Settling Basin Design and Performance

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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).

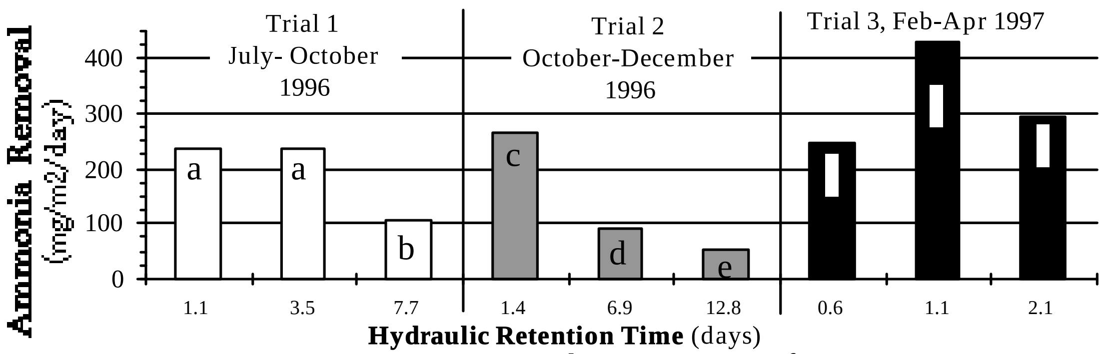


Fig. 1. Mass Ammonia Removal as a Function of HRT

*(*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.

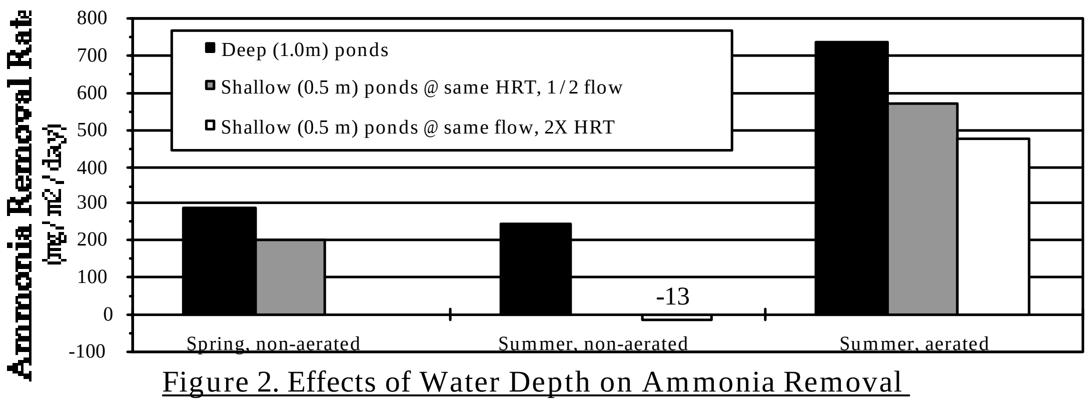


Figure 2. Effects of Water Depth on Ammonia Removal

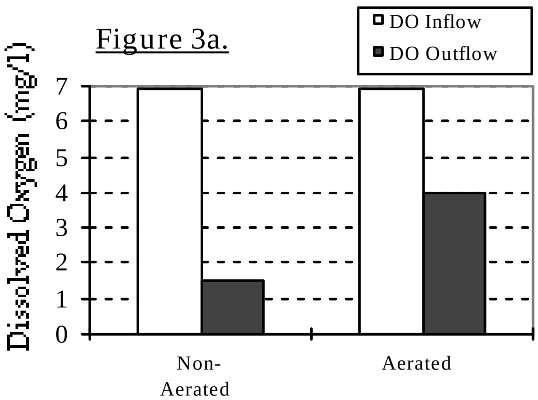
Experiment 3 - The Effects of Aeration on Mass Ammonia Removal Rates

