, disinfection procedures for both personnel and equipment, a waste management plan, pest control guidelines, and general husbandry and management procedures. This manual should also incorporate procedures to be instituted if a disease is detected or an outbreak occurs. Record keeping is paramount to the success of any biosecurity program because it can provides accurate historical information about the health status, weight gains, feed consumption, vaccinations or treatments, and management practices of the facility.

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Recirculating Aquaculture Systems as a Teaching Tool

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Virginia State University's Youth Aquaculture Program has been an effective approach to youth aquaculture education for the past decade. (Nerrie, B.L. and A.O. Reid. 1991) Secondary and vocational school aquaculture programs that VSU has assisted have been very diverse, including caged fish, recirculating aquaculture systems, and combination aquaculture/hydroponic units. Recirculating systems have been either purchased from aquaculture suppliers, or developed by schools from local materials. Tilapia, catfish, rainbow trout, and goldfish were utilized. System volumes range from 200 liter single tank units to 6000 liter multiple tank structures. A survey of ten participating programs was conducted to evaluate recirculating systems as a teaching tool. The major educational benefits included problem solving, water quality, environmental, economic, simplicity and public relations.

Although not originally planned, problem solving was the primary educational benefit that was experienced by students. The need for problem solving ranged from complex percent body weight feed quantity calculations, or determining fish weight by water displacement, to simple tasks such as retrieving dropped nets from the bottom of tanks. A common situation that required group discussion and test solutions, was the uneven flow of water among multiple tanks, sump and biofilter. Adult supervision was able to observe as teams were formed to develop solutions to obstacles that would occur on a regular basis.

In all cases students had minimal experience with water reuse systems. Some experience was indicated by students who maintained aquaria. Student leaders who took charge of these groups delegated responsibilities. The need for safety was identified as a key concern when groups were working with water and electricity. Group skills in developing simple solutions evolved that would utilize the resources available. Labor specialization resulted with individuals becoming experienced in a specific task. Innovations were developed. One such innovation was a weekend feeder using a timer activating an air blower to push feed from a platform into the tank.

Students learned about water quality and its importance not only to the fish being cultured, but also to biofilter effectiveness. Activities included monitoring and recording temperature, dissolved oxygen, alkalinity, pH, and ammonia. The relationships existing among each parameter, the cultured fish, quantity of feed offered, and bacteria associated with the biological filter were discovered. Graphs were developed to show fish growth over time. Mortalities due to poor water quality were common. This ecological concept was seen by many students as representative of the society in which we live. Humans have the ability to

maintain a sustainable environment for the benefit of all.

Other environmental lessons included waste removal. Although many original plans called for waste water and solids to be utilized as a fertilizer for plant production, it was not. The effort to integrate the material into a secondary production system was not made because of two main reasons. Students were unable to dedicate the time to identify a nearby site to develop plant beds, and it was too easy to discharge the waste into available sewer drains. A lack of educational "return" from the extra time and effort was reported by students.

Keeping the system as simple as possible was recognized as important. Low density fish populations minimized water quality problems. Each moving part would increase the probability of a serious difficulty.

The benefits of public relations was indicated to be the most important goal of a school's aquaculture system. Tours of school grounds would include stops at the recirculating system, and the opportunity for students to discuss their efforts. The initial primary goal was to harvest a product that could be consumed by school board members, and generate positive publicity for the agriculture program. Students realized the similarities between major political fund raising dinners and their own efforts.

Learning can be defined as gaining knowledge by study, instruction or experience. Recirculating aquaculture systems provide excellent experiential learning.

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The Aqua-Manna Experience

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Introduction

Aqua-Manna is located outside of Ladoga, Indiana, about a half-hour northwest of Indianapolis in an area known primarily for it's grain, dairy, and hog farms. From this background of traditional agriculture, Jim Bradley set out to convert his hog operation into an aquaculture facility. Through several years of experimentation and research, Jim and a close friend were able to develop recirculating systems and system components. Today, Aqua-Manna is a growing aquaculture enterprise specializing in the culture of tilapia and the innovative design of aquaculture technologies. The recirculating systems developed by Aqua-Manna are now used throughout the United States and Aqua-Manna has also established a facility, which has the capacity to raise 100,000 lbs. of tilapia/year.

History of Aqua-Manna

In 1978 Jim Bradley was a successful hog and grain farmer who was in the process of building a new furrowing house. In the years that followed, it became painfully evident to Jim that the economic outlook for the small, family hog farmer was dim at best. It was during this time that he first started to consider aquaculture as a viable alternative. Jim had read an article by the state aquaculture co-ordinator about yellow perch culture and he made a trip up to see LaDon Swann at Purdue University about the possibility. After more research into the "process" of fish farming and investigating current systems in use, Jim formed Aqua-Manna and removed the hog pens from the furrowing house in 1990. Aqua-Manna then began gaining experience with fish, holding bluegill and catfish in horse troughs using sump pumps and nylon filter bags to recirculate the water.

The following year Jim decided it was time to begin raising yellow perch. Important in this decision was a trip to a fish market in Ohio where Jim discovered first hand, the market potential for yellow perch. An Indiana high school, South Putnam High School, had recently started a recirculating aquaculture program. Jim also visited this new facility which laid the foundation for a new system design for the yellow perch culture. The system consisted of 800 gallon tanks with a settling chamber made out of a plastic barrel with a specially designed conical bottom and a biofilter which used film rollers for biomedia. They were able to get their first batch of yellow perch up to an average of 3/4lb. in a year. They soon discovered, however, that the normal market size yellow perch was three to four fish to one pound and that they would have to clean the fish before market. These problems were corrected during the next season.

Throughout this time Aqua-Manna had been researching and experimenting with new component designs, and talking with other entrepreneurs in recirculating aquaculture. A new biofilter was placed in production using a new type of biomedia, corrugated plastic sheeting, rolled up in a tank and used as a trickling filter. To increase efficiency they designed and built a new drum filter, subsequently named the SETO 5000, to replace their existing solids filtration. Once developed, Dr. George Libey started working with them testing and improving the new drum filter. After two years Aqua-Manna applied for and received a patent for the SETO.

With all the components designed, a friend of Jim's with interest in aquaculture bought two of these recirculating systems. The ensuing success of these systems led Aqua-Manna to expand its own facilities. A new building was built which could hold twelve of the new systems and the old furrowing house was transformed into a tilapia hatchery and fry grow out facility. Once investigative new animal drug permits became a requirement to sex reverse tilapia, Aqua-Manna began relying on outside breeders to supply their fry. The old furrowing house is now used a growout facility for the fry before they are transferred into the larger building. During this expansion, Aqua-Manna also hired an aquaculturist to help the technical aspects of nutrition and system management.

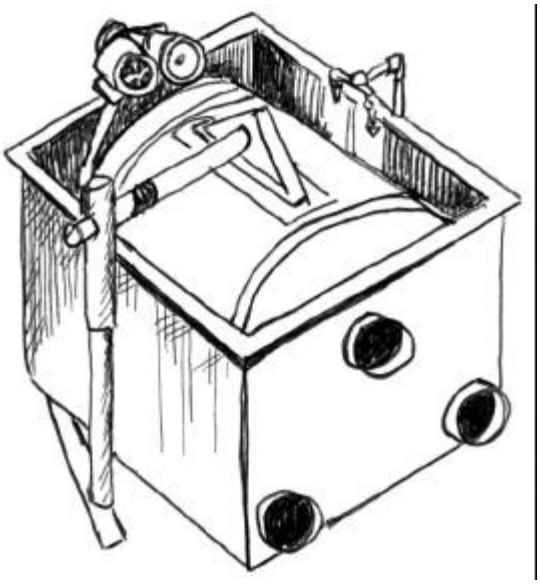
The new recirculating systems in the large building did well in the beginning, and they were able to reach production levels as high as 3,800 lbs per system. During this time they were also developing a market for the tilapia by working closely with another group of entrepreneurs, who were starting up their own live-haul business to supply various Asian markets throughout the Midwest. Aqua-Manna also began working with Purina Feeds to develop a tilapia feed for recirculating systems. The success of the new systems also led a farmer from Sheboygen Falls, Wisconsin to purchase two complete systems to raise yellow perch and these system are still in use today. Along with the new facility and increased production came local media, but problems were just beginning to surface. Technical problems with the pumps used with the systems started to occur along with production levels that stagnated at the 3800 lb. level. The main production problem was clogging of the biofilters. Through the use of a specialized, rotating, high-pressure sprayer, which was designed to clean the biofilters, along with the installation of different management practices they were able to overcome the production problems. Today, Aqua-Manna has been able to increase production levels to approximately 6000 lbs. per system. They have also continued to make improvements to their system along the way. A slightly different system was also set up for a farmer in La Porte, Indiana based upon the problems and successes of their own systems.

Facility and Recirculating System Description

The Aqua-Manna facility is a mixture of older farm buildings and the new fish barn. The fry growout building is a remodeled hog furrowing house with the center drain mostly filled in, the walls reinsulated, and a water reservoir was installed. The new fish barn is 50’ x 150’ pole barn with a ten foot insulated ceiling and four to six inches of spray insulation covering the walls. It is equipped with a small propane heater (30,000 btu),

electric water heater (60 gal.), three 2,000 gal reservoirs, a large (200 hp) backup generator, and a 1 hp blower to provide suction for the SETOs. Water is supplied to both the hatchery and fish barn from a 20 gpm well, which is more than enough to replace the approximate 6,000 gal of water used on the farm each day. The waste from both the hatchery and fish barn flow into a pit below an old hog growout building. The solids settle out in this pit and the clean water then flows into one of two lagoons that are on site. Water flow and electrical outages are monitored constantly by alarms for all buildings.

Figure 1: SETO 5000 Vacuum type drum filter.

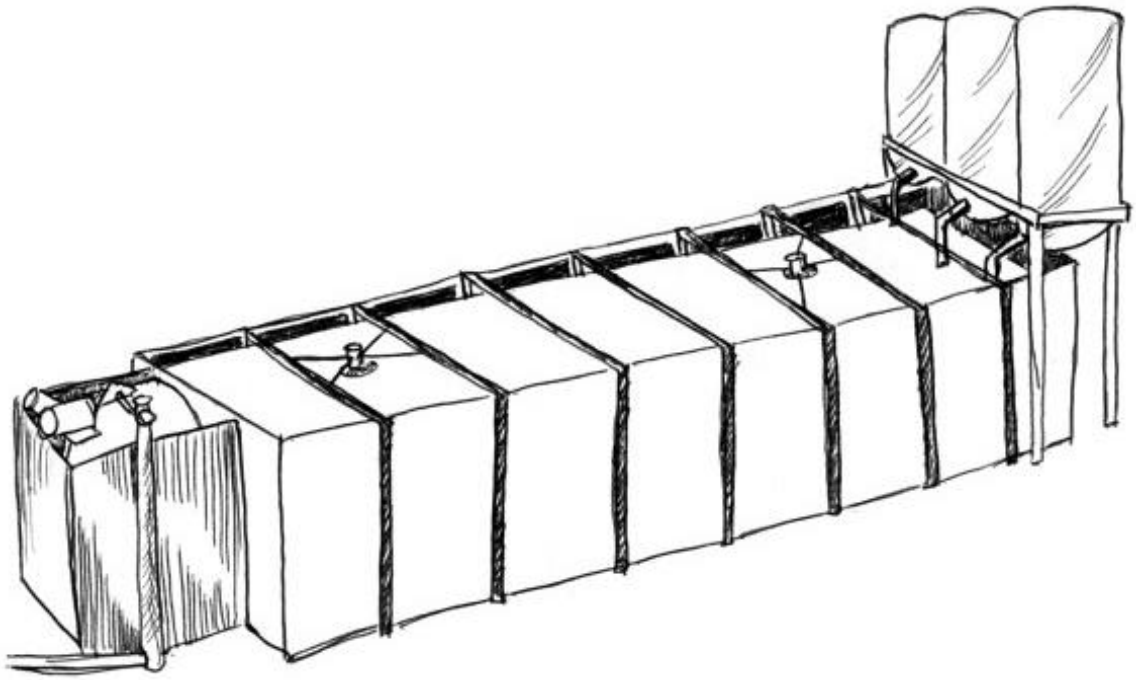


The system described here is the basic one designed by Aqua-Manna and there are several versions and alterations to this basic system. The Aqua-Manna recirculating system is designed for moderate amounts of fish production, 0.5 to 1 lb./gal. of tilapia. This system is able to support this production without the use of any exogenous oxygen because of the rapid flow rate, three to four tank volumes per hour. This rapid turn over allows for more aeration through the trickling filters and the only supplemental aeration is supplied by two 1/3 hp surface agitators. The flow rate also helps the trickling filters with their biofiltration by allowing more passes and therefore more nitrification to occur. The drum filter is a good solids filtration device for this system because of the high flow rate. A settling type filter would require an excessive amount of space. The SETO uses approximately 300 gal. of water each day, which is sucked off with the fish waste from the screen (Figure 1).

The basic system holds 7,000 gal. and consists of a 4'h x 8'w x 32'l culture tank. The culture tank is made of a snap together metal frame, with the bottom and side support supplied by plywood, and a 35mil PVC liner inside. Water gravity flows from the culture tank to the solids filter a SETO 5000. The SETO is a vacuum style drum filter and it

features a continuous drain and spray attachments for supplemental screen cleaning. It can handle a flow rate up to 500 gpm and provides up to 36 sq.ft. of filtering surface per minute. Clean water leaves the SETO and gravity flows back along the length of the culture tank to three high volume, low head, 1 ½ horsepower pumps. The water is then pumped to the top of the three trickling filters. The trickling filters, the BIO 5000, consist of a water conditioning tank filled with corrugated plastic sheeting and a rotating spray bar at the top. The BIO 5000 is 30" in diameter and 48" tall. It supplies 5000 sq. ft. of surface area, and can handle flows up to 170 gpm. From the biofilter water flows back into the culture tank through foam fractionators (Figure 2).

Figure 2: Aqua-Manna Recirculating Raceway



Jim Bradley has designed various other systems using these same components. In the hatchery building, the fry growout tank systems consist of two 1,000 gal. tanks. These two tanks share a SETO for solids removal and each has its own 1 1/2 horsepower pump and one trickling filter. With the addition of a surface agitator, this system can hold and grow more than 10,000 tilapia weighing 50gm each. The system which was set up in La Porte, Indiana is yet another adaptation of the same components. Two culture tanks (4'h x 4'w x 24'l) are connected to one SETO. From the SETO water flows to the two culture tanks, where a two horsepower pump, one for each tank, lifts it up to two trickling filters. Water flows back through the culture tank where there up to two surface agitators for additional aeration.

Cost Analysis

Throughout the past two years that the new fish barn has been operating, Jim has been able to estimate some the operating expenses for raising tilapia in his facility. Table 1 shows estimates of the variable operating costs for tilapia reared by Aqua-Manna and those reared in other recirculating systems (O'Rourke, 1990, Lasorda, et. al. 1991). Aqua-Manna is able to reduce costs of production in various categories: labor is reduced because the system can be operated by one person and weekly harvesting requires only two personnel, heating costs are reduced by the building insulation and the heat produced by the many pumps, and liquid oxygen is not required.

Table 1: Variable Operating Expenses for tilapia culture in three different recirculating systems.

	Aqua-Manna		**O'Rourke, 1990**		**Lasorda, et.al. 1991**	
Direct Operating Exp.	Cents/lb.	% of Cost	Cents/lb.	% of Cost	Cents/lb.	% of Cost
Feed	26.0	30%	29.0	20%	26.1	24%
Electricity	20.0	23%	11.0	8%	16.8	15%
Heating	1.5	2%	10.0	7%	3.3	3%
Liquid Oxygen	0.0	0%	20.0	14%	0.0	0%
Labor	5.0	6%	29.0	20%	16.9	15%
Fry	10.0	11%	11.0	8%	9.6	9%
Depreciation	15.0	17%	16.0	11%	18.2	17%
Maintenance	5.0	6%	10.0	7%	9.4	9%
Miscellaneous	5.0	6%	7.0	5%	10.0	9%
Total Cost per lb.	**$ 0.88**		**$ 1.43**		**$ 1.10**	

Past Experience and the Future of Aqua-Manna

The history of Aqua-Manna experience has been full of both successes and failures. Technical problems along with the need for a re-organization of Aqua-Manna'a corporate structure have taught Jim difficult but valuable lessons. One of the lessons learned however, is the need to constantly maintain and monitor the vital business relationships Aqua-Manna has formed over the years. One of the most important Jim has is with his bank and he considers constant communication a necessary component of his business.

Dealing with fish culture and system design is Jim's favorite part of the operation. After the aquaculturist left to pursue other career opportunities, Jim took over the day to day management duties. He has enjoyed the challenge of locating production problems and devising management practices to solve them. With this "hands on" approach Jim has able to constantly alter and improve the initial system design to increase production capacity. For example, Jim has found that with his large grow out tanks he only has to utilize two of the three biofilters at any one time. This allows him to adequately clean and unclog the third biofilter and this process of filter rotation not only maintains better water quality, but it also reduces electrical cost by running two pumps instead of three.

At this time Aqua-Manna offers its own recirculating systems and system components, ranging from commercial size to classroom scale systems. If a farmer or organization purchases a system, Aqua-Manna will deliver and help in the initial set up. Aqua-Manna also has services available to supply different sizes of tilapia, and they are a Purina fish food dealer in Indiana. If a farmer chooses to take advantage of these services and follows management practices suggested by Aqua-Manna, then Jim will also help with the marketing of their fish through the live-haul service which Jim uses.

Aqua-Manna has accomplished much over the past eight years, graduating from horse troughs to designing and managing an economically viable recirculating system. Further research and development projects include the design and use of airlift pumps and floating rotating biological contactors. The reduction of electrical costs will be a key feature of this new system. Jim is also in the process of planning an expansion of his current fish culture operation, which will increase capacity by three to four times. Aqua-Manna is also exploring the potential of other fish species to meet the demands of their growing markets. These projects along with design, consulting and production of recirculating systems for other farmers should keep Aqua-Manna on the path to success.

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Acknowledgements

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IT WORKED, BUT...
A Short, Abridged History of Shenandoah Waters

William K. Stackhouse
Shenandoah Waters

Understanding that this is one of four papers, two winners and two losers, I put myself in your position to see what I would want to hear from this group of experienced people were I to be just starting out. This is not an academic piece. I intentionally wrote it in the first person to move it away from abstract thinking and bring it into the world you live in. My eyes have always glazed over confronted with academic treatises.

To quickly dispel any question of which of the two camps I represent here; it is that of the "loser." Overall, I put $1.2 million into a combination of capital assets and working funds. We ran into a number of problems that eventually closed the door. But, success was mingled in with the difficulty. I'll talk to both for you.

I had gotten my engineering degree from the Air Force Academy, picked up an MBA from Auburn, and had done some work at the PhD level in Organizational Psychology. Having had project management experience in both the Air Force and industry and having helped two other businesses get off the ground, I felt prepared for my own new start. It was the mid 80s. The plight of the oceans and the promise of aquaculture had not yet universally dawned. And, I was ready.

I was looking for a business venture when a small article about hybrid stripers grown in a tank appeared in the Washington Post. The chef of a good hotel had tried and liked it. He was in the hotel next to the building I worked in. A short talk with him revealed the price he paid. A quick call to a manufacturer gave me a feed price. Some more calls got me to Virginia Tech and Dr. Libey who gave me grow out data. I hypothecated some facility sizing, staffing and start up costs and whipped it all into a spreadsheet. The profit margin popped my eyes. I had my business.

Of course, aquaculture was all new. The chef had paid $5.00 a pound and the feed was for catfish out of Mississippi. I pressed ahead with abundant confidence and unflagging energy.

My first task was to find water. Hard water. For two years I looked all over Virginia. Finally, I called the State Hydrologist who faxed a map of where such water could be found showing it in shades of gray. The area around Strasburg where 66 and 81 meet looked like an ink blob. Got some land on a contingency, sunk a test well and ran it over night with an ammeter on the pump. The ammeter showed a DROP in current over time rather than an increase in draw, as you might expect. The driller had hit a seam in the fractured karst limestone. As the flow continued, it had cleaned out the passages leading to the pipe and the head actually came up

from 300' to 75' and never moved through the worst drought even though we pumped at 100gpm. Water tests showed good, clean water with no appreciable iron or sulphur. I had my water.

My walk-around money came from some stock in one of the businesses I had helped start. Now, with a site in hand, I needed a big chunk of cash to get going. I tried many, many avenues. Banks (What a laugh as their risk tolerance is nonexistent). Venture capitalists (Not far from banks and, if you don't watch out, they will wind up owning your business). Angels (Private investors who are the best bets). And some weird ones with weird schemes. In fact, the largest single contact category in the database I kept was for financial purposes. Financing is the single greatest hurdle for most wannabe aquaculturists. The aquaculture business is very capital intensive.

Finally, I went down the Small Business Administration (SBA) loan road using a non-bank lender. A non-bank lender is a financial institution which has money to lend and has done sufficient work with the SBA that they have only to notify the SBA when the non-bank lender has made a loan guaranteed by the SBA. As I got into the paper work, it became clear that the amount of collateral available was not enough to build the one or two tank system I wanted for starters.

By this time, my spreadsheet had become the mother of all spreadsheets capable of spitting out full financials with ratio analysis in both accrual and cash basis at the change of a feed price. If I came across a variable, say fish management - two tanks started at a time vs one or, three months between starts vs two - it was worked into the sheet. While playing with the numbers, I discovered that the bigger the facility, the more equity became available. It was just economies of scale kicking in, but the appraiser ran by a set of rules dictated by profit margins. I resized the facility to six tanks and submitted the paperwork. I had my money. Or, so I thought.

In negotiating the final amount with the lender, I let myself be talked out of the built in safety margin. This proved to be the undoing of the enterprise. Problems arose from the start.

The money was planned around a Spring go. The bulk of the money didn't come through until early Fall. The entrance of the unused county road we had planned on renovating was gated off by a property sale and my lawyer said it would be two years in court to get it opened. We had to build an unplanned road. An unplanned hill had to be leveled to get enough space for the building pad. Rains washed out the entire month of October. One challenge after another. Before the first fish had arrived, the enterprise had taken heavy hits. But, I could always see a way through by working the magic spreadsheet. Fine tuning. Sharpening the pencil. However, each time I found a way, the chain of "ifs" lengthened. "If this works out, then that'll be OK."

I don't mean to deprecate the value of a spreadsheet. It is a wonderful tool. In constructing

one, you are actually modeling your business. It is the best exercise available in forcing yourself into the hard numbers. Problems emerge from those numbers you could not possibly imagine without one and it lets you prepare in advance. It is the closest thing to a crystal ball on this planet.

After losing one or two people, we wound up with a gallant group of four, each with his own strengths and weaknesses. I led the parade - laying out buildings, rendering tank concepts to executable designs, showing where to dig for lines, getting utilities in, etc. We all did the physical work. My problem at this point was I had to do too much "Do this next." work. An older gentleman was recommended to me. He showed up and looked to be fragile. I thought there was no way he could cut it; but, he went into the lineup anyway. In two or three days my, "Do this next." activity stopped. The others were naturally going to him and he was leading the "doing" part of the work which greatly freed me. He was a retired Army Master Sergeant. Gentle, suasive, and able to look at something mechanical and intuitively know how it worked.

For the most part, these people had come from extremely hierarchical work backgrounds. The military is avant garde in the people business next to most of the companies in the area. From the beginning, I wanted the people in the organization to feel this was their business, too. I wanted them to participate in finding and fixing problems which I knew they would know about long before me. One of the most difficult, yet important, things to do as a manager is to allow people who work for you the latitude to fail. If you ever want to grow their trust, you have to trust them first. This is particularly so for a small start up. You haven't time for union rules. It pays off. They never failed.

On more than one occasion during the night when no one was on site, we would lose power, or an alarm would go off, or a compressor would overheat and drop off line. In every instance, I was the last to be notified and by the time I had the word, someone was on site with the rest close behind. They thought and cared about the business. It was "we", not "us and them." They had transformed from a production line mentality to self starters and they loved it. They had taken the enterprise's mission to heart. That attitude carried us far beyond the point at which a standard new start would have failed. I view this as the finest organizational achievement of the effort.

We pressed on with the construction and soon had the roads, buildings and tank systems completed and we commenced to raise hybrid stripers. The system worked OK, initially. Soon, however, it became apparent we needed a modification to the solids filtration system.

The touchstone for the design was a PhD Fisheries Scientist with experience in recirc systems and not of Virginia Tech background. He was a consultant, highly paid relative to the rest. His view was that a 100 micron filter would do the job. I designed a system using de-watering grates from the mining industry. Water flows across a top lip at about the height of the main tank, goes into smooth, laminar flow and drops vertically across thin bars horizontally placed.

The bars are stacked vertically for about two feet where the configuration begins to move outward to be nearly horizontal to the ground. Like a "J" without the upsweep. It operates on the Coanda principle whereby a liquid in laminar flow will adhere to a smooth surface through about 120 degrees of turn. They were rated at the required 100 microns of particulate separation.

I had early on expressed concern about the material integrity of solid fish waste thinking it was very susceptible to breaking up. Turned out it was. We had built a solid fish waste emulsifying machine. When the fish grew to a point that they were turning out a lot of waste, they were also big enough to beat their own waste up when feeding and we broke up what was left with the filter.

I now had a major fix to do and not enough money left. I found a venture capitalist (VC) who pledged $300,000 in exchange for preferred stock and positions on the board. The first draw was for half the amount. With that we were to begin the retrofit, start on four new tanks (the building would hold 10 tanks and the VC wanted it all up), and begin an in-house breeding facility.

As we had phased the fish in over time, some tanks were lightly loaded and some were empty. One of the group came up with a plan to spread the fish around while we did the mod. This let us get some fish to market.

The fish were extremely well received. We would chill shock them and put them on ice. When they reached their destinations, it was not unusual for them to begin flopping on the counters. In the DC area, this hadn't been seen for years and the old fish guys were amazed. We had live haulers stopping by. Individuals were calling us. Distributors wanted in. One fellow wanted us to get into perch because the Great Lakes production had been curtailed. Another wanted us to build a facility in the Boston area. They had processing capability, but no fish. It was bittersweet success.

Construction on the filters had just begun when the VC changed account managers. The old one had been pro aquaculture, the new one was from hi tech, knew nothing about the business, and did little to hide his disdain for such a lowly industry. Our remaining money was quickly frozen while we were midstream on the mod, which was the only path to profit. Only one filter was completed. The water in that tank was very good and our best fish were grown there. We changed to tilapia because it was far more tolerant of high particulate levels and low oxygen concentrations. We changed from propane to oil heat, suspending house radiators in the water. We rigged three tanks sets so that the center tank of each was a settling tank.

The operation continued for almost two more years, limping along on the sale of the meager amount of fish of which the crippled facility was capable while I looked for money. With the track record and an obviously hostile VC on board, I got sympathies, but no money. Finally,

a series of severe March storms did us in. A heavy snow was followed by a warm front with rain which was pushed out by an Arctic event, all within two days. Temperatures dropped into the teens. There were 12 inches of glass-smooth ice covering the three quarters of a mile of hilly road between us and an oil truck. When the storms passed, we had 10 blocks of fish-impregnated ice. It was over.

Shenandoah Waters went into bankruptcy and came off the auction block at $85,000. The facility is in complete disrepair today.

SOME THOUGHTS WHILE STROLLING

1. Start small. If you have a system that is working, you can find money. Investors will put money up if you can prove your way will work. The best way to do that is to produce fish and put them in the market. They will buy a 2x system scale up, but not a 10x scale up.

2. Be patient as you work your way past the start up phase. Get the bugs out of your system here. Investors don't like startups. They are the most risky investment of all. There was no money available for technology demonstrators when I started. Today, the Center for Innovative Technology near Reston has money for start up equipment demonstrators.

3. Estimate everything in your disfavor. Expenses high, revenues low, ramp up long. When you do get a number, be prepared for it to double in both cost and time.

4. Do a self survey. If you go into it, can the family stand the down side? Can you? You can lose everything. Raising a living thing that eats is an every day job. Much as it looks like a production line, it isn't. There is no whistle that closes out the day and the line shuts down.

5. Disabuse yourself of the notion that it's easy. It's not. There is a lot to learn. Water chemistry, feed rates, fish size estimation, marketing, buying consumables, small business paperwork and much more than you have conceived of yet. Virginia Tech is an outstanding resource. So are your fellow aquaculturists. There are two types of people in the business - those who think they have the answer to the aquaculture equation and put their arms around what they know without sharing, and those who will survive. Find those who will share and do the same for them. You are building an industry. You can do it together, but not alone.

6. Come quickly to an understanding that it's expensive. Beginners will focus on finding cheap tanks. Tanks are about the least expensive item in the list. Experienced folks will focus on pumps, valves, heating, feed, fish handling and marketing.

7. YOU are in charge. It's your fall to take if it doesn't go. If your gut tells you something is wrong, straighten it out. Even PhDs are wrong sometimes. The U-tube at Virginia Tech is only half as deep as it should be because a PhD (not of Virginia Tech) who made up the tables, got it wrong.

8. If you deal with financial people, make sure they can help you. The non-bank lender was out of St Louis. The venture capitalist firm was itself a new start with a hi tech focus. They will ask you for references as they do due diligence. You do the same. Working with a VC is like making a match. It only works if both parties are compatible. Remember, they are selling you money and you are the buyer.

9. If you establish a board, make sure they understand things that eat, grow, and can die. My VC and entire board came from a hi tech production background. In manufacturing, if something is out of kilter, you can throw a switch, shut down the line and fix it. That's what the second account manager I had was about when the money was held up. He engaged in an in depth review while the opportunity to fix the filtration problem slipped away. By the time he finally realized what was happening, the amount of money it took to fix the problem had to have added to it the cost of a growout restart. The board looked good on paper, but didn't work. You might want an advisory council rather than a board to start with.

10. Have a tape recorder at every board meeting for everyone's sake.

11. From the outset, establish a professional relationship with an accountant and lawyer.

12. Realize you are in the fish business, not the new, innovative systems business. If you can do your job with warm spring water running through feed troughs, do it. Forget about recirc. It's a means to an end, not the end.

13. Use a proven system. The early on PhD consultant considered the Virginia Tech system to be Neanderthal. It worked then. It's still working now.

14. Eventually, recirc will take over. Regulations and operating parameters are closing in from all sides. Total particulate emission controls and total chemical release rather than parts per million will rule. The ditty, "The solution to pollution is dilution." is cute, but passé. Already, some species, tilapia being a prime example, can only be raised in closed systems in many states, Virginia being one. Be prepared for these new regulations. Have the land and the money earmarked to deal with them. They'll be expensive.

15. Eventually, big systems will take over. Economies of scale dictate this. Check what Cosco or Home Depot or Staples have done to their industries. On the other hand, niche markets will continue to exist. If you plan to be small, just try not to be on the big guy's turf when he moves in. Offer something different. Differentiate your product. Your market will switch in a heart beat if they can get acceptable fish appreciably cheaper.

16. The approved bullets in the fish medicine cabinet are few. This is a major risk factor when determining whether you should go into the business and a major factor for investors.

17. If you have people working for you, your business is your people. Your peoples' business is the business. You have to create the conditions and find the resources to allow your people to function.

19. Should you go for a loan, all your assets may be included in the collateral package and your wife will have to cosign. The financial people penetrate the corporate veil with personal contracts backing up the loan. Unless you are well heeled, your house will be on the line.

20. Do not allow yourself to be deceived by accrual accounting. It makes the business look better than it is. Keep a set of your own numbers that you generate. Some say to do this by hand. I believe a spreadsheet can do a better job, faster and more legibly. You can also run excursions on "what ifs" to improve your understanding of what the numbers really mean. This doesn't have to be a mongo spreadsheet - just enough to know how much money you have coming in and going out for the next few weeks or months.

20. Pay yourself. Many people who run numbers don't include their salaries. They plan to take what is left after the fish are sold. Would you really go into the business knowing you might make only $.50 an hour?

21. Don't let anybody get between you and the market. Many in the catfish industry were harmed by allowing the processors to grow as a separate group in the chain. Wall street money went into the processors when aquaculture got a play. It was OK as long as a balance existed between producers and processors. But, when processors began to proliferate, there were only two ways for profit margins to be sustained - the processors could either put a lot of time and money into increasing market size or, they could lower their price and grab market share. The latter was quicker and less expensive up front and that's what they did. As new processors came on line, the profit squeeze was passed on to the producers who got less and less while their expenses continued to rise. I believe the best bet for small producers is to establish an association or coop.

22. Get into your own fingerling production ASAP. You will be able to: control quality, control almost all foreign disease vectors and, take the pick of the litter. I am told that some fingerling producers will ship culls to their new or small or infrequent customers while the best go to preferred customers. You won't know what you get until too late.

23. If you take fish from the outside, have a quarantine area away from your growout tanks in another building. Don't put anything in the tanks that hasn't been checked out.

24. Keep data. Do your water tests religiously and put them in a database. Same for feed and all other consumables. Set it up so you can get a variety of graphs out. Some growers fail to keep data. I don't understand how these people have a clue as to what happened when something goes wrong. Bounce your actual numbers against your projections.

25. Have at least one or two people who really understand animals. One of our group used

to spend a lot of time between feedings just looking into the tanks. He developed a sixth sense and could provide a heads up long before more apparent symptoms were noted.

26. Beware of gravity. It never tires; but, you and your people do. Our tank tops were six feet above ground level. We had a rock ledge under the building pad that precluded putting them down. At first, it was easy hauling fingerlings and their feed up and over. We were doing it manually. The fish did grow, however. Each day the feed load to be lifted increased until we wound up with two people with slipped disks. Fish handling was equally tough. Design your system to as little manual lifting as possible.

27. Stay away from poly buildings. They're cheap up front, but cause no end of problems.

POSTLOG

You may wonder what my current conditions are and what feelings I may have.

My marriage is intact. Never a doubt there. We're childhood sweethearts and will be forever.

Bank account is a different matter. Savings gone. No appreciable equity was left in the house after the SBA settlement.

Would I do it again? Of course, but differently. I regret the failure, not the attempt. Remember, only one in five new starts makes it. I would rather leave this world having tried and failed than leave it wondering.

I would like to express my particular appreciation for the efforts of Dr. George Libey and his staff in their support of the venture.

Finally, good luck to all who choose to strap on a new business.

Critical Considerations for Greenhouse Tilapia Production

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Introduction

Several Louisiana tilapia growers have developed semi-standardized, greenhouse-enclosed green-water recirculating systems that have been shown to be cost-competitive when compared to other growout approaches currently in use throughout the U.S. These systems utilize net pens suspended within rectangular growing tanks to facilitate concurrent batch stocking and harvesting, allowing physical isolation of specific size- or family groups within a system. The typical layout utilized by these producers has also been adopted by growers in Florida, Illinois and Maryland, and is receiving considerable interest from potential growers in a number of other states and countries.

As Louisiana's greenhouse tilapia industry has developed over the past decade, we have gained a number of insights that bear consideration by established producers as well as individuals considering an investment in tilapia aquaculture. This discussion will attempt to address both audiences by briefly raising a number of questions that must be considered prior to an investment of money and time, and a number of technical considerations regarding production and management.

Planning Considerations

Although the basic Louisiana tilapia greenhouse configuration would appear to be adaptable almost anywhere, site selection can be critical to the long-term success of an operation. Often, an individual or corporation will develop a facility on a specific piece of property they already own, leading to on-going problems once production begins. Would-be tilapia growers should first define the scope of their proposed operation and then find a site to fit their needs.

Quality of the available water supply is probably the single most important characteristic of a tilapia production site. In many areas, well water contains excessive amounts of compounds such as hydrogen sulfide, iron, and even ammonia, precluding its use in live hauling tanks or even for daily make-up water requirements. If a municipal drinking water supply is used, care must be taken that it has chlorine, and not chloramine, in solution. Chlorine can be fairly easily eliminated through aeration and aging, and small amounts can be added daily to the culture system directly with little or no impact on fish or biofilters.

The alternative domestic-use supply treatment, chloramine, is far more persistent and must be neutralized chemically before the water can be safely used even for daily make-up needs. Chloramine is often utilized in less densely-populated areas, where disinfectant activity must persist in supply lines over long distances or periods of time. Apart from day-to-day requirements for make-up water, an on-site source of high-quality chemical-free water is essential for filling hauling truck tanks if you intend to market live fish. Chlorinated or chloraminated tap water cannot be used directly for hauling fish without chemical neutralization, which can be expensive for the volume of water on most over-the-road live haul trucks.

Access is the second most critical aspect of site suitability for a tilapia greenhouse. Access to roads for deliveries and shipments. Access to fuel and electricity. Access to labor, equipment and parts. Access to supplies and markets. Conversely, greenhouse characteristics and siting on the property itself should minimize opportunities for unauthorized access. Other site considerations can become important over time. Space for future expansion and regional demand for a greenhouse facility should also be evaluated in the event that the business exceeds or fails to meet expectations.

Many system components can be at least partially developed out of sweat and ingenuity. On-site greenhouse erection and tank construction are preferred approaches to conserve capital. In these situations, however, operators must have access to labor as well as the proper tools and specialized equipment, such as bobcats and/or backhoes for excavation, boom trucks for setting greenhouse trusses, and nail guns and compressors for constructing tank walls.

Preliminary equipment lists often leave out smaller items, like a good tool set with a storage cabinet. They are often the most essential for success. One item which is omitted all too often is an emergency generator. In some cases, generators can be sized and configured into the electrical supply to provide power only to air blowers and and/or aerators, without having to operate pumps, lights, and other non-critical systems. If pumps are left without power for any period of time, however, a means should be in place to prevent biofilters from becoming stagnant and suffocating. The solution to this problem can often be as simple as draining the filters to allow bacteria access to atmospheric oxygen until pumping resumes. Other solutions may be required, but they must be thought out and ready for implementation whenever power supplies are interrupted.

The biggest financial constraint for most operations is not the high investment and operating cost, *per se*, but rather the cash flow requirements that result from day-to-day operations and hard-to-plan-for miscellaneous costs. In addition to big expenses like feed, labor, fingerlings and energy, regular purchases will be required for all sorts of supplies like water monitoring chemicals, record-keeping materials, motor oil, hydraulic fluid, air filters, fan belts, phone message pads, etc.

Another financial problem that pervades many small systems is inefficiency. Equiment inefficiency must be continually analyzed. Methods to re-aerate return water from filters

without using electricity are a simple example. Labor inefficiency is another area that should be continuously evaluated. With proper planning and special structures in place, one Louisiana grower has devised a method to harvest and load a 10,000 lb. shipment on a hauling truck with only 3 people in less than 4 hours. This is particularly important for small systems where labor may be limited.

Many start-up operations fail to consider when seasonal demand is highest and plan their construction and stocking schedules accordingly. Once a steady state production level is attained, this seasonality has little impact, but first year cash flow can be significantly impacted by the month in which harvests are initiated (Table 1).

Table 1. Seasonal live market price impact in relation to start-up date on first year revenues for Louisiana tilapia production.

	Revenues First 12 Months	Revenues First 24 Months
January Start-up	$34,998	$208,379
April Start-up	$37,557	$210,938
July Start-up	$35,566	$208,947
October Start-up	$36,561	$209,942

From Lutz and Roberts, these proceedings.

Operational Considerations

Maintaining broodstock and rearing fry requires good culture skills as well as special feed, tanks and other equipment. As a result, in many instances it is more economical to purchase fingerlings than to try to produce them on site. In either situation the quality of fingerlings from a genetic standpoint can vary greatly. While a pure species pedigree is not a requirement for good production traits, but hybrid-derived strains can be hard to characterize after several generations of random breeding.

Growth, of course, is probably the most important production trait. Growth rate, growth uniformity and size at which growth slows or ceases are all factors to consider when evaluating available strains of fingerlings. Growth uniformity is important in relation to labor and facilities available for grading throughout the production cycle, as well as to feed conversion efficiency. Some hybrid-derived strains of tilapia may grow exceptionally quickly during the first months of life, only to practically cease growing at weights of 350-400 grams, especially if their ancestry includes large contributions by mozambique tilapia, *Oreochromis mossambicus*.

While mixed-sex culture of tilapia can be economically feasible with proper management and growout densities, predominantly-male fingerlings produced through sex reversal or from YY-male broodstock demonstrate distinct advantages in terms of growth rate and growth uniformity. Lutz and Roberts (in these proceedings) demonstrate that moderate improvements in growth increase profitability in Louisiana greenhouse systems to a greater degree than large improvements in feed conversion efficiency.

Temperature tolerance is also an important bioeconomic consideration when comparing tilapia species and strains. Blue and nile tilapia are genetically superior to mozambique tilapia in this respect also. The wrong genetic background in tilapia fingerlings can have practical consequences in terms of increased heating costs to maintain growth during cool weather, and in turn increase risks of carbon dioxide build-up in poorly ventilated greenhouses and production systems where heat must be excessively conserved.

Whatever the genetic background of any given production strain, however, the health status of every shipment of fingerlings entering a facility should be thoroughly evaluated. The potential risk of introducing diseases such as *Streptococcus sp.* dictate extreme caution in choosing a fingerling supplier. Fry and fingerlings are often in such short supply that growers are forced to accept suppliers' disease-free assurances at face value, a situation which has led to the contamination and shut-down of a number of facilities in recent years.

Regardless of whether you produce your own fingerlings or purchase them, feeding practices during early rearing of tilapia fry can have profound impacts on their performance through the rest of their life, until they reach slaughter weight. Diet during the first 3 weeks of life has been shown to determine the physiological development and competency of the tilapia digestive system (Bishop and Watts, 1998) and subsequent growth. Similarly, fish that are crowed and underfed as fingerlings never seem to realize their full growth potential thereafter, regardless of the growout conditions.

Research has also shown that feeding tilapia less than satiation diets in tank culture systems can result in greatly reduced growth throughout the production cycle (Kazmierczak and Caffey, 1995). For this reason, daily feed loads must be established based on biofiltration limitations and stocking rates adjusted accordingly to allow for full feeding per individual fish. Once significant size variation is established slower growers never appear to catch up to their faster counterparts, and less-than-optimum conditions serve only to magnify size variation.

Variations in feed conversion can have great impacts on profitability in tilapia systems, but mixed-size stocking prevents accurate determination of feed conversion and allows slower-growing runts and/or females to accumulate in production tanks. Conversely, in partitioned systems where size classes are physically segregated, the disturbance of grading must be minimized to avoid lost feeding days, especially as fish approach marketable sizes.

Although fluctuations in ammonia reduce the efficiency of feed conversion to some degree, frequent ration changes can have even more detrimental effects on feed conversion, even when using the same feed supplier. Changes in feed components, even sources of carbohydrates, can result in inflated feed conversions and lag times of several days or even more than a week before gut bacterial and enzymatic adaptation takes place and feed conversions return to levels associated with the previous diet. Accordingly, feed should be ordered in the largest lots practical, and new feed should be ordered well before the current supply runs out. Blending the last of the feed on hand with the new supply for at least a week before completely changing to the new feed appears to reduce this effect somewhat.

When projecting what their facilities will produce once operational, many growers fail to keep in mind the "learning curve" phenomenon. Aquaculture production is not like a factory operation; with a crew on an assembly line with a few simple tasks to learn. Some industry veterans have speculated that fish farming may never be truly industrialized due to the intuitive requirements and the need for intimate supervision of the production process. Inexperience, even of qualified personnel, will have to be reckoned with for the first several cycles, at least.

Production data from Louisiana systems (Lutz, unpublished data), bioeconomic modelling (Kazmierczak and Caffey, 1995), and empirical data (Malone et al., 1993, Golz et al., 1996) have shown that management of biofiltration and solids removal can profoundly impact water quality and fish performance in recirculating systems. Management in these areas is complex and intuitive due to feedback effects on total ammonia nitrogen and dissolved oxygen levels. The ultimate impact is to system profitability and economic survival (Table 2). Similar complexities in determining optimal levels of dietary protein and stocking densities in relation to biofiltration efficiency have been discussed by Kazmierczak and Caffey (1995) (Tables 3 and 4).

Table 2. Days to harvest and returns (cents/l/day) in relation to mechanical and biological filtration efficiency for tilapia fed 30% crude protein diet in recirculating aquaculture systems.

30% Crude Protein Feed	Mechanical	Filter	Efficiency	
Biological	0.50		0.33	
Filter Efficiency	Days to Harvest	Cents/L/day	Days to Harvest	Cents/L/day
1.00	247	0.034	250	0.033
0.98	263	0.029	265	0.028
0.90	293	0.018	294	0.018
0.85	333	0.009	337	0.008
0.80	403	-0.002	404	-0.003
0.75	502	-0.011	502	-0.011
0.70	603	-0.013	603	-0.014

From Kazmierczak and Caffey (1995).

Table 3. Returns (cents/l/day) for recirculating tilapia production in relation to biological filtration efficiency for three levels of dietary protein and fixed mechanical filtration efficiency.

Biological	Mechanical Filter Efficiency =0.50		
Fiber Efficiency	20% Protein: Cents/L/day	30% Protein: Cents/L/day	40% Protein: Cents/L/day
1.00	0.033	0.034	0.035
0.95	0.028	0.029	0.027
0.90	0.025	0.018	0.015
0.85	0.019	0.009	0.001
0.80	0.013	-0.002	-0.011
0.75	0.005	-0.011	-0.015
0.70	-0.003	-0.013	-0.015

Table 4. Returns (cents/l/day) for recirculating tilapia production in relation to biological filtration efficiency for four density levels and fixed mechanical filtration efficiency

	Mechanical Filter Efficiency =0.50			
Biological	Cents/L/day	Cents/L/day	Cents/L/day	Cents/L/day
Fiber Efficiency	0.007 1-g fish/L	0.09 1-g fish/L	0.11 1-g fish/L	0.13 1-g fish/L
1.00	0.035	0.042	0.048	0.041
0.95	0.027	0.031	0.032	0.030
0.90	0.015	0.010	0.001	-0.009
0.85	0.008	-0.010	-0.019	-0.026
0.80	-0.011	-0.018	-0.023	-0.026
0.75	-0.015	-0.019	-0.022	-0.024
0.70	-0.015	-0.017	-0.020	-0.021

The topics presented here are only examples of the types of insights gained through numerous trials and errors in the development of Louisiana's greenhouse tilapia industry. In summary, many critical aspects to profitability and economic survival of small recirculating systems require continuous evaluation and improvement through innovative means. Operators who insist on taking these considerations for granted are at far greater risk for failure than those that are continously scrutinizing their production processes, inputs, and management practices.

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The Use of Process Control Software for the Monitoring and Control of Aquaculture Systems

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Introduction

The field of aquaculture has been considered by many of its practitioners to be as much an art as a science; success of aquaculture operations has been closely associated with the intuition of the farm manager rather than with understanding of the physiology, ecology and behavior of the cultured species. Hence, farm managers have been hesitant to trust their crops to automated management systems. However, recent research and commercial operations have begun to adopt new technologies and aquaculture as a science is evolving (Lee, 1995). Real-time trending of system parameters provide the manager with unprecedented insights into the physical and biological conditions of the aquaculture facility. These insights would be impossible with manually monitored aquaculture systems because of the labor required to collect and enter data and then to prepare graphs and reports. Recirculating aquaculture systems have the most obvious needs for this technology but pond and offshore aquaculture systems can benefit as well.

Advantages and Benefits of Process Control Systems

The main reasons for applying process control technology to aquaculture is socioeconomic, especially in developed countries. Three major factors are responsible: (1) variable climate, (2) high labor costs and (3) increased competition for dwindling water and land resources coupled with an unsympathetic regulatory bureaucracy. These factors are pushing the US and other developed nations toward the use of intensive recirculating water filtration systems (Fridley, 1993). However, the price performance of current recirculating filtration technologies limits their use to high value species (Lee, 1995). High efficiency, automated filtration systems would reduce simultaneously the need for high quality make-up water and the volume of pollutant-laden effluent. Anticipated benefits for aquaculture process control systems are (1) increased process efficiency, (2) reduced energy and water losses, (3) reduced labor costs, (4) reduced stress and disease, (5) improved accounting and (6) improved understanding of the process.

The use of computer monitoring and automation in aquaculture has grown during the last ten years. Applications include food production (Rusch and Malone, 1991, 1993), feed management (Hoy, 1985), automated filtration systems (Whitson et al., 1993; Lee et al., 1995; Turk et al., 1997), vision systems (Whitsell et al., 1997) environmental monitoring and control (Hansen, 1987; Ebeling, 1991, 1993; Munasinghe et al., 1993) and integrated system

management (Lee, 1991, 1993; Lee et al., 1995; Turk et al., 1997). This migration toward intensification and automation parallels the development of other forms of agriculture. Automated broiler coops (Campbell, 1988; Allison et al., 1991), nursery greenhouses (Baker et al., 1988; Hooper, 1988; Jones et al., 1990), dairy barns and feedlots (Leonard and McQuitty, 1982) and crop irrigation systems (Rao et al., 1992) are demonstrating the profitable application of process control technologies. These agricultural production systems represent managed biological systems that supply commodity markets (i.e. high production and low profit margins) similar to intensive aquaculture systems (i.e. ponds, sea cages or tanks). Process control technology is big business; control system integration revenues were expected to reach US $10 billion in 1998 and the industry has been growing at a rate of >15%/yr over the last five years (Kuhfeld, 1994).

Use of process control technology in aquaculture will allow the aquaculture industry to: (1) site production closer to markets; (2) improve environmental control; (3) reduce catastrophic losses; (4) avoid problems with environmental regulations; (5) reduce management and labor costs and (6) improve product quality and consistency (Lee, 1995). The overall design and implementation (i.e. hardware and software) of an aquaculture process control system has been reviewed (Lee, 1991, 1995). Therefore, this review focuses specifically on process control software and its capabilities.

Process Control Software Characteristics

Operating Systems

The choice of computer platform and operating systems are the first choice to be made in selecting a process control system (Wolske, 1989; Chandler, 1994; Labs, 1994). The most appropriate criteria to use for selection are (1) functionality or suitability to task, (2) compatibility and interconnectivity, (3) architectural expandability and (4) price performance.

System Architecture

There are four basic designs for automated control systems used in aquaculture (Lee, 1995): (1) closed loop controller or data logger systems that are simple, inexpensive, local control systems, lacking communications capabilities but including some data storage (Szabo, 1993); (2) programmable logic controller (PLC) systems that perform control functions at the lowest system level, are highly redundant to avoid system failure, do not store the I/O as files and have limited display capabilities unless attached to a computer and monitor (Cleaveland, 1993a; Bonanomi 1994); (3) microcomputer-based supervisory control and data acquisition (SCADA) systems that are dedicated systems, allowing real-time analysis (analog and digital) and storage of I/O in a database for historical trending (Bailliet, 1987; Yingst, 1988); and (4) distributed control systems (DCS) that provide greater multi-tasking, redundancy and data storage capacity by networking multiple microcomputers and/or PLCs (George, 1992; Spennato and Noblett, 1992; Grenier, 1994).

Modules

I/O drivers. The first thing that process control software must do is acquire information from the process (i.e. analog and digital inputs and outputs; I/O). The software should provide a wide variety of I/O drivers that support industry standard I/O devices each of which will have its own specific protocols and reference manuals. These industry standard devices include sensors, meters, data multiplexers or PLCs. For each specific I/O device there is a specific I/O driver that should provide capabilities for automatic communication error detection, reporting and recovery and support for redundant communications.

Process database builder. The heart of the process control software is the process database, a representation of the process created using process control logic. The process

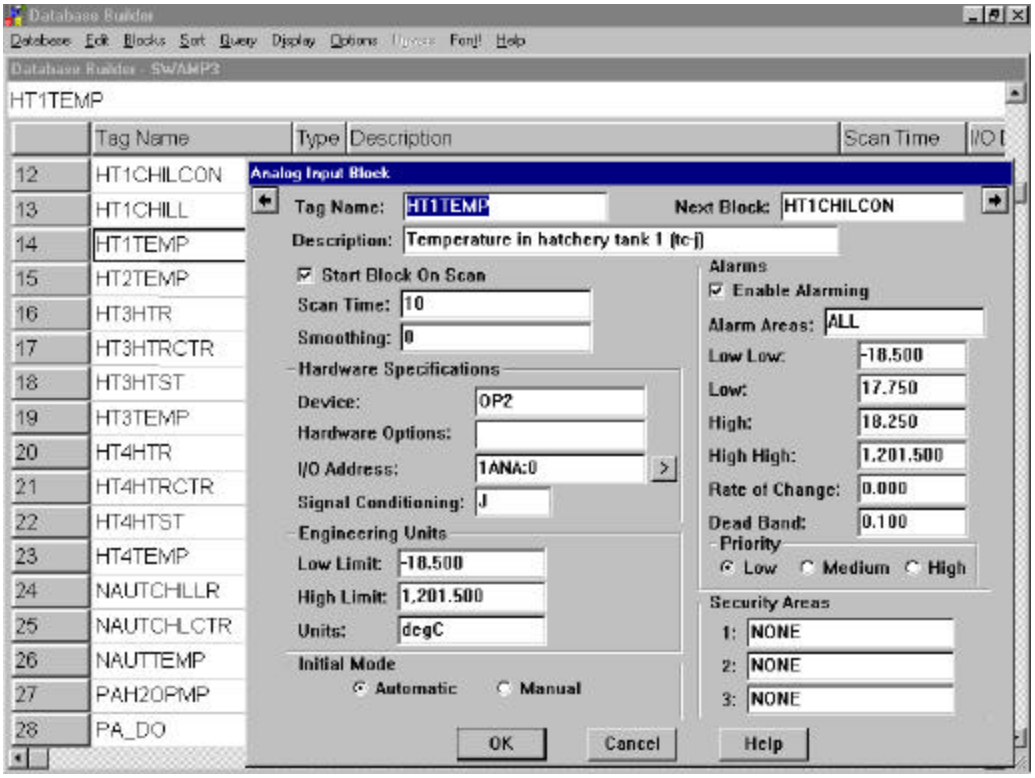

Figure 1. This database block is an Analog Input Block for temperature. It has fields for tagname, description, device and I/O addresses, engineering units, alarm set points and security areas. In the background are additional tagnames for other database blocks.

database consists of blocks (i.e. coded set of process instructions that perform a specific task) and chains (i.e. series of connected blocks that create a monitoring or control loop) (Figure 1). There are two general types of blocks; primary that read data from or write data to the DIT and secondary that manipulate data passed to them by a primary block. Blocks have also referred to as tags in certain software. Most process paradigms require several chains to be created. For example, the monitoring of temperature and control of a heater relay requires an Analog Input Block from a thermocouple to be connected to a Digital Output Block with a

low set point for temperature that will actuate a digital relay, thereby turning on a heater (see Figure 1).

Man-machine interface. If the database builder is the heart of process control software, then the man-machine interface (MMI) functions as the sensory system (e.g. eyes, ears and touch) for the software because it provides the window into the process (Cleaveland, 1993b; Labs, 1993). It requires output (e.g. video display and message boards) and input (mouse, track ball, keyboard, touch screens and voice activation) hardware. The MMI is the component of a process control system that most process managers use routinely because it allows the manager to acquire needed trending information and to interact with the process (Figure 2). Remember that you are using a personal computer so have the software application personalized to meet you specific requirements.

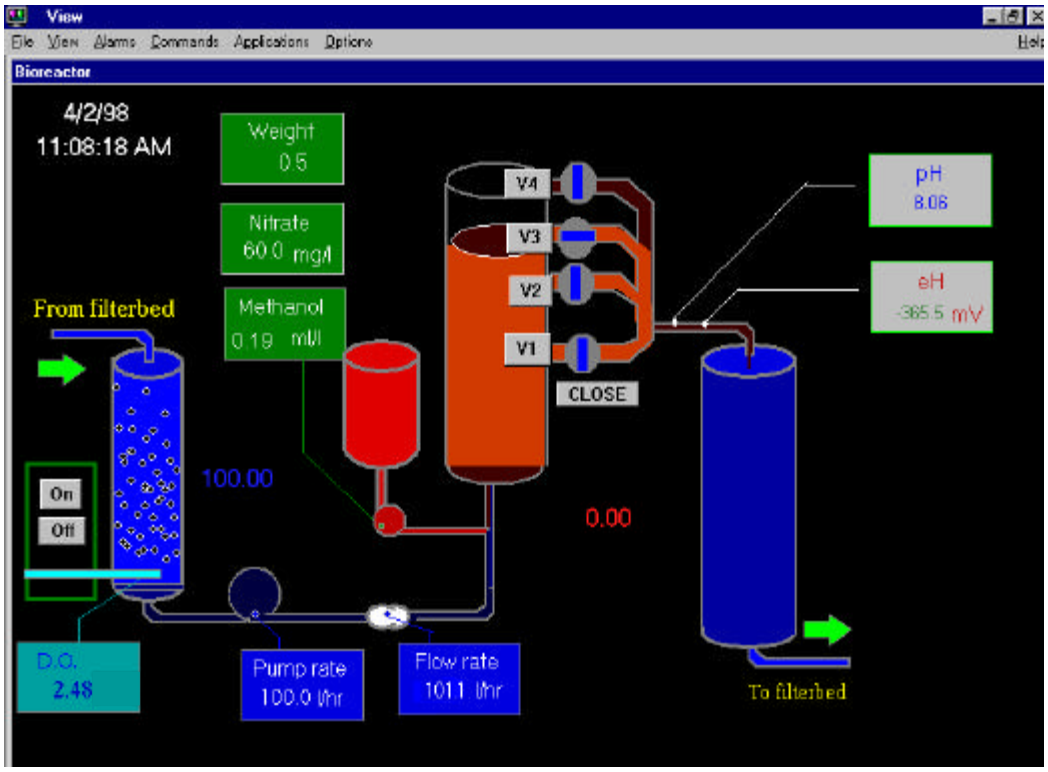

Figure 2. The MMI for an automated denitrification filter (Lee et al. 1995). Note the data windows, interactive buttons for valves, on/off buttons and animation of bubbles.

Historical trending. Historical trending is used to analyze process trends, archive process data, monitor efficiency of process, and analyze post-process data. The historical assign, collect and display programs allow the manager to sample real-time data from the DIT at user selected rates and then to store to disk and display as process displays. The historical assign program defines your collection strategy, allowing you to identify data that you want to collect (i.e. place in a database). The historical collect program collects data that is stored in disk files; historical display programs are used to display data in user-defined trend charts.

Recipe builder. This module allows the manager to design, implement and run recipes for a process. It also provides a flexible method for keeping an audit trail; this is particularly useful if the process requires the operator to change many process database values frequently. Examples of aquaculture applications would be batch processes such as algae or micro-invertebrate culture. The manager would first create a master recipe using the database builder and tagnames. This master recipe would embody the expertise of the algae culturist. For each particular batch of algae, it might need to be modified somewhat based on batch size and species so that a control recipe would be formulated from the original master recipe.

Tag group editor. This module simplifies recipe and display management by providing a means for accessing similar database information at different times using a single picture or symbol. For example, a large aquaculture facility is generally composed of many similar tank systems in which only some variables may vary (e.g. feeding rate, temperature and photoperiod). It would be unnecessarily repetitious to use the database builder to configure every individual system. The tag group editor allows you to reduce development time by defining one display and/or one control logic chain for all the similar groups of tagnames (i.e. tanks).

Report generator. The report generator is used to collect essential or critical data into a report for use by the manager or other users to make decisions on the process efficiency. Report generation can be internal to the process control software or require a NetDDE® link so that any DDE compatible application (e.g. Excel® or Lotus®) can be used to prepare reports. Either method can be automated such that certain reports are printed or displayed on a video monitor on a fixed schedule. Examples of useful reports would be production statistics, feed efficiency projections or weekly water quality records.

Relational databases interface. This interface module lets the manager collect and write real-time data from the process database to an external relational database (e.g. Access®, dBase® and Oracle®) for future use. These relational databases must conform to industry standards for open database connectivity (ODBC) and sort, query & logic (SQL). It also allows you to read data stored in relational databases and write it back to a process database.

DDE server. One of the attributes of the Windows® operating system is dynamic data exchange (DDE) in which real-time and historical data can be exchanged between two DDE compliant programs, using shared memory automatically. This exchange of data can occur on a single computer or across a network to a remote node. The ability to act as a server (application that provides data) or client (application that receives data) to other application software opens up many possibilities for control paradigms and report generation. In order for DDE to work, your computer's software must have both a NetDDE® server and client mode (these are provided in Microsoft's Windows for Workgroups™ and higher operating systems or may come as part of the process control software).

Security. The process control software should allow the manager to assign various levels of access to the different modules, monitor displays, critical program functions and databases comprising the complete software system. This is usually done through a password that enables a user to access certain security areas. A security area is a group of database blocks or chains with the same security level. A user who signs on in a particular security area can

change database blocks in that area but not in other security areas. In practice, this might mean that a technical level employee might be able to access the monitor displays and acknowledge alarms for their area of responsibility but that they could not make any changes to database blocks. A financial officer might only be able to access security areas dealing with materials flow and utilities. The manager could have access to all areas.

Alarm and messaging. Process control software should have capabilities for generating, displaying and storing a variety of alarms and messages. You should be able to route these alarms or messages to any computer linked to the system (i.e. node), printers, disk-based files, alarm summary displays, alarm history displays, message boards and phone dialers. The most common is a database block alarm in which a database block generates an alarm when block values fall outside the upper or lower set point, a change in state occurs or when communications fail. These alarms are displayed in an alarm manager display and can be routed to audible bells, message boards and/or phone dialers; they usually require acknowledgment from the user. The second is a block message that usually goes to a printer or alarm history file to document an event at that block. The third is a operator message that makes a historical record of important operator actions. The fourth is a system message that generates messages associated with errors in the software. The fifth is an application message that documents activity in another software module (e.g. recipe builder and historical collect).

Remote dialer. The remote software should make real-time, historical and alarm information available across a modem to other process control nodes in remote locations. To be most useful a remote node should be able to (1) receive real-time alarms and messages from the process node, (2) view the real-time monitor displays on the process node, (3) make changes to the database blocks, (4) retrieve and display historical data and (5) copy files over the modem. The remote utility should have adequate security in place so that only those users with privilege for a specific security area can access the process node from a remote node.

Statistical control. The theory of statistical process control (SPC) is based on the assumption that a process will remain stable (i.e. within statistical limits) unless an unexpected event occurs. The role of the SPC software is then to resolve this event from background process noise as soon as possible, connect the process back to its stable range and identify the cause for the instability (Dybek, 1989). A statistical control module enables the user to use statistical analyses to trend the process, setting the upper and lower control limits of the process based on any combination of input and output blocks. These modules provide not only control features but usually include a variety of statistical analysis presentation graphics (Wolske, 1989).

Artificial intelligence. Modern artificial intelligence (AI) systems can be divided into three main classes, expert systems, fuzzy logic systems and neural nets (Rock and Guerin, 1992; Bechtold, 1993; Studt, 1994). In the past, AI software was very expensive and had greatly varying functionality. Expert systems require defined rules (IF and THEN statements) or graphical knowledge (flow charts or logic trees) to be formulated by process experts (Bechtold, 1993, 1994). Fuzzy logic systems do not require defined rules or knowledge but use fuzzy rule-bases that emulate the intuition of process experts (Czogala and Rawlik, 1989; Karr, 1993). Neural nets behave differently in that they use three-dimensional neurons

(processing elements) to learn to control a process using incoming real-time data (Chester, 1992). While all of these systems have their specific advantages (Padala and Zilber, 1991), the use of fuzzy control logic most closely approximates the routine management decisions made by an aquaculturist who is part scientist and artist (Lee et al., 1995; Whitsell et al., 1997).

Simulation development. Process simulation can be used to replicate or model an existing or proposed process. It is most useful for evaluating the function of a control paradigm before implementation but can be used to fine tune or to train personnel in the operation of an existing process control system (Dowling and Sullivan, 1993). The simulation software should (1) operate on the same hardware and in the same operating system as the control system software, (2) allow development to be interactive, (3) have predefined algorithms as well as user-defined algorithms for process functions and (4) allow implementation with minimal changes to control system software. Interactive modeling in real-time is the key advantage of such systems; estimates of the time saved in implementing a new process control paradigm suggest that development time can be cut dramatically (Nisenfeld, 1989).

Basic Set-up and Operation

The first task is to use your specific I/O driver configuration software to specific the data that you need to acquire for the DIT. The second step is the creation of the process database, including reads and writes to the DIT, calculations, process control logic and outputs to MMI devices. The database builder is used to configure how each data point and database block will be processed. The third step requires the use of the graphics application to construct the MMI, archive and access data and generate reports. Once the process database is constructed, you use a draw program to create displays (i.e. easy-to-understand pictures) of the process data. You can then use any number of other modules (e.g. tag group editor, recipe builder, macro editor, historical collect and assign, DDE server and report generator) to customize the software to meet the manager's requirements. Finally, the manager will define the security areas in the system and assign security levels to all employees who will use it.

Purchase criteria

The selection of software almost always comes down to some combination of perceived price performance and trust in the manufacturer.

Functionality/intuitiveness. You should evaluate whether the potential software can accomplish the bottom line goals that you have set for your automated system. These should be production or economic goals not engineering goals. The software should not require an excessive time for the manager and staff to navigate through the screen displays and find the information that they need but may require higher level computer skills to install and set-up. The most effective way to evaluate the functionality of the product is to acquire a demonstration copy and verify all control functions, displays, alarms and messages, security procedures, DDE links and mathematical algorithms with valid and invalid data inputs before purchasing (Walters, 1994). Other good methods to access functionality is to (1) determine the extent to which the product is used in your industry, (2) discuss its functionality with

current users and (3) evaluate the vendor's experience in solving the kinds of problems that will be critical for your control system.

Modularity/flexibility. Modularity provides the benefit that system components can be added, moved or deleted as necessary without jeopardizing the integrity of the whole control system (Wolske, 1989; Walters 1994). This is important for both the software and the hardware. The benefits for modularity in software are that you will not have to buy unnecessary features and that you can upgrade features later. With hardware, the selection of modular communication devices, transmitters, meters, sensors and actuators means that a system can be implemented quickly and modified without major time delays. Modular design also means that once one aquaculture tank monitoring and control system is designed and implemented in your facility, it is easily replicated for all other tank systems.

Compatibility. Compatibility or connectivity is the measure of how a software product will function with the myriad other product choices that you will be making in designing and implementing your control system. In terms of hardware compatibility, it means your software should offer a wide range of I/O drivers that are simple to implement (Wolske, 1989). In terms of software compatibility, it means using software that contains most of today's enhancements (e.g. direct dynamic exchange, DDE; object linking and embedding, OLE; shared libraries or dynamic link libraries, DLL; object-oriented programming; wizards and multimedia systems). If the software is a proprietary product designed for only a small range of hardware, you will undoubtedly encounter a problem with interfacing a second party sensor or phone dialer.

Upgrade path/service. Upgrade path is the most critical aspect for evaluating a software program, yet it is the hardest to evaluate because its effects will be felt in the future. One of the salient characteristics of computer technology is that nothing will remain static for very long. In practical terms, this means that process control software will continue to improve; it will become more demanding on system resources, requiring software and hardware upgrades (Labs, 1992). The best recent example of this has been the migration of PC users from Microsoft's DOS™ to Windows™ to Windows for Workgroups™ to Windows 95-97™ to Windows NT™. There are three things that you should remember; (1) you do not have to upgrade, it's your decision (Huber, 1994), (2) if you buy from stable vendors, your applications will work well with whichever operating system it is designed to use, and (3) your process control system will become so valuable to you that you will be seeking to improve its productivity constantly.

Price performance. Finally, all the above criteria must be balanced against the cost of purchase of the software. This decision should be made based on a "Top Down" approach, meaning that the selected system must meet your economic goals not just make the process easier to manage (Christie, 1989; Lee, 1995). While the latter may be important to your employees, the real business reason for considering a process control system is to increase production, reduce labor and material costs and/or reduces waste.

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Water Quality – Types of Analyses and the Equipment Used

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In Aquaculture the quality of the water being used is critical to the success and viability of the products grown. Some of the parameters that are measured include:

- pH
- Alkalinity
- Hardness (Ca^{2+}, Mg^{2+})
- Dissolved Oxygen
- Temperature
- Ammonia, Nitrate and Nitrites
- Total Dissolved Solids/Salinity

pH

Sorensen first introduced the concept of pH in 1909 to measure the acidity of water used in the brewing of beer. It is a measurement of the H^+ activity in solution. The standard pH scale is 0 – 14 and this refers to the H^+ concentration of 10^0 to 10^{-14}.

$$pH = -\log\{H^+\}$$

The hydrogen activity may be thought of as the free ion rather than the total.
For example the pH of 0.1M HCl is ~ 1.03 and the pH of 0.1M Acetic acid is ~ 3.
This is because HCl is almost completely dissociated whereas acetic acid is mostly associated. The hydrogen activity is 10^{-3} in acetic acid.

The activity of the hydrogen ion can also be affected by the presence of salts in solution. In dilute solutions a cloud of neutral water molecules surrounds the H+. Whereas, if a significant amount of salt is added the H^+ moves through a cloud of charged species and is "less free". This means we can change the hydrogen ion activity (hence, pH) by adding an inert salt like KNO_3 or NaCl.

The warmer water gets the easier it is dissociated into H^+ and OH^-. Neutral pH is when $[H^+] = [OH^-]$, as the dissociation constant increases the pH changes i.e. as the temperature increases the more H^+ is free which reduces the pH value (more acidic).

For years pH measurements with the use of indicators was acceptable. In the modern lab the requirements are more stringent the standard method is to use the versatile glass pH electrode and an appropriate meter.

Thanks to modern technology, the potential of the external surface of the glass membrane parallels to a remarkable degree that of the hydrogen gas electrode, the primary reference for hydrogen ion measurements.

The glass electrode is still the standard measuring element in the measurement of pH. Although in recent years the use of microfabrication techniques has produced the solid state electrode which parallels the glass electrode very well. Each has its use in different applications, especially in areas where glass poses a hazard to the sample environment.

Orion offers a number of products to meet the needs of the market. Our line consists of the Standard, Ross and the Per**pH**ec**T**® electrode lines. The Standard line utilizes the Ag/AgCl reference junction and is economically priced. Ross utilizes the unique reference system that offers stable fast results regardless of temperature or sample composition.

The Ross electrodes give a better temperature compensation due to the liquid/liquid reference junction. It has no metal ions hence reduces the possibility of clogging of the reference with precipitated AgS.

The unique design of the Sure-Flow reference junction facilitates easy cleaning for difficult samples.

The per**pH**ec**T** line of pH electrodes with either Ross or Ag/AgCl reference offers the most accurate pH measurements that Orion has to offer especially when using the Per**pH**ec**T** line of pH meters containing our patented digital LogR™ technology.

The meters are either handheld or bench type with a variety of features which include waterproof, RS232, temperature compensation, automatic shut off, millivolt/ORP, reading 0.1/0.01pH range.

For customers that do not require the sophistication of an electrode and a meter but requires a screening device for pH we have AQUAfast™ test strips for the ranges 1 – 12 and 4 – 9 pH.

Selecting the Right pH Electrode

Cross-reference the required pH precision with the sample type or condition to find which Orion pH electrodes are appropriate for your application.

Required pH Precision	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.05 to 0.1**
Sample Type or Condition	Per**pH**ec**T** Model No.	ROSS Line Model No.	Standard Line Model No.	Tris Line Model No.	Micro Model No.	Economy Model No.
General Purpose Most sample types	82-02, 82-56, 82-72, 92-02, 92-06, 92-07, 92-56, 92-72	81-01/80-03. 81-01/80-05, 81-02, 81-04, 81-56, 81-72	91-01/90-01, 91-02, 91-04, 91-07, 91-56, 91-57, 91-62, 91-65, 91-72	71-02	—	91-06
Biological/Pharmaceutical Proteins, Tris, Enzymes	82-02, 82-03, 82-72, 92-72	81-01/80-05, 81-02, 81-03, 81-65, 81-72	91-01/90-02, 91-65, 91-67, 91-72	71-02, 71-03, 71-10	—	—

Required pH Precision	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.05 to 0.1**
Education/Student Use	82-56, 92-06, 92-07, 92-56	81-56, 81-65	91-07, 91-56, 91-57, 91-65	—	—	91-06
Emulsions						
Foods, Cosmetics, Oils	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-61/ 90-01, 91-65, 91-72	—	—	—
Petroleum Products, Paint	82-72, 92-72	81-01/80-03, 81-72	91-61/90-01, 91-72	—	—	—
Extreme pH						
pH > 12 or < 2	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-01/90-01, 91-65, 91-72	—	—	—
Acid/Fluoride	—	—	93-01/90-02	—	—	—
Flat Surfaces Foods, Cheese, Paper, Agar	82-35	81-35	91-67	—	—	91-36
Harsh Environments						
Field or Plant Use	82-56, 92-06, 92-07, 92-56	81-56, 81-65	91-07, 91-56, 91-65	—	—	91-06
Rugged Use	82-56, 92-06, 92-07, 92-56	81-01/80-03, 81-01/80-05, 81-04, 81-56, 81-65	91-61/90-01, 91-04, 91-07, 91-56, 91-57, 91-62, 91-65	—	—	91-06
High Ionic Strength Acids, Bases, Brines	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-01/90-02, 91-65, 91-72	—	—	—
Large Sample Sizes Tall Flasks or Bottles	—	—	—	—	98-26	91-26
Low Ionic Strength Treated Effluent	82-02, 82-72, 92-02, 92-72	81-01/80-03, 81-02, 81-62, 81-65, 81-72	91-01/90-01, 91-61/90-01, 91-02, 91-62, 91-65, 91-72	71-02	—	—
Non-Aqueous Solvents, Alcohols, etc.	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-61/90-02, 91-72	—	—	—
Semi-Solids Fruit, Meat, Cheese	82-63	81-63	91-63, **71-20**	—	—	—
Small Sample Sizes						
Test Tubes, Small Flasks	82-03, 82-35, 92-03, 82-63	81-03, 81-15, 81-35, 81-63, 81-75	91-03, 91-67	71-10	98-02, 98-03, 98-10, 98-26	91-16, 91-26
NMR Tubes	—	—	—	—	98-26	—
Micro-titer Plates	—	—	91-67	—	98-03	—
Steam Sterilizable	—	—	**91-90, 91-91, 91-92, 91-93, 91-94, 91-95**	—	—	—
Titration	—	81-01/80-03, 81-62, 81-66	91-64, 91-66	—	—	—
Viscous Slurries, Suspended Solids, Sludge	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-61/90-01, 91-65, 91-72	—	—	—
Waters						
Acid Rain, Boiler Feed, Distilled, Rain, Well	82-02, 82-72, 92-02, 92-72	81-01/80-03, 81-02, 81-62, 81-65, 81-72	91-01/90-01, 91-02, 91-65, 91-72	71-02	—	—
Drinking, Tap	82-02, 82-72, 82-56, 92-02, 92-06, 92-07, 92-72	81-02, 81-04, 81-65, 81-72	91-01/90-01, 91-02, 91-04, 91-07, 91-57, 91-65, 91-72	71-02	—	91-06
Sea water	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-02/90-02, 91-65, 91-72	—	—	—
Waste water	82-72, 92-07, 92-72	81-01/80-03, 81-65, 81-72	91-61/90-01, 91-07, 91-57, 91-62, 91-65, 91-72	—	—	91-06

Alkalinity

Alkalinity of water is due to compounds such as sodium or calcium hydroxide, carbonates or bicarbonates. The methods available for the measurement of alkalinity rely on either titration or colorimetric reactions some require the use of a photometer. Most of the kits available measure up to 300 ppm $CaCO_3$.

Most methods are based usually on titration using a buret or a “drop count” technique. Samples are titrated with an acid solution, which neutralizes the alkaline spieces present. Endpoint determination is observed by a color change or by titrating to a pH value of 4.5.

The volume of titrant is then used to calculate total alkalinity. Hence the terms total alkalinity or phenolphthalein alkalinity.

Both methods have limitations, since sample color or turbidity can affect the ability of the operator to detect the color change. Also the use of a burette or dropper is time consuming and not conducive to field use.

Orion offers a method for the measurement of Alkalinity using a standard pH meter and electrode with a specialized reagent and a pH conversion wheel.

The principle of the Orion test kit is the same as the conventional titration. A reagent composed of several acids react with the alkaline species in the sample. As a result the pH of the sample changes. The observed pH reading after the addition of the reagent varies directly with the total alkalinity. Each pH reading corresponds to a unique value for alkalinity, expressed in ppm $CaCO_3$.

Hardness

The methods available for calcium and magnesium hardness testing are all based on titration with EDTA. There are a few companies that utilize the titration in a kit form. The range of measurement for the kits is 0 – 30, 0 – 300 ppm and 100 – 4000 ppm. Orion Research offers a titration method for Hardness using our model 960 titrator.

We also have AQUAfast™ test strips for measuring total hardness in the range of 0 – 445 ppm.

Dissolved Oxygen

Dissolved Oxygen (DO) levels in natural water depends on the physical, chemical and biochemical activities in the water. The analysis of the dissolved oxygen content of water used for Aquaculture is a key component to a viable business.

The classical method of measuring DO in water is with the Winkler or Iodometric titration. This method is tedious and is a “snapshot” of the dissolved oxygen in the water and does not lend itself to measurements in the field. Modern methods include the use of meters and probes for the measurement of DO. Their portability and ease of operation and maintenance make them particularly convenient for field applications. The probes are either of the galvanic or polarographic types.
The oxygen sensitive membrane electrodes of the polarographic or galvanic type are composed of two solid metal electrodes in contact with supporting electrolyte separated from the test solution by a selective membrane.

The basic difference between the galvanic and the polarographic systems is that in the former the electrode reaction is spontaneous, while in the latter an external source of applied voltage is needed to polarize the indicator electrode. Polyethylene and

fluorocarbon membranes are used commonly because they are permeable to molecular oxygen and are relatively rugged.

Membrane electrodes are commercially available in some variety. In all of these instruments the diffusion current is directly proportional to the concentration of molecular oxygen in solution. The current is converted easily into concentration units by a number of calibration procedures.

The rate at which oxygen crosses the membrane is directly proportional to the partial pressure of oxygen in the solution. There are a number of factors that affect the sensor operation. The partial pressure of oxygen will change with altitude (barometric pressure). Since the sensor consumes oxygen, the sample must be stirred to present fresh oxygen to the membrane i.e. oxygen must arrive at the membrane faster than the sensor consumes oxygen.

The rate at which oxygen diffuses through the membrane varies with the temperature. Coefficients are typically 3 to 5% per ^{o}C. Changing the temperature from 20 to 15 ^{o}C can reduce the oxygen diffusion by 20%.

The best meters and probes have separate thermistors to measure probe temperature and correct for change in diffusion rate.

Exposure to high levels of gases such as Nitrous Oxide and Chloride can poison the sensor.

The sensor reads the partial pressure of the oxygen, to convert to a meaningful unit such as concentration means knowing the solubility of oxygen in water at that Temperature, Total pressure and Salinity. This is accomplished by look up tables also some meters have the tables built in to them.

We sometimes use percent saturation which is the actual concentration compared to the "theoretical" complete saturation.

To understand why the pressure, temperature and salinity affect oxygen solubility, consider Henry's law: "The partial pressure of a gas dissolved in a liquid is the same as the partial pressure of the gas in the vapor above the liquid".

In warm solutions the amount of oxygen that will hit the surface increases, therefore the oxygen content is reduces as a result of increases in temperature.

Oxygen Concentration in Air-Saturated Water

Temp. in ^{o}C	**O_2 mg/l**	**Temp. in ^{o}C**	**O_2 mg/l**	**Temp. in ^{o}C**	**O_2 mg/l**	**Temp. in ^{o}C**	**O_2 mg/l**
0	14.64						

1	14.23	11	10.99	21	8.90	31	7.42
2	13.83	12	10.75	22	8.73	32	7.3
3	13.45	13	10.51	23	8.57	33	7.18
4	13.09	14	10.28	24	8.41	34	7.05
5	12.75	15	10.06	25	8.25	35	6.94
6	12.42	16	9.85	26	8.11	36	6.83
7	12.11	17	9.64	27	7.96	37	6.72
8	11.81	18	9.45	28	7.82	38	6.61
9	11.53	19	9.26	29	7.69	39	6.51
10	11.25	20	9.08	30	7.55	40	6.41

Salts dissolved in solution also affect the dissolved oxygen concentration. Salts in solution take up water (hydrate) leaving less water for the oxygen to dissolve in.
As a result as the salinity increases the dissolved oxygen decreases.

Dissolved Oxygen probes and meters are calibrated using either water saturated air or air saturated water. This is due to the fact that the partial pressure of oxygen in water and the vapor phase are the same at equilibrium. In practice calibration is done in water saturated air, since it is very difficult to determine if water is fully saturated with air.

Orion offers a number of systems for the measurement of DO, they vary in feature such as temperature compensation, salinity correction, barometric correction, RS232 etc. The probes vary in the needs of the market that they serve, all probes feature a removable membrane cap with fill solution. They also vary in cable lengths and whether they are dual or single thermistors.

Ammonia, Nitrate and Nitrites

Measurement of Ammonia, Nitrates and Nitrites is very important in the Aquaculture market. High levels of Ammonia can kill fish. There are a variety of methods to measure these species most are based on analysis by titration. However, the ISE (ion specific electrode) has become a standard for quick low level analysis. Large ranges of species are available and methods for a number of diverse applications exist.

The total papers being written with applications for the use of ISE technology is increasing year after year. In 1989 alone there were almost 7,000 papers on ISE's.
Why so much interest in ISE? Well, because the technology:

- Well accepted
- Rugged and Durable
- Simple to use
- Inexpensive
- Numerous applications

The electrodes come close to the ideal analytical device “a probe that can be dipped in any sample and the concentration read out directly”.

ISE’s have a membrane that is slightly permeable to one specific ion. If there is a difference in the concentration of the ion on the two sides of the membrane, it will tend to diffuse from the high side to the low side, but the law of electroneutrality prevents this. The “tendency” to diffuse expresses itself physically as a potential difference.

The total number of ions that actually diffuse across the membrane is very small. However, the potential across the membrane is proportional to the logarithm of the difference in concentration on the two sides of the sensing membrane.

The types of sensing electrodes are Solid State, Liquid membrane, Glass membrane and Gas sensing electrode.

The solid state sensing element is a solid crystalline material i.e. Bromide, Chloride, Chlorine, Fluoride electrodes etc.

The Liquid membranes the sensing element is conductive plastic i.e. Ammonium, Calcium, Nitrate electrodes etc.

The Glass membrane the sensing element is a special type of glass i.e. pH and Sodium electrodes.

The Gas sensing electrode’s work by measuring the pH change caused by diffusion of a gas through a hydrophobic but porous membrane.

Orion has a large offering to the ISE user with electrodes from Ammonia, Nitrate, Nitrite to Water Hardness with the appropriate Ionic Strength Adjusters, calibration standards and filling and maintenance solutions.

We also offer AQUAfast™ test strips for Nitrate and Nitrite in the range 0 – 500 ppm and 0 – 80 ppm respectively.

Total Dissolved Solids/Salinity

Total Dissolved Solids and Salinity can be measured with a Conductivity electrode and meter. Based on the reading of conductivity value lookup tables will give the appropriate Salinity value, most meters have the lookup tables built in.

Conductivity is an inherent property of a material at a particular temperature and will always have the same conductivity. It can be measured using two parallel platinum plates of 1 sq. cm. at 1 cm apart.

The conductance of a sample depends on how the measurement is made i.e. how far apart the electrode plates are, the volume of sample between the plates etc. It is defined as the reciprocal of the resistance in ohms. The basic unit of conductance is ***Siemens*** **(S)** and was formerly called the mho.

Because the measurement gives conductance , techniques have been worked out to convert the value into conductivity, this is done by measuring the cell constant for each setup.

The cell constant (k) is related to physical characteristics of the measuring cell.

In practice the cell constant is entered into the meter and the conversion to conductivity is done automatically. The k value used varies with the linear range of the cell selected. Typically, a cell with a k=0.1 cm^{-1} is chosen for pure water measurements, while for environmental water and industrial solutions a cell with k of 0.4 to 1 is used. Cells with k values of up to 10 cm^{-1} are best for high conductivity samples.

Some Conductivity Values of Typical Samples

Samples at 25 ^{0}C	**Conductivity, uS/cm**
Ultapure Water	0.055
Power Plant Boiler Water	1.0
Drinking Water	50
Ocean Water	53,000
5% NaOH	223,000
50% NaOH	150,000
10% HCl	700,000
32% HCl	700,000
31.0% HNO_3 (Highest Known)	865,000

Some Typical Temperature Coefficients

Sample	**Percent/ °C (at 25 °C)**
Ultrapure Water	4.55
Salt Solution (NaCl)	2.12
5% NaOH	1.72
Dilute Ammonia Solution	1.88
10% HCl	1.32
5% Sulfuric Acid	0.96

98% Sulfuric Acid	2.84
Sugar Syrup	5.64

4-Electrode Cell Theory and Practical Advantages

The approaches discussed earlier can not correct for deposits which form on the surface of the electrodes, and which subtract from the measured conductivity of the sample. A more sophisticated approach uses the 4-electrode technique. The operational theory is discussed below. Not only is the 4-electrode technique superior in terms of ability to function in "dirty" solutions, but one cell with a single cell constant can cover almost the entire 7 decade range (except for pure water) of three ordinary cells. A number of technical advancements allow this.

4-Electrode Cell Measurement Theory

4-electrode conductivity measurements offer the user significant advantages, particularly in high conductivity solutions. These advantages include minimizing the effect on measurement accuracy from electrode polarization and contamination, as well as eliminating error from cable resistance and connector resistance.

4-electrode conductivity cells contain two drive (current) electrodes and two sense (voltage) electrodes. An alternating voltage powers the drive electrodes, and the alternating current that flows is measured to determine the conductivity. The voltage measured at the sensing electrode controls the amplitude of the alternating voltage applied to the drive electrodes. Since the sense electrodes are positioned in a low current area of the cell, and this voltage is measured using a high impedance circuit, it represents with high accuracy the strength of the electric field within the cell. Using this signal to maintain the cell field strength at a constant, the current that flows at the drive electrodes is proportional to the conductivity of the sample, and the errors due to polarization, contamination and cable resistance’s are minimal.

Polarization Errors

Polarization errors occur in the case of 2-electrode cells at the boundary layers between the measuring electrode and the ion conducting measuring medium. These effects can be compensated for with the 4-electrode system, and do not contribute an error.

Contamination of Electrode Surfaces

Deposits on the electrode surface of a 2-electrode cell have a similar effect to polarization errors that is the conductivity reading is lower than actual. These effects are also compensated with the 4-electrode system. Conductive deposits will have no effect on the accuracy of the cell, and errors due to insulating deposits have been shown to be three times lower than comparable 2-electrode cells.

Cable Resistance

Cable resistances add to the measured sample conductance in the case of a 2-electrode cell. This resistance is compensated for with the 4-electrode cell, and no error occurs. This is of particular importance in environmental work, where measurement in wells and boreholes may require cable lengths of up to 100 meters.

Geometry Related Errors - Fringe Field Effects

Fringe field effects also cause errors. This is the part of the measuring field that "bulges" outside the theoretical 1 cm cube described previously. This error can be calibrated out of the measurement, but can subsequently affect the measurement if anything interferes with the field, such as the side of the measuring vessel. Advanced conductivity cells are designed to minimize this effect. If the entire measuring field is contained within the body of the electrode, then the side of the sample vessel cannot cause fringe field errors.

Durability

Cell materials should be chosen to fit the needs of the application. For field and demanding laboratory applications, many users choose a cell constructed with an epoxy body and carbon measuring electrodes, as this has been shown to be extremely durable and chemically resistant. For especially demanding applications, some manufacturers supply probe guards, which can be attached to the probe for additional protection. For pure water applications, stainless steel is frequently the material of choice. It is very durable, can be manufactured to precise tolerances, and for low conductivity, low contact resistance’s are not required. For chemically reactive samples, glass and platinum are frequently the optimum choice, as they have the best overall chemical resistance of all commonly used cell materials.

Orion offers cells and meters for a variety of industries with different features such as Salinity, TDS, temperature correction, data-logging capabilities etc. The variety of probes range from glass with platinum to the epoxy graphite 4 cell probe.

Various Types of Meters and Transmitters for Use in Aquaqculture, Their Proper Placement, Maintenance and Operation

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Abstract not available at time of printing.

Water Quality Monitoring and the Fifth Age of Computing

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Abstract

Perhaps because of the perception of complexity and cost, only a small percentage of aquaculture practitioners have adopted computerized process control technology to achieve reductions in operating costs, and/or increases in production yields. Where utilized, such systems are frequently maintained by skilled employees using custom programmed applications dedicated solely to the monitoring high-value species.

Recent trends in the computer and networking industry are beginning to have an impact on the design of water quality instrumentation. Low-cost *application specific* monitoring and control instruments that are designed specifically for aquaculture applications are just now being introduced. Programming and operating these instruments is very similar to programming a cellular telephone. English language menu prompts entirely replace cryptic programming methods. The need for specialized programming skills is significantly reduced or eliminated.

We are now entering the age of ubiquitous computing –an era that some refer to as the *Fifth Age of Computing.* In this era, we will use all sorts of devices –each with more computing power than the PCs of the 1980s or the mainframes of the 1960s and 1970s. These devices will be optimized for specific applications such as managing recirculating aquaculture systems. But they will also be capable of inter-operating with other devices to create a complete network-based decision support system –all at a fraction of the cost you would expect.

The purpose of this paper is to introduce the Fifth Age of Computing where sensors will be connected directly to a network, and where the LCD instrument display will be replaced by a portable PDA or Windows CE computer. A special emphasis will be placed on discussing the important role that the Internet and wireless communications will play in the design of monitoring and control devices of the future.

Settling Basin Design and Performance

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Abstract not available at time of printing.

Constructed Wetlands for Water Treatment in Aquaculture

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Introduction

Wetlands

Natural wetlands have long been regarded as important ecosystems that provide habitat for many types of aquatic and riparian plants and animals. In addition, natural wetlands play an important role in restoring the quality of the water that passes through them by reducing suspended solids, removing nitrogen and phosphorous nutrients, and trapping or converting other natural or man-made pollutants (Hammer, 1997; Kadlec & Knight, 1996).

Considerable interest has developed in trying to understand the mechanisms at work within natural wetlands, and to model and incorporate their positive water treatment features into artificial or "constructed" wetlands (Moshiri 1993; Hammer 1991; Reed, Middlebrooks, & Crites, 1988). Within the last decade, numerous constructed wetlands have been built to replace the loss of natural wetlands, to provide additional plant and animal habitat, to provide new aesthetic and recreational environments for people, and for use as water treatment systems for several types of municipal, industrial, and agricultural wastewater.

Constructed Wetlands for Water Treatment

As water resources become increasingly scarce, and standards for the quality of wastewater effluents become more stringent, the traditional approach for wastewater treatment is becoming more expensive. Constructed wetlands are often selected as a less costly alternative to the more typical wastewater treatment plant. In some applications, this technology may be employed for less than 1/10th the cost of conventional sewage treatment systems. It often involves lower construction costs, lower maintenance costs, simpler designs, and lower pumping heads (Olson 1993).

Types of Constructed Wetlands

Constructed wetlands have been classified into two general types; free water surface wetlands (FWS) or subsurface wetlands (SF). Free water surface wetlands have their water surfaces exposed to the atmosphere while subsurface wetlands have their waters submerged within a layer of rock, gravel or other water permeable media with no water visible above ground (Reddy and Smith 1987, Reed 1990). FSW wetlands are usually less expensive to construct and operate, while SF wetlands may require less land, and can reduce public contact to the water within the system (U.S. EPA, 1992).

Kent Seafarms Constructed Wetlands

Kent Seafarms has operated a large-scale intensive hybrid striped bass production facility in the southern California desert since 1984. This operation near Palm Springs currently produces over 1.3 million kg of hybrid striped bass annually. These fish are raised in 96 circular concrete tanks at an average density of 50 kg/m3, utilizing a limited supply of 26°C well water.

Several years ago, we began a research effort to recirculate a portion of our water through a series of open-water ponds. The objective of this effort was to evaluate whether a fraction of the water flow could be nitrified and reused for additional production within our intensive striped bass rearing system. We utilized 14 fingerling production ponds of 0.6 hectare x 1 m depth each that were no longer needed for fish production purposes. These open-water ponds were connected in series and supplied with untreated and unsettled farm effluent having an average of 3-5 mg/l of total ammonia nitrogen (TAN). With little maintenance effort required, the ponds were shown to be capable of reducing TAN to 0.25 -1.0 mg/l, at input flows of up to 4,500 liters/minute (1,200 gpm) of untreated water. Although summer treatment was certainly a function of strong algal productivity, continued ammonia reduction through the winter months (when algal densities were very low) suggested that significant nitrification activity was occurring.