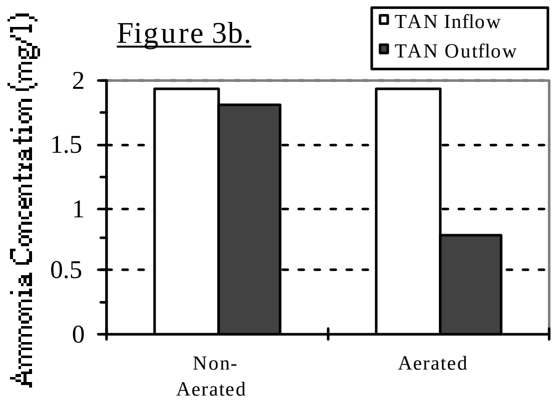
Since nitrification was a primary goal for our application of constructed wetlands, we realized that oxygen could become a limiting factor. Wetland plants have been shown to be capable of delivering oxygen from the atmosphere to the plants' root structure where it can be utilized by aerobic bacteria (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).

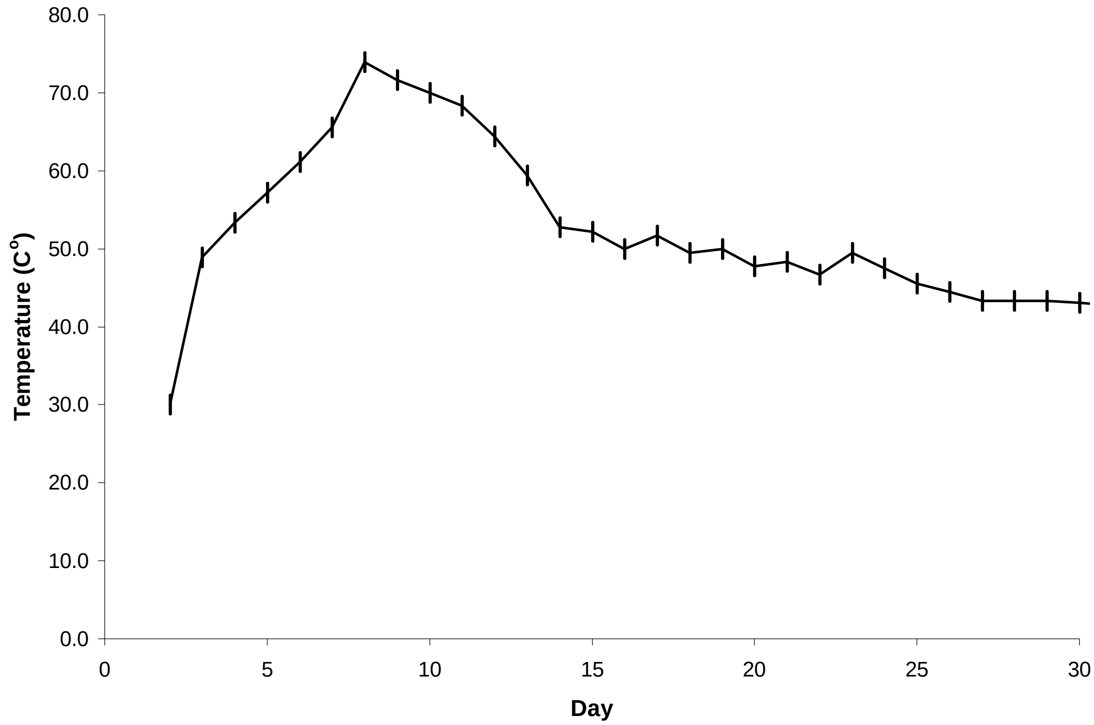

Figure 1. Temperature profile of composted fish wastes.

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).