Based upon these results, we believed it would be useful to undertake a program to develop FWS constructed wetlands, particularly if the added bacterial substrate of such wetlands could optimize nitrification without stimulating algal blooms common to open-water ponds.

Methods and Results

Beginning in 1995, Kent Seafarms, with funding provided by the Department of Commerce's Advanced Technology Program, designed and constructed an experimental aquaculture wastewater treatment system consisting of three separate components. It consists of a biological particulate removal system, a bacterial nitrification reactor, and a constructed FWS bulrush wetland for final nutrient and solids removal. This system is

being evaluated for its potential to treat and recirculate water leaving our striped bass tanks, as well as providing treated water to other agricultural and recreational users.

The design treatment goal for the recirculating striped bass production system is to maintain maximum ammonia concentrations at less than 3.5 mg/l. Water inputs consist of approximately 11,000 l/min of well water combined with an anticipated "treated" recirculated flow of 38,000 l/min (total flow of 49,000 l/min). This water is expected to support a standing crop of 400,000 kg of hybrid striped bass at a total daily feed level of 5,700 kg of feed.

The final treatment component of this system is a constructed FWS bulrush wetland. Its purpose is to act as a suspended solids clarifier and polishing nitrification reactor prior to recycling "treated" water back to the striped bass production system. The remainder of this paper discusses preliminary results of our experiments with this constructed wetland component.

Constructed Wetland Design

We constructed 28 parallel earthen FWS wetland study ponds, each approximately 274 m X 9 m (16 ponds) and 212 m X 9 m (12 ponds). Each pond has a surface area of 2,508 m^2 or 1,895 m^2, respectively. All ponds were designed with an average water depth of 46 cm (18"), except ponds 27 & 28 which were deepened to 92 cm (36") to study possible effects of water depth. Each pond was supplied in parallel with up to 1600 l/min of striped bass effluent water, via gravity flow from our striped bass production tanks through a centrally located water distribution canal.

To establish the bulrush communities in our ponds, we followed the practices recommended by Allen et al. (1991) and planted the excavated earthen ponds with two native southern California species of bulrush, *Scirpus californicus*, and *Scirpus acutus*. These plants were selected for their demonstrated hardiness in our desert climate, tolerance to high ammonia and solids loading, availability, and successful utilization for nitrification in other constructed wetlands (Gersberg et al. 1986; Surrency 1993).

The following experiments were designed to study the primary effects of hydraulic retention time, water depth, and supplemental aeration on nitrification (Ammonia--> Nitrite---> Nitrate) in bulrush FWS wetlands:

Experiment 1 - Effects of Hydraulic Retention Time on Ammonia Removal

Nine of the 274 m long experimental wetlands, fully vegetated with bulrush, *Scirpus californicus*, were used in this study. Three replicates of three different water inflow rates were established to compare the effects of different hydraulic retention times (HRT) on ammonia removal as well as other water quality constituents. This experiment was conducted in 3 separate trials:

1) in the fall of 1996, with HRT's of 1.1, 3.5 and 7.7 days,

2) in the winter of 1996, with HRT's of 1.4, 6.9, and 12.8 days, and
3) in the spring of 1997, with much shorter HRT's of 0.6, 1.1, and 2.1 days.

Water quality parameters of influent and effluent water were measured by Kent Seafarms personnel twice weekly for all nine ponds. They included water flow rates, total ammonia-N (TAN), nitrite-N, nitrate-N, total nitrogen, pH, alkalinity, carbon dioxide, CBOD, dissolved oxygen, TSS, VSS, and temperature (APHA/AWWA/WEF, 1995). Data was analyzed with two-level nested ANOVA with equal sample size (Sokal, R.R. and F. J. Rohlf. 1981).

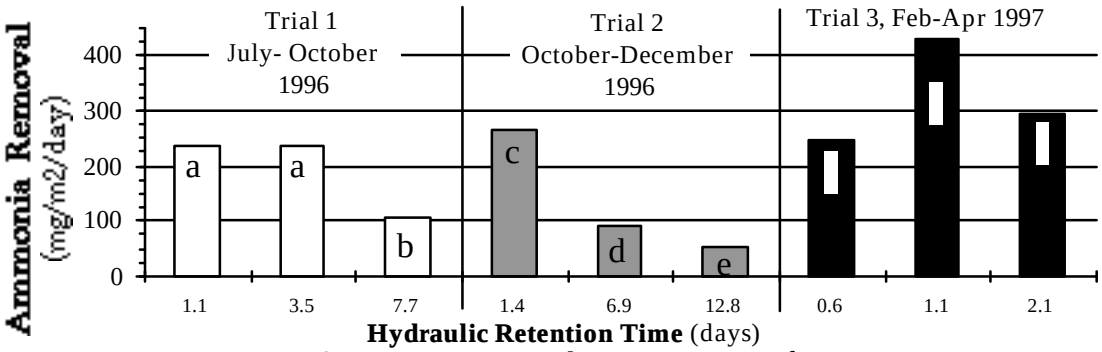


Fig. 1. Mass Ammonia Removal as a Function of HRT

*(*different letters within a trial are significantly different from each other at p<0.01)*

As shown in Figure 1, we observed significantly differing outcomes with respect to ammonia removal. The optimal hydraulic retention time (HRT) for the unaerated wetland ponds appeared to be no greater than 3.5 days, although no significant improvements were found with shorter HRT's.

The 0.6 to 3.5-day HRT ponds were able to remove between 237 to 433 mg $NH3/m^2$/day, depending upon season, whereas the best removal rate of the longer retention times was only 106 mg $NH3/m^2$/day for any season. However, in some cases, ponds with a 0.6-day retention time actually showed some net ammonia production. Because additional ammonia is generated during decomposition of organic material within the ponds (ammoni-fication), we suspect that these results were due to the breakdown of volatile suspended solids produced by the fish, which were efficiently settled out in the wetland ponds. We believe that a disproportionate share of solids were captured in the high flow ponds due to a relatively constant effluent VSS, irrespective of water flow.

Experiment 2 - Water Depth effects on Ammonia Removal Rates

Wetland treatment processes are usually thought to be functions of wetland area rather than wetland volume (Kadlec & Knight 1996). However, our aquaculture application of constructed wetlands is primarily used for nitrification of high water volumes (40,000 l/min) containing low effluent concentrations of ammonia, TSS, and BOD (<5 mg/l, <25mg/l, <30 mg/l, respectively). Such high flows and low concentrations are typical of many aquaculture effluents, but are unlike most other municipal or agricultural

wastewaters which are often very high in BOD, ammonia, and organic solids. We were interested in determining whether greater wetland depths could be cost-effective, particularly for recirculated aquaculture applications where nitrification is often more important than total nitrogen control.

Two of the wetland ponds were excavated twice as deep as the other experimental ponds. When these were planted with bulrush transplants, the water depth was lowered to the 46 cm (18") typical of the other experimental ponds, allowing the bulrush to become well established. Once the plants had established, the depth was increased to about 92 cm (36") inches.

After allowing a full summer of growth for the bulrush to fully vegetate, studies were conducted in these ponds from January of 1997 to the present. Samples of effluent from each wetland were measured twice each week for temperature, dissolved oxygen, pH, and ammonia. Weekly measurements were taken for alkalinity, total nitrogen, nitrate, nitrite, and VSS. These measurements were compared to those taken in the shallow ponds, with water flow set at either the same flowrate (half the hydraulic retention time) or at half the flowrate (equal hydraulic retention time).

Since we expected possible seasonal differences, we conducted several trials. The first trial was defined as spring for January to March 1997. The second trial was defined as early summer for May to June 1997. During the latter part of this study, we installed supplemental aeration in all the ponds, a decision based upon early results of Experiment 1. Therefore, in trial 3, we compared depth effects under late summer aerated conditions (Aug. - Sept. 1997).

As seen in Figure 2, average ammonia removal rates of the two deeper ponds was as good or better than the shallow ponds in each trial. During the spring (without aeration), the deep ponds showed an average ammonia treatment rate of 292 $mg/m^2/day$, whereas normal depth ponds at the same HRT of 1.7-days exhibited treatment of 200 $mg/m^2/day$. During the early summer, we decreased the HRT of the deep ponds slightly to about 1-day, and observed an average treatment rate of 247 $mg/m^2/day$ in the deep ponds, but observed negative treatment of -13 $mg/m^2/day$ in the shallow ponds at the same flow rate (1/2 the HRT of deep ponds). We suspect the shallow ponds became oxygen limited at high water flow rates. During the warm summer, effluent dissolved oxygen levels averaged less that 1.5 mg/l.

After supplemental aeration was added, average effluent dissolved oxygen levels increased to 3 mg/l or greater , and we observed improved treatment of ammonia in all ponds. The ammonia removal rates were increased most in the deeper ponds (an average ammonia removal rate of 737 $mg/m^2/day$), as compared to 537 $mg/m^2/day$ for shallow ponds operated at the same HRT (1/2 the flow rate), and 473 $mg/m^2/day$ for ponds operated at the same flow rate (1/2 the HRT). With and without aeration, the deep ponds performed significantly better in almost every trial.

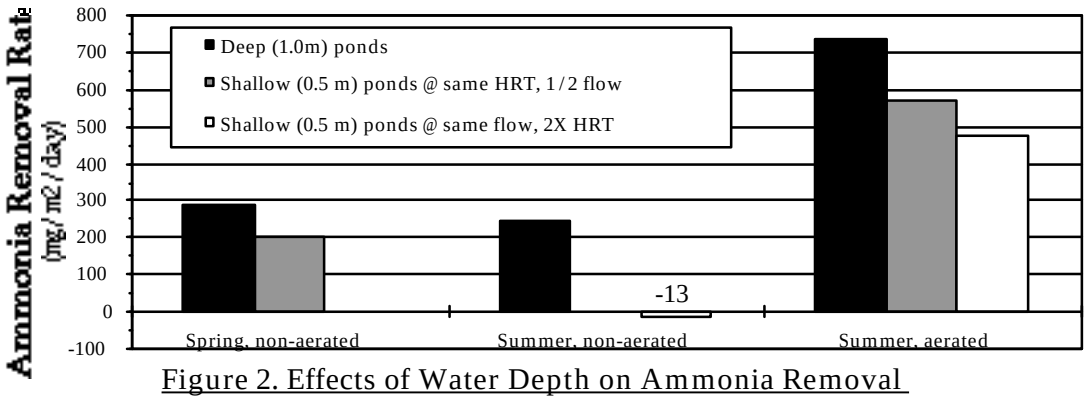


Figure 2. Effects of Water Depth on Ammonia Removal

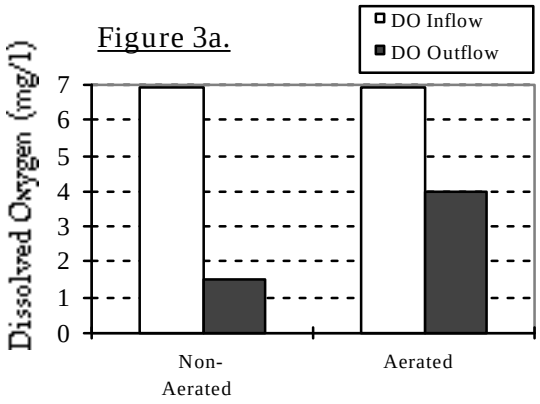
Experiment 3 - The Effects of Aeration on Mass Ammonia Removal Rates

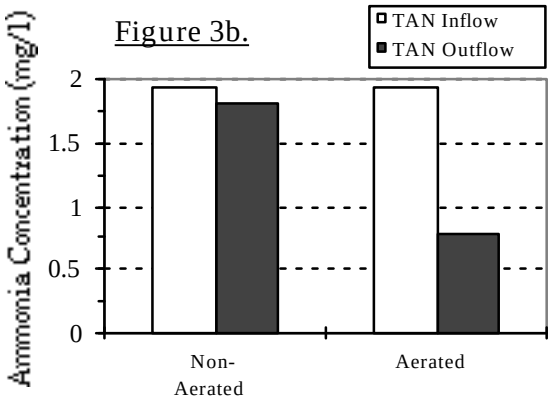
Since nitrification was a primary goal for our application of constructed wetlands, we realized that oxygen could become a limiting factor. Wetland plants have been shown to be capable of delivering oxygen from the atmosphere to the plants' root structure where it can be utilized by aerobic bacteria (Gersberg, 1986). However, the process is rate limited and controversy still exists as to whether such oxygen transport by plants is significant to the wetland's treatment capacity (Kadlec & Knight 1996). For our application, we believed we would have an oxygen shortfall if high hydraulic loading was to be achieved. Approximately 4.6 g of oxygen are required for nitrification of 1g of ammonia to nitrate (E.P.A., 1990). Since the effluent from our fish production tanks often reaches 3-4 mg/l of ammonia, we could expect an oxygen demand of at least 14 -18 mg/l of oxygen for nitrification alone, not including any other biological or chemical oxygen demand.

This experiment was developed to determine the effectiveness of supplemental aeration for economical enhancement of ammonia removal in constructed wetlands. Based upon the early results of Experiment 1, we were interested in whether aeration could significantly reduce the hydraulic retention time necessary for maximizing mass ammonia removal.

For this study, we excavated bulrush and soil to a depth of about 2 m below water level in equally spaced strips across each of four previously vegetated wetland ponds (six cut-outs per pond). In each cut-out, we placed a PVC pipe with three equally spaced air diffusers set about 2-3' below the water surface. All four ponds were aerated with a single regenerative blower delivering 2-3 cfm of air per diffuser. Twice weekly measurements were taken of the pond effluent for temperature, dissolved oxygen, pH, and ammonia.

Initial studies started in February of 1997 and compared aerated versus non-aerated ponds at two different HRT's. We repeated these same studies in early summer, April to May 1997, and late summer Aug. to Sept. 1997.





As shown in Figures 3a and 3b, the addition of mechanical aeration to provide supplemental oxygen to the wetland ponds was very important during the summer. Aeration was of most benefit in ponds receiving high water flows (short HRT). Aerated ponds operated at a 1-day HRT removed ammonia at an average rate of 470 mg/m^2/day. Aerated ponds operated at a 1/2-day HRT removed ammonia at an average rate of 295 mg/m^2/day. The ammonia removal rates for 1-day and 1/2-day HRTs represent a 23% and 160% improvement over non-aerated ponds, respectively.

Conclusion

Wetland wastewater treatment typically requires longer treatment times than other traditional approaches. Our retention studies indicated that passive wetlands can remove substantial amounts of ammonia over a 3 day retention time. Unfortunately, such effluent treatment rates seem long for aquaculture purposes, and might only be practical for treating final effluent discharges from highly recirculated aquaculture systems where effluent volumes are small. However, in the aerated wetlands, treatment time was substantially decreased such that constructed wetlands may have more usefulness for aquaculture reuse applications. In addition, “deep” ponds were 25% to 61% more productive at treating ammonia per square meter than “shallow” ponds, depending upon season. Added depth may provide an economical means to improve total treatment capacity, conserve land, and allow for better control over these systems.

The addition of constructed wetlands to Kent Seafarms operations appears to be a valuable asset for increasing fish production, conserving water resources, and lowering costs. These preliminary results indicate that under the right conditions, aerated bulrush wetlands may be capable of removing an average 200 to 400 mg NH3 /m2/day, or more.

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An Evaluation of Composted Fish Wastes

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Introduction

The qualities of waste materials from fish production facilities are highly variable, but can be considered in three primary groups: (1) pathogenic and bacteria or parasites, (2) therapeutic chemicals and drugs, and (3) metabolic products and food wastes (Beveridge et al. 1992; Piper et al. 1982). Of these, the first two are sporadic and are not yet the major concern among the byproducts of aquaculture, as evidence for their release in significant quantities is limited (Neimi and Taipalinen 1980; Odum 1974; Pitts 1990; Solbe 1982; Sumari 1982; UMA 1988). In typical single-pass fish culture systems, waste solids represents a significant proportion of the feed applied, with 300 g dry waste solids per kg feed suggested as an acceptable industry average (Willoughby et al. 1972; Mudrak and Stark 1981; Zeigler 1988). Using this average, the trout industry in the US produced approximately 18.3 million pounds of waste solids in 1997, presenting a waste management challenge to the producers. In recirculating aquaculture systems using low-density media filters, 14% of the feed weight ended up as sludge in the discharge from the system (Chen et al. 1993), but the individual design and mode of operation will determine the quantity of solids produced and captured within each culture system. In addition to metabolic and food wastes, fish carcasses from processing and from mortalities during production can present disposal problems.

Compost made from fish manure, sludge from biofilters, mortalities, or processing waste could provide an effective source of nutrient-rich organic matter. Instead of creating a disposal problem, composting these organic materials with a suitable carbon source creates a useful and potentially marketable product. Composting has been suggested and demonstrated as practical treatment method for fish processing wastes and mortalities (Frederick 1991; Liao et al. 1993), but has not been evaluated for fish manure or sludge from biofilters. This paper describes the analyses and evaluation of compost from fish processing wastes for the production of ornamental plants, and presents a description and initial observations on a system designed for composting fish manure and/or filter sludge.

Procedures

Fish processing wastes, primarily viscera, heads, backbones and skin from rainbow trout, were layered approximately 1:3 v/v with coarse hardwood chips in an aerated 3.3m x 3.3m wooden reactor vessel. The materials were layered to a depth of approximately 1.5 m, then allowed to compost in excess of 60 days. For plant trials, fish compost (FW) was compared with compost from wastewater biosolids (WB) for the production of dwarf nandina, and compared with compost from wastewater biosolids and municipal solid waste (MSW) for production of bluegrass-fescue sod.

Nandina Tests

Dwarf nandina was grown in a lathhouse in pots filled with mixtures of compost and pine bark at 0, 25, 50, 75 or 100% compost. A slow-release fertilizer (Osmocote, 18-6-12) was also added to each treatment at 5, 10, or 15 lbs/cu. yd. at the time of potting. Each treatment combination was replicated three times. Growth and color were evaluated visually by three observers using a scale of 1 to 10. A growth quality index (GQI) was determined for each plant by adding the maximum height plus the maximum width of each plant and dividing by two. The resulting number was multiplied by 0.01 x the corresponding plant density.

Sod Tests

Sod was prepared by seeding a bluegrass-fescue mixture (9:1 w/w) with compost from the different sources. Six seeding rates (4, 8, 12, 16, 20, and 24 lbs./1000 $ft^{2)}$ and three fertilization rates (0, 50, and 100 ppm as N in a 20-20-20 soluble fertilizer solution) were tested in two separate studies. Dry weight of grass cuttings and of the sod root mass were compared between the different treatments and compost sources.

Results

The fish waste compost reached 55^{o} C by the fourth day and continued to increase in temperature until day 6, at which time the aeration was increased from 15 minutes each 2 hours to 15 minutes per hour to stabilize the temperature (Figure 1). Subsequently, the temperature gradually declined over the 30 day period temperatures were recorded. The temperature profile was similar to those reported by Liao et al. (1993), except that the temperature reached a higher maximum prior to increasing the duration of aeration . The fish waste produced compost with good nutrient value, low heavy metal content, low soluble salts and low bulk, and compared favorably with other composts produced at the same facility using similar techniques (Table 1).

Element	FW	WB	MSW	RW	MP	CC
	---------- % by weight ----------					
C	39.2	24.5	39.8	18.7	5.3	37.4
N	1.5	0.8	1.8	1.6	0.3	1.4
P	0.3	0.6	0.6	1.0	0.8	0.3
K	0.2	0.5	0.3	1.1	0.3	0.7
Ca	1.1	2.7	1.5	2.3	0.4	2.6
Mg	0.2	0.4	0.2	0.6	0.3	0.3
S	0.1	0.1	0.3	0.4	0.1	0.6
Fe	1.2	3.9	0.9	4.0	0.1	1.2
Al	0.8	3.1	0.9	2.8	0.1	1.6
	----------mg/kg----------					
B	18	67	15	66	38	35
Mn	315	648	628	435	136	234
Cu	70	69	119	98	119	80
Zn	166	135	306	256	165	583
Na	248	690	275	1085	321	6306
Cl	<200	370	413	420	<200	5733
Pb	56	39	24	230	195	132
Ni	6	19.0	9.7	18.1	87.1	32
Cd	0.7	1.7	1.1	1.8	2.1	1.9
Cr	22	19.0	92.7	21.3	6.4	43.7
	----------mmhos/cm----------					
Soluble Salts	8.6	8.0	10.1	9.1	5.0	16.2
	----------grams/cc----------					
Bulk Density	0.45	0.53	0.51	0.60	0.39	0.49

Table 1. Chemical and physical properties of composted fish waste (FW), municipal solid waste (MSW), wastewater biosolids (WB), restaurant waste (RW), mixed paper (MP), and co-compost (MSW+WB).

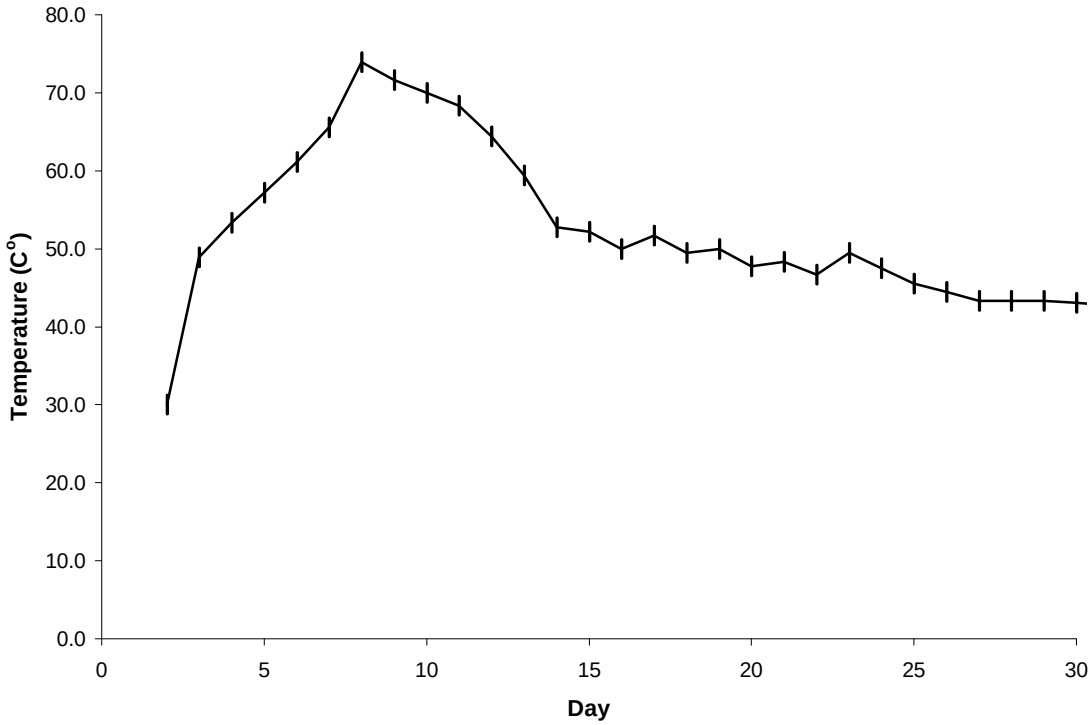

Figure 1. Temperature profile of composted fish wastes.

Nandina tests

Plant density ratings showed no significant difference on growth of dwarf nandina due to compost source (FW Vs WB). However, dwarf nandina grew better with increasing levels of compost and increasing levels of fertilizer (Figure 1). Development of fall color was slowed by the addition of compost and fertilizer. This effect was most pronounced in WB than in FW compost. Fall color development is a function of leaf chlorophyll content, which is enhanced with nitrogen addition either from increasing fertilizer rate or from nitrogen being mineralized from the compost.

Sod tests

By the end of the third cutting, 90 days after seeding, the WB compost had significantly greater dry weight of grass cuttings than the FW or MSW composts (Figure 2). All showed a significant response to the fertilizer application. The total surface density of the grass was greater at harvest in the WB and FW composts than in the MSW compost (not shown).

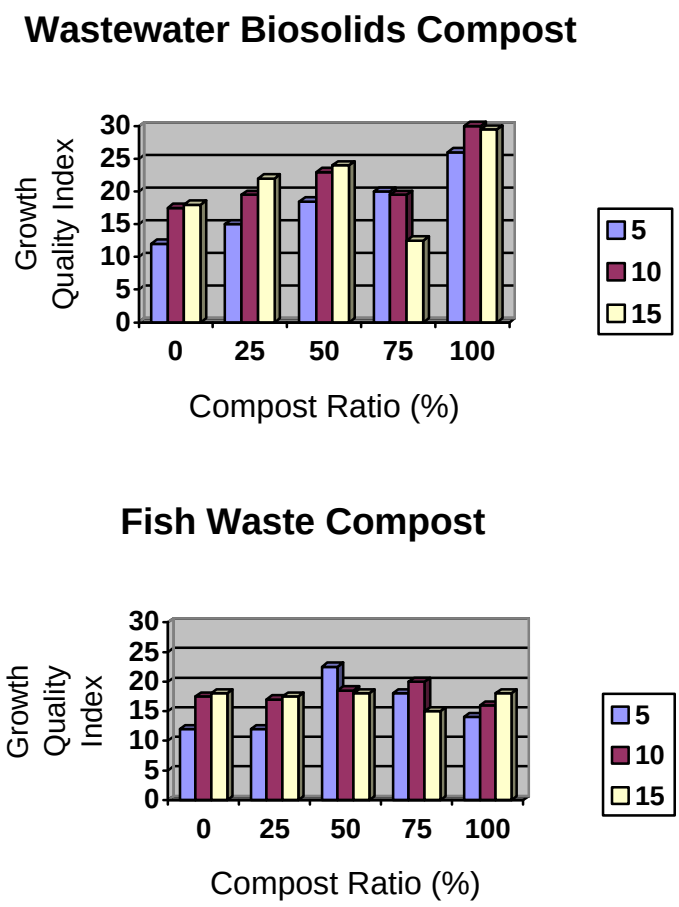

Figure 1. Effect of compost type, mixing ratio, and fertilizer application rate on growth quality index of dwarf nandina. The fertilization rates were 5, 10, and 15 lbs/cu. yd. of pine bark medium.

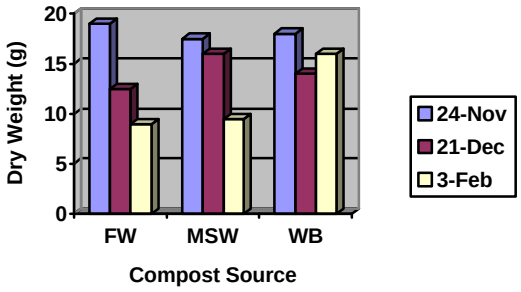

Figure 2. Effects of compost on dry weight of grass biomass. Sod was seeded 5-Nov.

Discussion

Fish wastes produce compost with good nutrient value and low heavy metal content, low soluble salts and low bulk. The rate of release of the nutrients from the fish waste compost appears to be relatively rapid compared to compost from other sources. This resulted in faster initial growth of nandina or grass, but an overall lower growth quality index for the nandina. However, the fish waste compost resulted in a better color rating for the nandina when compared to production with wastewater biosolids compost.

Based on the success and practicality of composting fish wastes from mortalities and from processing, we have also begun examination of composting for fish manure from flow-through fish culture systems. A pilot scale reactor for composting fish manure and filter sludge has been in use at the Mountain Horticultural Crops Research Station for over three years as the primary sludge treatment system for our fish facilities. Recently, a commercial filtration/composting system was constructed to evaluate this technology on a commercial trout farm. The commercial system consists of three aerated composting reactors above a sand filter drainage system. A representative diagram is shown in Figure 3. Composting may have application for recirculating aquaculture systems where sludge cannot be discharged into a municipal treatment system.

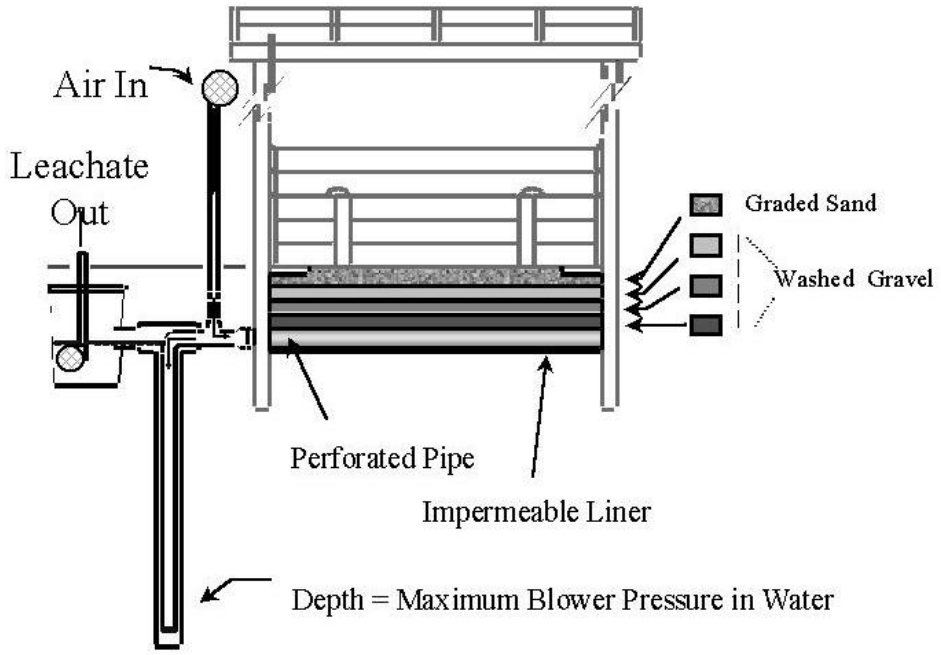

Figure 3. A schematic representation of a combination sand filter/composting system for composting fish manure.

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An Integrated Approach to Aquaculture Waste Management in Flowing Water Systems

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Abstract

The ideology that "dilution is the solution to pollution" is no longer acceptable. Limited water resources and an increased emphasis to reduce, manage, and control effluents has created a more difficult regulatory, economic, and social environment for new and existing aquaculture facilities. Consequently, technologies and strategies to manage and/or reduce the wastes generated during aquaculture production are being applied to abate aquaculture's impact on the environment.

This paper describes an integrated approach to aquaculture waste management in intensive flowing water systems. This approach closely links waste reduction to culture system design and management. Technologies reviewed are those used to minimize waste production, conserve water, and concentrate wastes into smaller flows during fish culture, as well as those used to remove wastes from fish farm effluents.

Introduction

An increased emphasis to reduce, manage and control effluents, as well as the growing competition for water resources and trends to conserve water resources, have created a more difficult regulatory, economic, and social environment for existing aquaculture facilities. Therefore, technologies and strategies to manage and/or reduce the wastes generated during aquaculture production are being developed to reduce aquaculture's effect on the environment.

Improved feed and feeding strategies have been developed to increase aquaculture production efficiencies and reduce waste feed and the amount of waste metabolic by-products generated per unit of fish production. Production strategies that maximize the efficient use of facility and natural resources and reduce the time required to gain marketable size have also been adopted to increase fish farm yields per unit water resource input and reduce the volume of waste stream that must be treated. Recent trends towards more stringent water pollution control and water use permitting have increased the adoption of technologies for aeration, oxygenation, water reuse, and effluent treatment. To meet the more stringent pollution discharge regulations has required use of

technologies that rapidly remove wastes (e.g., solid matter and phosphorus) from the system flow and that concentrate these wastes into smaller flows. The concentrated waste solids that have been captured can then be beneficially reused and/or disposed. The objective of this paper is to review the integration of these approaches in a management plan to reduce the discharge of aquaculture wastes from flowing water fish farms.

Technologies to Minimize Waste Production

Waste production depends ultimately on the type and amount of feed fed. Uneaten feed and feed fines can represent 1-30% of the total feed fed and can have a large effect on the cost of production and on the total solids production (total solids production is about 30-50% of the daily feed input). However, new feeds, feed handling, and feeding techniques can reduce waste and still achieve the desired feed conversions and growth rates (Mayer and McLean, 1995).

Waste feed can be automatically detected and fish fed to satiation using ultrasound or infrared technologies. These technologies have been developed to control feeding within sea cage systems and within circular culture tanks (Summerfelt et al., 1995; Derrow et al., 1996). The device developed for use with circular culture tanks places an ultrasonic probe in the tank effluent stand-pipe to detect uneaten feed and then turns off the feeder after a pre-determined quantity of waste feed has been detected. These devices can distinguish uneaten feed from the weaker signals resulting from fecal matter and can increase feed consumption by more than 50% without increased feed conversion rates (Durant et al., 1995).

Technologies to Minimize Water Use and Concentrate Wastes

Limited water resources, strict discharge regulations, and improved production efficiencies have increased the use of technologies that intensify production, and ultimately conserve water and concentrate wastes. An aggressive application of water treatment processes has been used to intensify production by increasing: the transfer of pure oxygen; and (when necessary) the removal of ammonia, nitrite, carbon dioxide, dissolved organic matter, and particulate organic matter. As well, ultra-intensive recirculating systems are being more widely adopted commercially as methods are developed to reduce the higher cost of production within these systems (Wade et. al., 1996; Timmons, 1997). Recirculating systems can be advantageous, because they minimize water use, concentrate wastes, reduce the waste load discharged, increase biosecurity, and allow fish farms to locate in better market areas. This section reviews the application of water treatment technologies to minimize water use and concentrate wastes.

Aeration and Oxygenation

Under the assumption that oxygen is often the most limiting factor in flowing water fish culture, many fish farms now incorporate pure oxygen transfer technology to economically increase carrying capacity by increasing the concentration of oxygen delivered to the fish

culture tank. Aeration and oxygenation increase the mass of fish that can be produced in a unit flow. However, using supplemental oxygen to increasing fish production in a unit of flow also increases the concentration of metabolic by-products (e.g., ammonia, carbon dioxide, and dissolved and particulate organic matter) in that flow. Removal of certain of these metabolic by-products may be required before discharge or to prevent the by-product from adversely affecting the fish if the flow is reused within ultra-intensive systems. From a waste treatment standpoint, concentrating the metabolic wastes into smaller flows is an advantage, because treatment processes remove higher concentrations more effectively.

Unhealthy concentration of carbon dioxide can accumulate and limit fish production under conditions supporting high fish densities with inadequate water exchange (i.e., high fish loading) and little aeration. Colt et al. (1991) estimated that carbon dioxide would become limiting in a fish culture system with no aeration after 14 to 22 mg/L of dissolved oxygen were consumed. Carbon dioxide problems are more likely to occur in intensive aquaculture systems that inject pure oxygen, because these systems have the oxygen to support higher fish loading rates and oxygen injection unit processes use insufficient gas exchange to strip much carbon dioxide. When aeration is used to supply oxygen to aquaculture systems, however, fish loading levels are lower than can be obtained with pure oxygen and enough air-water contact is generally provided to keep carbon dioxide from accumulating to toxic levels. Ideally, carbon dioxide stripping provides 3-10 volumes of air for every 1 volume of water, much more air than is required for adding oxygen to water alone. This large ratio of air to water volume is achieved more efficiently with cascade columns than with diffused aeration (Grace and Piedrahita, 1994; Summerfelt, 1996).

Rapid Solids Removal

The fecal matter of trout (and many other fish) is contained within a mucous sheath which can remain intact if the fecal pellet is removed soon after deposition. Shear forces (water turbulence, fish motion, pumps, etc.) can break apart the mucous sheath allowing the fecal matter to disintegrate into much finer and more soluble particles. Uneaten feed and feed fines can also break apart for similar reasons. When this particulate matter breaks apart and dissolves it releases ammonia, phosphate, and dissolved and fine particulate organic matter. It is harder to remove the dissolved and fine particulate matter than the larger particles, which deteriorates the water quality within the fish-culture system (especially in recirculating systems) and in the discharged effluent. Therefore, the best solids removal practice removes solids from the system as soon as possible and exposes the solids to the least turbulence, mechanical shear, or micro-biological degradation.

Solids are typically removed from fish farms by sedimentation or filtration processes. Conventional sedimentation and microscreen filtration processes remove solids generally larger than 40-100 µm; but, few processes used in aquaculture can remove dissolved solids or fine solids smaller than 20-30 µm (Chen et al., 1993a; Heinen et al., 1996b). The largest number of particles produced in the fish culture tank are < 40 µm, but the largest volume (and thus weight) of particles produced are > 40 µm (Cripps, 1995). Therefore, conventional sedimentation and microscreen filtration processes should be able to remove > 50% of the solids produced, assuming that there is minimal dissolution, leaching, or resuspension of the captured solids (due to flow hydraulics, fermentation, or denitrification).

Only two variations of the sedimentation or filtration processes do not store the solids removed within the bulk flow being treated: swirl settlers and microscreen filters. Swirl settlers continuously flush the concentrated suspended solids within a relatively small flow leaving the basin's bottom center drain, while microscreen filters are backflushed several hundred to several thousand times per day (Summerfelt, 1996). On the other hand, settling basins and granular media filters typically store the solid matter removed below (i.e., settling basins) or within (lamella or tube clarifiers, sand filters, and bead filters) the bulk flow being treated (Hunter, 1987; Malone et al., 1993). Significant degradation or resuspension/flotation of the solids matter can occur in settling basins and granular media filters because of their relatively infrequent backwash. This long term degradation allows for release of nutrients, dissolved organic matter, and/or particulate matter into the bulk flow (Garcia-Ruiz and Hall, 1996). For example, 30-40% of the filtered solids decayed between 24-hr backwash cycles while stored in floating granular media filters (Chen et al., 1993b).

One method used to rapidly remove settleable solids from the bulk flow is to use circular fish-culture tanks and to manage each tank as a "swirl settler" with a high and a low drain. Circular fish culture tanks function as swirl settlers when they are operated with two discharges. The relatively small discharge (5-20% of the total flow) leaving the tank's bottom center drain concentrates solids while the majority of flow (roughly 80-95% of the total flow) is discharged from the culture tank above the bottom-drawing drain or part-way up the tank's side wall (Figure 1) (Timmons and Summerfelt, 1997).

Solids removal costs in aquaculture are controlled more by the volume of flow treated than by the solids concentration. Therefore, concentrating settleable solids in double-drain circular-culture tanks has large economic implications by reducing the capital cost, space requirement, and headloss requirement of the downstream solids removal units (Timmons and Summerfelt, 1997).

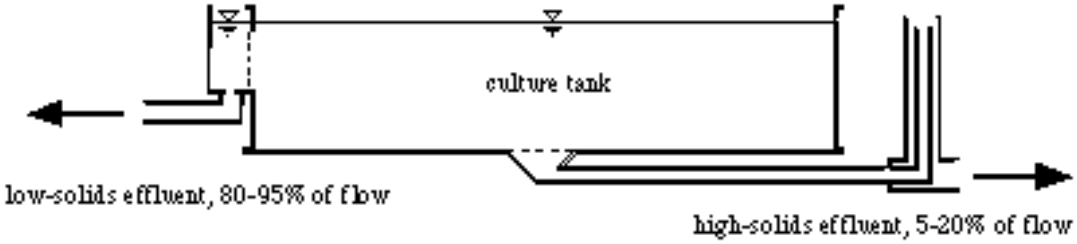

Figure 1. A circular culture tank with a "Cornell-type" dual-drain uses a center drain on the tank bottom and an elevated drain part-way up the tank sidewall to concentrate settleable solids (Timmons and Summerfelt, 1997).

Water Reuse

By their very nature, systems that treat and reuse water demand far less water resource and produce a much more concentrated and treatable discharge than a fish farm of similar production capacity that only uses water once (Phillips et al., 1991).

In an open recirculating system operating at steady state, the accumulation of wastes is controlled by the rate that the waste is produced (P_{waste}), by the efficiency that water treatment units remove the waste (i.e., the waste fraction removed, f_{rem}), and by the rate that the waste is flushed from the system. Liao and Mayo (1972) derived an equation to estimate the concentration of waste leaving a culture tank ($waste_{out}$) in a recycle system with a water treatment unit and a given fraction of water reused (R) :

$$waste_{out} = \left\{ \frac{1}{1 - R + (R \cdot f_{rem})} \right\} \cdot \frac{P_{waste}}{Q}$$

Most warm-water recirculating aquaculture systems operating in temperate climates use high fractions of reused flow (to conserve heated water), generally operating with $R > 0.99$, (equivalent to replacing less than 40% of the total system water volume daily, depending upon the total water volume of the reuse system). In such warm-water recirculating systems, waste accumulation depends mostly upon the f_{rem} across the water treatment units (Figure 2). Even in recirculating systems that use significantly more make-up water (R=0.90-0.99) to maintain cool- or cold-water temperatures, the accumulation of wastes in recirculating systems is largely controlled by the f_{rem} across the water treatment units and is little influenced by R until f_{rem} is < 0.5 (Figure 2). Therefore, the efficiency of water treatment is critical for maintaining water quality in reuse systems.

In a quasi-closed recirculating systems that only discharges water to flush solids, 100% of the total solids, BOD, and nutrients (disregarding denitrification) waste are captured and discharged in the backwash collector. Even in a fairly open cold-water recirculating system described by Heinen et al (1996b), where the make-up water continually replaces 6% of the reused flow (which amounts to a system volume exchange every 12 hours),

97% of the TSS produced daily are discharged during the microscreen filter backwash (Heinen et al., 1996a). In this system, the backwash water discharged only amounted to 0.5% of the bulk flow, contained 1200-2000 mg/L TSS, and was discharged separate from the system overflow. The system overflow only contained 4 mg/L TSS (about 3% of the total TSS discharged from the system). As well, the 80 µm sieve panel filters reduced the TSS concentration from between 7-11 mg/L to 3-5 mg/L, removing 54-68% of the TSS concentration carried in the bulk flow as it crosses the filter (f_{rem} = 0.54-0.68) (Heinen et al., 1996a). The particulate matter not removed across the microscreen filter accumulates within the recirculating system, causing 40-70% of the TSS concentration (by dry weight) in recirculating systems to consist of particles smaller than 20-40 µm (Chen et al., 1993a; Heinen et al., 1996b).

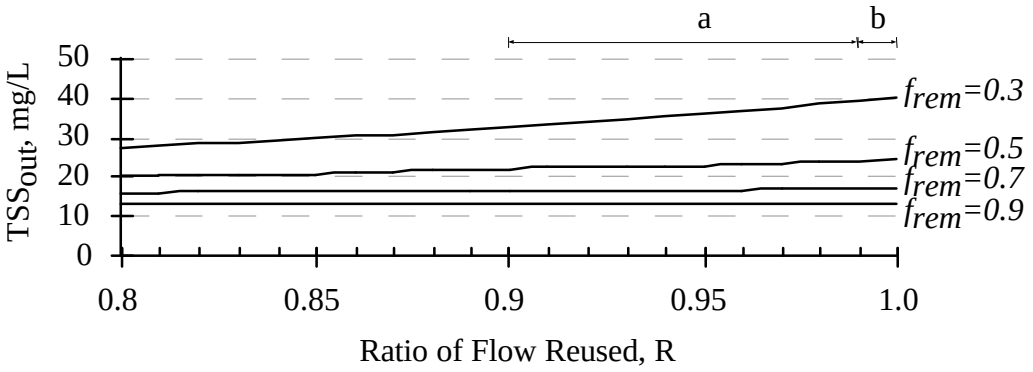

Figure 2. The TSS concentration leaving a fish culture tank (TSS_{out}) in a water reuse system (operating at steady state) is largely dependent upon the fraction TSS removed (f_{rem}) across the solids treatment unit and slightly dependent upon the ratio of flow reused (R). The letter designations (a) and (b) are placed to indicate the typical fraction of flow reuse for cold-water and warm-water recirculating systems, respectively.

Ammonia removal. Recirculating systems must control ammonia concentrations as well as maintain dissolved oxygen levels and remove solids and carbon dioxide (as discussed above). Without some form of ammonia removal, the accumulation of un-ionized ammonia to harmful levels in fish culture systems will limit the reuse of water to 10 to 20 mg/L of cumulative dissolved oxygen consumption, depending upon the sensitivity of the fish to ammonia and the water's pH (a lower pH allows for more cumulative oxygen consumption) and temperature (Colt et al., 1991). The primary method for removing ammonia in recirculating aquaculture systems is by bacterial oxidation. In systems incorporating biofiltration technologies, nitrate (not ammonia) is the major form of dissolved nitrogen discharged from these systems.

Technologies to Treat Effluents

Flowing water aquaculture systems often have two separate discharges (ignoring mortalities): (1) the system primary flow, which is relatively large in volume but contains enough particulate matter that it is passed through a solids removal unit before discharge; and, (2) the relatively small flow containing the concentrated

solids backwashed from the solids removal unit or flowing continuously from the bottom drain of a dual-drain culture tank or swirl separator.

The large volume effluent discharged from a flowing water fish farm generally contains dilute concentrations of wastes relative to effluent standards. However, even though the concentration of waste in most aquaculture effluents is relatively low, the cumulative waste load discharged to receiving watersheds can be significant due to the large flowrates involved. Therefore, the concentration and/or loading of metabolic waste products discharged from an aquaculture facilities are now regulated to reduce the risk of eutrophication of the receiving watershed.

Treating the discharge from fish farms can pose difficult and expensive effluent treatment problems, depending upon discharge regulations. First, compared to more concentrated wastes, dilute wastes have lower removal efficiencies and are more difficult to treat. Second, meeting strict discharge standards is made more difficult due to fluctuating waste material concentrations and discharged flows that can vary due to pipe, channel, and tank cleaning routines. And third, the distribution of the nutrients and organic matter among dissolved versus suspended and settleable fractions affects the method and difficulty of effluent treatment.

Phosphorus and nitrogen can be either soluble or bound with particulate matter. Most of the effluent nitrogen released (75-80%) is in the form of dissolved ammonia or nitrate, assuming good feeding practices (Braaten, 1991; Heinen et al., 1996a). The fecal solids contain about 1-4% phosphorus (on a dry weight basis) and about 2-5% nitrogen (on a dry weight basis) (Heinen et al., 1996a). Literature reviews indicate that the filterable or settleable solids contain most (50-85%) of the effluent phosphorus, but relatively little (about 15%) of total effluent nitrogen (Braaten, 1991; Heinen et al., 1996a). The large variability in the phosphorus fractionation between dissolved and particulate matter is largely due to the variability within the type and level of phosphorus in the feed.

Removal of suspended solids from aquaculture effluents is often achieved using settling basins, swirl separators, or microscreen filters (discussed below). Removal of some BOD and phosphorus is also achieved during solids reduction, because these wastes are largely distributed among the settleable and filterable solid fractions. Discharge of ammonia levels may or may not be regulated, but biological nitrification can be used to convert ammonia (which is toxic) to nitrate (relatively non-toxic), as discussed in an earlier section. Nitrate makes up the largest fraction of nitrogen discharged from a fish farm with nitrification and can be treated by biological denitrification (discussed below). However, the removal of dissolved phosphorus to very low levels is expensive and increases in complexity as the required effluent concentration decreases. Standard nutrient removal techniques include chemical precipitation and biological treatment.

Settling basins. Sedimentation occurs when particles having a specific gravity greater than the surrounding water are acted on by gravity so that the particles settle out

and are removed from the water column. Solids settling is dependent upon the size and the specific gravity of fish fecal matter. The specific gravity of fish fecal matter ranges from 1.005 to 1.20, depending upon conditions (Summerfelt, in press). Sedimentation is typically designed to occur in basins with hydraulics that minimize turbulence and provide time for interception of the particle with the bottom of the clarifier. The solids collect on the bottom of the basin, forming a sludge blanket, while clarified water passes out of the basin.

Traditionally, settling basins have been the most prevalent unit process used to remove solids from aquaculture effluents (in cases when any effluent treatment was used). Sedimentation has been an attractive effluent treatment process because it is simple, requires little maintenance, requires little head, and has a moderate cost. On the other hand, treating large volume aquaculture discharges with settling ponds requires a considerable amount of flat area (much more space than the other treatment units require); and, it is difficult for settling basins to achieve an effluent TSS concentration of < 6 mg/L due to resuspension of solids (Henderson and Bromage, 1988). Therefore, settling basins may not be an option for treating effluents to meet strict regulations on the discharge of TSS, especially if the TSS concentration discharged from the fish farm is typically < 6 mg/L. Nor is sedimentation an ideal method for removing suspended solids encountered in recirculating aquaculture systems. As a result of the settling characteristics of aquaculture solids (i.e., a large proportion of the particles are only slightly more dense than water and are < 100 µm), effective settling basins are often too large (or not effective) to provide adequate solids removal in recirculating systems. For these reasons, and to avoid storing solids in the flow, there has been a definite trend towards use of microscreen filters for rapid solids removal from aquaculture effluents.

Two variations on the principle of clarification by sedimentation have been used in an attempt to increase the efficiency of solids removal: (1) swirl settlers and (2) tube or plate settlers. Tube or plate settlers can reduce the required settling area, but biological growth on the tubes or plates generally requires draining, can result in particle and sometimes washing down the unit to remove the captured solids.

Swirl settlers Swirl separators, also called tea-cup settlers and hydrocyclones, operate by injecting the water at the outer radius of a conical tank such that the water spins around the tank's center axis. The primary water flow spinning inside the tank creates a secondary radial flow along the bottom towards the tank center. This appreciable radial flow carries settleable solids to the center drain and maintains the self-cleaning aspect of the swirl separator. In aquaculture, swirl separators are used in low head application to concentrate solids in a smaller underflow, around 5-10% of total flow. Swirl separators have traditionally been used to treat wastewater flows that contain particles of high specific gravity, e.g., sand and grit. Because the solids in aquaculture have specific gravity's only slightly greater than water, it is sometimes difficult to concentrate solids with swirl separators more effectively than with settling basins. Additionally, maintaining the proper hydraulics through the swirl separator is critical to its proper function

Microscreen filters. Microscreen filters are used to remove solids from aquaculture effluents and from the flows within water reuse systems. Microscreen filters have the advantages that they require little space, have a high hydraulic capacity, an acceptable pressure drop, and are relatively easy to install. They also are one of the few devices that rapidly removes the captured solids from the bulk flow, which reduces nutrient leaching and eliminates the potential for resuspension of the particle within the bulk flow. The three main microscreen variations are the drum, Triangel™, and disk microscreen filters.

Microscreen filters are sieves that strain water-bound particles larger than the filter screen (mesh) openings. Solids are cleaned from the filter continuously, periodically, or on demand by mechanisms that include hydraulic flushing, pneumatic suction, mechanical vibration, and raking (depending on the type of microscreen filter). Washing solids from the microscreen panels requires high pressures ($4x10^5$-$7x10^5$ N/m^2 [60-100 psi]) and wash water pumps can cycle several hundred to several thousand times daily (Summerfelt, 1996). Although several factors influence the volume of backwash produced, the pressurized backwash of microscreen filters has been reported to produce a sludge water volume of between 0.2-2% of the total passing flow. Pneumatic suction of the solids from the microscreens has been reported to reduced sludge water production by 50-100 fold compared to a typical pressurized-washing mechanism (Bergheim and Forsberg, 1993).

The size of the openings in the microscreen panel determines the hydraulic capacity of the unit, the fraction of particles removed, the sludge water production rate and concentration, and the filter wash frequency. The openings in the microscreen panel should be as small as possible, but the minimum size selected is controlled more by operational factors, such as hydraulic loading and backwash requirements, rather than by treatment requirements (Cripps, 1995). The optimum microscreen opening size may be situation specific, but the majority of openings sizes (i.e., the finer of the microscreen panel openings when two panels are used in series) that have been reported are in the 60-110 µm range. Reports of average suspended solids removal across microscreen filter units range from 22-70% within recycle systems and from 68-80% in flow-through systems (Summerfelt, in press).

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Investment and Management Aspects of Owner/Operator Scale Greenhouse Tilapia Systems

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Introduction

Several Louisiana growers have developed semi-standardized, greenhouse-enclosed green-water recirculating systems that have been shown to be cost-competitive when compared to other growout approaches currently in use throughout the U.S. (Lutz and Roberts 1997). These systems utilize net pens suspended within lined rectangular growing tanks constructed of treated lumber (Lutz 1996) to facilitate concurrent batch stocking and harvesting (Summerfelt et al. 1993), allowing physical isolation of specific size groups within a system. Data from three Louisiana tilapia greenhouse facilities with similar construction and operational procedures were compiled to allow an economic characterization of this particular approach to tilapia production.

The Model Facility and Baseline Budget

A model greenhouse tilapia facility based on Louisiana grower systems was analyzed. ABaseline@ development and operating budgets were constructed to reflect costs and returns with annual production of 100,000 lbs (Table 1). The presentation includes reasonable expectations of labor, management and capital contributed by owner operators. The model facility is based on three 16= wide by 80= long by 5= deep grow-out tanks, constructed of treated lumber, insulation board and a 40-mil liner. Land requirements total 0.9 acres, based on 150% of the required production tank and work area plus 0.5 acres to accommodate delivery and loading access and a sludge settling pond. Production tanks and surrounding work areas require a 5,990 ft^2 greenhouse for enclosure. A 2@ well is included to fill and supply daily make-up water to production tanks. New construction of an office and restroom with an on-site septic system, as well as an adjoining storage area, is assumed.

Table 1. Facility, equipment and operating costs for a 100,000 lb. per year tilapia greenhouse facility in Louisiana.

Item, Unit	No. Units	Cost/Unit	Total
Facility and Equipment			
Land, Acre	0.9	$2,500.00	$2,248
Permits	1		$450
Greenhouse, sqft.	5,990	$3.25	$19,469
Heating/Ventl., sqft.	5,990	$.50	$2,995
Water Well	1		$3,200
Tanks/Decking	3	$4,224.00	$12,672
Electrical Installation	3	$550.00	$1,650
Filters/Pumps	6	$5,200.00	$31,200
Plumbing/Fittings	3	$720.00	$2,160
Blowers, 2hp	3	$580.00	$1,740
Aerators, **2** hp	12	$625.00	$7,500
Generator, Diesel	1		$6,000
Net Pens w/hardware	18	$300.00	$5,400
Equipment, Tools	1		$5,180
On-Site Septic System	1		$1,980
Settling Pond	1		$1,000
Alarm System	1		$2,500
Storage	1		$2,000
Office/Restroom/Etc.	1		$6,000
Truck (3/4 ton), trailer	1		$26,000
TOTAL			$141,344
Operations			
Feed, lb	180,000	$ .17	$31,429
Fingerlings, 4.5g	75,988	$ .21	$15,959
Electricity	3	$6,105.00	$18,315
Hired Labor	1.25	$20,000.00	$25,000
Other (repairs, alarm monitoring, phone svc., etc.)			$8,000
Marketing, Promotion, Travel			$4,000
Insurance	1		$2,500
TOTAL DIRECT			$105,202
Estimated Depreciation		$14,143	

Direct Expenses and Depreciation: $1.19 per lb of production

Open-top automated air-washed bead filters are used in the model system, based on a patent-pending design developed by one of the cooperating growers. Aeration is accomplished through several means, including the use of airstones suspended at regular (0.3 - 0.5 m) intervals along tank walls and supplied with forced air from regenerative blowers. Floating vertical pump aerators are also utilized for supplemental aeration. These processes also serve to keep solids in suspension until they can be entrained in mechanical filtration units via perforated drains along the base of the tank walls.

A diesel generator sized to operate the entire facility in the event of a power outage is included. Net pens are required for segregating size groups. Equipment requirements include scales, dipnets, a monitoring and alarm system, feeders, an oxygen meter and water quality test

kit, telephones, a fax machine, and other necessary items for day-to-day operation. A ½ ton pickup truck and trailer are included for transporting construction materials, equipment, fingerlings, food fish for local sale, and other items as needed.

Operating cost estimates for the model facility are based on a feed conversion ratio of 1.8 lb of 32% protein feed (at $340 per ton) to 1 lb of tilapia weight gain. Fingerlings are stocked at an average weight of 4.5 g, with assumed survival of 94% to a harvest weight of approximately 1.4 lb. Growout is projected to take 8.5 months on average, with the first fish in a cohort reaching market size during the eighth month and the remainder harvested before the end of the ninth month. Electrical costs reflect $475 per month direct charges and $33.75 Aoverhead@ charges (office use, security lighting, etc.) per production tank. One full-time laborer at $20,000 annual salary and one quarter-time laborer paid at the same rate are required, in addition to owner-operator contributed labor and management. Owner-operators must determine the value of their contributed labor and management on a case by case basis. Repairs, alarm monitoring, office operations and related day-to-day expenses are estimated at $8,000 annually, with an additional $4,000 budgeted for marketing, promotion and travel activities. Annual insurance was estimated at $2,500.

Table 2. Cash flow illustration for 100,000 lb per year Louisiana tilapia greenhouse facility, July start-up. Values are for end of operating year.

	Year 1	Year 2	Year 3	Year 4	Steady State
Cash Outflows					
Construction	$55,135				
Equipment	$85,340				
Other Startup	$2,869				
Feed	$11,420	$31,428	$31,428	$31,428	$31,428
Hired Labor	$25,000	$25,000	$25,000	$25,000	$25,000
Utilities	$15,771	$18,315	$18,315	$18,315	$18,315
Fingerlings	$13,299	$15,959	$15,959	$15,959	$15,959
Other, Mkt.,etc.	$12,000	$12,000	$12,000	$12,000	$12,000
Insurance	$2,500	$2,500	$2,500	$2,500	$2,500
Total	$223,335	$105,202	$105,202	$105,202	$105,202
Cash Inflows	$35,566	$173,381	$173,381	$173,381	$173,381
Cumulative returns to operator labor, management and contributed capital	(187,769)	(119,590)	(51,412)	$16,767	

Based on estimated costs for facilities and operations and prevailing 1996-1998 Louisiana farm-gate prices to live-haul markets (see Table 3), a cash flow illustration was developed for the model facility (Table 2). Construction is initiated during month 1 and continues through month 3. Stocking begins during month 2 and continues monthly thereafter. Assuming the owner-operator supplies the required capital for facility development and operation and has an outside source of income to meet living expenses, the model facility shows a cumulative return to the owner-operator=s labor, management and contributed capital of almost $17,000 by the end of the fourth year of operation. Thereafter, cash inflows are expected to exceed cash outflows by approximately $68,000 annually.

Development of the cash flow illustration for the model facility revealed significant variation in first year cash inflow for different start-up months as a result of seasonal variation in market prices (Table 3). A July start-up date was assumed for the model facility to allow for less-than-ideal revenues during months 9-12 of operation and in light of the ready availability of fingerlings and favorable weather conditions for construction during the mid-to-late summer compared to other possible start-up dates.

Table 3. Seasonal impacts of live haul market prices (1996-1998 averages) on revenues during operating months 9-12 for a 100,000 lb per year Louisiana tilapia greenhouse facility.

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Start-up Month	**Month 9**	**Month 10**	**Month 11**	**Month 12**	**Total**
January	September	October	November	December	
Price/lb $1.60	$1.40	$1.60	$1.80		
Revenue	$2,271	$5,973	$11,381	$15,374	$34,998
April	December	January	February	March	
Price/lb $1.80	$1.80	$1.80	$1.70		
Revenue	$2,555	$7,679	$12,804	$14,520	$37,557
July	March	April	May	June	
Price/lb $1.70	$1.70	$1.60	$1.70		
Revenue	$2,413	$7,253	$11,318	$14,520	$35,556
October	June	July	August	September	
Price/lb $1.70	$1.80	$1.80	$1.60		
Revenue	$2,413	$7,679	$12,804	$13,665	$36,561

Of several factors that directly influence profitability in the greenhouse systems on which the model system is based, growth rate is the most important, followed by feed conversion ratio. Eknath et al. (1993) reported highly significant differences in growth among 8 distinct strains of Nile tilapia, *Oreochromis niloticus* in different farm environments in the Philippines. Similarly, Eguia and Eguia (1993) reported significant differences in growth among 3 strains of *O. niloticus* under restrictive and non-restrictive feeding regimes. Growth rate among cohorts of nile tilapia grown in Louisiana systems can vary greatly, even within the same strain. Ongoing data collection from Louisiana systems suggests that inadequate nutrition during the first month of life, crowding, and restricted feeding prior to a weight of 50 g can result in reduced growth of nile tilapia through the remainder of the production cycle (Lutz, unpublished data).

A number of feasible methods are available to improve growth rate of nile tilpia in these systems over that reflected in the model facility, including more frequent feeding, use of sex-reversed or genetically male (GMT) fingerlings, improved grading methods, reduced handling disturbance, more consistent or more digestible diets, and other approaches. Accordingly, the baseline operating budget and cash flow developed for the model facility were modified to reflect an increase in growth rate produced by any other these methods, with average time to harvest reduced from 8.5 months to 8 months (Figure 1). In contrast to the baseline growth pattern in which a portion of the cohort was not harvested until month 9, the entire harvest is completed by the end of month 8.

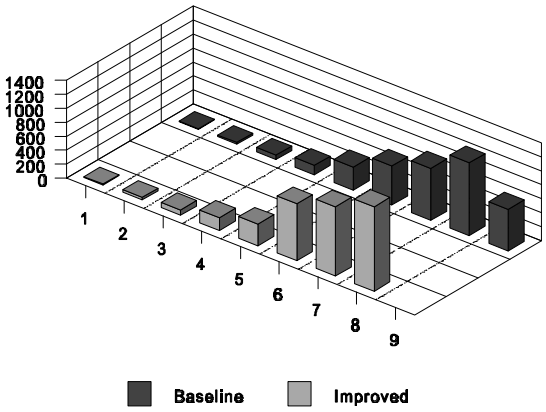

Figure 1. Kg biomass of nile tilapia cohorts from stocking through harvest.

The resulting cash flow and operating budget (Table 4) reflect a substantial improvement in facility productivity and profitability as a result of this moderate improvement in growth performance. Overall harvests are increased to 113,650 lb annually, and cumulative returns to the owner-operator=s labor, management and contributed capital reach $68,000 by the end of the fourth year of operation. Thereafter, cash inflows are expected to exceed cash outflows by approximately $82,000 annually.

Table 4. Cash flow illustration for 100,000 lb per year Louisiana tilapia greenhouse facility with grow-out reduction from 8.5 to 8 months average, July start-up. Values are for end of operating year.

	Year 1	Year 2	Year 3	Year 4	Steady State
Cash Outflows					
Construction	$55,135				
Equipment	$85,340				
Other Startup	$2,869				
Feed	$13,547	$34,444	$34,444	$34,444	$34,444
Hired Labor	$25,000	$25,000	$25,000	$25,000	$25,000
Utilities	$15,535	$18,315	$18,315	$18,315	$18,315
Fingerlings	$14,629	$17,555	$17,555	$17,555	$17,555
Other, Mkt.,etc.	$12,000	$12,000	$12,000	$12,000	$12,000
Insurance $2,500		$2,500	$2,500	$2,500	$2,500
Total	$226,555	$109,814	$109,814	$109,814	$109,814
Cash Inflows	$47,352	$192,248	$192,248	$192,248	$192,248
Cumulative returns to operator labor, management and contributed capital	(179,204)	(96,769)	(14,335)	$68,099	

Observed feed conversion ratios vary considerably in Louisiana greenhouse tilapia systems. Results of feeding comparably-priced rations from different suppliers indicate overall long-term feed conversions may vary from 1.4 to 2.0. The extent to which these differences reflect ration effects as opposed to facility or management effects has not yet been determined. Frequent changes in feed components appears to inflate feed conversion ratios as a result of lag times of several days or more in adaptation of gut bacteria and enzymatic activity. Preliminary data from Louisiana systems suggest these impacts may be minimized by blending remaining feed on hand with each new supply prior to completely switching over. To investigate the impact of feed conversion ratio on system profitability and productivity, the baseline operating budget and cash flow developed for the model facility were altered to reflect

a reduction in feed conversion ratio from 1.8:1 to 1.4:1 (Table 5).

Table 5. Cash flow illustration for 100,000 lb per year Louisiana tilapia greenhouse facility with feed conversion ratio reduction from 1.8 to 1.4, July start-up. Values are for end of operating year.

	Year 1	Year 2	Year 3	Year 4	Steady State
Cash Outflows					
Construction	$55,135				
Equipment	$85,340				
Other Startup	$2,869				
Feed	$8,657	$24,442	$24,442	$24,442	$24,442
Hired Labor	$25,000	$25,000	$25,000	$25,000	$25,000
Utilities	$15,771	$18,315	$18,315	$18,315	$18,315
Fingerlings	$13,299	$15,959	$15,959	$15,959	$15,959
Other, Mkt.,etc.	$12,000	$12,000	$12,000	$12,000	$12,000
Insurance $2,500		$2,500	$2,500	$2,500	$2,500
Total	$220,572	$98,216	$98,216	$98,216	$98,216
Cash Inflows	$35,566	$173,381	$173,381	$173,281	$173,381
Cumulative returns to operator labor, management and contributed capital	(185,006)	(109,841)	(34,677)	$40,487	

The resulting cash flow and operating budget also reflect a substantial improvement in facility productivity and profitability, although an improvement of this magnitude in feed conversion ratio would probably be somewhat less easily accomplished than the moderate improvement in growth performance illustrated in Table 4. Overall harvests are unchanged from the baseline at 100,000 lb annually, but cumulative returns to the owner-operator=s labor, management and contributed capital reach $40,000 by the end of the fourth year of operation. Thereafter, cash inflows are expected to exceed cash outflows by approximately $75,000 annually.

Many potential owner-operators in Louisiana and elsewhere may not be able to contribute the entire sum of capital required for construction and outfitting of production facilities and/or may not have other sources of income. To examine the impacts to profitability of trying to develop a greenhouse tilapia facility under these circumstances, the cash flow and operating budget of the model facility were restructured to reflect 1) an owner-operator contribution of only 40% of the capital required for facility and equipment, with the remainder borrowed for 84 months at 10% interest, paid back over 72 months beginning in month 13, 2) operating capital borrowed annually at 10% interest and 3) owner-operator salary set at $24,000 annually (Table 6).

Table 6. Cash flow illustration for 100,000 lb per year Louisiana tilapia greenhouse facility, with 60% of initial construction, equipment and other startup costs borrowed at 10% interest for 84 months (repaid over 72 months beginning in year 2) and an annual operating loan at 10% interest with operating costs including $24,000 owner/operator annual salary.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Steady State
Cash Outflows												
Construction	55,135											
Equipment	85,340											
Other Startup	$2,869											
Principal & Interest	$0	33,790	33,790	33,790	33,790	33,790	33,790					
Feed	$11,420	31,428	31,428	31,428	31,428	31,428	31,428	31,428	31,428	31,428	31,428	$31,428
Hired Labor	$25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	$25,000
Owner Labor/Mgt.	$24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	$24,000
Utilities	$15,771	18,315	18,315	18,315	18,315	18,315	18,315	18,315	18,315	18,315	18,315	$18,315
Fingerlings	$13,299	15,959	15,959	15,959	15,959	15,959	15,959	15,959	15,959	15,959	15,959	$15,959
Other, Mkt.,etc.	$12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	$12,000
Operating Interest	$5,719	7,105	7,105	7,105	7,105	7,105	7,105	7,105	7,105	7,105	7,105	$7,105
Insurance	$2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	$2,500
Total	$253,054	170,098	170,098	170,098	170,098	170,098	170,098	136,307	136,307	136,307	136,307	$136,307
Cash Inflows												
Loan	$86,000											
Revenue	$35,566	173,381	173,381	173,381	173,381	173,381	173,381	173,381	173,381	173,381	173,381	$173,381
Cumulative returns to operator labor, management and contributed capital	(131,481)	(128,198)	(124,915)	(121,632)	(118,348)	(115,065)	(111,782)	(74,709)	(37,635)	(561)	$36,512	

An examination of Table 6 suggests this scenario approaches the limits of debt load and owner-operator compensation the model facility can sustain. The level of debt prior to year 8 leaves little room for crop failures or for market prices to decrease. Prior to this point, system failures or unforeseen changes in markets could prove devastating. Minor improvements in growth and feed conversion could be expected to provide some increased level of "breathing room" in this area, but overall cumulative returns to the owner-operator's labor, management and contributed capital fail to reach positive numbers until early in the eleventh year of operation. Thereafter, cash inflows are expected to exceed cash outflows by approximately $37,000 annually, with an additional $24,000 salary directly to the owner-operator.

Summary

The cash flow illustrations and operating budgets developed suggest that even minor differences in inputs, operational management or debt structure can impact the probability of success or failure in identical recirculating systems. An improvement from 8.5 to 8 months average growout period was more beneficial than a reduction of feed conversion ratio from 1.8 to 1.4. Combined impacts of borrowing 60% of startup funds, annual financing of operating costs and a $24,000 annual salary draw for the owner-operator more than doubled the positive cash flow horizon and left no possibility for profitable operation at prices below 1996-8 averages.

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Economic Analysis of Land-Based Summer Flounder Aquaculture Systems Under Uncertainty

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Abstract

Firms practicing land-based aquaculture face both technological and marketing challenges. When rearing a relatively new aquaculture species, such as summer flounder (*Paralichthys dentatus*), growers face uncertainty in areas such as: mortality, growth rates, feed conversion, and a variety of technical parameters. In addition, given relatively high costs plus the high degree of uncertainty, growers must generally target niche markets, such as live markets, which adds another level of sales and price uncertainty.

This research develops a simulation model for land-based summer flounder systems that incorporates many aspects of uncertainty. The primary output is an expected distribution for net returns under various operating conditions and marketing strategies. With this model, various systems can be evaluated in terms of expected returns and the degree of uncertainty of the returns. Two specific examples are explored. One addresses the likelihood of system failure; the other focuses on the comparison of selling to live versus sushi-grade summer flounder markets.

Strategic Management -- Some Tools to Help Prepare for the Future

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INTRODUCTION

Would you like to improve your chances of success with your next risky investment in recirculating aquaculture system production?

The goal of this article is to introduce the reader to some important considerations in the decision to invest in a recirculating aquaculture system (RAS). Some tools - methods of evaluating the business, the competition and the market - are introduced. The overall theme is managing strategically, which includes planning the business.

The overall focus of this symposium is "on the principles of economics needed to establish and sustain RAS. It is aimed at informing and educating potential and existing recirculating business in this critical area."

Dr. Charles W Coale wrote in his paper presented in 1996 at the first of these annual conferences "An effective management system must be planned and implemented to generate sustained profits and growth for the RAS firm. …. Marketing and distribution plans should be developed with marketing budgets drawn **BEFORE stocking the production system with fish.** (The bolding is mine.)

Dr. Fred Conte wrote a WRAC pamphlet in 1992 on *Evaluation of a Freshwater Site for Aquaculture Potential*. While not specifically dealing with investing in a RAS, he wrote, "Potential developers and investors interested in aquaculture need information that allows them to assess an existing or potential business. They need information that allows an intelligent assessment of the level of risk associated with establishment or investment in a viable business or in an R&D venture."

Dr. Conte then identified three categories into which aquacultural businesses might be assigned (with some overlap and mixing possible). He suggested, and this author agrees, each category exhibited a different degree of risk. The first category was "R&D Aqauculture". Most of the business revenues come from venture capital investors, consulting fees, government grants or sales of turnkey systems for which only the seller has evidence of success. The level of risk would be great.

The second category was "Transitional R&D Aquaculture". Business revenues still depend heavily on investors, grants and consulting fees; however, the share of revenues

coming from sales of cultured product has increased and the share coming from sales of turnkey systems has become unimportant. The level of risk would be reduced depending on the track record and business plan/strategy.

The third category was "Viable Aquaculture Production". Business revenues are primarily based on sales of cultured product. Investors are usually shareholders or partners in the business, which may support expansion with a combination of proven technologies and innovation. This category would have the lowest level of risk among the three categories. Even a RAS business in this category would be exposed to the risks associated with any agriculture production enterprise. A person's tolerance for risk and uncertainty and their risk management skills may be important determinants of success in understanding and managing the agriculture risks associated with; production, marketing, financial, legal and human resource issues/problems.

The risks in aquaculture production are real and are significant. Investments in the best managed and operated RAS will still be classified as relatively high risk investments and; therefore, typically deserving (in a market sense) of higher returns.

Assumption Of Rationality

There are many books, pamphlets, video tapes, college and extension classes, Internet sites, software programs and consultants available for anyone to use in developing and organizing information to support the decisions related to investing in an RAS. Some help with business planning, strategic management, financial evaluation and market audits and strategies. Some are designed to help the investor understand the expected risks and returns of the investment while others are designed to help sell the investment opportunity to other investors. With all the helpful people and materials that have been available for some time, it is interesting that we still have any failures of RAS businesses.

Those who invest in aquaculture (RAS in this instance) are presumably rational people. One would expect them to compare the satisfaction they would expect to receive from their use of money, labor and management skill in a RAS to the satisfaction they would expect in alternative uses, or, at least the next best alternative use of those resources. In other words, the concept of opportunity costs should be well understood and applied.

No one in the past, present or future has or will purposely invest in RAS production without at least the belief that the investment is the best thing to do with their resources. The work is too demanding to do it for fun. There may be some non-monetary satisfactions from working with fish, producing food (being a farmer), being on the lead edge of an industry, being recognized as an innovator and entrepreneur or living in a rural area. Those put aside; the investor would still be expected to invest his resources where they would be expected to earn the highest return.

It is with that understanding that some tools useful in strategically managing a business are discussed in this article. Time and space are too limited to be complete, so what is covered is an introduction to very easy to use yet powerful decision support tools.

Strategic Management and Planning

Some definitions may be helpful in understanding what is meant by managing strategically. These definitions and tools are covered in more detail in Thompson and Strickland.

Strategy:	The pattern of actions which managers use to achieve the enterprise's objectives. The company's actual strategy is part proactive and part reactive.
Strategy Formulation:	The direction setting management function of conceptualizing the companies mission, setting performance objectives and crafting strategies. The end product of strategy formulation is a strategic plan.
Strategic Plan:	Statement outlining the company's mission and future direction, short and long-term performance targets, and strategies.
Strategy Implementation:	The whole range of managerial activities associated with putting the chosen strategies in place, supervising the pursuit of targeted results and achieving those targeted results.

Some of the tools used in managing strategically are similar to and useful in constructing what are usually know as the "business plan" or the "marketing plan" for a business. **Strategy** could be called **management's game plan** for satisfying customers, improving the RAS business's position in the market, and achieving predetermined performance targets. It provides a guide for ***how*** to conduct business and helps management make well thought out choices among alternative courses of action. It is a **road map** to desired results.

Strategy-making is fundamentally a **market-driven entrepreneurial activity** risk-taking, venturesomeness, business creativity, and an eye for spotting emerging market opportunities. One needs to cultivate **"outside-in thinking versus inside-out thinking."** The latter may cause management to miss outside threats or opportunities because it is not a market-driven and customer-driven approach

RAS business strategies can't be truly market and customer-driven without RAS business wide, **outside-in** entrepreneurial character dedicated to superior customer perceived value and achieving sustainable competitive advantage. The strategic management process consists of several interrelated managerial tasks or steps.

FIVE INTERRELATED MANAGERIAL TASKS

1	Deciding **what business** the RAS business will be in and forming a **strategic vision** of where the RAS business needs to be headed -- in effect, infusing the RAS business with a **sense of purpose**, providing **long-term direction**, and establishing a clear **mission** to be accomplished.
2	Converting the strategic vision and mission into **measurable objectives and performance targets**.
3	**Crafting a strategy** to achieve the desired results.
4	**Implementing and executing** the chosen strategy efficiently and effectively.
5	**Evaluating** performance, **reviewing** new developments, and **initiating** corrective adjustments in long-term direction, objectives, strategy, or implementation in light of actual experience, changing conditions, new ideas and new opportunities.

Strategy-making is a **dynamic process** where a RAS business's **mission, objectives,**

strategies, and **implementation** are always being reevaluated, refined and recast based on real time events and trends. In actual strategy-making process there are no clear boundaries between the tasks.

Strategies with one of or combinations of the following three generic competitive approaches are often found to be most appropriate.

THE THREE GENERIC COMPETITIVE APPROACHES

1	Striving to be the industry's **low-cost producer** thereby aiming for a cost-based competitive advantage over rivals,
2	Pursuing **differentiation** based on such advantages as quality, performance, service, styling, technological superiority, or unusually good value, and
3	Focusing on a **narrow market niche** and winning a competitive edge by doing a better job than rivals of serving the special needs and tastes of its buyers.

Industry and Competitive Analysis

Industry and competitive analysis utilizes a set of tools/concepts to develop a clearer picture of conditions in the industry and the nature and strength of the competitive forces. It helps one think strategically and form conclusions concerning whether the industry represents an attractive investment opportunity relative to other investments.

The purpose of industry and competitive analysis is to develop thorough answers to seven questions by probing for facts.

	Question	**Example**
1	What are the aquaculture industry's dominant economic traits?	Economies of scale Ease of entry and exit Capital requirements Scope of competitive rivalry
2	Which of the five competitive forces are most at work in the aquaculture industry and how strong is each?	Rivalry among competitors Threat of entry Competition from substitutes Power of suppliers Power of customers
3	What are the drivers of change in the aquaculture industry and what impacts will they have?	Customer attitudes & demographics Regulation Increasing globalization Population and income growth
4	Which companies are in the strongest/weakest competitive positions of importance to this enterprise?	Importers Pond producers Seafood capture Other livestock firms
5	Which players are likely to make which competitive moves and when?	
6	What are the key success factors, which will determine competitive success or failure?	Technological know-how Low cost production and distribution Image & ability to differentiate
7	Finally, how attractive is the industry, in terms of prospects for above average profitability, based on the information assembled?	

Company Situation Analysis

After thinking strategically about the business's external situation, one evaluates the business's strategic position in the environment. The approach in company situation analysis is to focus on the following five questions.

	Question	**Example**
1	How well is the present strategy working? Or, for a new company, how well is the strategy working for a similar company?	Market share, Growth Return on assets Return on equity
2	What are the company's strengths, weaknesses, opportunities and threats?	Internal Strengths & Weaknesses External Opportunities & Threats
3	Are the aquaculture business's costs and prices competitive	Could become "core competency" and leverage "sustainable competitive advantage"
4	How strong is the business's competitive position? Or How strong would the competitive position be?	Rank Vs competitors on KSA's etc Competitive advantages/disadvantages? Ability to defend vis-a-vis driving forces
5	What strategic issues/problems does management need to address in forming an effective strategic action plan?	The five competitive forces -- strategy? Is the company vulnerable to competitive attack from one or more rivals?

Swot Analysis

Evaluating a business's internal strengths and weaknesses and its external opportunities and threats is known as a *SWOT analysis*. With SWOT analysis one can follow the basic principle that whatever strategy is taken, it must produce a good fit between the business's internal capabilities and its external situation. The following list represent just a few examples of potential strengths, weaknesses, opportunities and threats a RAS may experience.

INTERNAL STRENGTHS

core competencies in key areas	proprietary technology (patents)
respected by buyers	adequate financial strength
utilizes economies of scale	proven management
cost advantages	superior technical skills

INTERNAL WEAKNESSES

no clear strategic direction	too narrow a product line
obsolete facilities or equipment	weak market image
no significant R & D	poorly organized distribution network
higher unit cost relative to rivals	subpar profitability due to .....

EXTERNAL OPPORTUNITIES

go after additional customer markets	diversify into related products
customer needs broader than product line	Vertical/horizontal integration possibility
rival firms complacent re: market	falling trade barriers

EXTERNAL THREATS

lower cost foreign competitor	new costly regulations
increasing bargaining power of customer or supplier	falling trade barriers
changing buyer tastes or needs	increasing sales of substitute items

This has been a quick review of some tools useful in preparing for the future in RAS production opportunities. Using these tools well will require a significant investment of time, but, it may improve your chances of success with your next risky investment in RAS. The following reference list contains many sources useful in developing business plans, market plans and strategic management skills.

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What Lenders Want: Financing Your Aquaculture Enterprise

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Introduction

Aquaculture is a "new" industry. Though fish have been farmed for thousands of years around the world, lenders view loan applications as higher risk enterprises because of their novelty. Because of this it is even more necessary than in other business plans, to present a clear, well projected image of the business.

The business plan, accompanied by the loan application package, is the one instrument the entrepreneur has available to "sell" his business to the lending institution. The plan should provide a crystal clear impression of the technical, marketing and financial aspects of the business. The lender, who may not know aquaculture operations, should be able to understand as much of the proposed business plan as possible.

What Lenders Want

Lenders surveyed for this paper stated that first and foremost they wanted a realistic document about the business. Reasonable financial statements, clear marketing and technical information and relevant analysis of potential problems the business could face ranked highly on their list.

Lenders also use certain flexible criteria to evaluate loans, including cash flow statements, financial ratios, ability to provide collateral, experience level of management and product market status.

The Business Plan

Lenders prefer to see a fully developed business plan for the operation. (See Appendix for an outline of a model business plan.) Survey respondents indicated that a plan that read well, was convincing and well documented would receive further evaluation on a more positive note than a "scantily" prepared submission.

Financial Statements

Lenders prefer minimum of four years of financial statements including most importantly the cash flow statement and income statement. Data should be projected monthly for the first two years, then quarterly thereafter. Most lenders indicated that they preferred

sensitivity analysis be conducted on the financials to show the impact of changes to the firm. (Changes could be anything from fish and feed prices to increased mortality.)

Financial Analysis and Ratios

At the top of the lenders list was the need for a cash flow statement. The primary question to be addressed, which if negative, will end the loan process, is "Can the company meet its financial obligations?" A positive cash flow throughout the projection period is essential. Lenders do, however understand the timing of harvests and expect the borrower to adequately fund the business either through debt or equity, in order to prevent negative cash flow periods.

The second most important financial aspect was the debt/equity ratio. This ratio is total liabilities divided by total equity. Needless to say, the higher this ratio, the riskier the business. The lender wants personal investment in the business. Survey respondents indicated that lenders required, depending on many other factors, from 10-30 percent personal investment in a business.

Most lenders stated that collateral was a tricky issue. Average stated required collateral was 60%. This is a qualified statement, that the stronger the proposal, the more flexible collateral requirements are.

Marketing

Lenders are taking a new and intensified look at the marketing plans of potential companies. They require price and quantity history. They want reassurance that the firm has a viable market that will perform to the expectations of your financial projections. If possible, show market growth trends; provide intent to purchase agreements and document any supply deficits possible.

Other Issues

Lenders are also interested in aspects other than financial ones. A very important issue is the experience level of the management team. Most survey respondents indicated that without adequate experience or training in the field, they were unlikely to fund a new venture. If management is not experienced in the field of aquaculture, it helps the application to hire someone on the management team who is.

Another critical issue for lenders is the willingness of entrepreneurs to sign personal guarantees for the debt. One respondent indicated that to his bank, this indicated a personal belief and trust in the business. Most banks indicated that they require personal guarantees on the majority of their loans of this type.

One surprising item that bankers considered was personal ability to survive a failure. As personal guarantees are nearly always required, the banks consider whether the individual

owners could survive the failure of the business. One lender stated, “If the business fails, there is one bankruptcy. There shouldn’t have to be two.”

Summary

Lenders want to finance successful businesses. The guidelines lenders use to evaluate loan applications are to protect not only themselves, but the clients as well. Evaluate the business plan on the criteria that lenders use before you submit it. This will increase probability of financing and a successful venture.

Appendix: Parts of a Business Plan

Executive Summary

The most important part of a business plan, particularly for those trying to finance a new business or expansion of an existing business is the Executive Summary. This is the first exposure to the business concept and plan that most lenders will have. Therefore, it must be concise, compelling and informative. It must entice and convince the reader that the rest of the plan, and therefore the business, has merit. The Executive Summary should address these issues:

1. How the company is organized (corporation, partnership, etc.), its stage of development (currently in operation or on paper) and the company's mission.
2. (Was it a fit with available resources or training? Was an unmet market opportunity recognized? What are the products to be offered?)
3. What is the target market?
4. Why can this company meet market needs and face the relative competition? (In other words, what is your competitive advantage or edge?)
5. Why is management capable of running this particular business? (Indicate training, background, previous employment, etc.)
6. Briefly list milestones for the business. For example, 1 million pounds per year by year 2, when the first products will be shipped, what percentage of what markets do you think you can obtain and by when.
7. Specify your financing plan. How much equity from owners do you expect? How much credit from lenders will you require? How will lenders be repaid and how will investors be compensated.

Company Description

1. Legal name and form of business

The company should have a legal status for the state in which it operates. This could be a privately held corporation, a publicly traded corporation, a partnership, a limited partnership, an individual proprietorship and many permutations in between. It should have a legal name for this status. This is the name the business will be known to the state in which it operates and to the Internal Revenue Service. Include the date of legal formation.

2. Company's mission and objectives

This should describe what the company's overall goal is and its objectives toward meeting that goal. A mission could be very general or specific, depending on the nature of the business.

3. Top Level Management

This will name and describe the qualifications of the business's management team. Stress any particular training, education or experience that will be beneficial to the business. Try to show that all areas of the business (including management, marketing, finance and operations) are well covered managerially.

4. Location and geographical information

This gives the physical address for the information and any details as to why this location is favorable for this endeavor.

5. Company development stage

This should describe where the company is as of the time of the plan. Is it just a well researched business on paper? Is this an expansion or combination of existing business(es)? How much prior experience in this field is the company bringing to the fore?

6. Company products and/or services

What does the company offer for sale? Is it live or processed? What does it offer besides the physical product? (Do you offer assistance to the buyers in dealing with the products? Are consulting services offered?)

Industry Analysis

1. Size and growth trends

What is the current size (dollars and quantity) of the industry? Give overall statistics for the whole industry and specifics for the part (by species and product form) of the segment. How fast are both the industry and the target segment growing?

2. Maturity of industry

Is this a mature industry? For most aquaculturists, with the exception of southern catfish farming and potentially natural spring trout farming, the industry is still in its beginning phases.

3. Potential impact of economic factors

What impact does the overall performance of the economy have on the business? For example, if interest rates are high (and therefore disposable income down), and the product is considered a "luxury" as many seafood product are, high interest rates could have a depressing effect on sales.

4. Seasonality

Does seasonality play a role in the business

5. Technological factors

Is the technology proven? Is it operational in other facilities? Is it operational in research facilities? What documentation/data can be provided to support these facts? Are there patents or proprietary processes that give a competitive edge?

6. Regulatory issues and permits

What are the significant regulatory guidelines with which the business must comply? How will they be complied with? What permits need to be obtained to operate? When

will they be obtained? Do any of the regulatory issues or permits effect this business differently than the competition and why?

7. Supply and distribution

What is the supply situation for the industry and how is it distributed?

8. Financial considerations

What does it take investment-wise to become a recognized competitor in this industry? How heavy is competition and how does that relate to the need to have heavy cash reserves ("deep pockets")? Are there impending regulatory changes that will require further investment? Consider regulatory agencies defining parameters for growout, treatment, shipping, etc.

The Target Market

1. Demographic/geographic areas

Who are the target market consumers? Consider this beyond the distributor. Where do the end consumers live? Are they ethnic? What is their socio-economic status? Is it a growing segment of the economy? It is important to consider whom the distributor sells to, because that will determine the level of his potential sales, and therefore, the company's.

2. Lifestyle and psychographics

What is the socio-economic buying pattern of the end consumer? Are they convenience oriented? Is there a definite "lifestyle" associated with heavy users of the product? (For example, in predominately two-worker households, you might find many food products purchased because of convenience. An opposite case, with one stay at home adult, convenience may not be as important. Certain cultural groups may have different values placed on freshness, form, convenience, etc.)

3. Purchasing patterns

First, how does the distributor purchase the product? What size shipments does he prefer and how often? How does he distribute the product (time and place)?

Does the end consumer purchase the product daily, weekly, monthly or on special occasions? How much do they usually purchase at one time? What product form do they prefer?

4. Buying sensitivities

Is the end consumer extremely sensitive to price fluctuations? Is this product a staple or specialty product for the consumer? Do they view other species as substitutes for the product (which could allow much price sensitivity)? Are there any particular physical attributes to the product that target consumers prefer? (Examples are size, color, etc.)

5. Size and trends of market

In the particular market segment for the product, in your geographic target, how large is the market? How is it growing? Is it seasonal? Are there religious and/or other cultural celebrations that effect demand?

The Competition

1. Competitive position

How is the company positioned against competitors? What advantages does the company

have? What are the disadvantages and how will they be dealt with? How does the pricing and cost structure compare with the competition?

2. Market share distribution

What percentage of the target market does the company intend to acquire? How is this reasonable? What share does the competition have? How is it distributed among the companies?

3. Barriers to entry

Are there any significant barriers to entry to the target market? Are there contracts, agreements to purchase, etc. that would keep new competition out? Are there financial considerations that would effect new competitors? Are there regulatory issues that will effect the emergence of new competitors?

4. Future competition

What new competition is suspected in the target market in the future? Are there definite operations coming online? How will new competition be dealt with?

Marketing and Sales Strategy

1. The company "message"

What is the main thrust of the marketing plan? (For example: We intend to deliver "X" pounds of product on a bi-weekly basis of uniform quality and size product. This will make it easier on the large distributor as he will no longer have to deal with purchasing irregular amounts at irregular times from natural harvests or smaller suppliers.)

2. Marketing vehicles

How will the marketing message get out? Will conventional advertising, promotional mailers, personal sales visits, trade shows, etc. be used?

3. Strategic partnerships

Is the company involved directly as the only partner/supplier with a distributor(s)? Does this relationship make the market more secure? Are there existing sales contracts? If so, how will contingencies such as shortages, excessive mortality, etc. be dealt with?

4. Other marketing tactics

Will the company participate in promotional ventures? Is there a quality program that provides benefits/reassurances to the buyer? Are volume discounts offered?

5. Sales force and structure

What kind and size of sales force will be hired? How are they organized? How are their goals set and what incentives are provided?

6. Sales assumptions

Are there any particular assumptions related to sales in the business plan? Are there price assumptions? Competitive assumptions? How will management deal with divergence from stated assumptions if forced by market conditions?

Operations

1. Plant and facilities

Describe the physical plant and facilities. Include as an appendix, a floor plan for the facility. Describe the general geographical area of the plant. Give the operational address for the facility.

2. Production plan

How much of what product will be produced and at what time intervals? Describe initial stocking plans, harvest plans and expected mortality. Give a breakdown of time schedules for production.

3. Equipment and technology

What equipment will be used in the facility? How many tanks? What type of filtration system? How does the system work, in simplified terms? What type of redundant or back-up systems will be in place? What kind of alarm or warning system will be used? Is there documentation that can be provided on the technology and its successful use elsewhere? If so reference it to an appendix.

4. Variable labor requirements

What are the labor requirements? (This refers to non-managerial labor.) Does it vary seasonally? Is there adequate access to the types of labor needed? Will management "scale-up" labor during the start-up phase? (If so, provide an estimate of the time schedule for this.)

5. Inventory management

How will inventory be tracked? This will include the fish stock. This also includes inventory of expendable items such as salt, sodium bicarbonate, feed, etc.

6. Research and development

Will the company be conducting any research and development at the facility? This includes testing feeds, new species, water treatments, equipment, etc. Please explain management's plans and why they will benefit the business. List any cooperating agencies, universities, and companies.

7. Quality control

How will the quality control system work? Is there a designated person in charge of this? If so, what are their qualifications for the position? What records will be kept regarding quality control? Is this in line with what the industry at large does?

8. Capacity utilization

What is the full capacity production limit for the facility? Will it be operating at that limit? Will the company scale up to that limit? If so, list milestones for reaching capacity. If the company is not going to be utilizing the facility to capacity, please explain why.

9. Safety, health and environmental concerns

Is the company in compliance with all regulatory agencies, including OSHA and EPA? What safety/health programs are in place to protect employees on the job? Will there be safety drills to deal with fire, contaminants, and other dangerous situations? (An example would be ozone usage.)

10. Management information systems

How will financial and operational records for your company be kept? Is the company computerized? Who has access/control over these systems? Are there adequate back-up procedures in place?

11. Other operational concerns

This is a "catch-all" category for anything that is not covered under one of the other topics. This is a good place to point out any operational advantages the company might have over competitors.

Management and Organization

1. Principals and key employees
List all the management and owners and summarize their expected contributions as well as their qualifications. List any key personnel and their contribution and qualifications. Reference current resumes in the appendix.

2. Board of directors
List all board members and explain why they are on the board. Explain any benefits obtained from having particular board members.

3. Consultants/specialists
List any consultants or specialists to be used during the course of operation. This will include accountants, attorneys, scientists, laboratories, etc. Explain the compensation plan. Explain what the duties of these consultants are and why they are vital to the business.

4. Management to be added
If management is to be added later, describe the position and function within the business.

5. Organizational chart
Include a reference to the appendix to a full organizational chart for your company.

6. Management style
What management style will be used? This can be from the informal "management by walking around" to a more formal directorial style? Explain the reporting system for regular and irregular operations. Explain proper response for operations irregularity.

Development and Exit plans

1. Long term company goals
What are the long term goals of the company? Is it expected to vertically or horizontally integrate or expand production into other facilities?

2. Growth strategy
What is the growth strategy and how will it be managed and financed?

3. Milestones
Provide a narrative and chart pointing out major milestones in the development of the company. This includes pre-groundbreaking time, plan writing time, etc.

4. Risk evaluation
What type of model will be used to evaluate risk of continued operations? What type of model will be used to evaluate risk of expanding operations? (This can be as simple as a SWOT analysis combined with financial spreadsheet sensitivity analysis or as complex as a statistical risk assessment.)

5. Exit plan
What are the criteria/procedure for voluntarily shutting down the business?

Financial Statements

1. Cash flow statement
The cash flow statement is the easiest and most important of all financial statements. It is

a direct statement of cash (revenues) in less cashes (expenses) out, leaving cash on hand. This is an important managerial statement. It is the record of (for historical or real statements) the ability to meet financial obligations and the forecast of ability to meet potential obligations..

2. Income statement

The income statement is a statement of profitability, not of cash left on hand as in a cash flow statement. The major difference is the inclusion of non-cash items such as depreciation and other non-cash adjustments. The income statement should be prepared on the same schedule as the cash flow statement.

3. Balance sheet

Many investors and lenders are interested in the balance sheet. Basically the balance sheet is a statement detailing assets, liabilities and owner's equity. The basic mathematical structure of the balance sheet is simple: assets equal liabilities plus owner's equity. This is normally prepared annually, but in start-up phases, lenders may like to see the statement quarterly.

4. Break even and other analyses

Perform analysis on your financial statements to ascertain the financial health of the business. Also, financial institutions will analyze the statements. Some analysis should be presented in the business plan. These are some of the more relevant ones.

a. break even analysis

b. liquidity ratios

current ratio = current assets / current liabilities

quick ratio = (current assets - inventory) / current liabilities

c. leverage ratios

debt to assets = total debt / total assets

times interest earned = earnings before interest and taxes / interest charges

d. activity ratios

inventory turnover = sales / inventory

fixed assets turnover = sales / net fixed assets

total assets turnover = sales / total assets

e. profitability ratios

profit margin = net income / sales

basic earning power = earnings before interest and taxes / total assets

return on total assets = net income / total assets

return on equity = net income / equity

5. Plan assumptions

List any assumptions that went into making the plan. Include areas such as funding, potential employees, etc. There should be a separate list of assumptions/explanations for all line items on the financial statements.

Appendix

This section will include all items too detailed for the body of the plan or items that do not fit any particular category. Any items referenced in the body (such as resumes, explanations of terms, contracts, etc.) should appear here. Letters of intent to purchase, supply consult, or assist belong here, after being referenced in the main text. Any other documentation requested by investors or lenders may be referenced and placed here. If the appendix is lengthy, it is often preferable to give it its own sub-table of contents.

Recirculating Aquaculture System in Japan

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Status of aquaculture in Japan

With the establishment of the 200 miles economic zone, aquaculture of fish are becoming more and more important in Japan. By 1992, the aquaculture production of Japanese flounder (Aquaculture 7,114 tons: Fishing catch 6,187 tons), red sea bream (65,699 tons: 14,243 tons) and yellow tail (148,691 tons: 55,427 tons) exceeded their fishing catch. And this status has continued in 1995 though there are some fluctuations in Japanese flounder. Out of the total aquaculture production in 1995, that of coastal culture was 1,314,551 tons (94.5%), and that of freshwater culture was 75,123 tons (5.5%).

Problems of aquaculture with open systems

Most of the saltwater fish culture is managed with net cages on the coast of Japan. Some kind of fish, such as Japanese flounder and Japanese prawn (Kuruma prawn) are reared with land based tanks by flow through method. Because these two types of fish culture depend on the natural sea and seawater, fish growth and management of the systems are affected by seasonal changes, weather conditions and other factors. Moreover, these two open fish culture systems discharge feces of rearing fish and leftovers directly to the sea. Therefore in some areas, they caused deterioration of the culture ground and water pollution. And sea areas suitable for the coastal aquaculture have become more and more limited. The another problem of flow through system is that the sea water taken from the sea is returned to it in only one to two hours. To use of electric power more effectively, this process should be improved. For freshwater aquaculture with race way (flow through), insufficiency of suitable water resources for aquaculture has become one of large issue.

Advantages of recirculating fish culture system

On the other hand, closed recirculating fish culture systems have the advantage of using very small quantities water for fish production compared with flow through systems. Therefore, it is easier to maintain an optimum temperature for rearing species and also to disinfect the rearing water. So we are able to shorten the rearing period to make a market size of fish. Closed systems have another advantages of less direct impact on the aquatic environment than open systems when the waste materials and discharge water from the system are managed properly.

Historical overview of studies on recirculating fish culture system

To save culture water, effective use of energy (oil and/or electricity), effective use of

land, and prevent pollution on environment, many studies have been conducted in the world during the past two decades (van Rijn, 1996; Losordo, 1998).

About forty years ago first scientific report on recirculating fish culture system was written by Saeki (1958) in Japan. Through some laboratory experiments, he studied oxygen uptake and degradation capacity of sand bed filter and he showed ammonia oxidation rate of sand in filter bed is 0.14 mg-ammonia per day per 10 g of sand. And he estimated that 300 g weight of filter sand should be used for culturing for 10 g of fish. Based on this standard design, he constructed three closed recirculating systems of 200 to 500 m^3 of water volume with gravel as filter media, and he carried out carp culture tests from 1961 to 1964 (Saeki, 1965). However, these systems are not in existence today. Hirayama (1965, 1966, 1974) also studied oxygen uptake and degradation capacity of sand bed filter for saltwater fish culture. And he also studied on the accumulation of dissolved organic substances in closed recirculation culture systems (1988).

During from 1977 to 1981, Mie Prefecture Fisheries Experimental Station studied on effective use of rearing water for Japanese eel (*Anguilla japonica*) culture with closed recirculating fish culture system. They estimated that the upper limit rearing density was at 25 to 30 kg/ m^3 when the supply of oxygen was done by aeration. Also they found that there was no difference on growth of eel when the water replacement rate were from 2 to 20 % per day. And they used a plastic filter media for closed fish culture for the first time in Japan.

In 1986, we (CRIEPI) have started the studies to develop closed recirculating fish culture systems for Japanese flounder from the viewpoint of obtaining optimum conditions for fish using electric power and also reducing the impact on the aquatic environment.

Recirculating aquaculture systems in Japan

Eel

Due to high value of both land and elvers, more and more intensive culture methods have been developed. The out door still water earthen ponds have been replaced by indoor tanks, built in green house, with water heating systems, aeration systems and water recirculation systems. Almost systems consist of octagonal shaped concrete tanks, settling tanks and pumps. Some of them also have gravel or plastic biological filter bed. However these systems appearance differ from eel production recirculating systems in Europe countries. In these system, rearing densities are from 20 to 40 kg per m^3 of water, flow through rates range from once per hour to per day, and water replacement rates are 5 to 15 % per day depending on fish size reared. This type systems are common in Japan. And some imported systems such as Danish Type with bio-drum do operate now in Japan.

Rainbow trout

Culture of rainbow trout needs a large amount of water and high replacement rate at near

100% per hour. There is a trout farm adopted recirculating system to rear juveniles due to insufficient spring water supply in Nagano Prefecture. A system consists of a slightly sloped rectangular fish tank, a filter for waste solids removal and a biological filter for nitrification. The solid removal filter with fluidized small pieces of plastic mat resembles to low density plastic floating bead filter though the direction of water flow is downward. The total water volume of the system is 30 m^3. The flow through rate is once per 20 to 30 minutes. Although water replacement rate is about 50 % per day, water volume used in a day is only 2 to 4 % comparing with ordinary flow through system.

Ayu

The system mentioned above is also adapted to rear juvenile Ayu (*Plecoglossus altivelis*). And Kanagawa Prefecture Fisheries Experimental Station has a experimental system for Ayu.

Japanese flounder

Our system (CRIEPI-type) was planned to produce 2,000 fish of 500 g in body weight (1,000 kg of fish), which is the minimum commercial size for cultured flounder in Japan. The system consisted of a fish tank (6 m in diameter, 16 m^3 of water volume), a settling tank (1 m^3), two biological filters (3 and 2 m^3), a heating-cooling unit (heat-pump 19,000 kcal/h), a circulation pump (480 L/min), an UV light (540 w), blowers (270 w by 3) and total water volume adjusted 22 m^3. The minimum necessities of filter media, aerator capacity, seawater for operation and bottom area of fish tank were calculated based on the results of other experiments such as upper limit rearing density: about 40 kg/m^2 (400g fish in body weight), ammonia excretion rate: 250 mg/day in 500 g fish, ammonia oxidation rate of well conditioned biological filters (223 mg/L/day) and respiration rate of the fish (Honda, 1988; Honda et al., 1991; Kikuchi et al., 1990, 1991,1992,1994). We also have two 10 m^3 systems at Akagi Testing Center in Gunma Prefecture.

Besides our systems, there are other two types of recirculation aquaculture systems for flounder in Japan now. In 1997, JIFAS (Japan International food and Aquaculture Society) has started the evaluation on the system consisting of some imported equipment from foreign countries with summer flounder from USA. The system consists of four fish tanks (5 m^3), some water treatment equipment such as particle trap, micro screen filter, ozone generator, form fractionator, UV light, trickling filter, mixed bead filter, oxygenator, and a heating-cooling unit. The system with bromine free artificial seawater operates now in Saitama Prefecture. And Hokkaido Industrial Technology Center has a JFAS-type system consists of nine fish tanks of 3 m^3.

Another one is called KSK-type after the name of the company dealing the system. The system consists of a fish tank and a biological filter. A pilot system has operated in Shiga Prefecture from 1997.

Puffer

A CRIEPI-type system consists of four fish tanks of 5 m in diameter has operated to produce Tora-fugu (*Fugu rubripes rubripes*) now in Shimane Prefecture from 1996.

This system is managed by a local fisheries association.

Other species

There are some trials to rear some saltwater organisms such as scorpaenid fish, abalone and others with recirculating aquaculture system.

Operation and variable cost of recirculating aquaculture system

We conducted rearing experiment with 2,000 juvenile (3.5g) of Japanese flounder with the above-mentioned 22 m^3 system in 1994 under 20 to 25 degrees centigrade. After 330 days of rearing, fish grew to 480 g in mean body weight and total fish biomass in the system became 844 kg. Rearing density per unit volume of water in the system reached 38.4 kg/m^3. Because 6 and 9 m^3 of the rearing water exchanged with fresh seawater at the measurement of fish body weight, the production per unit volume of seawater used was 22.6 kg/m^3. This result implies that 1 kg of flounder produced with only 44 L of seawater. Although there were some fluctuations of ammonia, nitrite and nitrate concentrations, these results indicate that intensive culture of Japanese flounder is possible with small quantity of seawater without daily water exchange and direct impact on the aquatic environment by using the closed seawater recirculating system.

In the 330 days of operation, 2,000 seedling fish, 842 kg of feed and 41,237 kWh of electricity were used to produce about 840 kg of founder. Unit prices of these items were 120 Japanese yen /fish, 350 yen/kg of feed and 11 yen/kWh respectively in 1994. Therefore, the cost for 1 kg production of the flounder was 1,180 yen (about 9 USD). This is not a great difference from the total cost of seedling, feed and electricity in the culture with open flow through systems, notwithstanding the operation of a heating-cooling unit to keep the optimum temperature for growth of the flounder. The cost of the closed system used in this operation was 1.5 to 2 times higher, however, compared with the flow through systems consisting of 6 m diameter fish tanks and other equipment (Honda and Kikuchi, 1997).

So next large issue that we have to do study is design on inexpensive and effective (cost effective) systems for industrial operation.

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Recirculation Technologies in Norwegian Aquaculture

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Introduction

In 1997 the production of salmonids in Norwegian fish farms exceeded 300 000 metric tonnes. Atlantic salmon (*Salmo salar*) is by far the most important with more than 90-95 % of the total production. However, the production of rainbow trout (*Oncorhynchus mykiss*) has increased considerably over the last 3-4 years. Typically, 90-95 % of the total production is exported (Table 1).

Table 1. Export figures for Norwegian aquaculture (metric tonnes, gutted).

Year	Atlantic Salmon	Rainbow Trout	Total
1988	68540	4058	72598
1989	98988	1336	100324
1990	111299	1049	112348
1991	131667	3266	134933
1992	132453	3825	136278
1993	142548	4625	147173
1994	196194	11958	208152
1995	207294	7497	214791
1996	238115	14813	252928
1997	261555	22054	283609

Although the production of salmonids has shown a considerable increase over the years (Table 1), marine species like turbot (*Scophthalmus maximus)* and halibut (*Hippoglossus hippoglossus*) have not yet reached significant production volumes.

In 1997, the number of public permits (licences) for the production of salmonids was 316 for freshwater smolt farms, and 820 for marine grow out farms, mainly open sea cages. In 1995 there were 46 permits for arctic char (*Salvelinus alpinus*), 48 for halibut, 2 for turbot, and 19 for European eel (*Anguilla anguilla*). Some of these permits are not yet in use. In addition, there are some 50 freshwater farms for salmon and brown trout restocking. The production of freshwater fish for consumption is however very limited in Norway (less than 500 tonnes per year). This is at least partly due to the very strict

environmental regulations, introduced in order to minimise the risk for: 1) eutrophication of fresh water resources, 2) disease transfer to wild fish stocks, and 3) runaway fish making a possible genetic impact on wild fish stocks.

The great availability of good quality fresh and saline water in Norway has undoubtedly contributed to the fact that recirculation has been considered uneconomical. To our knowledge, no recirculation systems are now in use for salmonids grow out in sea water, and less than 1 % of the about 100 million salmon smolts produced per year are grown in recirculation systems.

Over the last few years, however, there has been a growing interest for recirculation technology for a number of reasons:

- Less availability of water resources with good and stable quality, due to an increased number of water users and an increased demand for the best water resources.
- Increasing demand from salmon grow out farmers for early deliveries and larger smolts. For the smolt farmer, this may imply higher biomass production from the same available amount of water. To cope with the corresponding need for increased stocking densities and reduced specific water consumption rates, recirculation is considered a relevant solution.
- The environmental regulations have created a need for effluent water treatment technology, for systems able to reduce specific water consumption rates, and thus also for recirculation technologies
- The production of marine species (at the larval stage) has shown benefits in terms of increased growth and survival as a result of biologically treated, “conditioned” or “maturated” water with a well balanced microbial quality.
- There is a growing interest for small scale fish farms among Norwegian farmers and land owners in rural areas with available and appropriate fresh water resources. Due to the very strict environmental regulations in some inland areas with the corresponding need for effluent treatment in terms of particle separation and also disinfection, water conservation and recirculation technologies are considered the best solutions in many cases.

Recirculation in the Norwegian aquaculture industry

Up till now, most of the production in closed fish farms in Norway has taken place in single pass, flow through systems.

The driving forces for recirculation technologies have mainly been the demand for reduced (not necessarily minimised) water consumption rates, increased biomass production per unit volume of water, and more economically viable effluent treatment solutions to cope with the environmental issues related to particle separation and disinfection requirements.

From the conditions prevailing in Norway one may, with a few exceptions, characterise existing and developing recirculation technologies for production of cold water species (e.g. salmonids) by saying that:

1. There is more interest for semi-closed, “improved flow through” systems, than for traditional, closed recirculation systems with extreme recirculation rates and centralised water treatment units. The reputation among Norwegian fish farmers is not very good for that kind of system. For that reason, development of recirculation technologies has to a great extent taken place at research institutions.
2. Further, there is a drive towards local and complete recirculation solutions for each fish tank or a limited number of tanks (“tank-internal” recirculation).

In “tank-internal” recirculation systems the fish tank is utilised as the first particle separation unit. This is possible by means of effluent flow splitting where the water to be recirculated is taken from a stand pipe located in the centre of the tank and perforated in the upper part only. This water contains relatively small amounts of particles. The much smaller, but more particle containing water flow through the bottom screen is treated in a transparent swirl separator which is also used for visual control to avoid excessive feeding.

After swirl separation, disinfection is incorporated, if required. Normally UV-disinfection is considered the best solution, provided a good water quality in terms of low UV absorbance and low suspended solids concentrations (<5 mg SS/L). This is required to avoid enmeshment of microorganisms in particles, UV-light blockage and shadow effects. Further, biofiltration is required to reduce biofilm growth potential in UV aggregates, pipes and surfaces.

Existing and developing recirculation technologies

At present, 5-6 companies offer what may be called Norwegian recirculation technologies. With few exceptions, these companies are small, normally employing less than 10 persons. Some examples of technological solutions are given below.

A recirculation system (BIOFISH) developed for use in separate tanks or a small group of tanks is shown in Figure 1. The idea behind this system was developed by SINTEF in 1982, and the technology has been under further development, testing and documentation since then. It is commercialised by Procean as.

In BIOFISH a simple form of effluent splitting is used, where relatively particle free water is taken from the upper part of a standpipe located in centre of the tank. This water is recirculated through a combined aeration and biofilter unit as shown in Figure 1. Here a moving bed biofilter is now used (Kaldnes Miljöteknologi, KMT), where the biofilm carriers are small plastic cylinders with an internal cross and outside “wings” to simplify biofilm attachment and increase the area available for biofilm growth (Figure 2). Gas transfer is performed by means of a combined venturi and ejector type of unit located on the pipeline in the top section of the biofilter box. Air (or oxygen) is released inside the biofilter. Thus air lift contributes to biofilter media movement.

The water discharged through the bottom screen contains most of the faeces and waste feed particles. This flow is discharged through a narrow pipe designed for self-cleaning, to a transparent swirl separator used for particle collection and feeding control. Then this flow is microscreened and disinfected (UV), if required.

The main idea behind the local or "in-tank" recirculation concept is to obtain more flexible and independent operation of every single tank, simplified control of disease transfer from tank to tank, rapid and effective particle separation with a minimum of particle break-up and erosion, and improved control/avoidance of overfeeding.

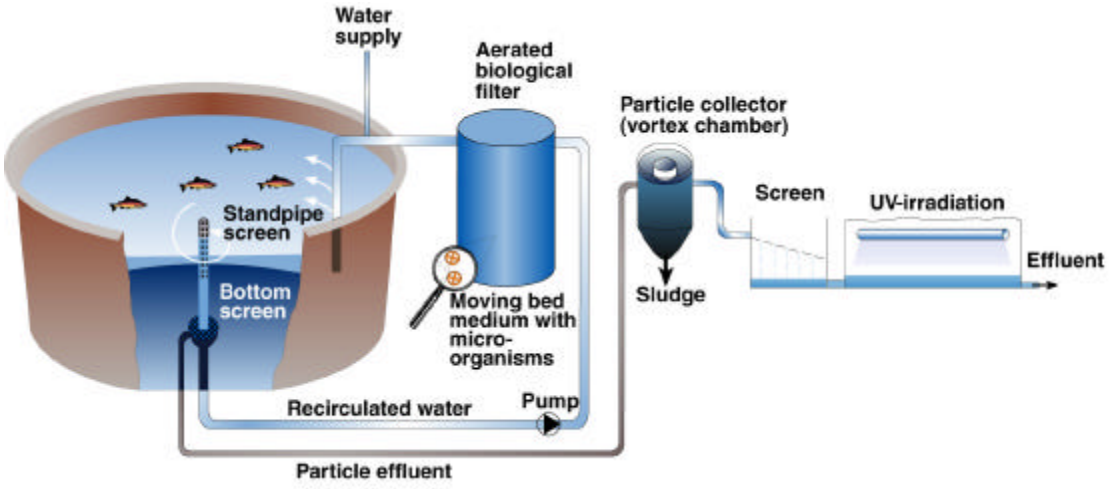

Figure 1. The recirculation system BIOFISH (Procean, P.O Box 1722, N-5024 Bergen, Norway).

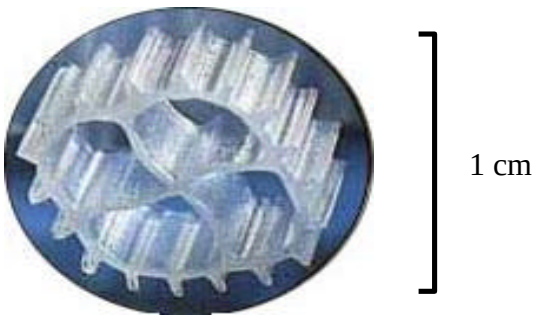

Figure 2. The KMT moving bed biofilter media (Kaldnes Miljöteknologi, P.O Box 2011, N-3103 Tönsberg, Norway).

Another and similar recirculation system, ECO-RECIRC, is offered by the company Aqua Optima (Figure 3). This system, however, is based upon a unique particle trap unit

(ECO-TRAP), originally developed by SINTEF in the early1990s and commercialised by Aqua Optima (Figure 4).

ECO-RECIRC is using effluent flow splitting by means of the particle trap system located at the bottom in the centre of the fish tank. The water to be recirculated is taken from the perforated part of the particle trap unit a short distance above the tank bottom, while the effluent water including most waste feed and faeces is discharged through the small spacing formed between the tank bottom and the particle trap plate. ECO-RECIRC uses a low pressure oxygen saturator. A traditional trickling type of biofilter is used, with fixed media ("Honeycomb") in the form of blocks of hexagonal vertical tubes, and a rotating spray bar for influent water distribution.

Figure 3. Schematic illustration of the recirculation system ECO-RECIRC (Aqua Optima, Pir-Senteret, N-7005 Trondheim, Norway).

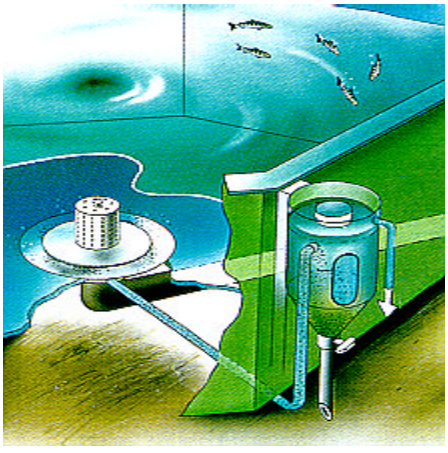

Figure 4. Schematic illustration of the ECO-TRAP connected to a swirl separator outside the fish tank. (Aqua Optima, Pir-Senteret, N-7005 Trondheim, Norway).

A recirculation system developed for the production of eel in small-scale systems with easily available and low cost components is shown in Figure 5.

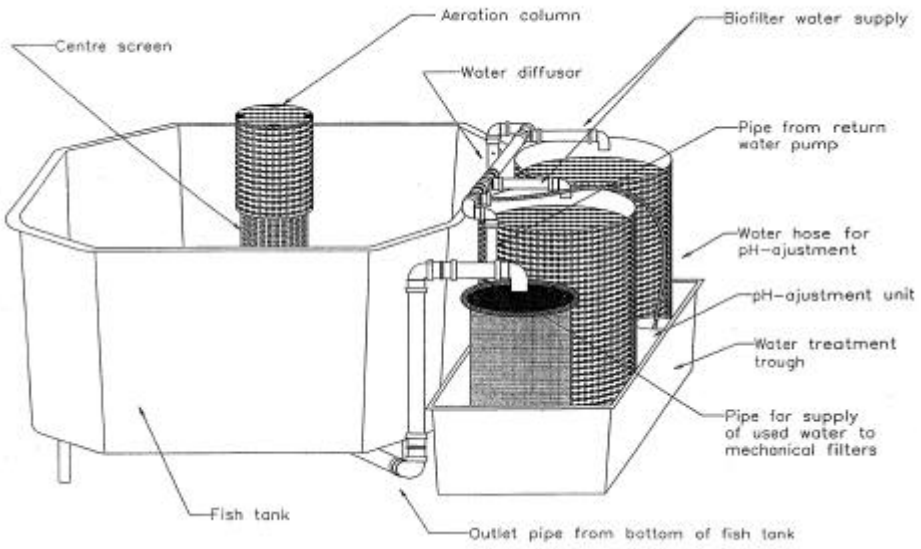

Figure 5. Schematic illustration of the recirculation system "Folkekaret" (Calcus, Tangen, N-7500 Stjördal, Norway).

A system that deviates from the principles of local and independently operated re-circulation units, flow splitting and feeding control based on local swirl separators is shown in Figure 6. This technology (SUN-Fish) is applied on marine species, mainly turbot, and is evidently more like traditional closed recirculation systems.

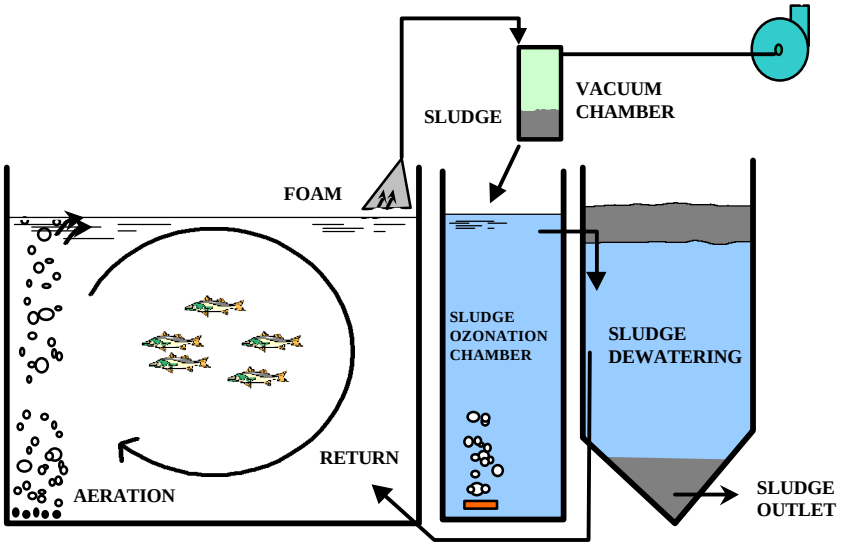

Figure 6. Schematic illustration of the SUNFISH recirculation system (PurAq, Fritznersgt 1, N-0264 Oslo, Norway).

In the system shown in Figure 6, mass balance calculations from turbot production showed that 74 % of the dry matter added as feed was metabolised by the fish, 8 % was removed in the biofilter and 18 % was removed through foaming and skimming. For flatfish, up to 9 shelves are used in the fish tanks to increase the area available for fish and thus increase the efficient production volume. For halibut a new farm in Western Norway have also incorporated the standpipe and moving bed biofilter principles from BIOFISH (Figure 7). This farm may also be operated as flow through.

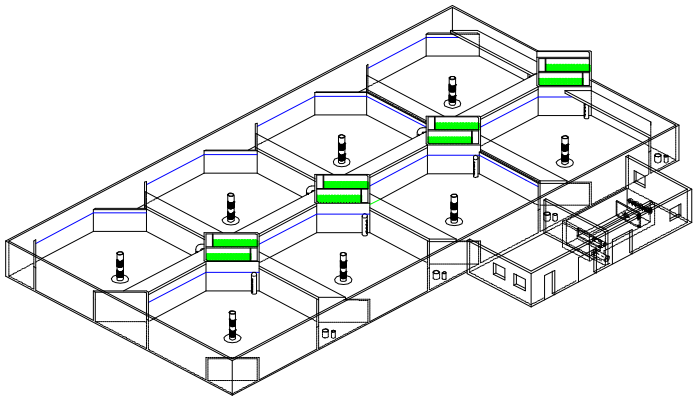

Figure 7. Overview of a halibut farm with flow splitting and moving bed biofilters, (approximately 1000 m^3 production volume, shelves not shown).

Recirculation systems performance – an example

Available data on recirculation systems performance in commercial operation are very limited. As an example, however, performance data from a 6 months testing and documentation period at a commercial farm using BIOFISH recirculation technology (Figure 1) for the production of Atlantic salmon smolts are presented below. The volume of the BIOFISH was 7.5 m^3, and microscreening and UV disinfection units were used for further treatment of the effluent water. This technical solution was designed to meet the strict regulations for effluent discharge to inland freshwater river systems. Production data and water quality data from the trial are presented in Tables 2 and 3, respectively.

Table 2. Production data from testing of BIOFISH at BANDAKSMOLT as.

Parameter	**Unit**	**Value**
Tank volume	m^3	7.5
Period	days	140
Average weight (start – end)	g	45 – 257
Mean specific growth rate	% bw/day	1.27
Maximum stocking density	kg/m^3	88
Specific water consumption rate (at maximum biomass)	L/min/kg	0.018
FCR (kg dry feed/kg growth wet weight)	-	0.81

Table 3. Water quality data from testing of BIOFISH at BANDAKSMOLT as.

Parameter	Unit	Average	Max	Min
Temperature	^{o}C	12.7	15.1	7.8
Oxygen	mg O_2 /L	8.7	13.9	5.8
pH	-	5.8	6.6	4.6
Ammonia – N (TAN)	mg N/L	2.8	7.8	0.8
Nitrite – N	mg N/L	0.2	0.6	0.02
Nitrate – N	mg N/L	3.3	8.3	0.8

As shown in Table 3 the concentration of TAN averaged 2.8 mg/L with a maximum value of 7.8 mg/L. We experienced that the start-up period for nitrification was very long, exceeding the 6 – 8 weeks (10 ^{o}C) normally reported in the literature. The water supply at this fish farm was very low in alkalinity (< 0.1mmol/L). This may have contributed to the prolonged start-up period for nitrification. The very smooth surface of the carriers and the corresponding delay in biofilm establishment is probably also important here.

Effective particle removal from the effluent is very important to ensure that the UV disinfection process is effective. High content of particles may lead to encapsulating and shadow effects, and thereby reduce the efficiency of the disinfection process. Efficient particle removal is of course also important, with respect to effluent discharge of nutrients from the system. Based upon an intensive sampling programme with strict control of factors like feed and water flows over a given period of time, a mass balance was calculated for suspended solids (SS), organic matter (COD), total phosphorus (Tot–P) and total nitrogen (Tot-N).

As an example a suspended solids (SS) mass balance on a dry matter basis is given in Figure 8. The mass balance calculation is based on the fact that the only net input of suspended solids (SS) to the system is feed. The dry matter given as feed was set to 100 % and the other figures were calculated relative to this. As shown in Figure 8 most of the SS leaving the fish tank (faeces and surplus feed) was removed in the swirl separator. Approximately 1.4 % of the dry matter given as feed was discharged in the effluent as SS. For COD, tot-P and tot-N the corresponding figures were 8.2 %, 10 % and 44 %, respectively. With UV disinfection after microscreening (40 μm), more than 99.9 % reduction of the total bacteria count (CFU) was documented.

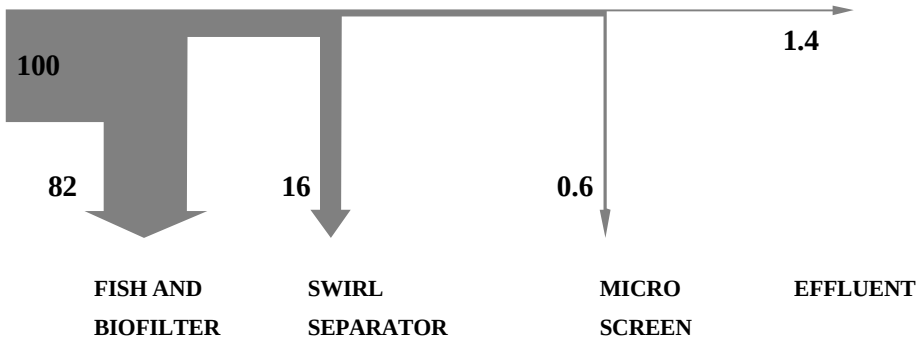

Figure 8. Example of a mass balance for SS in a BIOFISH tank with Atlantic salmon (125 g) and dry pellet feeding.

Summary and conclusions

- The use of recirculation technology is very limited in Norwegian aquaculture today. No sea farms use recirculation for Atlantic salmon grow out. In fresh water less than 1 per cent of the total annual production of approximately 100 million smolts is produced in recirculated systems.
- The interest among fish farmers for recirculation is however increasing, mainly for fresh water salmon smolt farms, small scale farms for fresh water species, and fry and grow out farms for marine species (halibut, turbot, etc).
- "Tank-internal", semi closed and simplified recirculation concepts seem to have the greatest application potential in Norway. A number of existing and developing concepts of this kind may be described as "improved flow through systems" aimed at reducing the water consumption rate rather than minimising it. These technologies include independent and local water treatment and recirculation units connected to every fish tank, or small group of tanks, and utilise to a great extent effluent flow splitting, swirl separation for particle removal and feeding control, and novel biofilm and gas transfer techniques.

Overview of Recirculating Aquaculture Systems in UK

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Abstract not available at time of printing.

Recirculating Aquaculture Systems in Korea - Development of an Environmentally Friendly Aquaculture System, Intensive Bio-Production Korean (IBK) System

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Introduction

Commercial recirculating aquaculture systems have been developing for decades for various purposes in many parts of the world, but the development has largely been delayed due to many constraints, including economic setback to produce food fish and technical problems yet to be innovated. Nevertheless, feeding aquaculture in inland waters and in the protected coastal seas in the future should be practiced with waste treatment for the reduction of pollution in the environment. We therefore need to develop the technology of environmentally friendly aquaculture systems as completely as possible not only to preserve our natural environment but also to sustain aquaculture production.

There exist two kinds of approaches in the water reuse systems, ecological and mechanical approaches (Muir, 1995). We can employ either ecological approach that recycle the water in the rearing chamber itself by natural nutrient recycling or mechanical approach which treats waste water in a separate treatment system and return the treated water to the rearing tanks depending on the available conditions. One example of the ecological approach is fish production in ponds, which are never drained. Fish can be harvested by seining and the pond can be restocked the next season. In this case a rather extensive area is required to keep the business feasible because the stocking density is relatively low. Therefore in industrialized countries like Korea with high human population and limited available land area, the ecological approach has not been economically feasible because the cost of land use is also extremely high even if available. So we should have chosen the way of water recirculating aquaculture system to produce fish economically in quantity, and we must pay more effort now and in the future.

For the success of aquaculture the attainment of profit against invested capital is an absolute must like any other business. For the recirculating aquaculture system capital investment for the construction of the farm is normally much higher than that of conventional production system, therefore the system should be designed and constructed so as to be able to manage at less running cost to compensate the initial capital investment. One must also expect better production than that from conventional systems, provided that optimum stable conditions in water quality parameters for fish growth be maintained through controlled system management.

History of Recirculating Aquaculture System Development in Korea

Laboratory Use of Recirculating Aquaculture System

Unable to get enough water for fish growing experiments, the authors have been using closed recirculating aquaclture systems for various fish growing experiments in the laboratory since from the first (Kim and Jo, 1974; Kim and Park, 1974; Kim et al., 1975; Kim and Jo, 1975; Kim and Jo, 1976; Kim et al., 1977; Kim and Jo, 1977a; Kim and Jo, 1977b; Kim and Jo, 1978; Kim, 1980; Kim and Lee, 1981a; Kim and Lee, 1981b; Kim et al., 1984; Kim and Oh 1895; Kim et al., 1887; Kim and Woo 1988; Saifabadi and Kim 1989; Kim et al., 1990).

Commercial Scale Recirculating Aquaculture System

In 1979, Kim (1980) started constructing a pilot scale recirculating fish culture system on the campus of National Fisheries University of Pusan (now Pukyong National University), and this facility has been used for various later experiments (Kim and Kim, 1986; Kim and Woo, 1988; Kim et al., 1991). A couple of other units of the recirculating aquaculture system based on the same principle have been set up elsewhere in Korea and they are now under practical fish production. This recirculating aquaculture system has been designated as ‘Intensive Bio-production Korean System (IBK System)’ and the description herewith presented is mainly an explanation of this system.

Some other types of recirculating aquaculture systems have been practiced in Korea. In 1970s, submerged gravel filters were employed by eel farmers only for a short time. Later, rotating biological disc filters have also been employed by some land-based marine fish farmers as well as some freshwater fish farmers, but they have been gradually disappearing now. The reason why these systems could not continue development seems to be that the farmers think only biofilter could solve everything in fish farms.

Basic Principles for the High Density Fish Culture

For the growing of fish at high densities some critical factors must be met for the wellbeing of the fish in the system. There are a variety of factors that affect the health of fish leading to the performance of fish production business. Of these factors the most important factors must be kept in mind to develop any high-density fish culture system let alone closed aquaculture system. To meet these factors the strategy must contain both hardware structure design and software management technology.

The Most Important Factors for Fishpond Management

The following factors are absolutely essential for the management of intensively stocked fishponds either in closed system or in open-air ponds.
(a) Solid wastes removal
(b) Removal of suspended solids
(c) Removal of dissolved organic matters
(d) Removal of dissolved inorganic wastes (ammonia and others)

(e) Oxygenation or aeration
(f) Pumping or water movement
(g) pH correction (for completely closed system especially where make-up water is soft)

Safety or Security Management

As today's aquaculture tends to become highly intensive, and more sophisticated instruments or machines are employed, the farmers must be prepared to cope with any damage of devices or failure of power supply. At the same time the manager of the farm should be informed about any abnormality in the farm.
(a) Emergency standby power supply
(b) Warning system

Feeding Practice

Feeding technology for fish in the rearing system may seem to be quite easy, but the most difficult yet hard to manage is the feeding practice. It can be said that one who can manage the feeding regime properly could be designated as a well trained and promising fish grower.

Proper feeding of quality feeds is an absolutely important practice. Never feed overfeed and any uneaten feed must be quickly removed, if any. Any uneaten feeds remaining in the water quickly impart absolutely valuable ingredients, which have water-soluble characteristics such as vitamin Bs and most minerals, into water. This heavily deteriorates the quality of rearing water, leading to the encouragement of the growth of pathogenic organisms. Some farmers are much concerned about using water stable feeds, but this practice could help only to a negligible extent if the uneaten feed remains in water for any extended time.

Other Factors for Fish Farm Management

For the normally managed fishponds that are intensively stocked may not require any additional treatment but for most fish farmers it has been inevitable to use additional treatment such as disease control. It also necessitate some special input such as heating or cooling of water where this helps provide more optimum conditions for the fish under growing only for particular purposes such as rearing juvenile stages, stimulating spawning, and so on.

Description of the Recirculating Aquaculture System in Korea

Tilapia are reared mainly in the recirculating aquaculture system in Korea. The extent of water recycling varies depending on each farmer who constructs their own farm system employing filter units, but most recirculating fish farms are of partial water recirculating system, which is not based on the result of investigations.

The Intensive Bio-production Korean System (IBK system), which was originated from

the system by Kim (1980) has continued improvement through modification up to now. Very recently some institutions including governmental and educational bodies have already employed this system or under planning to construct this system very soon. Normal density of tilapia in this system has been at least 5% of the water volume in the rearing tank and they keep normal growth until they reach more than 10% of the water volume without any disease outbreak. In extreme cases fish over 20% of water volume were able to keep their health though the growth rate was decreased.

The IBK system has been successfully tested to grow a number of freshwater fish species including tilapia, Israel strain of common carp, channel catfish and eels both *Anguilla japonica* and *A. anguilla*.

The Principle for the Design and Construction of the IBK system

Main principles for the system development of the recirculating aquaculture system have been based on the basic principles for the high-density fish culture as explained before. In addition, the aspects of security and economical feasibility have always been taken into consideration. Though the system consists of concrete works and most routine work is manually operated, the system seems feasible for producing a few hundred metric tons of fish annually only by the hands of a couple of persons.

Structural Characteristics of the IBK System

- Employment of only trouble-free components (*low sophistication*),
- Low pumping head at the pumping station (*energy saving*),
- Large filter unit (*stable and marginal filter capacity*)
- Integration of water treatment processes in the same component (*simplification*)

The system design is very simple and does not employ highly sophisticated parts. The system *structurally* consists of rearing tanks, small sedimentation tanks, a pumping station, and multiple sections of the biological filter. Open channels connect these components.

The rearing tanks, in use at present, are circular tanks and have dual drains, one for the main recirculation of the water in the system, and the other one for the quick separation of solid waste materials, which have been produced in the rearing tank.

Pumps to move the water are placed at one place, and multiple pumps are installed to prevent any failure in water movement in case of mechanical failure of any pump. Laymen can operate the system because the routine work is quite simple and most work is manually operated, thus minimizing any damage caused by instrumental failure during the operation.

A separate final wastewater-receiving tank is provided. The tank consists of two sections, which are alternately used. During the time when one section is used the other section is dry up. When the one section is receiving the wastewater from sedimentation tanks every

day and from the sections of biological filter when cleaned, solid wastes are settled down and decanted clear water is discharged.

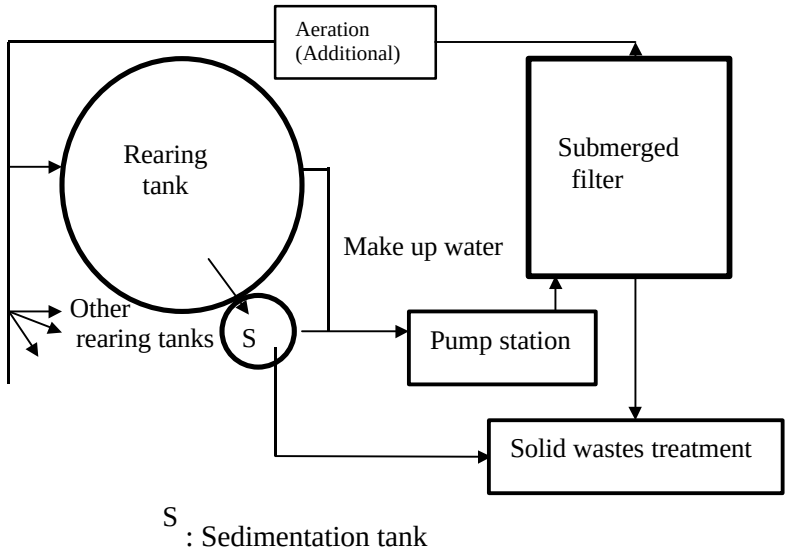

Figure 1. Diagram showing the path of the flow in the Intensive Bio-production Korean System (IBK System) to grow tilapia in Korea.

Functional Characteristics

- Early removal of solid wastes (*right after each rearing tank*)
- Efficient removal of dissolved organic matter and suspended solids at the pumping station (*with simple device but without additional cost*)
- Gas exchange at the pumping station (*with simple device but without additional cost*)
- Very slow flow speed in filter tanks (*efficient settlement of suspended solids*)
- Large turnover rates in the rearing tanks (*large circulation water volume at low cost*)

Functionally solid wastes are removed from each rearing tank right after produced. Then they are moved to the sedimentation tank, which is located right next to the rearing tank. The solids settle down on the bottom of the sedimentation tank where they are little disturbed until flushed out. Solid wastes are thus separated from the system water at a very early stage after being produced.

The system has relatively low head between rearing and filter tanks, therefore low pressure high volume axial flow vertical pumps are used to circulate the system water thus saving the cost of power consumption to a large extent. The difference between the tops of rearing and filter tanks is normally 50 cm. One 5.5 KW pump can lift as much as more than 500 cubic meters of water per hour.

Main pumping station is so constructed that it can also serve for gas exchange such as aeration and release of carbon dioxide, and the stripping of dissolved organic matter and

most of fine suspended solids in addition to water moving. For instance, when the oxygen level before passing the pumps is 2.5 mg per liter, it is increased to 5.5 mg per liter. That means the same pumping station is used for these three functions. In future the pumping stations will be improved to increase the gas exchange capacity to a considerable extent. Figure 2 shows the sectional view of the pumping station.

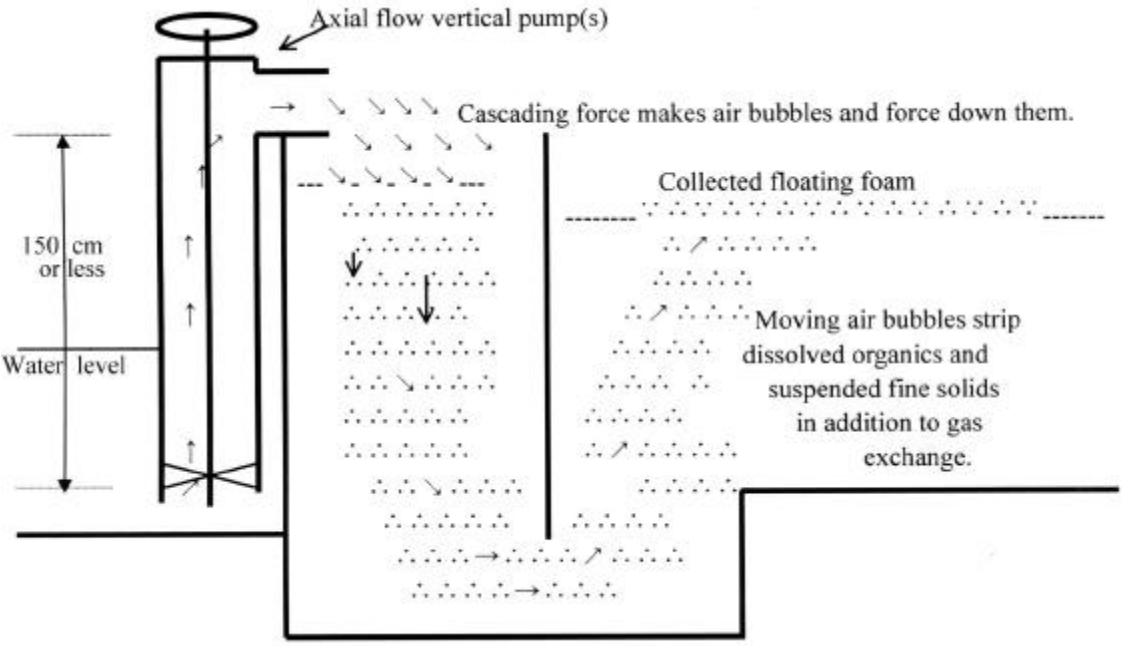

Figure 2. Diagram showing the sectional view of pumping station. The pumping station serves for aeration, carbon dioxide removing of carbon dioxide, dissolved organic matter and fine suspended solids in addition to water moving.

The large biological filter serves mainly for nitrification, but it also effectively traps suspended solids, if any after fractionated at the pumping station. Because the biological filter is very large sudden fluctuation of water quality parameters is checked at minimum. To prevent any fluctuations of filtering capacity owing to periodic cleanings of filter sections, which bring about lag stage after cleaning and senile stage before cleaning, the filter is divided into many sections, at least 5, preferably more than ten compartments for staggering cleanings. At a fish farm that can produce about 100 metric tons of tilapia per year, the biological filter has 36 sections.

A Commercial Tilapia Farm Employing IBK Recirculating Aquaculture System

The system consists of fish rearing tanks, sedimentation tanks, a pumping station, biological filter chambers, and open channels. For the final sedimentation of all discharged wastes, a system of separate dry-bed settling chambers receives all effluent waste water and decanted water is again received by a final pond which spill out excess water into a rice daddy field which is also owned by the same owner.

Daily exchange ratio of water is less than 1% of the total amount of water (2,500 cubic meters) in the system, with current standing crop of over 40 metric tons of large to medium sized fish and more than 300 kg of daily ration. It is expected to increase the amount of daily ration up to 400 kg.

Some items on the farm are described as followings:

Area covered by fish rearing facility : 3,526 square meters
Rearing tanks: A total of 64 tanks, 1,446 square meters
16 tanks of 4.2 m in diameter (221.6 square meters, each 13.9 square meters)
48 tanks of 5.7 m in diameter (1,224.8 square meters, each 25.5 square meters)
Sedimentation tanks:
A total of 32 sedimentation tanks, each for every 2 rearing tanks, for the early removal of solid wastes. Each sedimentation tank measures 0.75 or 0.8 m and depth is about 1.5 m.
Pumping station for Recirculating:
The pumping station serves for water circulation, oxygenation, and removal of carbon dioxide, dissolved organic matter and fine suspended solids.
Four vertical axial flow pumps of 5.5 kw each are installed at present, and 1 standby pump is ever ready to replace any pump damaged.
Biofilter section:
36 sections of submerged biofilter (900 square meters including walls and channels)
Dimensions of each chamber: 4 m x 4.3 m x 1.7 m (D) = 29 cubic meters
Filterant each tank: Corrugated PVC roofing plates (surface area: 4,600)
Estimated average flow speed in the filtrant: 3 mm per second.
Annual production targeted: 80-100 metric tons of tilapia of more than 1 kg each
Species cultured at present: Tilapia
Required amount of water per day: 20 (now)-50 cubic meters
Water source: 1 well water (one 0.5 hp suction pump capable of pumping 50 per day)
Standby electric generators : 2 units of 75 kw generators in 50 room
Final waste treatment basin 4.2 m x 22 m (92.4)
(Address: Samseong Nongsusan Co. Ltd. located at: 432-1 Samsong-ni, Pulun-myon, Kanghwa-gun, Inchon Metropolitan City 417-830 Republic of Korea)

Concluding Remarks

Korea has a small land area and water resources are highly limited. The pollution of water and air has been a serious problem for the survival of the nation. In 1998 the central government declared that all cage farms in the inland waters be discontinued after the terms originally permitted, almost all of which fall in before 1999. Majority of the cage farms have already been dismantled. The bulk of freshwater fish has so far been produced from the net cage farms. The only substitution for outgoing fish production from the cage farms is expected by the development of the closed recirculating fish culture system which should be environmentally friendly as well as economically feasible especially in the era of the global open market.

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Shellfish Diseases and Their Management in Commercial Recirculating Systems

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Introduction

Intensive culture of early life stages of bivalve shellfish culture has been practiced since at least the late 1950's on an experimental basis. Production scale culture emerged in the 1970's and today, hathcheries and nurseries produce large numbers of a variety of species of oysters, clams and scallops. The early life stage systems may be entirely or partially recirculating or static. Management of infectious diseases in these systems has been a challenge since their inception and effective health management is a requisite to successful culture. The diseases which affect early life stage shellfish in intensive production systems and the principles and practice of health management are the subject of this presentation.

Shellfish Diseases and Management

Diseases of bivalve shellfish affecting those reared or harvested from extensive culture primarily consist of parasitic infections and generally comprise the reportable or certifiable diseases. Due to the extensive nature of such culture, intervention options or disease control are limited. In contrast, infectious diseases known from early life stages in intensive culture systems tend to be opportunistic in nature and offer substantial opportunity for management due to the control that can be exerted at key points in the systems.

In marine shellfish hatcheries, infectious organisms can enter the system from three sources: brood stock, seawater source and algal food source. Once an organism is established in the system, it may persist without further introduction. Bacterial infections are the most common opportunistic infection in shellfish hatcheries. Viral infections have also been reported and generally are transferred from infected brood stock. Case histories and their management in intensive systems, both complete and partially recirculating, will be reviewed for the following diseases.

Vibriosis of Larval and Juvenile Bivalves.

Vibrio infections in larval shellfish are aggressive and rapidly progressing infections. Larval shellfish have little capacity for repair. Entry of the pathogens has been documented from all three potential sources of contamination. Vibriosis is managed buy surveying the system bacteriologically to locate the contamination source and taking

appropriate corrective action which may include increased water filtration, brood stock disinfection or screening and algal food culture decontamination.

Hinge Ligament Infections of Juvenile Shellfish.

Ligament infections, caused by gliding bacteria, are one of the most common and cosmopolitan infections among juvenile shellfish. The consequences of infection are dependent on the size of the affected bivalve. They are caused by gliding or myxobacteria which are able to utilize the shellfish ligament as a sole nutritional source.

Subpallial Bacterial Infections.

Subpallial bacterial infections of juvenile bivalves are persistent and occasionally debilitating conditions. Such infections utilize an invasive pathway through the mantle tissue. The infection is size dependent and tends to be chronic as the shellfish increase in size. The nature of these infections varies by species. Vibrios are common etiologic agents in oysters while gliding bacteria affect certain clam species. A variety of sanitation measures may be required to control this disease.

Viral Infections of Larval and Juvenile Shellfish.

Iridovirus and herpes virus-like infections have been observed in larval and seed bivalves from several continents. The source of the infections is contaminated brood stock but sanitation practices between separate closed culture systems in commercial hatcheries can dramatically limit the spread and impact of the infections. Technology has not yet been developed to screen for these diseases in brood stock on a production basis but such methods are needed to eradicate the diseases from closed systems.

Parasitic Ciliate Subpallial Infections

Opportunistic parasitic ciliates also invade juvenile shellfish through the mantle tissue and can be an extremely persistent infection. These organisms are introduced with bulk seawater used to either establish a closed system or as replacement water in flow through systems.

Approaches to Health Management in Intensive Bivalve Culture Systems

General approaches to health surveillance, management and sanitation in intensive shellfish husbandry will be presented. These approaches include bacterial monitoring and management, water filtration and treatment, brood stock selection, isolation and disinfection, management of bacteria in stock and expanded algal food cultures and sanitation procedures for equipment and facilities.

Diseases of Flatfish

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Introduction

Many marine flatfish are high value species, which have been heavily exploited, in commercial fisheries around the world. Concerns on the effects of the overfishing of natural stocks, and also because of the uncertainties and risks associated with the activity has resulted in a great deal of effort being given to the development of aquaculture systems for the rearing of marine flatfish. Like all other living organisms (perhaps with the exclusion of prokaryotes), flatfish are susceptible to a wide range of diseases and parasites. In addition, certain species may be particularly sensitive to environmental changes or the presence of contaminants, which in turn may affect disease susceptibility by reducing the immunocompetance of the host or initiate direct toxic effects. Because of the limited space available, this overview will only highlight some of the principle diseases of flatfish, including pathologies associated with environmental and nutritional factors which may be of importance in intensive aquaculture systems.

Virus Diseases

Most fish viruses are known from cultured species and although an ever increasing number are being found in wild fish, their effect on wild populations and possible impact in culture situations is poorly understood (Wolf, 1984, 1988; Plumb, 1993). There is little doubt however, that viral pathogens constitute one of the most serious disease threats to the successful rearing of marine species. The following is a list of selected virus infections reported to cause disease in marine flatfish.

1. Birnavirus infections are widespread in marine fish and in culture situations and have been associated with high mortalities in fry of Japanese flounder (= Hirame or bastard halibut) (*Paralichthys olivaceus*) in Korea, turbot fry in several commercial farms in Norway and Atlantic halibut (*Hippoglossus hippoglossus*) in Scotland and Norway. Birnavirus infections have also been implicated in mortalities in wild populations of southern flounder (*Paralichthys lethostigma*) in an estuarine location in the USA. The virus has also been detected on eggs of turbot (*Scophthalmus maximus*) and Dover sole (*Solea solea*) and is known to be vertically transmitted via this route in some species.

2. Lymphocystis is a widespread iridovirus disease affecting many marine fish species. It is mainly confined to epidermal lesions, although internal organs can be affected in extreme cases, with fish possibly showing poor condition and ascites. The disease can occur at very high prevalence under culture conditions and mortalities have been reported in various

species; however, most natural infections are benign. Fish may be disfigured by the presence of the lesions, which consist of clusters of massively hypertrophied cells. The affected cells do not persist and eventually slough off, releasing virions to the environment**.** Transmission is thought to be horizontal via this route.

3. Viral haemorrhagic septicaemia (VHS) caused by a rhabdovirus is a well recognised serious pathogen of salmonid fish which is increasingly being found in a variety of marine fish species (Dixon *et al.*, 1997). VHS outbreaks have occurred in cultured turbot in Germany, UK and Ireland. Clinical signs were consistent with those reported from salmonids and the disease affected older fish as well as juveniles. The source of infection was not identified. The susceptibility of other marine flatfish is at present unknown.

4. Other viruses known to affect turbot include a putative paramyxovirus which has not been associated with disease in cultured fish but is known to produce severe clinical signs in experimental infections, including widespread haemorrhaging, accumulation of ascitic fluid in the peritoneal cavity and exophthalmia. Herpes virus infections in turbot have been associated with mortalities in juvenile cultured turbot in Scotland and the virus has also been isolated from wild turbot. The infection produces "giant cells" and epithelial hyperplasia in the skin and gill tissue. Affected fish are more sensitive to environmental stress, transport and handling. Epizootic haematopoietic necrosis virus (EHNV, a ranavirus) is currently only known as a pathogen of freshwater perch and rainbow trout, although a similar virus has been recorded in turbot. The potential significance of the turbot virus is presently uncertain.

5. Erythrocytic necrosis virus (ENV, an iridovirus) is the causative agent of viral erythrocytic necrosis (VEN). A wide range of marine fish species are affected by this pathogen, including several flatfish species. There are possibly several types of virus that are involved in this disease since there have been several different sized viral particles identified. Severely affected fish can become anaemic, characterised by gill and visceral pallor. Mass mortalities have not been reported. Of potential importance for aquaculture, there is evidence that this virus may increase the susceptibility of fish to other pathogens and conditions of lower oxygen levels.

6. There are several recognised viral pathogens of Japanese flounder (Kimura & Yoshimizu, 1991). Hirame rhabdovirus causes a severe haemorrhagic disease with pale gills, ascites and gonadal distension being the principle clinical signs. The disease has only reported from Japan. Viral epidermal hyperplasia or necrosis, caused by a herpes virus, can cause epizootics in larvae and juveniles fish in hatchery situations. Similarly, hatchery reared juveniles are the most susceptible to viral nervous necrosis virus (a nodavirus). The infection produces marked vacuolisation in brain and retinal tissues and results in behavioural disturbances and significant mortalities. A similar nodavirus-like agent has been reported from juvenile Atlantic halibut, turbot and barfin flounder from Japan.

7. Winter flounder papilloma, (Pleuronectid papilloma) would appear to have little significance and is similar to papilloma found in the North Sea dab (*Limanda limanda*).

Lesions can resolve without treatment and there is little scar tissue formation. Affected fish may be unsightly and may therefore have reduced market value.

Bacterial Diseases

Numerous bacterial pathogens have been reported from marine fish but relatively few specifically from flatfish (Austin and Austin, 1993; Kusada and Salati, 1993; Muroga, 1995). As for viruses, bacteria are amongst the most serious disease threats for aquaculture, primarily because of their direct transmission and ability to proliferate rapidly in the crowded conditions frequently encountered in culture conditions. Such conditions greatly facilitate the rapid spread of infectious agents. This section provides examples of the major bacterial pathogens known to affect flatfish. These include members of the genera *Listonella* (=*Vibrio*), *Aeromonas, Edwardsiella, Enterococcus,* and *Flexibacter.*

1. Vibriosis is generally recognised as the most serious bacterial disease of cultured marine fish. Infections with members of the genus rapidly become systemic and produce similar clinical signs of haemorrhaging around the fins and mouth and petechiae in the musculature. Internally, all the organs may be affected and enteritis may be present. As the disease advances, tissue necrosis becomes a prominent feature. Wild fish may frequently harbour sub-clinical infections with these and other bacteria and extreme caution should be taken post capture in the care of fish obtained for broodstock. If pathogens are present, even at low levels, disease signs may rapidly develop when the fish become stressed. Chemotherapeutants are available for vibriosis but, increasingly, drug resistant forms are appearing. Vaccines initially developed for salmonid use, against *V. anguillarum*, are currently used in some turbot farms.

2. Furunculosis caused by *Aeromonas salmonicida* is a well-known disease of freshwater fishes; however, it may also affect marine fish, including several flatfish species. This bacterium, or its "atypical" variant have been isolated from open ulcers from wild European flounders (*Platichthys flesus*) and it is likely that it is a regular constituent of the microbial flora associated with ulceration in other flatfish. Several other bacteria are associated with ulcerative lesions including *Vibrio* and *Pseudomonas* spp. However, the importance of these organisms as primary pathogens in flatfish culture is debatable.

3. Other bacterial pathogens of Japanese flounder have caused significant losses. Enterococcal infections caused by *Enterococcus seriolicida* (primarily recognised as a pathogen of yellowtail (*Seriola quinqueradiata*)) and *Edwardsiella tarda* give rise to a variety of clinical signs, typical of systemic haemorrhagic infections.

4. *Flexibacter* species are now well recognised as pathogens of various flatfish species, including turbot and Dover sole. Infections with the opportunistic pathogen *F. ovolyticus* on eggs of halibut gives rise to disease symptoms in juvenile fish and it is likely that similar infections of eggs may also affect other flatfish in hatchery situations. Infections in older turbot can produce systemic disease symptoms (Mudarris & Austin, 1989) and these are a

significant problem for turbot culture. Similar infections in Dover sole give rise to the so-called "black patch necrosis" (Bernardet, *et al*., 1990).

Fungal Diseases

The most important fungal or fungal-like pathogen of marine fish is *Ichthyophonus hoferi*. Several flatfish species are known to be susceptible and epizootics in wild populations of plaice (*Pleuronectes platessa*) and yellowtail flounder (*Limanda ferruginea*) have been reported (McVicar, 1986; Rand, 1994). Infections are generally chronic in nature and affect a variety of organs and tissues. Fish usually become emaciated and mortalities may occur after several weeks. Transmission is primarily by ingestion of infected tissues or water borne spores. Ensuring cultured species are not fed infected material provides the principle method of avoidance of the disease.

Ulcerative mycosis (UM) affects many species of North American estuarine fish, including the southern flounder (*Paralichthys lethostigma*) and the ocellated flounder (*Ancylopsetta dilecta*) (Noga *et al*., 1991). Two fungi have been isolated from affected fish, *Aphanomyces* (possibly more than one species) and also occasionally *Saprolegnia*. There does not appear to have been any reports of these agents causing losses in cultured marine fish.

Parasites

Parasitic infections in cultivated marine fish are primarily limited to monoxenous species not dependent on intermediate or paratenic hosts for successful transmission (Paperna, 1987). Although many parasites have the potential to cause serious infections in marine aquaria, relatively few are currently recognised as significant threats to the effective mariculture of flatfish. Wild caught broodstock or juveniles are clearly at greatest threat from existing parasitic infections, which may be transferred to other stocks if not carefully quarantined. This section draws attention to those parasites, which may cause problems in intensive culture situations.

1. Among pathogenic protistan parasites are the ciliates *Cryptocaryon irritans* and *Trichodina* spp. Both parasites can proliferate rapidly and produce serious skin lesions, which may become infected with other pathogens. Mortalities in heavily infected fish probably result from osmotic imbalance (McVicar and MacKenzie, 1977). *Uronema marinum* is a known pathogen of aquarium fishes, including flatfish such as the plaice and is a continuing problem in turbot culture. The microsporean *Glugea stephani* causes multiple xenomas within the intestinal epithelium of plaice and flounder. These can result in the death of the host. *Pleistophora hippoglossoides* infects the muscle of Dover sole and American plaice *Hippoglossoides platessoides* and can render the fish unmarketable (Dyková, 1995) and another muscle infecting microsporean, *Tetramicra brevifilum* can be a problem in turbot culture. Myxosporean parasites are extremely common marine fish parasites. However, only *Ceratomyxa drepanopsettae*, *Myxidium sphaericum* and *Unicapsula muscularis* have been recognised as potential pathogens in flatfish. The first

two species are capable of inducing pathological change in the epithelial lining of the gallbladder and the muscle parasite; *U. muscularis* causes a condition known as 'wormy halibut' in *Hippoglossus stenolepis*. Infections with *Platyamoeba* are increasingly reported in turbot culture from certain areas in France and Spain. The susceptibility of other cultured flatfish species to this pathogen is unknown.

2. Monogenean parasites are also known to be pathogenic to various flatfish in culture situations. *Gyrodactylus unicopula* is pathogenic to juvenile plaice, *Neoheterobothrium affine* causes an inflammatory response in the gills of summer flounder and *Entobdella* species have been reported to cause problems in brood stocks of Dover sole (McVicar and MacKenzie, 1977). The pathogenicity of certain Benedeniid monogeneans including *Neobenedinia* and *Benedinia* is recognised. Since they exhibit low host specificity and have a wide distribution, their potential ability to cause mortality in culture situations should not be overlooked.

3. Most parasitic Copepoda undergo a free-living stage during their lifecycle. The majority undergo a series of moults through naupliar (free-living), copepodid, chalimus and adult stages. Flatfish are parasitised by a number of different genera including, *Acanthochondria, Bomolochus, Caligus, Haemobaphes, Hatschekia, Lepeophtheirus, Lernaeocera, Neobrachiella,* and *Phrixocephalus.* The majority of these have not been previously reported as being a problem for captive fish. However, all have the potential to cause problems in culture due to their direct mode of transmission and apparently innocuous species, present at low levels in wild fish may rapidly proliferate in culture situations. There are several potential sources of infection, primarily from introduction of wild fish with low numbers of parasites into naïve, susceptible stocks. Potentially, fish could be infected by the introduction of water containing infective naupliar stages or eggs.

Members of the family Caligidae (*Lepeophtheirus* and *Caligus*) are known to cause problems in culture. These parasites typically have direct life cycles. The life cycle of *Lepeophtheirus* is typified by two free living naupliar stages, a copepodid stage, four chalimus stages, two pre-adult stages and an adult stage. *Lepeophtheirus pectoralis* has been consistently isolated from moribund plaice in marine aquaria. This parasite can cause severe damage to the epidermis. The closely related salmon louse (*L. salmonis*) is a cause for concern in farmed salt-water salmonids. During initial trials in rearing cultivated turbot, massive infections with a *Lepeophtheirus* species have been observed. *Caligus curtus* appears to have a low host-specificity and it has been reported in high numbers in marine fish aquaria, often associated with moribund or dead fish, including flatfish. The penellid, *Lernaeocera branchialis* utilises flatfish as intermediate hosts with gadoids as final hosts. Although unlikely to be a problem in flatfish culture because of the absence of the final host, the larval forms can cause extensive damage to the gill filaments in flatfish, leaving them non-functional.

4. Other potential parasite pathogens include the isopod *Gnathia* sp. which, when present in large numbers can contribute to mortalities. However, these parasites have mainly been recognised as a problem in marine aquaria. Digenean metacercariae of *Cryptocotyle* and

Stephanostomum can give rise to heavy infestations in a variety of flatfish species, but avoidance of the snail intermediate hosts provides an effective control strategy for culture situations.

5. In hatcheries feeding extensively reared copepods to larval fish, the possibility of the transmission of helminth parasites from infected copepods should be recognised. Although apparently not a widespread problem at present, it has been recommended that intensively reared copepod diets should be developed (Bricknell *et al.*, 1997).

Environmental And Nutritional Factors

It is generally accepted that fish maintained in poor conditions will be stressed and that it is usually several factors in combination, which are involved in the onset of disease in the broadest sense. These factors are many and varied and include temperature, crowding, dissolved oxygen concentration and diet, as well as pollutants and the presence of potential pathogens. Direct toxic effects can cause significant pathological changes in many tissues and organs. The delicate epithelial surfaces of the gill filaments and skin frequently exhibit the first signs of acute toxicity. Chronic changes may then develop in the gill and other tissues, with liver, as the main organ for the detoxification of xenobiotics, frequently involved. In the controlled environment of modern aquaculture facilities, the presence of toxic compounds is minimised. However, the possible toxic effects of certain chemotherapeutants should be recognised and treatments administered following strict guidelines. In wild stocks the use of flatfish, diseases are employed as a biomarkers for monitoring biological effects of contaminants. In European waters, several external diseases, including ulceration, lymphocystis and epidermal hyperplasia/papilloma as well as hyperpigmentation are monitored in dab (*Limanda limanda*) and flounder (*P. flesus*). Increasing effort is being directed toward the standardised use of gross and microscopic liver pathology in international monitoring programmes. Although the presence of putative preneoplastic and neoplastic lesions offer a sensitive indicator of the presence of genotoxic contaminants in the environment, the range of lesion types is not the same for all flatfish species and the susceptibility of several commercial species for these lesions is unknown. The effect of dietary factors on growth performance is well recognised and imbalances or deficiencies in the diet can induce pathological changes in various tissues and may predispose fish to infectious diseases. Myopathy of skeletal muscles, hepatic lipoidosis and ceroidosis and anaemia are amongst the main pathological manifestations associated with lipid/fatty acid imbalances and there are many reports of specific pathological changes associated with a great variety of dietary components. From this perspective, the use of histopathology, and liver pathology in particular, offer an important tool for the general health assessment and nutritional status of cultured stocks.

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Chemotherapeutics and Treatment Calculations Used in Aquaculture

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Chemotherapeutics (drugs) are commonly used in the agriculture industry to combat disease. Unfortunately, there are relatively few chemotherapeutics approved by the U.S. Food and Drug Administration (FDA) for use in the food animal segment of the aquaculture industry. These include three antibiotics (oxytetracycline, sulfamerazine, and a sulfadimethoxine-ormetoprim combination), an external parasitcide (formalin) and an anesthetic agent (tricaine methanesulfonate). However, to use these compounds for foodfish requires adherence to strict FDA guidelines. These include that the compounds are (1) used for the prescribed indications including species and life stage, (2) used for the prescribed disease, (3) used at the prescribed dosages for the prescribed amount of time, (4) purchased from an approved source or distributor, (5) used according to good management practices, and (6) used so that adverse environmental effects do not occur.

In addition, there are a number of compounds which are categorized as Unapproved New Animal Drugs of Low Regulatory Priority which can be used judiciously for foodfish. These include such substances as acetic acid, calcium chloride, magnesium sulfate, papain, and sodium chloride.

Administration of the correct amount of drug or chemical can often present a difficult challenge. However, by following four standard steps, a treatment calculation can be correctly and rapidly calculated. First, determine the total amount of water to be treated. Second, use a conversion factor to determine the number of grams (or mls) required to get 1 ppm. Then, multiply by the number of ppm desired to get the final amount (grams or mls) needed to get that dose for that amount of water. Finally, divide by the strength of the compound (ie. 1.0 for a 100% compound, 0.5 for a 50% compound, etc. This session will use examples to demonstrate how to correctly calculate treatments for either a flow-through or a static bath system.

Appendix A

Appendix A: Guide to Drug, Vaccine, and Pesticide Use in Aquaculture. 1994. Prepared by the Federal Joint Subcommittee on Aquaculture, Working Group on Quality Assurance in Aquaculture Production, in cooperation with the Extension Service and U.S. Department of Agriculture, Texas A&M University, College Station, TX.

FDA – Regulated Drugs for Aquaculture

The drugs listed in this section include FDA-approved new animal drugs as well as unapproved new animal drugs of low regulatory priority for FDA. Federal approval of new animal drugs applies only to specific products that are the subject of approved new animal drug applications.

Active ingredients from sources other than the listed sponsors are not considered approved new animal drugs. Such products cannot legally be marketed or used.

States and other jurisdictions may impose additional regulatory requirements and restrictions on FDA-regulated drugs for agriculture.

Table 1. FDA - Approved New Animal Drugs

Trade Name	*NADA Number*	*Sponsor*	*Active Drug*	*Species*	*Uses*
Finquel (MS-222)	42-427	Argent Chemical Laboratories, Inc.	Tricaine methanesul-fonate	Ictaluridae, Salmonidae, Esocidae, and Percidae. (In other fish and cold-blooded animals, the drug should be limited to hatchery or laboratory use.)	Temporary immobilization (anesthetic)
Formalin-F	137-687	Natchez Animal Supply	Formalin	Trout, salmon, catfish, large-mouth bass, and bluegill Salmon, trout, and esocid eggs	Control of external protozoa and monogenetic trematodes Control of fungi of the family Saprolegniacae
Paracide-F	140-831	Argent Chemical Laboratories Inc.	Formalin	Trout, salmon, catfish, large-mouth bass, and bluegill Salmon, trout, and esocid eggs	Control of external protozoa and monogenetic trematodes Control of fungi of the family Saprolegniacae

Trade Name	*NADA Number*	*Sponsor*	*Active Drug*	*Species*	*Uses*
Parasite-S	140-989	Western Chemical Inc.	Formalin	Trout, salmon, catfish, large-mouth bass, and bluegill	Control of external protozoa and monogenetic trematodes
				Salmon, trout, and esocid eggs	Control of fungi of the family Saprolegniacae
				Cultured penacid shrimp	Control of external protozoan parasites.
Romet 30	125-933	Hoffmann-LaRoche, Inc.	Sulfadimethoxine and ormetoprim	Catfish	Control of enteric septicemia
				Salmonids	Control of furunculosis
Sulfamerazine in Fish Grade[1]	033-950	American Cyanamid Company	Sulfamerazine	Rainbow trout, brook trout, and brown trout	Control of furunculosis
Terramycin for Fish	038-439	Pfizer, Inc.	Oxytetracycline	Catfish	Control of bacterial hemorrhagic septicemia and pseudomonas disease
				Lobster	Control of gaffkemia
				Salmonids	Control of ulcer disease, furunculosis, bacterial hemorrhagic septicemia, and pseudomonas disease
				Pacific salmon	Marking of skeletal tissue

[1]According to sponsor, this drug is not presently being distributed.

Table 2. Unapproved New Animal Drugs of Low Regulatory Priority for FDA[1]

Common Name	*Permitted Use*
Acetic acid	Used as a dip at a concentration of 1,000-2,000 milligrmas per liter (mg/L) for 1-10 minutes as a parasiticide for fish.
Calcium chloride	Used to increase water calcium concentration to ensure proper egg hardening. Dosages used would be those necessary to raise calcium concentration to 10-20 mg/L calcium carbonate. Also used to increase water hardness up to 150 mg/L to aid in maintenance of osmotic balance in fish by preventing electrolyte loss.
Calcium oxide	Used as an external protozoacide for fingerling to adult fish at a concentration of 2,000 mg/L for 5 seconds.
Carbon dioxide gas	Used for anesthetic purposes in cold, cool, and warmwater fish.
Fuller=s earth	Used to reduce the adhesiveness of fish eggs in order to improve hatchability.
Garlic (whole)	Used for control of helminth and sea lice infestations in marine salmonids at all life stages.
Hydrogen peroxide	Used at 250-500 mg/L to control fungi on all species and at all life stages of fish, including eggs.
Ice	Used to reduce metabolic rate of fish during transport.
Magnesium sulfate (Epsom salts)	Used to treat external monogenetic trematode infestations and external crustacean infestations in fish at all life stages. Used in freshwater species. Fish are immersed in a solution of 30,000 mg/L magnesium sulfate and 7,000 mg/L sodium chloride for 5-10 minutes.
Onion (whole)	Used to treat external crustacean parasites and to deter sea lice from infesting external surface of fish at all life stages.
Papain	Used as a 0.2% solution in removing the gelatinous matrix of fish egg masses in order to improve hatchability and decrease the incidence of disease.
Potassium chloride	Used as an aid in osmoregulation to releave stress and prevent shock. Dosages used would be those necessary to increase chloride ion concentration to 10-2,000 mg/L.
Povidone iodine compounds	Used as a fish egg disinfectant at rates of 50 mg/L for 30 minutes during water hardening and 100 mg/L solution for 10 minutes after water hardening.
Sodium bicarbonate (baking soda)	Used at 142-642 mg/L for 5 minutes as a means of introducing carbon dioxide into the water to anesthetize fish.
Sodium chloride (salt)	Used as a 0.5-1% solution for an indefinite period as an osmoregulatory aid for the relief of stress and prevention of shock. Used as a 3% solution for 10-30 minutes as a parasiticide.

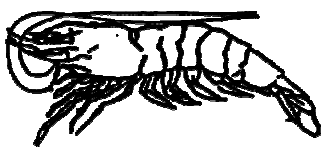
Common Name	*Permitted Use*
Sodium sulfite	Used as a 15% solution for 5-8 minutes to treat eggs in order to improve hatchability.
Urea and tannic acid	Used to denature the adhesive component of fish eggs at concentrations of 15 g urea and 20 g NaC1/5 L of water for approximately 6 minutes, followed by a separate solution of 0.75 g tannic acid/5 L of water for an additional 6 minutes. These amounts will treat approximately 400,000 eggs.

[1]FDA is unlikely to object at present to the use of these low regulatory priority substances if the following conditions are meet:

1. The drugs are used for the prescribed indications, including species and life stage where specified.
2. The drugs are used at the prescribed dosages.
3. The drugs are used according to good management practices.
4. The product is of an appropriate grade for use in food animals.
5. An adverse effect on the environment is unlikely.

FDA=s enforcement position on the use of these substances should be considered neither an approval nor an affirmation of their safety and effectiveness. Based on information available in the future, FDA may take a different position on their use.

Classification of substances as new animal drugs of low regulatory priority does not exempt facilities from complying with other federal, state, and local environmental requirements. For example, facilities using these substances would still be required to comply with National Pollutant Discharge Elimination System requirements.



Potential Zoonotic Infections in Cultured Foodfish

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Introduction

From limb and life-threatening injuries to carpal-tunnel syndrome, almost every commercial occupation carries a degree of physical risk. In the production animal workplace, the spread of disease from livestock to humans represents a small but perpetual hazard. Not surprisingly, each type of animal-rearing enterprise features its own array of potentially transmissible pathogens. Within piscine aquaculture and processing facilities, the agents that are most likely to cause human illness are bacteria.

Bacterial pathogens associated with live foodfish are generally ubiquitous to freshwater and/or marine environments, and may or may not be commonly isolated from cutaneous or enteric sites in healthy fish. In contrast, disease-causing bacteria that are more typically introduced to foods by way of environmental pollution or through post-harvest handling (e.g. *Shigella* spp., *Listeria* spp., *Clostridium* spp.), are far less likely to be encountered in fish farms utilizing closed systems. The spread of these bacteria to humans is usually through ingestion of fish products, therefore, they constitute a greater risk to end-consumers.

Transmission of bacterial pathogens to fish handlers occurs primarily through skin breaks, either via puncture wounds obtained during fish handling, or through water inoculation of pre-existing cuts. The accidental consumption of contaminated water represents another potentially significant route of infection. Fish-borne bacterial pathogens may cause human disease that remains localized to the skin or gastrointestinal tract of the host, or systemic spread may occur by way of vascular channels or serous surfaces. Generalized infections are more common in human individuals with immunosuppressive disorders.

Human bacterial diseases acquired from fish are often difficult to diagnose and treat. Diagnosis can be hampered by the failure of both human and veterinary laboratories to grow and accurately identify fish-borne bacterial species.(67) Additionally, routine bacterial cultures may not be always be performed, due to a general lack of success in isolating confirmed pathogens from human cellulitis patients.(34) Consequently, traumatically-induced fish-borne infections are probably drastically underreported. Factors that can hinder therapy in individual human cases include a deficiency of bacterial sensitivity data, and chemotherapeutic resistance. Resistance to antibiotics such as ampicillin, chloramphenicol, sulfonamides, and tetracyclines has been associated with the

presence of specific R plasmids found in bacteria such as *Aeromonas hydrophila*, *Edwardsiella tarda*, and *Vibrio anguillarum*.(4) Interestingly, bacteria resistant to commonly used antibiotics have been recovered not only from cultured fish, but also from the environment immediately surrounding fish farms.(61)

As applied to fish-borne contagions, the term zoonosis can be a source of minor confusion. Cited as "a disease of animals that may be transmitted to man under natural conditions (e.g. brucellosis, rabies)"(1), this narrow definition essentially excludes fish-associated bacteria that are pathogenic to humans, but have not been demonstrated to cause disease in fish (e.g. *Erysipelothrix rhusiopathiae*, *Salmonella* spp.). Another important distinction is that pathogens that cause disease in both humans and fish independently, i.e. without conclusive evidence of transmissibility (e.g. *Citrobacter freundii*, *Lactobacillus* spp.), should not be considered zoonotic .

It should be noted that disease acquisition from cultured foodfish is not necessarily limited to fish farmers, fish processors, and fish consumers. Individuals at varying degrees of risk in other vocations include veterinarians, research scientists, and retailers.

Aquaculture-associated Bacteria Potentially Pathogenic to Humans

Included are pathogens that have been reported to cause disease to fish handlers in aquaculture or processing facilities, plus other bacteria that have a reasonably high zoonotic potential in these settings. This list is far from complete, as the literature contains periodic case reports of human disease caused by fish-associated bacteria such as *Klebsiella* spp.(48), *Pseudomonas* spp.(8), and *Yersinia ruckeri*(18).

1. *Aeromonas* spp. (motile aeromonads)

   These Gram-negative, facultatively-anaerobic rods can be isolated from both fresh and salt water sources, and from the gastrointestinal tracts of healthy fish(53) among other animals. Motile aeromonad species, including *A. hydrophila*, have been circumstantially, if not definitively, associated with disease in fish. Well-established syndromes that implicate aeromonads include a bacteremic condition known as “motile aeromonas septicemia”, and the dermal and muscular excavations of “red sore” (*Aeromonas* spp. combined with *Epistylis* spp. protozoa and other pathogens). Human exposure to pathogenic aeromonads has been demonstrated to occur through both wound infections, and via ingestion of contaminated water or foods.(19,27,32,36) *Aeromonas hydrophila*, *A. sobria*, and *A. caviae* are the *Aeromonas* species most commonly involved in human infections.(33,44) Conversely, *A. salmonicida* is considered to be an obligate fish pathogen that is of no known danger to humans.(40) Fatal and non-fatal manifestations of human *Aeromonas* spp. infection include gastroenteritis, cellulitis, endocarditis, myositis, meningitis, osteomyelitis, and septicemia.(19,28,36,62) There is evidence of increased risk to persons with liver disease, malignancies, or other immune-compromising disorders.(36)

2. *Edwardsiella tarda*

Reptiles and freshwater fishes are thought to be the predominant natural reservoirs of this Gram-negative bacterial rod.(70) *E. tarda* causes serious septicemic disease in a wide range of fish species(35), despite its role as a normal intestinal inhabitant of fish.(63) Additionally, *E. tarda* is responsible for the economically significant condition known as "emphysematous putrefactive disease of catfish". *E. tarda* is the only member of its genus that is a recognized human pathogen.(68) Documented routes of transmission to humans include penetrating wounds and consumption of contaminated water or infected fish.(37) Wound infection in humans may remain localized (e.g. deep soft tissue abscesses), or progress to generalized disease (e.g. septicemia with meningitis).(18,35,68) Human edwardsiellosis is more common in tropical or subtropical regions(63), and neonates, infants, and individuals with pre-existing illnesses are apparently predisposed to *E. tarda* infection.(63,68)

3. *Erysipelothrix rhusiopathiae*

Erysipelothrix rhusiopathiae is a non-motile, non-sporulating, facultatively-anaerobic Gram-positive rod that can be isolated from a wide range of animal species, and decomposing matter of animal origin.(23) Despite its ubiquitous presence in the environment, the principal reservoirs for *E. rhusiopathiae* infection are latently-infected carrier animals such as domestic swine and rodents.(69) *E. rhusiopathiae* has been associated with both freshwater and marine fish, where it can be found in the external body mucus, possibly acquired through post-harvest contamination.(39) Whether or not the bacterium actually exists on surface of living fish, *E. rhusiopathiae* is not considered to be a fish pathogen.(54,69) Transmission to humans is predominately through minor skin wounds, and opportunistic exposure is the most important factor governing human infection.(69) There are three well-defined forms of human *Erysipelothrix* infection: mild localized cutaneous, rare diffuse cutaneous, and septicemic (often with endocarditis).(23) The comparatively common localized form (also known as "fish rose", "fish-handler's disease", or "erysipeloid of Rosenbach") is a self-limiting condition that has a strong occupational association with fishermen, fish and shellfish handlers, veterinarians, bacteriologists, and butchers, among others.(23,69) The more generalized manifestations of erysipelas may be exclusive to individuals with pre-existing poor health, as humans are thought to be innately resistant to *Erysipelothrix* infection.(69)

4. *Leptospira* spp.

Historically, human leptospirosis has been sporadically related to aquaculture. From 1975 to 1983, 24 human leptospirosis cases occurred in association with non-fish aquaculture facilities in Hawaii.(2,38) Coincidentally, during the same time period, several trout farmers in England contracted infections with *Leptospira interrogans* serogroup *icterohemorrhagiae*, resulting in flu-like symptoms, jaundice, and even death.(51) Despite the seriousness of this outbreak, a subsequent study revealed that other English fish farmers in the region did not have *Leptospira* spp. antibody titers, thus indicating only a moderately-increased occupational risk for leptospirosis.(21) Although associated with aquatic environments, the true reservoirs for these aerobic,

flexible, helical, Gram-negative bacteria are feral rodents, other small mammals, and amphibians. (3) Fish are not a common source of leptospirae, and naturally-occurring piscine leptospirosis has not been documented.(38,51,54) Invariably, the link between human leptospirosis and aquaculture appears to involve the contamination of waterways or fish feeds by rodents, seagulls, or other terrestrial vectors.(13,21)

5. *Mycobacterium* spp.

Mycobacteriosis in fish is a gradually progressive systemic granulomatous disease that affects both natural and farmed populations of freshwater and marine fish. Piscine mycobacteriosis is usually caused by one of three species of aerobic, Gram-positive, non-sporeforming, non-motile, pleomorphic acid-fast bacilli: *Mycobacterium fortuitum*, *M. marinum*, or *M. chelonae*.(9,12,20,29,49,60) Reservoir sources of mycobacterial infection include both carrier fish and the environment,(10,14,20,24,25,41,43,58), and proposed routes of piscine transmission are ingestion of contaminated materials(24,25,41,52,57,59), through damaged gill or skin tissue(14), and via transovarian passage in ovoviviparous fishes.(11,41,56) Mycobacteriosis outbreaks are not unusual in intensively cultured foodfish(30,57,58), however, individual case reports suggest that zoonotic infections are more often derived from home aquaria. Popular terms for localized mycobacteriosis associated with aquarium cleaning include “fish tank granuloma” and “fish fancier’s finger”.(6,40,42) Due to antibiotic resistance, such infections may be refractory to treatment, requiring appendage amputation in rare circumstances.(55) Immunosuppressed individuals tend to have an increased potential for deeply disseminated mycobacterial infections.(40)

6. *Plesiomonas shigelloides*

Currently classified within the family *Vibrionaceae*, *P. shigelloides* is a facultatively-anaerobic, motile, Gram-negative bacillus that is widely-distributed in animal and human alimentary tracts, soil, and water.(7,22) This microorganism favors fresh and brackish waters within tropical and subtropical regions.(5,7,32) Consequently, in temperate climates, plesiomonad replication is facilitated by warmer temperatures.(7) Although *P. shigelloides* can be isolated from fish tissues such as skin, gills, and intestines, this bacterium does not appear to be an important fish pathogen. In humans, *P. shigelloides* is responsible for enteric infections (chiefly related to raw seafood consumption), and extra-intestinal disease ranging from cellulitis induced by puncture wounds, to sepsis, meningitis, arthritis, or endophthalmitis.(22,32) Risk factors associated with *P. shigelloides* infection include raw oyster consumption, travel to Mexico, crabbing, and compromised host immunity.(7) Fish handlers, veterinarians, aquaculturists, zoo keepers, and water sports performers are thought to be vocationally predisposed.(7)

7. *Streptococcus iniae*

First reported in 1976 as a cause of abscesses in captive freshwater dolphins(47), *S. iniae* garnered attention in early 1996 when nine cases of human *S. iniae* -induced

disease were associated with the cleaning of cultured tilapia by Canadian consumers.(65,66) During this outbreak, human patients were infected through lacerations or puncture wounds acquired during fish preparation. Local cellulitis was the most common problem caused by *S. iniae* infection, although one individual suffered from septic arthritis, meningitis, and endocarditis. *S. iniae* had not been recognized as a human pathogen prior to this episode, possibly due to a generalized failure to accurately identify it.(65) Conversely, this Gram-positive, non-motile, non-sporeforming, facultatively anaerobic, coccus has been known to colonize the dermis and cause invasive disease in a variety of farmed fishes (tilapia, rainbow trout, coho salmon, hybrid striped bass), often with high mortality.(16,45,46) Lesions in affected fish typically include meningoencephalitis, epicarditis, and other manifestations of septicemia such as ascites, cutaneous hemorrhage, exophthalmia, and corneal opacity.(46)

8. *Vibrio* spp.

These Gram-negative, motile, facultatively-anaerobic, straight or curved rods are ubiquitous in marine environments, and they tend to proliferate in response to a seasonal increase in water temperature.(15,26) Additionally, vibrios may be isolated from brackish or fresh waters(28,31), and from the external surface and gastrointestinal tract of finfish. *Vibrio* spp. such as *V. salmonicida, V. anguillarum, V. damsela, V. alginolyticus, V. vulnificus*, and *V. ordalii*, may act as primary or secondary fish pathogens, responsible for ulcerative dermatitis and/ or bacteremic lesions in saltwater teleosts. In the United States, the four most common *Vibrio* spp. associated with human disease are *V. parahemolyticus, V. vulnificus, V. cholera* type 01 (the agent of classic cholera), and *V. cholera* non-01. Of this group, the most dangerous species, and perhaps the most likely to be caused by fish-related puncture wounds, is *V. vulnificus*. Similar to other *Vibrio* spp., *V. vulnificus* has been known to cause human gastroenteritis (e.g. following the ingestion of undercooked shellfish), however, chronic deep-seated soft tissue infections and septicemia are more common outcomes. Several well-defined predisposing factors to *V. vulnificus* infection include underlying liver disease, alcoholism, diabetes, hemochromatosis, and immunosuppressive disorders.(17,31,32,50,64) The overall mortality rates for individuals with untreated and treated *V. vulnificus* infections are 50-90% and 25%, respectively.(15,17,50,64)

Some Recommendations for the Prevention of Zoonotic Disease in Aquaculture Facilities

Guidelines established for the prevention of aquaculture-associated human disease should be based upon fish health considerations, employee health considerations, and biosecurity.

A. Fish Health Considerations

For any fish-rearing or processing facility, it is reasonable to assume that the potential for zoonotic bacterial disease increases in proportion to the numbers of actively-infected fish within the facility at a given time. The maintenance of disease-free stock is therefore a

paramount concern for both the profit margin and for the safety of fish handlers. One key to keeping fish healthy is to start with healthy fish. In this regard, procedures such as segregated quarantine, prophylactic anti-parasitic therapy, and the sacrifice of specimens for medical evaluation and bacterial culture of internal organs, are advocated as routine practices for all newly imported lots, even when fish are obtained from proven providers. Recognizing that most bacterial fish pathogens are opportunistic invaders, the mitigation of physiologic stressors is a universally-acknowledged method of decreasing fish disease. Limiting stress usually involves committed attention to factors such as water quality, overcrowding, and excessive or inappropriate handling. A final animal health consideration is the generation of antibiotic resistance by bacteria. In fish disease outbreaks caused by resistant bacteria, effective treatment is often delayed, thus exposing workers to infected fish for extended amounts of time. Additionally, zoonotic infections acquired from repeatedly treated fish are more likely to be medically intractable. In order to decrease the occurrence of antibiotic resistance in aquaculture facilities, antibiotic therapy should be based strictly upon bacterial isolation and antibiotic sensitivity results.

B. Employee Health Considerations

The relevant literature consistently suggests that the incidence and severity of fish-associated zoonotic infections are dependent in part upon the immune status of the human hosts. Therefore, it is suggested that persons who handle large numbers of farmed fish on a regular basis receive an initial baseline health screen (including a tuberculin test), followed by scheduled periodic medical examinations. General safety and hygiene training of aquaculture personnel should include specific information relative to the management and reporting of fish-associated injuries. Additionally, it is imperative that persons with preexisting viral, neoplastic, metabolic, or other immunocompromising conditions be made aware of their increased risk for zoonotic infection.

C. Biosecurity

Infected stock are not the only potential source of pathogenic fish-associated bacteria. Biosecurity measures to decrease the introduction of pathogens into fish-holding facilities include: 1) the use of a sanitary and protected water supply, 2) physical barriers to prevent contamination by biological vectors such as birds, rodents, and human visitors, and 3) the education of employees in principles of aquaculture hygiene.

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Biological Denitrification Using Upflow Biofiltration In Recirculating Aquaculture Systems: Pilot-Scale Experience and Implications For Full-Scale

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Introduction

Recirculating aquaculture systems (RASs) rear high densities of fish while the culture water is continuously recycled, thereby employing water conservation techniques. Since fresh water addition is minimized, the quality of the culture water can deteriorate quite rapidly from the accumulation of ammonia and particulate waste generated from the metabolism of feed. Aquaculturists employ common wastewater treatment techniques in RASs to yield an environment that is conducive to rearing aquatic organisms. Solids removal is typically achieved through clarification or filtration, while nitrification is employed to convert ammonia to nitrate, via nitrite, in order to prevent free ammonia toxicity (8). The combined implementation of the nitrification process and decreased water exchanges leads to the accumulation of nitrates over time in recirculating aquaculture systems (3). Chronic toxicity to certain fish species (6), as well as tightening water regulations with regard to nutrient discharge, have led to concern over the accumulation of nitrates in recirculating systems.

Biological denitrification can be used to remove nitrates from RAS waters. Denitrification is the dissimilative reduction of nitrate (NO_3^-) to nitrogen gas (N_2), through the production of nitrite (NO_2^-) and gaseous nitric oxide (NO) and nitrous oxide (N_2O) intermediates.

$$NO_3^- \longrightarrow NO_2^- \longrightarrow NO_{(g)} \longrightarrow N_2O_{(g)} \longrightarrow N_{2(g)}$$

This process is performed by heterotrophic bacteria under anoxic conditions and uses nitrate as a terminal electron acceptor in the presence of a carbon and energy source.

An electron donor is required as a carbon and energy source to fuel the denitrification process. Dissolved organic carbon (DOC) compounds accumulate in RASs as a result of the introduction of feed, and the extent of accumulation is greatly affected by fish stocking densities and feeding rates (5). However, these systems typically possess relatively low concentrations of DOC (3). Wastewater treatment plants often add an exogenous carbon source, such as methanol or acetate, when a carbon deficiency exists (2, 11), though the associated cost does not make this an attractive option for aquaculturists. Growing

interest has been expressed for using biosolids as a carbon supplement in the denitrification process. Fermented municipal sludge and swine waste have been shown to be good electron donors, effecting enhanced denitrification rates over methanol and acetate alone (7). Fish waste and uneaten feed constitute a source of organic matter produced within the fish culture unit that can be used to generate a suitable carbon source for the denitrification process (1, 10). Since this organic matter is in the particulate form and not readily available for microbial use, hydrolysis and fermentation can be applied to convert these substances into volatile fatty acids (VFAs), which can be more easily consumed by denitrifying microorganisms (4, 7). The use of an organic substrate that is prevalent in the system is aimed towards the development of a self-sustaining treatment process. In addition, the amount of particulate waste requiring disposal is reduced by converting a fraction of the particulate matter into a soluble form that is consumed by the denitrification process.

Biofilters are an attached growth process in which a biofilm is generated from the propagation of microorganisms on an inert surface. Biofilters maintain a higher active fraction of biomass, as compared to suspended growth environments, which enables the use of a smaller reactor (9). The efficient operation and compact size makes biofilters an attractive treatment device for the aquaculture industry, as is illustrated by their wide scale use in the performance of nitrification. Complete nitrogen removal can be achieved in recirculating aquaculture systems through the implementation of a coupled biofiltration treatment scheme employing nitrification and denitrification.

This study was designed to investigate the removal of nitrates from recirculating aquaculture system waters using a denitrifying biofilter to reduce nitrate to nitrogen gas and a supplemental carbon source provided through the fermentation of fish food. Implications for full-scale operation are discussed.

Materials and Methods

Biofilter. A pilot-scale biological denitrification system comprised of an upflow, fixed film column and two fermentation units (Figure 1) was operated at the Virginia Tech Aquaculture Center (Blacksburg, VA). Low (1.13 kg NO_3 -N/m^3/day) and high (2.52 kg NO_3 -N/m^3/day) nitrate loading conditions were studied at a hydraulic loading rate of 3.0 m^3/m^2/hr. A fixed film biological denitrifying column (4.0 m x 15.2 cm) was constructed with schedule 40 clear PVC pipe connected by schedule 80 PVC couplings. The column was packed with 0.044 m^3 of 2-3 mm floating, polystyrene media (Biostyr®, Krüger, Cary, North Carolina) possessing a specific surface area of 1000 m^2/m^3. A steel screen retained the media within the column. The column was seeded with activated sludge obtained from a denitrification basin at a local municipal wastewater treatment plant (Blacksburg, VA).

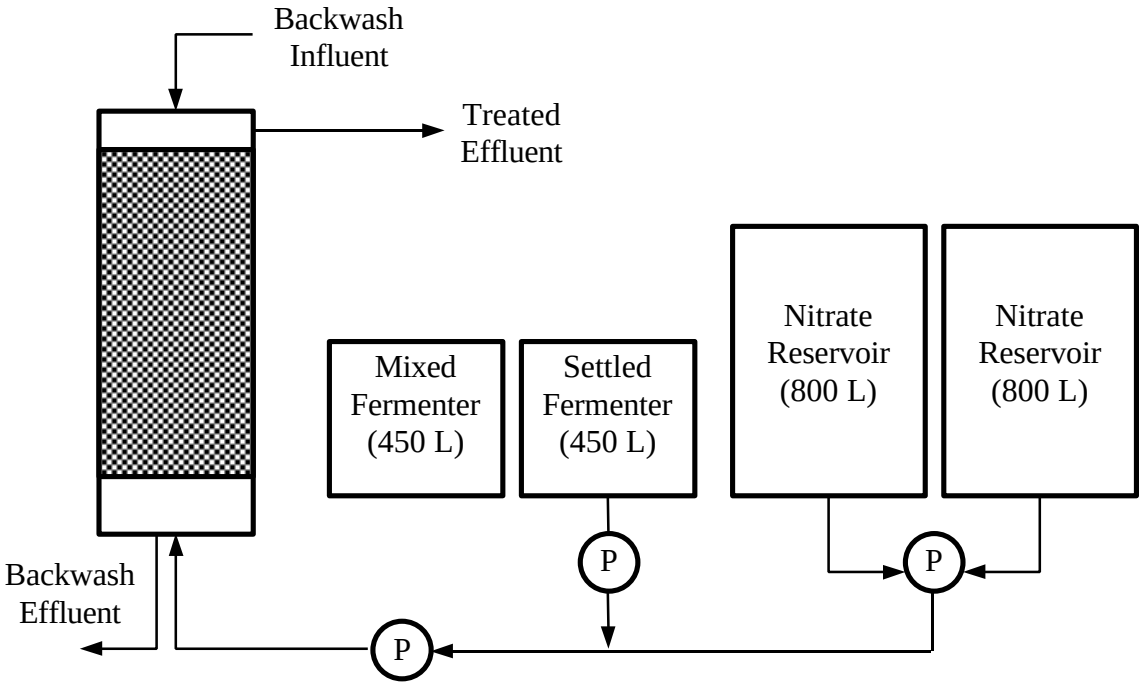

Figure 1. Pilot-scale system comprised of an upflow, denitrifying biofilter, two fermentation units, and two nitrate stock reservoirs. P represents pumps.

Fermentation. Commercial fish food (Southern States Cooperative, Inc., Richmond, VA) was provided as the fermentation source. The feed was ground prior to addition in order to facilitate hydrolysis. Sodium bicarbonate ($NaHCO_3$) was added as a buffer to maintain a neutral pH. Mixing was achieved in each fermenter with one submersible pump (1/6 hp). Pilot-scale fermentation was conducted under two operational regimes during this study using 450 L tanks. From days 1 – 101 fermentation was conducted in one tank, operated as a sequencing batch reactor (SBR) with a solids retention time (SRT) and hydraulic retention time (HRT) equaling 3 days. The daily wastage from the fermenter was collected, settled in buckets, and the supernatant was transferred to a 380 L storage container. Fermented supernatant was then pumped from the storage container into the denitrifying column. On day 102, fermenter operation was modified to allow for the continuous pumping of supernatant directly from the fermentation tank into the column during the SBR decant phase. This was accomplished by increasing the complete fermentation cycle to a 48 hour period and adding a second fermenter so that operations for each fermenter were offset from each other by 24 hours. During this second operational regime, the two fermenters were operated as modified SBRs on a 6 day SRT and 3.5 day HRT.

System Operation. A synthetic nitrate wastewater was prepared daily in two tanks (800 L each) using industrial grade sodium nitrate ($NaNO_3$) (Chilean Nitrate Corporation, Norfolk, VA) and tap water. The nitrate feed and fermented supernatant were pumped and mixed in-line prior to entering the upflow column. The system was operated on a 24

hour cycle, with maintenance occurring in the last hour. After 23 hours of operation, the column was shutdown and backwashed to remove excess biomass. In order to effect media bed turnover for efficient biomass sloughing, backwashing was achieved by draining the column and then adding pressurized tap water in a downflow manner. At the same time, the fermenters were either settled or wasted and fed.

Results and Conclusions

Fixed film denitrification was investigated under two different nitrate loading conditions. During the high nitrate loading period, the flowrate was decreased from 3.0 $m^3/m^2/hr$ to 1.5 $m^3/m^2/hr$ from day 283 through 306 in order to address high nitrite concentrations detected in the column effluent. Table 1 outlines the loading conditions for each phase of this study.

Table 1. Nitrate and hydraulic loading conditions for the denitrification system. Average values are provided ± standard error.

Parameter	Low nitrate loading	High nitrate loading	
Period of study (days)	1 - 200	201 - 282, 307 – 346	283 - 306
Influent concentration*			
(mg NO_3-N/L)	38.5 ± 1.0	85.3 ± 1.7	64.8 ± 6.4
(mg NO_2-N/L)	0.65 ± 0.31	2.94 ± 0.46	14.6 ± 5.6
Mass loading (kg NO_3-N/m^3/day)	1.13	2.52	0.96
(kg NO_2-N/m^3/day)	0.02	0.09	0.22
Mass removal (kg NO_x-N/m^3/day)	0.81	2.21	1.08
Hydraulic loading (m^3 /m^2/hr)	3.0	3.0	1.5

*Measurable influent nitrite concentrations were detected only during the high nitrate loading phase under the low hydraulic loading.

The pH increased through the denitrification column from 7.08 ± 0.07 to 7.87 ± 0.12 under low nitrate loadings, and from 7.33 ± 0.03 to 8.59 ± 0.05 under high nitrate loadings. The pH in the fermentation process averaged 6.31 ± 0.06 and 7.41 ± 0.02 during the low and high nitrate loadings, respectively.

COD to NO_3-N Ratio. In order to prevent the reduction of sulfate (SO_4^{-2}) to hydrogen sulfide (H_2S), the denitrification column was originally run under carbon limiting conditions during the low nitrate loading phase. Available carbon limiting conditions

prevailed for influent soluble chemical oxygen demand (sCOD) to NO_3-N ratios less than 5 and resulted in incomplete nitrate removal (Figure 2a) and measurable effluent nitrite concentrations as high as 12 mg NO_2^-N/L (Figure 2b). For influent sCOD to NO_3-N ratios above 5, high total nitrogen removals greater than 95% were consistently achieved, except in one case where the influent pH fell below 7.0. This influent ratio corresponded with a consumption ratio of 4.62 ± 0.28 mg sCOD/mg NO_x-N for complete nitrogen removal. COD was detected in all effluent samples (Figure 2c), with an average concentration of 22.5 ± 3.02 mg sCOD/L even when NO_x removal was incomplete.

During the high nitrate loading phase nitrate removal efficiencies greater than 99% were regularly seen (Figure 3a). However, effluent nitrite concentrations were greater than those measured during the lower nitrate loading, reaching values as high as 34 mg NO_2^- N/L (Figure 3b). The presence of measurable COD in the effluent suggested that carbon limitation was not the problem (Figure 3c). In order to remedy the high effluent nitrite problem, the hydraulic loading was decreased by 50%, thereby doubling the column retention time. After observing several days of complete nitrogen removal during the low hydraulic loading period, operation was returned to the original flowrate. At this point, nitrate removal efficiencies greater than 95% were achieved and effluent nitrite remained at or below 1 mg NO_2 -N /L for the final 2 months of the study (data not shown). During the low nitrate loading phase, visual inspection revealed that biomass growth was concentrated at the bottom of the column where a majority of the nitrogen removal occurred, while sparse microbial colonization prevailed at the top. The improved efficiency that resulted from a decreased hydraulic loading was attributed to an acclimation period during which biomass growth occurred throughout the entire column as a result of increased contact time with substrates. It was thought that this increase in biofilm density enabled the removal of higher nitrate concentrations. Complete nitrogen removal was achieved for a COD to NO_x -N consumption ratio of 3.07 ± 0.58 mg sCOD/mg NO_x-N during the high nitrate loading, but did not correspond to a distinct influent sCOD to NO_3-N ratio and exhibited great variability. When the nitrate loading was increased, the amount of fish feed added to the fermenters was elevated to raise the soluble COD production. Even though the fermenters were settled prior to supernatant removal, a greater amount of suspended solids were visually detected in the carbon source line leading to the column. It is possible that a portion of these fermentation solids were retained within the column and as a result, the hydrolysis of influent fermentation solids may have occurred to generate a COD source not measured by filtered samples.

Summary and Recommendations

The results of this study demonstrated the feasibility of using a fermentation generated carbon source in the denitrification of high nitrate recirculating aquaculture system waters. The fermentation of both fish waste and fish food generated volatile fatty acids that were assimilated by denitrifying organisms. In addition, limiting the amount of available carbon supplied to the denitrification system resulted in an increase in effluent nitrite and incomplete nitrate removal, while influent COD to NO_3-N ratios greater than 5

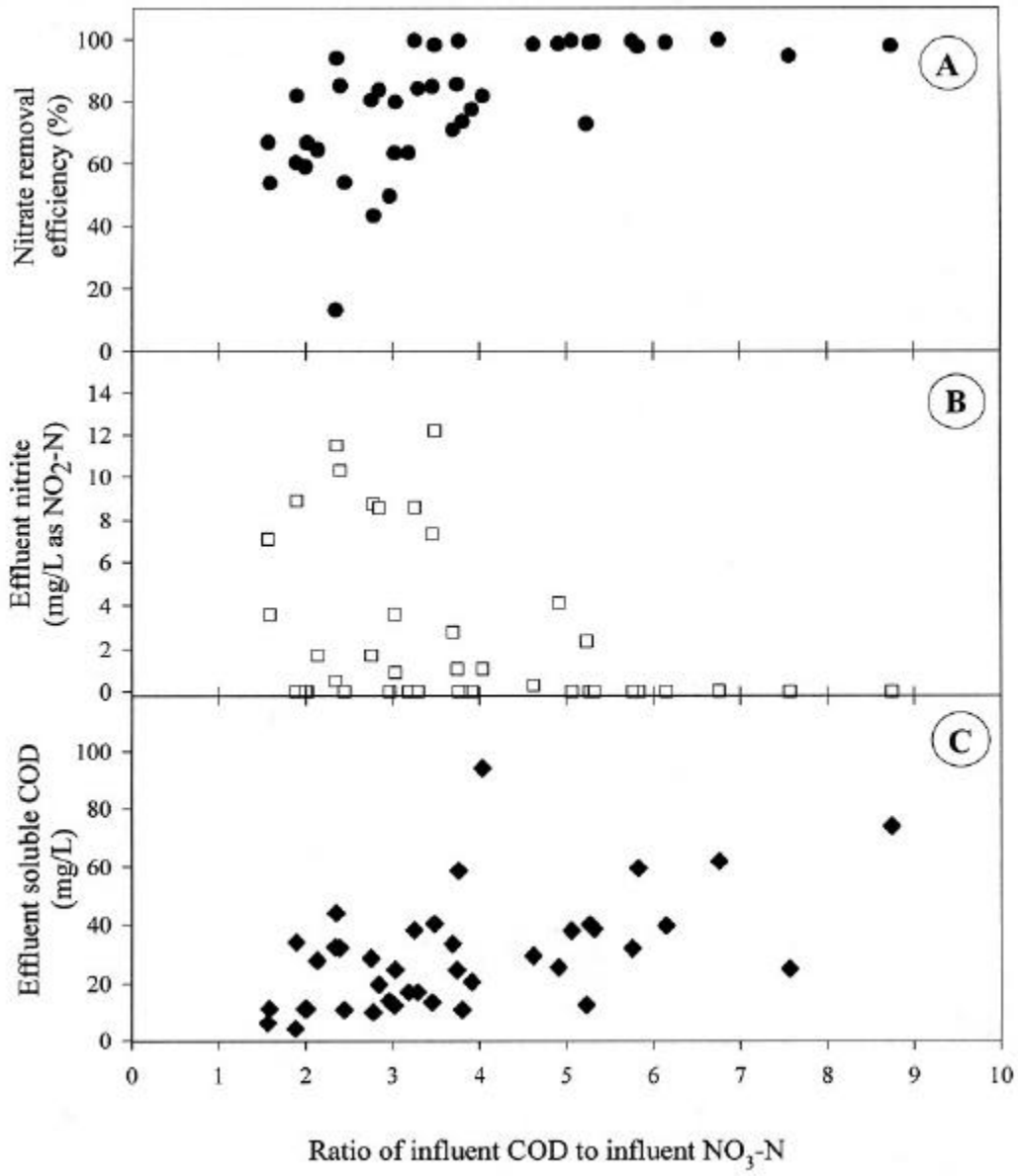

Figure 2. Denitrification column performance during the low nitrate loading phase with respect to (A) nitrate removal, (B) effluent nitrite concentration, and (C) effluent soluble COD concentration, as a function of the influent COD to influent NO_3-N ratio.

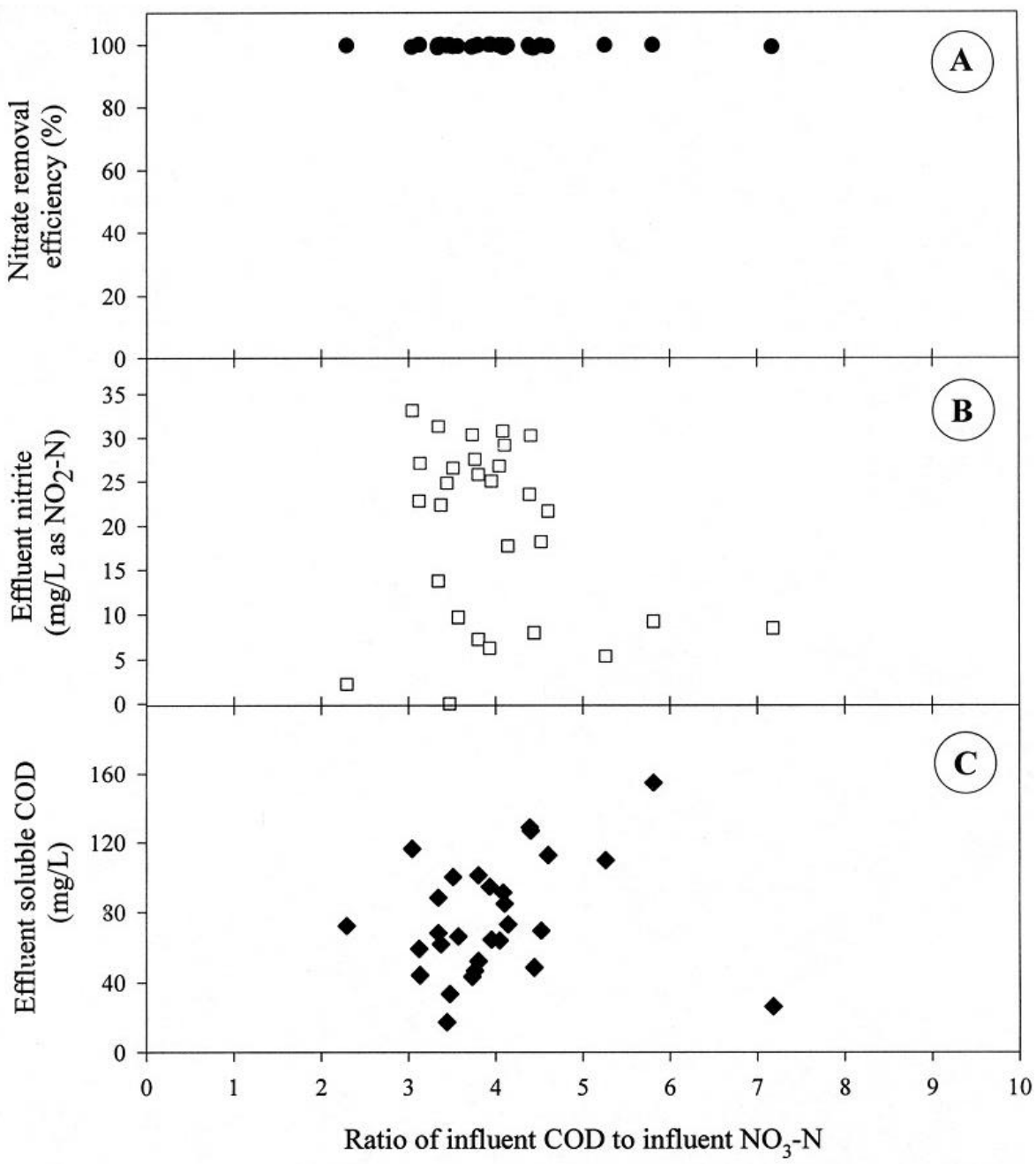

Figure 3. Denitrification column performance during the high nitrate loading phase with respect to (A) nitrate removal, (B) effluent nitrite concentration, and (C) effluent soluble COD concentration, as a function of the influent COD to influent NO3-N ratio. Data represent days 201 to 282, prior to lowering the flowrate.

typically achieved high total nitrogen removals greater than 95%. To prevent nitrite accumulation as well as the discharge of significant amounts of carbon that would return to the fish culture tank, a denitrification system using fermented fish waste or food as the carbon source to produce volatile fatty acids should be operated close to this ratio.

The nitrate loadings examined in this study were lower than the maximum nitrate concentrations observed in nitrifying closed recirculating aquaculture systems not employing denitrification. However, nitrate concentrations in the fish rearing tanks increase gradually over the span of a growth period and it may be possible to maintain concentrations at manageable levels by applying denitrification as a sidestream process so that extreme concentrations do not result. In order to evaluate the efficiency and self-sustainability of this denitrification system at increased nitrate concentrations, additional studies are recommended. It is anticipated that a full-scale recirculating aquaculture facility would generally have several culture tanks containing fish at all stages of growth and would be able to provide a more consistent source of fish waste for the fermentation process. However, this aspect of the treatment system must be evaluated further to determine if complete self-sustainability is possible, or whether an external carbon source must be partially supplemented.

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Denitrification in Recirculating Aquaculture Systems: From Biochemistry to Biofilters

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Introduction

Relatively little efforts have been made to remove nitrate in recirculating aquaculture systems. This is partially due to the fact that, unlike other forms of inorganic nitrogen (ammonia and nitrite), nitrate does not pose a direct threat to organisms cultured in aquaculture facilities. Most cultured fish species are able to grow in nitrate-rich waters although recent evidence has pointed to nitrate stress in hybrid striped bass (Hrubec et al., 1996). A more common problem associated with high nitrate concentrations in fish culture systems is the formation of nitrite due to an incomplete reduction of nitrate in oxygen-poor zones. As most culture systems harbor such zones (e.g. pipes and low-flow areas where organic matter accumulates), relatively high nitrite concentrations can often be detected in nitrate-rich fish culture systems. Discharge of effluent water is an additional problem related to nitrate-rich fish culture systems. When discharged to surface or groundwaters, nitrate may lead to eutrophication in the former and drinking-water contamination in the latter. These environmental and public health considerations have lead to stringent regulations on nitrate discharge in many countries and permissible nitrate levels in effluent water are now as low as 11.6 mg NO_3-N/l (European Community Directive).

Studies on nitrate removal in fish culture systems were reviewed by van Rijn (1996). In all these studies nitrate removal was accomplished by denitrification, a process carried out by facultative anaerobic bacteria which, in the absence of oxygen and presence of metabolizable organic matter, are capable of reducing nitrate, nitrite, nitric oxide or nitrous oxide to N_2. The present contribution summarizes some of the main environmental factors regulating denitrification and, in addition, summarizes our current research on denitrifying organisms and nitrate removal in recirculating aquaculture systems.

Nitrate removal by microorganisms

A wide array of microorganisms is capable of reducing nitrate to more reduced inorganic nitrogen compounds. Most of these organisms have a heterotrophic mode of metabolism, i.e. the requirement for an organic carbon source for growth. Microbial nitrate reduction is either carried out for assimilatory or dissimilatory purposes (Table 1). Assimilatory nitrate reduction, a process in which nitrate is reduced to ammonia followed by ammonia assimilation into cell biomass, takes place in the absence of reduced inorganic nitrogen compounds. The dissimilatory pathway, in which nitrogen oxides serve as electron

acceptors for energy generation by the cells, primarily takes place in the absence of oxygen and is a process carried out by two distinct bacterial groups. One group reduces nitrate to ammonia while the other reduces it to nitrogen gas. Bacteria belonging to the latter group are called denitrifiers. The ratio of available organic carbon to nitrate in the environment is the main determinant for which of these two latter processes takes place. At high ratios, nitrate is reduced to ammonia whereas denitrification is the preferred pathway at low ratios (Tiedje, 1990).

Nitrate removal from aquaculture systems is based on creating optimal conditions for growth of denitrifying organisms as only these organisms cause a net removal of inorganic nitrogen from the water. From the above it follows that in order to create such conditions several factors have to be taken into account: a) reduced inorganic nitrogen compounds should be present, b) oxygen should be absent, and c) the C/N ratio should be low enough to exclude the growth of organisms which reduce nitrate to ammonia.

Table 1. Biological nitrate reduction*

Process	Regulator(s):	Organisms
Assimilatory nitrate reduction ($NO_3^- \rightarrow NO_2^- \rightarrow NH_4^+$)	NH_4^+	plants, fungi, algae, bacteria
Dissimilatory nitrate reduction		
Dissimilary nitrate reduction to ammonia ($NO_3^- \rightarrow NO_2^- \rightarrow NH_4^+$)	O_2, C/N	anaerobic and facultative anaerobic bacteria
Denitrification ($NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$)	O_2, C/N	facultative anaerobic bacteria

* adapted from Tiedje (1990)

Denitrifying bacteria

Many different species are capable of denitrification. Especially the genera *Pseudomonas, Alcaligenes, Paracoccus* and *Bacillus* comprise many denitrifiers (Knowles, 1982). In the natural environment, a complex interaction of physical, chemical and biological conditions governs the predominance of a particular denitrifying species. In denitrifying reactors, species composition is influenced by the nature of the added carbon source (Grabinska-Loniewska, 1991). Addition of complex organic carbon sources will give rise to a higher species diversity than when simple organic carbon sources are used. In this context, denitrifying reactors are often operated with methanol as this carbon source causes the development of a distinct microbial population and, hence, a predictable performance of the reactor. It should be noted, however, that even with addition of simple organic compounds to denitrifying reactors the resulting denitrifying population is often far from predictable. Other forms of organic matter present in the reactor such as those liberated by the decay of microorganisms or present in the water to be treated may give rise to a diverse microbial population. A highly versatile bacterial

composition and dynamic bacterial colonization pattern was found on sand particles derived from fluidized bed reactors used for nitrate removal from fish culture water (Sich and van Rijn, 1997).

In view of the large diversity of denitrifiers, denitrification takes place at a wide range of environmental conditions (temperature, salinity, etc.). Unlike nitrification, where the species diversity is narrow, single environmental determinants do not have a measurable effect on denitrification.

Nitrite accumulation by denitrifiers

Denitrification often coincides with an accumulation of intermediates in the denitrification pathway. One of these intermediates, nitrite, is extremely toxic to fish and as such it is important to understand the factors underlying nitrite accumulation during this process. In denitrifying bacteria exposed to low levels of oxygen, nitrite accumulation resulted from differential repression of nitrite reductase synthesis and activity, as compared to nitrate reductase (Coyne and Tiedje, 1990; Korner and Zumft, 1989). Shifts in the pH values of the medium were also found to affect nitrite accumulation (Almeida et al., 1995; Beccari et al., 1983; Thomsen et al., 1994). Competition between nitrate and nitrite reductases for common electron donors is an additional factor causing nitrite accumulation by some denitrifiers (Betlach and Tiedje, 1981; Kucera et al., 1983; Thomsen et al., 1994). The choice of carbon source was shown to affect the level of nitrite accumulation in denitrifying reactors (McCarthy et al., 1969). The carbon source may lead to specific enrichment of nitrite-accumulating bacteria, as was found in a study on denitrifying reactors where addition of fermentable substrates enhanced the growth of such bacteria (Wilderer et al., 1987). Alternatively, individual denitrifiers may accumulate nitrite when grown on different carbon sources (Blaszczyk, 1993; Nishimura et al., 1979; 1980; van Rijn et al. 1996). Temporary carbon starvation may lead to nitrite accumulation in denitrifying bacteria with constitutive nitrate reductases and inducible nitrite reductases (Barak, 1997, Table 2). Finally, in a

Table 2. Maximum nitrate and nitrite reduction rates during carbon starvation of *Pseudomonas* sp. Strain JR12 isolated from a fluidized bed reactor*.

Starvation period (h)	V_{max} NO_3^- (mM NO_3^--N/g protein/min)	V_{max} NO_2^- (mM NO_2^--N/g protein/min)
0	0.298 ± 0.00	0.353 ± 0.03[a]
12	0.300 ± 0.01	0.253 ± 0.05[b]
24	0.321 ± 0.03	0.204 ± 0.03[b]
36	0.285 ± 0.04	0.185 ± 0.01[c]

*different superscripts indicate significant differences within maximum nitrite reduction values (students T-test, $p<0.05$)

recent study on a denitrifying bacterium isolated from a denitrifying fluidized bed reactor used for nitrate removal in a recirculating aquaculture facility, nitrite accumulation

resulted from light exposure. It was shown that at light intensities as low as 5% of full sunlight intensity, nitrite accumulated as a result of light inhibition of nitrite but not of nitrate reduction (Barak et al., 1998).

Application of denitrification in recirculating aquaculture systems

Relatively few studies have been conducted on nitrate removal in recirculating systems. As most recirculating systems are not closed but are operated in a semi-closed mode, nitrate levels are controlled by means of a daily discharge of nitrate with the effluent water. Passive denitrification in low-oxygen areas of the recirculating system, furthermore, reduces the nitrate concentrations in these systems.

Most of denitrification reactors employed in (experimental) aquaculture facilities are based on immobilization of denitrifiers on suitable media (plastic, sand). Within these reactors, anoxic conditions are created by flushing the reactor with N_2 gas (Whitson et al., 1993) or by operating the reactor at retention times low enough to secure a complete, biologically-mediated, oxygen depletion within the reactor. As denitrification is primarily a heterotrophic process, the inlet stream should be supplied with a suitable carbon source. Alcohols and sugars are often used for this purpose (Balderston and Sieburth, 1976; Otte and Rosenthal, 1979; Whitson et al., 1993; Honda et al., 1993; Abeysinghe et al., 1996).

Another, cheaper carbon source for denitrification is the organic carbon produced in the fish culture units (fish feces and unutilized feed). Arbiv and van Rijn (1995) demonstrated the potential use of this latter carbon source for nitrate removal in recirculating aquaculture systems. In this study, organic matter was periodically withdrawn from a fish culture unit and led into a sedimentation basin where high redox potentials were maintained by a constant flow-through of oxygen and nitrate-rich water from the culture unit. Under these conditions it was found that degradation of sludge resulted in the release of short-chain volatile fatty acids. Before being returned to the culture unit, water withdrawn from the sedimentation basin, devoid of oxygen but rich in nitrate and volatile fatty acids, was led through a fluidized bed reactor where denitrifying bacteria reduced nitrate to N_2 using volatile fatty acids as a carbon source (Aboutboul et al., 1995). The latter method not only caused a considerable reduction of nitrate from the culture systems but also proved to be an efficient means for decomposing the organic sludge produced in the fish culture unit (van Rijn et al., 1995; van Rijn and Nussinovitch, 1997). By means of this treatment system water loss was extremely small since neither sludge nor water were discharged. It should be noted, however, that since all the nitrogen added with the feed is retained within the system, a considerable larger nitrification unit is required when using this treatment scheme than in systems where sludge is discharged.

Recently, a new type of denitrifying reactor was developed (Nussinovitch et al., 1996; Tal et al., 1997) in which instead of immobilization, the denitrifying bacteria are entrapped within polymeric beads. These freeze-dried polymeric beads, co-entrapping bacteria and a suitable carbon source, provide the advantage that denitrification is initiated immediately upon introducing the beads in nitrate-rich water. Whereas the product has been successfully tested in marine and freshwater aquariums, its full-scale use in aquaculture facilities remains to be examined.

Denitrification and phosphorus removal

Reduction of phosphorus concentrations in intensive fish culture systems is mainly accomplished by increasing the dietary phosphorus availability. Once released into the culture systems, phosphorus is generally left untreated and is discharged with the effluent water either in the organic or inorganic form. Although intensive fish culture systems are a considerable source of phosphorus pollution, relatively few studies have been conducted on phosphorus removal in these systems (Adler et al., 1995; Abeysinghe et al., 1996). In Europe as well as the USA, legislative measures to reduce this pollution source have been implemented and the expectations are that discharge restrictions/fees will become more severe in the future.

Treatment of phosphorus by standard chemical and physical methods to very low levels is expensive and increases in complexity as the required effluent concentration decreases. Enhanced biological phosphorus removal from domestic wastewaters in activated sludge plants is accomplished by alternate stages in which the sludge is subjected to anaerobic and aerobic conditions, respectively. Under these conditions, phosphorus after being released from the bacterial biomass in the anaerobic stage, is assimilated in excess (luxury phosphorus uptake) by these bacteria during the aerobic stage. Phosphorus is subsequently removed from the process stream by harvesting a fraction of the phosphorus-rich bacterial biomass (Toerien et al., 1990). Recently, evidence was provided for single-stage phosphorus removal by denitrifying bacteria (Barker and Dold, 1996). Under anoxic conditions, the latter bacteria were shown to be capable of luxury phosphorus uptake with nitrate serving as electron acceptor.

We tested the phosphorus removal capacity of denitrifying sludge obtained from a fluidized bed reactor operated on fish culture effluent. A concomitant nitrate and phosphorus removal was found (Fig. 1A). As assimilatory phosphorus requirements are related to assimilatory nitrogen requirements, it could be estimated by determination of the disappearance of both nitrogen and phosphorus from the medium that phosphorus uptake was in excess of biosynthetic phosphorus requirements by the bacteria present in the sludge. Pure bacterial cultures were obtained after enrichment of the sludge with phosphorus, nitrate and acetate. As was observed with crude sludge, also these isolates were capable of combined nitrate removal and luxury phosphorus uptake (Fig. 1B). The observation that phosphorus concentrations increased upon depletion of nitrate from the medium may serve as an additional indication for the fact that these bacteria were indeed capable of luxury phosphorus uptake (Fig. 1B). An electron microscopic examination of bacteria incubated under denitrifying conditions in the presence of phosphorus clearly revealed the presence of considerable concentrations of polyphosphate inclusion-bodies (not shown). Once stored within the denitrifying biomass, the phosphorus can be removed from the culture system by means of a periodical, partial harvest (wasting) of the denitrifying biomass. To what extent this process can be adapted to recirculating fish culture systems is currently under investigation.

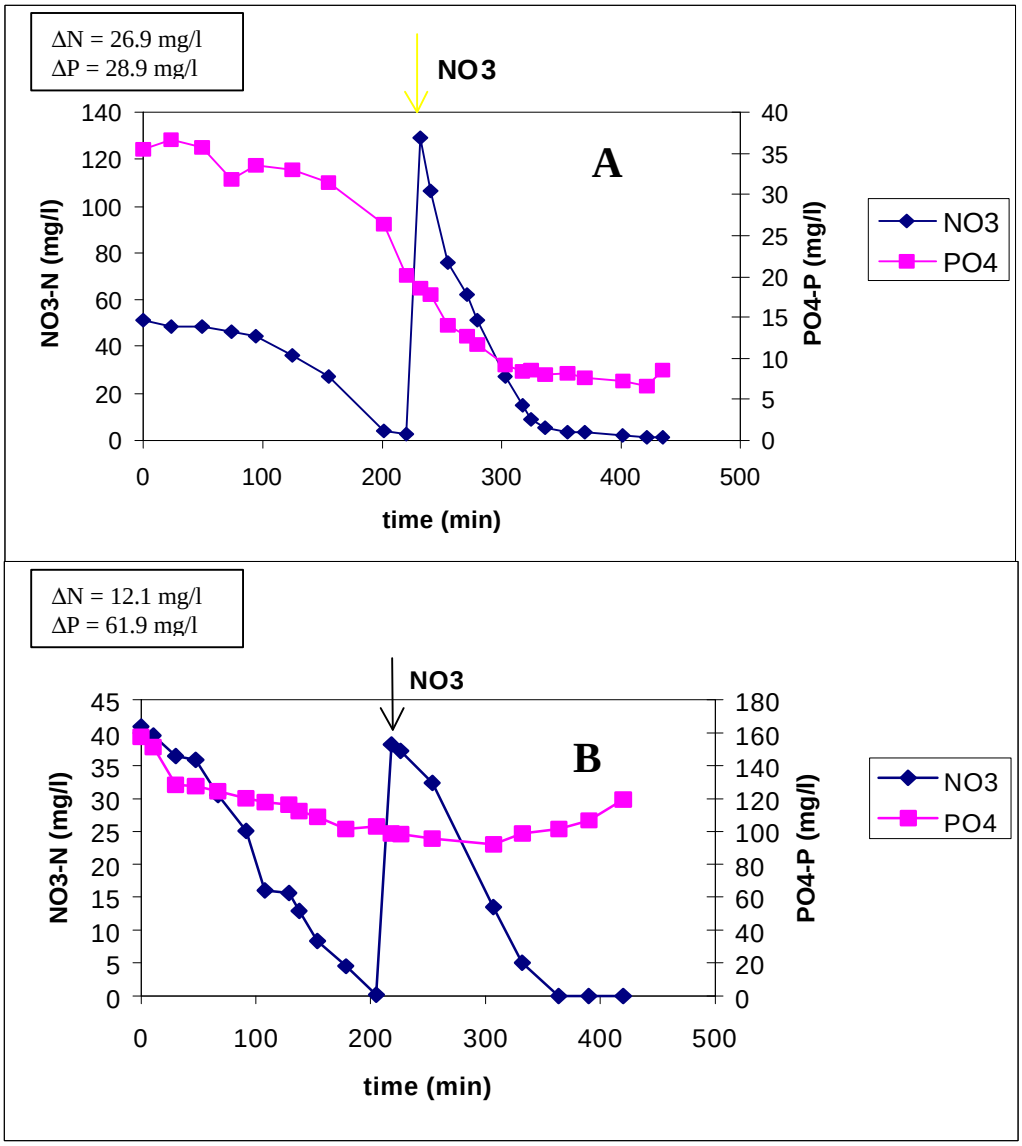

Figure 1. Combined nitrate and phosphate removal by (A) denitrifying sludge from a fluidized bed reactor and (B) a denitrifying strain *(Pseudomonas* sp.) isolated from the sludge of a fluidized bed reactor. Values of ammonia and phosphate removal during both experiments are inserted. After depletion, nitrate was added at times indicated by arrows.

Conclusions

Biological water quality control in recirculating aquaculture systems has so far focused mainly on the prevention of accumulation of ammonia through the induction and management of nitrification. Accumulation of other inorganic nutrients such as nitrate and phosphorus has received little attention since high concentrations of these nutrients do not impose a direct threat to most cultured organisms. Reduction of environmental pollution by using recirculating technology is considered an important advantage over other fish culture technologies. Present recirculation technology reduces pollution by

more than 50% in comparison to traditional flow-through systems but still are a considerable source of pollution by discharge of organic matter, nitrate and phosphorus. Although proven to be feasible, full-scale commercial use of denitrification systems has thus far not been initiated. It is expected, however, that with increasingly stringent discharge regulations, methods for nitrate removal will be incorporated either within the treatment-process stream or in the effluent stream of recirculating aquaculture systems. The finding that, in addition to nitrate removal, denitrifiers are capable of luxury phosphorus uptake provides the interesting possibility to remove both pollutants in a single treatment step.

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Nitrite Accumulation in Denitrification Systems – The Role of Dissolved Oxygen and Substrate Limitation

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Denitrification Using Upflow Biological Filtration – Engineering Aspects of the Technology

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Comparison of Aquaculture and Broiler Production Systems

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Introduction

Natural fish populations are being decimated and rapid growth of fish farming is supplying an ever increasing fraction of the fish market. USDA statistics show the world commercial fishery landings have decreased from 101 million metric tons to 98 million metric tons in the last three years and that USA per capita consumption rates of fish have decreased in the last several years from 7.4 kg to the current level of 6.6 kg per capita, despite documented health benefits of eating fish (USDA, 1994). Of the current seafood consumption, 20% is supplied from aquaculture (Scientific American, November, 1995).

Aquaculture must continue and accelerate the current trend of supplying the increasing need for fish and seafood products. There are strong opinions in the scientific and agri-business communities as to where this increase in aquaculture production will come from-indoor or outdoor culture systems. Outdoor culture proponents argue that the costs of producing fish from indoor systems are too high to ever allow commodity levels of product to be produced from such systems. Outdoor culture proponents also maintain that their systems take advantage of provisions of nature, e.g. sunshine and algae production, and that the initial system costs are low for pond structures. Further, outdoor proponents argue that fish production should concentrate in developing countries where labor and land are inexpensive. While the arguments for outdoor culture are valid, they do not eliminate the potential of indoor culture systems as viable production units for the competitive production of fish products. The technologies available today are dramatic improvements over what was “state of the art” just a few years ago. We believe it is no longer an issue as to whether indoor systems will be the dominant form of aquaculture in the future, but rather, the speed at which this industry will grow to meet the ever increasing need for safe seafood products.

Lessons from the Poultry Industry

A strong resemblance exists between the tilapia industry as it nears the 21st century and the broiler industry of the last half of the 20th century. The broiler industry did not exist at the beginning of the 20th century but grew to become a $40 billion industry at the retail level by the end of the century. It began as a backyard hobby and grew to employ hundreds of thousands of people. Tiny specialized companies formed the basis of what became the vertical integration model and was copied by the rest of agriculture by the end of the century.

All the elements appear to be in place for the tilapia industry to follow the broiler industry model:

- ability of tilapia to utilize a low cost corn/soy diet
- rapidly dropping costs of production with new production technology
- potential for having the lowest cost fish meat on the market
- consumer demand driven by the elasticity of demand
- potential for vertical integration and economies of scale

If the tilapia industry is to duplicate the growth rate of the broiler industry, it must produce a low cost product. Chicken became the most popular meat choice because it is a low cost, tasty, and healthful product. As the price of any meat product drops, demand increases. If tilapia becomes the lowest cost fish on the market, it will not only have a commanding presence in the fish and seafood market, but also help expand the fish portion of the total meat market.

Americans are unlikely to ever eat tilapia in the way that they eat chicken, pork, or beef. Nevertheless, an additional 50% increase in the fish consumption per year or 7 pounds per capita per year within the next 20 years could be expected. That would require a production level of 2 billion pounds of tilapia by the year 2018. To reach that level, production would have to increase by 100 million pounds each year for the next 20 years! Will this happen? It should happen if tilapia can become one of the lowest cost fish meats and highest quality available.

The broiler industry required 50 years to learn three important lessons:

- vertical integration
- further processing
- branding

Learning from the experience of the broiler industry, the tilapia industry has the opportunity to telescope that 50 year process into a much shorter time period, perhaps as few as 10 years.

Vertical Integration. Vertical integration is the ownership or control of all or most of the production stages. In the broiler industry that means that a single "Integrator" owns or closely controls the feed mill, hatchery, processing plant, farms and marketing of broiler meat. Broiler integrators do not generally own farms. Instead they closely control farm production through the use of contracts. For the tilapia industry that would mean a single company would own or closely control the production of feed, fingerlings, fish, processing (if any) and marketing.

Why is vertical integration such a good idea? Vertical integration allows a company to coordinate the capacity utilization of each stage of production, establish a single profit center, and control quality from beginning to end. It is the state of the art in the organization of an agribusiness enterprise.

Further Processing. As the broiler industry brought down the cost of production, it became possible to sell further processed and value added products because the price of these products came within reach of consumers. Further processed products have two benefits to integrators: first, they provide a higher margin of profit, and second, they provide a more stable income over time. For the tilapia industry, the benefits of further processing are obvious. American consumers do not want to deal with fish bones and entrails; they want a fish filet at a reasonable cost. Low cost whole tilapia will allow the tilapia industry to sell a low cost tilapia fillet.

Branding. The final important lesson learned by the broiler industry was that a branded product provides more returns than a non-branded product. A branded product must meet both the following conditions to be successful:

- it is widely recognized by consumers
- consumers are willing to pay more for the product

A good example of branding in the broiler industry is Perdue Farms. Perdue spends approximately 5 cents per pound in advertising to increase the sales price of the branded product by 8 cents per pound. In Perdue's marketing of the branded product, Frank Perdue makes fun of unbranded poultry parts by calling them "unidentified frying objects".

Economic Comparisons

We will make a comparison among outdoor systems, indoor systems and commercial broiler production. The outdoor economics will be taken from catfish production in the USA, since complete data is available for such systems. Catfish production is a mature industry in the USA and as such, the costs of production are well documented. Effects of initial capital investment and system productivity will be predicted for indoor production costs. Projected production costs for tilapia will be made based upon the technology or management improvements expected over the next 5 years.

Analysis

Comparison to Catfish Pond Production. We will compare predicted costs of tilapia production based upon performance data collected at Cornell University with previously published data for Mississippi catfish production from large outdoor ponds. Tilapia component costs are based upon current Cornell University data and experience with an indoor 220,000 kg/yr tilapia farm recently built near Cornell University (Cayuga Aqua Ventures, LLC, or CAV). The Cornell data were obtained from a prototype 60,000 L tank system similar to the tank systems described in Tables 1 and 2. Where reasonable, component costs are kept the same between the tilapia and catfish examples, so that differences in production costs are the result of management and system costs and not subjective values used for say liability insurance.

The production levels from both systems are 590,000 kg/year. This comparison is intended to show the strengths, weaknesses and similarities of the two production systems. Prices, depreciation values, and associated economic factors are given in Table 3 for both Mississippi pond catfish production and a northeastern USA indoor system producing tilapia where the average outside air temperature is 9°C. Costs associated with

catfish production are as given by Keenum and Waldrop (1988). Depreciation, repairs and maintenance for the tilapia example were calculated in a more simple fashion than used in the catfish analysis; differences in this cost component due to calculation method are minimal. Feed price is adjusted upward from that given by Keenum and Waldrop to be reflective of current feed prices; the same feed price is used for both tilapia and catfish.

Characteristics of the indoor tilapia fish farm are given in Table 2 and system cost details (capital investment) are given in Table 3. Effects of overall system costs and productivity per unit volume of water will also be demonstrated later in this paper. The parameters given in Table 2 are somewhat conservative. Cornell has operated systems with twice the densities listed and fed at rates considerably above 2% per day for sustained periods with success. The indoor tilapia system design is based upon upflow sand filters using large sands (D_{10} = 0.6 mm and D_{eq} = 1.1 mm; upflow velocity of 3.5 cm/s), double drain flow configurations to minimize the water treatment volume for suspended solids removal, and modest carrying capacities (100 kg/cubic meter).

Labor requirements. The authors' experiences with a range of tanks from 2 to 8 m are that tanks of various sizes require similar man-hours to manage. In effect, it is the number of tanks and not the size of tanks that is important in determining management hours required. Our experience indicates that efficient growers can manage a series of tanks averaging 20 to 30 minutes per day per tank system (11,000 L). Labor includes daily water chemistry measurements, fish feeding, filter maintenance, and tank cleaning. Weekly maintenance of two to three additional man-hours per tank system for major cleaning activities and preventative maintenance is also necessary. Assuming a 40 hour work week, this suggests one person could manage 7 to 9 tank systems (average of 4.3 to 5.3 man-hours per tank system per week). Since many operations on a farm require two people, a facility could be designed assuming two full-time employees/owners to maximize labor efficiency. Hourly or contract labor would be employed for special tasks, e.g. harvesting, hauling, processing, etc. This then defines the size for the basic production unit used in the present analysis as a 16 tank system. Some adjustments in labor requirements might be allowed depending upon the tank size (our analysis for tilapia production assumes 4 full-time employees). Losordo and Westerman (1994) used 8 hours per day to manage an eight tank facility with a 3 tank nursery (approximately 50% of the labor per tank used in our cost analysis).

Comparison to Broiler Production. Ultimately, fish production from aquaculture will have to compete with other commodity meats such as poultry. It is instructive to compare predicted costs of production for fish from indoor and outdoor facilities with those of broilers. Broiler production data is based upon recent USDA statistics (USDA, ERS 1996 a, b, c) and the authors' personal knowledge gained from 20 years working in the industry. USA broiler production is now based upon vertical integration with the broiler grower being the contract farmer. The farmer owns the building, provides husbandry, and pays the majority of the utilities. For these services the farmer is paid approximately \$0.09 to \$0.11 per kg of broiler produced. Thus, all costs associated with building ownership, depreciation of capital equipment, labor and utilities (electric and water and generally about 50% of the fuel heating costs) are borne by the farmer. The productivity per worker has increased from 95,000 kg of broilers per year in 1951 (Watt Publishing,

1951) to 950,000 kg per year in 1991 (Perry, 1991). Similar achievements have been made in equipment, housing, and nutrition and genetics; North (1984) provides an extensive description of all facets of commercial poultry production. It is interesting to note that broiler production in the 1950's was around 5 million kg per year. The productivity per unit of worker and total broiler consumption of the 1950's is very similar to the current productivity standards of the USA tilapia industry (7 million kg per year) and the productivity per person in the fish farming business is approximately 25,000 to 110,000 kg per year. There is obvious room for improvement in the fish production business.

Results and Discussion

The predicted tilapia production costs are given in Table 4 and are compared to the production costs of catfish and broiler production on a $ per kg basis and as a percentage of total costs. Overall, the tilapia production costs were slightly higher than the catfish production costs, $1.62 per kg versus $1.56 per kg. The major point of the comparison provided in Table 4 is that when indoor tilapia production is practiced on a similar scale as the large USA outdoor catfish ponds, the costs of production are also very similar. Initial system costs for tilapia and catfish are similar: $1.37 (tilapia) and $1.44 (catfish) per kg per year of production. These investment costs are roughly 3 times the initial capital investments for broiler production of $0.49 per kg per year of production capacity.

Labor savings obtained from converting from outdoor production to indoor farming was a primary factor that drove the poultry industry to confinement housing. As mentioned earlier, the labor productivity for indoor broiler production is roughly 8 times more productive than indoor tilapia fish farming. Ultimately, indoor fish production has two distinct advantages over poultry production: feed conversion efficiency and productivity per unit area of building. Broiler production has feed conversion efficiencies of approximately 2.00 (2.09 bird weight, feed to gain ratio on feed energy levels of 3,170 kcal/kg and protein levels of 19.5%), while tilapia conversions are currently in the 1.3 to 1.5 range for feed energy levels of approximately 2,500 kcal/kg. The yearly meat output per unit floor area from the tilapia system is 255 kg/m^2 compared to 122 kg/m^2 from a broiler house. Thus, net economic productivity per year from a fixed tilapia production facility could be higher, even though the costs of production per unit weight are higher compared to broilers. The advantage for fish production systems is their higher potential rate of return per year from a fixed facility.

Projected Costs of Production for Tilapia. At this point, there is considerable information available as to what an expected cost of tilapia production could be for large scale operations and what kind of labor savings could be anticipated over the next 5 to 10 years. For example, many utilities will reduce electrical rate charges by 25% once a load of 500 kW is reached. As previously discussed, we may expect labor requirements to reduce to 50% of the current example. Catastrophic fish insurance would no longer be deemed necessary, since the farmer would begin to become self-insured. System costs would be expected to reduce by 25% over current costs due to improvements and refinements in system designs. The predicted costs based upon this scenario are given in Table 5 (broiler production costs are listed again for sake of comparison).

Conclusions

Tilapia production appears to be competitive on the commodity meat market when labor and system cost efficiencies are employed for a large scale indoor fish system. Recent improvements in system costs and labor and system efficiencies associated with larger tank sizes are largely responsible for the improvements in economic competitiveness. A comparison with catfish pond production at a similar scale of production showed that tilapia production costs were very near those of catfish ($1.62 per kg tilapia versus $1.56 per kg catfish). The costs of tilapia production are still significantly higher than commercial broiler production, e.g. $0.65 per kg for broilers. However, this difference is primarily attributed to equipment, ownership and labor costs which are much more efficient in broiler production than tilapia production, $0.073 per kg versus $0.47 per kg. The competitive advantage of indoor tilapia production is that the weight production per unit area of building per year is approximately twice the productivity of a commercial broiler house on a live weight basis and that tilapia (fish) are more efficient converters of feed into flesh.

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Table 1.
Economic parameters used for catfish (Keenum and Waldrop, 1988) and tilapia production analysis.

	catfish	tilapia
Feed cost (32% protein, $/kg)	$0.40	$0.40
Feed/gain ratio	2.00	1.40
Harvest weight, kg	0.57	0.68
Fingerlings, $/fingerling	$0.075	$0.060
Cumulative mortality, %	5	5
Electric costs, $/kWh	$0.085	$0.077
Oxygen cost, $/kg)	na	$0.19
Depreciation (straight line, zero salvage; 7 yrs equipment, 20 yrs bldg)	--	--
Interest on investment	11%	11%
Interest on operating capital (based upon 50% of total operating costs), %	10%	same
Repairs and maintenance (% of initial cost)	~5%[a]	5%
Labor ($/man year include 35% fringe benefit rate)		
1- manager	$35,000	$47,000
1- foreman	$26,000	$34,000
3- workers catfish and 2- tilapia	$36,000	$33,000
Total personnel costs	$97,000	$114,000
Total land area, hectares	131.0	2.0
Land value, $/hectare	$1,975	$2,500
Harvesting and hauling, $/kg	$0.09	$0.09

[a]Keenum and Waldrop (1988) perform a very elaborate analysis of repairs and maintenance, but from a simple practical approach, there is minimal difference from using 5% of the initial cost.

Table 2.
Production system characteristics associated with tilapia indoor system.

Size of building	1,780 m^2
Growout tank	16 tank facility (7.6 m diameter x 1.4 m deep) 60,000 L
Yearly harvest	590,000 kg
Design parameters	
Density	100 kg/cubic meter
Feeding rate (depends on fish size)	2% to 3% body mass per day
Feed conversion rate (feed/gain)	1.40 kg/kg
Supplemental oxygen	0.4 kg oxygen per kg of feed fed
Oxygen absorption efficiency	75%
Power per tank system	9 kW (3 pumps each 1,500 Lpm capacity)
Fish target size	680 g
Daily water exchange, % of system volume	5%
Temperature difference for water exchange	19.4°C
Fuel cost, $/100,000 BTU	0.62
Building infiltration, air volumes/hr	2

Table 3.
Capital cost characteristics associated with tilapia water reuse system.

Growout tank: 63 m^3 (60,000 liter)	$2,000
3- 3 kW pumps	$6,400
Oxygen and CO_2 control units	$2,500
Electronic controller	$750
Feeders (2)	$750
Sand biofilter	$4,000
Tank total cost per individual unit	**$16,400**
16 growout tanks Cost	$262,400
Quarantine hatchery /fingerling area (series of small tanks)	$9,000
Total tank costs	**$271,400**
Other Equipment	
Backup generator (2 @ 80 kW)	$32,000
Monitoring system	$10,000
Ice machine (2 ton unit)	$4,000
Feed bin and auger system	$16,000
Harvesting system	$8,000
Water heating system	$8,000
Waste catchment unit	$5,000
Ventilation system	$4,000
Water wells (2)	$8,000
Fish handling equipment	$10,000
Subtotal Other equipment	**$105,000**
Total Equipment Costs (7 year depreciation period)	**$376,400**
Building Costs	
Quarantine area	$14,400
Laboratory and office space	$6,000
Building space	$259,840
Septic/restroom	$4,000
Subtotal building Costs (20 year depreciation period)	**$284,240**
Land costs (non depreciated)	$20,000
Direct cost for complex	$660,640
Contingency costs (20%)	$132,128
Total funds required (equipment, building, land and contingency)	**$812,768**

Table 4.
Comparison of tilapia, catfish and broiler production costs for farms with a yearly fish production of approximately 590,000 kg; costs shown on a per unit weight of production and percentage of total cost by category.

	$ costs per kg produced			% of Total Cost		
	tilapia	catfish	broiler	tilapia	catfish	broiler
Ownership costs ($/kg)						
Depreciation	0.14	0.11	contract	8.6	7.1	--
Interest on investment	0.07	0.10	contract	4.3	6.4	--
Catastrophic fish insurance (3%)	0.07	--	contract	4.3	--	--
Liability insurance + land taxes	0.01	0.01	contract	0.6	0.6	--
Subtotal	0.29	0.22	0.05	17.9%	14.1%	7.7%
Costs of goods services ($/kg)						
Feed	0.55	0.81	0.39	34.0	51.9	60.0
Fingerlings (chicks)	0.10	0.14	0.09	6.2	9.0	13.9
Oxygen	0.14	--	--	8.6	--	--
Subtotal	0.79	0.95	0.48	48.8%	60.9%	73.9%
Operating expenses ($/kg)						
Chemicals	--	0.05	0.06	--	3.2	9.2
Repairs & maintenance	0.07	0.04	--	4.3	2.6	--
Heating water	0.02	--	--	1.2	--	--
Heating air	0.03	--	--	1.9	--	--
Electric 0.16	--	--	9.9	--	--	
Other utilities	--	0.08	0.02	--	5.1	3.1
Management labor + fringe	0.19	0.17	0.04	11.7	10.9	6.2
Misc. 0.01	--	--	0.6	--	-	
Interest on operating capital	0.06	0.05	--	3.7	3.2	--
Subtotal	0.54	0.39	0.12	33.3%	25.0%	18.5%
Total cost of production ($/kg)	1.62	1.56	0.65	100%	100%	100%

Note: Broiler costs are broken down for comparison based upon contract grower payments and allocation of costs between grower and integrator.

Table 5.
Projected costs of tilapia production given expected improvements over the next 5 years compared to current production costs for tilapia and commercial broilers.

	Tilapia	**Projected Tilapia**	**Broiler**
Ownership Costs, $/kg			
Depreciation	$ 0.14	$ 0.10	
Interest on Investment	$ 0.07	$ 0.05	
Catastrophic Fish Insurance (3%)	$ 0.08	--	
Subtotal	**$ 0.29**	**$ 0.15**	**$ 0.05**
Costs Goods Services ($/kg)			
Feed	$ 0.55	$ 0.42	$ 0.39
Fingerlings	$ 0.10	$ 0.04	$ 0.09
Oxygen	$ 0.14	$ 0.09	--
Subtotal	**$0.79**	**$0.55**	**$0.48**
Operating Expense			
Chemicals	--	--	$0.06
Repairs & Maintenance	$ 0.07	$ 0.05	--
Heating Water	$ 0.02	$ 0.01	--
Heating Air	$ 0.03	$ 0.02	--
Electric	$ 0.16	$ 0.10	--
Other Utilities	--	--	$ 0.02
Phone	--	--	--
Management Labor + Fringe	$ 0.19	$ 0.10	$ 0.04
Misc.	$ 0.01	$ 0.01	--
Interest on operating capital	$ 0.06	$ 0.01	--
Subtotal	**$0.54**	**$0.30**	**$0.12**
Total Cost of Production ($/kg)	$1.62	$1.00	$0.65

Timing the Wave

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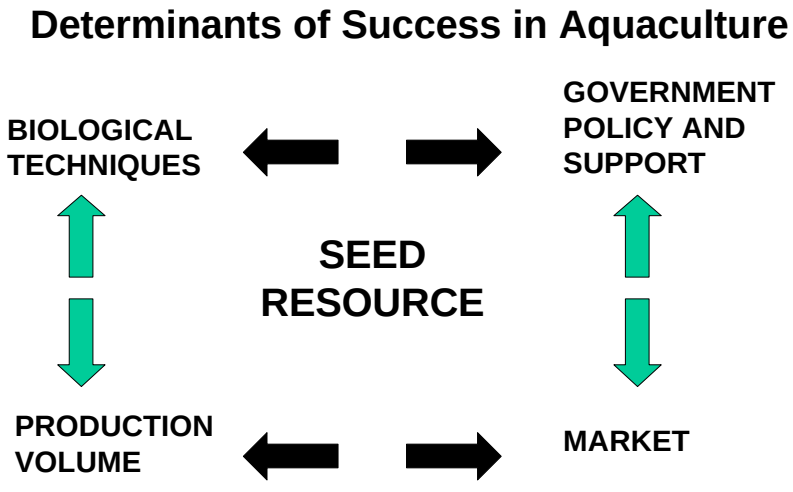
In order for a species to be successful in aquaculture, 5 key components must come together, driven and bonded by intelligent people and sufficient investment (diagram 1). Arctic charr has been a tantalizing potential success story for almost twenty years but the synchronization of these components has not yet been realized, although recent developments in some sectors makes it seem that the surge wave in arctic charr culture is pending. However, it is intriguing to try to "judge the timing of the wave" given that not all the components are yet in place.

This presentation will provide an update on the five key components, describing their current status and problems that still exist. The work will cover recent research results, market findings and production scenarios. Important to the fishfarmer considering arctic charr culture, will be the explanation of what we know and what we don't know about the fish, what systems have been tried, what disease concerns are being addressed and what costs can be expected.

Diagram 1:



The Pacific Northwest Experience With Production Intensification Through Recirculation

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Introduction

The first thing that must be clarified in this paper is that it is written to describe the experience of only a small percentage of the total aquaculture industry in the Pacific Northwest. In British Columbia most of the industry by far, in terms of mass and crop cash value, consists of grow out systems that are not amenable to recirculation technologies. By this, I am of course referring to sea cage culture of salmon. Fortunately for enthusiasts of recirculation technology all is not lost on the Emerald coast. The salmon industry is a valuable commodity industry that is globally competitive. Prior to taking advantage of cheap flowing water and culture space in the ocean, expensive smolts must be produced in fresh water. The cost of smolt production is a fundamental and substantial input to the overall cost of salmon production. In an era when farm gate wholesale prices for salmon are barely above the cost of production, and are in some case below the cost of production, the economics of the salmon hatcheries can no longer be ignored. It is intended that this paper showcase some of the advantages that recirculating technology brings to the industry in this regard. There have recently been efforts at converting several large scale hatcheries in British Columbia to recirculating systems. These projects will form the basis of the numerical examples presented in the paper. The names of the projects have not been mentioned in the text to prevent unwanted disclosure of commercial activity.

General Overview of Recirculation Technology in the Aquaculture Industry in the Pacific Northwest

As noted in the introduction, the primary focus of the paper is technically based in British Columbia as opposed to the broader geographic region. There are reasons for this beyond the local preferences of the author. It had been hoped when the paper was initiated that there would have been more case examples from our neighboring states to help me offset the idea that all interesting recirculation projects are either in Europe or the eastern United States. There are of course a few good examples of fine recirculation projects in the region but the broader trends still tend to limit the number of these types of projects in the Pacific Northwest states. I am hopeful that this will change and would gladly change this opinion if someone can tell me that there are actually commercial or industrial scale recirculating system facilities hidden in the region.

As part of the background research for this presentation, we conducted a telephone survey of many notable people in the aquaculture industry in the region to gauge the potential or existence of the utilization of recirculating technology in their specific area.

Much as expected there was little focus on this subject in many of the areas surveyed. The reasons for this ranged from legislative restrictions, to environmental concerns to just plain too much free water.

In Alaska, we spoke to Raymond Ralonde at the University of Alaska. We discussed the state of the industry generally and some of the trends that appear to be underway. As is well known in the west, fish farming is technically illegal in Alaska. This does not mean that fish culture does not occur however. In fact some of the largest hatcheries in the world are in Alaska and many of them do contribute to what could be considered to be farming. Ocean ranching relies heavily on the salmon produced in these hatcheries and is responsible for 186 million salmon on the world market each year. This is a very successful form of aquaculture and huge volumes of fish are harvested as a result of this practice but it is about as far from the theme of this conference as is possible while still talking about fish. The hatcheries do have the potential to utilize recirculation technology for many of the same reasons as described in the British Columbia examples but currently most are operated on a flow through basis. This is partially due to the fact that these hatcheries focus on raising very small fish with high water quality demands and that there is currently very little restriction in Alaska on the use of groundwater and surface water for this purpose. There is more interest in recirculation technology for use in niche markets in Alaska such as in holding facilities for lobster and geoduck. There are substantial cost drivers for this given the higher costs of maintaining water quality in salt water and the large price differentials between live and dead product in these species. Geoduck is $12 a pound live compared to $3 a pound dead meat for example.

In Idaho, we spoke with Dr. Ernie Brannon at the University of Idaho. As expected, most of the aquaculture in Idaho is driven by the nature of the water resource. Much as the course of the industry in Alaska is set by their access to the open ocean, Idaho is driven by its plentiful ground water resource. It is probably true that you could not get a permit in today's regulatory environment to do what has been done in Idaho but what's done is done and it is very successful. Idaho produces 42,000,000 lbs of trout and several hundred thousand lbs of Tilapia each year with some of the lowest total input costs in North America. Given this state of affairs, there is little incentive to pursue true recirculation based culture systems. There is some work of interest in serial reuse technology that is potentially transferable to recirculation systems that are worth mentioning. Much of this research is in the field of dietary science. Specifically, the use of high lipid (grain product) feeds instead of fish meal based feeds. This could theoretically, result in lower phosphorous and ammonia levels in fish culture water, lower the cost of feed and reduce the industry's dependence on fish meal industry. There is also work being done on feed formulations to reduce fecal disintegration, which would ease solids removal, by settling or mechanical filtration. All of these benefits would transfer directly to farmers using recirculation technology.

In Oregon, we were unable to find many examples of recirculation technology at work. The state government appears not to have been particularly supportive of aquaculture. There are several large hatcheries operating on flow through, but beyond this there does not seem to be much happening.

In Washington state we spoke to several people, Dr. Shulin Chen and Dr. Gary Thorgaard at Washington State University and Ed Jones at the Taylor Untied Oyster hatchery. Washington state has been home to many large aquaculture projects, specifically salmon hatcheries, in part due to funding for such work as a result of damage to wild stocks done by power projects on the Columbia River. Most of these projects have been flow through. Washington State University has a recirculation lab where they conduct genetics research. This facility uses recirculation primarily due to water restrictions on campus. Dr. Chen is doing some promising work on combined solids removal/biofiltration technologies and is refocusing his efforts on the shell fish industry. This industry is very valuable commercially in Washington State and is worth approximately 50 million dollars annually. It also holds some substantial promise for expansion into recirculation technology. Taylor United operates a successful shellfish hatchery that produces 10 species of algae and 6-8 species of shellfish at any given time. The prime reason for going to recirculation was heat conservation. Source water is at 10 C while optimum culture temperature is closer to 25 C. This is obviously too great a temperature differential to make up with heating in a flow through system. The secondary factor at the hatchery that drives the recirculation program is the fact that the shellfish make better total use of the food in the water by allowing multiple passes. The system volume here is changed out about two to three times per day. There are also several examples of closed systems in use for depuration and holding of shellfish.

In Alberta, conditions both commercial and regulatory, are similar to some US states which have experienced good growth in recirculation technology, notably Minnesota and Iowa. Here an interesting blend of tight environmental regulation on ground water use and effluent discharge are combined with a government attitude that is generally willing to support the concept of aquaculture as a reasonable option for family farm diversification. There is also a good dose of pioneer or frontier style entrepreneurial spirit here where farmers seem to be willing to explore new technologies. The current farms that utilize recirculation technologies are primarily engaged in the production of trout fingerlings for restocking programs. There is also a recirculating system in Calgary producing Tilapia for the live market niche in the province. Some particularly interesting work is gong on at Lethbridge Community College and the Eastern Irrigation District. Both of these facilities have built fully recirculating warm water facilities for the culture of grass carp. Both of these facilities would not have been able to do this work without the use of recirculation due to the fact that they are on essentially potable water supplies of limited capacity and the heat differential is far beyond what could economically be achieved by any other means. The final bit of interesting work in the province is at the Alberta Research Council facility at Vegreville. They have constructed a new closed system for conducting research into recirculating technologies particularly for cold water species such as trout. This facility is now easily as well equipped as any of the labs in the eastern US and has a mandate to develop economically feasible and environmentally sustainable technologies for diversifying rural farms in Alberta into aquaculture.

In British Columbia, the vast majority of aquaculture by value and tonnage is conducted in net pens off the coast as was previously mentioned. There is also a well developed wild salmon enhancement hatchery program and some sophisticated laboratory work at

the Department of Fisheries and Oceans Biological Station in Nanaimo. There is also a large shellfish industry in the province. While not as large as the industry in Washington state, it faces the same pressures in that coastal water quality is being compromised by the encroachment of urban development. This is forcing the industry to utilize sophisticated depuration plants and to consider recirculating technologies for hatcheries. There is also some interesting work in the area of Sturgeon culture with recirculating technologies. British Columbia however has a long history of governmental interference with aquaculture so it is unlikely that a commercial Sturgeon industry will develop in the province any time soon despite the availability of the brood stock at the college. Similarly there has been a restriction on Tilapia culture in the province which has allowed the Vancouver live market niche to be satisfied by producers in Idaho. There is some current interest in relaxing these restrictions somewhat but the first facilities of a commercial scale are at least a year away. The greatest current interest to pursue recirculation technology therefore falls to the salmon hatcheries.

Historical Overview of the British Columbia Salmon Farming Industry

In order to place a discussion of technology change in context, it is appropriate to briefly review the history of the industry.

The Salmon producing industry in the Pacific North West is an industry that can be defined by the obstacles that is has had to overcome.

Beginning as a wave of entrepreneurship in the late ‘70’s, the industry had become a “gold rush” by the mid-80’s. Well over a hundred salmon farms were operating on B. C.’s west coast and mostly concentrated in the Jervis Inlet region approximately 50 miles north of Vancouver. In 1986, a harmful algae bloom and the mass mortality that it caused drew the attention of media and the public to the industry and it’s problems such as mort disposal, escapage, disease and drug-use. The government reacted with a two year moratorium on the licensing of new sites as it tried to establish some groundwork for regulations.

In 1989, a second, more intense harmful algae bloom on the Sunshine Coast hit the industry already on the ropes from low market prices caused by the rapid increase in the production of farmed salmon mostly in Chile and Norway. Many companies were pushed over the edge into receivership. The remaining companies gobbled up and conglomerated the assets of the failed ventures as they abandoned the Sunshine Coast and moved operations hundreds of miles to the north, hopefully into algae-free waters.

Increasing pressure from environmental and native groups led to five-year moratorium on new farm licenses beginning in 1992 as the government undertook an intensive environmental review. Even though the review awarded the industry with a clean bill of health, opposition to the industry from environmental, native and fisher groups has continued to intensify focusing on the production of Atlantic Salmon and risks inherent in introducing a non-native species into an eco-system.

And finally last year, the Supreme Court of B. C. ruled that "native interest on Crown Land is equal to the Crown's interest" thus any new fore-shore leases must also be processed and approved by a Native level of government which as yet is undefined.

This pressure to restrict the industry's access to the water resource is in fact, one of the key drivers in forcing B. C. Salmon farmers to consider recirculation technologies in their hatcheries. The restrictions on ocean sites has prevented the industry from gaining the economics of scale enjoyed by Chile and Norway and so production economics must be sought elsewhere. In addition, new or expanded ground water use licenses are unlikely to be issued.

Overview of the Reasons for Pursuing Recirculation in the Salmon Hatcheries

As mentioned in the introduction, the prime reason for pursuing recirculation technologies in the hatcheries is the economic benefit. Recirculation technology is an economically viable alternative for Salmon hatchery operations. This benefit has been demonstrated in other countries and on the east coast of Canada where almost all recent hatcheries have been built to incorporate recirculation technology.

In fact, moving towards recirculation technology may be the only option in a region where the various levels of government have stated that there will be no more lakes made available for rearing smolts and expect to start paying for your water. Areas previously overlooked for hatchery construction or expansion are being revisited with recirculation in mind.

The continuing pressure of environmental concerns around the issues of water pollution and energy conservation helps strengthen the case of recirculation. With the majority of the effluent being filtered, treated and then recycled through the culture tanks, only a small amount of discharge is released. The recycling of water also reduces the energy that has been traditionally spent pumping water at the well head and heating water that was only to be used once. Last of all, the move towards a greater degree of control over the water quality in recirculation systems often results in a higher water quality in which to grow fish. There are cases where the incoming make-up water is not as clean as the recirculated water even where the fish densities are extremely high.

Examples of Audits leading to Implementation of Recirculation Technologies or Plans to do so.

Water Cost

There are some cases which have very clear pay back periods or where there was no choice but to utilize recirculation technology because of very substantial water usage surcharges. When a municipal water authority audit was conducted to find the city's largest water users, the aquaculture program at the local college was found to be in the top five total water users in the city. Water changes were assessed as "an incentive to reduce consumption". This water bill was in excess of the total capital and O & M

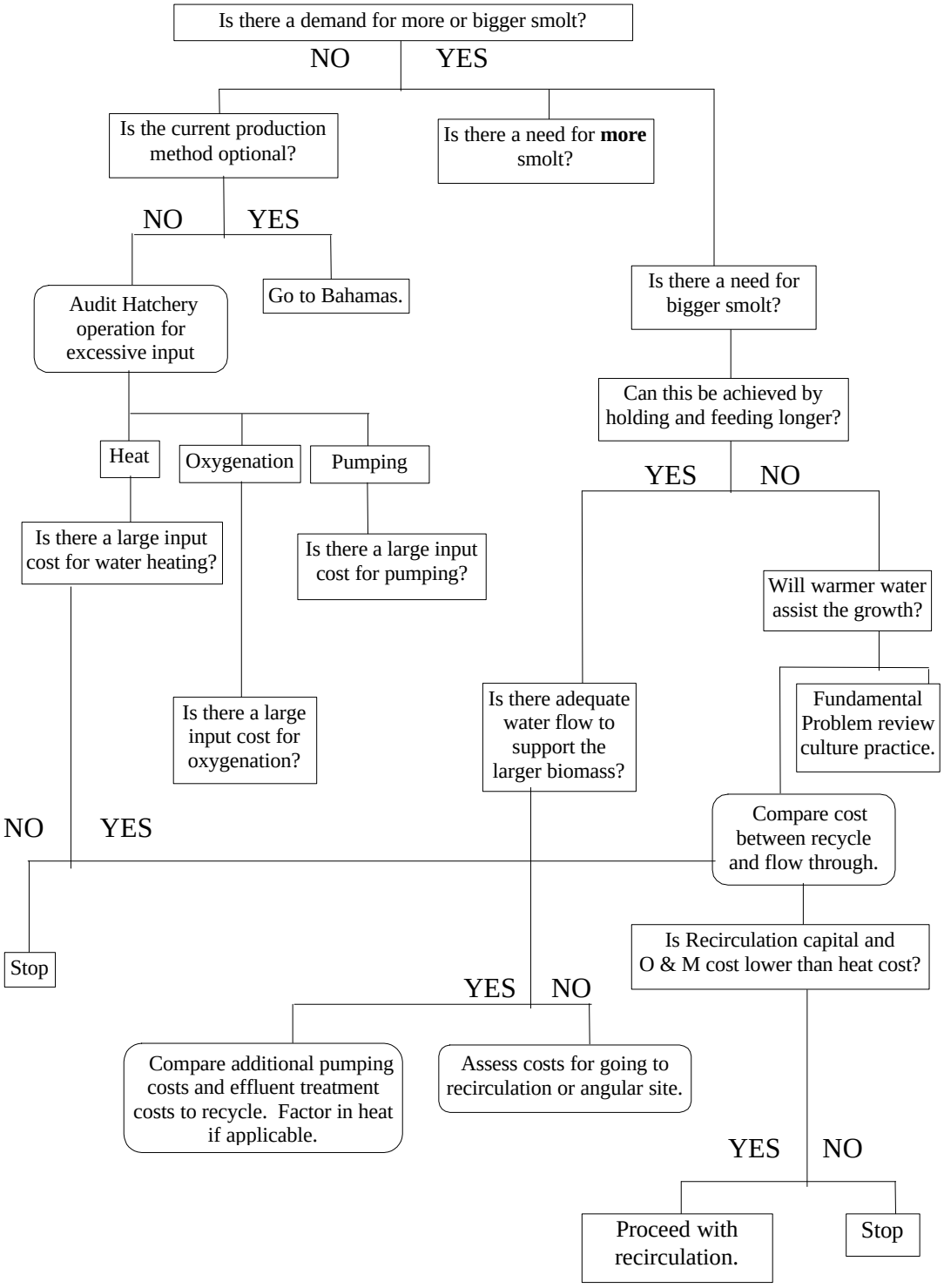

Figure 1: Hatchery Decision Tree for Intensification through Recirculation.
Note: Decision tree has been simplified by excluding feed conversion, diet, genetics and management practices from considered factors.

budget for the aquaculture program. Faced with this dilemma, the choice to proceed with conversion to recirculation was clear. The conversion of the existing facility is now complete and the staff is planning to expand into another greenhouse to work with warm water species. The capital costs of the conversion were minimized by using as much college labor, donated material and grant assisted research projects on equipment as possible. An analysis of the capital cost of this conversion is not particularly useful for designers or consultants planning green field projects or large scale conversions of existing facilities. It is however probably quite relevant to the methods and materials that might be used by an actual small scale farmer in an initial effort with recirculation. The cost of operating the system is actually quite low. In this example, the primary mechanical cost is pumping the water. They were able to use a fairly low head loss design in this facility with a total recirculation pumping head of about 12 feet. At 200 gpm and 7cents/kwhr, this cost is really very minimized at $36.00/month. This is an extreme case as the densities are very low allowing solids removal by swirl separator and setting tubes and aeration primarily by fall through packing media. Obviously the costs of operating such a simple system pale in comparison to a $3.35/1000 gal municipal water charge. To put this in perspective at 200 gpm that is a $28,944.00/month water bill Luckily, it is in Canadian dollars. Better still they don't have to face it any more.

Water Availability

In some cases, cost is not as much an issue as is water availability. When one company wanted to diversify their hatchery from Coho production to a combination of Coho and Atlantics, they were faced with the problem that their new production strategy would require operation at higher capacity during the summer. In normal operation the hatchery is fed by a blend of creek and ground water. Unfortunately, during the summer their water license limits them to groundwater alone. The ground water capacity is only barely sufficient to cover current needs. In order for the expansion to proceed recirculation would have to be utilized. Offsetting the cost of the recirculation treatment cell was the fact that going to recirculation allowed for the reduction in size of the boiler that was going to be purchased for the new area. This was a cost savings of approximately $30,000.00. The greatest savings of course is more difficult to quantify. The true benefit of this conversion is the full utilization of the site allowing for overhead costs to be spread over a larger number of smolt. There is also the business advantage of the added production and diversification that would not have otherwise been possible.

Pumping Cost

At another facility, it was thought that pumping costs were relatively high with 45 psi or 104 feet of groundwater pumping losses. With a typical recirculating system operating between 15 and 25 total feet of head loss it seemed reasonable that there could be a case made for converting one large water use area in the hatchery. This area had a drum filter already in place and a sump that would be suitable for locating the recirculation pumps. Even assuming a recirculation pumping requirement of 25 feet, there was still the opportunity to reduce pumping losses by 80 feet of head.

At $.07/Kwh, 70% pump efficiency and 90 % motor efficiency, the following calculation was done to find the monthly cost savings in eliminating this head loss differential.

$$\$/\text{month} = \frac{1000 \text{ gpm} \times 80 \text{ ft.} \times .746 \times .07 \times 30 \times 24}{3960 \times .7 \times .9}$$
$$= 1205.66 \ \$/\text{month}$$

This is a substantial savings for a facility of this scale but it is not adequate to justify proceeding with a conversion when taken alone.

Heat

At the facility there were additional cost factors which would lead to a more justifiable conversion argument. An energy audit was conducted and it was found that an annual heating cost difference of $86,853.75 existed between the recycle system and the flow through version.

Work on the conversion of this hatchery is waiting to proceed pending the results of similar conversions being undertaken elsewhere by this company.

Summary

In the Pacific Northwest, several factors, operating separately and in combination are impelling the aquaculture industry to seriously consider recirculation technologies. Although political and environmental forces are tightening the parameters of water use and limiting the geographical areas in which to operate, it is the cost of production, the proverbial bottom line that is the engine driving the industry towards a more cost effective use of its primary resource, water.

Definitions

In order to clarify some of aspects of the paper, I have included a brief list of definitions for words or phrases that I was concerned might have multiple interpretations.

Pacific Northwest- There are certainly several different definitions of this region, ranging from Washington and Oregon only to a much broader climatic region. I have chosen to define the region as including the states of Washington, Oregon, Idaho and Alaska. I have also included the Canadian provinces of Alberta and British Columbia.

Recirculation System- I have defined this as any system which utilizes water treatment technology to treat and continually reuse water for the culture or holding of aquatic animals.

Serial Reuse- I have not considered serial reuse systems as recirculating systems although some of the practices and research in this area could be usefully transferred to more closed systems. These systems take advantage of large volumes of flowing water to

culture fish in a series of culture areas, usually raceways or ponds, and usually with the only treatment being the addition of oxygen.

Intensification- I have loosely defined this as any process by which greater aquaculture production can be achieved utilizing the same water resource.

Recirculation Rate- I have used the European convention of referring to the recirculation rate based on a percentage of flow as opposed to percentage of water volume changes per day. This allows for easier comparisons of heating and pumping costs between flow through and recirculation systems.

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The European Experience with Production Intensification

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Introduction

Aquaculture in Europe is an active and diverse industry. It operates in a wide range of environments and production systems, producing a number of species targeted towards expanding domestic and export markets. With the exception of the more remote inland and coastal regions, the land mass is highly developed and intensively populated, with high concentrations of manufacturing, service and recreational functions, and increasing value being placed on natural resource protection. An educated and relatively sophisticated populace demands environmental awareness in both policy and consumer choice.

In this context, a resource-intensive sector such as aquaculture faces particular challenges requiring a range of technical, managerial, and strategic responses. In both inland and coastal areas, aquaculture has come under increasing scrutiny, with greater constraints on water supply and discharges, land or water column occupancy, and the efficiency of use of various inputs. At the same time, competitive pressures and the potential for economies of scale have increased the commercial imperatives for expanding production within individual enterprises and at specific sites. A consequence of these pressures has been a drive towards intensifying production, and doing so in a manner that enhances production efficiency and reduces external impact. While artesian or traditional forms of aquaculture are likely to remain in Europe, and will be valued for their "natural" attributes, mainstream commercial production may be expected to become increasingly intensive.

This paper describes some of the trends in intensification in European aquaculture, using specific examples of the coastal cage culture sector, involving Atlantic salmon and Mediterranean seabream; pond or tank culture, involving turbot, rainbow trout and channel catfish; and recycle systems, involving European eel and African (*clarias*) catfish. Key trends are described, and the technical and management issues involved in developing competitive production capable of meeting regulatory and consumer criteria are considered. Finally, the potential directions for intensive aquaculture in Europe are discussed, together with the relevant issues of technology development, market and regulatory response and strategic competitiveness.

Background

Within Europe, the aquaculture sector is an active and diverse industry, operating in a wide range of environments and production systems, from traditional extensive operations to highly intensive, technologically-sophisticated units. It produces a range of species – though as in North America these are still grouped around a small number of core subsections – targeted toward developing expanded domestic and export markets, with increasing consciousness of product uniformity, quality control, and productive efficiency (Ruckes, 1994; Young and Muir, 1997). With the exception of the more remote inland and coastal regions, the land mass is highly developed and intensively populated, with high concentrations of manufacturing, service and recreational functions, and increasing value being placed on natural resource protection and enhancement. An educated and relatively sophisticated populace demands environmental awareness in both policy and consumer choice.

Table 1 provides an outline of current European finfish production in Norway, demonstrating the relative importance of species such as Atlantic salmon (55.2%) and rainbow trout (28%) in total production, though shellfish – oysters, mussels and clams – represent greater quantities in volume terms. Table 2 provides a more detailed breakdown of the major subsectors of the complete aquaculture industry, including shellfish (STAQ, 1996). The production focus on traditional salmonids is based primarily on the remarkable record of production in Norway and Scotland. Confining production to EU countries alone, excluding Norway's estimated 20,000t of salmon production in 1997**,** reduces the region's output to around 485,000 and the contribution of salmon to some 25%. Though the salmonid sectors are intensive, they are primarily based on cage culture in open coastal waters. Although the technology is increasingly sophisticated, intensification *per se* has involved very little modification of the basic holding systems, and is primarily related to the more intensive utilisation of specific site areas, the expansion of the production scale, and the derivation of scale and management-related production efficiency (Torrissen, 1996). Within the rainbow trout sector, the traditional pond-based portion-sized trout sector in the UK and mainland Europe has grown only gradually, and has more recently been supplemented – particularly in France, Norway, Finland, Sweden, Denmark and Germany – by the production of larger (>1kg) trout grown in cages in fresh and brackish waters (FEAP, 1998). The other substantial species group, apart from the traditional central European subsector of pond carp production (typically semi-intensive, using 2-3 year production cycles) is the cage culture of seabass and sea bream, using techniques similar to those of cage salmonid production in the Mediterranean region. Fuelled by good market prices and increasingly available hatchery production, the sector has grown particularly rapidly, though it is now increasingly constrained by declining market prices. In the shellfish production sector, raft and longline production of mussels (*Mytilus edulis* and *M.galloprovincialis*) has also grown notably, but has suffered recent declines in some areas due to algal blooms and increasing market saturation (Tacon, 1998).

Table 1. Overview of European aquaculture 1993-1997

Species	1993	1997	% yr	Key features
Rainbow trout	190522	227510	4.5	portion sized and larger, widely produced
Eels	5386	7675	9.3	specialised: Italy, Netherlands, Denmark
Carp	53611	57008	1.5	mainly common carp, E. Europe and Germany
Clarias catfish	900	1150	6.3	specialised: Netherlands, Belgium
Channel catfish	1750	500	-26.9	mainly Italy
Arctic char	714	1160	12.9	Sweden, Norway, Iceland, France
Sturgeon	451	652	9.7	mainly Italy, France
Atlantic salmon	252999	445612	15.2	Norway, Scotland, Ireland, Faroes, Iceland
Sea bream	12027	35326	30.9	Greece, Turkey, Italy, Spain, Malta
Sea bass	10382	24900	24.4	Greece, Italy, Turkey, France, Malta
Turbot	1424	3250	22.9	Spain, France, intensive systems
Halibut*	70	138	25.4	Norway, experimental in Scotland, Iceland
Grey mullet**	2060	2200	3.3	Italy, Spain – lagoon systems
Other mullet**	250	343	17.1	France, Greece – lagoon systems
Senola**	30	30	0	Majorca, mainly experimental
Bluefin tuna**	20	20	0	Spain, experimental
Total	**532596**	**807474**	**11**	

Source: FEAP, 1998; FAO, 1997

Table 2. Major aquaculture production systems in Europe (Source: STAQ, 1996)

System	Species (estimated production '000t)	Significant locations	Notes
Terrestrial			
Lagoons, parcs / salinas	Seabass, seabream, other breams, mullet (5)	W and S coast Portugal, Mediterranean coast of Spain, France, Italy, Greece, Algarve / SW	Traditional coastal areas, collective / artesian practices
	Oysters, clams (20)	Spain, W coast France	
Ponds	Common carp, other cyprinids (15)	Inland France, Belgium, Germany, Austria, some UK	Traditional inland areas, increasing sport fish / restocking
	Rainbow trout (120)	France, Denmark, N and W Spain, N Portugal, UK, Ireland, Germany, N Italy, N Greece	Rowing water culture in earth ponds
	Eels, catfish, sturgeon (2)	N/Central Italy, France, Spain,	
	Crayfish (1)	Sweden, France, UK	Eels more traditional. Also in open water bodies
	Atlantic salmon (0.5)		
	Seabass / Sea bream (0.1)	UK (Scotland)	Now less significant
	Turbot/halibut/sole/ other flat fish (3)	Spain (Canarias), N W Spain, Central Portugal, France, Sweden, UK	Limited development

System	Species (estimated production '000t)	Significant locations	Notes
Tanks / Raceways	Eels, catfish, sturgeon (2)	Netherlands, Belgium, N Germany, France, UK (Scotland)	Mainly turbot, sometimes in heated effluents
	Tilapia (0.5)	Belgium, UK	Usually in recycle systems
	Arctic charr (neg)	UK (Scotland), Finland	Heated effluents or recycle systems
			Experimental – recycle systems
Immersed Cages	Atlantic salmon (80)	UK (Scotland), Ireland, Sweden, Denmark	Major production sector
	Rainbow trout (10)	France, UK (Scotland), Ireland, Finland	increasingly produced in coastal waters, also lakes
		Finland, Sweden, France	France has produced coho (Pacific) salmon and sea trout
	Arctic charr / other salmonids (2)	Greece, Italy, Spain, France	Major production
	Sea bass/bream (25)	Spain (Majorca)	sector Experimental/ pilot scale
	Amberjack (0.1)		Experimental only
	Halibut (neg)	UK (Scotland)	
Enclosures	Sea bass/bream (0.5)	Italy, Greece	Small scale only
Raft / longline (suspended culture)	Mussels (150)	NW Spain, N Italy, Greece, Ireland, UK	Major production sect
	Oysters (1)	Ireland, UK	
	Scallops (1)	Ireland, UK	
Pole/bed (bottom culture)	Mussels (150)	Netherlands, UK, Ireland	Relaying and dredging
	Oysters (150)	Ireland, N & W France, S UK, Spain, Portugal, Italy	Major production sector in traditional areas
	Scallops (5)	W France, Spain, Portugal, UK	Major production sector
	Clams (50)	France, Spain, Portugal, Itlay, Greece	Experimental only
	Abalone (neg)	Ireland, France, Spain, Portugal	

By contrasting these significant and active sectors with well-established technologies and markets, three other broad categories of production can be identified (see Table 2): traditional forms of aquaculture, typically extensive and semi-intensive, e.g., involving bed and bouchot shellfish culture; lagoon-based production of mullets and other breams (F-C, 1995); new species development, some of which (e.g. turbot, sole) have been in place for some time (Jones, 1994; Stephanis and Divanach, 1994; Kestemont and Billard, 1993), many of which (e.g., *Seriola* - amberjack) have changed little since original trials. Others, such as halibut and the Siberian sturgeon *(Acipenser baeri)* appear to be poised for a certain level of growth. These are primarily based on existing forms of production, commonly culture, but might also use intensive onshore production. Specialised intensive production – based primarily on eels, African *(Clarias)* catfish (Bovendeur, et al. 1987; Karnstra, 1992; Dijkma, 1992) and tilapia – using waste heat and intensive recycle systems, rely on environmental tolerance of the species chosen and their potentially high

market value to provide viability for the relatively expensive production systems (Dickson, et al. 1993).

In addition to these ongrowing categories, an increasingly sophisticated hatchery sector can be identified, gradually using more intensive approaches to provide the requisite level of control over reproduction timing, seed quality and market opportunity (STAQ 1996). Though insignificant in biomass terms, this sector continues to hold a disproportionate share of value, and represents a far higher concentration of technology investment.

As in North America, the European aquaculture sector has had an active engagement in technology development. In many respects, European aquaculture has undergone similar processes and cycles of technology expectation, production cost, and performance limitation, misplaced (or premature) technology investment, and a gradually maturing recognition of the potentials and certain technology approaches (Muir et al, 1996). The changes in technology that occurred during the last two decades have been incremental rather than in a breakthrough pattern. Improvements have occurred in fundamentals, such as genetic base, health management and feeding efficiency, and the particular benefits of well targeted sources and applications of technology.

Current issues and constraints

With the exception of its more remote inland and coastal regions, in which some of the aquaculture sector is located, the European land mass is highly developed and intensively populated. With the correspondingly high concentrations of manufacturing, service and recreational functions, and relatively high per capita incomes, opportunities exist for expanding markets for quality products. Increasing value is placed on natural resources and the maintenance of their quality (EC, 1995). Issues such as biodiversity (Beveridge et al, 1994) are increasingly important. As a result, an educated and relatively sophisticated populace demands environmental awareness in both policy and consumer choice. This dynamic is compounded by increasing buyer concentration; though differentials exist between European countries, supermarkets increasingly dominate retail sales of fish products. Given their concerns for image and reputation, fish products will be subject to criteria similar to those applied to other food sales, and may well represent higher-profile targets for raising the “green” credentials of competing chains (Young and Muir, 1997).

In this context, a resource-intensive sector such as aquaculture faces particular challenges, which have required from the industry a range of technical, management and strategic responses. In both inland and coastal areas, aquaculture activities have come under increasing scrutiny. Greater constraints have been applied to aquaculture water supplies and discharges, land or water column occupancy, and on the efficiency of use of the various inputs to production (EC, 1995; Muir and Beveridge, 1994). At the same time, competitive pressures in expanding sectors and the potential for economies of scale in many operations have increased the commercial imperatives for expanding production within individual enterprises and at specific sites (Muir and Young, 1997). A natural consequence of these pressures has been a corresponding drive towards intensifying

production, but, as far as is possible, doing so in a manner which both enhances productive efficiency and reduces external impact. Artesian or traditional forms of aquaculture are likely to remain in Europe, and will be particularly valued for their "natural" attributes. However, mainstream commercial production, by far the most significant component of the industry, may be expected to become increasingly intensive. While more challenging technical approaches, such as offshore aquaculture and onshore recycle systems are under consideration, the most common circumstance is that of intensifying existing sites and systems (Prickett and Iakovopoulous, 1994).

A notable accompaniment of expanded production has been the fall in market price and the drive to reduce production costs. Improvements in growth rate, food conversion, maturation management, and disease control can all contribute, and, as in the case of the pioneering Atlantic salmon sector, costs for more efficient operators have dropped from approximately US$5.00 kg^{-1} in the late 1980s to current levels of US$2.00 kg^{-1}. In the Mediterranean, seabream production costs have dropped from around US$9.00 kg^{-1} to US$6.00 kg^{-1} over the same time (Muir & Young, 1997). These compare with even lower production costs internationally; in the US, average 1996 farmgate price of channel catfish was US$1.70 kg^{-1} (*Fish Farmer*, 1997), with tilapia production costs as low as US$1.00 kg^{-1} quoted for new large-scale tropical projects (Little, 1997; *pers. comm.).*

The emergence of the European Union as a more coherent regional political and economic group has also brought its own consequences. At a strategic level, a range of policies have been adopted in an attempt to stimulate domestic food (and fish) production, to promote economic growth in disadvantaged regions, to create a free market within member states, to open trade to poor countries, and to standardise legislative environments (STAQ, 1996). The impact of these policies may be confusing and contradictory at best, but may bring both positive and negative impact to bear. With respect to aquaculture and its intensification, current issues include the relative availability of investment support for quality upgrading, the unification of environmental management philosophies, funding policy for industry-linked research, and the relatively open competition from non-EU suppliers.

The role of technology

From the foregoing, it can be seen that the technology of intensification has a significant but variable role in the European aquaculture sector, and careful application of selective technologies is a matter of increasing importance in more strongly competitive environments. The increasing scale of many aquaculture operations also leads to a more widespread use of bulk handling technology, larger scale monitoring and control systems, and automation. As elsewhere, a mix of technologies can be identified. These technologies have evolved around specific systems, and a range of relatively standardised elements, such as aerators, fish pumps, cage modules, tank units, and feeder systems.

The origin of aquaculture technologies within Europe has patterned those found in other sectors. Technologies have been borrowed from marine engineering, oil industry

technology, the water treatment industry, materials sciences, and the agricultural, chemical and food processing sectors. A small but increasing degree of intra-sector research and development has occurred as the industry grows, with more Europe-wide sales prospects, justifying specialist attention. Systems such as the UK "Technology Foresight," ROPA ("Realising our Potential" Award) and "Teaching Company" programme, and the EU "CRAFT" also offer routes for combining academic research with commercial enterprise, particularly in the small and medium enterprise sector. These research and product development systems have been available to aquaculture, though the bulk of such work has to-date been concerned with biological science in fields such as reproduction, genetics, and health management.

Developments are commonly carried out on an *ad hoc* basis within production, supply, and service companies. Because product development and trial periods vary, producers accept a certain degree of risk when accepting relatively untried technology, particularly, though not exclusively, in the recycle system and offshore cage sector (STAQ, 1996). The response to demands of existing sectors has not been revolutionary; instead systems developers have introduced gradual improvements. In this respect, changes towards intensification are often brought about through a process of dialogue between developers and producers, with external pressures an ultimate element in commercial decisionmaking. Thus, while there may be incentives for change, the decision of how or how much to modify an existing production system (e.g., should some supplementary aeration or oxygenation be added, or a pond layout modified, or should the production system be modified radically) will still depend on the technical confidence and the commercial judgements of the producer (Muir, 1993). As elsewhere, a certain collective mentality may also apply, at least at a national level with industry leaders influencing others. To this might also be added the potential role of the multinational aquaculture company, and the related tendencies to apply similar technologies, using standard suppliers, at all production sites. However, this has not been a significant phenomenon to-date, partially due to historical circumstances, as with the takeover of established and equipped national enterprises with local supply and service contracts.

Current approaches

The key problems concerning the mainstream aquaculture sector in Europe have been noted, and the response of intensification identified. Clearly, intensification alone is not the typical development response, and it has to be carried out within a defined context. The most critical of these is not surprisingly the "cost envelope," i.e., the available range within which any production system might be viable, modified as appropriate by the perceptions of technical or commercial risk (Stephanis, 1995; 1996). As elsewhere, declining margins and a higher degree of competition have limited the range of options, and have also tended to favour incremental rather than radical investment. Unlike much of North America and many other parts of the world, energy costs have traditionally been high in Europe. Although market deregulation and tariff reductions for certain user categories have reduced actual prices for many aquaculture producers, prices remain significantly higher (typically \$0.1 - 0.15 kWh^{-1}) in most of Europe. A possible exception

to the incremental approach is the occasional "new venture aquaculture" development, increasingly rare as the pioneering phase of aquaculture production has passed, and more common in terms of export promotion, particularly for package recycle systems and offshore aquaculture.

Another increasingly critical factor is that of quality management, i.e., the need to plan and control production flows and to record the production circumstances of all stocks through the system (Muir and Bostock, 1994). This tends to favour more precisely managed systems, in terms of water and waste management, feed systems, inventory and monitoring processes. Therefore, intensive production systems tend to be favoured where investment is applied. The importance of feeding efficiency itself tends to drive management towards more closely graded operations, hence, a higher degree of stock control, grading, and "fine-tuning" to meet the needs of specific stock batches. In addition, the gradually increasing pressure for so-called "green" products has lead to greater attention being devoted to rearing conditions and handling procedures.

There is also a growing, if not completely enthusiastic awareness of sustainability issues, particularly at inland and nearshore coastal sites (Folke and Kautsky, 1992; Stewart, 1995), though to-date this has not proceeded much beyond the intention to reduce physical disruptors, demonstrate some degree of harmony with surrounding ecosystems, and if not to support, at least to avoid diminishing biodiversity and cultural diversity. Though the wider principles of ecosystem engineering are yet to become established, physical features, layouts, use of restorative space, and control of external interactions are becoming slightly more common. Though unjustifiable in broader sustainability terms, the concept of a self-enclosed production system, possibly supporting some local conservation objectives, is appealing.

At the technical level, therefore, producers and system developers have taken up a number of changes (STAQ, 1996) including:

1. More closely managed stock control, with simplified systems of stock pumping and transfer, as well as improved monitoring, better precision in feed input (Bjordal and Juell, 1993; Blyth et al, 1993), and inventory programming.

2. Move from simple settlement devices to more closely engineered swirl concentrator or screen filter designs. Self-backwashing rotating disc and drum screen filters targeting known particle sizes and using water or air washes are increasingly common, and recent developments have included conveyor belt filters which can more readily remove finer particles.

3. Closer attention devoted to tank or raceway hydraulics, and to inlet and outlet designs, oxygen and metabolise profiles, and feed and stock distribution; dual outlets are increasingly being considered, separating solids into two streams, though it is still sometimes problematic to adapt inlets and outlets to meet a range of stock sizes.

4. Closer assessment and design of heat budgets, particularly in association with recycle systems and the potential effects of system heating through pumps, aerators and biomass.

5. Greater use of oxygenation, in association with more closely controlled temperature, feeding regimes, and activity levels, and with feedback sensors to reduce wastage. However, aerators are still widely used, but as in North America, are more carefully selected and designed to meet specific operating requirements.

6. Gradually increased use of ozone and foam fractionation devices to improve water quality and clarity, and use of ozone itself for sterilisation; flooded or trickling biological filters still represent a mainstay of production; denitrification is not commonly used, though may be partially supported in anoxic subsystems. However, current interest in higher recycle rates is increasing the case for specific incorporation of these stages.

7. Improved control and management information systems linking temperatures, stock, system and treatment process conditions, feeding systems, stock behaviour, etc.

Based on these trends and developments in intensification, a number of subsectoral changes can be observed (STAQ, 1996; Muir *et al,* 1996; STAQ 1998).

Apart from the traditional forms of eel culture in Italy, eel and catfish production has primarily built up around the basis of package recycle systems, usually based on simple solids removal, trickling biofilters and partial ozonation. This had developed particularly in Northern Europe, where in the Netherlands the sales of "fish barns" proved to be attractive for a number of agricultural farmers wishing to diversify. The technical objective was to create "plug and play" systems, though this had never been achieved in practice, and most systems required more detailed management than anticipated. A necessary element had been the environmental tolerance of the species and the potential for high biomass output related to high growth rate and stocking densities, and the implications of marketing the product had been less carefully considered. In practice, a number of technical constraints, combined with reducing market prices and increasing energy costs, has reduced the output of this sector and led to the closure of smaller units. The recent increase of eel export from China, and the potential supply of *Clarias* from other sources, such as Thailand, Philippines and Bangladesh, has further discouraged new entrants. By contrast, primarily in Italy, eel and channel catfish production has been carried out in earth ponds, traditionally fed with gravity water supplies, or more commonly supplemented by pumping. The channel catfish sector uses semi-intensive techniques with a single-year production cycle. The European industry lacks the major research and development resource which has made American catfish production so efficient. However, intensification has proceeded along the lines of that pursued in North America, with the gradual introduction of aerators and supplemental oxygenation, though future directions might be constrained by competition from imported North American producers (Neubacher, 1995). Siberian sturgeon *(Acipemer baeri)* are also being grown in ponds

and tanks, mainly in France and Italy. Though still in their early stages, techniques are being developed, and more intensive systems may be feasible.

As in North America, the potential for intensive production of tilapia and carp had been considered since the 1970s. Trials in intensive and recycle carp culture, particularly in Germany, have dated from that era and had contributed significantly to the wider understanding of intensive water management and recycle system performance (Meske, 1976; Otte and Rosenthal, 1979). However, this development, though technically interesting had never proceeded due primarily to the lack of market demand for carp, particularly in the post-Perestroika period. By contrast, intensive tilapia production has been established, if at a minority level, with initial interest surrounding the use of waste heat from power stations or industrial processes. The most common are the *Oreohcromis niloticus* and *O. aureus*, or for saline waters, *O. mossambicus* or *O. spilurus*, grown at densities of up to 50 – 60 kg m^{-3} at optimal temperatures of around 24 - 30°C, taking 5 – 8 months to reach 200 – 400g. To date, the most notable and longest lasting such project has been the joint-venture operation at the Tihange nuclear power station in Belgium, producing tilapia intensively on a year-round basis, using elliptical GRC tanks and warmed intake water. A recent venture in the UK, using textile mill wastewater has just closed; though contractual problems were cited, concerns about potential profitability had also been noted. The most significant moves in intensive production of tilapia have taken place in Israel, where a range of semi-closed and complete recycle systems is currently under development and in commercial production (Simon and Kinsbursky, 1997). Two general approaches can be described:

1. A modified traditional system using Taiwanese rounded square ponds with water circulated by paddle-wheel aerators at each corner, and a central sump for waste collection and solids removal (Mires and Amit, 1992), and;

2. More complete reuse systems involving ponds or tanks, together with nitrifying and denitrifying biological filtration, with the objective of maximal water conservation (Arviv and van Rijn, 1994).

Though neither of these systems has supplanted the core sector of pond production of tilapia and carp, they are under active development and may be expected to gain interest as water management and its cost becomes a more pressing issue in the region.

The production of rainbow trout *(0. gairdnerii)* in simple earth ponds has been one of the mainstays of European aquaculture. This subsector remains a distinctive contributor to rainbow trout production along with lake- or coastal-based cage culture, and occasionally intensive tank and raceway culture. A range of intensification can be observed, including use of aeration and oxygenation of conventional trout ponds or earth raceways, redesign of earth ponds to improve hydraulics and waste removal, and conversion of earth ponds to spiral flow concrete tanks with supplementary oxygen control. The use of simple back channels (waste collection ponds) is increasingly common even in relatively simple systems, and these are not infrequently used as

sumps from which water can be recycled during low water flow periods. A small subsector in rainbow trout production uses intensive tanks and raceways in highly intensive oxygen-based systems. However, since Forster *et al*, 1977 illustrated the difficulties of operating these intensive tank-based systems profitably, they have not developed strongly. Large raceway-based systems (typically 200 to l000t or more per units), using pumped or spring water are being operated successfully in Italy Spain, Portugal, and France, usually with supplementary oxygenation, though some have closed due to production inefficiency.

The onshore production of Atlantic salmon has been one of the main areas of technical development in intensive systems in Europe, stimulated in the mid-late 1980s by expectations of continued market margins and the theoretical benefits of managed onshore environments. Considerable investment had been committed, particularly in Scotland, Norway, Iceland and the Faroes, generally based on large circular or elliptical tank systems with supplementary aeration and/or oxygenation and high stocking densities, typically 40kg m^{-3} or more (Blakstad, 1993). In Portugal, a similar development made use of saline groundwater at optimal temperatures, with controlled oxygenation, photoperiod controlled smolt supply and high density tank rearing. In almost all cases, except where artificially subsidised, these systems did not prove to be competitive, and have been converted to other uses, such as marine flatfish or salmon broodstock production. Some production continues in Iceland, where energy costs are still marginally favourable, but performance will be highly dependent on the effectiveness of oxygenation and mixing regimes currently being developed.

Marine flatfish; turbot, and halibut, and also Dover, Japanese and Senegal sole have been produced in intensive systems, primarily tanks or raceways fed with saline groundwater, heated industrial or power station effluents, or directly pumped seawater. The most significant sector in terms of production is that of turbot, whose production is primarily concentrated around Northern Spain, with other producers in France and Portugal. In some cases, systems have been converted from earlier intensive salmonid systems, which had been unprofitable to turbot systems, where the higher market price of turbot was expected to help support the higher capital and operating costs. These systems have remained in operation but are increasingly concerned by pressures on market prices, and henc production margins. Intensive onshore halibut systems are also being promoted as one of the possible routes for its production, and though these are largely untested, the species appear to tolerate relatively high stocking densities. Intensive systems for halibut species are relatively simple, usually involving concrete or frame and liner raceways, in some cases organized to provide internal layers to allow the fish to “stack” more effectively. Oxygenation systems are increasingly common in reducing the costs of water exchange and maintaining optimal environments.

Seabass and seabream production; based on the traditional lagoon culture systems in the Mediterranean coastal region, a number producers have developed more intensive ponds or earth raceways for these and associated marine species. The cost of production has been kept within acceptable boundaries using relatively simple pumping and aeration systems, typically based on developing slowly circulating pond

environments. Wastes are usually discharged directly, often into the main lagoon areas, where they serve to enrich productivity. Several intensive onshore systems had also developed for these highly demanded warm-water marine species, particularly in Cyprus, Italy, Spain (Canary Islands) and Portugal. The intensive onshore systems are often based on concrete raceways with directly pumped seawater and supplementary oxygenation. The cost of production has been high compared with most cage units (STAQ 1991; Blakstad, et al, 1994), producers have found it difficult to remain competitive. Key systems have been subjected to redesign to improve hydraulics, gas management and waste management.

Other species; Arctic charr have recently attracted attention, particularly because of their surprisingly high stocking dersity tolerance (active growth at up to 80 kg m^{-3}) and their potentially interesting marketability; to date, systems have been similar to those of present generation intensive trout and salmon production, i.e., tanks or raceways, aeration, solids removal, and biological filtration. The wolf-fish or sea catfish *(Anarichas lupus)* has also been examined experimentally, having similar potential for high stocking density, together with rapid growth rate. However, its marketability is uncertain, as there are still substantial wild fish landings at prices which are currently well below the potential cost of production in intensive systems. In fresh water, there is also a small amount of intensive production of sport fish – primarily fry and fingerlings, for restocking into open waters or into the increasingly common commercial put and take fisheries.

Other package systems have been developed for a range of species and are typically marketed to non-specialist investors on the basis of their complete independence from external environments, their high degree of control, their priority, and their ability to supply markets optimally. These systems are commonly based on water recycle units, usually with conventional biofilters, solids removal, oxygenation, and ozone or UV sterilisation units. In some cases filter configurations such as rotating 'Biodrums' may be used, but as these generally require more energy, they tend to be superseded by static filters. Simpler systems have standard tank or raceway configurations and sequential common flow paths, which may be split up into sub-modules. More advanced designs may have closer detail in tank hydraulics and waste flows, and will tend to use "sidestreams," i.e., partial flows being directed to specific treatment units. In some cases, additional heating and/or cooling circuits may be used (Bawden, *pers comm,* 1998). Generally, these package systems have had a variable record, and have proved most effective (in production terms) for robust species such as carp, tilapia and African catfish.

Hatcheries, for various species, but particularly for the major groups of salmonids, seabass and seabream, have shown perhaps the strongest trends towards intensification in recent years. Intensification of hatcheries has been particularly stimulated by the increasing demand for year-round production, and by increasingly competitive environment demanding higher productivity from available facilities and management inputs. Within the salmonid sector, much of the change has concerned the establishment of temperature controlled operations for year-round production, either using heat exchangers, or increasingly, using partial or complete recycle systems. In

other cases (e.g., the Shetland Islands), water recycle systems were established at the outset to overcome water supply constraints, and have only subsequently been operated with temperature management as a key objective. Many of these systems are based on proprietary units in which solids removal and ozonation are used as primary treatment stages, and a certain number have been subsequently re-engineered to improve their performance and productivity (Bawden, *pers comm, 1998).* In the case of seabass and bream, intensive recycle systems have been developed in a number of locations, to compensate for inadequate or poor quality water supplies, to reduce heating costs, and/or to maintain water quality within the system. Many such systems have been developed using quite complex layouts and components, with a range of automated features, biofilter units employing specialised granular media, foam fractionaters, ozone units, and high-specification heat exchangers. However, a number of hatcheries have also developed their systems subsequently to initial installation, some of which may be more simply designed.

Future developments

Though its potential significance might still be questionable, at least in the medium term, it would appear that the more intensive, primarily land-based aquaculture sector will continue to occupy a useful role in overall production in Europe. Based on current activities and recent trends, and subject to the factors discussed earlier, a number of technological trends and developments can also be identified for the European intensive aquaculture sector, though their timing and impact will be subject to a range of other influences. These include:

- the existence of commercial and/or legislative incentives to control wastes and improve the environmental credentials of aquaculture production; though more intensive systems are rarely more sustainable in the broader context, public perceptions of the importance of controlled waste discharge and good animal husbandry conditions may well outweigh concerns for additional capitalisation or energy costs.

- the development of more comprehensive evaluation/management packages for intensive production. A range of assessment tools need to be developed to improve the ability to assess the potential for developing or re-engineering intensive systems, linking technology specification with performance and production cost criteria. This would be justified by the use of more closely targeted objectives by major producer groups, plus the need to identify clear development and operational criteria for technology packages.

- the adoption of more closed production units in open waters, involving either closed bag systems, partially enclosed systems, and/or time-linked devices for waste removal and recycling. Interest is already developing in the USA, Norway and Scotland (Institute of Aquaculture, 1998), and a number of potential systems are in the course of evaluation and pre-commercial testing. Suitably viable

approaches might involve a production cost envelope of no more than 10% above current operating costs and would involve important improvements in the capture of unused or metabolised therapeutic compounds and of unused feeds.

- a move from partial to complete recycle systems. Where companies have started to invest in water treatment equipment and face continuing or increasing pressures of water supplies and/or waste management, the logic of improving water management through better control of water use and quality, and reusing treated water, starts to become more compelling (STAQ, 1998). At this stage, the advantages of more complete water quality and temperature control can be incorporated, delivering particular benefits in situations where production planning becomes more critical. Though in practice, farm managers may need to be convinced of the practicality of controlling management risks. A gradually increasing record of use and effectiveness would provide a more positive basis for change.

- the use of more intensive systems for specialised production sectors particularly the higher value new species, for organic production (Debio, 1996) and for specialised hatchery sectors. A mix of factors including the need to isolate non-indigenous species, the need to create optimised conditions for demanding efficiency targets and the need to control production for specific temporal and quality factors, will tend to justify the higher capital and operating costs entailed. In some cases, existing intensive installations may be adapted for new species; in others systems may be intensified, and in a small number of cases, new projects may be developed.

  a move towards better and more integrated control packages – increasingly necessary to manage more sophisticated systems, and to deliver optimised performance in changing environments according to production targets; considerable development has already taken place, but the use of PC-based decision-support systems is likely to be increasingly common (Muir and Bostock, 1994).

Conclusions

The intensive aquaculture sector occupies a distinct position in the European aquaculture industry, but more highly intensive tank, raceway and recycle systems are relatively insignificant in overall terms, and are subject to significant cost pressures. However, the same cost pressures, together with an increasing concern for environmental management, are increasing the intensification of some of the more traditional pond and tank sectors, requiring an increased use of similar technologies, particularly for water management, feed control and waste treatment. In addition, the coastal aquaculture sector, which has contributed much of the recent growth in production, is likely to have to adapt practices and systems, to move more decisively offshore, or demonstrate improved environmental containment.

The future for the more intensive sectors will depend on a number of inter-related factors, including:

- structural changes within the industry and the strategic decisions concerning production sites, scene of operation and product image, together with strategic decisions by major retail groups.

- trade potential and access to imported products based on less complex or expensive production approaches; key areas include channel catfish, tilapia and tropical shrimp.

- the practical enforcement of environmental regulation and the acceptance by consumers of the necessary price changes.

- the extent to which technology will be available at acceptable costs, and can be applied without unnecessary risk or interruption to market supply.

- the levels of investment available for commercial and pre-commercial research and development, and the effectiveness of industry associations and technology suppliers in testing, developing and proving newer applications at suitable commercial scales.

In this context, while highly specialised systems are unlikely to occupy a significant share of future production, land-based systems can be expected to continue and possibly even expand, using similar quantities of water at higher productivity levels and returning lower levels of wastes to external environments. New species are likely to use modifications of existing systems, though highest value species may justify some intensification. Loadings in inshore coastal waters are also likely to be further controlled, and intensification and process control will become more common. All of these changes will require further investment in technology, and in the case of existing production, will require better developed skills in upgrading and delivering profitability from technology investment. The research and development sector has been moderately successful to-date, but may require better co-ordination and product targeting to maintain competitiveness in global marketplace.

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The Impact of Fish Handling Equipment

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VI. Summary

Trends in Feed and Feeding Strategies

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Introduction

Feeds and feeding strategies are often over-looked opportunities of a recirculating aquaculture system. Though feed costs represent a lesser portion of total production costs in a recirculating system than in a single pass system, feed characteristics may significantly affect production efficiency, water quality, and both operating and capitol costs of the recirculating system. Feeding strategies should deliver feed at rates which maximize growth, minimize feed waste, and supply the biofilter with a steady supply of metabolites while maintaining a "natural" environment for the fish. Profit optimization, within marketing constraints is the continuing goal of commercial projects.

Feeds

Feeds formulations specifically designed for use in recirculating systems are not commonplace, mainly because the interaction of diet formulation and system function has not been thoroughly studied. However, the waste minimization strategies for trout and salmon production in flow through systems can give insight for improving contemporary diets for recirculating systems. Current feed formulations can be improved by altering their nutritional and physical characteristics.

It has been observed and reported that feed type influences fecal consistencies. In addition, there are also differences among species in fecal consistency, tilapia are noted for a consistent fecal cast, rainbow trout have semi-cast feces, and hybrid striped bass have constant diarrhea. Fecal consistency could possibly be a factor that can be managed through diet formulation.

Dissolved solids from feed inputs have an affect on the color of the culture system water and indirectly affect fish behavior. Dark colored water would allow less light penetration, possibly providing a more suitable environment for some species and also minimize outside disturbances to the fish (i.e. human interactions). Water that is clear has the advantage of allowing easy observation of fish for management purposes. Water color and clarity could be modified to a certain extent by feed ingredients and with color additives to the feed.

Nutritionally, feeds must meet species requirements for optimal growth while preventing nutrient excess at the same time. Feeds formulated with protein content in excess of requirement or made from poorly digestible ingredients should be avoided. The protein requirement of fish is actually a requirement for essential amino acids and a nitrogen source (i.e. nonessential amino acids) used to make body proteins. Though fish can utilize protein for energy, this results in increased ammonia production by the fish increasing nutrient load on the biofilter. Net protein utilization (NPU, body protein gain divided by protein fed) can be improved by sparing protein from energy metabolism by optimizing the protein to energy ratio of the feed. Improvement of NPU can also be accomplished through feeding an "ideal protein", or a protein of high biological value. In feeding an ideal protein you are presenting a pattern of amino acids which match the species requirements, but not exceeding the requirements.

The digestibility of a carbohydrate varies among fish species, generally raw or uncooked carbohydrates are better utilized by omnivorous species (catfish and tilapia) compared to carnivorous species (salmonids) (NRC 1993). Undigested carbohydrates increase the volume of feces excreted which must be removed from the culture system by a solids separator. Digestibility of both protein and carbohydrates is affected by the processes applied to the feed or feed ingredients.

The processing method used to form the pellets, steam pelleting or extrusion, affects the digestibility of a feed and its physical characteristics such as buoyancy and durability. Temperature, pressure and duration of exposure to these elements can either enhance or reduce the digestibility of carbohydrates and proteins in a feed. The digestible energy of starch for salmonids is increased by heating through gelatinization. Excessive temperatures can cause a browning effect which can create indigestible lysine-carbohydrate linkages reducing the digestibility of carbohydrates and reducing the biological value of protein. Newer, low temperature extrusion processing methods are being developed which produce the desirable qualities of traditional extrusion processing but at significantly reduced costs.

The pellet density can cause a pellet to sink or float depending on processing methods. From the management perspective floating feeds have been preferred because observation of feeding activity is much easier. However, floating feeds can create competition for surface feeding territory and stratify the fish population with smaller fish pushed to deeper positions. Less stratification can be observed among fish fed sinking pellets. However, from a management perspective, sinking pellets do not allow observation of feeding activity.

Heating of the starches improves the durability and water stability of a pellet. Pellet durability is important in automated feed systems where conveyors may create excess fines. Feed fines are not consumed by the fish increasing the load on the solids removal system and possibly the biofilter if the fines pass through solids removal. Fines can be removed from the feed delivery system by incorporating sieves at strategic locations. Water stability of feed is mainly a concern in shrimp production where pellets may be in

the water for several hours before consumption. However, water stable feed may be an advantage in a recirculating system in the event that feed is wasted and must be removed in the solids separator. Improved water stability would increase the amount of whole feed reaching the separator facilitating feed removal. The prevention of feed waste must be the primary goal of a feeding strategy.

Feeding strategies

Feeding strategies can be divided into delivery, timing, and quantity of feed. Managers should select feeding strategies which are compatible with their recirculation system, fish species, and budget. However, in high overhead situations such as recirculating aquaculture, the primary consideration is the how to maximize total yearly production through feeding strategies.

Traditionally, feed has been delivered to culture tanks by hand, demand or automatic feeders. Hand feeding is a good management tool to observe fish and maximize feed intake by feeding fish to satiation. Good managers can almost eliminate feed waste that may occur using other feed delivery systems. However, hand feeding is time consuming and probably only practical for small production systems with small quantities of feed. Demand or pendulum type feeders can reduce the amount of labor required for feeding while achieving near maximal feed consumption. Feed waste is reduced by proper calibration of the pendulum.

Feed delivery in large scale recirculation systems is best accomplished through automatic systems. Automatic systems reduce the labor associated with feed handling, but require more time in tracking growth and biomass of individual tanks of fish. The feeding of a ration, expressed as % body weight per day, must be accurately calculated to ensure that no feed is wasted. Satiation feeding or maximum feed intake is difficult to attain by automatic feeders feeding a predetermined amount of feed.

Feed back mechanisms developed for use on aquaculture tanks have improved automatic feeding systems to reduce feed waste while increasing feed intake. Ultrasonic waste feed controllers (Summerfelt et al 1995) can detect uneaten feed exiting the tank and deactivate the feeder for a period of time to prevent feed waste. Hankins et al (1995) found that ultrasonic feed controllers improved fish growth over that of pendulum demand feeders or ration feeding. In that study, satiation hand feeding resulted in the highest growth rates with ultrasonic feed controllers were second.

Feeding frequency can influence the water quality of the recirculation system. Dissolved oxygen (DO) and total ammonia nitrogen (TAN) concentrations are of primary importance in recirculating systems. By increasing the number of feedings per day and the day length over which the feed is offered, peak TAN and low DO concentrations can be decreased, reducing stress. Phillips et al (1998) found that increased feeding frequency increased the mean daily DO concentration and reduced the mean daily TAN concentration. This reduction in TAN variability could benefit the biofilter microbes by

supplying a more constant source of nutrients, thereby improving biofilter efficiency. The increased DO could reduce the oxygen input to the system, reducing production costs.

Conclusion

Fish production in recirculating systems can be improved by management of feeds and feeding strategies. Feeds should be selected based on nutritional criteria such as high protein digestibility and optimal protein to energy ratios to reduce excess ammonia production in the system. Physically, the feed should be durable to withstand handling by each particular feed system. Feeding systems and frequency can be modified to reduce waste feed, improve water quality, and increase productivity. By optimizing both feed and feeding strategies, total system productivity can be increased, increasing the profitability of recycle systems.

Currently feeds and feeding systems should be specifically designed for each culture system. However, in the future, recycle systems will be designed only after the criteria for feed and feeding systems have been clearly specified.

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Effluent Management: Overview of the European Experience

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Abstract

The specific effluent loading from European salmonid culture has been reduced by 50 - 70 % since 1980, mainly due to: improved feed quality and feeding strategy; better farm management; and improved culture system design. Danish authorities require that freshwater farms use high quality feed and strict feeding management regimes with a maximum FCR of 1.0.

Local discharges to receiving waters, especially at freshwater sites, have also been greatly reduced as a result of environmental legislation requiring the use of effluent treatment, or refusal to grant consents for new facilities to discharge to freshwater. A wide range of regulations and standards relating to fish farming, and subsequent effluents, exists throughout the EU and in other non-EU European countries. Typically, discharge consents in land-based farms are based on water discharge volumes, or on nutrient quantities or concentrations.

Effluent treatment systems, such as microsieves and swirl separators, normally remove about 50 % or more of the suspended solids and phosphorus emanating from flow-through farms. Recent research shows that reduced water consumption, or pre-concentration of the waste solids, for example using within-tank particle concentrators and separate sludge outlets, can greatly increase treatment efficiency. Several studies indicate that traditional effluent settling ponds are inefficient or useless as primary separators. They are though more suited to secondary de-watering. In large land-based marine farms, multi-stage treatment systems combining a retention pond, foam fractionation and micro-algae/bivalve filtration, have demonstrated promising solids and dissolved nutrient removal efficiencies. The running costs of a recently developed system combining effluent micro-sieving and sludge processing, at large salmon hatcheries, was estimated as about US $ 0.2 - 0.5 per kg of smolts, i.e. 2 - 7 % of the production costs.

Fish-farm discharges, water abstraction and feed usage are taxed in some countries. These can amount to a significant proportion of the production costs.

Regulations controlling Wastes

General

There are a wide range of regulations and standards throughout Europe controlling the discharge of effluents from fish-farms. These were reviewed in 1992, at the 'Fish farm Effluents and their Control in EC Countries' Workshop (Rosenthal, 1994). Regulations from 19 EU and non-EU countries were presented.

Most of the legislation still conforms to that described by Rosenthal (1994), especially with respect to effluents from land-based farms. Some concepts and models used to regulate the local impacts of cage-based farms have though been initiated. In this brief description, only regulations from a few European countries can be described.

Land-based Farms

Freshwater recipients

Inland, land-based farms necessarily utilise rivers, or lakes as primary recipients. The impacts of salmonid farm discharges on freshwater resources are well documented (NCC, 1990; Oberdorff and Porcher, 1994), providing clear evidence that strict regulations are required.

On the Jutland peninsula in Denmark for example, it is common for several trout farms to be situated along the same river. Negative impacts on the recipient, such as oxygen depletion, elevated nutrient concentrations and reduced biotic diversity, have been reported in the 1960s and 70s (Markmann, 1977). In the early 1970s stricter environmental legislation was enacted, and since then few new farms have been granted a license (Stellwagen, 1993). The main regulations governing the operation of river-based trout farms are as follows (Stellwagen, 1993; Jokomsen, pers. comm.):

- the maximum allowable quantity of feed used is mainly based on the median minimum flow rate of the river;
- the feed conversion rate (FCR) should not exceed 1.0 (kg feed/kg weight gain);
- the feed used should meet the following quality standards, i.e. minimum 5.7 Mcal/kg dry matter (DM), metabolic energy minimum 74 % of gross energy, maximum 9 % total nitrogen (TN) and 1 % total phosphorus (TP) of DM, maximum 1 % dust;
- the allowed limits of increased concentrations from passage through the farm (outlet conc. - inlet conc.) are, BOD 1 mg/L, SS 3 mg/L, TP 0.05 mg/L, TN 0.6 mg/L (NH_4-N 0.4 mg/L), dissolved oxygen (DO) outlet minimum 60 % of saturation;
- there are no charges for effluents from fish farms.

The introduction of these water quality limits has resulted in the need for effluent treatment using technology, such as sedimentation ponds and microsieves. Both often combined with biofilters (Heerefordt, 1991). Effluent monitoring is conducted by the environmental authorities and by the farmers themselves (Dansk Dambrugerforening,

1993). As a result of this range of management and technology intervention, the nutrient loading from Danish trout farms was greatly reduced during the period 1980 - 1991 (Warrer-Hansen, 1993), in terms of the mass flow of nutrients (kg) per tonne of production: from 600 to 247 for BOD (59 % reduction); from 180 to 49 for TN (73 %); and from 30 to 6 for TP (80 %).

Discharge consents for fish-farms in England and Wales typically specify the volumes of discharge water parameters, i.e. outlet - inlet BOD, SS and NH_4 concentrations and DO saturation in the outlet (Lloyd, 1993). The application of treatment technology is not a statutory discharge licence requirement. The associated costs of monitoring, licence approval, and administration by the National Rivers Authority and the abstraction of water are borne by the fish-farmers. In Scotland, freshwater fish-farm licensing requirements are based on local water quality objectives (Kelly, pers. comm.).

In Wallonia, southern Belgium fish-farmers are taxed in direct proportion to the quantity of feed supplied (Peng *et al.*, 1997). Taxation does not though take into account the quality of the feed which can strongly affect the waste production.

Marine recipients

The expansion of fish-farming in Norway is not permitted at sites with freshwater recipients (Leffertstra, 1993), so the majority of hatcheries/smolt farms are situated on the coast with an outlet to the sea. In most cases, the recipient capacity is, with high water exchange and favourable topography, sufficient to accept these discharges. Some farms are however loading sites with a limited organic waste acceptance capacity, and hence they are liable to oxygen deficits and particle sedimentation (e.g. fjords with sills).

In Norway, licenses to discharge are administered by the county environmental authorities. In order to avoid negative impacts from fish-farm effluents in vulnerable recipients, the authorities require a biological study of the seabed at the outlet point. If the local seabed is significantly affected by organic waste, the fish-farmer is advised to assess methods to reduce the effluent discharge, e.g. effluent treatment. Usually, the authorities require a study of the recipient conditions as part of an application for farm expansion (Maroni, pers. comm.). This is to be funded by the farmer.

Cage Farms

Freshwater sites

Freshwater cage culture of rainbow trout is commonly practised in Finland, Sweden, Scotland and in NE Germany. In Scotland, some salmon smolt production is conducted in lake cages.

Scottish cage culture discharge consents are, in some regions, based on specific water column TP standards which must not be exceeded, thus ensuring that the oligotrophic nature of the lakes (lochs) is maintained (Burbridge *et al.*, 1993). Limits can be placed on production via three, usually separate, methods (Kelly, pers. comm.):

♦feed usage and TP content of the feed;

♦total permissible fish biomass;

♦TP concentration in the ambient water.

In Sweden, the licensing system is based on maximum limits of cage volume, feed consumption, fish production and N and P annual loads (Enell, 1993). The feed quality standards (N, P, metabolic energy) are similar to Danish standards. Some requirements must be met prior to the establishment of a fish-farm:

♦the most appropriate location must be selected;

♦the best available environmental protection technology which is environmentally justifiable and economically realistic, must be used;

♦there must be no substantial detriment effects on the ecosystem.

Regulations and administration relating to aquaculture in Sweden are so restrictive that the industry has been effectively stifled in recent years.

Marine sites

In order to identify coastal areas suitable for aquaculture, the so-called LENKA system was introduced in Norway (Kryvi *et al*., 1991). A more comprehensive management system called MOM (Modelling Ongrowing fish-farms Monitoring), that integrated the elements of environmental assessment, monitoring of impacts and environmental quality standards into one system, has recently been developed (Ervik *et al*., 1997). The MOM system is considered a valuable regulatory tool in planning fish farms (modelling) and for the determination of the degree of exploitation of operational fish-farm sites (monitoring).

Waste Management Techniques

Feed and Feeding Management

The feed derived waste production in salmonid farms has been significantly reduced, due to an increased energy density (increased fat : protein ratio) with a lower content and an improved bioavailability of protein and phosphorus (Bergheim and Åsgård, 1996). A recent report (Peng *et al*., 1997) however, demonstrated a wide range of feed quality was still available on the European market (10 commercial diets): from 16.8 to 26.9 g DP/ MJ DE (DP: digestible protein, DE: digestible energy) and from 0.85 to 1.42 % P. In terms of kg weight gain, using these diets in rainbow trout fingerling production, the waste production was 36 - 105 g N/kg, 6.2 - 15.3 g P/kg and 563 - 1111 g organic matter.

Land-based Farms

Flow management

Oxygen is commonly added to the salmon tank or farm inlet water in quantities of up to 160 - 200 % saturation. This is primarily to increase productivity, but also assists effluent management. The specific water consumption of Atlantic salmon can be reduced from 1 - 2 l/kg/min, down to about 0.2 l/kg/min. The outlet waste concentration in the farm

effluent will then be a factor of 2 - 5 times greater than a non-oxygenated site, assuming the same food conversion ratio. This will influence effluent management in two main ways. Firstly, higher fish density in oxygenated fish tanks can improve self-cleaning, reducing the need for manual cleaning and flushing of tanks and improve the culture environment. Secondly, the more concentrated waste stream will more suitable for the application of separation technology.

Waste pre-treatment

Several recent studies, such as those by Cripps (1995), have shown that there are significant advantages to be gained by pre-concentration of wastes, prior to the main effluent treatment processes. Solid wastes can be partially separated from the main carrying flow either temporally or by location. Temporal concentration is achieved by allowing wastes to build up within the tank, either in the culture area or a separate downstream sedimentation zone. These solids are then flushed to waste intermittently, as described above. This traditional method is probably the most common method of pre-treatment, at sites where, deliberately or otherwise, pre-concentration is conducted.

A newer method that appears to function well is the use of within-tank separation technology, such as that produced by AquaOptima (I. Schei, pers. comm.). Here, the bottom flow dynamics of the culture tank are manipulated to increase the settlement of the solids that would otherwise have been carried out of the tank in an uncontrolled manner in the primary effluent stream. These settled solids are diverted to a separate solids outlet with a flow rate that is often well below 3 % of the primary flow. The sludge flow at the majority of sites using this technology is further concentrated using small hydrocyclones at each tank outlet.

The advantage of pre-concentration is that the hydraulic loading on the solids separators, such as microscreens, is substantially reduced, allowing treatment effort to be targetted where it is most required. This also reduces sludge volumes requiring dewatering, because backwashing rates are reduced. A further advantage of pre-concentration is the formation of a filter mat on the microscreens, that enhances particle separation and removal (Cripps, 1995).

Treatment technology

Various designs of sedimentation basins are common throughout the European fish-farm industry. They range in design from simple ponds dug downstream of the farm, up to compact second stage cones, or advanced basins incorporating automatic sludge removal and flow manipulation. Simple designs are often adapted from spare ponds or tanks. Despite their widespread use, they are, in any form, rarely suitable for the treatment of the primary effluent because of inadequate flow dynamics and sludge removal problems. Sedimentation is appropriate for the localised (i.e. within tank) pre-concentration of wastes, and for second stage de-watering of separated sludge within a multi-stage treatment system. This latter use is though rare within Europe.

Several authors have described the available types of particle separators, including Wheaton (1977) and Cripps and Kelly (1996). Within about the previous 5 years, microscreen sieves for the separation of particles in the effluent have become more

widespread. Triangle, rotary drum (Hydrotech) and rotary disc (Unik) screens are in common use. More advanced models incorporate automatic particle load switches for intermittent operation, thus reducing sludge volumes produced by screen backwashing. The solid removal potential of microsieves has been clearly demonstrated in recent studies at Scottish hatcheries (Kelly *et al*., 1996; Kelly *et al*.,1997). A wide range of screen mesh sizes is used, ranging from 200 - 60 µm (30 um for microscreens at the farm inlet). Cripps (1993) and Kelly *et al*. (1996) indicated that 60 µm seemed to be a reasonable compromise between hydraulic capacity restrictions and particle removal potential.

In a Norwegian test of the Unik Filter (Ulgenes 1992a), removal efficiencies, using a combination of 250 and 120 µm pore screens, were suspended solids (SS) 16 - 94 %, total phosphorus (TP) 18 - 65 % and total nitrogen (TN) 1 - 49 %. Efficiency was generally improved using a smaller pore size, of 60 µm, on the downstream screen: SS (67 - 73 %), TP (43 - 74 %) and TN (38 - 67 %). Ulgenes (1992b) also tested the treatment efficiency of a drum filter commonly used in Europe (Hydrotech), fitted with a 60 µm pore size screen. Treatment efficiency varied considerably within the ranges SS (67 - 97 %), TP (21 - 86 %) and TN (4 - 89 %). Efficiency was found to vary proportionally with the waste effluent concentration, again indicating the advantages of particulate pre-concentration. A similar test using a drum filter (mesh size 70 µm) for the treatment of the effluent at a German trout farm was reported by Eichholz and Rösch (1997). The average treatment efficiencies found were lower than reported in the Norwegian tests (Ulgenes, 1996a,b).

As the number of farms employing primary effluent treatment increases, the quantity of sludge resulting from these separation activities, will increase. This sludge requires thickening and stabilisation. The waste production from all Norwegian farms during 1990 was estimated as 8,320 t N and 1,440 t P (Ibrekk 1989). The actual proportion of the total number of farms employing sludge treatment techniques is small. Currently, sludge treatment and disposal options available include: transfer to domestic wastewater treatment facilities, landfill dumping, infiltration through soil filters and use as a crop fertiliser (Cripps and Kelly, 1996). If the farm is located near a mains sewage system, linked to a treatment works of adequate size to cope with the loadings and fluctuations in loading that will be produced by a farm, then sludge can be discharged directly to the sewer. This is the situation, for example, for wastewater from Danish eel recirculating systems. More often the farm is located in a rural community with little or no intensive sewage treatment, or with no communal sewer system. In this case, the sludge will have to be transported, in the same way as septic tank liquor, by vehicle to a treatment works. This will incur a transport cost, in addition to treatment charges levied by the operators of the treatment works.

Sedimentation, as a first step for de-watering of sludge water, is efficient at producing a settled sludge. The settling velocity of particles after microsieving is fairly high (Warrer-Hansen, 1993), and a settling removal of 85 - 90 % in a thickening tank at an overflow rate of 1 m h^{-1} has been achieved (Bergheim *et al*., 1993). After a settling period of less than 24 hrs, the DM content is in the range 5 - 10 %. This sludge has to be further processed (Bergheim *et al*., 1993). Stabilisation by adding lime appears a suitable method for the further treatment of settled sludge from fish farms (Mäkinen, 1984; Liltved *et al*.,

1991). A multi-stage system for sludge treatment, developed in Europe, was described by Bergheim *et al.* (1997).

For the reduction of both solids and dissolved nutrients in effluents from large marine land-based farms, Hussenot *et al.* (1997) described a multi-stage treatment system. The recommended system combines particle settling in a retention lagoon, foam fractionation and micro-algae/bivalve filtration. Experimental tests indicate a potentially high solids (SS, POM) and dissolved components (TAN, PO_4, SiO_2) removal efficiency.

Cage farms

Waste collection

Waste collection or removal from cages is difficult, and so only a few methods have been tested in Europe, with varying success. These include: collectors, closed cages, water column and sediment pumps. Bergheim *et al.* (1991) described a cage sludge collection system with a horizontal area of 50 m^2, corresponding to 40 % of the cage area. It was reported to have collected 75 - 80 % of the settleable particles during a 4 month period. The collected material, with a dry matter content of 5 - 15 %, was pumped daily from a sump at the bottom of the trap. The collection efficiency of a similar German system was found to be highly dependant on the action of wild fish eating and disturbing the collected material (Wedekind, 1997).

The *Lift Up* system (Lift Up A/S) for the collection and subsequent removal of waste particles and dead fish has been described as operating efficiently (Braaten, 1991). The system comprises a coarse mesh net around the outside of the cage. The lower part of the net forms a finer mesh net funnel. Waste material is pumped intermittently to a coarse screen located above the water level on the cage collar. Independent test results estimated that almost 100 % of waste pellets larger than 6 mm were collected within minutes (Braaten, 1991).

Closed cages, in which the containing structure is made of a solid material, such as high density polyethylene rather than netting, have yet to make any commercial progress in Europe. During the past 5 years, economic constraints have limited the development of this system, but at present industrial and research interest is increasing again.

The use of fish-farm sludge for land application can sometimes be limited because of high levels of both zinc and cadmium, in excess of levels in cattle manure (Table 1). These metals must have originated in the fish feed.

TABLE 1. Trace metal content of fish farm sludge (Bergheim, 1997) and cattle manure (A. Fludal, pers. comm.) compared with recommended maximum concentrations for unrestricted land application (Norwegian Department of Agriculture, 1996).

Metal	**Fish farm sludge**	**Cattle manure**	**Recommended max. conc.**
Copper, mg/kg DM	14 - 68	75	150

Zinc,	"	478 - 608	220	400
Lead,	"	1.7 - 4.3	1.8	60
Cadmium,	"	0.60 - 0.86	0.20	0.80
Chrome,	"	1.0 - 2.3	2.4	60
Nickel,	"	10 - 19	1.7	30

Effluent Treatment Costs

A complete system for effluent treatment and sludge handling at land-based salmonid farms has been estimated to increase the total production costs by up to 7 % (Table 2). The treatment costs can however be reduced to about a third if these units are outside. The break-even level for economically sustainable effluent treatment is closely connected to the size of the farm (Muir, 1981), because the allowable additional capital costs for effluent treatment increases with the annual fish production.

Generally, the profit margin of trout producers is low (Peng *et al.*, 1997), so the investment and operational costs therefore need to be correspondingly low. Under poor growth conditions, such as warm summer periods with reduced fish growth, the extra costs of sludge collection using cage funnels can represent a heavy burden to the farmer (Wedekind, pers. comm.).

Devices for collecting wastes can be useful tools to control feed losses in both land-based and cage-based farms. In Norway, the "Lift-Up" system for the collection of waste feed and dead fish in sea cages also functions in this respect to improve the feed utilisation (Johnsen *et al.,* 1993). The manufacturers claim a potential reduced production cost of 0.2 US $, due to the improved control of the feeding and the fish stock (Table 2).

Charges for discharges, abstraction of water or feed usage can amount to1 - 5 % of the production costs. In Great Britain, fish farmers are also charged for the licence application and advertising ("one off" costs) each at a cost of 1,000 - 1,700 US $ (Kelly, pers. comm.). Such charges are often in addition to effluent treatment costs.

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TABLE 2. Effluent treatment costs and charges in European salmonid production. Comparisons should not be made between different culture systems.

Type of production	Effluent treatment facilities or effluent charge	Annual costs, US $			Costs per kg produced fish, US $	% of total production costs	Comments
		Fixed	Operating	Total			
Hatchery producing 100 t Atl. Smolt/year (1 mill. Individuals/year). Norway (Bergheim, 1997; Knutsen, pers. comm.)	Screening (microsieves) - sludge thickening (gravitational tank) and stabilisation (adding lime)	10,500 -48,000	7,000 - 8,200	19,700 - 55,000	0.20 - 0.55	2 - 7	Treatment costs dependant on extra investments as building and fittings (Mundal, pers. comm.)
On-growing freshwater cage farms producing 100 t rainbow trout/year. Germany (Wedekind, 1997)	One PVC funnel per 10 fish cages (5 t prod./year), totally 20 funnels. Sludge pumping and thickening (gravitational tank)	11,500	9,100	20,600	0.20	9 - 10	Treatment costs under optimal conditions: 0.08 US$/kg (3 - 4 % of tot.). (Wedekind, pers. comm.)
On-growing sea water cage farm producing 300 t Atl. Salmon/year. Norway (Johnsen et al. 1993)	Collecting nets for excess feed and dead fish (“Lift-Up” system). Sieving system for feed pellets			< 19,600	- 0.20 - 0.07	< 4	The system is considered to reduce the total production costs (e.g. less feed loss)
Land-based trout farms in Wallonia, Belgium (Peng *et al.* 1997)	Charge based on annual feed used: 0.077 US $/kg				0.08	3 - 5	
Land-based trout farms in England & Wales (Kelly, pers. Comm.)	Charge based on abstraction and discharge of water (supply: 100 L/s)				0.03 - 0.09	1 - 5	Costs for licence application/advertising not included

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The Importance of Biosecurity in Intensive Culture

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Introduction

The explosive growth of worldwide aquaculture has resulted from culture intensification and from an increased number of species being cultured in an increased number of locations. As culture intensification has proceeded, catastrophic loss from infectious disease outbreaks has been repeatedly identified as a major cost to industry productivity. Major causes of disease-related financial loss are direct losses, market losses and costs resulting from lost opportunity. Direct losses include mortality, facility closure orders, restriction of movement orders, and the inability to replace stock. Market losses include reduced quality of survivors (e.g., from reduced growth rates and lower yields or reduced product quality), a restricted market for healthy stock because of damage to a facility's reputation, and missed markets. Examples of opportunity costs are diversion of management and labor and underutilization of the fish production facility (Paterson et al., 1991).

The purpose of this paper is to describe, 1) how increased intensification results in an increased risk of infectious disease outbreaks, 2) summarize the major risk factors for infectious disease outbreaks in finfish culture, and 3) describe ways to use the principles of biosecurity to decrease the risk that outbreaks of infectious disease will occur at facilities where intensive culture of finfish is an economic necessity.

Increased intensification results in an increased risk of infectious disease outbreaks

Crowding increases the vulnerability of a population of animals to disease and death from opportunistic and obligate pathogens. The theory behind why this increased vulnerability occurs has been well-established since the early 1900's. As described in the review by Anderson (1982), Hamer (1906) suggested that the course of an epidemic depends on the contact rate between susceptible and infectious individuals. This "mass action principle" states that the rate of disease spread is assumed to be proportional to the product of the density of susceptibles times the density of infectious individuals. In addition to Hamer's mass action principle, Kermack & McKendrick (1927) established the threshold theorem. According to the threshold theorem, the introduction of infectious individuals into a community of susceptibles will not lead to an epidemic outbreak unless the density of susceptibles is above a certain critical threshold density. Therefore, culture intensification creates ideal conditions because not only does the density of susceptible animals increase, but the introduction of even one infectious individual will result in

proportionately more contacts with susceptible animals, thereby increasing the risk of an outbreak.

Many fish culturists reason that if they start a cohort with more fish, they will be able to "make up for" losses if an infectious disease outbreak does occur. Unfortunately, the disease dynamics are such that this strategy does not result in the ability to culture more fish. Results from infectious pancreatic necrosis (IPN) experiments (Fig. 1) where one infectious fish was added to each of 12 tanks of various densities of susceptible rainbow trout fry, demonstrate that at the end of 60 days there were no more fish remaining in the high density tanks than in the low density tanks (Bebak, 1996).

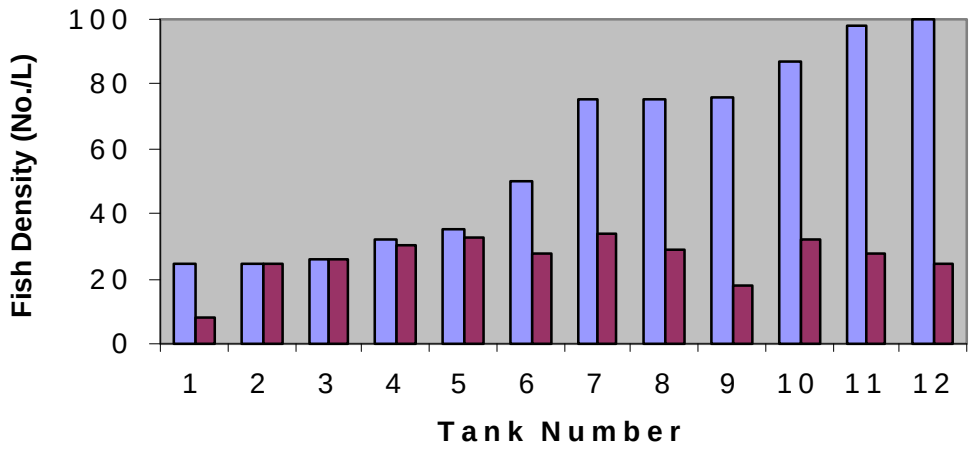

Figure 1. Rainbow trout fry densities at the beginning and end of epidemics of IPN

When fish culture density is not strongly influenced by economic factors, the fish culturist naturally, through experience, keeps cultured fish populations below their critical threshold density. An example of this tendency toward the threshold number of susceptibles can be seen in Piper et al. (1982), which recommends that a "rule of thumb that can be used to avoid undue crowding is to hold trout at densities in pounds per cubic foot no greater than 0.5 their length in inches". In laboratory experiments on the effect of density on IPN epidemics in rainbow trout, Piper's cutoff turned out to be the cutoff above which an IPN epidemic was more likely to occur (Bebak, 1996). An additional example of threshold densities can be seen in Wedemeyer and Wood (1974), who published a table of hatchery pond loading rates for chinook and coho salmon. Above these loading rates they found that infectious disease outbreaks were more likely to occur.

Facilities that culture fish for conservation purposes are more likely to have the freedom to culture fish below the population's critical threshold density. Economics require that food fish production facilities must intensively culture finfish. Fortunately, the minimum

threshold density of susceptible individuals for an infectious disease outbreak will change as the environmental conditions change. The principles of biosecurity can be used to increase that threshold density of susceptibles and decrease the risk that an infectious disease outbreak will occur.

Biosecurity

Intensive biosecurity practices have been more commonly employed in European and Japanese fish hatcheries than in North American fish hatcheries (Amend and Conte, 1982). Biosecurity, or "hazard reduction through environmental manipulation" (Plumb, 1992), is often defined as practices that reduce the number of pathogens that enter a facility. This paper will use an expanded definition for biosecurity, which consists of management practices and procedures that 1) reduce the risk that pathogens will be introduced to a facility, 2) reduce the risk that pathogens will spread throughout the facility and 3) reduce conditions that can enhance susceptibility to infection and disease. Often one would like to think that implementing biosecurity practices on the fish farm will prevent entry of even a single pathogen. Realistically, biosecurity for food fish production accomplishes pathogen reduction rather than pathogen elimination.

Reducing the risk that pathogens will be introduced to a facility

Entry of pathogens through the water supply (usually when fish are present) and through the introduction of fish to a facility have been identified by epidemiologic studies as major risk factors for outbreaks of infectious disease in cultured finfish (Thorburn, 1987; Jarp et al., 1993; Bebak et al., 1997). Any food fish production facility that plans to intensify culture in a given water supply, and 1) uses a water supply with a resident population of fish or 2) imports fish into the facility, can expect to experience infectious disease outbreaks if no changes in these two management practices are made.

Ideally, a farm would use a pathogen-free water supply that is protected from contamination and would purchase only certified eggs to restock the facility. Unfortunately, not all farms have access to a pathogen-free water supply, nor do all farms culture species that are readily available as eggs. If a pathogen-free water supply is at risk of contamination, or is unavailable, then incoming water should be disinfected. Ozonation and ultraviolet radiation are the most commonly used methods. If possible, the facility should only be restocked with fish hatched from certified eggs that have been disinfected upon arrival at the facility (Appendix 1). If fish must be imported into the facility, then strict quarantine procedures should be implemented (Appendix 2). In addition, fish should only be purchased from a reliable source with certified broodstock that has been kept in a pathogen-free and/or disinfected water supply. The risk of pathogen introduction can also be reduced by keeping the number of different suppliers to a minimum. Farms that culture species that are not available as certified eggs should actively support research on broodstock development and egg production.

As biosecurity practices are considered, begin with the areas where the population is most susceptible (e.g., egg and fry rearing areas). Management practices that may be implemented to further reduce the risk of introduction of pathogens include:

- Wash hands with anti-bacterial soap upon entering the facility.
- Disinfect footwear or change footwear to disposable, or disinfected non-disposable, boots before entering the facility.
- Access to egg incubation and fry facilities should be restricted to a minimum number of well-trained individuals.
- Reduce the number of visitors to a minimum and/or only people working on the farm should be allowed into the facility.
- Disinfect wheels of delivery vehicles when they come onto the facility and when they leave. Establish a visitor parking area on the periphery of the facility grounds.

Reducing the risk that pathogens will spread throughout the facility

Meticulous husbandry is an essential component of an effective biosecurity plan. Feces, uneaten feed, algae, aquatic plants and other decomposing debris provide a substrate for opportunistic pathogens to flourish. Tank surfaces should be kept free of uneaten feed, feces, algae and aquatic plants. Inflow and outflow pipes, aerators, spray bars and any other equipment inside the tanks should be cleaned frequently.

It is critically important that every part of the rearing system be constructed so that the system can be easily cleaned as necessary. All parts of recycle systems including the biofilters, low head oxygenators (LHOs) and CO_2 strippers should be accessible for cleaning. Clean-outs should be installed to access pipe interiors. Construction materials should be non-porous and easy to clean and disinfect. Avoid the use of wood. If wood is to be used, it should be considered disposable. Wood use should be limited to temporary structures and these structures should never be transferred to another site.

Culling dead and sick fish is a very important strategy that can reduce the spread of pathogens from fish to fish. How culling will be accomplished should be considered early on in facility design. Culling should be done at least once a day or, if possible, on a continuous basis. Culled live fish should be humanely killed and not allowed to die from suffocation.

Monitoring is an important part of early identification, isolation and treatment of a problem. How monitoring will be accomplished should be considered early on in facility development. Ideally, daily observation of the fish should be possible. Dim lighting and very large tanks with limiting viewing access limits the possibility of visual inspection of fish, one of the most valuable tools for detecting an incipient problem. Culled fish should be periodically assayed for pathogens. Records on growth and feed conversion ratios can be used to detect subclinical problems. Consider keeping a susceptible species as sentinel fish.

Other important management practices that will decrease the risk that pathogens will be spread around the facility include:

- Frequent hand-washing with anti-bacterial soap should be standard practice.
- Disinfectant and rinse areas should be readily accessible for disinfecting buckets, nets, dissolved oxygen meters, thermometers and other equipment.
- Tanks and equipment should be disinfected before using for a different group of fish.
- Even when tanks are on the same recycle loop, each tank should be regarded as a discrete rearing unit and the potential for cross-contamination should be minimized.
- Strategically schedule culture activities. Minimize the number of different personnel working with a particular group of fish. As soon as any suspicious mortality above baseline levels occurs, only one person should be allowed to work with affected fish. Alternatively, if personnel resources are limited, work should be done on the unaffected tanks first, leaving the affected tanks for last.
- Aerosol transmission of pathogens can occur. Consider placing barriers between tanks.
- Minimize transfer of fish between tanks.
- Whenever possible, employ the use of vaccination as a disease prevention management tool.

Reduce conditions that are stressful to the fish and that can enhance susceptibility to infection and disease

Stress associated with crowding, low water flow, poor nutrition, poor water quality and other husbandry related factors will render fish more susceptible to, and aggravate the consequences of, infection with opportunistic and obligate pathogens. There are many strategies that can be used to increase fish vigor and reduce stress. Some of these include:

- Use of gentle fish crowding and other methods of gentle fish handling
- Monitor water quality parameters to verify that they remain within recommended limits.
- Poorly nourished fish are more susceptible to disease. The fish feed schedule and feed characteristics should be such that the fish receive the best nutrition possible.
- Purchase eggs and fish only from optimum year class broodstock.

Summary

Intensive culture of finfish increases the risk of infectious disease outbreaks that can have catastrophic effects on a facility's ability to meet production goals. Effective biosecurity can help decrease the risk that infectious disease outbreaks will occur. But, effective biosecurity if very difficult to implement after a problem begins. Biosecurity should be

considered in the early stages of intensification of an existing facility and in the early design of a new facility. Biosecurity should not be considered to be a static, unchanging set of rules and procedures. Biosecurity is implemented in a dynamic biological system. Once they are in place, biosecurity plans and protocols should be constantly reevaluated and changed as necessary.

Appendix 1. Egg disinfection procedures

Very few disinfectants have properties that can be safely used around fish eggs and still have quick-acting, broad-spectrum activity. In addition, the disinfection of eggs for food fish falls under the regulatory jurisdiction of the FDA and only disinfectants that are included as FDA-Approved New Animal Drugs or Unapproved New Animal Drugs of Low Regulatory Priority (LRP) for FDA may be used (Federal Joint Subcommittee on Aquaculture, 1994). Iodophors (organic iodine complexes), are one commonly used option. Iodophors, which are LRP drugs, are generally used at 100 ppm for ten minutes after water hardening to disinfect fish eggs. One advantage of iodophors is the amber color which indicates the disinfectant is effective. Once the color turns yellow or colorless, it is no longer effective. With other disinfectants, it is more difficult to determine if the solution is effective (Amend and Conte, 1982).

Appendix 2. Quarantine

Quarantine is designed primarily to prevent introduction of pathogens into a facility from which eradication would be difficult or impossible. Isolation is the key to quarantine. Quarantine can be costly, and should be considered early in the facility design phase. There is no "recipe" quarantine protocol that covers all fish species cultured in all conditions. The following guidelines should be included when developing quarantine protocols for a facility. Many of these recommendations are included in (Harms, 1993).

- Quarantine protocol development should take into account the species, age and source of fish being quarantined.
- Length of quarantine should take into account information about incubation periods and development times for the pathogens that are known to present a risk. Although 30 days is often given as the "standard" quarantine period, it could be longer or shorter depending on pathogen life cycles and expression of clinical disease in warmwater vs. coldwater conditions.
- Quarantine should protect against foreign or exotic pathogens to avoid the introduction of a potentially serious, "new" problem.
- Do not use prophylactic antibiotics as part of a quarantine protocol. Prophylactic antibiotic use is illegal and can have serious consequences for the development of bacterial resistance to antibiotics.
- Quarantine must be closed. Any addition of fish to ongoing quarantine resets the quarantine clock to day zero.
- Fomites (e.g., nets, buckets and hands) and aerosols can breach even well-designed isolated quarantine systems. Minimize aerosols with tank covers

and by maintaining quarantine and exhibit tanks in separate rooms. Quarantine equipment should be used only in quarantine.
- Personnel should wash hands before going between areas and should save quarantine work for last.
- Consider keeping water temperatures at the upper end of the species optimum range to speed up pathogen life cycles.
- Introduce production system water before transfer so that fish can acclimate to it.
- Some authors recommend keeping fish densities as low as possible to minimize stress. Alternatively, consider exposing the fish to the same conditions they will encounter in the production system, so that a problem may be detected before the fish are moved out of quarantine.
- Consider transferring fish to a new tank within the quarantine system if dealing with the possibility of stages of organisms that can be left behind when the fish are moved from the tank.

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Culture Tank Designs to Increase Profitability

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Abstract

Tank-based, cold-water fish farms tend to use large inputs of high quality flowing water to maintain water quality during production. However, increasing the profitability of tank-based, cold-water aquaculture farms in today's regulatory environment requires strategies and technnologies to optimize the use of the water resouce, feed input, and stock management, as well as strategies that minimize the total waste discharged. Culture tank design has a dominating influence on all of these variables and ultimately on profitabilty.

The objective of this paper is to review several culture tank designs, with focus on increasing the profitability of tank-based, cold-water fish farms. This paper describes the design, use, and cost implications of fish production within circular culture tanks, raceway tanks, and hybrid raceway tanks that have been modified to create a series of mixed-cells within the same raceway. This paper also reviews how the cost of fish production is impacted by culture tank size, carrying capacity, stock management, and waste management.

Introduction

Larger systems and enhanced production management strategies have helped to reduce the cost of production in tank-based, cold-water fish farms. However, current production technologies are being challenged by lower farm gate prices and the implementation of new state and federal regulations that govern the total maximum daily load (TMDL) of wastes and/or the concentration of wastes discharged from fish farms.

The type of culture tanks used and their management have a significant influence on fish farm profitability. Culture tanks, their water distribution and collection components, support equipment (e.g., fish feeders, oxygen probes, flow or level switch, etc.), and floor space requirement add up to a large portion of fish farm capital. As well, the management

of the culture tanks and the control of their waste discharge can constitute a large portion of farm operating costs. Therefore, a large financial incentive exists to select the best culture tank, scale, and operating strategy to optimize fish farm profitability.

This paper discusses the design rationale, use, and cost implications of circular culture tanks, raceway tanks, and a new mixed-cell rearing raceway-type tank. The advantages and disadvantages behind each culture tank design are summarized as they influence water use, hydraulic characteristics in the tank, feed input, stock management, solids degradation, solids flushing, and ultimately, overall effluent management. First, however, this paper reviews how issues of culture tank scale, carrying capacity, and stock management influence the cost of fish production, and how rapid solids removal from the culture tank can effect waste management.

This culture tank information can be generally applied to either flow-through designs or water recirculating systems.

Scale Issues

The capital costs per unit culture tank volume decrease significantly with increasing volume. For example, only about a 5-fold cost increase is required to achieve a 10-fold increase in culture tank volume. Also, the costs of miscellaneous equipment and labor decrease when a given culture volume can be achieved with a few larger culture tanks rather than with many smaller tanks. Use of fewer but larger tanks (1) requires the purchase and maintenance of fewer feeders, dissolved oxygen probes, level switches, flow meters/switches, flow control valves, and effluent stand-pipe structures; and (2) reduces the time required to analyze water quality, distribute feed, and perform cleaning chores (i.e., the times are about the same for a larger tank as for a smaller tank).

However, the advantages achieved through the use of larger tanks must be balanced against the risk of larger economic loss if a tank fails due to mechanical or biological reasons. There are also difficulties that could arise in larger culture tanks when removing mortalities, grading and harvesting fish, and controlling flow hydraulics, e.g., water velocities, tank mixing, dead-spaces, and settling zones.

Carrying Capacity Issues

Production efficiencies are being boosted by increasing the carrying capacity of culture tanks. The carrying capacity is influenced by feeding rate, spatial requirements, oxygen consumption, inlet and outlet dissolved oxygen concentrations, water exchange, water pH, and waste production and removal (Losordo and Westers, 1994). For example, doubling the hydraulic exchange through a tank will double the carrying capacity of the tank (i.e., production is doubled with only a small increase in capital, assuming that water is not limiting). However, super-saturating the dissolved oxygen in the water flowing into the tanks has also been popular, and often a more cost effective method to improve the profitability of cold-water fish farms. For example, if the oxygen concentration entering a culture tank was increased from 10 mg/L to 14 mg/L, the available oxygen in the supersaturated flow would double the carrying capacity of the system, assuming an outlet dissolved oxygen concentration of 6 mg/L. Supersaturating the flow with dissolved oxyen

can be achieved cost effectively with many different oxygen transfer devices, even in low head applications (Boyd and Watten, 1989).

However, when a culture tank or a group of culture tanks operating under serial or parallel water reuse receives inadequate water exchange to flush the fish wastes, i.e., at excessive fish loading rates, the dissolved carbon dioxide and ammonia produced will accumulate in the culture tank and can limit fish production. Intensive farms can use the water flow without worry of ammonia and carbon dioxide limitations (assuming no biofiltration or air-stripping) up to a cumulative dissolved oxygen consumption of about 10 to 22 mg/L, depending upon pH, alkalinity, temperature, and the fish type and life stage (Colt et al., 1991). After reaching this cumulative oxygen demand, the water flow cannot be used again unless it is passed through a biofilter and air-stripping unit to reduce its ammonia and/or carbon dioxide accumulations.

Stock Management Issues

Total system production can be doubled through the use of a continuous production strategy, rather than a batch production strategy (Watten, 1992; Summerfelt et al., 1993; Hankins et al., 1995). The maximum economic productivity of the culture system (e.g., single culture tank, row of culture tanks, or entire fish farm) can be obtained with year round fish stocking and harvesting, because continuous production maintains the culture system at or just below its carrying capacity. Heinen et al. (1996a) showed that rainbow trout stocked every 8 weeks and harvested weekly acheived a steady-state annual production (kg/yr) to maximum system biomass (kg) ratio of 4.65/yr. Similar results on a commercial farm would have a large positive effect on production costs.

Continuous stocking and harvesting strategies require frequent fish handling. Harvesting and grading fish can add considerably to the labor cost, and a convenient mechanism that can be used to grade fish and harvest each culture tank must be incorporated into the culture tank design. Simply netting the fish out of the tank, or using a net to crowd the fish for harvest or grading is an obvious solution. Fish can also be lifted out of the tank with a pump or cage once crowded. Crowding and grading can also be achieved with crowder/grader gates that move down the length of a raceway or pivot around the center of a circular culture tank. Using automated equipment to save on labor and avoid hand grading is essential to reduce costs.

Waste Management Issues

The concentration of waste discharged from most tank-based, cold-water fish farms is relatively low under normal operating conditions. However, the large flowrates involved can make the cumulative waste load (i.e., total maximum daily load) discharged from cold-water farms significant. Consistently meeting strict discharge standards can also be difficult because pipe, channel, and tank cleaning routines can produce fluctuations in discharge flowrates and in the consistencies and concentrations of waste material. The distribution of the nutrients and organic matter between the dissolved, suspended, and settleable fractions affects the choice of method used and difficulty of effluent treatment. The filterable or settleable solids contain most of the phosphorus discharged from tanks (50-85%), but relatively little of the total effluent nitrogen (about 15%) (Braaten, 1991;

Heinen et al., 1996b). Most of the effluent nitrogen released (75-80%) is in the form of dissolved ammonia (or nitrate when nitrification is promoted). The variability in the nutrient and organic material fractionation between dissolved and particulate matter is largely dependent on the opportunity for particulate matter to break-apart, because the production of smaller particles increases the rate of nutrient and organic matter dissolution. Fecal matter, uneaten feed, and feed fines can be rapidly broken into much finer and more soluble particles by water turbulence, fish motion, scouring along a tank/pipe bottom, and pumping. It is much more difficult to remove dissolved and fine particulate matter than larger particles. Therefore, culture tank designs and operating strategies that remove solids rapidly and with the least turbulence, mechanical shear, or opportunity for micro-biological degradation are important to help the fish farm meet discharge limits.

Circular Culture Tanks

Circular tanks have been widely used in land-based salmon farms in Norway, Scotland, and Iceland (Karlsen, 1993), as well as in North America and other parts of the world. Circular tanks used for salmon and trout production are generally large, usually between 12 to 42 m in diameter tanks (although smaller tanks are used in hatcheries and smaller farms), and with diameter to depth ratios ranging from 3:1 to 10:1 (Karlsen, 1993).

Circular tanks have several advantages: they can provide a uniform culture environment; they can be operated under a wide range of rotational velocities (with relatively small waterflow compared to raceways) to optimize fish health and condition; they can be used to rapidly concentrate and remove settleable solids; they allow for good feed and fish distribution; and, they can permit designs that allow for visual or automated observation of waste feed to enable satiation feeding (Timmons and Summerfelt, 1997).

Relatively complete mixing of the water in circular culture tanks is necessary to prevent flow from short-circuiting along the tank bottom and to produce uniform water quality throughout the tank. The water exchange rate can then be set to provide the fish with good water quality throughout the entire culture tank, even when operating up to maximum carrying capacity.

The velocity of the water rotating in the culture tank must be swift enough to make the tank self-cleaning, but not faster than the desired fish swimming speed. The tank becomes self-cleaning at water rotational velocities > 15 to 30 cm/s, which are adequate to create a secondary radial flow strong enough to move settleable solids (e.g., fish feed and fecal matter) along the tank's bottom to its center drain (Burrows and Chenoweth, 1970; Mäkinen et al., 1988). To maintain fish health, muscle tone, and respiration, a review by Losordo and Westers (1994) indicated that water velocities should be 0.5-2.0 times fish body length per second. For salmonids, Timmons and Youngs (1991) provided the following equation to predict safe non-fatiguing water velocities: $V_{safe} < 5.25/(L)^{0.37}$. where L is the fish body length in cm and where V_{safe} is the maximum design velocity (about 50% of the critical swimming speed) in fish lengths per second. In circular tanks, water velocities are usually somewhat reduced in a torroid region about the tank center,

which allows fish to select a variety of water velocities, as compared to raceway designs where velocities are uniform and much slower.

The self-cleaning attribute of the circular tank is also related to the overall rate of flow leaving the bottom-center drain and to the swimming motion of fish re-suspending the settled materials. However, only about 5 to 20% of the total flow through the tank is required to flush settleable solids from the tank's bottom-center drain, because the water rotational velocity and the swimming motion of the fish control the transport of settleable solids to the tank's bottom center drain (this is the principle behind the use of dual-drain tanks to concentrate settleable solids). Therefore, the flow through the culture tank does not have to be increased beyond that required to support a selected carrying capacity, assuming that the water inlet structure is designed properly.

The water inlet structure must be designed correctly to obtain uniform water quality, select specific water rotational velocities, and achieve rapid solids flushing. According to studies from the SINTEF Norwegian Hydrotechnical Laboratory (Skybakmoen, 1989; 1993), the tank rotational velocity is roughly proportional to the velocity through the openings in the water inlet structure. The impulse force created by injecting the flow into the tank controls the rotational velocity in the tank and can be regulated by adjusting either the inlet flow rate or the size and/or number of inlet openings (Tvinnereim and Skybakmoen, 1989).

Results from the SINTEF Laboratory indicate that injecting flow through an open-ended pipe creates poor mixing in the central-torroid zone (resulting in short circuiting of the flow), much higher velocity profiles along the tank wall than in the tank central-torroid region, resuspension of solids to all tank depths, and poor flushing of solids from the bottom. Additional SINTEF results indicate that distributing the inlet flow using a combination of both vertical and horizontal branches achieves uniform mixing in the culture tank, prevents short circuiting of flow along the bottom, produces more uniform velocities throughout the tank; and more effectively transports waste solids along the tank bottom to the center drain.

Because of their capability to concentrate settleable solids at their bottom and center, circular fish culture tanks can be managed as "swirl settlers." A portion of the flow (5-20% of the total) is withdrawn through the bottom-center drain with the bulk of settleable solids, while the majority of flow is withdrawn free from settleable solids at an elevated drain. Timmons and Summerfelt (1997) reviewed the application of dual-drains in circular culture tanks. Use of dual-drains has been reported used to help remove settleable solids from fish culture tanks since 1930. Patents covering specific dual-drain tank designs have been awarded to Lunde et al. (1997) (U.S. Patent No. 5,636,595) and Van Toever (1997) (U.S. Patent No. 5,593,574). A non-proprietary design, the "Cornell-type" dual-drain tank, is a circular culture tank with a center drain on the tank bottom and an elevated drain part-way up the tank sidewall (Timmons et al., in press). Separating the two drains so that one is part-way up the tank sidewall and the other is in the tank center makes the "Cornell-type" dual drain tank easy to install, even as a retrofit on existing circular culture tanks. Also, because the elevated drain in the "Cornell-type" design is part-way up the tank

sidewall, it does not capture many of the solids that sometimes “plume” up in the center of circular culture tanks under strong radial flows.

Depending on the settling velocity of fish fecal matter, use of the dual-drain approach can greatly increase the concentration of solids being removed from the bottom center drain. Dense and intact fecal matter can settle well, at a rate of 2-5 cm/s (Warrer-Hansen, 1982). Lunde and Skybakmoen (1993) report that 91% of the fecal matter and 98% of uneaten feed has been concentrated into the bottom flow leaving dual-drain culture tanks. However, different aquaculture feeds produce biosolids with variable settling velocities; finer and/or less dense particles may only settle at 0.01 cm/s (IDEQ, 1998), which would not allow solids to concentrate effectively at the bottom center of dual-drain tanks. Under the correct circumstances, the dual-drain approach has large economic implications; it can reduce the capital cost, space requirement, and headloss requirement of the downstream solids removal units (Timmons and Summerfelt, 1997).

Whether an internal or external stand-pipe is installed, a velocity of 30 to 100 cm/s should be used to size the bottom drain pipe and the stand-pipe, which would allow the heaviest/largest solids to rapidly flush through the pipe. Juell (1991) reported settling velocities for five different salmon diets (5-12 mm pellet diameter) ranged between 15.2 to 17.9 cm/s. However, sinking fish feed settles at different rates, depending on how the feeds were produced.

A simple, fast, and reliable method that can be used to remove mortalities from the bottom center drain is necessary to decreases labor costs, as well as to reduce the spread of fish disease and to maintain water level in the culture tank. There are a variety of approaches to address this need (Timmons and Summerfelt, 1997). A method in use at the Freshwater Institute simplifies the removal of dead fish from large circular tanks by incorporating the center drain outlet screen into the inner pipe of a two-pipe center post system (Figure 1). To remove dead fish, the inner pipe is raised inside of the fixed center post while the external standpipe over the mortality drain is removed, producing a surge of flow down through the center drain that carries the dead fish out of the tank (Figure 1).

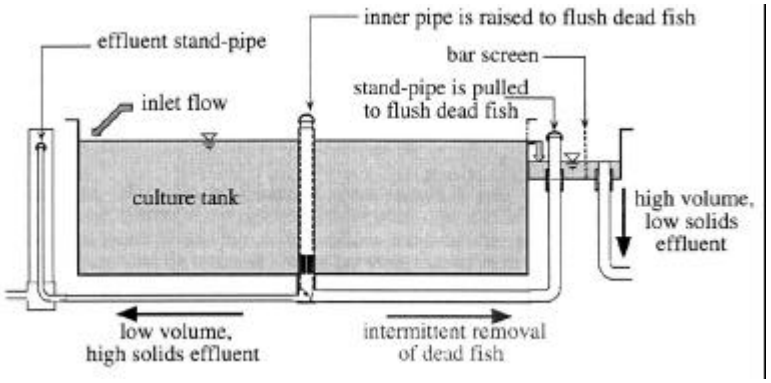


Figure 1. A concentric pipe system to flush solids and remove dead fish from the bottom center drain; also shown is an elevated side-wall drain for removing the high volume, low solids effluent, and a smaller bottom center drain pipe for removing concentrated settleable solids (Timmons and Summerfelt, 1997).

Raceway Tanks

Raceways are the most common rearing tank design prevailing in locations where aquaculture has tapped into huge groundwater resources. Such is the case with aquaculture in Idaho, which contains the largest producer of rainbow trout in the world (MacMillan, 1992). In Idaho, raceway dimensions are typically around 3-5.5 m wide, 24-46 m long, and 0.8-1.1 m deep (IDEQ, 1998). Raceways usually have a length to width ratio of 1:10 and a depth < 1.0 m, and require a high water exchange rate, e.g., one tank volume exchange every 10 to 15 minutes (Westers, 1991).

Water enters the raceway at one end and flows through the raceway in a plug-flow manner, with minimal back mixing. The plug-flow produces a concentration gradient along the axis in dissolved metabolites such as oxygen, ammonia, and carbon dioxide. The best water quality exists at the head of the tank, where the water enters, and then deteriorates along the axis of the raceway towards the outlet. As oxygen is often the limiting criteria, fish may congregate at the head of the raceways and cause an unequal distribution of fish density throughout the tank. It is also more difficult to distribute feed throughout raceways than it is within circular tanks.

The velocity of water through the raceway is generally 2-4 cm/s, so a substancial amount of solids settle in the rearing area. However, these solids are slowly moved downstream through the rearing area with the assistance of the swimming activity of larger fish (Westers, 1991; IDEQ Quality, 1998). A series of baffles spaced at intervals equaling the width of the raceway and placed perpendicular to the flow can be used to create high water velocities (20-30 cm/s) between the bottom of the raceway and the bottom edge of the baffle. The baffles allow solids to be continuously swept from the raceway (Westers, 1991). However, the Idaho Division of Environmental Quality (IDEQ, 1998) report that baffles can be troublesome, because they must be moved to work the fish and can provide a substrate for biosolids growth in the summer.

In practice, raceways are managed based on their oxygen design requirements, rather than for their cleaning requirements (Timmons and Young, 1991). The velocity required to flush solids from unbaffled raceways is much greater than the velocity required to supply the oxygen needs of the fish. However, the high water exchange rate supports high fish densities (Timmons and Young, 1991; Westers, 1991). Even so, raceways are incapable of producing the optimum water velocities recommended for fish health, muscle tone, and respiration.

Raceways are designed to minimize cross-sectional area and promote the maximum velocity, which is why many raceway systems are operated in series, with the discharge of the upstream raceway serving as the inflow water of the next one downstream. Some rearation is provided by hydraulic drops between raceways in series.

Because of their aspect ratios, raceways are very convenient culture tanks for managing fish when crowding or grading. Crowders or graders can be placed in the raceway at one end and slowly worked down the axis of the tank.

Raceways can be constructed side-by-side, with common walls, for maximizing the utilization of floor space and reducing construction costs. However, when constructed without common walls, because of their large aspect ratio (L:W), raceways require 1.5 to 2.0 times as much wall length as circular tanks (Westers, 1991). Circular tanks can also better structurally handle the weight of the confined water and can thus use thinner walls than rectangular tanks.

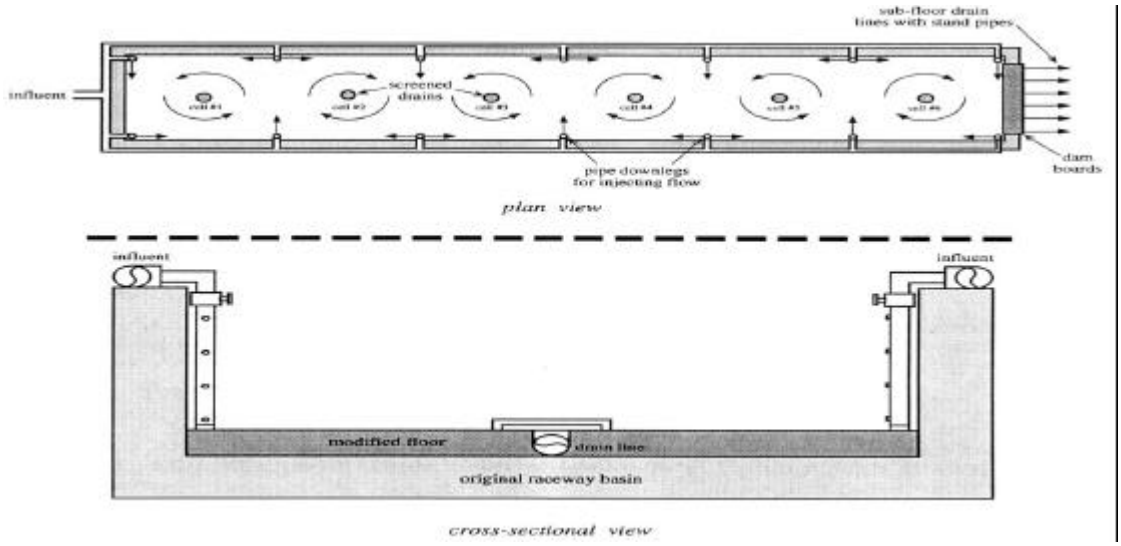
A quiescent zone devoid of fish is usually placed at the end of a raceway tank to collect the settleable solids that are swept out of the fish rearing area (Westers, 1991; IDEQ, 1998). These solids collection zones are the primary means for solids removal to meet discharge permitting at many large trout farms (IDEQ, 1998). The overflow rate recommended to capture solids in the quiescent zone is < 1 cm/s. Settled solids should be removed from these quiescent zones as frequently as possible; settling zones are cleaned occasionally as often as daily and at least twice per month (IDEQ, 1998). However, this prolonged storage allows for some nutrient leaching, solids degradation, and solids resuspension (due to fermentation of the organic matter). Suction through a vacumm pump is the most common method for removing solids from the quiescent zone (IDEQ, 1998) and sometimes from the fish rearing areas. Even with efficient vacuum systems, operating labor for solids removal has been reported to exceed 25% of the total farm labor (IDEQ, 1998).

Mixed-Cell Raceway Tanks

We have noted that circular tanks offer the advantages of elevated water velocities, uniform water quality, and good solids removal characteristics whereas linear raceways make better use of floor space and facilitate harvesting, grading, and flushing operations. The cross-flow tank is a recent hybrid design that incorporates the desirable characteristics of both circular tanks and linear raceways (Watten and Beck, 1987; Watten and Johnson, 1990). Water is distributed uniformly along one side of a cross-flow tank via a submerged manifold, and is collected in a submerged perforated drain line running the length of the opposite side. The influent is jetted perpendicular to the water surface with sufficient force to establish a rotary circulation about the longitudinal direction. Comparative production trials with hybrid stripped bass (Watten and Beck, 1987), tilapia (Watten and Johnson, 1990), rainbow trout (Ross et al., 1995), and lake trout (Ross and Watten, In Review) have been positive but application has been hampered by the need for the small diameter, fixed, and submerged inlet jets and drain ports, as well as costs associated with rounding the lower side areas to streamline flow. The rectangular mixed-cell tank avoids these problems while achieving the same overall objective: a hybrid tank design. Here, a standard raceway section is modified to create horizontal counter rotating mixed cells with cell length equal to vessel width (Figure 2). Cells receive water from vertical pipe sections extending to the tank floor and positioned in the corners of the cells. Vertical pipe sections incorporate jet ports that direct water into the cell tangentially to establish rotary circulation. The pipe sections can be swung up and out of the water during fish crowding or grading operations. Water exits each cell through a centrally located floor drain. Hydraulic characteristics of the tank have been established and indicate that tank performance approximates that of a circular tank (mixed-flow reactor), both with and without fish present. Water velocities averaged 15, 12, and 12 cm/s for tank surface, mid

depth, and bottom regions and were sufficient to scour and purge fecal solids. Cell interaction was significant with cell to cell exchange rates representing about 3 to 4 times the tank inflow rate. This characteristic contributed to the observed uniform distribution of fish throughout the vessel. Further, the energy requirement of the design was kept low (just 1.32 m of water head) through use of a large number of low velocity inlet jets. Given that the tanks drain is similar to that of a circular tank, application of double-drain solids concentration is feasible and desirable.

Figure 2. Illustration of a mixed-cell raceway tank.



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Value-Added Market Opportunities For Small and Medium Scale Businesses

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Overview of the U.S. Seafood Market

In the late 1980's the National Fisheries Institute, the leading trade organization for the United States fish and shellfish industry, adopted a theme "20 by 2000" signaling their anticipation that U.S. per capita consumption of seafood would rise to 20 pounds by the end of the century. However, since that time, or more precisely, since 1987 when consumption set a record of 16.2 pounds, seafood consumption in the United States has been drifting lower and in 1996 reached just 14.8 pounds per capita.

With flat to declining consumption, the question becomes *Are there opportunities in the U.S. seafood market for small and medium scale companies?* While the short answer to this question is "yes," it is important to understand the underlying dynamics of the U.S. seafood market before looking at specific opportunities and strategies for growth within a "no growth" market.

U.S. Seafood Supply

The United States seafood supply is made up of domestic capture fisheries, aquaculture production and imports. While U.S. seafood production increased significantly in the 1990's, setting a record in 1993, domestic landings have peaked and will likely decline as the annual catch quotas for several leading species, such as Alaskan pollock and Pacific cod, have been lowered. Thus while domestic seafood landings (capture fisheries) totaled 3.9 billion pounds (round weight) in 1987 and 8.2 billion pounds in 1993, landings have been decreasing since. In 1996, the last year for which full data is available, domestic landings totaled 7.5 billion pounds. Aquaculture production, while increasing in the United States, added approximately 750 million pounds in 1996, primarily catfish, trout and salmon (also clams, oysters, tilapia, striped bass and other species).

Table 1. Status of Major U.S. Fisheries

Species	1996 Catch (Million Lbs)	10 Year Trend
Alaskan Pollock	2,623	Level to slight decrease
Pacific Salmon	877	Up
Cod	637	Pacific Cod up, Atlantic cod down
Flounders	460	Up (mostly Pacific species)
Crab	392	Decreasing
Herring	318	Increasing
Shrimp	317	Decreasing
Clams	123	Decreasing
Rockfishes	95	Decreasing
Mackerel	65	Decreasing

The United States is a net importer of seafood both in terms of volume and value. In 1996 the U.S. had a seafood trade deficit of $4.7 billion on imports of $6.7 billion and exports of $3.0 billion. Leading seafood imports include shrimp, tuna, lobster and salmon.

It is important to note that much of the growth in supply, both domestically and via imports is the result of aquaculture. As capture fisheries continue to decline, the role of aquaculture will become even more import. In the past decade aquaculture has gone from being a stepchild to the U.S. seafood industry to its future salvation. Aquaculture now commands respect from all segments of the U.S. seafood industry, importers, wholesalers and retail and foodservice buyers. The aquaculture industry has arrived.

U.S. Seafood Usage

While U.S. per capita consumption may be flat or declining, the mix of products that make up the leading seafoods consumed in this country is changing. Many of the seafoods experiencing growth in consumption are from aquaculture.

When it comes to examining seafood consumption in the United States it is better to look at the parts rather than the whole. For example, a major element of U.S. seafood consumption is canned tuna and recent declines in tuna consumption may significantly affect the overall per capita figure while having little or no impact on the industry as a whole. What is significant for aquaculture is that salmon, shrimp and catfish have recorded gains in consumption over the past decade. If we produce it, at reasonable value, the market will respond.

To understand U.S. seafood consumption it is important to understand the U.S. seafood consumer. Through this understanding can come strategies for small and medium scale companies to serve segments of the U.S. market and achieve success. Niche marketing.

Table 2. Top 10 U.S. Seafoods 1990-1996 **Source: National Fisheries Institute**

		Pounds Per Capita						% Change
	1996	1995	1994	1993	1992	1991	1990	1990 vs 1996
Total	**14.8**	**15.0**	**15.2**	**15.0**	**14.8**	**14.9**	**15.0**	**-1.3%**
1. Canned Tuna	3.200	3.400	3.300	3.500	3.500	3.600	3.200	0%
2. Shrimp	2.500	2.500	2.600	2.500	2.500	2.400	2.200	+13.6%
3. Ak Pollock	1.620	1.520	1.520	1.200	1.230	0.990	1.270	+27.6%
4. Salmon	1.440	1.190	1.113	0.995	0.871	0.970	0.730	+97.3%
5. Cod[1]	0.918	0.983	0.928	1.030	1.076	1.120	1.380	-33.5%
6. Catfish	0.899	0.864	0.855	0.988	0.907	0.770	0.700	+28.4%
7. Clams	0.518	0.567	0.544	0.589	0.616	0.580	0.610	-37.0%
8. Flatfish[2]	0.384	0.302	0.361	0.623	0.507	0.380	0.570	-32.8%
9. Crabs	0.333	0.319	0.312	0.375	0.333	0.320	0.290	+14.8%
10. Scallops	0.269	0.244	0.292	0.257	0.272	0.250	0.300	-10.0%

[1] Atlantic and Pacific cod combined.
[2] Sole, flounder, halibut.

One of the reasons U.S. seafood consumption, on a per capita basis, has not reached higher levels is likely due to the fact that many Americans are of English and central-European origin where seafood was not a primary part of the diet. As a result, for many Americans (Asians and Scandinavians excepted) seafood was an "acquired" taste. A recent survey of U.S. consumers found that 12 percent of the respondents indicate they do not eat seafood, 32 percent were classified as "light (1 to 4 times in past four months) seafood consumers," 29 percent as "medium" (5 to 10 times) seafood consumers and 21 percent as "heavy" (11 or more times) seafood consumers.

Reasons For Eating Seafood

Americans consume, or do not consume, seafood for a variety of reasons including ethnic background, personal preferences, age, income, education and geographic region. In a 1994 survey[3] heavy seafood users reported that taste (96%) was the primary reason for eating seafood followed by nutrition (79%), meat substitute (66%), variety in the diet (64%) and special occasions (27%). While health may be an underlying reason for eating seafood, it is secondary to taste.

Reasons For Not Eating Seafood

When non-seafood consumers were asked why they did not eat seafood, the responses varied including: taste, difficulty in preparation, cost, rejection by one or more family members and problems handling fresh fish[4].

Eating More Seafood

When all seafood consumer groups (heavy, medium, light and non-users) were asked what it would take to increase their seafood consumption, the three seafood usage groups all gave "lower prices" as their top responses. Forty-two percent of non-users responding stated that "nothing" would cause them to eat more seafood[5]. Seafood marketing strategists believe the responses by non-seafood users indicate it would be difficult to convert this segment to seafood consumption. A better strategy would be to target light and medium users and induce these consumers to eat more seafood. Retail price promotion has proven to be an effective tool in reaching these consumers. Since all responding groups cited the need for easier preparation as a purchase criterion, the trend toward value-added seafood products may also increase consumption. Seafood safety was not a primary concern to survey respondents even though considerable negative publicity has been generated regarding this issue.

U.S. Seafood Consumer Demographics

As consumer surveys indicate, the U.S. market is far from homogenous when it comes to seafood consumption. For example, heavy seafood users are generally older (55-64 years

[3] Simply Seafood Magazine Consumer Survey
[4] Source: National Fish and Seafood Promotion Council
[5] California Seafood Council Consumer Survey

old), better educated and have higher incomes. Given the high price of many seafoods, such as shrimp, crab and lobster, these demographics are not surprising. However, according to the Bureau of Labor Statistics, African-Americans spend 26 percent more on seafood at home than the national average. Most likely African-Americans consume fresh catfish at rates higher than the national average. Asian consumers purchase far more whole fish (head on) than other groups. In reality, most U.S. seafood markets are niche markets with their own unique demographic characteristics.

Some U.S. Seafood Market Micro-Segments:

Asian	- Live fish, whole fish (high and low priced)
Hispanic	- Whole fish, low-priced species, dried fish
African-American	- Catfish

Size of the U.S. Seafood Market

For 1996, the U.S. seafood supply consisted of 13.7 billion pounds (round weight equivalent). This included 6.15 billion pounds of imports and 7.5 billion pounds of domestic landings. Aquaculture production, primarily catfish, trout, salmon, totaled less than 1 billion pounds. The U.S. seafood market had a wholesale value of $19.5 billion and a consumer value of $40.9 billion.

Growth Prospects for the U.S. Seafood Market

While the U.S. seafood market is not growing on a per capita basis, the market is increasing in overall volume. Per capita seafood consumption was 14.8 pounds in 1992 and 1996. However, population growth increased the overall market by 150 million pounds on an edible weight basis. This equals 450 million pounds on a round weight basis (equivalent to the current total output of the U.S. catfish industry). Using 1995 as the base year and 15.0 pounds per capita as base consumption, the U.S. market will require an additional 585 million pounds per year of seafood by the year 2010 based upon population growth alone.

This figure equals 1.6 billion pounds round weight; equivalent to the current size of the largest fishery in the United States, the North Pacific Alaskan pollock fishery. In reality most major U.S. fisheries are declining although two of the largest, Alaskan pollock and salmon re stable.

Role Of Value-Added In The U.S. Seafood Market

If the market is not growing, or the business is not profitable, one strategy for growth is through adding value to products currently produced. In the context of aquaculture products, there are several definitions of “value added” which may apply. They are:

Value-added to the Producer: Further processing of a product that provides revenue greater than the incremental cost of additional processing and/or further processing that increases sales volume without a decrease in profit margin.

Value-added to the Wholesale Seafood Buyer: Products which: reduce labor, decrease waste, provide easier stocking/storage/distribution, increase profit margins, increase sales volume, retain marketable life through distribution and come with market support.

Value-added to the Consumer: Products which have an increase "perceived value" (price/quality), provide greater convenience, are easier to prepare, taste good, are healthy, efficiently packaged and provide good storage life.

To see how value-added works, walk through a supermarket and locate all the products made from turkey. Start in the deli department and find smoked turkey breast, turkey pastrami and sliced turkey breast. Next move to the frozen food section and find the dinners and entrees made with turkey. Finally, move on to the meat department and check out the whole birds, parts, ground turkey and other items.

Creative Marketing Strategies For Value-Added Products

How to Develop Value-added Products

There is no "off the shelf" program involved in developing value-added products. However, there are some steps and strategies that individuals and companies can use to come up with product ideas that add value. For example:

- ✓ Talk to your customers. Find out what they need that they are not now getting.
- ✓ Talk to consumers. What do consumers want from products like yours?
- ✓ Know your own strengths and weaknesses.
- ✓ Brainstorm ideas.
- ✓ Be unique.
- ✓ Be flexible.
- ✓ Start small, learn from your mistakes.

Applying the Four "P's" of Marketing to Value-added Products

Product Strategies – *Differentiating*

- ✓ Make it unique (through processing and packaging)
- ✓ Size (make it bigger or smaller than normal)
- ✓ Appearance (red trout for example)
- ✓ Product form (butterfly fillets, skinless products, meat-only)
- ✓ Flavors (garlic sauces, marinades, spices, herbs)
- ✓ Convenience (easy to prepare, pre-cooked, portioned)
- ✓ Gift products (canned, retort pouched, boxed)
- ✓ Your product as an ingredient (stuffings)
- ✓ Make a niche product (snack, organic, natural ingredients)

Place Strategies – *Finding The Right Niche*

- ✓ On-site sales
- ✓ Local outlets (stores, gift shops, farmers markets, restaurants)

- ✓ Small independent and/or upscale retailers
- ✓ Ethnic markets
- ✓ Perishables-oriented stores
- ✓ Specialty seafood distributors
- ✓ Events (State Fairs, local celebrations)
- ✓ Caterers
- ✓ Tourist-based gift shops
- ✓ Direct mail (advertised on the Internet, magazines, catalogs)

Promotion Strategies – *Creating Image and Awareness*

- ✓ Develop a brand (that conveys an image)
- ✓ Create a logo (that supports the brand)
- ✓ Develop "signature" recipe concepts (for customers to use)
- ✓ Write your story (your business is unique)
- ✓ Your location makes you unique (take advantage of it)
- ✓ Find promotional tie-ins (with complimentary products)
- ✓ Use public relations (to get your message out)
- ✓ Advertise wisely

Price Strategies – *Developing Perceived Value*

- ✓ Identify premium price niches (uniqueness, limited supply)
- ✓ Make it easy to buy (small quantities, fast delivery, outstanding service)
- ✓ Understand buyer economics (visit stores/restaurants, study menus, ask questions)

Recommendations

Do Your Market Research First

Before launching major production, most aquaculture producers need to confirm whatever assumptions they have made regarding the marketability of their output.

- ✓ How big is the current market?
- ✓ Can the market absorb more supply without a major drop in prices?
- ✓ What price (farm gate) can the producer realistically expect for his products?
- ✓ Who is the competition? What are their production economics?
- ✓ What legal requirements exist for processing and packaging?

Start Small

Big mistakes are costly and sometimes fatal. Small mistakes can be learning experiences.

- ✓ Start with pilot scale production if possible.
- ✓ Limit initial orders of printed materials (promotional literature and packaging)
- ✓ Service a few customers well at the beginning.
- ✓ Seek objective evaluation regarding product quality.

Set Realistic Goals

If the market is $5.00 per pound, should you anticipate sales at $4.50, $5.00 or $5.50? When developing sales plans it is best to take a conservative approach on price. While the market price may be $5.00, this might be for suppliers that have developed long-term relationships with their customers and have a proven track record of delivery.

When it comes to production, don't over promise and under deliver. Buyers have long memories when it comes to being shorted on product they have purchased. Supply continuity is perhaps the most import element in the sales equation, even more important than price. Retailers with advertisements must be assured they will have product to meet their commitments. Restaurants with menu items based upon your product don't want to tell their customers they are out.

Sell it Yourself Initially

The best way to learn about your product and the marketplace is to sell it yourself. Make the sales calls; take the orders, delivery the goods. If you start your business using a broker to sell your product you will never learn what you need to know about the dynamics of the market. Once the business is in full production and sales are running smoothly you may want to consider sales agents. Brokers can provide a range of services, including invoicing, credit authorization and product delivery, but producers still need to have a thorough understanding of their market.

The Importance of Feed to the Economic Success of the System

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To date, the emphasis in Recirculating Aquaculture Systems (R.A.S.) has been on engineering, system design and monitoring. During the first conference in 1996, only two papers dealt specifically with feeds. It is this presenters opinion that too little attention is paid to feed/feed quality and its impact on the total system success, including profitability. The current situation can be summarized accordingly. (Table 1)

Table 1. Summary of Current Situation

- Diet is usually one of the highest production costs representing between 20 and 60% of total production cost.
- Most growers do not measure the differences in diet value and its effect on profitability
- Because of weak fish prices, more growers are wanting and selecting lower priced diets
- There are more manufacturers of aquaculture diets producing a wider range of products – more options
- Similar appearing diets may vary in value as much as 75%

It is well recognized that feed is a cost however seldom is feed viewed as an investment. Who gives consideration to the "engineering" of feed formulation and its profit potential?

In the planning phase where budgeting occurs, feed is given a line item cost where it is plugged into a model based on certain assumptions of performance. What happens though when the feed costs increase 5, 10, 20%? What happens when water quality deteriorates to the point where feed input is reduced or ceased until water quality recovers? The entire projections are blown out of the water. Growth is disrupted, days to market lengthened, cash flows are inadequate, ultimately profitability breaks down. Recently, at another aquaculture conference, an R.A.S. entrepreneur shared with me that he's only able to feed "50% of what he's supposed to be able to feed". Whether it's due to poor system design, poor feed quality, poor management or all of the above, he's dead in the water! "Paper fish", those that are grown in models don't distinguish between mediocre and superior feeds. They don't require good water quality and they never die. Unfortunately, there is no market for "paper fish".

Clearly, the continuing objectives of aquaculturists are to reduce costs and be the low cost producer. Ultimately, the real objective is to increase the difference between the value received for the product produced and the input costs or profitability.

There are numerous companies offering a wide range of diets so how do you make the right selection, the one that's best for the profitability of your R.A.S.?

Diet Cost Per Pound is widely used to select feed, but bear in mind that you may get what you pay for with poor performance.

Diet Cost Per Pound of Gain goes a step further factoring in Diet Cost & Feed Conversion Rates, a performance measure.

Ultimately, the profitability of an R.A.S. should be the most business minded means of feed selection. Income Over Diet Cost measures the return on the feed invested.

In order to fairly collect the data needed to make these evaluation Protocols (Table 2) in field trials must be adhered to.

Table 2. Protocol - Field Trials

- Rainbow Trout was the targeted species
- Commercial farms – practical growing conditions – farmer managed – professionally assisted
- 2 diets – coded for confidentiality; all diets used were commercially available
- 2 reps per diet
- No. fish per rep 1500 +
- No. of days 90+
- Demand feeders or hand fed to satiation
- Market value of fish $1.25 per lb.
- Objective: Focus on profits (Income Over Diet Cost)

Bear in mind that Diet A was from one supplier while Diet B was from four different suppliers. Clearly, based on Diet Cost alone, Diet B was the best choice. (Table 3.)

Table 3. Diet Cost Per Pound

Trial No.	Diet A	Diet B	Difference
1C	$0.194	$0.161	$0.033 (20.5%)
2C	$0.189	$0.178	$0.011 (6.2%)
3C	$0.220	$0.204	$0.016 (7.3%)
4E-BT	$0.250	$0.200	$0.050 (25.0%)

Using Diet Cost Per Pound of Gain, the results were mixed as to which was the best choice. (Table 4.)

Table 4. Diet Cost Per Pound of Gain			
Trial No.	**Diet A**	**Diet B**	**% Difference**
1C	$0.316	$0.291	+ 8.6%
2C	$0.278	$0.290	- 4.2%
3C	$0.262	$0.275	- 4.7%
4E-BT	$0.545	$0.686	- 20.6%

Breaking it down still further, Income Over Diet Cost offers a measure of profitability. All trials were equalized to 100,000 pounds of gain. Clearly, Diet A in all cases generated greater return than Diet B. (Table 5.)

Table 5. Income Over Diet Cost Equalized to 100,000 lb. of gain for the best feed.			
Trial No.	**Diet A**	**Diet B**	**Difference**
1C	$93,378	$87,296	$6,0873 (6.5%)
2C	$92,250	$82,008	$10,242 (11.1%)
3C	$99,877	$83,436	$16,441 (19.7%)
4E-BT	$82,892	$51,131	$31,761 (62.1%)

Based on these results, it requires only a 2% increase in growth to completely pay for a 10% increase in feed cost. Additionally, a 1% increase in processing yield offsets that same 10% increase in feed cost.

How can such results exits? There are numerous Diet Related Factors which influence feed performance and profitability. (Table 6.)

Table 6. Diet Related Factors Associated with Performance – Profits	
Energy Content	Fineness of Grind
Nutrient Energy Ratio	Method of Processing
	Pelleting
	Expanding
	Extrusion
Ingredients/Digestibility	Negative Factors
	Pesticides
	Mycotoxins
	Anti-metabolites
Ingredient Stability	Changing Formulations
Palatability	Pellet Size, Uniformity & Stability
Fines	

This dilemma of feed selection becomes increasingly difficult as the feed options available increase. What can be done to derail this diet dilemma?

- Understand and accept the potential for increased profits from the use of proper diets and make a personal commitment to do something!
- Make your supplier your success partner: Qualify, share information, communicate regularly, and set goals and work together to achieve them.
- Conduct diet trials on your farm: Dedicate 10-30% of production capacity, budget resources, confirm performance data on your farm, compare to the best, use professional help and proper test protocols and do computer modeling.
- **Focus on profits!**

Digestibility Issues of Feeds for Water Recirculating Systems

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Director of Nutrition
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Introduction

Feeding fish in their aqueous environment takes on dimensions beyond those considered in feeding land animals. As fish production systems become less dependent on natural food organisms and more dependent on prepared feeds, the need for nutritionally complete feeds becomes more critical. In highly modified environments such as water recirculating systems, nutritionally complete feeds are a necessity and the digestibility of these feeds can play a large role in the success or failure of the aquaculture production system.

The concept of nutrient availability has universal acceptance in the area of animal nutrition. The principle is attributable to the fact that nutrients in feedstuffs are recognized to be incompletely digested and metabolized by animals. The nutritional value of a feed or feedstuff is based not solely on its chemical composition but also on the amount of the nutrients or energy the fish can absorb and use.

This presentation will consider the importance of feed digestibility in water recirculating systems. Consideration will be given to factors that affect the digestibility of nutrients as well as methods of evaluating the digestibility of various feedstuffs. Utilization of available nutrient data in feed formulation will also be discussed

Importance of Feed Digestibility

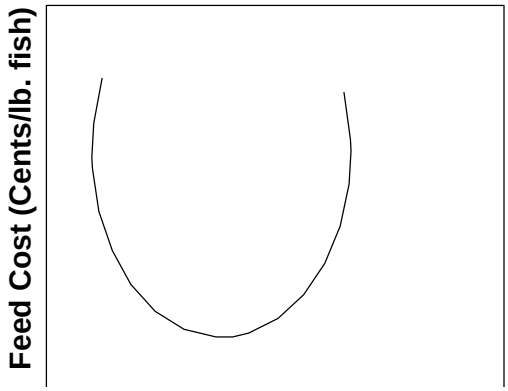
The bioavailability of nutrients or energy in feedstuffs for fish can be defined mainly in terms of digestibility or, in the case of energy, metabolizability. Digestibility refers to the fraction of the nutrient or energy in the ingested feedstuff that is not excreted in the feces. Metabolizability describes the fraction of the digested energy that is not excreted in the urine or through the gills. Both digestible energy (DE) and metabolizable energy (ME) have been used to express feedstuff values for fish (National Research Council, 1981, 1983) but many researchers use and report only DE values because of difficulties in obtaining ME values for fish.

Feed digestibility impacts a number of production parameters and issues; not least of which is economics. Digestibility is one of the major factors that effects the efficiency of feed utilization. Economic efficiency (i.e., feed cost per pound of fish) is determined by multiplying feed conversion by the feed cost per ton of diet. In that digestibility impacts feed

conversion, it also impacts the feed cost per pound of fish. The relationship between feed cost per ton of feed and feed cost per pound of fish produced is illustrated in Figure 1 below. The shape of the curve is a function of the efficiency of feed utilization.

Feed digestibility, by definition, has an impact on nutrient excretion to the environment. The excretion of waste nutrients to the environment is of particular concern in water recirculating systems; especially those with biological filter systems. If the waste nutrient load presented to the bacteria in the biological filter system is dramatically altered by significant shifts in the digestibility of the diet, water quality can suffer to the point where a system shutdown can occur. This can produce high mortality and markedly reduce profits.

An emerging issue for all animal production systems, including aquaculture, is their effect on the environment, and by far the main concern is the concentration of nutrients in manure. In the United States, legislation is being enacted to regulate and modify manure disposal methods. Several European and Asian countries have already imposed strict measures on farming activities as a means to limit pollution (Headon, 1992; Schwartz and Hoppe, 1992). Similar measures have been taken in some regions of the U.S. to deal with agricultural pollution (Brown, 1992). In addition to feeding for maximum performance and profitability, nutritionists must now consider feeding regimes that minimize excretion of critical nutrients.



Factors Affecting Digestibility of Feedstuffs

Digestibility of nutrients from various feedstuffs is affected by a great number of factors. Although it is beyond the scope of this presentation to address all of the factors that influence digestibility, several of the more prominent ones will be highlighted.

Probably the single greatest factor influencing the digestibility of a given feedstuff is the species of fish to which it is being fed. The differences in digestive physiology and biochemistry that exist among the various species of fish is quite remarkable when compared to the land dwelling species that are raised in commercial agriculture. With this variation in mind, the other factors discussed in this section should be viewed as generalities; realizing that they may not apply to all aquacultured species.

The apparent digestibility of a complete feed depends, to a large extent, on the digestibility of the protein, fat, carbohydrate and ash fractions of the selected dietary ingredients for the particular species being fed. Although not a complete data set, apparent digestibility factors for a number of ingredients and species can be found in the National Research Council=s Nutrient Requirements of Fish (1993). Diets composed of highly digestible ingredients generally exhibit a highly digestibility coefficient than diets containing less digestible ingredients.

Processing of ingredients and finished feeds can also have a significant impact on their digestibility. Proper handling and processing of fish meal is essential to prevent production of high levels of biogenic amines. These breakdown products of proteins can lead to impaired digestion and poor performance if they are at high levels. Stability of fish oil and residual oil found in fish meal is essential to prevent oxidative rancidity from occurring. Oxidized fats and oils are poorly digested and may also produce deficiencies of fat soluble vitamins.

Some ingredients, such as soybean meal, require heat processing to eliminate a trypsin inhibitor factor before they can be fed to fish or other monogastrics. The degree to which soymeal is toasted is a critical factor in determining its digestibility. The meal should be toasted enough to eliminate the trypsin inhibitor, however, if excessive toasting occurs the availability of a number of amino acids (especially lysine) is markedly reduced.

Processing of the finished feed itself can also play an important role in its digestibility. This topic is being covered in detail in another of the presentations and thus will not be discussed here other than to say that one should give consideration to this factor in any production system.

A number of management practices can also effect the digestibility of a feed, especially in a recirculating system. It has been found in a number of species that as meal size increases, digestive and absorptive efficiencies decrease (Solomon and Brafield, 1972; Elliot, 1976; Windell et al., 1978; Andrews, 1979). Thus, more frequent feedings of smaller meals will tend to increase the digestibility of a given diet.

Water quality and dissolved oxygen levels will also play a role in how well fish can digest and absorb their feed. Of course in recirculating systems, the digestibility of the diet can also impact a number of water quality factors. Sorting out which came first can be a difficult and frustrating task.

Any discussion of ingredient digestibility would not be complete without at least mentioning enzymes. A discussion of enzymes should be a topic in and of itself to do it justice, but a few generalizations will be noted here. Many of the differences observed between species, with respect to the digestibility of a given ingredient or nutrient, are a function of whether a given species possesses an endogenous source of a digestive enzyme. Advances in biological

engineering are allowing for production of a number of enzymes on a commercial scale. These products can enhance the digestibility of a number of nutrients including: carbohydrates, proteins, lipids, and minerals. Key factors to consider as we go forward with enzymes in fish feeds will be the optimums of pH and temperature versus those of land-based homotherms.

Methods of Evaluating Digestibility

Methods for evaluating the digestibility of feeds and ingredients fall into the two general categories of biological and chemical analyses. Biological methods would include measuring production parameters such as growth, growth rate, and feed conversion ratio. Measuring the deposition of specific nutrients in the carcass is another way of evaluating the availability and balance of amino acids and the availability of some essential elements.

Digestibility coefficients can be determined for feeds and ingredients via indirect and direct methods. The indirect method involves the use of a nondigestible marker, such as chromic oxide (Cr_2O_3), which is included in the diet at a low concentration. It is assumed that the amount of the marker in the feed and feces remains constant throughout the experimental period and that all of the ingested marker will appear in the feces. The digestibility of the nutrient in question can be determined by assessing the difference between the feed and fecal concentrations of the marker and the nutrient or energy. The direct method involves measuring all the feed consumed by the fish and all of the resulting excreta. This method has only been used successfully with rainbow trout and is very difficult to employ.

A number of chemical tests can also be used to measure ingredient and diet quality. These tests address a number of issues previously described as they relate to ingredient digestibility. Several chemical tests for protein quality are used to measure the effects of processing of ingredients on protein quality. These tests include: pepsin digestibility, protein dispersibility index, potassium hydroxide solubility index, and urease index. Most of these tests were designed for soybean meal, but some are applicable to other protein sources including animal and marine by-products.

Lipid quality can be assessed by measuring hydrolytic and oxidative rancidity. Tests that aid in measuring oxidative rancidity include: peroxide value, thiobarbituric acid test (TBA), anisidine value, and 20 hour AOM test. Hydrolytic rancidity is generally measured as free fatty acid values.

Feed Formulation Considerations

Formulation of diets requires three major inputs. Firstly, one must know the nutrient requirements of the fish to which the diet will be fed and from this knowledge establish the nutrient specifications for the diet. Such nutrients will be provided by various ingredients and therefore knowledge of the content of these same nutrients within the ingredients is the

second requirement. Because a least-cost situation is desirable, the final requirement is to know the current market price of the selected ingredients. With this information, numerous computer programs are able to generate least-cost diets.

In order to formulate the most cost effective diets, whose impact on the recirculating system and ultimately the environment can be predicted, one must formulate based on digestible or metabolizable values. Although values exist for a number of ingredients and a few species, the data set is far from complete. Obtaining good digestibility values for ingredients is difficult for fish due to their aqueous environment, however, it is precisely this data that will be required as we move forward to meet the challenges of feeding fish while at the same time giving consideration to the impact our diets have on the environment.

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Selection of Pelleted, Expanded, and Extruded Feeds

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Feed represent 50-60% of the production costs of farmed fish making it the single most significant costs to farmers. The first fish feeds were typically moist, semi-moist or steam pelleted with very low levels of fat concentration. These early diets tended to fall apart easily which fouled the water. Additionally they had limited shelf life. Fish feed sold in the United States for recirculating aquaculture systems is now far more sophisticated and is typically made via an extruder, an expander, or a steam pellet mill. Options include sinking, slow sinking, and floating. Each one of the three pelleting processes can be defined. The industry trend is evolving rapidly towards extruded or expanded products and away from steam pelleting.

Of primary concern to recirculation aquaculturists are feed cost, amount of fines, size, digestibility, buoyancy, vitamin and nutrient contents, shelf life, water stability, durability, palatability, and shape. All of these factors are affected by the manufacturing process which still remains as much an art as it is a science. Not only does each machine act differently, formulations and ingredients differ and individuals add their own interpretations concerning their opinion of an "ideal feed".

Steam Pelleting

Steam pelleting of fish feeds has been employed since the 1950's. The initial stage of production of any feed involves grinding the raw ingredients. After the ground mash is premixed, steam is added to condition and partly gelatinize the starches which assist in pellet binding. The mash is typically exposed to steam for short periods of time (less than 35 seconds), and exposed to processing temperatures of 100-180° F. Steam pellets are typically cylindrical in shape and are made 1.5 to 2 times longer than in diameter and marginally hard with a glassy exterior. A good example of what a pellet looks like would be to look at a rabbit feed. The conditioned mash is forced through a die and the resulting pellets are cut by a series of knives to a predetermined length. After the pellets are cut to their desired length, they are blown dry with a final moisture content of 9-10%. The final product has almost a glazed look to it and it is fairly dense and will sink. Advantages to pelleting include:

1) Less energy is required during manufacture.
2) Less heat means less destruction of heat sensitive nutrients, medications, and vitamins.
3) Initial cost is less.

Disadvantages of pelleting included:

1) Shorter cooking time and lower cooking temperatures and resultant pressure do not fully gelatinize the starch resulting in marginal pellet durability. Pellet binder which is "nutritionally blank" must be added to the formulation.
2) Product can only be made to sink because of its greater density
3) The sharp ends of the pellets combined with the softer nature cause breakup of the feed and a greater incidence of fines.
4) The smallest sized pellet that can be made is roughly 2.4 mm.
5) Feeding behavior is not easy to determine when the feed sinks.
6) Total fat content can not exceed 20%.

Extruded

Extruded feed has been catching on since the early 1990's and may be the product of choice for the future. The premixed mash is introduced into an extruder barrel where significant amounts of moisture are added. This high moisture mash is then exposed to intense pressure, heat and friction which results in starch gelatinization two to three times that found in steam pelleting. In many extrusion lines, the mash is brought up in moisture and temperature in a preconditioner before it enters the extruder barrel. Preconditioning the mash can help improve palatability, digestibility, durability, and potentially allows feed to be made faster than without preconditioning. Processing temperatures during extrusion can reach up to 300°F. When this super heated mixture is then forced through a die, a rapid reduction in pressure occurs which causes the pellets to expand and potentially float. Upon exiting the die, the moisture level of extruded pellets is 10-15% higher than in steam pellets, so significantly more amounts of energy must be expended to dry the product to 10% moisture. Advantages of extruded feed include:

1) Fat levels higher than 20% are possible.
2) The expansion can be controlled to allow the product to sink, slow sink or float.
3) Floating feed can be an effective management tool for feed behavior observation.
4) Higher pressure, temperature and cooking time makes both the carbohydrates and proteins more available resulting in better feed conversion ratios (feed cost per pound of fish weight gain makes up for the slightly higher price)
5) Better digestibility means less waste for the system to handle.
6) Carbohydrates are used as binders so "nutritionally blank" ingredients are not required to bind the product. Better feed conversions and reduction in total fecal load is the result.
7) Structural integrity allows for smaller, more consistent sizes.
8) Pellets are durable, uniform and have few fines.
9) The reduction in fines, combined with lower solid and dissolved wastes contribute to improved water quality. Better water quality leads to improved fish health and better performance of the solid removing device and biofilters.

Disadvantages of extruded feed include:

1) Nutrient, medication and vitamin degradation is higher because of the additional heat used in the manufacturing process forcing these ingredients to be supplemented at higher levels.
2) The initial equipment costs, combined with nutrient degradation and a slower production rate force extruded feed to be slightly more expensive the steam pelleted feed (average cost of .01/pound higher).
3) Product is less dense and will fill up a bulk truck before the truck reaches it's maximum weight limit (typical bulk trucks might be able to hold 40,000 pounds of extruded feed and 42,000 pounds of pelleted feed).

Expanded

The expanded feed manufacturing process is similar to that of extruded feed except the expandite cooked mash must be sent through a pellet mill to form the pellets which typically results in sinking pellets (some units when combined with skilled operators can produce floating feed as well). Expansion does not require as much moisture as extrusion and the pellets can be dried without heat which reduces operating costs. Expanders produce denser pellets than extruders but not as dense as a steam pellet (the exterior glazing associated with steam pelleting does not appear). There are only a few expanders currently employed in the United States to produce fish feed.

Comparison of Feed Manufacturing Techniques			
	COMPRESSED PELLETS	EXTRUDED	EXPANDED
Initial feed cost	lowest	highest	intermediate
Starch gelatinization %	<40	>80	60-80
Max. temp. (F)	180	300	300
Max. fat level %	20	40	30
Digestibility	good	best	better
Sinking available	yes	yes	yes
Floating available	no	yes	possibly
Slow sink available	no	yes	possibly
*Fines upon receipt %	1 to 6	<1	<1
Vitamin and nutrient degradation	lowest	highest	intermediate
Feed conversions	worst	best	intermediate
Uniformity of feed	variable	excellent	good
Availability	most mills	some mills	few mills
*Fines can result from poor handling practicing of finished feed or minimal grinding			

The chart on the previous page is made assuming some generalizations. Actual performance is predicated upon ingredients, grinding, individual machines and operator choices.

Summary:

Advances in fish feed manufacturing technology have given the fish farmer several types of feed from which to choose. Extruded and expanded processing methods improve durability and digestibility. Additionally, extrusion adds the ability to produce a variety of feed buoyancy tailored to the needs of the system, farmer, and fish .Extruded feed typically produces feed with the best feed conversion numbers as well as producing product uniform in size/shape/quality. Expanded product typically is about as good as extruded product and at times is very difficult to tell apart from extruded. Steam pelleting is preferable when adding medication, but is not as desirable because of its limitations concerning buoyancy and feed conversion numbers. Size of ground pre-manufactured product together with species being raised, digestibility, and amount of fines all vary from manufacturer to manufacturer. System limitations might give the advantage to one feed over the other. Initial up front cost of a feed many times will not give you the true cost to raise your fish to market size. It is critical for the fish farmer to have a strong working relationship with, not only the feed representative, but also the nutritionists responsible for formulating their diets.

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Formulating Feed for Tilapia Reared in Recirculating Systems

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Introduction

Producing feed for Tilapia reared in recirculating systems presents several challenges. Not only do the fish have to grow rapidly under high density rearing conditions but the complete feed, has to have low environmental impact. Peleted feeds are not recommended for water reuse systems. Extruded feeds, including crumbles impart both greater digestibility and better water quality characteristics.

Nutrient requirements normally applied to practical feed formulations are not adequate in high density rearing situations. Nutritional contributions of vitamins, minerals, key lipids, protein and energy from the environment can not be counted on to contribute to growth. In addition to completely meeting nutritional requirements, the quality of ingredients and economic constraints play major roles in commercial feed formulation.

Many feed ingredients can be used to meet nutritional requirements but not all ingredients should be major components of complete feeds. Many are not sufficiently digestible, and some contribute to the production of excessive body fat or fillet pigmentation.

Ingredient Quality

Quality feeds can only be made with quality ingredients. Quality assurance begins at the feed mill with ingredient reception. Before grains are received, several tests for mycotoxins are performed as standard operating procedure. Corn is rejected if Aflatoxin levels exceed 20 ppb or Fumonisin is found at levels above 1 ppm. Wheat is screened for D.O.N. and is rejected if levels exceed 5 ppm. Fishmeal is accepted or rejected based on histamine levels.

Ingredient Analysis

After acceptance, periodic samples of ingredients are taken, and analysis for protein, fat, fiber, ash and moisture are carried out. These data, along with amino acid, and fatty acid profiles are used to update the nutrient specification matrix. The use of the nutrient matrix in feed formulation programs will be discussed at a later point. However, it is important to periodically update the matrix, as seasonal nutrient variability within key ingredients can impact extrusion characteristics, and final feed quality.

Quality Assurance

During extrusion bulk density of the product is measured, and extrusion parameters are adjusted to meet final characteristics. The completeness of float or sink and the amount of fines produced, are periodically monitored and adjustments in extrusion conditions (amounts of water , steam, oil and feed mash input rate) are made to produce a feed that meets customer specifications.

This loss in moisture as well as the amount of fines generated, and the loss of product upon start-up of the extruder are collectively termed shrink. The ingredient moisture level at reception, can range from 10 to 14 % and the moisture level in the finished product after drying of 6 - 8%. A shrink rate or percentage of the total feed mash, of 5% or below can depending on the extrusion situation be an acceptable cost, but increasing levels of shrink impact the final cost of the feed and ultimately profitability. In situations where shrinkage is high or variable, formulation, extrusion operation and ingredient quality or all three must be reexamined.

Fish Oil Specifications

While Tilapia can effectively utilize soy oil, fish oil is still the major oil component in most Tilapia feeds. However, its use requires special standards. In the commercial arena a key is to purchase cold processed fish oil. Upon arrival additional antioxidants are added. The addition 250 - 500 ppm BHA & BHT can be added by the supplier or by the manufacturer at ingredient reception. Fish oils acceptable for use in fish feeds should contain less than 3% free fatty acids, less than 1% moisture, less than 1% nitrogen and less than 20% Totox defined as (2 X (peroxide value) + (Anisidine Value). Fish oil should not be stored in heated tanks as increased storage temperature can contribute to increased oxidation.

Fish meal is used to maintain palatability as well as meet essential amino acid requirements. Fish meals are sold by protein levels, ash levels, and the temperature of processing. Principal indicators of fish meal quality are Salmonella SP negative, less than 500 ppm Histamine and stabilized with atleast 250 ppm Santoquin.

Finished Product Analysis

Finished feeds are periodically tested to assure that tag specifications in accordance with national regulations are being met. In the United States quality control procedures are in place to verify national standards established for both feed ingredients and finished feeds. In this way feed tags provide some guarantee for purchases of the freshness and quality of feeds. Additionally, feeds should be periodically monitored for non-nutrient components. Mycotoxins, Thiobarbateric Acid, histamine, as well as levels of feed protectants, Ethoxiquine, Vitamin E, and Vitamin C should also be periodically monitored. Samples

should be taken from every 5th. bag of 50 to 60 bags and pooling the samples. Quantitative testing should only be performed by an approved laboratory for testing.

Finished Product Storage

Finished products are stored at ambient temperature of six months after manufacture. Ambient temperature rather than frozen storage is utilized so that should a concern be raised that a feed is not performing as expected, the comparison can be made with feed of the same "age" but stored cool and dry. Complete records should be kept for each batch of feed delivered to farmers. These data should include details of date of delivery, batch number, and quantity delivered. Many of the issues brought to the feed manufactures attention are the result of improper storage conditions.

Feedstuff Digestibility

Even though both Catfish and Tilapia are omnivores, digestibility of feedstuffs is different between the species. While it is not universally accepted, it is not appropriate to use a diet formulated to rear Catfish in ponds for Tilapia in recirculating systems. Wilson and Poe, 1985 have shown that extrusion as compared to peleted processing increased the digestibility of energy but had no effect on the digestibility of protein. Popma, 1982 described the difference in digestible energy between Catfish and Tilapia fed the same feedstuffs. Differences in digestible energy of key ingredients used in both Catfish and Tilapia commercial feeds are summarized in the following table.

Common Feedstuff Digestibility Differences

Ingredient Digestible Energy (Mcal / g)		
Ingredient	Catfish	Tilapia
Alfalfa, 17% Protein	0.67	1.01
Corn Grain		
Raw	1.10	2.46
Processed	2.53	3.02
Menhaden Fish Meal	3.90	4.04
Molasses	3.47	2.94
Soybean Meal, 48% Protein	2.58	3.34
Wheat Flour	2.55	2.89

Ingredients selected for use in Tilapia feeds can significantly impact the digestibility of the finished feed. Growth, feed conversion and pollution generated are directly related to the degree of digestibility of the finished feed and the amount and type of feces produced.

Feedstuff Selection

Feedstuff selection for recirculating systems is not only limited by unit costs for energy, protein, amino acid composition and ingredient digestibility but the level of phosphorus is also a consideration. The phosphorus / nitrogen of many ingredients such as animal by-product meals, with the exception of fish meals, have a high P / N ratio. Generally plant protein ingredients such as soybean and corn gluten meals have lower P / N ratio, which is a desirable characteristic for inclusion in low environmental impact diet formulations.

An example of a derivative criteria the phosphate / nitrogen ratio of several ingredients provided by Cho et al 1994 can be added to the nutrient specification matrix. The nutrient matrix will be discussed at a later point but it is important to know that actual nutrient levels as well as derivatives such as the P / N ratio can be used to assist in formulating low impact aquafeeds.

Feed Stuff Selection
Phosphorus/Nitrogen Ratio

Ingredient	Protein	Nitrogen	Phosphorus	P / N
Herring Meal	**72**	**11.52**	**1.00**	**0.087**
Feather Meal	**85**	**13.60**	**0.70**	**0.051**
Corn Gluten	**60**	**9.60**	**0.70**	**0.073**
Peanut Meal	**47**	**7.52**	**0.60**	**0.080**
Soybean Meal	**48**	**7.68**	**0.65**	**0.085**
Wheat, Soft	**11**	**1.73**	**0.30**	**0.174**
Yellow Wheat	**9**	**1.42**	**0.25**	**0.176**
Poultry Meal	**58**	**9.28**	**2.40**	**0.259**
Menhaden Meal	**62**	**9.92**	**3.00**	**0.302**
Wheat Midds	**17**	**2.72**	**0.91**	**0.335**
Meat /Bone Meal	**50**	**8.00**	**4.70**	**0.588**

U.S. discharge standards do not at present dictate low phosphorus standards. Coincidentally, many recirculating systems in turn discharge 1% or less of the rearing capacity on a daily basis. However, discharge standards of that small amount of water that is discharged will increasingly come under more restrictive regulations. Additionally, the Aquaculture produced fish can and have commanded increased values in the open market, due in part to the clean and wholesome image espoused by some marketing efforts.

Vitamin Requirements And Stability

Vitamin requirements for Tilapia have been determined for only vitamin C, Stickeny et al. 1984, Soliman et al. 1986; vitamin E, Satoh et al. 1987; Riboflavin and Pantothenic acid, N.R.C. 1993. Eventhough the complete vitamin requirements for Tilapia not been established, high density rearing conditions, make it necessary for the commercial feed

manufacturer to provide a complete vitamin package. The commercial feed manufacturer in addition must provide a guarantee for 3 months after production of stated tag claims.

Extrusion manufacture increases digestibility of fish feeds over peleted feeds. At the same time vitamin stability during ingredient mixing, grinding and extrusion is a major challenge for the commercial feed manufacturer. The relative stability varies with the vitamin Coelho, 1991.

	Very High	High	Moderate	Low	Very Low
Vitamin:	Choline Chloride	Riboflavin	Thiamin Mononitrate	Thiamin HCl	Menadione
		Niacin	Folic Acid		Ascorbic Acid
	Ascorbic Polyphosphate	Pantothenic Acid	Pyridoxine		
	Sulfate				
	Monophosphate	Vit. E	Vit. D3		
		Biotin	Vit. A		
		B 12			

Recent advances in the stabilization of vitamin C made by Hoffman LaRoche, Pfizer and BASF, have resulted in chemically stabilized forms, Ascorbic 2-Polyphosphate, Ascorbic 2-Sulfate and Ascorbic 2-Monophosphate. These chemically stabilized forms of vitamin C are highly stable during extrusion manufacture. Earlier efforts to stabilize vitamin C using lipid encapsulation did not result in a products able to with stand the temperatures and moisture levels of extrusion manufacture. Commercial manufacture of aquafeeds seldom if at all uses an unstabilized form of vitamin C.

Vitamins are generally supplemented in excess of requirements to allow for losses during manufacture, shipping and storage prior to feeding. While new forms of vitamin C have greatly improved the cost effectiveness of vitamin C fortification, over formulation of other vitamins for extruded aquafeeds is still commonly practiced today.

Vitamin Addition Before Extrusion

Vitamin	Percent Overage
A - Acetate	**150**
D 3 – Cholecalciferol	**130**
E	**110**
Thiamin	**250**
B 12	**130**
Biotin	**110**
Folic Acid	**110**
Riboflavin	**110**
Niacin & Choline	**110**

Hurdle Strategy Of Feed Manufacture

After a feed is made the interaction between cationic minerals, vitamins and unsaturated fatty acids is seemingly in a race toward oxidation The wholesomeness of a finished feed is often dictated by how well it is stabilized. A well made feed contains several additives and ingredients that serve as hurdles to slow the oxidation of essential nutrients in a finished feed. Traditional feed formulation may include one or two of these feed protectants but the production of compete feeds should incorporate a more complete approach.

Hurdle Strategy For Wholesome Feed Manufacture

- BHA, BHT in Fish Meal and Oil
- Ingredient Arrival Testing
- Vitamin E Supplementation
- Stabilized Vitamin C Supplementation
- Extrusion Pasteurization
- Mold Inhibitors
- Feed Quality Assurance Testing

Practical Feed Formulation

Practical formulations commonly use no more than six to eight feedstuffs. The nutrient data matrix is utilized to meet minimum and maximum restrictions. The minimum and maximum restrictions along with the nutrient data base and ingredient costs are used in linear programs to optimumize the mixture of ingredients that best meet the nutrients considered.

The level of dietary energy is adjusted to provide the optimum protein: energy ration for the size of Tilapia being fed. The amino acid profile of the protein is balanced for essential amino acids. In this example Methionine is the first limiting essential amino acid. Even though the Methionine level in the commercial feed profile does not meet the standard reference level of 0.85 % of the diet, the sulfhydro amino acid requirement is met with a combination of cystine and Methionine levels. Based on the ingredient amino acid profiles, once the minimum levels lysine, methionine and threonine are met the rest of the amino acids will be available in excess.

Whether a feed completely floats, sinks, or partially sinks is dictated by the level of starch in the formula as well as the degree of striation of the starches. The float as well as the degree of pellet durability can be adjusted by the selection of feed stuffs. The amount of water and oil added internally to the feed can either enhance or inhibit the striation of starches.

Least Cost Formulation Restrictions for Tilapia Feed

Nutrient	Restriction (Percent) Minimum	Maximum
Protein	32.5	
Fat	4	6
D.E. (Kcal / Kg)		
Fiber		4
Lysine	1.95	
Methionine	0.77	
Met. & Cystine	1.10	
Threonine	1.05	
Arginine	1.90	
Starch	22.5	
Ash		7.25
Available Phosphorus	0.6	0.9
Calcium	0.7	
Phos. / Ratio		0.17

Nutrient Composition Of Typical Tilapia Feeds

	Nutrient Composition of Typical Tilapia Feeds			
Fish Weight	< 2.0 Gms.	2 to 10 Gms.	10 to 50 Gms.	50 to 545 Gms.
Nutrient				
D.E. - Min.	4.0 Kcal / g	3.8 Kcal / g	3.5 Kcal / g	2.9 Kcal / g
Protein - Min.	48	45	40	36 or 32
Lipid - Min.	10	10	10	10 to 5
Fiber - Max.	4	4	5	5
Ash - Max.	7	7	9	9
Starch - Min.	12	14	20	24
Ca. - Max	1	1	1	1.5
Avail. P04 - Min.	0.6	0.6	0.6	0.6
Lysine - Min.	2	2	1.9	1.7
Methionine - Min.	0.9	0.85	0.85	0.7
Threonine - Min.	1.2	1.2	1.2	1

Next Steps

There is a continual need to provide more efficient, cost effective diets for Tilapia reared in recirculating systems. New ingredients and strategies to enhance nutritional value of finished feeds need to be continually evaluated. The ultimate goal of this process is to expand the range of cost effective raw ingredients. In the immediate future maximizing

quality by furthering the understanding of the interaction among supplemental enzymes and the major dietary ingredients.

Acknowledgments

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Biological Filters: Trickling and RBC Design

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Fish produce a variety of wastes including solids, ammonia, carbon dioxide and other materials. These wastes must be removed from the culture water or they become toxic to the fish. Many methods have been developed to remove the wastes fish produce. However, in this paper we will concentrate on removal of ammonia and nitrite, both of which are highly toxic to fish and other aquatic organisms.

In fresh water systems there are two common methods used to remove ammonia: ion exchange and biological filters. In brackish or salt water systems ion exchange is not a viable alternative because salt in the culture water quickly (usually in a matter of minutes) saturates all of the adsorption sites on the ion exchange media. Thus, biological filters are the only widely used method of removing ammonia and nitrite from all types of aquacultural systems.

Biological filters consist of some solid media that serves as a surface on which bacteria can attach and live. Water containing ammonia and/or nitirite flow over this media (and the bacteria attached to it). The bacteria remove the ammonia from the water and use it as an energy source to drive their life processes. These bacterial excrete nitrite, require oxygen and produce carbon dioxide as byproducts of their respiration. A different group of bacteria remove the released nitrite and convert it to nitrate. These bacteria use the nitrite to nitrate conversion for an energy source, they use nitrite and oxygen, and produce nitrate and carbon dioxide. The ammonia to nitrite conversion produces hydrogen and uses up alkalinity. Although many bacteria species can participate in these conversions it is usually assumed that the ammonia to nitrite conversion is carried out primarily by *nitrosomona* sp. and the nitrite to nitrate conversion by *nitrobacter* sp. (Water Pollution Control Federation, 1983). Thus, the primary purpose of biological filters is to remove ammonia and nitrite from aquatic culture systems.

Management of water chemistry is one of the most important considerations in recirculating aquacultural systems. Proper system management results in the minimization of stress, which in turn leads to healthier fish and more profitability. The different components in a recirculating system are designed to control one or more water quality functions, such as ammonia, temperature, dissolved oxygen, or solids. Biological filters are designed to maintain the various forms of inorganic nitrogen (e.g., ammonia, nitrite, and nitrate) at levels that are healthy for the fish being cultured.

Basic Nitrogen Cycle

Nitrogen plays an important role in the structure and make-up of all living organisms. In the aquacultural environment, nitrogen exists in the inorganic forms of nitrate, nitrite, ammonia, and nitrogen gas and in many forms of organic nitrogen. The nitrogen cycle in recirculating system aquaculture can be described pictorially by Figure 1. Nitrogen originates from the atmosphere primarily in the form of nitrogen gas. Animals excrete nitrogen in the form of ammonia, amino acids, urea, and uric acid. Plants excrete nitrogen in the form of amino acids and proteins. Also, nitrogen is released through decomposition of dead animals and plants, uneaten feed, and bacterial cells and wastes.

The presence of nitrogen gas in recirculating system waters is usually of little importance, because very little of it is fixed into organic matter. The concentration of nitrogen gas in recirculating system waters depends on the partial pressure of atmospheric nitrogen compared to dissolved nitrogen, as well as temperature and salinity of the water. Only when nitrogen gas becomes super-saturated does it become problematic to recirculating system aquaculture.

Plants in recirculating system waters release amino acids and peptides. However, compared to the amounts of nitrogenous compounds released by animals, those released by plants are of little consequence (Spotte, 1979). Wastes in recirculating aquacultural systemsCurea, amino acids and uric acidCare rapidly broken down (in a process called mineralization) into ammonia by heterotrophic bacteria. This mineralization process is depicted in the nitrogen cycle (Figure 1) where the organic compounds are broken down into their inorganic components of which ammonia predominates.

The two processes in the nitrogen cycle that are of major importance in recirculating system aquaculture are nitrification and denitrification. Ammonia is oxidized to nitrite and then to nitrate through a series of biochemical reactions called nitrification. Denitrification is primarily a reduction of nitrate to nitrogen gas by anaerobic bacteria. Nitrification as it relates to biological filtration in recirculating aquacultural systems will be the focus of this paper.

Ammonia, nitrite, and nitrate are all highly soluble in water. Ionized ammonia, NH_4, exists at equilibrium with un-ionized ammonia, NH_3, in water. The relative concentration of ionized and un-ionized ammonia depends primarily on temperature and pH**C**the higher the temperature and pH, the higher the concentration of un-ionized ammonia. Unless otherwise noted in the text, ammonia will refer to total ammonia, which is the sum of ionized and un-ionized ammonia (often refereed to as total ammonia nitrogen or TAN). Nitrite exists at equilibrium with nitrous acid in water, with the relative concentration again depending on pH and temperature. Nitrite, when mentioned in the text, will refer to the sum of nitrite and nitrous acid. Nitrate is the conjugate base of nitric acid, a strong acid. Since strong acids usually dissociate completely in water, nitrate exists in its conjugate base form only.

Nitrogen Control

Of the many forms of nitrogen present in aquacultural system waters, ammonia, nitrite, and nitrate are considered to be of major importance. Nitrogen gas, if super-saturated, can cause morbidity and mortality. However, nitrogen gas can easily be stripped from system waters by agitating the water in some fashion (Speece, et al., 1988; Parker, et al., 1984). Organic forms of nitrogen are rapidly broken down by bacteria in aquatic systems to inorganic forms of nitrogen; the primary inorganic form is ammonia. Aqueous ammonia can be toxic to fish and other aquatic organisms at relatively low concentrations (see Boyd, 1979 for a good summary of the toxic effects of ammonia). Therefore, ammonia must somehow be controlled, converted to a non-toxic form, or removed from aquacultural system waters.

Nitrification Kinetics

Nitrification is the oxidation of ammonium to nitrate via nitrite. Nitrification is carried out by a few species of autotrophic bacteria; bacteria that derive their energy from these oxidations and not from oxidation of carbon compounds (Painter, 1970). The importance of nitrification is that it produces an oxidized form of nitrogen (i.e., nitrate) that may participate in denitrification reactions. When denitrification is complete, the result is the loss of readily available nitrogen from water.

Nitrification in recirculating aquacultural systems typically occurs by the action of two genera of autotrophic bacteria: *Nitrosomonas* and *Nitrobacter*. Autotrophic bacteria derive their energy from inorganic compounds, as opposed to heterotrophic bacteria that derive energy from organic compounds. Ammonia removal is a two step process, where ammonia is converted to nitrite by *Nitrosomonas* and nitrite is converted to nitrate by *Nitrobacter*. Equations 1 and 2 (Water Pollution Control Federation, 1983, USEPA, 1975, and Boyd, 1979) show the chemical reaction of this conversion:

$$NH_4^+ + 1.5\,O_2 \rightarrow 2\,H^+ + H_2O + NO_2^- \quad \textbf{(1)}$$

$$NO_2^- + 0.5\,O_2 \rightarrow NO_3^- \quad \textbf{(2)}$$

The reactions shown in Equations 1 and 2 release energy that is used by *Nitrosomonas* and *Nitrobacter* for cellular growth and maintenance. Oxygen serves as an electron acceptor and is the only electron acceptor that can be used by *Nitrosomonas* and *Nitrobacter* (Water Pollution Control Federation, 1983).

Growth of nitrifiers is very slow and cell yield per unit of energy is low. Most of the energy produced in the oxidation of ammonia and nitrite is used by nitrifying bacteria to produce new bacterial cells. One school of thought considers the slow growth to be inevitable while others believe that higher growth rates are possible given the right, but currently unknown conditions (Painter, 1970). Autotrophs are relatively inefficient, compared to heterotrophs, in energy

usage to form cellular material. Ecologically, low energy efficiency yields a small biomass production capable of oxidizing a large quantity of ammonia (Fenchel, 1979). Nitrifiers use a lot of energy to produce a small amount of cell mass. In biofilter performance, this is a desirable characteristic, since much ammonia and nitrite are removed with relatively few cells produced. Biofilters will be slower to clog and small volumes of sludge will be produced.

Stoichiometry

The stoichiometric (chemical balance) requirements of ammonia oxidation were described by Gujer and Boller (1986) as:

$$NH_4 + 1.90_2 + 2\ HCO_3 \rightarrow NO_3 + 1.9\ CO_2 + 2.9\ H_2O + 0.1\ CH_2O \qquad \textbf{(3)}$$

where CH_2O represents cell biomass. Equation 3 can be used to predict three stoichiometric requirements of nitrification: oxygen requirements, alkalinity consumption and biomass production. The oxidation of 1 g of ammonia requires 4.34 g oxygen and 7.14 g alkalinity and produces 0.21 g of bacterial cells, 1.98 g acid, and 4.43 g nitrate.

When oxygen, alkalinity, and micro-nutrients are excluded, the growth limiting substrate for *Nitrosomonas* is ammonia and for *Nitrobacter* is nitrite. *Nitrobacter* also grow faster than *Nitrosomonas*. Because nitrification proceeds from ammonia oxidation to nitrite oxidation, the overall kinetics of nitrification are usually controlled by ammonia oxidation (Water Pollution Control Federation, 1983).

Factors Limiting Nitrifier Growth

The ability of biological nitrification to adequately control ammonia and nitrite in recirculating aquacultural systems depends on a variety of factors that limit nitrifier growth. Studies on the kinetics of nitrification show how effective nitrifiers are under ideal experimental conditions, i.e., oxygen and alkalinity are sufficient and ammonia is the only limiting factor. However, under normal operating conditions, there are a variety of factors that, individually or in combination with each other, will reduce the efficiency of biofilter operation. One important consideration about biofilter performance is acclimation. Biofilters can usually be adapted to water quality and operating conditions that, according to theory, should normally cause the nitrifying system to fail. Most successful biofilter systems operate outside of ideal laboratory conditions much of the time. However, these operating biofilters are running under a balance of conditions within the biofilter and culture system. Operating at or just outside of the limits normally considered safe in laboratory experiments can be done, but be careful! You must monitor water quality and be able to correct problems when they occur, there is not much forgiveness and catastrophic failures can happen.

pH

The interactions of pH, nitrification, and water quality can be quite complex. In general, nitrification is most efficient at pH levels ranging from about 7.5 to 9.0. At the higher pH ranges (8.5 - 9.0), nitrification rates are fastest given sufficient ammonia. However, at the low ammonia concentrations usually found in aquacultural systems, operating at a pH of about 7.0 can be efficient. Because pH also effects the relative concentration of ionized and un-ionized ammonia in water and nitrifying bacteria use the ionized form, operating at a pH of about 7.0 usually increases the efficiency of the recirculating aquacultural system. Another positive effect of operating at the lower pH is that the toxicity of ammonia to fish increases with increasing pH, so operating in the lower range also reduces ammonia toxicity.

Alkalinity

Equations 1 and 3 illustrate the relationships of acid produced in the oxidation of ammonia and destruction of alkalinity by the consumption of bicarbonate ions in cell production and neutralization of generated acid. The stoichiometric relationship (Equation 3) indicates that 7.14 g of alkalinity (as $CaCO_3$) are used to oxidize 1 g of ammonia. Therefore, nitrification produces acid and uses alkalinity, so alkalinity in recirculating system aquaculture must be continually monitored and adjusted. Many basic solutions can be used to buffer, or add alkalinity, to recirculating systems, including sodium bicarbonate, calcium carbonate, sodium hydroxide, etc. Care is needed in the selection of the buffer, as too much of a strong buffer (e.g., sodium hydroxide) can lead to wide swings in pH, which is stressful to the fish and nitrifying bacteria. Buffers that contain calcium (e.g., lime or calcium carbonate) can lead to excessive calcium build-up in the recirculating system. When the calcium becomes supersaturated, subsequent additions of lime cause precipitation of calcium carbonate in the system, unavailable alkalinity, and a mess. Many aquaculturists prefer to use sodium bicarbonate (baking soda) as an alkalinity supplement because it produces small changes in system pH , is readily available, and inexpensive.

Temperature

Temperature directly affects growth and nitrification rates of nitrifying bacteria. Jones and Morita (1985) isolated an ammonia oxidizing bacteria capable of nitrification and growth at temperatures of -5° C. Optimal growth occurred at 22° C for cells grown at 5° C and lethal temperatures were about 29° C. Cells grown at 25° C had optimal growth temperatures of 30° C and lethal temperatures of 38° C (Jones and Morita, 1985). Basically, research on temperature and its effects on nitrification show that nitrification occurs and can be acclimated to conditions that are also favorable to aquatic species. Nitrification rates are slower at lower temperatures and increase linearly through the range of temperatures found in most aquacultural applications (Wortman, 1990).

Dissolved Oxygen

Dissolved oxygen is critical for nitrification to occur. As dissolved oxygen levels decrease to 1.0 mg/L in biological filters, dissolved oxygen rather than ammonia becomes the growth limiting factor. To prevent dissolved oxygen from becoming a limiting factor, water entering a biofilter should have minimum oxygen levels of 2.0 mg/L (Water Pollution Control Federation, 1983). Biofilter designs using trickling or rotating biological contactors benefit from natural oxygenation occurring as air flows past media covered with biofilms.

Light

Designs for biological filters should prevent too much light from contacting the bacterial surfaces. Olson (1981) found light intensities less than 1% of sunlight intensities were inhibitory to nitrifying bacteria. Light is believed to oxidize cytochrome C in both species of bacteria. *Nitrobacter* is more sensitive to light because it contains less cytochrome C than *Nitrosomonas* (Olson, 1981). Horrigan, et al. (1981) found similar results for light inhibitors and concluded complete darkness was superior to diurnal cycling of light regimes for nitrifying bacteria.

Salinity

Kawai, et al. (1965) found that nitrification in saline waters was maximal when done at constant salinities. Fresh water nitrifiers were completely inhibited in saline waters. Salt water nitrifiers were also found to be more sensitive to oxygen concentrations than fresh water nitrifiers. Bower and Turner (1981) noted that abrupt changes in salinity probably shocked nitrifiers, thus reducing their ability to remove ammonia and nitrite. Slowly acclimating working biological filters to salinity conditions results in successful transitions from one salinity level to another. A maximum change of 5 ppt should not adversely affect biofilter operation. However, gradual changes in salinity over several weeks is preferable.

Other Water Chemistry Concerns

Many chemicals have been found to be inhibitory or toxic to nitrifying bacteria. A general rule is if a substance is toxic to fish, then it is probably toxic to the bacteria. Chemicals used to treat fish for a variety of diseases and parasites can be toxic to nitrifying bacteria at therapeutic levels for fish. Antibiotics are generally toxic. Treatments used to remove external parasites, such as formalin, potassium permanganate, or peroxide, oxidize bacteria, as well. System design should include a means to take biofilters off-line during short treatments and allow for water to be flushed from the system prior to reestablishing flow.

Particulates in system waters can have several effects on biofilters. Particles that are larger than the pore sizes in the filter media can clog the filter, and lead to reduced filtering capacity and efficiency. Some nitrifiers will grow on particles that reside in the system for extended periods of time and may actually perform the majority of nitrification occurring in the system (at the expense of the nitrifier populations on the biofilter media). If the system is flushed or

filtered for particulate, the nitrifiers are removed from the system and nitrification may essentially cease for a period of time. Most of the particulate are made up of organic compounds that will break down rapidly in the system from heterotrophic bacterial activity. This break down consumes oxygen needed by the nitrifiers and fish in the system.

Filter Configurations Used

There are litterly hundreds of biofilter configurations. However, they can be classified into one of several groups, the groupings based primarily on how they operate. Submerged filters are designed to keep the solid media in the filter continuously submerged in the water. Upflow submerged filters have the water flow from bottom to top, while downflow submerged filters have the water flow from the top toward the bottom. The oxygen supply for the bacteria in a submerged filter must be supplied from the water, a factor that often sets the flow rate through the filter at a higher value than would be necessary if the flow rate were dictated by ammonia removal only. Submerged biological filters tend to plug fairly easily unless the media has a high void percentage and is at least 2 cm in diameter.

Trickling filters look much like a submerged filter (i.e. they consist of a tube or tank filed with media through which water is passed). However, they are operated differently in that the free water surface in the filter is maintained below the media. The culture water is pumped to the top of the filter and uniformly distributed over the top of the filter. As the water trickles down over the media it absorbs oxygen from the air in the filter and supplies ammonia and/or nitrite to the bacteria growing on the media. If properly designed, trickling filters rarely plug, they are quite stable over time, but they require some pumping head (at least the height of the filter). Their primary advantage is the oxygen for the bacteria in the filter comes from the air in the filter. Thus, they are well aerated, and the water flow rate through the filter is independent of oxygen supply.

Rotating biological contactors (RBC=s) typically are designed in one of two configurations. The first consists of a horizontal shaft that has flat or corrugated circular plates attached to it. The plates are typically spaced at least one cm apart along the shaft. The shaft is attached to bearings and mounted above a tank such that about 40 to 45 percent of each plate surface is below the top of the tank. Waste water is pumped into the tank and the RBC is rotated by a motor such that the plates rotate in and out of the water during each revolution. Bacteria grow on the plate surfaces and as the bacteria enter the water they remove ammonia or nitrite and as they rotate through the air they extract oxygen from the air. The second RBC configuration replaces the disks with a drum filled with some light weight media (e.g. plastic) that has a high surface to volume ratio and a high void ratio. As the drum rotates the bacteria on the media are alternately supplied with ammonia or nitrite from the wastewater and oxygen from the air. RBC=s are generally quite stable in operation, have a high ammonia removal efficiency compared to some other biofilters, and they require very little head loss (typically 2 to 3 cm of water). Their primary disadvantage is that they require a power source to turn them and mechanical breakdown can be a problem, particularly with a poorly designed unit (Hochheimer, 1990; Wheaton, et al., 1991).

Fluidized bed biological filters consist of a bed of sand or other heavier than water media that is small in diameter. Water is pumped up through the sand at a fast enough velocity to Afluidize@ the sand (i.e. suspend the sand grains in the vertical column of flowing water). Bacteria grow on the sand grains and as the water passes by the fluidized sand the bacteria extract ammonia and/or nitrite. Fluidized sand filters require a small foot print for the size of the filter because the small sand grains provide a very high specific surface area per unit of volume of filter. These filters require continuous pumping and have an essentially constant pressure drop across the filter the pump must overcome (Summerfelt and Cleasby, 1996).

There are several types of bead filters including those using heavier than water and those using lighter than water beads (Timmons, 1997; Delos Reyes and Malone, 1998). Most systems use a small tank specifically designed to provide the flow and operation desired for the bead filter. The tank typically has an upflow configuration and a screen across the top of the bead bed to prevent the beads from exiting the filter. Wastewater is pumped upward through the bead bed. Bacteria on the bead surfaces provide nitrification of the ammonia and nitrite and the beads provide a screening effect that traps considerable solids. Thus, bead filters can be used as solids removal devices or as biofilters (Beecher et al., 1997).

Start-up

Start-up must be considered when designing and operating recirculating aquacultural systems. Establishing and maintaining a robust population of nitrifying bacteria that is capable of removing the intended ammonia load is critical to success. Operators of recirculating aquacultural systems must acclimate the nitrifying bacteria population to unique conditions and develop a population that will be sufficient to remove levels of ammonia produced when fish are introduced into the system.

Bower and Turner (1981 and 1984) concluded from their studies that seeding filters with filter media from established filters could significantly reduce new system start-up times. Addition of 10% wet filter media from established seawater systems reduced start-up time 81% (4 days compared to 21 days) for ammonia removal and 89% (4 days compared to 37 days) for nitrite removal compared to controls. The use of dry filter media from established filters, seawater from established filters or wet filter media from freshwater filter systems produced considerably less reductions in filter start-up time than did the addition of wet filter media from seawater systems. Additions of commercial additives provided variable results, none of which were as rapid as the wet filter media additions.

Seeding of freshwater systems was examined by Carmignani and Bennett (1977). The authors found that addition of approximately 3% wet filter media from an established filter decreased start-up time by 48% compared to control filters. Ammonia and nitrite at levels above 15-20 mg/L can become toxic to nitrifying bacteria. Ammonia and nitrite levels must be monitored at least daily during start-up to prevent toxic levels from building up.

System start-up presents problems for many recirculating aquacultural system operators. Nitrifying bacteria populations grow slowly and do not quickly adapt to change.

Heterotrophic bacteria (bacteria that populate systems and remove organic carbon substances from the water) can out compete nitrifying bacteria. Starting the biological filter with media from existing and similarly operating filters coupled with inorganic ammonia additions, in lieu of fish, can be an efficient way to start biofilters in less than a month=s time.

Design of a Trickling Filter for Ammonia Removal

The basic concept of trickling filters is to provide a surface on which microbial films grow. Trickling filters come in many configurations and contain various media types. Traditional wastewater treatment trickling filters use rock for a media and are typically short in height, large in diameter, and cylindrically shaped. Trickling filters for aquaculture are predominately cylindrical and, with the advent of light weight, plastic media, the filters can be made tall in relation to their diameter. Media types are either dumped or fixed. Dumped media allows for randomly packed filters and media shapes are usually some configuration of hollow cylinders, spheres, or other regular shapes. Fixed media resemble corrugated fiberglass roofing materials and are arranged in vertical, horizontal, or angular orientations to water flow.

Water containing a dissolved substrate flows over an exposed microbial film in a trickling filter and is biologically oxidized to form a more stable material. The biofilm cannot utilize a substrate unless it is transported to the microorganisms. Substrate flux (in this case ammonia removal) within the biofilm results in a lower substrate concentration surrounding the microorganisms than the concentration of ammonia in the bulk liquid. Closed aquaculture systems are ammonia limiting (as opposed to those in wastewater treatment, which are oxygen limiting) and rely on physical processes for mass transport of ammonia to the biofilm and not on diffusion. Therefore, it is essential that ammonia is constantly made available to the microorganisms for maximum ammonia removal.

Factors Affecting Trickling Filter Performance

Hydraulic Loading

Hydraulic loading rates are very important design considerations for both trickling and rotating biological contactor filters. The total influent flow rate per unit of biofilter cross sectional area is defined as the hydraulic loading rate and is expressed as flow per unit area ($m^3/m^2 \cdot d$). The lower limit of hydraulic loading is the minimum wetting rate (MWR), which is the lowest flow rate that wets all of the media in the filter. The MWR is important since media not wetted will not support bacterial growth. Grady and Lim (1980) reported that one manufacturer of random packed media recommended a minimum hydraulic loading of 29 $m^3/m^2 \cdot d$ (Norton Actifil). Roberts (1985) reported minimum hydraulic loadings of 32 to 55 $m^3/m^2 \cdot d$ for random packed media (plastic pall rings). For design purposes, a MWR of 50 $m^3/m^2 \cdot d$ is considered safe.

The upper irrigation rate (UIR) is the maximum flow rate in a filter before scouring of the

biofilm occurs. In high void fraction media, like those used in many biofilters, exceeding the (UIR) usually causes scouring of the biofilm and loss of active nitrifying surfaces. Roberts (1985) reported UIR values of 72 to 188 $m^3/m^2 \cdot d$ for randomly packed plastic media (plastic pall rings). Grady and Lim (1980) reported a UIR range of 234 to 350 $m^3/m^2 \cdot d$ (Dow Surfpac). A design UIR of 300 $m^3/m^2 \cdot d$ should be acceptable.

The relationship between filter performance and hydraulic loading should not be mistakenly considered as synonymous with substrate loading. At a constant substrate influent concentration, increases in the hydraulic loading rate decreases the percent substrate removed. For the same conditions, the mass substrate removal rate increases (Grady and Lim, 1980). This is logical since, as the flow increases, the residence time decreases in the filter and for a constant concentration, the mass of substrate input to the filter increases. Research by Hochheimer (1990) shows that mass loading of ammonia to biofilters is a limiting factor (i.e., because ammonia is a limiting nutrient and diffusion of ammonia to bacteria in the biofilter limits removal). When operating and designing biofilters, this means that flow rates to biofilters should be as high as possible (but under UIR limits of 300 $m^3/m^2 \cdot d$) while minimizing pumping costs.

Mass Transport

Movement of substrate (ammonia, nitrite, oxygen, etc.) to and wastes (nitrite, nitrate, etc.) from bacterial cells is often a limiting factor in trickling filter performance. Hochheimer (1990) developed equations to describe the diffusive and mass transport relationships in a trickling filter. Media in a working biofilter becomes coated with a biofilm, resulting from the growing bacterial population. The two components where mass transport become important are within the biofilter (transfer of substrate(s) to the surface of the biofilm) and then within the biofilm. Getting substrate to the surface of the biofilm is associated with concentrations of the individual substrates in the culture system water and movement of the water through the biofilter. Work from Hochheimer (1990) indicates that ammonia concentrations are too low to be influenced by diffusion in the water flowing through the biofilter. Physical mass transport of the ammonia then becomes the dominant factor in determining availability of ammonia to the nitrifying bacteria. The other substrates (oxygen and alkalinity), if kept at recommended levels, are dominated by diffusion.

Bacterial cells growing within the biofilm require all nutrients to diffuse into the biofilm to become available to the growing cells. Similarly, waste products from the bacteria must diffuse out of the biofilm. Within the biofilm, diffusion is the primary transport method of substrate to bacterial cells. Again, because ammonia concentrations are so low, diffusion becomes the most limiting factor in ammonia removal. Nitrite behaves similarly to ammonia in both the water and biofilm components.

The significance of these transport processes is that flow rate of water through the biofilter becomes important in determining the effectiveness of a trickling filter (or any nitrification processes) in recirculating aquacultural systems. Designs of trickling filters should strive for

flow rates that are near the UIR so that maximum mass transport of substrate to the biofilm is achieved. Designs should also allow for air flows through the trickling filter to maximize oxygen availability.

Depth

Trickling filter depth is primarily determined by available space in which the filter is being placed and the weight of media. Filter containers for biofilters with heavy media must be adequately constructed to hold the combined weight of media, water, and biofilms. The filter depth must be adequate to allow for both steps**C**ammonia and nitrite removal**C**to take place. However, no good design information is available for determining the most efficient depth. Presently, most designs consider available area, weight of media, and costs for filter containers to determine filter depth. In trickling filters depth is usually directly proportional to pumping costs.

Cross Sectional Area

Cross sectional area of a biofilter is defined as the top area of the filter container. For systems with multiple filters, the total cross sectional area is determined by summing the individual areas. The cross sectional area is important in the calculation of the hydraulic loading rate.

Void Ratio

Void ratio is the proportion of free space volume in a filter to the total filter volume. In a trickling filter there are voids that are not filled in by the media. High void ratios reduce clogging and allow for air to move more freely in the filter. Remember, trickling filters work by allowing a thin film of water to flow across media surfaces. Filters with low void ratios tend to interrupt this thin flow of water and trap many solid particles. Clogged filters must be cleaned, which often leads to reduced filter efficiency.

Specific Surface Area

Specific surface area is defined as the surface area of a particular media per unit volume. Since bacteria attach to the surfaces of the media, it is the surface area that determines how much nitrification can occur. It is desirable to have a large specific surface area to minimize the volume of filters required in a particular system. Floor space and ceiling heights usually determine available space for biofiltration, so adjusting specific surface area is one way to obtain a desired filtration capacity in a given volume. However, most media costs are proportionate to specific surface area. The challenge in design is to maximize specific surface area while concurrently maintaining relatively high void fractions, low costs, and adequate filter flow rates. Usually filter design involves an iterative process of selecting media, calculating volumes and cost, and then evaluating outcomes.

Media Type and Size

There are a wide variety of media types and sizes available for trickling filters. These include rocks, sand, plastic media (designed for biofilters), packing materials, and corrugated plastic shapes. Any material that is non-toxic to the bacteria and fish and is stable in a water environment should be acceptable.

Trickling Filter Design Example

The following section will show an example for the basic design of a trickling filter for a recirculating aquacultural system. Water quality requirements and design estimates are conservative. The design example will be for a single culture system to grow hybrid striped bass with a maximum carrying capacity of 9072 kg (20,000 pounds).

Basic Design Assumptions

Several assumptions are made about the recirculating aquacultural system. Water exchanges are necessary to replenish water that evaporates and water lost from the system due to solids removal. Critical variables in the design that impact filter sizing are total mass of fish at maximum loading, system temperature, daily feeding rate, and density of fish in the system.

1. There is 100% reuse with weekly exchanges of 20% of the system water volume and daily additions of water to maintain system volume.

2. Hybrid striped bass in the system average 0.7 kg (1.5 pounds) each at the end of the growing season.

3. The system temperature is to be maintained at 24°C (75°F).

4. The fish are fed at 2% of body weight on a daily basis.

5. The maximum fish density in the system is 120 kg/m**;** (1 pound per gallon).

6. The system exchanges water at least 2-3 times per hour with the biological filter.

Media Data

The type of media and its specific surface area will directly affect the filter volume. Selection of the media should consider specific surface area, weight, void ratio, cost per unit of surface area (not volume), availability, type of material, and durability. Design of the filter is an iterative balance between cost and volume. Remember, media that is too small will tend to trap particles and clog from bacterial film growth. Also, the material must be strong enough to support the weight of media above it, not be toxic to bacteria or fish, and must not break down under normal operating and cleaning conditions.

Parameter	Value

Type	plastic rings
Diameter	2.5 cm (1 inch)
Void Fraction	0.92
Specific Surface Area	220 m**5**/m**;** (67 ft^2/ft^3)

Water Quality Requirements

The following water quality requirements apply to hybrid striped bass (Hochheimer and Wheaton, 1997):

Parameter	Limit
Dissolved Oxygen	> 5.0 mg/L
pH	6.5 - 9.0
Alkalinity (total as $CaCO_3$)	50 - 400 mg/L
Ammonia (as NH_3-N)	0.0125 mg/L
Nitrite (as NO_2-N)	0.1 mg/L
Carbon Dioxide	0- 15 mg/L
Nitrogen (gas)	< 110% total gas saturation
Total Suspended Solids	< 80 mg/L

Design Calculations

Water Volume

At a density of 120 kg/m**;**, the total volume of water required is:

$$Volume_{Water} = 9072 \text{ kg of fish} \div 120 \text{ kg/m}^3$$
$$Volume_{Water} = 75.7 \text{ m}^3$$

Feed Consumption at Maximum Production (per day)

This design uses ammonia loading calculations that are based on the amount of feed fed on a daily basis. It is assumed that ammonia excreted by the fish is proportional to the amount of feed put in the system. The amount of feed fed per day varies with the size of the fish. At early life stages, the fish require feedings of about 6% or more of their body weight. For fish close to harvest weight (and when the system is likely to have the greatest loading of ammonia) feeding rates range from 1.5% to 3.0% of body weight per day. The greatest total mass of feed that will be put in the system is assumed when the fish are at harvest weight and the maximum mass of fish will be in the system. A feeding rate of 2% of body weight is assumed for this example. Thus, for the production of 9,072 kg of fish:

$Mass_{Feed}$ = 9,072 kg of fish x 0.02 kg /kg of fish

$Mass_{Feed}$ = 181 kg

Waste Production and Oxygen Consumption

Colt (1986) proposed a mass balance approach to oxygen requirements and waste production. This approach determines the oxygen requirements of a fish culture system (including biological filtration) based on the mass of feed fed on a daily basis. The following show the relationships developed by Colt (1986):

1 kg of feed requires	0.21 kg of oxygen
1 kg of feed produces	0.28 kg of carbon dioxide 0.30 kg of solids 0.03 kg of total ammonia

Oxygen Requirements

With 187 kg of feed fed per day, and assuming that 0.25 kg of oxygen (0.21 kg of oxygen per kg of feed (Colt, 1986) plus an additional 20% as a safety factor) are required by the fish in the system for respiration and by bacterial respiration for nitrification and carbonaceous biochemical oxygen demand. The oxygen requirements will be:

Oxygen = 0.25 kg O_2 / kg feed x 181 kg feed/day

Oxygen = 45.3 kg O_2 / day

Typical oxygen transfer efficiencies range from about 5% to greater than 90%. The transfer efficiency will have to be considered when determining the total oxygen requirements of the system. For the purposes of this example, a system will be needed to supply at least 45.3 kg of oxygen per day.

Ammonia Production

Ammonia is found in two forms within aquatic systems, ammonia (often reported as NH_3, NH_3-N, or un-ionized ammonia) and ammonium (often reported as NH_4 , NH_4 -N, or ionized ammonia). Ammonia and ammonium exist in chemical equilibrium in the aquatic system. Un-ionized ammonia is highly toxic to aquatic animals and must be removed from the system. The pH and temperature of the system determines the relative concentrations of ionized and un-ionized ammonia in an aquatic system. At low pH values and temperatures, ionized ammonia predominates and at high pH values and temperatures un-ionized ammonia predominates. Total ammonia nitrogen (TAN) is the measurement of the combined concentrations of un-ionized and ionized ammonia, which accounts for pH and temperature.

The TAN produced in the example system is:

TAN = 181 kg feed/day x 0.03 kg TAN/kg feed
TAN = 5.4 kg TAN/day

Thus, a filter system would be required to remove 5.4 kg TAN per day to keep the fish healthy.

Ammonia production is not constant throughout the day. Typically ammonia production from fish in a closed system is cyclic with peaks occurring several hours after feeding. Experience has shown that an average hourly ammonia loading, based on a daily ammonia loading rates, is adequate to determine when for ammonia concentrations may become lethal in a closed system.

The maximum concentration of total ammonia ([TAN] in mg/L) in this example is the estimated hourly load divided by the volume of water in the system and the estimated filter exchange rate (2 times per hour):

[TAN] = (5.4 kg TAN/day x 1000 g/kg) ÷ (24 hours/day x 75.7 m^3 x 2 exchanges/hr)
[TAN] = 1.5 mg/L

Filter Design

Design of the physical requirements for a trickling biofilter can often require an iterative process and is based on water quality requirements and production levels.

Ammonia Removal Rate

At the design temperature of 24°C and a TAN concentration of about 1.5 mg/L, the ammonia removal rate is estimated to be 1.0 g TAN/$m^2 \cdot d$ (Wortman, 1990; Gujer and Boller, 1986).

Filter Surface Area

The surface area of the trickling filter required to remove the ammonia produced in the closed system is:

$Area_{Filter}$ = 5.4 kg TAN/d x 1000 g/kg ÷ 1 g TAN/$m^2 \cdot d$

$Area_{Filter}$ = 5,400 m^2

Filter Volume

The volume of media needed is a function of the surface area required and the specific surface area of the media from media data:

$Volume_{Media}$ = 5,400 m^2 ÷ 220 m^3/m^2

$$Volume_{Media} = 24.6\ m^3$$

Filter Dimensions

The determination of the dimensions and number of filters to use in a system is based on space requirements and limitations within a filter unit. Since recirculating aquacultural systems are typically ammonia limited, mass transport of ammonia is a crucial factor in filter performance. In general, the greater the flow rate of water through a filter, the greater the ammonia removal rates will be because more turbulence is created. Research by Hochheimer (1990) revealed that there is an upper and lower limit for hydraulic loading in a biofilter. Hydraulic loading is a function of flow rate and the cross-sectional area of the filter.

The minimum hydraulic loading for a filter ensures that all media in the filter is continually wetted, thus preventing bacteria from drying out. The maximum hydraulic loading rate prevents scouring of bacteria from the media in a filter. For randomly packed media, a minimum hydraulic loading of 30 $m^3/m^2 \cdot d$ and a maximum hydraulic loading of 225 $m^3/m^2 \cdot d$ can be used for design purposes (Hochheimer, 1990). Design of the filters requires a balance of the number of filter units, diameter and height of each individual filter, and the total flow rate of water through the filter system. The determination of filter dimensions can be iterative and is as follows.

Total flow through the filter per day is the volume of the culture system multiplied by the number of filter exchanges per day. It is desired to have at least 2 exchanges per hour, so the total flow rate is:

$$\text{Total Flow} = 75.7\ m^3 \times 24\ \text{hours} \times 2\ \text{exchanges per hour}$$

$$\text{Total Flow} = 3{,}634\ m^3/d$$

Using a configuration to filter total system flow, assume 6 filters and then the flow rate per filter is:

$$Flow\ Rate_{Filter} = 3{,}634\ m^3/d \div 6\ \text{filters}$$

$$Flow\ Rate_{Filter} = 605.6\ m^3/d$$

The volume needed for each filter unit is:

$$Volume_{Unit} = 24.6\ m^3 \div 6\ \text{filters}$$

$$Volume_{Unit} = 4.1\ m^3$$

The dimensions of each filter unit can be calculated from the maximum hydraulic loading rate. To determine the cross-sectional area:

$$Area_{Cross\text{-}Sectional} \geq 605.6\ m^3/d \div 225\ m^3/m^2 \cdot d$$

$$Area_{Cross\text{-}Sectional} \geq 2.7\ m^2$$

Assuming a cylindrical shape, the diameter of the cylinder for each filter unit would need to be:

$$Diameter^2 \geq (4\ x\ Area_{Cross\text{-}Sectional}) \div \pi$$

$$Diameter^2 \geq (4 \times 2.7\ m^2) \div \pi$$

$$Diameter \geq 1.85\ m$$

Thus, if a diameter of 2.0 m is assumed, then the height of the filter unit is:

$$Height = Volume_{Unit} \div Area_{Cross\text{-}Sectional}$$

$$Height = 4.1\ m^3 \div (\pi \times (2.0\ m)^2 \div 4)$$

$$Height = 1.31\ m$$

Then, the filter dimensions would be:

Height	= 1.3 m
Diameter	= 2.0 m
Volume	= 4.1 m^3
Cross-Sectional Area	= 3.1 m^2
Number of Filter Units	= 6

If the filter dimensions are not suitable for the physical conditions of the closed system, the above calculations can be reiterated with new values to fit the particular situation.

The biofilter units are usually filled with dumped plastic media. This type of media is specified because it provides a large specific surface area at a relatively economical cost. Other media could be used but care must be taken to provide enough surface area for the complete removal of ammonia in the system. Media of smaller specific surface area will require more voluminous filter units, thus more floor space.

The design presented here is conservative, but allows for flexibility resulting from many of the unknowns in biofilter design. There are many designs and configurations for biofilters that can be used for aquaculture. All of the different biofilter designs have positive, as well as negative traits. However, proper operation of closed systems is essential for success and a good operational plan can accommodate for the negative aspects of a particular design.

Rotating Biological Contactors

Design of RBC=s is very similar to other biofilters. The object is to get the waste water to move past the RBC so the nitrifying bacteria can remove the ammonia and the nitrite from the water. The factors noted above and by several other authors (Hochheimer, 1990; Hochheimer and Wheaton, 1991; Wheaton et al., 1991) effect the operation of an RBC and the bacteria on the RBC the same as they do any other nitrifying bacteria. Thus, this discussion will not be repeated here. The focus of this section will be on those design factors unique to RBC=s.

Because an RBC rotates through both an aquaous and an air phase, the oxygen is supplied by the air and the ammonia and nitrite by the water. The RBC is typically operated with a 35 to 45 percent submergence. Thus slightly less than one-half of the time the bacteria will be in the water and slightly more than one-half of the time the bacteria will be in the air. There are several constraints on the rotational speed of the RBC. The bacteria grow on the plate or media surfaces of the RBC. If the rotational speed gets too high the shear forces generated by the plates moving through the water will exceed the adhesion of the bacteria for the plate surface and the bacteria will be stripped off of the plates. Thus maximum rotation speed (i.e. revolutions per minute (RPM)) is generally limited by the lineal velocity of the fastest moving part of the plate as it moves through the water. This maximum velocity is ill defined because it is dependent on the plate surface characteristics (which is a function of the construction materials and the geometric design of the plate or media surfaces), the health and age of the bacteria, and other factors. It should also be noted that the maximum lineal velocity is a fixed value for a given application, but one of the design variables is the diameter of the RBC plates or drum. The larger the diameter, the greater the lineal velocity of the outer rim of the plates for a given number of revolutions per minute (RPM) of the RBC. For example, a two meter diameter RBC operating a 4 RPM has a much higher lineal speed at the rim of the plates than a 1 meter diameter RBC operating at the same RPM.

Another limit on the speed of rotation of the RBC is related to the oxygen concentration in the wastewater and the drying rate of the air. Any one bacteria must not be left in the water phase so long that it runs out of oxygen before remerging into the air. Similarity the period of time the bacteria is in the air must not be sufficient to dry the bacteria out so it can no longer function. These two factors place a lower limit on the speed of the RBC.

Between the two limitations discussed above is a wide range of rotational speeds that can be used in design of RBC=s. Selection of the optimum RPM of the rotor appears to be more of an art than a science. However, Antonie (1976) showed that ammonia removal by RBC=s was enhanced at peripheral speeds up to 0.305 m/sec (1 ft/sec), but above this value the ammonia removal was constant with increased peripheral speeds. Wortman (1990) in his biodrum studies used 10.37 cm/sec (0.34 ft/sec) peripheral speed. Paolini (1985) showed when RBC=s were used for COD (Chemical Oxygen Demand) removal, the removal of soluable BOD, influent BOD and RBC rotational speed interacted. For a given influent BOD with all other variables remaining constant increased rotational speed increased COD removal. Paolini (1985) also concluded that under limiting oxygen transfer conditions, the maximum COD removal rate is an approximately linear function of the square root of the disk rotational

speed, regardless of the wastewater type and the RBC system used. Friedman et al. (1979) showed that RBC removal leveled off, the value where the removal leveled off was a function of the influent COD. Weng and Molof (1974) found that nitrification by a RBC increased when speed was increased from 0.1 to 0.34 m/sec (0.3 to 1.1 feet/sec). Easter (1992) indicates that the Libey system used at Virginia Polytechnical and State University operated their RBC=s at 3 RPM (peripheral velocity of approximately 0.94 ft/sec). Gilbert et al. (1986) found in commercial installations most RBC=s were driven at a peripheral speed of about 0.3 m/sec (1 ft/sec), but this varied somewhat over the 105 units they surveyed.

Power consumption has been shown to increase as the RBC=s rotational speed increases (Fujie et al., 1983; Gilbert et al., 1986). Gilbert et al. (1986) surveyed 29 sewage treatment plants that had RBC=s. They found that energy usage was a function of rotational speed, wastewater temperature, the amount and configuration of media surface area, degree of submergence of the media, amount of biofilm growth on the RBC plates, and the efficiency of the motor and drive systems. Fujie et al. (1983) developed equations to predict the power consumption by RBC=s operating in sewage systems, primarily for BOD or COD removal. They found that power consumption per unit area of RBC surface at low speeds was proportional to the RPM squared and at high speeds was proportional to RPM cubed. This was attributed to the fact that at low speed the flow in the RBC tank was laminar and at higher speeds the flow became turbulent.

In contrast to the effect of rotation speed on power consumption, higher rotational speeds result in greater oxygenation in the RBC tank and usually better removal rates. Biodrums will provide considerably more oxygenation than will plate type RBC=s at the same RPM, but they will require greater power consumption. Fujie et al. (1983) found that the power consumption dropped as the RBC diameter decreased, but the COD (and probably ammonia) removal per square meter of floor space also decreased.

Thus, the concensus of those using RBC=s appears to be to maintain a peripheral velocity for the RBC of approximately 0.30m/sec (1 ft/sec) and to adjust the RPM to as low a value as possible while maintaining the peripheral speed. Disk diameter is limited by physical strength of the shaft and bearings and the space and power needed to house and operate the RBC. Most RBC=s used in aquacultural applications are in the 3 m (9 ft) or smaller in diameter. The length is usually determined by the lengths supplied by manufacture and the surface area needed for ammonia and nitrite removal.

Submergence Depth

RBC=s operate such that some proportation of the discs or drum is submerged in the water. Grady and Lim (1980) presented data to show the optimal submergence for an RBC is 35 to 50 percent. Practically constructing the RBC so the rotor bearings are above the water level is much easier. Thus, the submergence of the rotor is almost always somewhat less than 50 percent, in the optimal range as found by Grady and Lim (1980). The exact percent submergence depends on the bearing and shaft design as much as anything else. Most designers attempt to maximumize submergence of the rotor while keeping the bearings out

of the water.

Ammonia and Nitrite Removal Rates

Westerman et al. (1993) used an upflow sand filter in combination with an RBC on a full scale tilapia culture systems. They found that TAN (Total Ammonia Nitrogen) removal rates by the RBC ranged from 5.5 to 18.5 g/hr and nitrite removal rates varied from 9.4 to 22.6 g/hr. The RBC they used had a surface area of 470 square meters and a hydraulic loading rate of 0.28 L/m^2-min.

Easter (1992) developed an equation to predict the TAN removal for a RBC operating on hybrid striped bass recirculating system. For his three stage RBC the perdiction equation was:

$$S/So=e^{(-K(\text{Stage Number})/W^n)}$$

Where,

S = Effluent ammonia Concentration (mg TAN/L)
S_o = Influent ammonia concentration (mg TAN/L)
W = Mass loading of substrate (mass/area of biofilter) (g TAN/m^2 biofilter/day)
K = Empirical constant
n = Empirical constant

Values for the empirical constants are given in Table 1 below as provided by Easter (1992).

Table 1. Values for the constants in Easter's (1992) ammonia removal equation.

Filter Configuration Analyzed	n	K
RBC Stage 1 Only	0.55	0.14
RBC Stage 2 Only	0.14	0.11
RBC Stage 3 Only	0.18	0.06
All 3 Stages Together	0.36	0.08

Easter (1992) used detention times of 2.3 minutes per stage. The tank containing all three stages had a volume of 1,930 L and the flow rate was approximately 285 L/min. Each stage of the three stage RBC had 536 m^2 of surface area thus providing a hydraulic loading rate of 0.18 L/min/sq meter of filter surface area Using these data Easter (1992) found that the three stage RBC removed approximately 30 percent of the TAN on one pass as long as the influent TAN was above 0.2 mg/L. He also found that the mass removal of TAN by the filter was linearly related to the influent TAN loading in g of TAN/ m^2 of media/day and that the effluent TAN concentration rose quite rapidly from zero to about 0.2 mg/L and then followed an a nonlinear relationship with further increases in influent TAN.

Westerman et al. (1993) used a RBC with 470 m^2 of surface area, a flow rate of 130 L/min and a hydraulic loading per tank cross-sectional area of 160 L/min-m^2. The hydraulic loading calculated by dividing the flow rate by the filter or specific surface area was 0.28 L/min-m^2. He later indicated that the RBC could probably have been loaded more heavily. Fujie et al. (1983) reported the hydraulic loading of several treatment plants using RBC's for BOD (biochemical oxygen demand) removal. Their results showed hydraulic loading rates ranging from 0.024 to 0.06 L/min-m^2. Thus, loading rates vary widely depending on the design, the material being removed, and the effluent concentration desired. However, loading guidelines for ammonia and nitrate removal from aquacultural systems by RBC's is very limited.

Miller and Libey (1985) found mass removal rates of an RBC to vary some with the loading rate. At a fish stocking density of 227 kg/m^3 of catfish the RBC removed 0.78 g N/m^2 /day; at a stocking density of 118 kg/m^3 the RBC removal rate was 0.63 g N/m^2 /day; and at a stocking density of 57 kg/m^3 the RBC removed 0.19 g N/m^2 /day. The culture tank TAN concentrations were: 1.46, 1.26, and 0.36 mg/L for the high, medium and low feeding rates, respectively. This data was collected when the system water temperature was approximately 27.5 ^{0} C. As one might expect the RBC removed greater amounts of ammonia when the stocking density and the concentration of ammonia were higher.

Number of Stages

The number of stages used in a RBC can, theorically, be infinite. However, practical limitations usually limit the number of stages to three to five. Each stage is really a separate filter but works on the same wastewater stream in series. Thus, the raw influent to the first stage is what exits the tank immediately upstream of the RBC. The second stage sees the effluent of the first stage as its influent and so on for all other stages. Because heterotrophic bacteria usually grow faster than nitrifiers, the first stage of an RBC tends to be primarily a BOD or COD removal device unless the wastewater organic content is very low. As the wastewater moves to the second and subsequent stages the RBC tends to first begin removing ammonia and then nitrite with the final product being nitrate, assuming the RBC is sized and operated correctly.

In the ammonia and nitrite removal process it is interesting to compare the results observed by several authors. Easter (1992) using hybrid striped bass systems found that the TAN concentration in the RBC effluent was linearly related to the TAN in the influent and that the mass removal of TAN by a RBC was linearly related to the TAN loading on the RBC. He also stated that equation 1 above could be used to predict the ratio of the effluent to the influent TAN concentration. Westerman et al. (1993) found that their RBC removed about 250 mg TAN/ m^2 -day and provided 67 $\pm$ 18 percent removal of TAN and 59 $\pm$11 percent removal of nitrite-nitrogen when operated at 27-28 ^{o}C . Wheaton et al. (1994) in their development of RBC designs used TAN removal rates in mg TAN/m^2 /day of: 379, 193, and 122 at 30, 25, and 15 ^{o} C, repetitively. In the way of contrast Jansen et al. (1995) cited nitrification rates of between 2 and 4.48 g N/m^2 (2000 to 4480 mg N/m^2) for RBC:s operating on municipal wastewater. The large differences in these values result from the ammonia concentrations used in the two applications. Ammonia concentrations in municipal wastewater is many times higher than is allowable in aquacultural systems. Thus, the lower removal rates are what may be expected in aquacultural applications.

Design of RBC

The problem is to design an RBC for a striped bass culture system containing 20,000 lbs (9071 kg) of fish that are being fed 2 percent of body weight per day with a pelleted feed. It is further assumed that 3 percent of the feed becomes ammonia and the system operates at 24 ^{o}C. Based on this temperature and several other assumptions relative to flow rates, ammonia concentrations, and other variables it will be assumed that the RBC will remove 0.75 g TAN/m^2 -day (this is higher than what Miller and Libey (1985) found).

Ammonia production = (fish weight) (% body weight fed per day) (TAN produced per kg feed fed)

Ammonia produced = (9071 kg fish) (0.02) (0.03)

= 5.44 kg ammonia produced per day

Specific surface area needed = (Ammonia produced/ day)/ (Ammonia removal /m^2 /day

= (5.44 kg/day) / (0.75 g TAN/ m^2 /day)

= 7253 m^2

At this point one has to decide the diameter of the disks and calculate the length of unit needed based on the disk spacing along the shaft. This decision will be influenced by whether the unit will be purchased or will be constructed from available materials. Let us assume that we will use a commercially produced unit that is 3 m in diameter and has plates spaced every one cm along the shaft. Assuming the plates are flat the area of each plate is:

Area per plate = π (Radius)^2 (two sides of plate)

= π (1.5m)^2 (2)

= 14.2 m^2

The number of plates needed are:

Number of Plates = 7253 m^2 / 14.2 m^2

Number of Plates = 511 plates that are 3 m in diameter

Assume the plates are spaced every cm along the RBC shaft. Then the length of the RBC can be determined:

Filter length = (511 plates) (1 cm per plate)

= 511 cm = 5.11 m = 201.1 inches = 16.8 ft

The volume occupied by the filter is:

Filter volume = π R^2 (length)
= 36.12 m^3

Based on Easter-s (1992) tank volume to filter volume recommendation of 2.14:1 tank volume to filter volume, The tank to contain the filter must be:

Tank Volume = (36.12 m^2) (2.14)

= 77.3 m^3

The rotational speed of the filter is based on a peripheral velocity of the disks of 0.3 m/sec (1 ft/sec) as discussed above. Therefore, the disk rotational speed is:

(RPM) (Circumference of RBC) = 0.3 m/sec

$$RPM = \frac{(0.3 \text{ m/sec})\ (60 \text{ sec/min})}{\pi\ (3\text{m})}$$

RPM = 1.91 Revolutions per minute

Loading rate on the filter must then be calculated to determine the flow through the filter. In some cases the flow through the filter may be dictated by other than the filter design in which case the filter would have to be designed about a flow rate as a design constraint. For purposes here it is assumed there are no external constraints on the flow rate. Loading rates vary considerably depending on the use (i.e. BOD or ammonia reduction), influent concentration and other variables. However, Easter (1992) reported a loading rate in the VPI system of 0.18 L/min-m^2, Westerman et al. (1993) reported a loading rate of 0.28 L/min-m^2, and Miller and Libey (1985) used a loading rate of approximately 0.8 L/min-m^2. In this example a loading rate of 0.2 L/min-m^2 will be used. Thus the flow rate will have to be:

Flow rate through the filter = (0.2 L/min-m^2) (7253 m^2)

= 1450 L/min = 383 gal/min

The number of stages to be used depends on the organic content of the water, flow rate and several other variables. However, for our example four stages should be ample. The first stage could be larger than the others if there is a high organic content. If not, the four stages should be about the same size.

The structural design is all that remains for the RBC. Structural design is beyond the space allowed here but the following comments will be offered. During early use of RBC-s in aquacultural applications there were a considerable number of failures of the shaft and/or drive train of the filter. One must design the mechanical parts of the RBC to withstand 24 hour per day operation over long periods of time. The shaft and bearings must be designed to withstand the load of the RBC when it is completely broken in (not just its dry weight) and the shaft must be designed based on fatigue and not just strength. The wet weight of a broken in filter includes the bacteria growing on the filter. Film thickness data is not plentiful, but several authors have suggested that the films may get to be 4 or more mm thick (Grady, 1982). The density of these films are essentially the same as that of water. Thus, these films add significant weight to the RBC.

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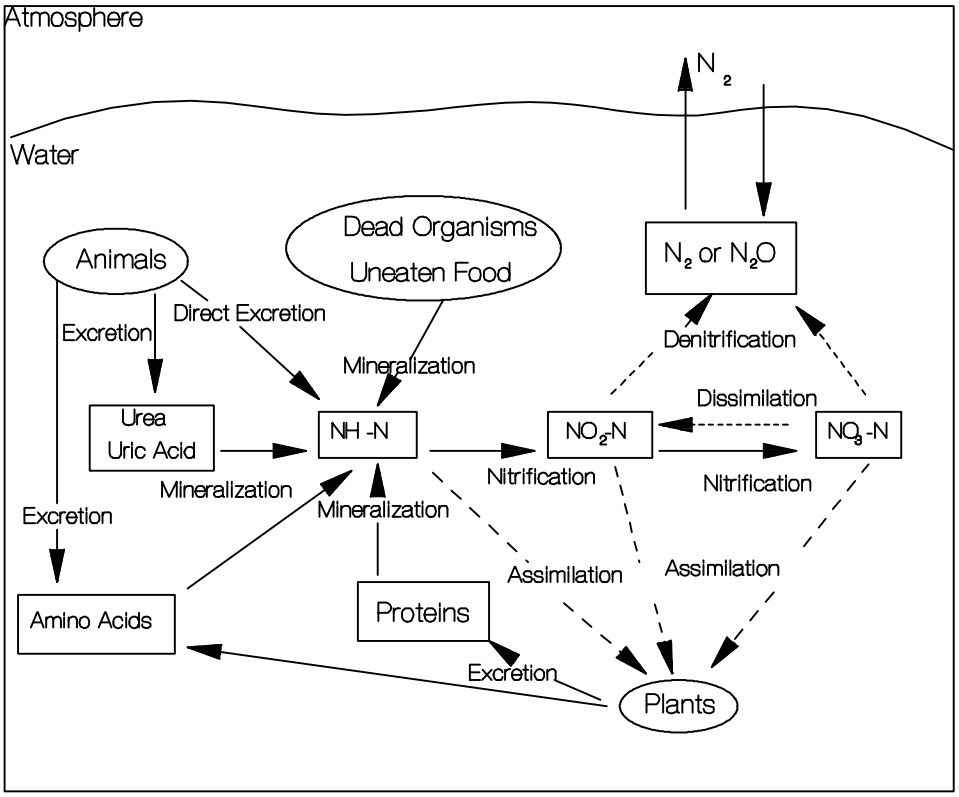

Figure 1. The nitrogen cycle in closed system aquaculture (Spotte, 1979)

Sizing and Management of Floating Bead Bioclarifiers

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Introduction

The use of bead filters with floating plastic media dates back to the mid-1970's when they were utilized as biofilters to support high density rearing of food and game fish in Idaho (Cooley 1979). Although successful, adoption of these early air-washed bead filters at other sites was limited. In the late 1980's, work performed at Louisiana State University demonstrated that a hydraulically washed bead filter was capable of providing solids control (clarification) and biofiltration for a high-density catfish rearing system (Wimberly 1990). Development of mechanically washed units (Malone 1992, 1995), which were compact and simple to operate, overcame many of the operational difficulties experienced by earlier designs. Shortly thereafter, the "bubble-washed" or "hourglass" configuration (Malone 1993) was developed and tested for use on outdoor ornamental or garden ponds. Since 1989, bead filters have been tested on food fish holding systems (such as tilapia, catfish, striped bass, and trout), along with a wide variety of specialized applications (including ornamental fish, alligators, crawfish, crabs, and oysters). This paper summarizes what is known about the use of floating bead filters, with particular emphasis on their biofiltration capabilities and their proper management for combined solids capture and nitrification.

Bead Filter Types and Operation

To meet the definition of floating bead filter used here, the unit selected must display two modes of operation: 1) a fixed-bed filtration mode employing upward flowing water, and 2) a fluidized backwashing mode. The floating bead filter must also utilize a media consisting of small spherical 3 - 5 mm plastic beads that float and do not contain any additives that may kill bacteria or be harmful to fish. The media should display a specific surface area of about 1150 m^2/m^3 (350 ft^2/ft^3) assuring that sufficient surface area exists for biofilm development. Rod-shaped beads with a maximum dimension of 3-mm (1/8-inch) are acceptable, but flattened disk-shaped beads are not. Porosity of the bed must exceed 35 percent. While filters of the principal author’s design are illustrated here, the fundamental processes occurring in all bead filters are the same. However, cost, reliability, and ease of operation vary among designs.

Bead filters are classified as "Expandable Granular Biofilters." They are designed to function as a physical filtration device (or clarifier) by removing solids, while simultaneously encouraging the growth of desirable bacteria that remove dissolved wastes from the water through biofiltration processes. The granular nature of the bead bed allows it to be cleaned to release solids and excessive biofloc, while providing large amounts of surface area for the nitrifying bacteria to attach. This permits large amounts of wastes to be treated using a relatively compact filter. Bead filters capture solids through four identifiable mechanisms, which include straining, settling, interception, and adsorption (Ahmed 1996; Drennan et al. 1995; Malone et al. 1993). They perform well in the control of suspended solids across a broad spectrum of sizes with nearly 50 percent of fine solids in the 5-10 micron range, being removed in a single pass (Ahmed 1996). Although inherently excellent clarifiers, the market for the bead filters is largely generated by their ability as biofilters.

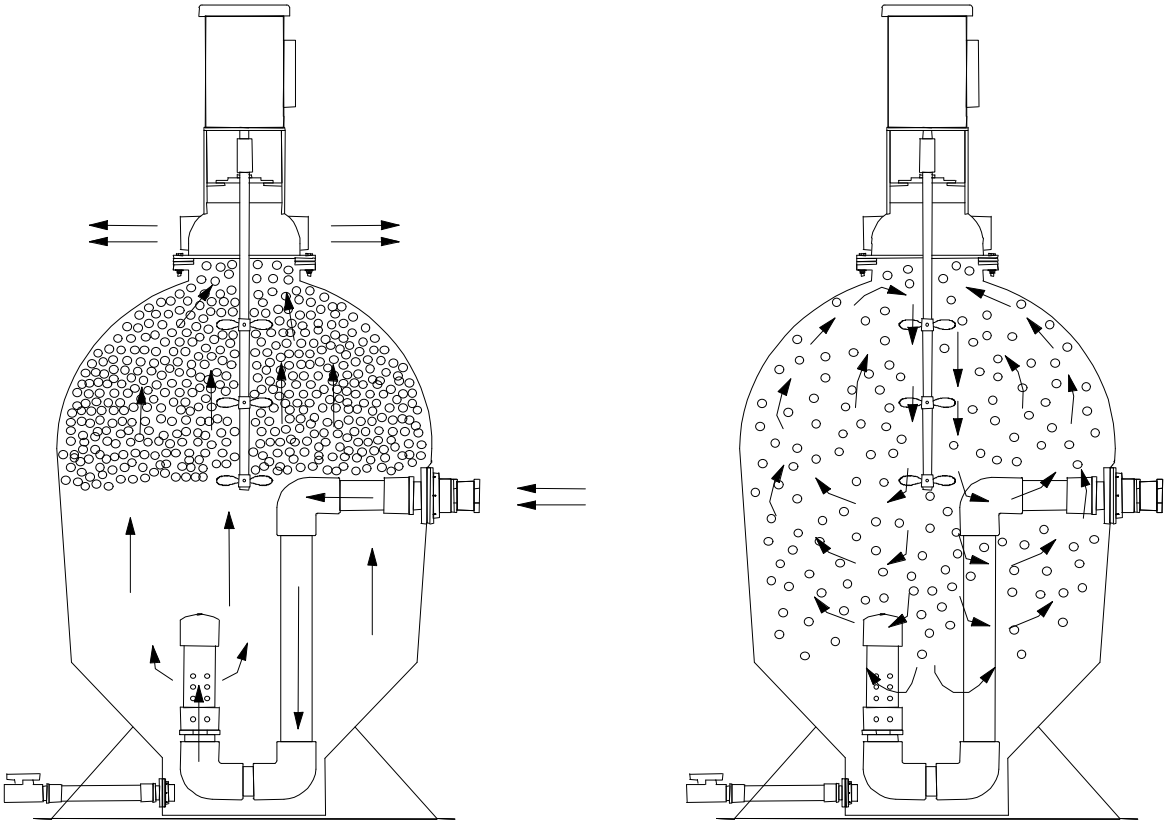

Figure 1. The Propeller-Washed Bioclarifiers are aggressively washed once a day or once every other day (Malone, 1992).

Bead filters differ primarily in their mode of backwashing. The means of backwashing is critical since it should be done in a way that the removal of accumulated solids in the system would not adversely impact the biofilm in the bead bed. Perhaps the most common type is the propeller-washed bioclarifier, consisting of a filtration bed of floating

plastic beads that are intermittently washed by motor-driven embedded propellers. The propeller-washed bioclarifiers are operated in the filtration mode most of the time (Figure 1). As recirculating water passes through the bed, suspended solids are captured and the biofiltration processes are active. Backwashing or cleaning of the bead bed is accomplished by turning off the pump and/or closing the inlet valve and then activating the mixing motor and propellers. The objective of the backwashing step is to release solids and excessive biofloc trapped between the beads. This is accomplished by the hydraulic shear forces induced by the propellers as the beads are thrust downward into the expansion zone and by contact between the beads as they swirl. The propeller-washed bead filters are designed to input a lot of cleaning energy in a short period of time. Excessive washing just damages the biofiltration performance without benefiting clarification. Once the bed has been expanded and agitated for several seconds, the mixing motor is turned off and the settling mode of operation is initiated. Typically, the filter is left idle for 3 - 5 minutes. The beads float upward reforming the filtration bed, while the sludge is concentrated in the settling cone. The final mode of operation is sludge removal. Settling is very effective and it is not necessary to drain the filter completely. Commonly, the sludge drain line is equipped with a clear segment of pipe, which allows the clarity of the discharged water to be observed. As soon as the draining water appears to be as clear as the rearing tank's water, the sludge valve is closed. This approach greatly reduces water loss without impacting filter performance.

While propeller-washed units dominate large-scale operations with units of up to 2.8 m^3 (100 ft^3), bubble-washed units are most frequently employed for small-scale systems. Bubble-washed bead filters, typically less than 0.28 m^3 (10 ft^3), are designed to be self-washing when drained. The discharge of the filter is equipped with a valve (or check valve) that prevents the back-flow of air into the filter when the sludge (or drain) valve on the bottom is opened. This causes a vacuum to form within the filter housing. An air inlet valve, located on the side of the filter just below the washing throat, is opened so that air can be sucked into the filter as it drains (Figure 2). This constriction is critical because as the water leaves the filtration head, the beads are fluidized downward, and pass through the narrow throat where they are scrubbed further by the rising bubbles. The washing process is complete once the filter is drained and all the beads have dropped into the expansion chamber. Readjusting the valves and refilling the filter with the recirculation pump starts the next filtration cycle. In contrast to propeller-washed units, bubble-washed bead filters lose the entire water volume contained in the filter during backwashing.

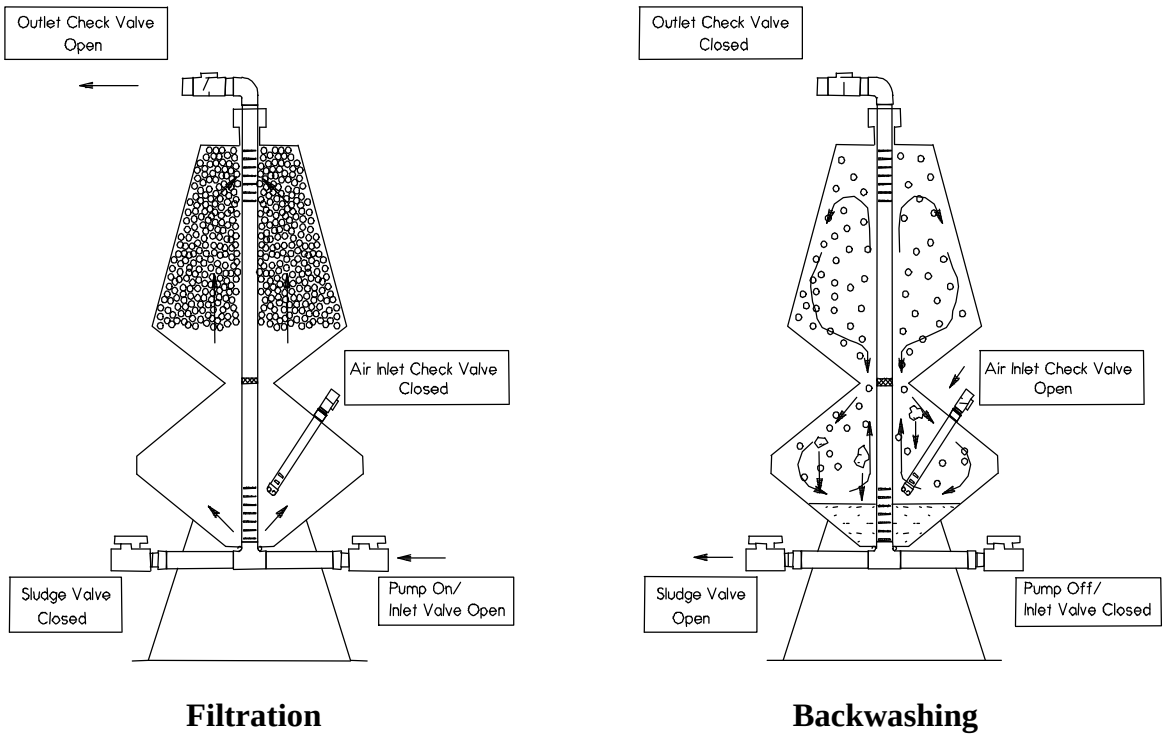

Figure 2. Bubble-washed bead filters use a constricted throat (Malone 1993) to intensify air washing. These units work best when backwashed frequently.

Management for Nitrification

The bead bioclarifier management plan for high nitrification rates assures that: 1) water quality conditions favorable for nitrification exist, 2) an appropriate mass of nitrifying bacteria reside in the filter, and 3) critical nutrients are rapidly transported to the bacteria (Figure 3). All three issues must be addressed to assure that the bead bioclarifier displays a high rate of nitrification.

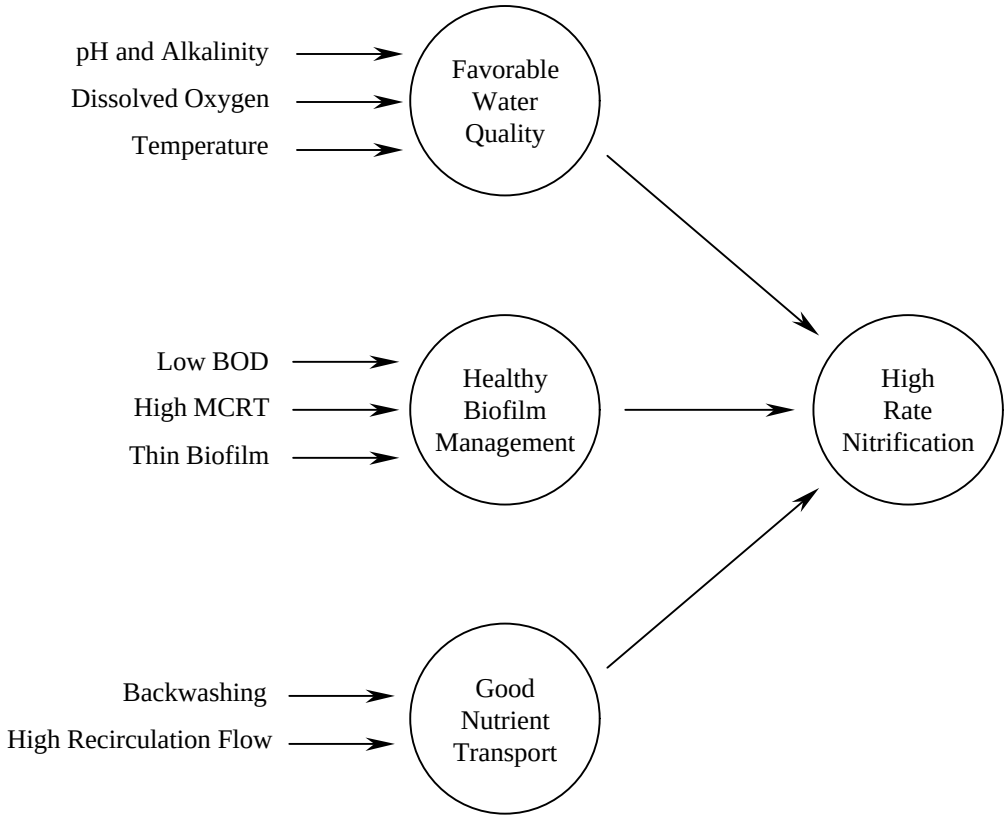

Figure 3. Good nitrification rates are easy to achieve with a floating bead bioclarifier provided attention is given to the filter's management.

Water Quality

Temperature. Floating bead filters have been used for a wide variety of applications ranging from the warmwater production of tilapia to coldwater production of salmon and trout. However, only the warmwater (20-30^{o} C) applications have been extensively documented. Conversion rates in coldwater (10-20^{o} C) applications are generally assumed to be lower, but there is little evidence to substantiate this inference. Additional studies are needed in this area. Typically, the authors use the ornamental criteria for coldwater growout applications.

Oxygen. The most important water quality parameter is oxygen. Nitrification in bead bioclarifiers is not substantially influenced by oxygen as long as the oxygen level in the filter effluent is above 3.0 mg/L. When the dissolved oxygen level coming out of the filter is above 3.0 mg/L, it is generally safe to assume that most of the bed has enough

oxygen to keep the nitrifying bacteria working at top speed. By the time effluent oxygen levels drop to about 2.0 mg/L, portions of the bead bed will be impaired by low oxygen. Below this level first *Nitrobacter*, then *Nitrosomonas* will slow down as the rate of oxygen diffusion into the bacterial biofilm begins to limit the nitrification process. High rate nitrification requires that the entire bed be kept working at maximum speed. The oxygen supply is controlled primarily by the flow rate through the filter.

Alkalinity. For all practical purposes, bicarbonate ions define total alkalinity levels in a recirculating system. The nitrification process consumes alkalinity at a rate of about 6-7 mg $CaCO_3$ per milligram of TAN converted (EPA 1975). This consumption of alkalinity must be addressed by water exchange or by direct chemical addition. The chemical preferred by the authors for this purpose is sodium bicarbonate ($NaHCO_3$), more commonly known as baking soda. Sodium bicarbonate has many desirable properties, including a high water solubility (>100,000 mg/L at 25 ^oC), and a low potential for overdosing since it takes a relatively large amount to raise the pH substantially. Sodium bicarbonate is safe to both fish and humans, and is widely available commercially in bulk quantities.

The amount of sodium bicarbonate required will be virtually the same regardless of the target alkalinity value selected. Procedures for calculating dosages have been clearly defined (Loyless and Malone 1997). If water exchange is minimal, the bicarbonate dosage requirement can be as high as 0.24 kg/kg feed (0.24 lb/lb feed). Generally a moderate sized system will require the addition of sodium bicarbonate every two to three days. Optimum nitrification is normally associated with alkalinity levels above 100 mg $CaCO_3$/L, but systems can be operated at lower levels within the bounds of the criteria because of safety factors applied to the nitrification capacities of the floating bead bioclarifiers.

pH and Carbon Dioxide. Bicarbonate additions not only increase the bicarbonate supply but also help raise the pH, benefiting the nitrification process. Inhibition of the nitrifying bacteria under growout conditions is noticeable once pH drops below 7.0 (Loyless and Malone 1997; Allain 1988; Paz 1984; Siegrist and Gujer 1987). When peak performance is demanded from a floating bead bioclarifier, a pH value in the range of 7.5-8.0 is normally recommended.

The ratio of bicarbonate ions over dissolved carbon dioxide concentration controls the system's pH. As the system is loaded, the carbon dioxide produced by the fish and bacteria rises. This carbon dioxide accumulation will cause a drop in the pH. At the same time, the nitrification process consumes bicarbonate ions. The combination of high dissolved carbon dioxide and low bicarbonates can create a radically low pH in the range of 4-5, which severely inhibits nitrifying bacteria. If the pH remains low after the alkalinity has been adjusted, then the system has high carbon dioxide levels. The CO_2 levels are controlled by the stripping rate of the aeration and degasification devices. Carbon dioxide is not normally an issue in systems employing blown air for aeration (Loyless 1995), but must be watched carefully in systems operating in enclosed buildings

and in systems using pure oxygen since oxygen injection equipment usually do not provide adequate gas exchange to strip carbon dioxide. Design guidelines for carbon dioxide stripping towers have been established (Grace and Piedrahita 1994; Colt and Bouck 1984).

As recommended, the authors adjust majority of the bead bioclarifier high-density growout systems they operate to a pH in the range of 7.5-8.0 with alkalinity falling between 150 to 200 mg $CaCO_3$/L. High carbon dioxide levels encountered (5-15 mg/L) often force values on the lower end of the pH range (7.5) and the upper end of the alkalinity range (200 mg $CaCO_3$/L) to be targeted (Loyless and Malone 1997). Selection of a target pH above 8.0 is generally avoided due to the increasing prevalence of the toxic unionized molecular form of ammonia (NH_3) at higher pH values (Huguenin and Colt 1989).

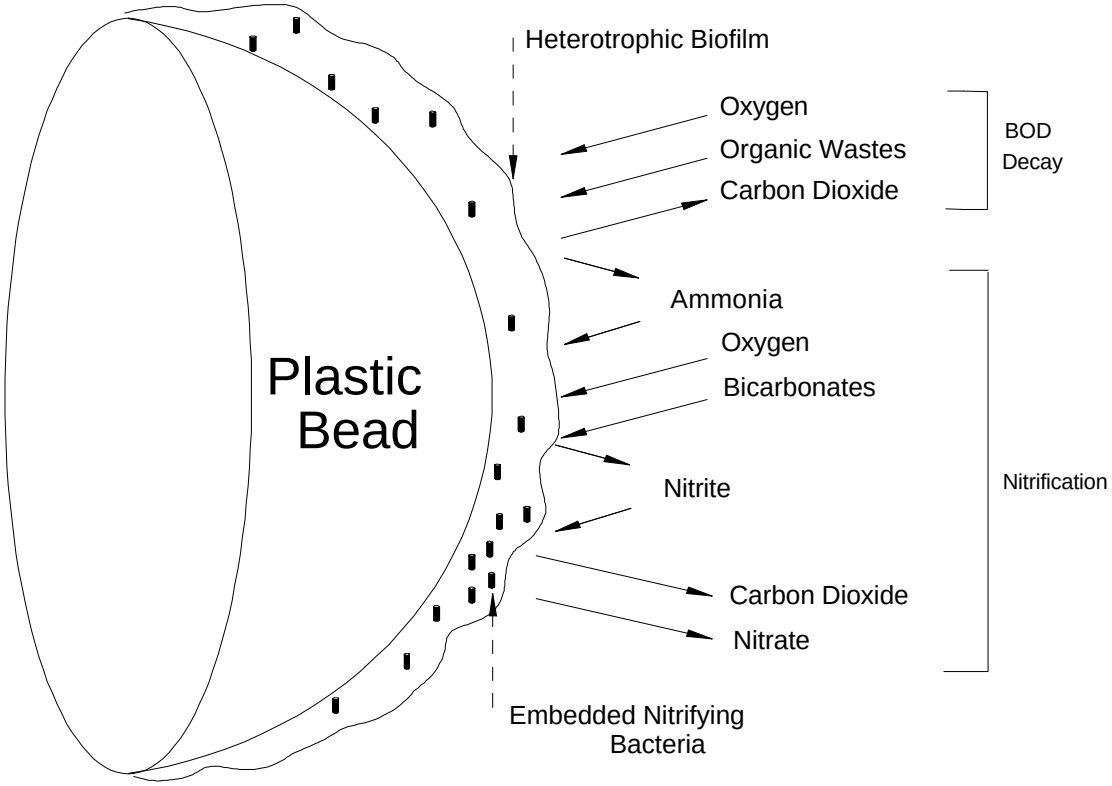

Figure 4. Each bead is coated with a heterophic bacterial film containing a population of nitrifying bacteria. There are approximately 20 million beads in a cubic meter (550,000 per cubic foot) with a surface area of about 1150 m^2/m^3.

Biofilm Management

In the biofiltration mode, bead bioclarifiers operate as fixed-film reactors. Each bead (Figure 4) becomes coated with a thin film of bacteria that extracts nourishment from the recirculating water as it passes through the bead bed. There are two general classifications of bacteria that are of particular interest: heterotrophic and nitrifying. The two bacteria co-exist in the filter, and understanding their impact on each other as well as on the filter is critical.

The group of heterotrophic bacteria encompasses a great number of genera/species, which share the common characteristic of extracting nourishment from the breakdown (decay) of organic matter. About 60 percent of the organic matter consumed is converted to bacterial biomass, whereas, the balance (40 percent) is converted to carbon dioxide, water, ammonia, and other chemicals. Biochemical oxygen demand (BOD) is largely an indirect measure of the biodegradable organic material in water. If the BOD in the water being treated is very high (> 20 mg -O_2/l) and conditions are favorable, the heterotrophs will quickly dominate the bead bed because of their rapid growth (doubling their population every ten to fifteen minutes). This allows for quick overpopulation of heterotrophs, which consume large amount of dissolved oxygen, and compete for space with slower growing nitrifying bacteria.

Nitrifying bacteria are specialists, extracting energy for growth from the chemical conversion of ammonia to nitrite and nitrite to nitrate. Nitrate is a stable end product that is generally non-toxic, unlike ammonia and nitrite. Nitrifying bacteria are generally assumed to be composed of two genera (*Nitrosomonas* and *Nitrobacter*), although recent studies indicate that other genera are involved (Hovanec et al. 1998; Hovanec and DeLong 1996). They are very slow growing and sensitive to a wide variety of water quality factors. It is not surprising that most bead filters used for biofiltration are managed to optimize conditions for nitrification.

Acclimation. Development of a biofilm layer on the media is required for biofiltration. Initially the biofilter has no bacteria and the culture must be started. The process of growing the initial bacterial culture in the biofilter or adjusting an established culture to a change in loading is called acclimation. The best way to acclimate a recirculating system with a biofilter is to just add a few hardy fish, turtles, or molluscs to the system and start to feed them. The heterotrophic bacteria will grow rapidly and quickly attach themselves to the beads. The nitrifying bacteria, however, are very slow reproducers and may require almost thirty days (2 - 3 weeks is more typical) to establish themselves.

Figure 5 illustrates the classical pattern of TAN and nitrite concentrations observed during filter acclimation with animals (Manthe and Malone 1987). The process starts with an increase in TAN concentration. You will know that the first group of nitrifiers responsible for ammonia conversion to nitrite are present in large numbers when the ammonia excreted by the fish stops accumulating and suddenly (within 36 hours) drops to near zero level. At the same time there will be a sudden rise in nitrite level, followed

by a gradual increase which will continue until suddenly the second group of bacteria, *Nitrobacter*, catch up with their new food supply and the nitrite concentrations plummet. The filter is now considered acclimated to a light loading. This initial stage of acclimation is critical because during this period, populations of bacteria which can effectively attack the specific wastes produced by the animals become established and these bacterial populations adjust to operate under the water quality conditions and temperature regime found in your system. This unique culture of bacteria will remain in the biofilter for years if it is just treated with a little common sense.

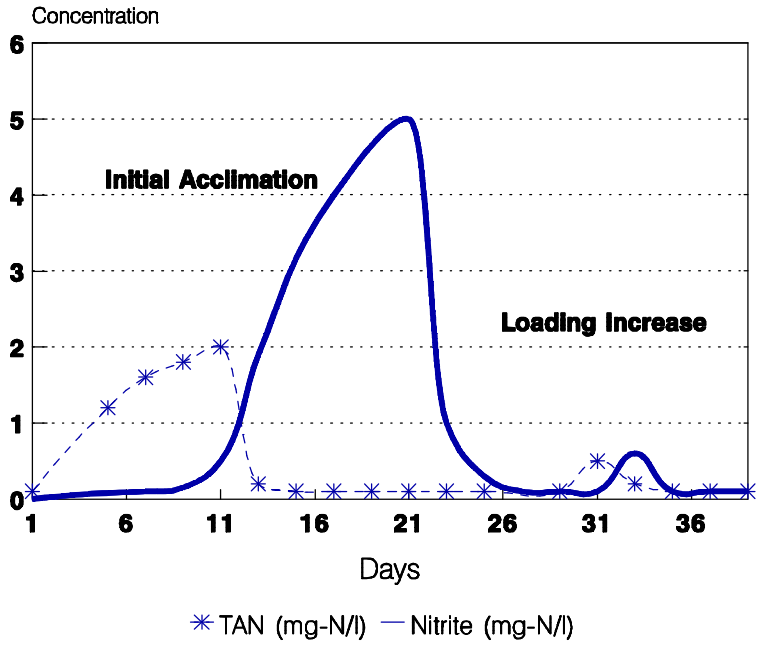

Figure 5. Acclimation of a bead filter with fish should take about three weeks. The nitrite peak is always higher than ammonia peak.

Backwashing. Organic solids not only breakdown to produce ammonia, but also encourage rapid heterotrophic bacteria growths that compete with the nitrifiers for space and potentially limiting nutrients such as oxygen (Zhang et al. 1995; Matsuda et. al. 1988). This phenomenon is not unique to bead filters; studies by Figueroa and Silverstein (1992) on rotating biological contactors, and Bovendeur et al. (1990) on trickling filters both associate increasing BOD levels with declining rates of nitrification. Backwashing removes the bulk of the heterotrophic bacteria, the captured TSS which form a major portion of their food source, and unfortunately, a lot of nitrifying bacteria. If the interval between backwashing is too short, the nitrifying bacteria will not have time to re-establish their population and a gradual washout occurs, dramatically limiting the nitrification capacity of the filter. The latter situation is avoided by managing the "Mean Cell Residence Time" (or MCRT) of the biofilm in the filter. A floating bead bioclarifiers optimum nitrification performance occurs when sludge accumulation

concerns are properly balanced with MCRT concerns by adjusting the backwashing frequency.

Once the basic water quality issues are addressed, backwashing becomes the principal management tool. It can be used to dramatically improve nitrification. This aspect of bead bioclarifier management has been extensively studied experimentally, and evaluated by a mathematical model (Golz 1997). These studies indicate that two classes of bioclarifiers exist. Hydraulic and air washed units fall into the "gently washed" category. These filters display reduced biofilm abrasion during backwashing and must be washed at a high frequency. Optimum performance for heavily loaded filters occurs when the filters are washed several times daily (Sastry 1996; Wimberly 1990). Conversely, propeller-washed and paddle-washed filters inflict a relatively heavy biofilm damage during backwashing, and are considered "aggressively washed." They must be backwashed infrequently, usually every other day, to allow growth of biofilm, thus, avoiding MCRT problems (Chitta 1993; Malone et al. 1993). Ironically, both classes of filters display nearly the same peak conversion rate of about 350-450 g TAN/m^3-day (10–13 g TAN/ft^3 -day).

Flow rate. Another important issue in optimizing a biofilters operation is nutrient transport. Assurance that the bacteria within the biofilm are always presented with sufficient levels of TAN and oxygen to keep the nitrification process proceeding at a high rate is very important. Maintaining good water quality in the rearing tank does not assure that the bacteria, which are residing in the depth of a packed bed of beads, are seeing these same conditions. Good nutrient transport requires rapid mixing first between the rearing tank and the biofilter, and secondly, even flow distribution within the bead bed. Biofilms actively consume (or convert) essential nutrients, which rapidly deplete supplies in the water immediately adjacent to them. Water must flow quickly and evenly through the bead bed to assure that the depleted waters are uniformly and rapidly displaced. If excessive solids or biofloc clogs a section of the bed then the nitrifying bacteria become inactive, lowering the performance of the bed as a whole.

The water recirculation rate of about 50 Lpm/kg feed-day (6 gpm/lb feed-day) is recommended to assure good oxygen delivery to the bioclarifier. This recirculation rate also assures adequate circulation between the rearing tank and bioclarifier, which assures tank TAN build-ups due to poor mixing are avoided. Extensive observations (Sastry 1996; Chitta 1993; Wimberly 1990) show that the oxygen consumed in filtration (or OCF, Manthe and Malone 1987) is around 165 g/kg feed (75 g/lb-feed**).** Experience has shown that filters operated with effluent oxygen levels below 2 mg/L are clearly not operating at their maximum capacity because of oxygen delivery problems (Golz 1997; Manthe et. al. 1988). When oxygen levels in the holding tank are maintained between 5 and 6 mg/L, the recirculation criterion includes a safety factor of about 50 percent.

In the authors' experience, the biofiltration capacity of bioclarifiers always improves with flow rate. The filters operate best with high flow rate and low removal efficiencies. Removal efficiencies can be calculated from Equation 1:

$$E = \frac{TAN_I - TAN_E}{TAN_I}(100) \quad (1)$$

where: E = Single pass removal efficiency (percent)
TAN_I = Influent TAN concentration (mg N/L)
TAN_E = TAN concentration in the effluent from the filter (mg N/L)

TAN removal efficiencies in the range of 25 percent are usually targeted when high nitrification performance is demanded. If the efficiency of a bed exceeds 50 percent, significant additional nitrification capacity can be realized by increasing flow rates. This raises the mean TAN concentration in the bed improving the gradient of diffusion into the biofilm, which results in improved conversions.

Ideally, recirculating systems should be designed so that back pressure on the pumps is low, minimizing energy requirements. The operational back pressure of floating bead bioclarifiers is dependent on the backwash frequency and feed loading rate. Bead filters that are “aggressively washed” (propeller- and paddle-washed) should be operated with a pump capable of delivering the required flow at pressures of about 69 kPa (10 psi) to accommodate extended backwash intervals of 1-2 days. “Gently washed” filters (air injected and hydraulic) can be matched with a lower head pump (34.5 kPa [5 psi]) if they are operated under a high frequency washing regime (>2 backwashes per day).

Management Strategy

A good biofilm management plan must address the needs of the nitrifying bacteria in terms of water quality, nutrient transport, and, biofilm harvesting. Table 1 summarizes the operational ranges for three operational levels. Since the water quality aspects are easily addressed, biofilm management efforts focus on backwashing and its impact on nitrifying bacterial biomass levels and flow rate through the bed. Periodic monitoring of the biofilters performance facilitates optimization in situations where peak nitrification performance is demanded. A drop in oxygen in the bioclarifier effluent usually evidences problems with water circulation rates. If the dissolved oxygen level coming out of the filter is less than 2 mg/L then the performance of the bioclarifier is (or on the verge of being) severely impaired by oxygen limitation. If the tank dissolved oxygen levels are above that prescribed in Table 1, then the problem rests with the pump or the backwashing regime of the filter. If the problem is not corrected the bioclarifier will first generate nitrite, then TAN conversion rates will fall, and in extreme cases, off-flavor problems with the fish will occur. Monitoring is not normally required when filters are operated at or below their recommended design capacities. These filters are normally set at a convenient backwash interval (once a day is problem is not corrected the bioclarifier will first generate nitrite, then TAN conversion rates will fall, and in extreme cases, off-

flavor problems with the fish will occur. Monitoring is not normally required when filters are operated at or below their recommended design capacities. These filters are normally set at a convenient backwash interval (once a day is generally good for all types) and only pH is monitored every other day or so to detect alkalinity exhaustion.

Table 1. The operational ranges for the management factors controlling nitrification in floating bead bioclarifiers are known.

Management Factor		Operational Range		
		Broodstock	Ornamental	Growout
Temperature, ^{o}C		20 - 30	20 - 30	20 - 30
Effluent Oxygen, mg/L		> 2.0	> 2.0	> 2.0
Feed Loading, kg/m^3-day [lb/ft^3-day]		< 4 < 0.25	< 8 < 0.5	< 16 < 1.0
Flow rate, Lpm/m^3 [gpm/ft^3]		$\geq$ 400 [$\geq$ 3]	$\geq$ 400 [$\geq$ 3]	$\geq$ 800 [$\geq$ 6]
Alkalinity, mg $CaCO_3$/L		> 50	> 80	> 100
pH		6.5 - 8.0	6.8 - 7.0	7.0 - 8.0
Backwash Interval, days	Aggressively washed	1 - 7	1 - 3	1 - 2
	Gently washed	1 - 3	1 - 2	0.5 - 1

Sizing Rationale

The primary method for the sizing of floating bead bioclarifiers is based on a volumetric organic loading rate. The ultimate source of organics in a recirculating system is the feed; therefore the sizing criterion is expressed in terms of weight of feed applied daily per cubic meter of beads (kg/m^3-day). This criterion assumes:

1) the filter is being employed as a bioclarifier,
2) organic loading is the principal factor controlling nitrification conditions within the bioclarifier,
3) the organic/nitrogen ratio is relatively consistent across a wide spectrum of feeds,
4) the filter is managed to sustain nitrification.

The criterion of 16 kg/m^3-day (1 lb/ft^3-day) has been widely tested and has proven to be robust in the commercial sector. At this feeding level, the filters can reliably provide

solids capture, BOD reduction, and nitrification while sustaining water quality conditions suitable for the growout of most food fish species. TAN and nitrite levels can be expected to remain well below 1 mg N/L. At this level the filter's biofiltration function is not stressed. This allows sufficient reserve nitrification capacity to tolerate the range of feed protein contents, and management strategies encountered in most commercial applications. Reduction of the criterion to 8 kg/m^3-day (0.5 lb/ft^3-day) allows the reliable maintenance of water quality conditions suitable for more sensitive species; particularly ornamental goldfish, koi, and tropical fish where fin quality, coloration, and appearance are critical to marketing objectives. Finally, a loading guideline of 4 kg/m^3-day (0.25 lb/ft^3-day) is used for breeding and broodstock maintenance programs where pristine conditions are justified by the value of the stock. Peak carrying capacities for the various bead filter models discussed in this paper vary from 24-32 kg/m^3-day (1.5-2.0 lb/ft^3-day) when filled with standard spherical beads. However, at these higher organic loading rates backwashing of the filters must be knowledgeably tuned to avoid problems (Sastry 1996; Chitta 1993; Wimberly 1990).

Another approach to sizing bead bioclarifiers is in terms of volumetric nitrification capacity (Malone et al. 1993). This criterion is based on the observation that a wide spectrum of floating bead (and other) biofilters are found to display areal conversion rates with a magnitude of about 300 mg TAN/m^2-day (28 mg TAN/ft^2-day) in recirculating systems with TAN and nitrite levels between 0.5 and 1.0 mg N/L. The authors suspect that this plateau of performance reflects TAN diffusion constraints as the biofilm thickens in response to increased loading (Harremoes 1982). Below a TAN concentration of about 1.0 mg N/L, laboratory evidence and empirical observations indicate the conversion rate declines with the TAN concentration (Chitta 1993). However, the relationship is complex and is impacted by the bead filter design, backwash frequency, the bed's porosity, flow rate, and a variety of other parameters. Thus, over, the years the authors have tended to simplify the process by utilizing volumetric conversions that are related to the areal conversions through the media's specific surface area (typically 1150-1475

Table 2. Volumetric TAN conversion rates (VTR) used to size floating bead bioclarifiers for warmwater applications.

Loading Regime	Feed Loading kg/m^3-day [lb/ft^3-day]	Expected Concentration mg N/L		VTR g TAN/m^3-day [g TAN/ft^3-day]
		TAN	NO_2-N	
Broodstock (very light)	< 4 [< 0.25]	<0.1	<0.1	70 [2]
Ornamental (moderate)	< 8 [< 0.5]	<0.3	<0.3	180 [5]
Growout (heavy)	<16 [< 1.0]	<1.0	<1.0	350 [10]

m^2/m^3 [350-450 ft^2/ft^3]) without going through the painstaking process of estimating specific surface area. The result is a conservative design table (Table 2). This table can be used in conjunction with Equation 2 to estimate the size of the bead filter:

$$V = (1-I_s)(E_{TAN})\ W / VTR \qquad (2)$$

where: V = volume of the bead bed in m^3 (or ft^3)
I_s = *In situ* nitrification fraction (unitless)
E_{TAN} = TAN excretion rate in g TAN/kg feed (or g TAN/lb feed)
W = Feed rate in kg/day (or lb/day)
VTR = Volumetric TAN conversion rate in g TAN/m^3-day (or g TAN/ft^3-day)

The *in situ* nitrification fraction recognizes the effect of nitrification occurring on the sidewalls of tanks, and in particular, the systems piping (Mia 1996). A value of $I_s = 0.3$ is conservatively estimated, although values in excess of fifty percent are frequently observed. The TAN excretion rate is normally assumed to be around 30 g/kg (13.6 g/lb) for a 35 percent protein feed typically used to support warmwater fish (Malone et al. 1990; Wimberly 1990). This value may be proportionally increased when a high protein feed is employed.

Three levels of performance for the bead bioclarifiers have been defined (Malone and DeLosReyes 1997): 1) broodstock (lightly loaded, very clean), 2) ornamental (moderate organic loading, clean), and 3) food fish growout (heavy organic loading, tolerable water quality). The volumetric conversion rates are assumed to decline with substrate concentration, as would be the case with TAN diffusion limitation. The values can be expected to hold for fresh and saltwater applications where the temperature is maintained between 20 and 30 ^oC.

The design values given are conservative with the indicated values easily achievable when the filters are managed to sustain nitrification. However, the bead filter nitrification performance can vary widely (Figure 6). Peak conversion rates are almost always associated with careful management (Sastry 1996; Chitta 1993; Wimberly 1990). Bead filters primarily operated for clarification display nitrification performance that are largely supplemental (DeLosReyes and Lawson 1996; DeLosReyes 1995; MP&L 1991).

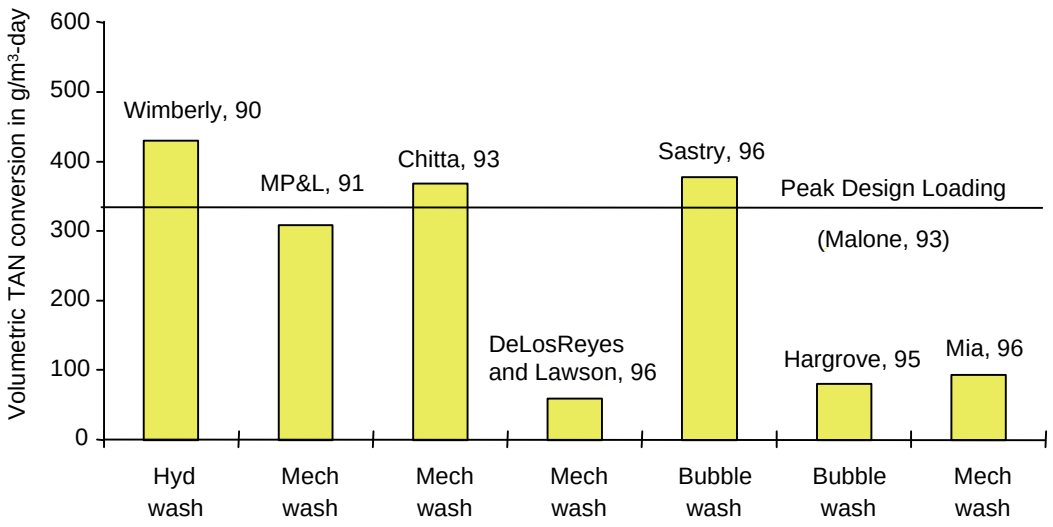

Figure 6. Bead filter performance can vary dramatically with loading and management.

Performance Evaluation

The volumetric TAN conversion rate (VTR), the volumetric nitrite conversion rate (VNR), and the volumetric oxygen consumption rate of the biofilter (OCF) can be used as principal parameters for evaluation and comparison of biofilter performance. The volumetric TAN conversion rate can be obtained by using Equation 3:

$$VTR = K_c (TAN_I - TAN_E) Q / V \quad (3)$$

where: VTR = volumetric TAN conversion rate in g TAN/m^3-day (or g TAN/ft^3- day)
Q = flow rate through the filter in liters per minute or Lpm (or gpm)
K_c = conversion factor of 1.44 (or 5.45)
TAN_I, TAN_E, and V are as defined previously.

The actual level of nitrification occurring in the filter may be higher since TAN is a by-product of heterotrophic breakdown of nitrogen rich organic compounds and biofloc. Despite its limitations, VTR allows the relationship between design and management parameters to be more closely examined.

The volumetric nitrite conversion rate (VNR in g NO_2-N/m^3-day or g NO_2-N/ft^3-day) is defined by Equation 4:

$$VNR = VTR + K_c (NO_{2I} - NO_{2E}) Q / V \quad (4)$$

where: NO_{2I} is the influent nitrite concentration in mg N/L
NO_{2E} is the effluent nitrite concentration in mg N/L
VTR, K_c, Q, and V are as defined previously.

As this equation illustrates, the readings of influent and effluent nitrite must be combined with the volumetric ammonia conversion rate to determine the level of *Nitrobacter* activity since nitrite is being produced as the ammonia is converted within the bed. Because of this phenomenon, the apparent nitrite removal efficiency may be near zero (i.e. influent and effluent values are nearly identical), although the filter may be vigorously processing nitrite to nitrate.

The volumetric oxygen consumption rate (OCF in g O_2/m^3-day) is very helpful in the management of bead filters. It indicates the total amount of bacterial activity within the filter, and can be obtained using Equation 5:

$$OCF = K_c (DO_I - DO_E) Q / V \quad (5)$$

where: DO_I is the influent dissolved oxygen concentration in mg O_2/L
DO_E is the dissolved oxygen concentration in mg O_2/L in the filter effluent
K_c, Q, and V are as defined previously.

OCF measures the combined respiration of the nitrifying bacteria, the heterotrophic bacteria extracting soluble BOD from the water column, and the heterotrophic bacteria responsible for the breakdown of solids (sludge) held in the filter. The apparent oxygen consumption rate of the nitrifying bacteria (OCN in g O_2/m^3-day or g O_2/ft^3-day) can be computed directly from the volumetric conversion rates for nitrification using Equation 6 since we can estimate the amount of oxygen required for nitrification from chemical equations:

$$OCN = (3.47\ VTR + 1.09\ VNR)\ 0.97 \quad (6)$$

The factor 0.97 (unitless) corrects for oxygen assimilation during bacterial growth. The volumetric oxygen consumption rate that can be attributed to heterotrophic activity (OCH in g O_2/m^3-day or g O_2/ft^3-day) can then be calculated by difference (Equation 7):

$$OCH = OCF - OCN \quad (7)$$

The ratio of OCN to OCF expressed as a percentage is a valuable indicator of the efficiency of a backwashing protocol. A high OCN percentage (>50 percent) indicates that the nitrifying population is relatively high, i.e. the heterotrophic bacterial population has been successfully controlled without excessive loss of the nitrifying population. The OCN percentage tends to drop under lightly loaded regimes as the backwashing interval is extended allowing for more complete digestion of accumulated sludges. The nitrification capacity, however, is not adversely impacted as substrate (TAN) availability, not biofilm diffusion characteristics, limit the conversion process.

Table 3 presents operational ranges for selected performance parameters that can be expected for the three loading regimes, following the management guidelines suggested in Table 1. These data must be interpreted carefully. The range of values collected reflects changes in organic loading regimes as impacted by backwash frequency and the highly variable *in situ* nitrification. In most cases, the filters were backwashed only as often as required for the water quality objectives for TAN and nitrite to be met. Thus, a lightly loaded broodstock filter can display an OCF as high as a growout filter that is generally washed frequently. VTR and VNR values are generally held below the filter's peak capabilities by competition from bacteria growing on the tank and pipe walls. These nitrifying bacteria populations tend to flourish, benefiting from the low BOD found in the water column. Optimum filter performance generally occurs when the OCN percentage for a given loading regime is highest. Monitoring the OCN percentages while varying the backwashing frequency will generally allow the best backwash frequency to be quickly identified.

Table 3. Typical values for the performance parameters under conditions derived from operational filters. Values derived principally from Wimberly (1990) and Sastry (1996).

Performance Parameter	Units	**Typical Operational Value**		
		Broodstock	Ornamental	Growout
VTR	g TAN/m^3-day	35-105	70-180	140-350
	g TAN/ft^3-day	1-3	2-5	4-10
VNR	g N/m^3-day	35-105	70-180	140-350
	g N/ft^3-day	1-3	2-5	4-10
OCF	kg O_2/m^3-day	0.7-2.5	1.4-2.5	2.5-3.0
	g O_2/ft^3-day	20-70	40-70	70-85
OCN/OCF	%	25-35	25-35	45-55
OCH/OCF	%	65-75	65-75	45-55

Discussion

In this paper, we have summarized research findings and empirical evidence based upon technology that has remained essentially unchanged since the last summary of capabilities of bead bioclarifiers in Malone et al. (1993). The technology has moved from the research laboratory into the commercial sector where floating bead filters are

enjoying a reasonable degree of acceptance as bioclarifiers (Lutz 1997). Hundreds of commercial scale units are now being used. The authors have limited this paper to a description of the performance characteristics typical of these commercial units, although we are forced to substantiate many of the statements with research results since commercial scale performance is often poorly documented. However, at least three aspects of ongoing research are worthy of note here, as these findings will have significant impact on commercial use and performance patterns in the upcoming decade.

First, the nitrification performance plateau described in this paper reflects recognition of: 1) water quality conditions that facilitate high rate nitrification, 2) establishment of basic operational strategies with respect to flow rates and backwashing, and 3) the use of 3-5 mm spherical polyethylene beads. The primary objective of ongoing research efforts is to design beads to improve our ability to hold substantial amounts of nitrifying bacteria, while providing protection for biofilm during backwashing. Additionally, the increased porosity provides more volume to store bacteria postponing the loss of hydraulic conductivity that impairs the bed's performance as oxygen transport drops. This strategy appears to be successful with ongoing experimental units displaying net conversion rates approaching double those at equivalent loading previously documented (Beecher et al. 1997).

Secondly, the recent computer model analysis (Golz 1997; Golz et al. 1996) has suggested the use of a "high frequency" backwashing strategy, which has proved itself valuable at least for "gently washed" filters. This strategy recognizes that eventually, as organic (feed) loading rates are increased in response to improved nitrification performance, accumulation of solids will adversely impact the filters. In the extreme, optimization of nitrification will dictate a minimization of solids accumulation within the filter. This can be accomplished with the modified beads whose high degree of biofilm protection permits backwash intervals of only an hour or two. At this high frequency the residual free (non-biofilm) solids in the filter drop to such a low level that all the secondary impacts of solids accumulated from the clarification function are eliminated. The heterotrophic food supply is eliminated, freeing a larger portion of the biofilm for the nitrifiers. Figure 7 illustrates the impact of high frequency backwashing on the peak performance (to date) of an experimental bubble-washed unit. Not only did this unit substantially raise the peak performance plateau established by earlier floating bead filter researchers (Sastry 1996; Chitta 1995; Wimberly 1990), it also entered the volumetric conversion realm of fluidized beds (Thomasson 1991) while functioning as a bioclarifier. The usefulness of the strategy is currently being tested with the aggressive propeller washed filters while new self washing pneumatic hull designs are being refined to eliminate the need for automation of the backwashing sequence.

Finally, the increased porosity of the modified media in combination with the high frequency washing strategy has permitted the operation of floating bead bioclarifiers with airlift pumps (DeLosReyes et al. 1997). Both experimental and commercial prototypes have been tested and shown to be capable of delivering high flow rates (30-37.8 Lpm (8-

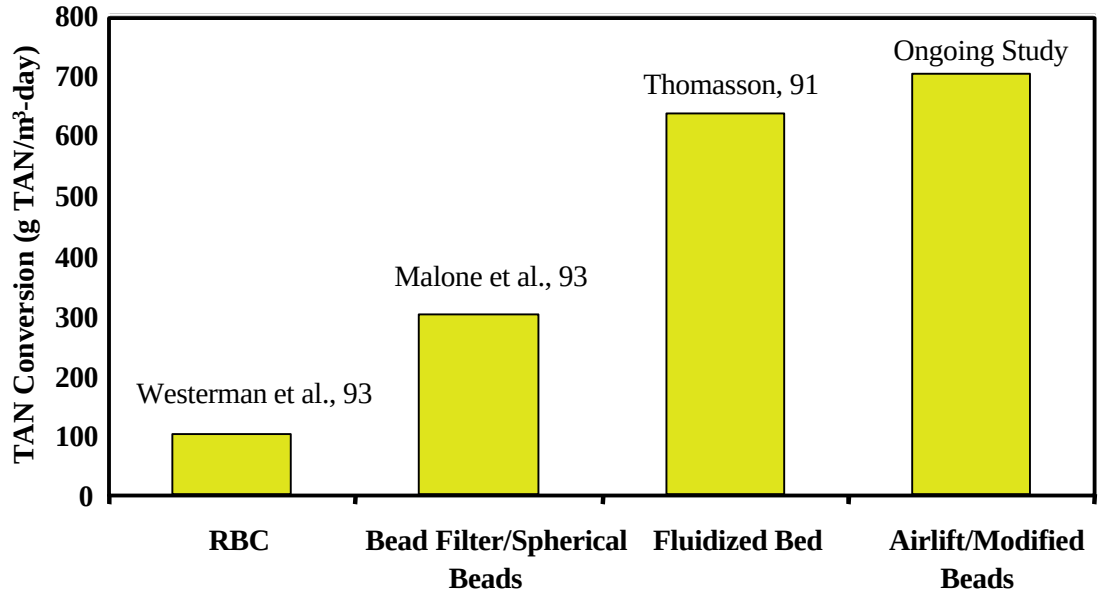

Figure 7. Volumetric TAN conversion rates of selected biofilters. Use of modified media and high frequency backwashing has shown promising results in ongoing experimental work on airlift bead bioclarifiers.

10 gpm)) with total headloss of about 30 cm (12 inches). Ongoing research in this area is specifically directed at the development of commercial scale prototypes.

Summary

Recognizing that the prime factor inhibiting widespread adoption of recirculating technologies is economics, the authors have advocated the use of floating bead filters as "bioclarifiers" (providing both solids capture and biofiltration) to permit the simplification of recirculating systems. Experimental and commercial use of the units has allowed extensive evaluation and establishment of reliable warmwater sizing guidelines for broodstock, ornamental, and growout conditions. The nitrification capabilities are controlled to a large extent by management. In this regard, particular emphasis is placed on pH and alkalinity control, oxygen delivery through adequate flow, and appropriate backwashing. The floating bead bioclarifiers using spherical beads have performance plateau around 350-450 g TAN/m^3-day (10–13 g TAN/ft^3 -day). Ongoing research into the use of modified beads, high frequency backwashing, and airlift recirculation indicate that dramatic changes in both the appearance and performance levels of floating bead bioclarifiers can be expected in the next few years.

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Application of Fluidized-Sand Biofilters to Aquaculture

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Introduction

There is considerable debate as to the most appropriate biological filter technology for intensive aquaculture applications. The four major filter types used are: fluidized sand beds, trickling filters, rotating biological contactors, and floating bead filters. This paper focuses on the authors' experiences applying fluidized-sand biofilters (FSB) to indoor fish systems in both cool and warm water environments.

All biological filters are designed for the same function of oxidizing ammonia and nitrite to the fully oxidized form of nitrate. This phenomena is well described by Timmons and Losordo (1994). For simplicity, the production of total ammonia nitrogen (TAN) may be assumed to be 3% by weight of the fish feed being fed per day. So, if 100 kg of feed are fed per day to a particular tank system, then there will be approximately 3 kg per day of TAN produced. The biological filter must be designed to fully oxidize this TAN production, else the TAN concentrations in the tank will rise above design levels.

Given a defined rate of TAN production, a suitable biological filter must be designed. From a practical perspective biofilter selection is less critical in small production systems, i.e., systems that feed at rates below 50 kg of feed per day, than for larger farming systems. In small systems, biofilters can be over-designed and the added cost is generally not of critical importance to the overall economic success of the venture. Smaller operations are not competing in the wholesale market, but in niche markets and providing service or other product attributes that allows premium pricing to the seller/grower.

Conversely, for large production systems feeding 100 kg or more per day into a single fish culture tank system, economic designs for the biological filter become much more critical. We feel that the primary benefit of the FSB system is the ability to scale the biofilter to the system needs without paying large economic penalties as the FSB is scaled to an appropriate size. It is conceivable that a several hundred ton per yr facility might be operated on one to three biofilters for the entire facility. Once designed properly, in terms of sand size and degree of bed fluidization, the cross sectional area of the FSB system can be increased until the necessary volume of sand is obtained to oxidize the TAN load that is imposed.

General Design Approach

FSB can be designed following the steps listed below:

1) determine the TAN load
2) determine the sand volume required to match TAN load
3) select the design depth of sand bed
4) select the sand size in relation to flow rate available or desired
5) design the water delivery system

TAN Load

As previously discussed, the TAN production may be assumed to be 3% of the daily fish feeding rate:

$$\text{TAN (kg/day)} = 0.03 \times F \qquad (1)$$

where F = fish feeding rate per day, kg/d

Sand Volume and Nitrification Rates

Nitrification rates and efficiencies within FSB's have been measured as a function of sand size (Table 1) using replicated 10 cm (Cornell University) and 15 cm (Freshwater Institue) FSB reactors. The sands were fluidized at fixed velocities that were set to achieve bed expansions of 50% with clean sand (e.g., a bed that is 1 meter in static depth would be 1.5 meters in depth when expanded). At Cornell University, inlet concentrations were 0.6 to 0.7 mg/L TAN, temperature 26 C, pH 7.3, 6 to 7 mg/L DO, and TSS < 10 mg/L. At the Freshwater Institute, inlet concentrations were 0.5 to 0.6 mg/L TAN, temperature 15 C, pH 7.3 to 7.5, 10 to 11 mg/L DO, nitrite 0.04 to 0.06 mg/L, and TSS < 10 mg/L (Tsukuda et al., 1997).

Note that the TAN removal rates in Table 1 are expressed on a unit volume basis, instead of on a surface area basis. Low density medias such as RBC's and trickling towers provide nitrification rates proportionate to surface area provided by the media, but research suggests that nitrification rates in granular medias are much more closely related to volume of media than surface area provided by the media. The large surface area provided by small sands provides no advantage in terms of nitrification rate.

The fine sand biofilters, however, have demonstrated a much higher TAN removal efficiency (90% removal) when compared to the large sand biofilters (10-17%). The high removal efficiencies found with the finer sands are in part due to the low velocities required to fluidize fine sands (see section 2.3 below). The low velocities require larger FSB and longer hydraulic retention times than would a biofilter treating the same flow but with a larger sand.

Fine sands are not recommended for use in warm-water systems, however, due to possible difficulties controlling excessive biosolids growth. Control of biosolids growth is still an

issue when fine sands are used in cold-water applications, but biosolids growth is manageable at the colder temperatures.

The results (Table 1) show that FSB biofilters used at warmer temperatures (i.e., 2.7 kg/d/m^3 @ 26°C) remove ammonia at a much higher rates than at cooler temperatures (i.e., 0.5-1.5 kg/d/m^3 @ 15°C). Based upon these numbers, it seems safe to use a nitrification rate of 1.0 kg TAN/day/m^3 static bed as a design value for warm water systems and a rate of 0.7 kg TAN/day/m^3 clean static sand for cold water systems (15°C).

The required sand volume can be calculated given the TAN load and the TAN removal rates per unit volume of sand.

Table 1. Average TAN removal rates and efficiencies measured across cold-water (15°C) and warm-water (26°C) biofilters as a function of sand size.

Sand retained between sieve mesh sizes	40/70	20/40	18/30
Cold-Water (15°C) Systems (Tsukuda et al., 1997)			
TAN removal rate, kg/d/m^3 clean static bed	1.5	0.51	0.51
TAN removal rate, kg/d/m^3 expanded bed	0.41	0.35	0.35
TAN removal efficiency, % each pass	90	10	10
Warm-Water (25°C) Systems (M. B. Timmons, unpublished data)			
TAN removal rate, kg/d/m^3 clean static bed	NR	2.7	2.7
TAN removal rate, kg/d/m^3 expanded bed	NR	2.7	2.7
TAN removal efficiency, % each pass	NR	17	17

NR = not recommended due to excessive biofilm growth

Design Depth of Sand Bed

Choice of sand depth is related primarily to the physical constraints of the building ceiling height, whether the sand filter can be partially submerged into the ground, and whether any additional elevation is required to gravity flow back to the culture tank through aeration and/or oxygenation unit processes. In in any case, the design should produce as much sand volume as practically possible. The larger the sand volume and therefore lower TAN load per unit volume of sand -- provides a factor of safety for the overall design. It also minimizes the biological film growth per unit particle of sand, which will minimize sand bed growth and management problems related to changing expanded sand bed depths.

When fine sands are used, growth of biofilm can increase the expanded bed depth to the point that sand will be flushed from the reactor into the rest of the system. Therefore, fine sand biofilters are usually designed for eventual expansion of the biofilm-coated sand bed to achieve 200 to 300% of initial static sand depth (e.g., if a clean sand depth is 1 m before fluidization, after 50% fluidization the clean sand will be 1.5 m, once a thick biofilm grows in this bed the total sand expansion may be 200%, or around 3 m of total depth).

Sand Size in Relation to Flow Rate Available

Selecting the sand size relates to the previous discussion on sand depth. The overall design for the fish system will include calculating flow rates to maintain target levels for the various water quality parameters, primarily oxygen, ammonia, and carbon dioxide. Depending upon the type of oxygenation and CO_2 stripping units being used, large variations in required design flow rates can result. Thus, often the design of the different components of the overall system is manipulated until the flow rates for the different water quality parameters being controlled by the different system components are somewhat in balance.

Selecting the sand size and bed expansion (see section 2.3.1) determines the velocity through the biofilter. Selection of a finer sand will requires lower water velocities than selection of a larger sand. Because of the different water velocity requirements, at a given flow rate through the biofilter, the finer sands will result in a bigger biofilter than if a larger sand had been selected.

Suppliers of graded filter sands usually report the effective size (D_{10}) and uniformity coefficient (UC) of their sand. Fish farmers purchase sand for FSB's by specifying either an effective size or some range of sieve sizes (Table 2), in addition to an acceptable uniformity coefficient for the sand (where smaller UC's result in sands with less variation in particle diameter). Specifying sand that is sized through a 20/40 mesh means that the largest sand passes a 20 mesh sieve (D_{eq} = 0.841 mm) and the smallest sands are retained on a 40 mesh sieve and are larger than 0.42 mm. There is always some small percentage of sands that can be considered "dust" but this should be just 1 to 3% of the total mass of

Table 2. The opening size of each U.S. sieve series designation number (as reported by Perry and Chilton, 1973).

Sieve Designation Number†	Size of Opening, (mm)	Sieve Designation Number†	Size of Opening, (mm)
4	4.76	35	0.500
5	4.00	40	0.420
6	3.36	45	0.354
7	2.83	50	0.297
8	2.38	60	0.250
10	2.00	70	0.210
12	1.68	80	0.177
14	1.41	100	0.149
16	1.19	120	0.125
18	1.00	140	0.105
20	0.841	170	0.088
25	0.707	200	0.074
30	0.595	230	0.063

† Number of meshes per inch.

sand. Upon start-up of a new FSB, the bed will flush the small sand from the system for several days. Several culture tank flushings are required to clear the fines from the system, which should be accomplished before fish are added to the system.

The "effective size" (D_{10}) is defined as the opening size which will pass only the smallest 10%, by weight, of the granular sample. The D_{10} provides an estimate of the smallest sand in the sample and is the size used to estimate the maximum expansion at a given water velocity (AWWA, 1989).

The "uniformity coefficient" (UC) is a quantitative measure of the variation in particle size of a given media and is defined as the ratio of D_{60} to D_{10}.

The D_{90} is the sieve size for which 90% of the grains by weight are smaller. The D_{90} provides an estimate of the largest sand in the sample and is the value used during design to calculate the water velocity required to fluidize even the largest sand to some minimal expansion, e.g. 20%. One should be sure to check that the design fluidization values meets this minimum requirement. The D_{90} can be estimated from the effective size (D_{10}) and the uniformity coefficient (Cleasby, 1990):

$$D_{90} = D_{10} \cdot \left(10^{1.67 \cdot \log (UC)}\right) \tag{2}$$

The "mean size" (D_{50}) is the sieve size for which approximately 50% of the grains by weight are smaller. The D_{50} provides an estimate of the average size of the sand in the sample and is the value used during design to estimate the average bed expansion at a given superficial velocity. Using the uniformity coefficient of the sand, you can approximate the mean sand size (J. Cleasby, Iowa State University, pers. comm.):

$$D_{50} = D_{10} \cdot \left(10^{0.83 \cdot \log (UC)}\right) \tag{3}$$

If desired, the specific surface area of the static sand bed (S_b) can be approximated from the static bed void fraction (ε 0.45) and the sphericity of the sand (Ψ 0.75):

$$S_b = \frac{6 \cdot (1 - \varepsilon)}{\Psi \cdot D_{50}} \tag{4}$$

Expansion

A failure of the FSB to properly expand can result in severe problems. Under-fluidization of the FSB will result in bed channeling with water leaving the biofilter untreated. Degrees of poor fluidization will result in the larger sands moving to the bottom of the bed and becoming static. Such areas then are apt to become anaerobic or anoxic resulting in denitrification and other undesirable water chemistry changes, e.g. sulfide gas production.

Our recommendation is to choose an overall clean sand expansion of around 50% when designing the FSB system. Sand expansion is a function of water temperature and of

several sand characteristics (Summerfelt and Cleasby, 1996). Water velocity requirements increase with increasing expansion and increasing sand size (Table 3).

The influence of water temperature on viscosity, as well as variations in sand characteristics from different quarries, can create some error in estimating expansion velocity requirements for a given sand (illustrated in Table 3). Therefore, the numbers in Table 2 and as reported by Summerfelt and Cleasby (1996) should only be used for preliminary design estimates; a hydraulic test on a sample of the sand selected should be completed to determine the actual expansion velocities on a case by case basis. Construct hydraulic testing columns with care given to how the flow is distributed and use at least 1 m sand depth. Our experience with these test columns has shown that their flow distribution mechanism has a large impact on fluidization velocities in small columns (10-15 cm diameter) using shallow sand depths.

Table 3. Water velocities required to expand sand 20, 50, 100, and 150 percent with effective sizes (D_{10}) of 0.24, 0.45, 0.60, and 0.80 mm. Two velocities are reported in each cell, #1/#2: the first velocity is an average of measurements made during fluidization tests in 10 cm diameter columns where flow was distributed under a mesh screen used to support the sand bed (tests were at 15°C); the second velocity is the velocity that was predicted for the mean sand size (D_{50}), taken from the table shown in Summerfelt (1996).

	Sands Tested			
Retaining sieve mesh sizes	40/70	30/50	20/40	18/30
Effective size (i.e., D_{10}), mm	0.24	0.45	0.60	0.80
Uniformity coefficient	1.8	1.4	1.4	1.3
D_{50}, mm	0.37	0.59	0.79	0.99
Velocity requirements, cm/s				
20% expansion	0.5/0.4	0.7/0.9	0.8/1.4	1.3/1.9
50% expansion	1.0/0.8	1.3/1.5	1.9/2.2	2.7/2.9
100% expansion	1.4/1.4	2.0/2.4	3.1/3.3	4.6/4.2
150% expansion	1.9/1.9	2.7/3.1	4.1/4.2	5.9/5.2

Biosolids Management

The down side of the smaller sand sizes is flocculation growth in the FSB bed, especially as water temperature increases (Thomasson, 1991; Monoghan et al., 1996; Timmons, unpublished data). Biofilm growth on sand decreases this particles' effective density, which causes these particles to migrate toward the top of the biofilter column and increases the total biofilter expansion. Heterotrophic growth continuously occurs and also tends to trap sand particles in its growth. This biological growth plus the dead bacteria from biofilms also migrates to the top of the sand column. The smaller sands can be trapped in this flocculant material and remain at the top of the sand column. When the biosolid-coated sands remain at the top of the column, the shearing of biofilm material from the sand particles that occurs at the bottom of the bed in the vicinity of the orifice on the horizontal laterals does not occur. If the FSB reactor vessel has translucent walls, one can easily observe the interface between the fluidized sand and the flocculant layer. Using small sands, $D_{10} < 0.42$ mm (sieve size #40), the growth of the flocculant layer in warm

water systems can grow out of control unless actively managed. The FSB operator must have a regular routine of removing the flocculant layer, else the whole sand bed could become engulfed. Removing the flocculant layer will also generally require replacement of sand, especially when fine sands are used. Replacement of sand has an inherent disadvantage beyond the obvious problems (sand cost and labor) in that the fine material with the new sand will foul the water column. Depending upon the fish species and the rigor of the required water quality, pre-flushing of the new sand may be required.

Cornell University research experience using sands that have $D_{10} > 0.42$ under warm water conditions has been that the beds have no appreciable collection of flocculant material at the top of the FSB. This is a large advantage in terms of simplifying management. The disadvantage is that the larger sands require higher fluidization velocities and this reduces the size of the biofilter.

For nearly 10 years, the Freshwater Institute has consistently managed fine sand (D_{10} = 0.20-0.25 mm) FSB's in several recirculating rainbow trout culture systems. The FSB's operated reliably during this period, with TAN removal efficiencies typically ranging from 70-90%. Biosolids growth in the FSB's was usually controlled by siphoning biosolids from the top of FSB's as their beds reach a maximum depth, and then replacing lost sand as needed (Bullock et al., 1993; Heinen et al., 1996; Summerfelt and Cleasby, 1996; Tsukuda et al., 1997). The Freshwater Institute has also controlled biofilm thickness by shearing the biofilm in-vessel, using a pump to transport the flocculant particles from the top of the biofilter to the bottom of the bed, where shear forces are greatest (Figure 2). The biofilm stripper effectively maintained bed expansion at a fixed level and reduced biofilm thickness without trading-out sand (unpublished data).

In the Freshwater Institute's cold-water recycle system, Tsukuda et al. (1997) found that biosolids did not accumulate within expanded beds using sands with effective sizes of 0.60 and 0.80 mm. However, biosolids did sometimes collect in a distinct layer above the expanded sand layer. Siphoning the biosolids layer was simple with these larger sands, because the expansion depth of these sands remained fairly constant and the biosolids could be removed relatively free from sand. Because the biosolids layer is expanded, it is also fluid, which greatly reduces sand loss and the need to replace old sand with new sand (when larger sands are used). Therefore, a siphon withdrawing flow and biosolids from one point in the biofilter can remove all fluidized biosolids at depths above this level (for all sand sizes).

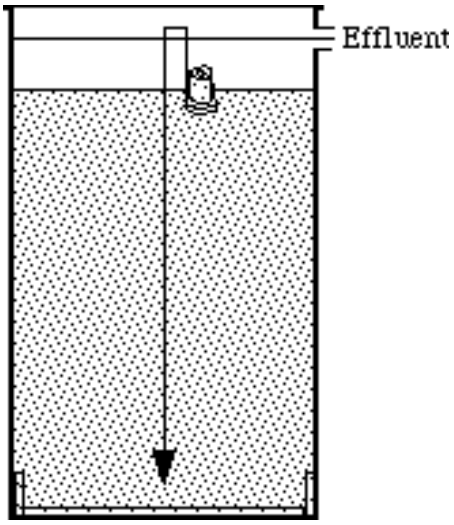

Figure 1. A small magenetic-drive submersible pump was able to withstand the abrasive effects of the sand being pumped and helped to strip biofilm and control bed depth (Freshwater Institute, unpublished data).

FSB Water Delivery System

Designing the FSB's water delivery system involves appropriate sizing of the plenums, pipes, and orifices to promote equal fluidization of the sand bed. Generally this involves using a collector plenum that receives water from the pumps and then assigning a given number of laterals to this plenum to provide an effective lateral grid across the bed floor. Maximum spacing of laterals center to center is in the 15 to 30 cm (6 to 12 inch) range. The basic idea is that the cross sectional area of the pipe "upstream" of a group of laterals or orifices should be 2 times the additive area of all the laterals or orifices. This results in the pressure gradient being dominated by the loss across the reduction section so that each reduced section (e.g. lateral or orifice) will see approximately the same pressure regardless of its location along the lateral (orifice case) or lateral attached to a collection plenum/manifold. This approach ensures that the flow will be approximately the same to each of the laterals from the manifold/plenum or from a lateral to each orifice.

We try to maintain the following area ratios:

$1.5 < \text{manifold/laterals} < 3$
$2.0 < \text{lateral/orifices} < 4$

As a rule of thumb, we have found that flow distribution manifolds designed according to these criteria have a total pressure requirement (in m or ft of water pressure) equal to three times the sand depth plus the height that the water must be lifted from the floor sump to the top of the biofilter. Therefore, total pumping head requirements range from 5 to 11 m (16 to 36 ft), depending mostly on the depth of the biofilter column. For precise pressure estimates, the hydraulic gradeline should be calculated across the piping from the pump sump to the water depth in the FSB column.

Summerfelt (1996) and Summerfelt et al. (1996) give a more detailed discussion on how to estimate pressure losses through the FSB system and how to size laterals and plenums/manifolds. An example of how a spreadsheet can be used to size the pipe manifold, pipe laterals, and distribution orifices is provided (Table 4).

Table 4. Example of the use of a spreadsheet to calculate the size of the FSB manifold, pipe laterals, and distribution orifices. Values that are in BOLD are user assigned numbers and (except for the expansion velocity) must be entered in a somewhat iterative procedure until the criteria in italics are met.

expansion velocity, cm/s	**2.6**	
expansion velocity, ft/min	5.1	
Flow Rate, gpm/ft^2	38.0	
Diameter of sand tank, inches	72	
Diameter of sand tank, ft	6.0	
Area of floor cross section, ft^2	28.3	
Total flow, gpm	1,074	
Lateral pipe diam, inches	**3.00**	
Lateral pipe area, sq inches	7.07	
Lateral Length, avg, feet	4.80	note: for round tank, avg L as 86% of tank D
Lateral spacing, inches	**12**	
Number of laterals (calc)	7.0	
Number of Laterals assigned	**6**	i.e. you have to have a unit number
Orifice diameter, inches	**0.563**	
Orifice area, in^2	0.248	
Orifice spacing (='s lat space) inches	12	
Number of orifices/lateral	11.6	assigned in pairs
Total # of orifices assigned per lateral	**12**	
Orifice area per lateral, in^2	2.99	
Total Orifice area, ft^2	0.124	
Pipe area : orifice area	2.4	*recommended between 2 to 4*
manifold area : lateral pipe area	**1.5**	*recommended area ratio is 1.5 to 3.0*
Min Req Manifold diameter, inch	9.0	(using one header pipe for all the laterals)
Min Req Manifold diameter, inch	6.4	(using two header pipes for all the laterals)
Orifice Coefficient (0.6 to 1.0)	0.8	
Velocity across orifice, ft/s	24.1	
Head loss across the orifices	9.0	*This number needs to be > sand depth*

Sizing of Orifices

Orifice size is selected to fluidize the bed by assuming the pressure loss across the orifice is greater or equal to the static sand depth:

$$C\ V^2/2g > \text{Depth} \quad (5)$$

where C is the orifice coefficient (decimal), g is the acceleration due to gravity (m^2/s), and Depth is the static sand depth (m). Orifice coefficient values are in the range of 0.6 to 0.8. While the choice of this orifice coefficient does not appear to be terribly significant, since the known value in the equation will be the flow rate, small changes in C can significantly affect the estimate of the pressure loss term. The severe negative consequence of using a C value that is too low is that the bed may not fluidize in all regions. We have used a C value of 0.7 in past designs, or used a C value of 0.6 and selected an orifice size to create a pressure loss 1.2-1.5 fold greater than the sand depth.

Design Example

Design a FSB for a warm water system using a 20/40 sized sand for a feeding rate of 100 kg feed/day and for a 20/40 sand.

TAN Load.

TAN Load = 100 kg/feed/day x 0.03 kg TAN/kg feed = 3 kg TAN/day

Volume Sand (V)

V= (3 kg TAN/day) / 1 kg TAN/day/m^3 = 3 m^3 sand required

Depth of Sand (h)

h = 2 m (unexpanded; placed on floor level; selected based upon ceiling height and elevation required to gravity flow back to culture tank through aeration column and/or oxygenation column)

Cross sectional Area of Bed (A)

A = V/h = 3 m^3/2 m = 1.5 m^2

Fluidization Velocity

For a 20/40 sand, Table 2 can be used to estimate D_{10} (40 mesh) = 0.42 mm
If the sand has a UC of 1.5, equations 2 and 3 can be used to estimate D_{90} and D_{50},

D_{90} = 0.42 mm $10^{1.67 \times \log 1.5}$ = 0.83 mm
D_{50} = 0.42 mm $10^{0.83 \times \log 1.5}$ = 0.59 mm

An estimate of the velocity required to expand the bed 50% can be looked up in Table 3: i.e., a 20/40 sand with D50 = 0.59 mm will fluidize 50% at around D_{10} = 1.3-1.9 cm/s. To check if the largest sands will expand, the velocity required to expand a 0.83 mm sand was looked up in Table 3 and was estimated to be anywhere from 1.0-2.2 cm/s. The design example will use 2.0 cm/s.

Flow Rate

Given the expansion velocity of 2.0 cm/s and the cross sectional area of the bed (1.5 m^2), the required flow rate is

$$Q = Vel \times A = 0.020 \text{ m/s} \times 1.5 \text{ m}^2 = 0.039 \text{ m}^3\text{/s} \times 60\text{s/min} = 1.8 \text{ m}^3\text{/min (474 gpm)}$$

From a mass balance on oxygen, the required flow rate (1.8 m^3/min) in this example would have to carry around 10 mg/L of available oxygen to meet the average respiration needs of the fish consuming 100 kg feed/day. Therefore, to achieve the available oxygen needs the flow would have to pass through an oxygenation unit to achieve on average a 15-17 mg/L of dissolved oxgyen before entering the culture tank.

In a cold-water application, sands with D_{10} of around 0.25 mm are selected because of the high nitrification efficiency that can be achieved. These biofilters are usually oversized, because the sand selection locks in a velocity of near 1.0 cm/s and the recirculating flowrate is controlled by the oxygen requirements of the fish.

Plugging Concerns

A major concern in operating FSB's is the plugging of the lateral systems with sand. This can happen if the check valves in line with the pumps and biofilter malfunction and do not close at the time pumps are shut down. Check valve failure should be rare, but if it ever does happen, water will siphon out of the biofilter to the pump sump (which is at a lower elevation) and carry sand into the pipe laterals until the pipes are plugged. To prevent this, top of the line swing check valves should be used to reduce the chance of failure. In the event of a failure, laterals can be unplugged, usually in a matter of hours, with the use of clean-outs on the pipe laterals at the top of the biofilter (Summerfelt et al., 1996). One must be prepared for plugging of the pipe laterals if the biofilter is to be restored to operating mode.

Currently, we have been successful in preventing this siphoning action by placing swing check valves above or below the pump (s). We have used heavy, brass or PVC swing check valves with a solid rubber swing flap or a brass swing flap and a well machined seat ledge. These valves are still working effectively after several years of operation. Others have used siphon breaks to let air into the manifold above the biofilter when pumps are shut down, which allows the water in the pipe manifold to drain into the biofilter and prevents siphoning. The Freshwater Institute has tried a siphon break such as this and found it to be undesirable, because the air filling the laterals and manifold is forced through the sand bed when pumping is restored. The large slug of air passing through the biofilter has caused significant volumes of sand and biosolids to dump out of the biofilter. This phenomena is probably much more of a problem with the finer sands and the associated mass of biosolids that accumulate in these biofilters. Similarly, any air leak into the pumping and lateral system will also promote sand loss from a bed and prevent proper operation, especially when smaller sands are used.

Some allowance should be made to prevent airlocks when check valves are employed. Simply, take a look at the system and if there is the potential for air lock to occur, make provisions to allow for air to escape from the pump. This is a typical problem if the

pumps are submerged and the collection sump is drained once a pump is turned off. When the sump area is refilled, the pipe above the pump will have trapped air and will prevent the pump from moving enough water to open the check valve.

Cost Basis

As stated in the beginning of this paper, our main argument for using FSB's is that their cost per unit of TAN treated is low compared to competing technologies. This is only true for larger systems. Cayuga Aqua Ventures, LLC (CAV) has recently installed 1.83 m diameter by 4.6 m high FSB systems using a static depth of sand of 2.14 m. Volume of sand in these systems is 5.61 m^3. Using the TAN nitrification rate of 1 kg TAN/day/m^3 indicates a nitrification rate of 5.61 kg TAN per day per FSB. Using equation to calculate the fish feeding load that could be imposed is 187 kg feed per day. These are rather impressive numbers. Performance at CAV lends credibility to these estimates to date. CAV uses a design value of 100 kg feed per day for these systems.

Costs provided by CAV for their FSB tank systems are approximately $2,200 for the fiberglass reactor vessel, $800 for a fiberglass plenum/manifold, plus the costs of pipe and valves. CAV estimates approximately 50 man hours to fully plumb a system to the fish tank unit.

Summerfelt and Wade (1997) report that two FSB biofilters built recently at two commercial fish farms treating flows of 1.5 to 2.3 m^3/min cost around $6000, including biofilter vessel, sand, piping, valves, shipping, and labor for installation. These prices were around five times less than the estimated cost for a installing a trickling filter of similar TAN removal capacity (Summerfelt and Wade, 1997).

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Comparative Performance of Biofilm Reactor Types: Application of Steady-State Biofilm Kinetics

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Ammonia toxicity in aquaculture is often circumvented through application of fixed biofilm reactors designed to encourage nitrification. Nitrification incorporates two consecutive reaction steps:

$$NH_3\text{-}N \xrightarrow[R_1]{} NO_2\text{-}N \xrightarrow[R_2]{} NO_3\text{-}N$$

Where R_1 represents the rate of formation of NO_2-N, and R_2 represents the rate of formation of the end product NO_3-N. Reactors used are classified hydraulically as plug-flow, plug-flow with dispersion, and mixed flow. Reactor type must be chosen carefully given its effect on treatment system performance as measured by cost, maintenance, required volume and changes in water chemistry. To characterize these effects and to demonstrate their design implications, we developed algorithms that predict performance given reactor type, inlet conditions and certain steady-state biofilm kinetic parameters. Model use focused on intermediate product formation (R_1) and conversion (R_2) given the sensitivity of fish to NO_2-N at relatively low concentrations. For example, our RBC and fluidized bed data base indicated R1 and R2 could be expressed as first order reactions. Hence

$$R_1 = d[NH_3\text{-}N]/dt = -k_1[NH_3\text{-}N]$$

$$R_2 = d[NO_2\text{-}N]/dt = -k_2[NO_2\text{-}N],$$

and the corresponding rate of change of intermediate product is:

$$R_1 - R_2 = k_1[NH_3\text{-}N] - k_2[NO_3\text{-}N]$$

where k_1 and k_2 are rate constants. Integration allows the rates above to be expressed in terms of the initial concentration of the reactants NH_3-N and NO_2-N; i.e. for plug flow reactors effluent concentrations are:

$$[NH_3 - N] = C_A e^{-k_1 t}$$

$$[NO_2 - N] = \frac{k_1 C_A}{k_2 - k_1}\left[e^{-k_1 t} - e^{-k_2 t}\right] + C_B e^{-k_2 t}$$

The end product of nitrification is then:

$$[NO_3 - N] = C_A\left[1 + \frac{k_1 e^{-k_2 t}}{k_2 - k_1} - \frac{k_2 e^{-k_1 t}}{k_2 - k_1}\right] + C_B\left(1 - e^{-k_2 t}\right) + Cc$$

Where C_A, C_B and C_c are inlet concentrations of NH_3-N, NO_2-N and NO_3-N, respectively; and t is water residence time in the reactor. Algorithms for the mixed flow reactor were established in a similar manner allowing reactor types to be compared with identical k_1, k_2, and t values. For example, Figure 1 shows NH_3-N removal in a plug flow reactor exceeds that provided by the mixed flow type but plug-flow operation results in higher effluent NO_2-N at a fixed NH_3-N removal efficiency (Figure 2). Figure 3 and 4 shows the net change in NO_2-N (plug-flow reactor) is related to the product k_1t, the inlet concentration ratio NO_2-N/NH_3-N, and the ratio k_2/k_1. We also applied a model based on the kinetics of steady-state biofilms to estimate the k_1 and k_2 coefficients needed in the conversion algorithyms. The biofilm model equates the energy derived from substrate utilization and the energy required for cell maintenance which includes the effect of shear stress on biomass loss. The model provides an estimate of biofilm thickness and substrate fluxes when substrate concentrations exceed a calculated minimum concentration required to maintain a biofilm. The biofilm model can be used to quantify the effects of changes in media density on fluidized bed reactor performance.

Figure 1.

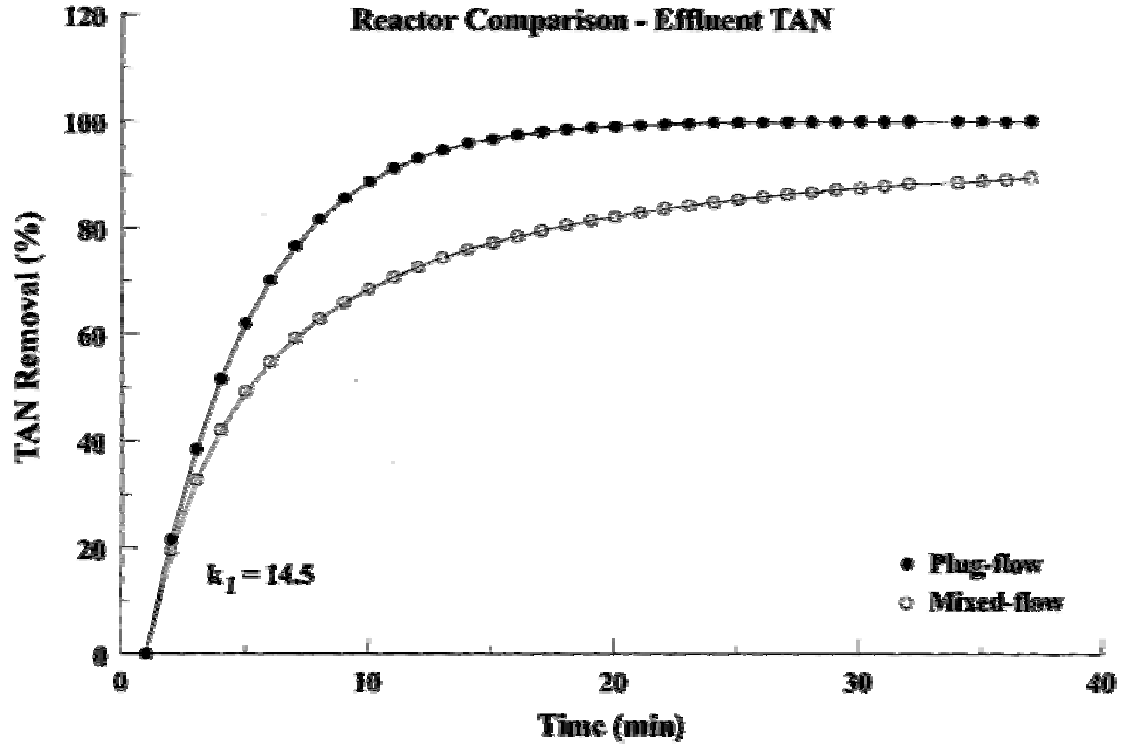


Figure 2.

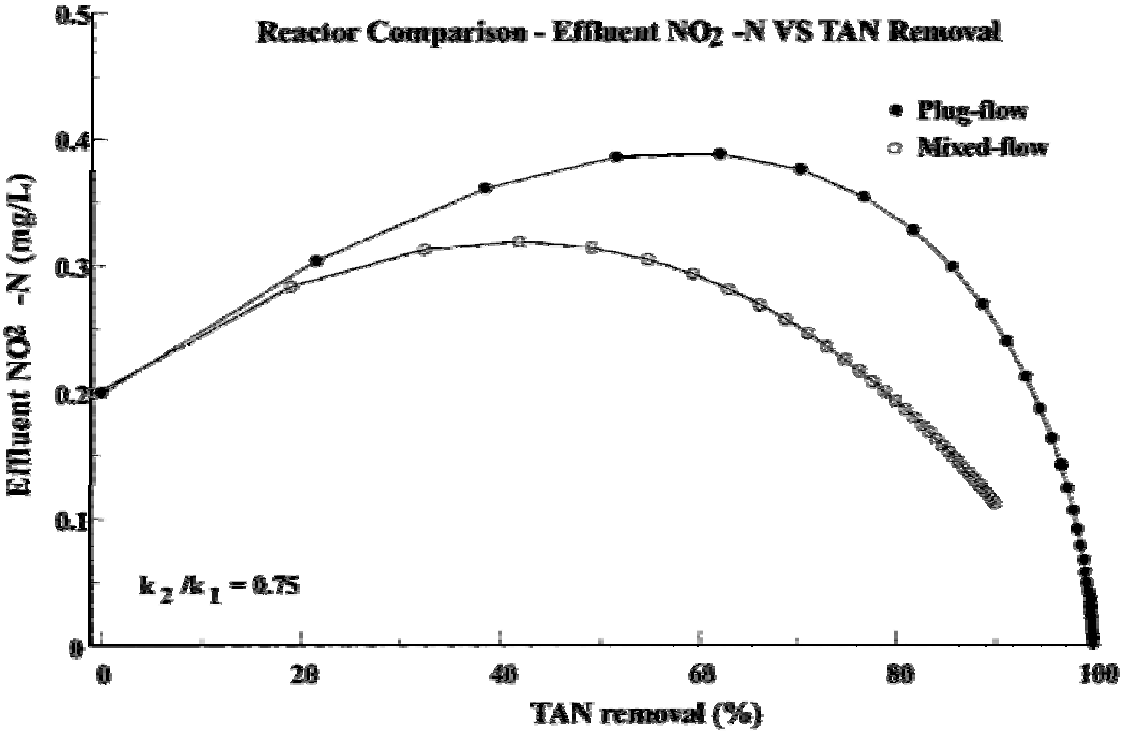


Figure 3.

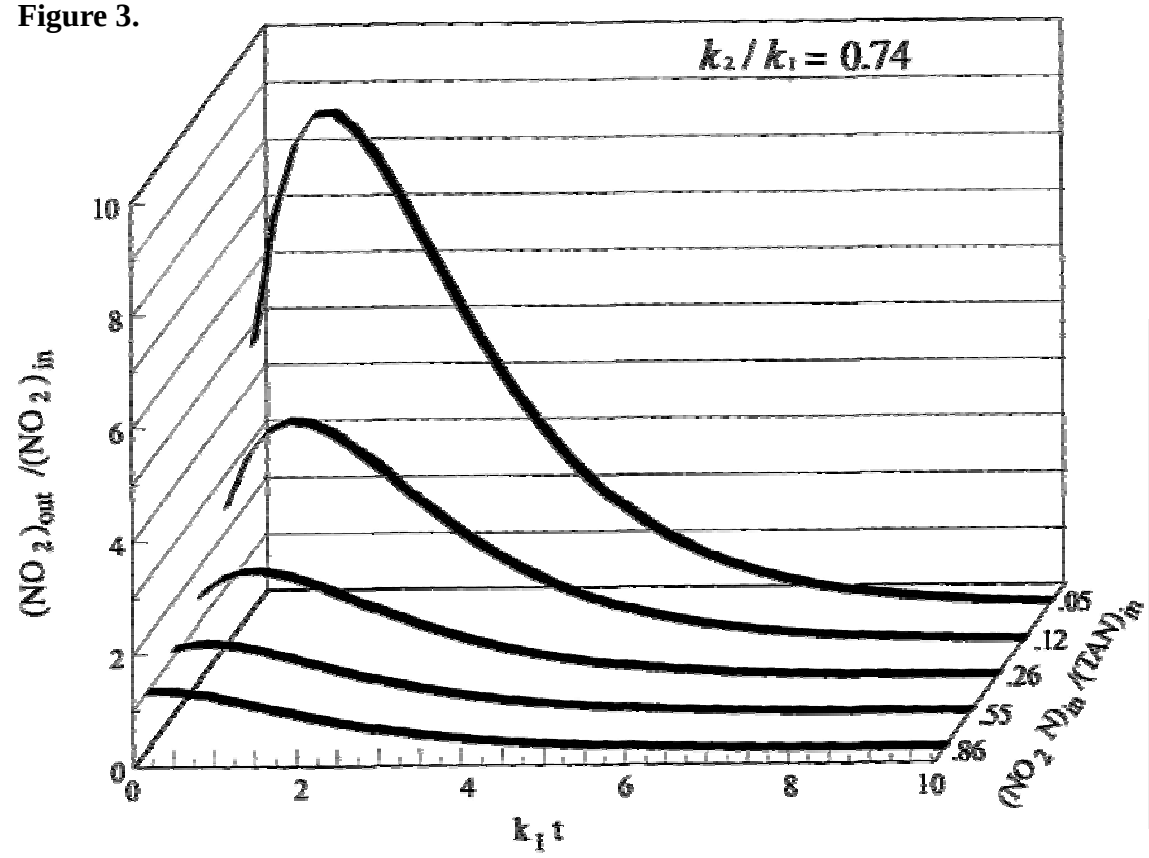
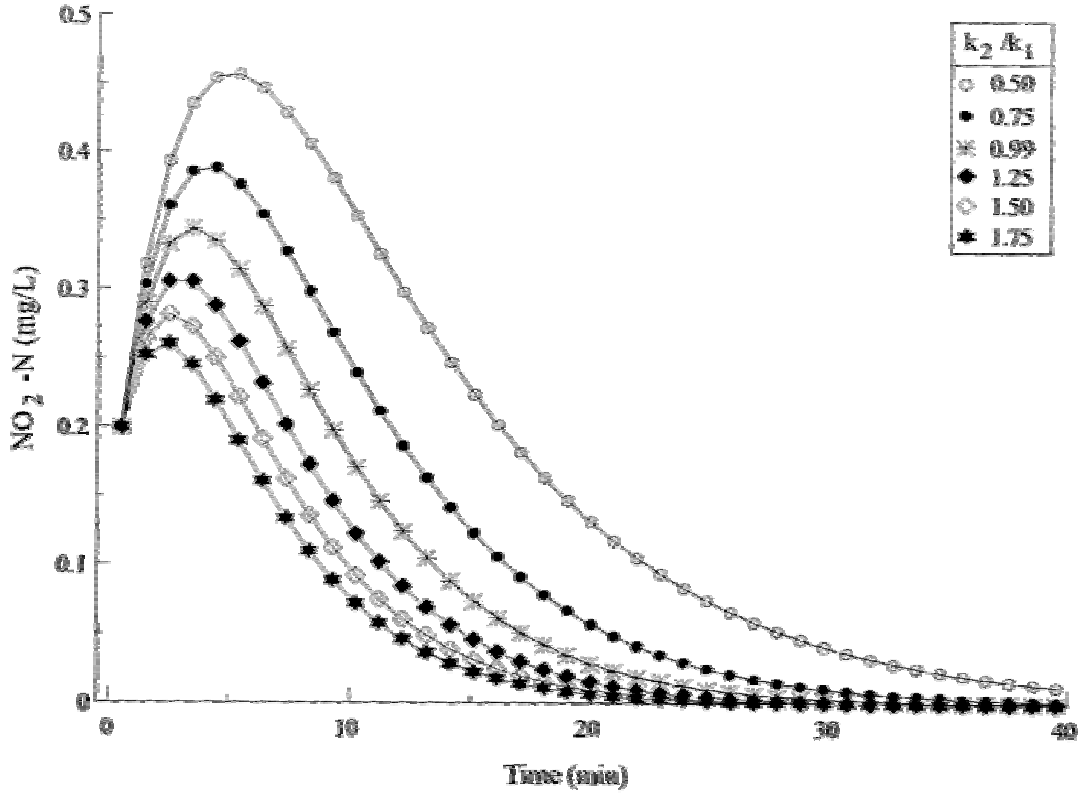


Figure 4.



Immediate and Stable Nitrification in Biofilters by Microbial Manipulations

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Abstract

Microbial populations of autotrophic nitrifying microorganisms were developed, that can withstand the inhibitory factors present in the aquaculture environment and function well in their presence. These microorganisms were further developed to possess high affinity to biofilter solid supports, such as plastic beads, enabling us to attach them to the supports in a strong and long-lasting way. By pre-coating these microorganisms onto biofilter solid supports, the start up time needed to operate nitrifying filters was practically eliminated. The activity of the microbially pre-coated biofilter solid supports was better than that of un-coated, conventional biofilter solid supports, and lasted for many months in fresh and seawater rearing facilities.

Introduction

Nitrifying biofilters are crucial to maintaining low levels of ammonia and nitrite in commercial recirculating aquaculture. The common start up time for new nitrifying biofilters is several weeks (Rosati, 1997) and the outcome is not predictable. The build up of microbial populations in these biofilters is left to chance, allowing the heterotrophic microorganisms a free hand at the expense of the more sensitive nitrifying autotrophs. This paper demonstrates how these hurdles can be overcome by microbial manipulations.

Results and Discussion

Nitrifying microorganisms are sensitive to inhibitors present in the water of aquaculture facilities (Horowitz and Horowitz, 1997). In order to obtain better nitrification, we isolated mixed nitrifying microbial populations from various natural environments and aquaculture facilities, and subjected them to microbial enrichment and selections procedures. The resulting mixed microbial populations performed better than the original microbial cultures when introduced to a green water tilapia recirculating system (in the case of fresh water nitrifying microbial populations) (Horowitz and Horowitz, 1997) or to a recirculating superintensive shrimp production system (in the case of seawater nitrifying microbial populations).

The majority of the nitrification activity in aquaculture production systems is performed by nitrifying microorganisms which are attached to a solid surface (e.g., the biofilter solid support surface), rather than free swimming microorganisms (Horowitz and Horowitz, 1997). Using microbial enrichment and selection techniques, we developed nitrifying microorganisms that possess high affinity to plastic biofilter solid supports, such as beads. This enabled us to attach these microorganisms to the biofilter support surface in a strong and long-lasting way. We pre-coated biofilter solid support with the new mixed population of nitrifying bacteria and studied the effect of the bacterial pre-coating on the potential of biofilter nitrification activity. The pre-coated solid support was incubated inside a tilapia tank in a recirculating green water system and was compared to a biofilter solid support that was not coated. During the test period, the 10,000-liter round tank occupied 250 Kg of fish that were fed about 1% of biomass per day (Horowitz et al., 1997). After a month, the microbially pre-coated and un-coated solid supports were tested for ammonia and nitrite removal potential. A significantly higher nitrification ability was exhibited by the microbially pre-coated solid support. Both ammonia and nitrite removal onset was immediate, and the ammonia and nitrite removal rates were much faster with the microbially pre-coated solid support than with the un-coated solid support. The un-coated solid support suffered a long lag time before ammonia and nitrite removal was detectable, apparently due to interference by heterotrophic microorganisms and organic matter (Figure 1).

The nitrification activity of microbially pre-coated solid support that had been incubated inside a tilapia tank in a recirculating green water system for five months was compared to the nitrification activity of fresh microbially coated solid support that had not been exposed to the fish tank. After the five months of exposure to the recirculating green water tilapia system, the microbially pre-coated solid support maintained its enhanced activity for removing ammonia and nitrite, and was as good as freshly prepared pre-coated solid support (Figure 2). Thus, microbial pre-coating of the nitrifying biofilter solid support has a long lasting positive effect on the biofilter nitrification potential and performance.

Ammonia removal was rapid and identical in the pre-coated and un-coated solid supports after 9 months of incubation. However, for nitrite removal, the advantage of pre-coating the biofilter solid support with the specialized nitrifying bacteria over the conventional approach of using un-coated beads was noticeable even after 9 months of continuous incubation in a tilapia green water system. Nitrite removal activity of the 9 months old microbially pre-coated solid support was immediate and fast, whereas the nitrite removal activity of the 9 month old solid support which was not pre-coated was slower, and suffered a long lag time before it started to show activity (Figure 3). Thus, microbial pre-coating enables the more sensitive nitrifiers (those that convert nitrite to nitrate) to maintain their stronghold on the biofilter solid support surface and withstand competition by other microorganisms.

The nitrifying microbial populations that were developed for fresh water systems and coated onto biofilter supports are presently applied in several tilapia recirculating production systems. The nitrifying microorganisms which were developed to perform well in a salt water shrimp culture environment were successfully coated onto biofilter

solid support, and are currently being used in recirculating intensive shrimp production system biofilters. By pre-coating these microorganisms onto biofilter solid supports, we were able to reduce the start up time needed to operate nitrifying filters to one to two days. Thus, there is no down time, and no risk of initial ammonia and nitrite accumulation for the fish and shrimp.

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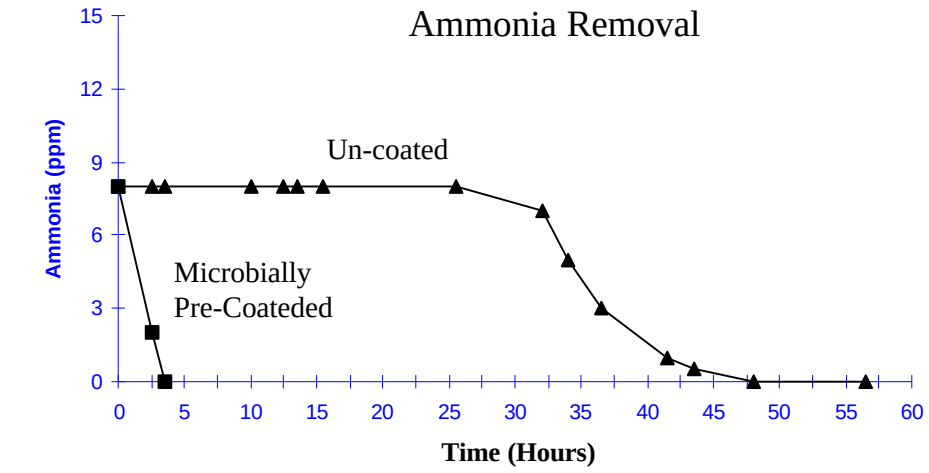

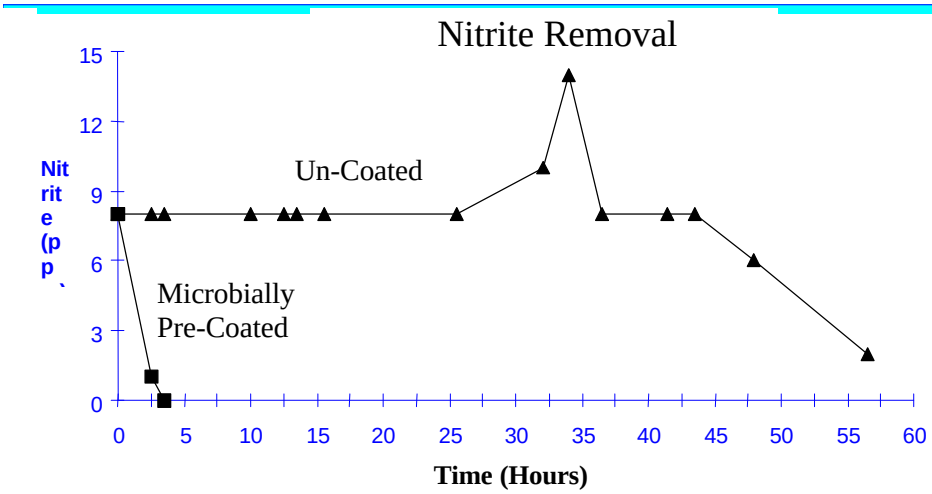

Figure 1. Removal of ammonia and nitrite by microbially pre-coated and un-coated solid supports that had been incubated inside a tilapia green water recirculating system for one month.

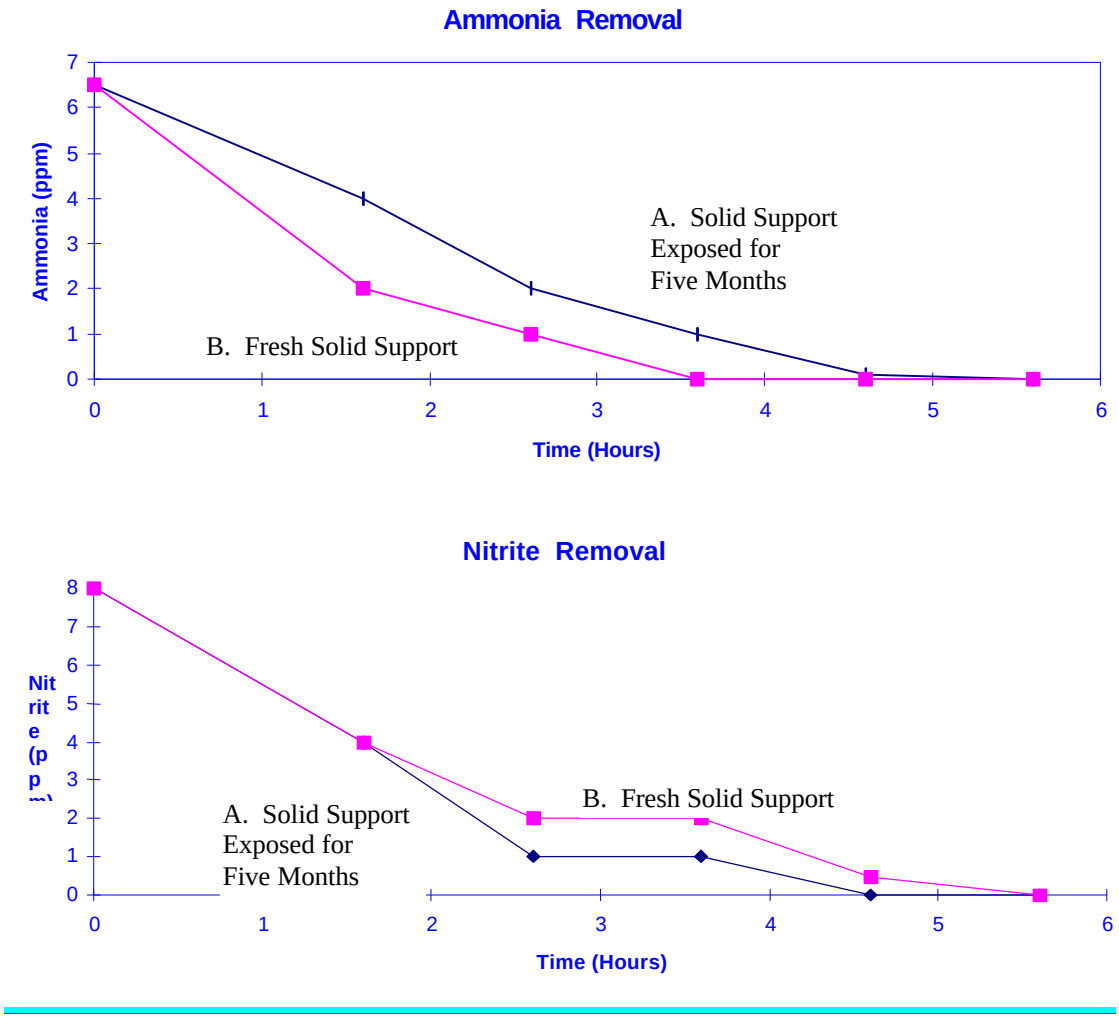

Figure 2. Removal of ammonia and nitrite by microbially pre-coated solid support which had been incubated inside a tilapia tank in a green water recirculating system for five months (A), and by fresh microbially coated solid support which has not been exposed to the fish tank (B).

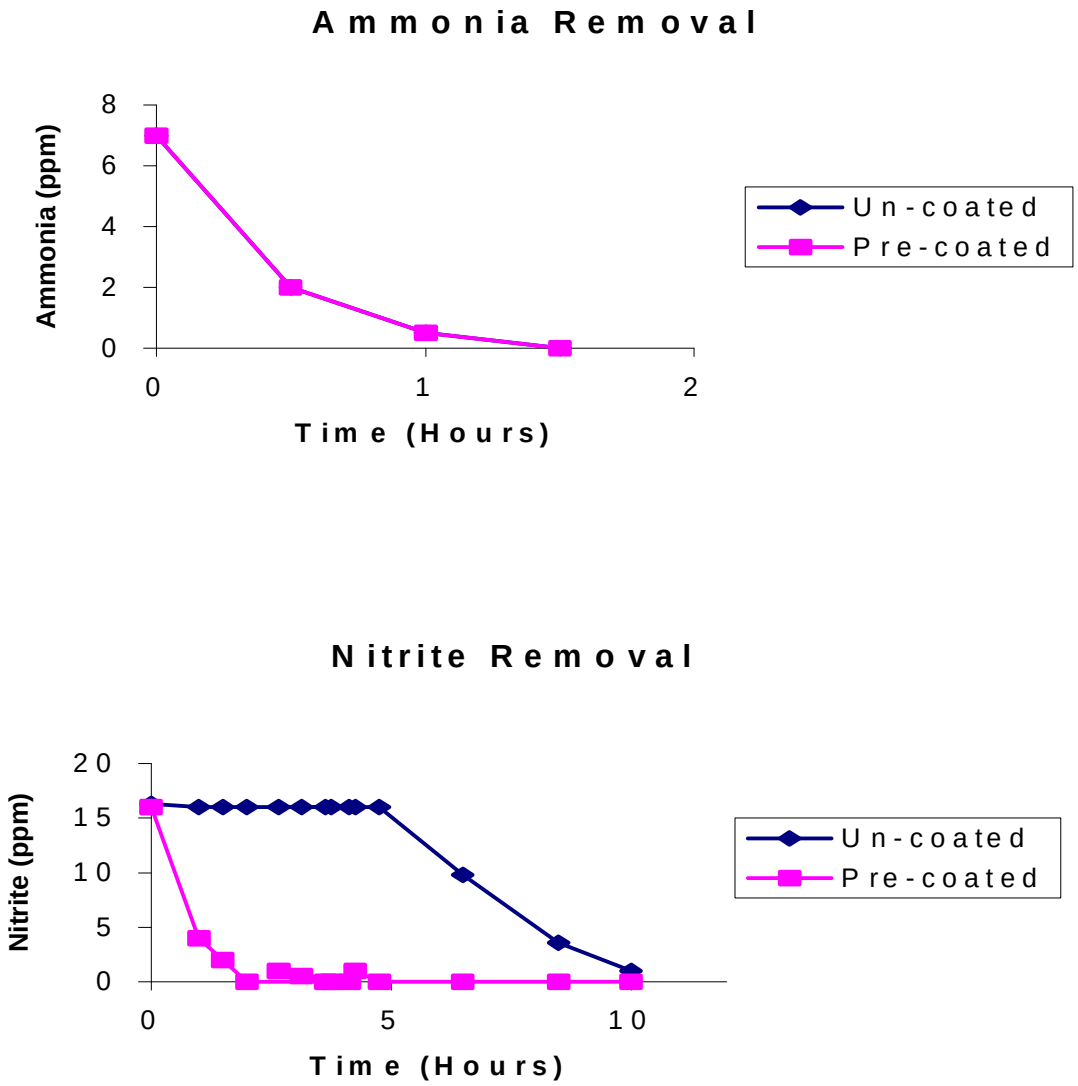

Figure 3. Removal of ammonia and nitrite by microbially pre-coated and un-coated solid supports that had been incubated inside a tilapia green water recirculating system for nine months.

Design of an Emergency Aeration System for Intensive Aquaculture Raceway Systems

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This report summarizes the results of a Senior Design Project in the Biological Resources Engineering Department at the University of Maryland to design an emergency aeration system for intensive raceway production of trout. The system was tested by simulating both loading characteristics and fish respiration in a raceway, through a series of simulations using a deoxygenating slurry delivery system. The deoxygenating agents, sodium sulfite and cobalt chloride, in the slurry were delivered into a 2 m^3 holding tank as an impulse, step input and as a continuous input to simulate various test scenarios. The deoxygenating system was tested by monitoring dissolved oxygen concentrations in the holding tank for the three different inputs as a function of time. Several different aeration systems were designed and along with several commercial systems, subjected to the three loading scenarios. Dissolved oxygen levels were monitored for an extended period to ensure that the aeration system was able to maintain acceptable levels during a prolonged emergency scenario.

Development and Evaluation of a Feedback Control System for Dynamic Control of Dissolved Oxygen in Intensive Recirculating Aquaculture Systems

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Abstract

Over the past hundred years, agriculture productivity in the United States has reached record levels through mechanization, intensification, and automation. The short history of aquaculture has also seen a similar trend of increasing production levels in both open pond systems and indoors intensive recirculation systems. Improved monitoring and control of these production systems will yield a reduction in the risk of catastrophic losses and stress, in effluents and their potential environmental impact, in cost of production by maximizing yield per dollar of capital, and most importantly an overall improvement in product quality.

Low concentration of dissolved oxygen is the major variable limiting production in intensive aquaculture systems. With production densities approaching one pound of fish per gallon of water, supplemental oxygen is required to maintain optimal growing conditions. The high cost of on-site generation or transportation and storage of liquid oxygen makes it critical, for economic reasons, that pure oxygen be used in the most efficient manner possible. The ability to adjust oxygen concentration to meet constantly changing oxygen demand should have a significant impact on the overall economics of pure oxygen use. An improved understanding and control of dissolved oxygen in intensive systems will yield:

1) real time control of oxygen levels in the production tank,
2) elimination of high and low oxygen levels following feeding and other disturbances, thus reducing opportunities for stress induced diseases,
3) a quicker response to the faster changes in water quality as systems are pushed closer to their carrying capacity limits, and
4) automation of a critical process to reduce labor requirements and management responsibility.

This is one aspect of an overall research program to apply modern control system analysis to intensive aquaculture recirculating system, design and develop control algorithms and systems for optimizing water quality parameters and automate routine functions. This project developed a negative feedback control system for dissolved oxygen in intensive recirculating aquaculture systems. Control algorithms were developed and computer simulated for maintaining the dissolved oxygen levels in the

system at a specified set point, given a range of system loading and disturbances. System disturbances, influencing dissolved oxygen levels from baseline metabolism, include such dynamic changes as intensive feeding activity of the fish and stress response to some external stimuli. Several prototype control systems of varying design and cost were constructed from “off-the-shelf” components and installed on a research recirculation system at the Department of Biological Resources Engineering, UMCP. These systems were then evaluated based on their performance, i.e. ability to maintain a given oxygen set point under several fish stocking densities and system disturbances, and their overall economic savings compared to current systems used in the industry.

Growth of Mercenaria Seed Clams in a Recirculating Nursery System Utilizing Computer-Control and Fluidization Technology

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Commercial hatcheries have utilized a number of approaches for taking young seed clams (1 mm) and growing them through the nursery phase to a size suitable for field planting (10 mm). The current developmental design of the recirculating seed clam system implemented at the University of Georgia Shellfish Aquaculture Laboratory consists of six clear cylindrical upweller units (5 cm in diameter, 76 cm in height); a 400 L feed reservoir; a solids separator; a bead filter (0.03 m^3); and utilized during the summer a 0.375 kW (0.5 hp) chiller unit. A 0.075 kW (0.1 hp) magnetic drive centrifugal pump provided a system water flow rate of 40 Lpm. A high water flow velocity (3.6 $\pm$ 0.2 Lpm) was maintained in each of the upweller units to fluidize the seed mass. Fluidizing the seed mass allows for the high density culture of seed by providing a more uniform distribution of food, and transporting waste material away from the seed mass. Culture density in each upweller unit reached approximately 5.5 g whole wet weight clam per cm^2 and greatest biomass growth rates (0.06 d^{-1}) were observed when an effective daily ration of approximately 2% dry weight of algae per g whole wet weight of clam was provided. Feeding of the seed clams from an algal storage reservoir and backflushing of the system bead filter were computer-controlled.

Fish Health Management of Recirculating Systems

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Fish producers today have very limited choices for controlling fish disease problems. Many bacteria that infect fish are now resistant to the only two FDA approved antibiotics. A fish health prevention/maintenance program is presently recognized as a required management practice by fish producers to lessen the risk of diseases,. This management approach has become particularly critical for producers using recirculating systems. Fish health prevention/maintenance programs require many elements including quarantine procedures, examination and monitoring for fish pathogens, and prophylactic treatments for parasites. Developing fish health prevention protocols are necessary to reduce likelihood of bacterial and parasitic diseases.

The vital key in the prevention of disease outbreaks is water quality. It well known that recirculating systems water quality can go from good to bad very quickly. When this happens dreaded disease problems often appear and seem to never go a way. Monitoring and managing of water quality parameters on a daily schedule is necessary management practice for recirculating facilities.

The greatest disease problem facing tilapia producers is Streptococcus (Strep). Strep is a rapidly emerging disease in the aquaculture industry using recirculating systems. Since control of this problem is difficult (Requiring extra label use of antibiotics in many cases), a fish health management plan is needed for reducing this problem.

Fish (Tilapia especially) should be checked and monitored for Strep at recirculating facilities. CNA agar with 5% sheep blood can be used for isolating Strep from fish. This media is well suited for screening for gram positives such as Strep. The brain (nervous tissue) or the intestines are used as the inoculum from fish. Plates are incubated for no more than 96 hrs. Suspicious colonies are gram strained. Those colonies that are gram positive cocci in pairs or short chain are further screened using the catalase test. Strep is catalase negative while many other gram positive cocci such as Staphylococcus are catalase positive. The number of fish (60 fish in most cases) in samples should follow American Fisheries Society Fish Health Section Blue Book procedures for pathogen detection.

It is critical that producers have a quarantine procedure in place for new fish arrivals at their facilities. It is at this stage where fish are checked for potential diseases problems. Fish are examined for parasites and Strep before moving them to production tanks. Also fish should

be treated prophylactically for external parasites before moving regardless of parasite intensity of fish.

Once in production tanks, fish should be sampled two to three times during the course of production to monitor for parasites and for Strep. A planned management program adds to expense of the operation but is preferred to having to shut down completely and disinfect an entire system.

Since fish are going to be sacrificed for a Strep check, they should be also examined for parasites especially Gyrodactylus (Skin Flukes). Research indicates that Strep infections are more likely to occur when trauma occurs to the epidermis. A heavy infection of skin flukes attaching to skin could create such epidermal trauma. Prophylactic treatments for external parasites must be part of a management plan. When fish are moved or transferred to new tanks a standard practice should include treatment for external parasites.

When developing a production facility, a fish health management plan should be use in guiding its construction. A producer should have a production system that is easily treatable and manageable for diseases. A facility that uses a few large units would most likely have difficulty in treatment and management of a problem leading to a shut down for disinfecting the system, thus having no production for months. If a disease gets into a facility with many small units, individual systems can be isolated and disinfected without total facility shut down.

Application of Industrial Monitoring and Control for an Experimental Carbon Dioxide Stripper in a Recirculating Aquaculture System

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Personal computers and generic industrial control software and modular hardware are well suited for monitoring, data collection, and control in aquaculture applications. This mix of components was chosen for the following reasons: PC's provide cost advantages over PLC based solutions, industrial control software offers a rich feature set, and modular hardware provides flexibility for input and output signals. This strategy was used to organize data from multiple locations in a recirculating aquaculture system using an experimental carbon dioxide stripper.

A standard desktop 486/66 computer running Windows 95 with an available serial port for RS-232 communication was used for this application. As the computer was placed in an office environment rather than in the laboratory it did not need to be an industrial version. Personal computers are relatively inexpensive machines that can be used simultaneously with other applications such as word processing in non-critical process monitoring and control environments. Additional stability is gained by dedicating the machine to data acquisition and control.

The user interface must be operator-friendly to facilitate data monitoring, collection, and analysis. We used Genesis by Iconics, a PC based industrial software package with scripting features for control algorithms and a customizable user interface. For our application, the software was used to collect and display data for the user in the office. Monitored data are summarized in a main display with additional detail such as pulsed-bed biofilter status, CO2 scrubber status and tank status, being easily selected by pressing a button for the appropriate display. Historical trending is also displayed for review of trends in collected data. Data from a CO2 gas phase monitor is used to control a three stage-carbon dioxide scrubber coupled with a pure oxygen contactor. The monitor uses an infrared detector to generate an analog signal proportional to CO2 readings over the range of 0 to 10% by volume.

The application uses modular Dutec® hardware for in-lab collection of data and control. The system uses a single RS-232 cable to send data to the office where the computer is located. It can be further expanded by using additional base units and the RS-422 or RS-485 communication protocols. The Dutec model used in this project consists of a base unit with 16 Analog or Digital signals and an expansion unit, allowing an additional 16 Digital I/O points. Individual modules were purchased according to the type of signal. The cost of this unit is leveraged most effectively when all 16 input/output locations are used.

Water level, dissolved oxygen, temperature, and flow rate are among the standard types of data collected. The flexibility of the Dutec base unit allowed us to purchase individual modules for each type of input or output provided which included DC digital inputs and outputs, AC analog voltage inputs, and AC analog current inputs.

As the electronics industry is constantly advancing, newer products offering additional features and simplicity of use continue to arrive on the market. This system will be able to adapt to changes in available products. Because a generic design was used, the sensors, the hardware, and software can be interchanged or replaced if necessary. At the same time, as configured, this system has adequate monitoring and control features for most aquaculture applications.

The Use of Commercial Probiotics in the Production of Marine Shrimp Under No Water Exchange

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Abstract

The effect of a commercial bacterial supplement (probiotics) on the high density production of *Penaeus setiferus* in an outdoor tank system with no water exchange was studied, using high (45%) and low (20%) protein diets and high aeration. At $\alpha = 0.05$, the 3 months study revealed no significant difference between tanks treated with the commercial bacterial supplement and those that were not, for the mean shrimp survival, shrimp final yield, and shrimp final weight. However, some differences were significant at $\alpha = 0.08$. The probiotics treatment had no effect on the nitrogen cycle in the tanks. The commercial bacterial supplement was further tested for its microbial activity on shrimp sludge. No major differences were noted in respiration and chemical oxygen demand (COD) of the treated and control sludge samples. However, at the end of the test, biological oxygen demand (BOD) in the treated sludge was lower than that of the untreated sludge. Thus, based on this work and other studies of probiotics' use in aquaculture, it appears that commercial bacterial supplements might have some advantage, but more studies are necessary to answer this issue unequivocally.

Introduction

The issue of using commercial bacterial supplements (in liquid or powder forms) to benefit aquaculture production systems is controversial (Jory, 1998). This work describes the potential of probiotics use in high-density *P. setiferus* production systems with no water exchange.

Results and Discussion

A commercial bacterial supplement (BioStart HB-1&HB-2) was added according to the manufacturer (AMS) instructions to 6 test tanks of *P. setiferus* grown in an outdoor high-density production system with no water exchange and with high aeration. Three of the tanks were fed with a high (45%) protein diet, and the other three were fed with low (20%) protein diet. The 6 control growout tanks were fed as above, but did not receive the probiotics supplement. The volume of each tank was 10 m^3 and each tank had a 15 cm layer of clay soil on the bottom. The 3 months study revealed no significant difference between tanks treated with the commercial bacterial supplement and those that were not, at both the 45% and 20% protein diets, for the mean shrimp survival, shrimp final yield, and shrimp final weight at $\alpha = 0.05$ (Table 1). At $\alpha = 0.08$, however, some significant differences were noted.

Table 1. Mean shrimp survival, final yield, and final weight of *P. setiferus* treated or untreated with a commercial bacterial supplement (BS) after 3 months in an outdoor tank system with no water exchange. Feeding was with a 45% or 20% protein diet.

Treatment	Survival* % $\pm$ STD	Final Yield* Kg/m^2	Final Weight** g $\pm$ STD
45% + BS	84.1 $\pm$ 19.67	0.380	9.03 $\pm$ 1.681[a]
45% - No BS	94.1 $\pm$ 4.14	0.482	10.24 $\pm$ 1.247[b]
20% + BS	72.5 $\pm$ 24.61	0.413	11.40 $\pm$ 1.458[c]
20% - No BS	85.9 $\pm$ 7.14	0.431	10.03 $\pm$ 1.040[d]

* There is no significant difference at $\alpha = 0.05$ between treatments in each of these columns.

** There is no significant difference at $\alpha = 0.05$ between treatments in this column, except between a and c (a<c). At $\alpha = 0.08$ there is a significant difference in this column between the following treatments: a and b (a<b) and c and d (c>d).

The levels of ammonia, nitrite and nitrate in the experimental tanks were followed with time. There were no striking differences in the pattern of ammonia, nitrite, and nitrate accumulation with time in the tanks that received the commercial bacterial supplement and the untreated controls. The build-up of ammonia and nitrite levels with time was, however, related to the protein level in the feed. As expected, the tanks fed with the 45% protein diet had significantly higher levels of ammonia and nitrite than those fed with the 20% protein diet. Accumulation and removal rates of ammonia and nitrite were not affected by the probiotics addition.

The commercial bacterial supplement was further tested for its microbial activity on shrimp sludge. Shrimp sludge was incubated in the lab with and without probiotics addition. No major differences were noted in the respiration and COD between the

treated and untreated sludge. However, at the end of the test, BOD in the treated sludge was lower than that of the untreated sludge (Table 2).

Table 2. The effect of a commercial bacterial supplement (BS) on shrimp sludge – a lab study.

Treatment	Respiration mg O_2/l/hr after 1 day	COD ppm t=0	COD ppm 2 days	COD reduction in 2 days	BOD ppm t=0	BOD ppm t=2	BOD reduction in 2 days
Control sludge	2.02	89	77	13%	4288	3520	18%
Sludge + BS	2.20	87	79	9%	3104	352	89%

Based on the present work and on other studies of probiotics' use in aquaculture (Jory 1998; Queiroz and Boyd, 1998), it appears that there is no clear benefit for adding such bacterial supplements. However, some of the differences that were noted, especially BOD removal and shrimp size with low protein feed, need to be studied further. Similarly, Queiroz and Boyd (1998) found higher yield of catfish (at $\alpha = 0.10$) with the addition of another commercial probiotics product. Better understanding of the reasons for such effects may lead to better probiotics products in the future.

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A Study of Selected Fish Feed Binders: Effect on Generated Waste Quantity and Quality

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Abstract

Aquacultural effluent and the potential for pollution from it are some of the most widely discussed problems both within and outside of the aquaculture industry. Recirculating aquacultural systems are intensely stocked with fish, feeding on high-protein feed, to obtain production values that offset the high capital and operating costs of such systems. In these systems, approximately 3% of the fish feed is discharged as ammonia and 30 to 60% as solid waste rich in organic matter content. Such a wastewater has a potential to degrade the receiving water quality quite significantly.

This paper presents the results obtained from a series of experiments, conducted at the University of Maryland (UMCP) with hybrid striped bass, on the study of the effect of selected binders on generated waste quality and quantity. It also compares the UMCP findings with those from similar studies at Cornell University, Illinois State University Normal, and Louisiana State University Baton Rouge, using trout, tilapia, and catfish, respectively. The main objective of the presented study was to determine the effect of adding binding supplements to fish feed on fish growth, culture water quality, and culture system filter performance.

At UMCP, initially nine preliminary diets, including a control, were tested and then four, including a control, were further investigated. Treatment diets for preliminary studies were prepared using carageenan, sodium alginate, wheat gluten, guar gum, nutra-binder, bentonite, lignin sulfonate, and Pel-Plus as supplemented binders in a basal feed. Preliminary trials used all binders at a relatively high percent (10%) of the feed. Wheat gluten or nutra-binder (NB) at 5%, lignin sulfonate (LS) at 3%, and bentonite (B) at 5% of the feed were the three binders that were used for more detailed tests (secondary trials) after preliminary trials.

At UMCP, hybrid striped bass showed poor acceptance of feeds containing 10% guar gum, sodium alginate, wheat gluten, or bentonite as binder material. Weekly measured water quality parameters and solids characteristics (particle size distribution) during the secondary trials were not significantly different among the four treatments at the 5% level of significance. Somewhat similar results were reported by investigators at the other universities.

Effect of Chemotherapeutants on Nitrification in Fluidized-Bed Biofilters in a Recycle Rainbow Trout Culture System

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Two commonly used fish therapeutants, formaldehyde and benzalkonium chloride (roccal), were evaluated for their effect on the nitrification efficiency of fluidized-bed biofilters. The therapeutants were added at conventional concentrations to two small-scale (2200 L) recirculating trout culture systems which each contained six fluidized bed biofilters operating in parallel. Biofilter efficiency was measured, before and after treatments, by determining ammonia and nitrite removal efficiencies at ambient conditions, and when challenged with a spike of ammonium chloride at a concentration four times that of the ambient TAN. Three formalin treatments in recycle mode ranging from 167-300 ppm had no significant effect on biofilter efficiency. Four roccal treatments from 1-2 ppm were conducted; three bath treatments and one recycle treatment. None of the roccal treatments had an immediate effect on ambient nitrification but a delayed drop in biofilter efficiency was observed after 3-5 days with no effect detectable after 7 days in all of the treatments. There was no catastrophic drop in nitrification efficiency caused by any of the treatments. In only one instance did roccal treatment have a deleterious effect on nitrification when the biofilters were challenged.

Water Quality Limitation of Fixed Film Biofilters for Recirculating Aquaculture Systems

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The existing research, demonstration, and commercial recirculating aquaculture systems almost exclusively use fixed film biofilters for nitrification. The main advantage of this type of process is that the biofilm can maintain a relatively long cell detention time that accommodates the low growth rate of nitrifying bacteria. Due to the nature of the diffusion controlled process that occurs in a biofilter, the nitrification rate of a fixed film filter is directly related to ammonia concentration in the system. Based on biofilm theory, this paper presents a mathematical model for ammonia removal in a recirculating system, considering mass transfer through a biofilm, feeding rate, and volume and water exchange rates of the system.

Minimum concentration of substrate

A biofilm is a layer-like aggregation of microorganisms attached to a solid surface. Because the mass transfer in a fixed film process is diffusion controlled, there must be a minimum substrate concentration maintained in the bulk water to create a concentration gradient that drives the nutrient transport across the biofilm. In addition, a stable nitrifier population requires an adequate concentration of substrate. According to Rittmann and McCarty (1980), the minimum substrate concentration, S_{min} ($g.m^{-3}$), can be calculated as:

$$S_{\min} = K_S \frac{b}{Yk - b}$$

Where, K_S= half-velocity coefficient ($g.m^{-3}$); b = specific bacterial decay (day^{-1}); Y= yield of bacterial mass per unit of substrate mass ($g.g^{-1}$); k= maximum specific rate of substrate use ($g.g^{-1}.day^{-1}$).

Substrate flux into a biofilm

The flux of substrate into a biofilm (or removal rate), J ($g.m^{-2}.day^{-1}$), can be estimated by the formula of Atkinson and Davis (1974):

$$J = h\, kL_f X_f \frac{S_S}{K_S + S_S}$$

Where, η = the effectiveness factor; L_f = thickness of the steady-state biofilm (m); S_S = interfacial concentration of substrate ($g.m^{-3}$); X_f =bacterial density in biofilm ($g.m^{-3}$). A detailed description of this calculation can be found in Rittmann and McCarty (1980 and 1981).

Recirculating aquaculture systems

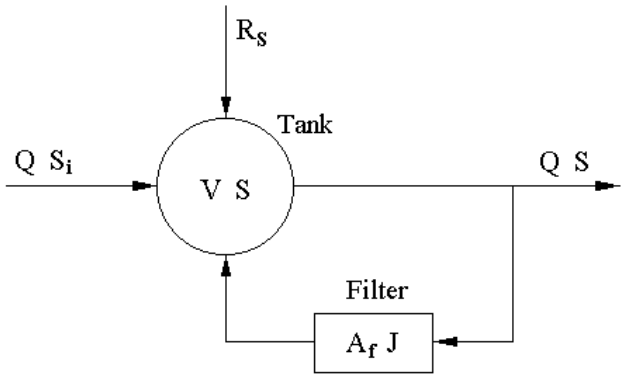

Fig. 1 Substrate transfers in a recirculating aquaculture system.

For a recirculating aquaculture system (Fig. 1), the equation of substrate mass balance can be expressed as:

$$V\frac{dS}{dt} = R_S R_f W_f - A_f J - (S - S_i)Q$$

Where, A_f = biofilm area (m^2); Q = water exchange rate ($m^3.day^{-1}$); R_f =daily fish feeding rate (g feed (g fish)$^{-1}$.day^{-1}); R_S = the ratio of substrate production to feed mass (g ammonia (g feed)$^{-1}$); S = substrate concentration ($g.m^{-3}$); S_i = substrate concentration of inflow water ($g.m^{-3}$); t = time (day); V = water volume (m^{-3}); W_f = total fish weight (kg).

Simulation and discussion

The ammonia nitrification process is simulated here since it's important for recirculating aquaculture. The relationship between ammonia concentration and removal rate for different values of biofilm parameters is indicated in Fig. 2. Due to energetic and kinetic constraints, a minimum concentration is needed to support a steady-state biofilm. Below the minimum concentration, biofilm growth occurs at a negative rate and the monolayer of bacteria gradually disappears. As a result, no steady-state-biofilm will exist, and substrate flux will be zero. When ammonia concentration is above the minimum level, but not very high, the relationship between ammonia concentration and removal rate is approximately linear (Fig. 2).

For recirculating aquaculture, simulation is carried out for a system with a 20 m^3 water tank and a PBF-10 filter (Aquaculture System Technologies, LLC, 1996). The biofilm area of the filter is about 370 m^2. It is assumed that the ammonia concentration of the inflow and the initial water bulk are zero, the daily fish feeding rate is 2.5%, and the ratio of ammonia production to feed mass is 3%. The values of the biofilm parameters are assumed to be the same as curve 2 in Fig. 2. Thus the minimum ammonia concentration is 0.286 $g.m^{-3}$, and the relationships between ammonia concentration, removal rate, and

fish biomass can be determined (Figs. 3 and 4). It is clear that different minimum amounts of fish mass must be maintained for different water exchange rates, to keep the ammonia concentration above the minimum level. Otherwise, the ammonia removal rate will be zero (Fig. 4) and the biofilm will be destroyed. When fish mass is more than the limit, both ammonia concentration and its removal rate have an approximately linear relationship with fish mass (Figs. 3 and 4).

This paper gives the initial results of the water quality limits of fixed film biofilters used for recirculating aquaculture systems. Note that BOD_5 interaction has not been considered, and the kinetic parameters used in the simulation are based on non-aquaculture wastewater. Additionally, further studies are needed, especially on experiments for parameter calibration, model validation, and effective application.

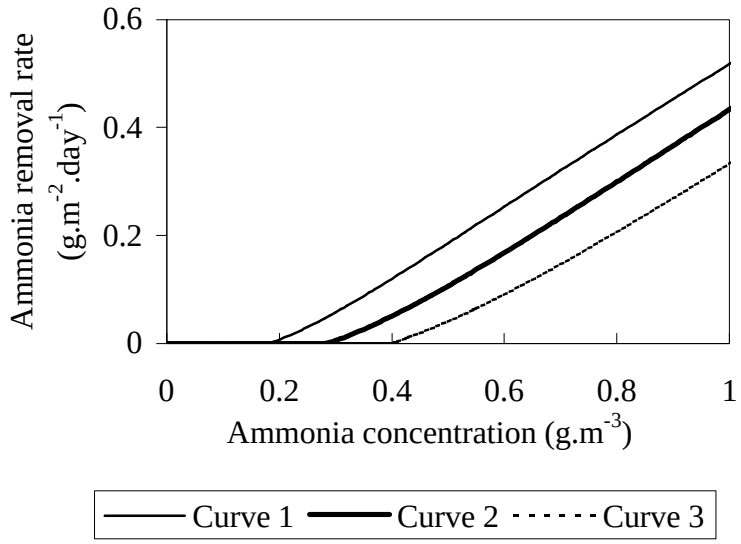

Fig. 2 Relationship between ammonia concentration and removal rate.

Curve 1: K_S=2 g.m^{-3}, k=2.0 g.g^{-1}.day^{-1}, Y=0.3 g.g^{-1}, S_{min}=0.182 g.m^{-3} ;
Curve 2: K_S=2 g.m^{-3}, k=2.0 g.g^{-1}.day^{-1}, Y=0.2 g.g^{-1}, S_{min}=0.286 g.m^{-3} ;
Curve 3: K_S=2 g.m^{-3}, k=1.5 g.g^{-1}.day^{-1}, Y=0.2 g.g^{-1}, S_{min}=0.40 g.m^{-3} .

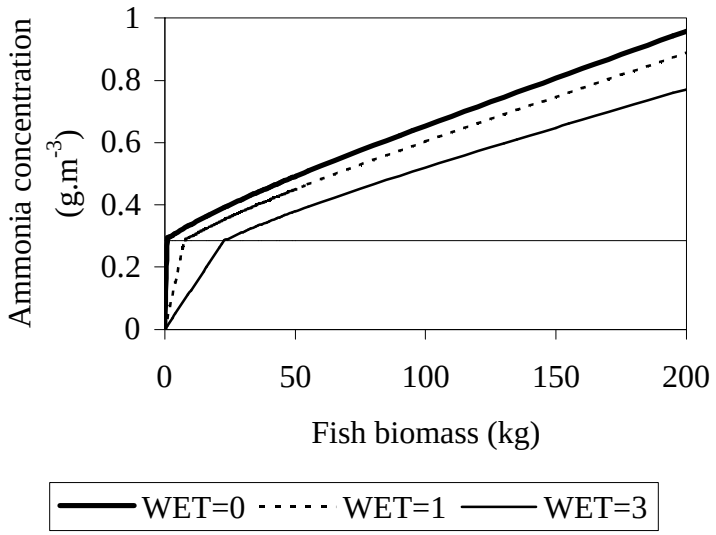

Fig. 3 Computed result of ammonia concentration vs fish mass. WER is water exchange times of the total water volume per day.

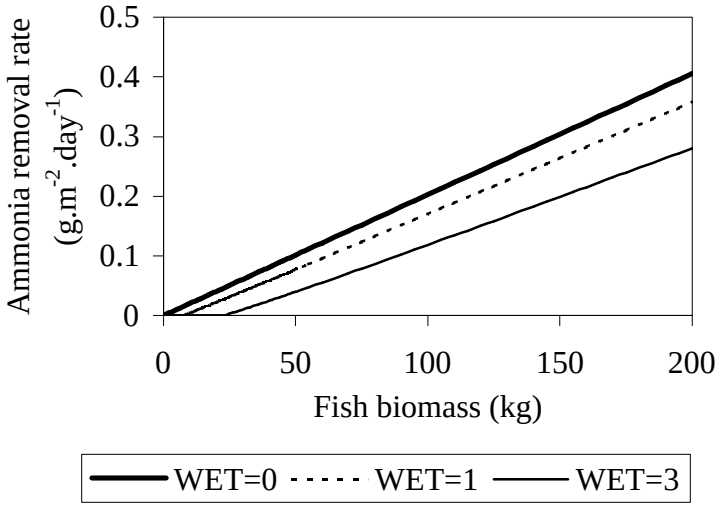

Fig. 4 Computed result of ammonia removal rate vs fish mass.

Aquaculture Engineering Design of Tilapia Breeding System in a Freshwater Recirculating System

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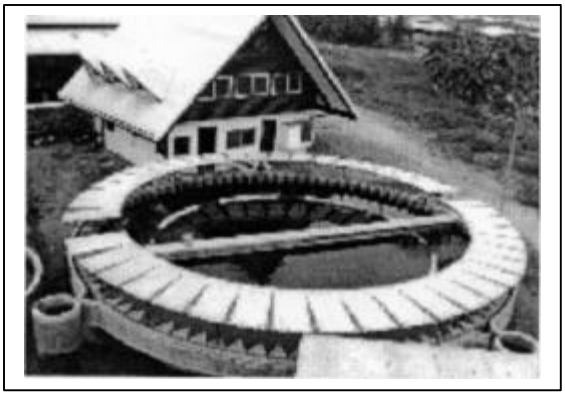
Abstract

Production of male tilapia individuals using hormone has become increasingly popular in the aquaculture industry and its effect on human health has not been known. Tilapia male individual grows faster compared to females. Tilapia fry supply in the Philippines is mainly dependent from hatcheries in fishponds, cages and fishpens in lakes and reservoirs. With the rapid expanding growout production system, degradation of the natural bodies of water and the absence of management policies will pose a problem for many aquaculture operations. There is therefore a need to design tilapia breading system that is environment friendly and poses no problems on consumers in the design and construction of pilot tilapia breeding system in a freshwater recirculating system in Cabuyao, Laguna, Philippines.



The breeding system is composed of male compartment, female compartment, fry compartment and fry collector with a total area of 154m^2. Five hundred (500) female (*Oreochromis niloticus*) and one hundred (100) male (O.areus) tilapia breeders were stocked in their respective compartment to evaluate the system performance in the production of male tilapia fry. The average recorded hybrid fry production in five (5) months was 29,008 per month. Based on five hundred (500) female breeders used, the average production rate was 58 fry/female/mo ranging from 37.4 to 74.2 fry/female/month. The production per unit area of the system equivalent to 188.4 fry/m^2/mo ranging from 121.5 to 241.0 fry/ m^2/mo. The percentage of hybrid male production based on random sampling (n=300) from first batch progeny grown in growout rearing tank for three (3) months was 91%.

System redesigning and re-engineering using alternative source of energy could be considered potential household backyard fry production component to supply the fry requirement of the industry. Further design improvement and development of the system for cost effective and efficient fry collection to minimize handling should be given emphasis.

Keywords: tilapia, breeding system, aquaculture engineering, and recirculating system

Performance of a Prototype Zeolite Recirculating Aquaculture System

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Abstract

A prototype demonstration recirculation aquaculture system (RAS), using a natural zeolite to remove ammonia, successfully supported and grew coho salmon (O*ncorhynchus kisutch)* for a period of one year.

The system has a total water volume of 4.0 m^3 (4000 l) distributed over two 1.3 m^3 volume circular rearing tanks, one 1.0 m^3 volume settling tank and a 0.4 m^3 volume zeolite column. Less than 5% of the water volume was replaced daily.

The rearing tanks are equipped with a split drain system. Solids are removed using one third of the 120 lpm recirculating flow, and are discharged via a central bottom drain into the settling tank. From there, the solid free water is pumped through the zeolite while injected with high purity oxygen and ozone.

Two thirds of the flow exits the tanks by way of a central standpipe, located at mid-depth. This flow is pumped to the top of a 2.0 m tall oxygen/ozone enhanced packed column for oxygenation and degassing of carbon dioxide. Adding ozone to the column retards biofouling of the packing media.

Temperature and dissolved oxygen were monitored continuously, total ammonia nitrogen and pH were recorded daily, total alkalinity and carbon dioxide were measured occasionally. Temperatures were maintained at an average of 12.0^{0}C, dissolved oxygen near or slightly above saturation. Because the normal pH of the water is 7.8, initially the pH was adjusted to maintain un-ionized ammonia at recommended concentrations. However it was soon noticed the salmon tolerated higher concentrations and pH adjustments were discontinued. Despite high ambient un-ionized ammonia concentrations of up to 0.35 mg/l, fish showed no signs of ammonia toxicity (gill hyperplasia) but ceased feeding at concentrations in excess of 0.20 mg/l.

The pH ranged from 7.8 to 8.0 most of the time and carbon dioxide registered from 30 to 35 mg/l. Total alkalinity increased, over time, from 300 mg/l to up to 1000 mg/l. Both calcium and sodium concentrations increased as a result of zeolite regeneration with a solution of NaCl and NaOH.

Ozone prevented biofouling of the zeolite and simultaneously disinfected the recirculation flow. Water clarity, most of the time, approached drinking water quality. Neither fungal nor bacterial infections were observed, even on fish with eroded snouts.

Fish growth was normal, feed conversion averaged one. The system was designed to support a maximum biomass of 208 kg (80 kg/m3), it maxed out at a biomass of 260 kg of 60 g fish and a daily feed input of 2.8 kg. This biomass represented a rearing density of 100 kg/m^3 (6.25 lbs/ft^3), a loading of 2.2 kg/lpm (18 lbs/gpm). Zeolite was regenerated with a 2.0 percent salt solution elevated to a pH of 11.5 to 12.5 with sodium hydroxide, allowing degassing of the ammonia.

Zeolite columns were regularly regenerated after feeding 10 kg of food. By that time the ambient total ammonia nitrogen concentration was at 20 mg/l, un-ionized ammonia between 0.25 and 0.35 mg/l.

Bacterial floc routinely obstructed rearing tank discharge plumbing and became especially bothersome once daily feed exceeded 1.5 kg. Some improvements were made in design to simplify clean-out, and routine maintenance readily controlled the floc.

The system's design and operating parameters were applied to estimate the costs of large systems. To construct a similar system at commercial scale costs approximately $3.00 per pound annual production capacity. Production costs (utilities, feed, chemicals, annual labor) for a coldwater species range from $1.50 to $1.75 per pound.

The results obtained thus far with the coho salmon are very encouraging and further studies are warranted.

An Integrated Recirculating System for the Production of Oysters and Shrimp

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Aquatic animal production can be increased beyond what has been achieved without requiring additional water resources or causing additional environmental impact. In traditional culture the carrying capacity of a production system is ultimately limited by the accumulation of toxic metabolites such as NH_3 and CO_2 in the water. To increase the carrying capacity of a traditional aquaculture production system beyond its normal limit, specific waste treatment processes must be added to remove the limiting metabolites. Temperate zone re-circulating aquaculture production systems are examples of what can be done to increase the carrying capacity of an aquaculture system. However, these waste treatment measures add costs to the production, and commercially successful examples are rare. Two recent developments, the Partitioned Aquaculture System being developed at the Clemson University and the Integrated Recirculating Systems being developed at the University of Hawaii, are both noteworthy since they have gone beyond the present day waste management technology and demonstrated that cost competitiveness is possible for integrated recirculating systems.

The University of Hawaii Integrated Recirculating Oyster/Shrimp Production Systems is based upon a simple concept. In an oyster/shrimp system, the excess nutrients in the shrimp tank can be used to produce marine algae, such as *Chaetoceros* sp. The algal water is then pumped to a fluidized packed oyster column where oysters are suspended individually in a stream of high velocity water from the shrimp tank. The oyster feed on the algae, thereby eliminating oyster food cost while reducing the excessive nutrient load caused by the incomplete utilization of the shrimp feed. After the algae has been removed by the oysters, the water is returned to the shrimp tank to be reused. Up to 95% of sustained water reuse has been achieved. The normal range of water reuse is 80% to 90%. The system rests on two patents: The first is the Fluidized Bed technology, and the second is a pending patent application on the controlled production of marine algae in an open system. The ability to control the algal species is important to the success of the system, since it must be the right food for the oysters. By controlling the nutrient input to the tank, and by making sure there are sufficient oysters to remove algae continuously, a desired dominate algal species in the system can be maintained.

A venture capital group has licensed the patents from the University of Hawaii and created the Kona Bay Oyster & Shrimp Company in 1997. The company has begun its operation and is expected to reach full production in late 1998. Flat-bottomed, twenty-eight foot diameter round shrimp tanks with center drains are used. Circular water

motion is maintained in the tanks to remove all settleable solid. The oyster columns, 18 inches in diameter and 6 feet in height, can contain about 3,000 55-gram size American Cup oysters.

This paper shows the design steps for such a system.

Design and Construction of a Commercial Biosecure, Closed, Recirculating Shrimp Production System

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Production losses from disease (i.e. viruses) have had a serious negative economic impact on marine shrimp farming world-wide. The need for specific-pathogen-free (SPF) broodstock that are either geographically or environmentally isolated from common diseases has become a priority. The latter is more difficult to accomplish because of possible sources of contamination from influent sea water, shared facilities and shared personnel. The establishment of commercial, environmentally isolated broodstock also necessitates the use of totally, closed recirculating water filtration systems to contain the costs of water replacement due to declining pH and nitrate accumulation.

A commercial biosecure facility composed of 4-100 mt raceway systems has been designed and constructed. The system is composed of 4-3.3 m W X 33 m L X 1.3 m D concrete raceways housed in greenhouses. Each raceway has a central concrete partition and a 1.6 m deep settling basin at one end. All effluent water is drawn from a screen standpipe located in the middle of the settling basin. Filtered water is returned to the surface of the raceways along the central partition at 1-2 m intervals. In addition, a cleaning system consisting of notched 5 cm polyvinyl chloride (PVC) pipe located along the lateral walls and medial partition suspends uneaten feed and particulates off the bottom. Two of the raceways have a combination upflow bead (2.2 m^3)/fluidized sand (1.44 m^3) biofilter system supplied with water from a 2-1 hp pumps (200 lpm). The other two raceways have a reciprocating biofilter (8.9 m^3) supplied by an airlift pump (500 lpm). All four raceways have protein skimmers and activated charcoal filters. The tanks and filters were all new construction and artificial sea salts were used to establish and maintain the salinity (5-25 ppt). Each raceway was designed to produce >100 shrimp m^{-2} for a total of 40,000 biosecure adult broodstock. In addition, the raceways were used to acclimate 5.5 X 10^6 postlarvae before they were stocked into production ponds.

This research project was supported by Woods Brothers Shrimp Farm, Gila Bend, AZ and a State of Texas Higher Education Coordinating Board Technology Development and Transfer grant (# 004952-079).

Procedure for Analyzing the Technical and Economic Risk of a Recirculating Aquaculture System

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Since the economic results of investing in an aquaculture enterprise are unknown at the time the investment decision is made, it is advisable to analyze the uncertainty and risk of such an investment. This is particularly true when the potential aquaculture enterprise includes a recirculating system. Recirculating systems require large capital expenditures for building and equipment which give rise to high fixed costs and high operating leverage. If the investment is financed with a combination of debt and equity, the investors have both operating leverage and financial leverage, and increases in either tend to increase business risk. In addition, a recirculating aquaculture system is subject to technical failures which can result in critical death losses of fish.

One method of analyzing the risk of a potential investment is to simulate outcomes on paper prior to committing funds to physical facilities. The accuracy and usefulness of the simulation depends, of course, on the accuracy of underlying assumptions and the comprehensiveness of the model of the firm which is being simulated. Data collected from established recirculating systems contributes to the accuracy of underlying assumptions, and computer software allows simulation of fairly complex models of an aquaculture enterprise.

A spreadsheet was developed based upon the commercial-scale recirculating system in operation at Illinois State University. It contained information pertaining to revenue, capital costs, and operating costs including feed costs, feed conversion ratios, and fish growth rates. Output cells in the spreadsheet included net income, net present value, modified internal rate of return, breakeven volume measured in dollars of sales, and breakeven volume measured in kilograms sold. Estimates of probability density functions for various sources of technical and economic risk and uncertainty were derived from best available information and incorporated into the spreadsheet. A commercial risk analysis software which was based upon the Latin Hypercube sampling technique was used to quantify the impacts of various sources of risk and uncertainty on profitability and acceptability of the investment. Sources of risk and uncertainty were ranked from most important to least important based upon standardized beta coefficients which were generated by the risk analysis software.

Modeled sources of risk and uncertainty related to physical structures were annual repair and maintenance expenditures and salvage value. Information on salvage value was critical to computation of net present value and modified internal rate of return. Modeled

sources of risk and uncertainty related to fish growth were stocking weight of fingerlings, survival rate, and average daily rate of gain. Other modeled sources of risk and uncertainty included per unit feed cost and feed conversion ratio; per unit prices of LP gas, water, oxygen, and electricity; the hourly labor wage rate; and the price of fingerlings.

Based upon the assumption that 46,800 fingerlings weighing approximately 20 g would be stocked each year, a simulation based upon 1000 iterations generated the following results for output cells:

Output	Mean	Standard deviation
Net profit after taxes (annual)	$15,430	$5,554
Net present value (WACC = 14%)	($25,633)	$19,536
Modified internal rate of return	10.0%	0.3%
Breakeven volume – dollar sales	$88,309	$4,127.87
Breakeven volume – kilograms sold	21,145	1,665

The net present value (NPV) and modified internal rate of return (MIRR) analyses were based upon a five-year planning horizon. Results indicated that under the assumptions utilized, the investment could be expected to generate a 10 percent rate of return after taxes. The minimum MIRR generated by the simulation was –1.5 percent, and the maximum value generated was 18.6 percent.

Sensitivity analysis was utilized to determine which sources of risk and uncertainty had the strongest impacts on output values. The five most important sources of variation for net profit after taxes, NPV, and MIRR, were price per kg of fish at harvest, average daily rate of gain, feed conversion ratio, survival rate, and cost of feed per kg. The five most important sources of variation for breakeven volume measured in dollars of sales were feed conversion ratio, price per kg of fish at harvest, hourly labor wage rate, cost of feed per kg, and fish survival rate. The five most important sources of variation for breakeven volume measured in kg of sales were price per kg of fish at harvest, feed conversion ratio, hourly labor wage rate, cost of feed per kg, and fish survival rate.

With slight modifications, the spreadsheet can be used to analyze recirculating aquaculture systems of different scale and technical makeup. Although the analysis described above did not include a true bioeconomic model, it is possible to incorporate such information into a spreadsheet at the cost of greater complexity.

The Effect of Biological Air Purifying System With Aquatic Animal-Plant Integrated Greenhouse

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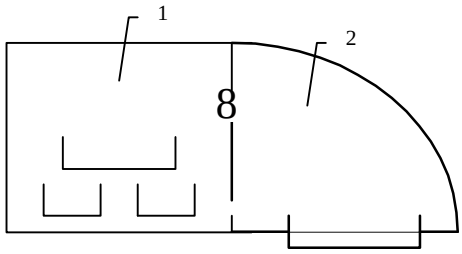
Abstract

Two different types of the joint greenhouses for aquatic animal-plant integrated system were developed at the Agricultural Bioenvironment Engineering Institute of Zhejiang Agricultural University in China. The joint greenhouses form mutual compensation system for exchange CO_2 and O_2 between the aquatic-animal housing and plant-growing greenhouse. The CO_2 from aquatic-animal housing can be used as a nutrient resource for the vegetable or flower inside the greenhouse, the plant photosynthesis product O_2 will purify and improve the air quality inside the animal housing. One of these is the back to back' interaction greenhouses (Fig1),

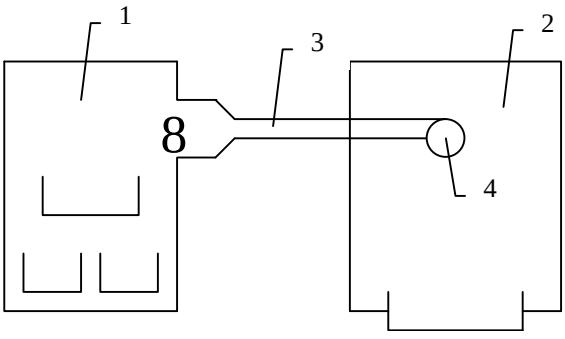


1. aquactic-animal housing
2. plant greenhouse

Fig. 1 Back to back interaction greenhouses system.

Dynamic variations of CO_2 concentration related to operating time was measured and measured with LI 6200 portable photosynthesis system.

Another type of interaction greenhouses is connected with pipe (Fig. 2)



1. aquactic-animal housing
2. plant greenhouse
3. Conecting pipe
4. Pipe with holes

[1]Fig. 2 The interaction greenhouses system with pipe connecting

Dynamic variation of CO_2 concentration was measured too and the simulated equation of CO_2 variation of aquatic-animal housing is as follows:

$$C_1 = 807 + 260e^{-\frac{t}{5000}}$$

C_1: The CO_2 concentration variation related to time of aquatic-animal housing

The simulated equation of plant greenhouse is as follows:

C2: The CO_2 concentration variation related to time of plant greenhouse

$$C_1 = 681 + 358e^{-\frac{t}{5000}} - 632e^{-\frac{t}{1366}}$$

The data indicates that when the ventilation system for air exchange is operating, for the back to back' interaction greenhouse system, the mean value of concentration of CO_2 inside plant greenhouse increase from 320ppm to 780ppm after half hour and the mean value of concentration for CO_2 inside aquatic-animal housing decrease from 1100ppm to 800ppm. For the interaction greenhouses system with pipe connecting, the mean value of concentration of CO_2 inside plant greenhouse increase from 360ppm to 780ppm and the mean value of concentration for CO_2 inside aquatic-animal housing decrease form 1100ppm to 700ppm after one hour, the measure results indicated that the hole position of the distribution pipe is one of the important factors of CO_2 concentration equality, this paper proposed some principles of air exchange system design.

The measure results indicated that the interaction greenhouses of aquatic-animal plant integrated system is an efficient method for purifying air in aquatic-animal housing, and it is used for not only purifying air, but also water recycling and economizing energy.

Integrating Hydroponic Plant Production with Recirculating System Aquaculture: Some Factors to Consider

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Abstract

Aquaponics, the integration of hydroponic plant production with recirculating fish culture systems, is gaining in popularity among hobbyists and receiving attention in the commercial sector. Although the number of commercial operations is still small, at least two large suppliers of aquaculture and/or hydroponic equipment have introduced aquaponic systems in their catalogs and many schools are beginning to include aquaponics as a learning tool in their science curricula. With such high interest, aquaponics appears to be on the threshold of increased technological development and greater application.

Growing plants with fish requires some modification of the design criteria and operational procedures of standard recirculating aquaculture systems. Properly-designed aquaponic systems emphasize plant production, which receives about 90% of the culture area and generates 65-70% of the revenues. Raising and marketing plants require skills that may be unfamiliar to aquaculturists. Other factors to consider in adopting aquaponic technology involve:

Aeration. Plant roots require DO levels that are comparable those required by fish. DO levels should remain high throughout the hydroponic component and throughout the each mass of densely packed roots. Formation of anaerobic zones will cause root death. Rapid water exchange, intermittent dewatering or induced turbulence are used to ensure adequate root aeration.

Solids removal. Rapid removal of settleable and suspended solids from an aquaponic system reduces mineralization, which may decrease some dissolved nutrients to levels that limit plant growth. Aquaponic systems vary from daily or weekly removal of solids to no solids removal at all in some configurations.

Biofiltration. In a properly-designed aquaponic system with a high ratio of plant growing area to surface area for fish production, the hydroponic component should provide sufficient biofiltration, through direct ammonia uptake by the plants and nitrification on the submerged surface areas, so that a separate biofilter is not required. This is an important economic justification for integrating hydroponic plant production in a recirculating aquaculture system. Hydroponic technique. The hydroponic methods that are generally used in aquaponic systems are raft culture, nutrient film technique and ebb and flow systems with either gravel or sand

substrates. Each method requires special design considerations and has advantages or disadvantages depending on the plant crop being cultured.

Suitable fish species. Tilapia are the most common species cultured in aquaponic systems. Not all fish species are suitable. For example, hybrid stripped bass cannot tolerate the elevated levels of potassium, produced through supplementation, that are desirable for rapid plant growth.

Planting densities. It is essential that plants be given adequate space for robust growth. If plant densities are too high, plants will elongate, reducing market value, and lack of air circulation and moisture buildup will foster disease and pests outbreaks.

Stocking rates. Since aquaponic systems emphasize plant production and the fish rearing component is relatively small compared to the plants, stocking fish at extremely high densities and using pure oxygen systems are not practical or cost effective. Fish should be stocked at less than 100/cubic meter to increase individual growth rates, lower feed conversion and promote health.

Water source and exchange. The nutrients or contaminants in source water can impact plant growth and should be assessed. Water exchange should be minimized to maximize nutrient retention time in the system.

Base and nutrient addition. Potassium and calcium bases will neutralize acidity as well as supplement essential plant nutrients that are low in fish waste.

Nutrient and gas recovery. Hydroponic plants can not only recover waste nutrients from fish but also carbon dioxide that is sparged from the culture water and contained by a greenhouse.

Nitrate control. A partially anaerobic solids zone can be used to regulate nitrate levels by adjusting the cleaning frequency. High nitrate levels favor vegetative growth in plants while low nitrate levels promote fruiting.

pH. pH should be maintained at 7.0 for optimum nutrient availability while maintaining adequate nitrification.

Temperature. The optimum temperature is 24C for vegetable production and 30C for tilapia production. If possible, the temperature should be adjusted to favor plant production.

Solar radiation. Commercial hydroponic plants grow best in intense sunlight and should not be shaded. Low wintertime solar radiation in temperate regions will prolong plant production cycles.

Pest and disease control. The need for pest and disease control will be reduced by providing growing conditions that minimize stress. Biological control methods are appropriate for

aquaponic systems. Pesticides and antibiotics should not be used.

Monitoring. At prescribed stocking, planting and feeding rates, aquaponic systems require a minimum amount of monitoring. Only pH is monitored on a regular basis.

Management and labor. Aquaponic systems should be designed for ease of management and should minimize labor requirements. For profitability it is important to reduce operating expenses.

Ground Limestone as a Biofilter Media for Hybrid Stripped Bass Culture

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A pilot study was conducted to evaluate ground limestone as a biofilter media in a recirculation system containing hybrid striped bass. Two replicated biofilter configurations were used. Each system consisted of a rearing tank (122 cm diameter, 67 cm deep), settling tank (102 cm square, 21 cm deep), biofilter and re-oxygenation column (76 cm height, 15 cm diameter) containing Koch rings. The biofilter type and media consisted of either a pulsed bed near buoyancy plastic bead filter or a pulsed bed ground limestone filter. In the pulsed bed limestone and plastic bead filters, 3 kg of media were placed in each column (16 cm diameter, 260 cm height) with two columns per system. A timer-relay-ball valve assembly directed 22.7 l/min of water flow through each column at 30 s intervals. The intermittent flow expanded and mixed the bed during the 30 s of flow, shearing excess microbial growth. Estimated surface area per square meter of each material was, near buoyancy beads, 960 m^2/m^3 and limestone, 4000 m^2/m^3. Temperature was set at 23 C, water hardness adjusted to 150 ppm with calcium chloride and pH maintained above 6.5 by the addition of saturated lime solution. Each unit was stocked with 24 kg of hybrid striped bass averaging 397 g/fish. Fish were hand fed commercial feed twice daily to satiation. The effect of limestone on rearing unit pH and alkalinity was measured independently from ammonia removal rates to avoid any effect pH change may have on ammonia removal rates. During this period lime dosing was shut off. Ammonia removal rate based on a surface area basis was higher for the pulsed bead filter. When ammonia removal rate was calculated as per unit of bed volume, ammonia removal rate was higher for the limestone filter and the efficiency of ammonia removal was also higher with the limestone biofilter. Biological oxygen demand (BOD) measured in the rearing unit was similar between the two filter types. Suspended solids were higher in the limestone treatment. In addition to providing surface area for nitrifying organisms, limestone increased both pH and alkalinity of the water (Table 1). Use of limestone as a biofilter media resulted in less saturated lime solution used to maintain rearing water pH. After 2 months of operation, the limestone bed height had dropped by half and new limestone was added to return bed volume to original depth. Limestone media provided a reasonable nitrification rate and improved both pH and alkalinity but the rearing tank water remained cloudy or milky throughout the study. This turbidity was not due to the addition of lime to control pH. After three months, fish mortality (1-2 fish/day) was observed only in tanks with limestone filters. Microscopic inspection of the gill tissue from dead fish revealed small imbedded limestone fragments. In addition, it was discovered that limestone silt had trapped organic matter at a low point in the system and the trapped material became anaerobic. In summary, limestone supported reasonable nitrification rates, elevated pH and increased alkalinity of the water. The disadvantages include higher suspended solids,

gill irritation and a propensity of limestone silt to trap organic material resulting noxious undesirable by-products. Limestone has potential as a biological filter media if suspended limestone is removed and care is taken to avoid anaerobic pockets within the system.

Table 1. Biofilter ammonia removal and rearing tank water chemistry.

Measurement	Plastic Bead	Limestone
NH_4 removal rate, g/m^2 day (surface area)	0.41	0.30
NH_4 removal rate, g/m^3 day (bed volume)	0.39	1.47
NH_4 removal efficiency %	29.3	35.0
Rearing tank NH_4, ppm	0.38	0.46
Rearing tank BOD, ppm	4.02	4.26
Rearing tank Suspended Solids, ppm	2.4	6.0
Water pH and alkalinity with no base addition (CaOH)		
Rearing tank pH	5.6	6.2
Rearing tank alkalinity, ppm	27.9	49.0

Evaluation of an Aerated Floating Plastic Media Biofilter Within a Recirculating System Used to Produce Food-Size Yellow Perch

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A moving bed biofilter consisting of aerated floating plastic media (Purac Engineering, Inc.) was installed within a recirculating system used to produce food-size yellow perch. The ridged tubular media is 7-8 mm long, 10 mm in diameter, and provides roughly 98% void space as a loose-packed bed. The manufacturer reports that the media has roughly 333 m^2/m^3 of surface area when filling 67% of reactor volume. For the present study, about 4.25 m^3 (150 ft^3) of "unwetted" media was divided into two equal portions and added to the two biofilter vessels (each 3.66 m diameter and 1.22 m sidewall depth). Each biofilter was operated at 0.95 m (3.1 ft) water depth. About 40.5 L/s (640gpm) of water flow and 20.4 L/s (43 cfm) of diffused air was split between the two biofilters, producing a volumetric gas:liquid ration of 0.5:1. The water flow was first filtered through a single drum filter (Hydrotech) operated with 40 μm sieve panels before entering the two biofilters.

The alkalinity of the system was maintained at or above 60 mg/L (as calcium carbonate) by addition of sodium hydroxide.

The water pH and TSS concentration were taken at least once per week. Ammonia, nitrite, oxygen, and carbon dioxide concentrations were measured before and after each biofilter three times a week. This data was used to determine the ammonia, nitrite, and carbon dioxide removal rates and efficiencies across the moving bed biofilter. The arial and volumetric nitrification rate of the media are reported and compared to rates reported for other aquaculture biofilter types.

Prediction and NMR Determination of Fluid Film Thickness and Velocity Distribution in Nitrifying Trickling Filters

Valdis Krumins

Biological trickling filters are a common means of removing nutrients from recirculating aquaculture systems. Design of trickling filters is currently based on rules-of-thumb or empirical loading curves. More rigorous design requires accurate descriptions of such parameters as wetted area, mass transport into and out of the biofilm, and shear forces on the film. These parameters are functions of fluid flow rates; therefore, knowing the distribution of flow rates would enable one to model these phenomena for the entire filter. Such models could then be used to optimize several aspects of trickling filter design, including packing media and irrigation rates.

In this work, nuclear magnetic resonance (NMR) is used to image miniature nitrifying trickling filters. The NMR images show the location of biofilm, packing media, and water, and also display the velocity of any flow. Therefore, they can be used to compute the distribution of flow rates and to observe any changes in flow patterns caused by the presence of an active biofilm.

In addition, a probability density function (PDF) of local flow rates is independently developed using only the irrigation rate, packing material properties, and fluid properties as inputs. Preliminary results show good agreement between the NMR images and the theoretically determined PDF.

The Chilean Aquaculture Industry and the Role Played By the Universidad Catolica Del Norte in Its Development

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Introduction

The explosive growth of the aquaculture industry in Chile over the past decade would not have been possible if the country did not have good natural conditions with extensive coastal areas, lakes and rivers that provide optimal environmental conditions for farming, and also the existence of technicians and professionals able to meet the industry demands. Also, the existence of high quality fishmeal produced in Chile provides enough feed production to support the aquaculture activities.

The present work presents a brief description of the most important aspects of the species farmed in the country and the role played by the Universidad Católica del Norte in its development.

Farming of Endemic Species

Scallop farming.

In 1983 Trench et al. and in 1984 Disalvo et al. published the main data and technique culture about scallop farming, used until now. With the development of the "Centro de Acuacultura e Investigaciones Marinas" , a donation from the Japan International Cooperation Agency (JICA) to the Universidad Católica del Norte in 1985 began the development at commercial scale of scallops, and the hatchery techniques, natural larvae collection and ongrowing systems were then established (Illanes, 1988; DiSalvo, 1988).

There are currently 27 companies operating with investments of more than US$40 million that produced 8264 t in 1995 (SERNAP, 1995), this production placing Chile as the third scallop producer in the world. The average nominal price over the past 5 years has been US$13.3 per kg increasing to US$ 14.9 per kg in the case of fresh chilled scallops (Anonymous, 1997).

Seaweed Farming

Main seaweed farmed is *Gracilaria* spp., and there are 268 authorized seaweed farming concessions, with a 75% of them located in the south and 12% in the north of Chile.

The regular FOB prices were for dry seaweed US$1.9 per kg, but at present due to the unstable Asian markets and a strong decrease in the prices stopped all the exportation and only a few farms continue operating, to supply the local demand only.

Farming of Exotic Species

Salmon and trout farming

The introduction of salmonid species in Chile with the idea of running ocean-ranching began between 1905 and 1910 with the importation of 400.000 eggs of S*almo salar, Salmo trutta* and *Oncorhynchus mykiss*. Between 1924 and 1930 200.000 eggs of *Oncorhynchus tschawytscha,* 114.000 eggs of *O.nerka*, and 225.000 eggs of *O. kisutch* were introduced. Only in 1979 the first cage culture system was established and in 1986 it reached a production level of 900 t (Uribe, 1988), and 141.400 t in 1995 (Anonymous, 1997). Due to the location of the Universidad Católica del Norte in northern Chile, no research has been done in salmonids, that are grown in southern Chile.

There are currently 90 companies in Chile oriented to salmon and trout farming, which have approximately 361 farming authorized concessions, and the salmonids produced are exported to Japan (59.6%), USA (29.8%) and the European Community (6.3%).

Red abalone farming

The red abalone *Haliotis rufesces* was introduced by Universidad Católica del Norte (UCN) and Fundación Chile from California in the'80. There are at least 4 abalone ongrowing farming centers and three hatcheries, one of them belonging to the UCN.

Due to the Chilean Aquaculture and Fisheries Law, this species must be cultured in inland tank systems in northern Chile, but in the South its culture in long-lines systems was permitted.

Japanese abalone

This species was introduced by Universidad Católica del Norte and JICA at the end of the '80, and after six years of an important amount of research in artificial feed, aquaculture engineering, cost analysis, and other bioengineering factors, the UCN and JICA designed hatchery facilities with a production capacity of 500.000 seed per year, and all this seed will be ongrowing by a national corporation with an investment capital of US$1.000.000.

Oyster Farming

The first assay of Pacific Oyster (*Crassostrea gigas*) culture was made in 1978 by the Universidad Católica del Norte and Fundación Chile, with 20.000 seeds (2 at 5 mm) imported from Moss Landing (California, USA) (Hauer, 1988). From that starting point it has moved geographically to the South of Chile, where more than 94% of the total production is located (Anonymous, 1997).

There are 15 companies (individuals and trade unions) authorized to farm oysters, with a production of 1.130 t in 1995. Prices for fresh-chilled oysters have shown a rising trend reaching US$ 6.9 per kg in 1995 and US$ 5.97 per kg for frozen oyster (SERNAP, 1995).

One of the main problems in oyster farming is the impossibility of natural breeding because of the low temperature of the Chilean seawater, therefore, its production is highly dependent on the existence of two hatcheries located in Coquimbo area, which can produce the required seeds.

Australian prawn farming

The Australian prawn *Cherax tenuimanus* was introduced at the end of 80 decade by UCN and national business people, and reactivate this activity just this year through National Grant, that permit the development of a model farm and hatchery facility with the idea of start a new interesting aquacultural business.

Potential Species in Study at UCN

From 1986 the UCN was studying the biological aspects of three local species with a great potential for national and international markets, and they are:

Chilean flounder: (*Paralichtys* sp.) until now the UCN has achieved spawning in captivity and culture of larvae descending from these broodstock. Right now the UCN will be increasing the laboratory capacity to pilot scale with an initial production of 3.000 juveniles for 1998 and 10.000 juveniles for 1999. During this program studies on hatchery and nursery facilities, transport , and sea cage design systems will be carried out.

Chilean river prawn: *Cryphiops caementarius* is the only Paleomonidae specie in Chile, and since 1983 the UCN was studying adequate technology to develop a hatchery and ongrowing facility system (Rivera et al., 1983). Only last year Morales (1997) defined the hatchery techniques to reach the postlarval stages in only 45 days. With these results the possibility to continue building new ongrowing earth ponds will be open, because up to this discovery the only source for prawn seeds were the rivers, which provide limited supplies.

Sea urchin farming: the UCN has currently developed the technology for farming and stocking the local edible sea urchin (*Loxechinus albus*), with a larval phase of 20 days and survival rates over 30%, then they are cultured on policarbonate plates in race-way tanks of 10 t until 4 mm, then they are relocated in baskest hanging from long-line systems and ongrowimg there during 8 months (20 mm), and then they are ready for stocking natural areas (Guisado et al., 1988).

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Determination of the Primary Ammonia Removal Design Criteria for Biological Filters

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Abstract

Ammonia is one of the primary waste materials produced by aquatic species, which is toxic even in low concentrations. Therefore, recirculating aquaculture systems must have some means for ammonia removal. Thus, systems commonly employ nitrifying biological filters to convert ammonia to nitrite and thence to nitrate which is itself non-toxic even in high concentrations. This research investigated whether the ammonia inflow concentration or the ammonia loading rate to the biofilter was the more important biofilter design parameter. Five ammonia inflow concentrations and ammonia loading rates ranging from 0.5 – 8.57 mg NH_4/L and 109 – 2456 mg NH_4/L per filter per day were applied to each of five identical biodrums through a series of ten tests. Total ammonia removal and nitrite levels were monitored in each of the filters. Ammonia inflow concentrations, ammonia loading rates, temperature pH, dissolved oxygen levels and flow rates to the filters were measured and controlled by a semi-automated, synthetic wastewater system. Regression analysis yielded a relationship of ammonia removal versus ammonia inflow concentration and ammonia loading rate (R^2 = 0.93), implying that the interplay of both parameters is necessary in predicting biofilter performance. Percentage ammonia removed was inversely and linearly proportional to loading rate. Increase in flow rate, hence loading rate, under low ammonia concentration in the system, increased mass ammonia removal.

In-Situ Passive Waste Removal in Circular Fish Culture Tanks

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A new approach to removing solid waste from recirculating aquaculture tanks was demonstrated, that incorporated part of the culture tank as the settling basin. Tank modifications included a dual standpipe design with an orifice to control discharge and the addition of a false bottom plate to form a quiescent area for solids settling. Three false bottoms and one control (no false bottom) unit were designed and tested in a 1 m^3 circular domed bottom fiberglass tank. The hypothesis that the standpipe/false bottom modifications would remove more waste from the water column than the standpipe modifications alone was tested. The hydraulic characteristics of the tank were determined using tracer studies. A completely mixed flow was present with only one of the false bottom designs, while the other three designs approached completely mixed flow. In addition, the effect of the false bottom designs on the velocity profile of the tank was analyzed. Results of the solids analysis indicated that this method of solids filtration is commensurate with other solid filtration units currently used in production scale recirculation systems. However the benefit from using the false bottoms in terms of solids removal (the reduced floor space) was outweighed by the extra amount of labor needed to maintain the tank and reduced tank circulation. Based on all the results, the control tank design is suitable for production if used as a primary filter for solids removal.

A Prototype Tilapia/Hydroponic Greenhouse Recirculating Production System for Institutional Application

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A recirculating tank production system was designed and tested during 1996 and 1997 under greenhouse conditions for the dual purpose of producing fish and plants for human consumption, principally for application in correctional institutions. Overall size of the rectangular tank was 7.3 m long by 2.4 m wide by 1.5 m tall with a total water capacity of approximately 18,190 l in the entire system. The tank was divided into three sections: a fish growing section (approx. 13,650 l), a sump area, and a biofilter area - each approximately 2,270 l. The fish growth area was subdivided using **2** inch diameter plastic mesh material into a primary area (9,100 l) and a secondary area (4,550 l). Water circulation was provided by 5-two inch airlift pumps located between the sump area and the biofilter. Water flowed by gravity from the biofilter, through the grow tank, and through the sump area, returning to the air lift pumps. The circulation rate was approximately 475 lpm.

Similar tank systems were installed in greenhouses located in Blacksburg and Petersburg, Virginia in 1996. The first season of testing was May - November and included mechanical aspects of tank system physical functions, water use and water quality monitoring, fish production and management, and use of effluents for irrigation and plant production. Prior to the 1997 season, several engineering design changes were made to the tank systems, as well as biological management changes for fish and plant production.

Application goals for this greenhouse recirculating system were to produce a crop of food fish every 5 to 6 months and to reuse the effluent water for both irrigation and nutrient inputs into greenhouse vegetable crops. Tilapia was used in theses tests, while vegetables tested included tomatoes and lettuce. Lettuce was grown using a nutrient film technique system over the fish tanks.

Fish Production

Nine hundred tilapia, average weight 45 g, were stocked in the primary production area during May, 1997. Fish were fed frequently by hand and with automatic (belt) feeders. Water temperature, dissolved oxygen, and pH were monitored twice daily. Approximately 2.35 kgs of sodium bicarbonate was added weekly to maintain alkalinity and pH levels in the system. Routine maintenance involved weekly sump flushes. Fish harvests were made during October. For 1997 the combined production data from Virginia Tech and VSU was: fish survival was 92% with an average size 439 g. Total fish harvested was approximately 340

kgs with an additional harvest of 700 fish that averaged 124 g each from the secondary growth area.

Effluent Uses

After 2 months of operation, approximately 3,500 l of water had been released and replaced with new water to maintain water quality levels for fish production. Tank water was tested for plant application as a nutrient source. Lettuce grown using tank effluent performed similarly to control lettuce until it reached 110 g size, when signs of nutrient deficiencies were indicated. Nutrients in the effluent water were inadequate at the fish densities tested for commercial vegetable hydroponic systems.

The Speedy Text to Identify Optimal Growth Temperature for Aquatic-Animals

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Abstract

The optimal growth temperature for aquatic animals, such as soft-shell turtles is affected by natural environment or experimental conditions. When water temperature is controlled above 24°C~25°C, the soft-shell turtles look very active. However, if the temperature falls below 20°C, the food intake of soft-shell turtles is significantly reduced. The heating facilities are widely applied to cultivate soft-shell turtles to dispel the hibernation period and the turtles will gain weight all year long. We have studied effect of water temperature on turtle's heart rate. The aim of this study is to provide certain scientific guidelines for fast cultivation of soft-shell turtle by investigating effects of water temperature on its physiological mechanism.

Experiments were performed in the ponds of the Agricultural Bio-environment Engineering Institute, Zhejiang Agricultural University. The experimental subjects were healthy adult soft-shell turtles. Their weight varied in the range of 226~280g (253g on average). Heart rate was taken by pH-38 ECG recorder. Water bath was applied to control water temperature, recording electrodes were well attached to four legs of turtle. To simulate temperature change in Zhejiang Province, the test temperature was controlled between 5~35°C and measurement was taken every 5°C.

In order to find consistent experimental conditions, Turtle was used to characterize an adaptive process of heart rate to the change of water temperature.

Experiment data show that the heart rate was constant after the turtle was kept in water for 40 minutes with the temperature unchanged. The heart rate was measured as a subject had been kept in one chosen temperature for 40 minutes.

The variation of heart rate as a function of temperature is plotted in Figure 1.

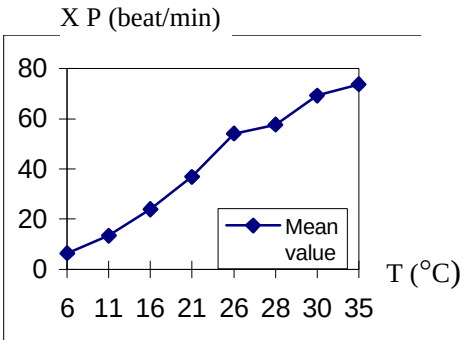

Fig. 1 The relationship between the mean value of heart rate and the water temperature

The results provide the clear evidence of that the heart rate of turtle is linearly proportional to water temperature:

$P=-16.429+2.737T$ $(P>0)$

$R^2=0.9812$

P: heart rate (beat/min)

T: water temperature (°C)

Mean value:

$$\bar{X}=\frac{\Sigma_{Xi}}{n}$$

The relationship between the sum of square and temperature is showed in fig 2.

The relationship between the coefficient of variation and temperature is shown in fig 3.

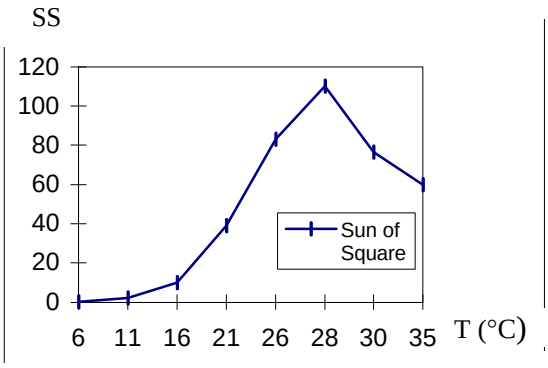

Fig. 2 The relationship between the sum of square and water
SS—Sum of Square
$SS=\Sigma(Xi-X)^2$

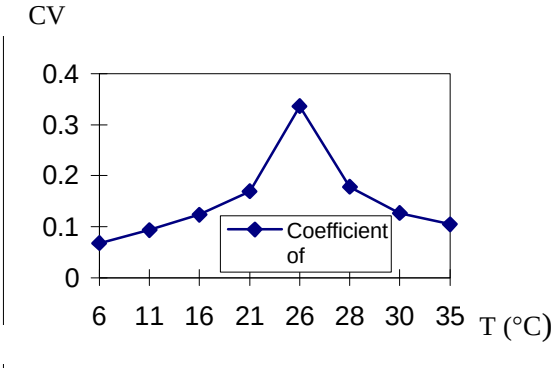

Fig. 3 The relationship between the coefficient of variation and water temperature
CV—Coefficient of Variation

$$CV=\frac{\sum (Xi-\bar{X})}{\bar{X}}$$

Through statistical analysis the heart rate of aquatic-animal is closely indicates a protective mechanism for animals to adjust their breath, digestion, and metabolism to the change of environment.

Nevertheless, the data indicates that heart rates have the largest variation as the temperature falls between 26°C to 30°C. Many experiments suggest that this temperature range is optimal for soft-shell turtle growth in the sense of large food intake, rapid weight gain. In this optimal growth temperature range, the heart rate variation of soft-shell turtle

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is not only affected by physiological mechanism, but also its behavior such as food intake and activity. That is a part of the reason to comply with the large variation of results in that temperature range, the conclusion is as follows:

Heart rate is linearly proportional to the temperature:

$$P=-16.492+2.737T \ (P>0)$$

In the optimal growth range (26°C ~30°C), relationship of heart rate and temperature presents large variations. Similar to homoiothermous animals, heart rate is affected by animal behavior in the optimal growth temperature.

To identify the optimal growth temperature for other types of poikilothermal animals, our study suggested measure heart rate as a function of temperature. The temperature that shows large variation may serve as the best cultivated range. Heart rate-temperature measurement will provide a quantitative method to quickly identify the optimal growth range for poikilothermal animals.