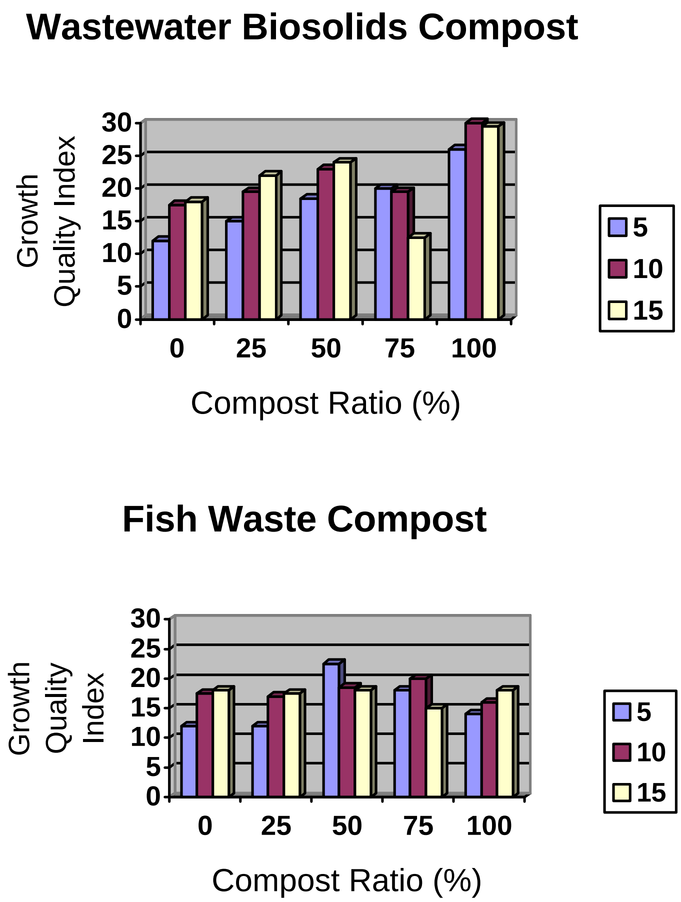

Figure 1. Effect of compost type, mixing ratio, and fertilizer application rate on growth quality index of dwarf nandina. The fertilization rates were 5, 10, and 15 lbs/cu. yd. of pine bark medium.

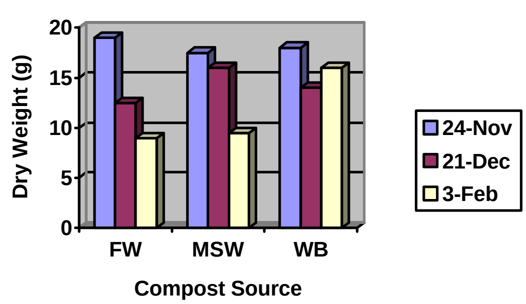

Figure 2. Effects of compost on dry weight of grass biomass. Sod was seeded 5-Nov.

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.

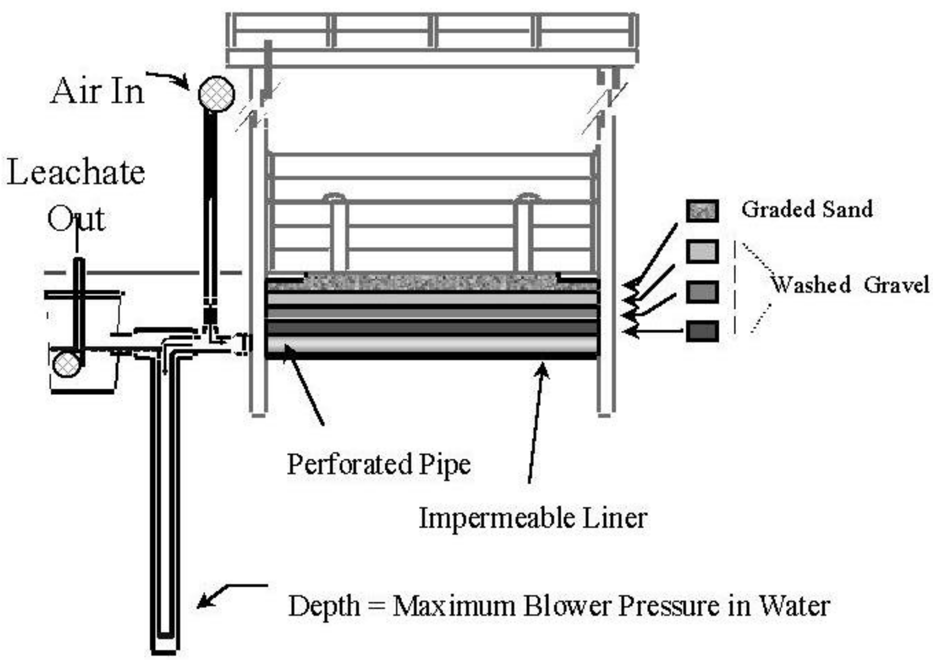

Figure 3. A schematic representation of a combination sand filter/composting system for composting fish manure.

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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).

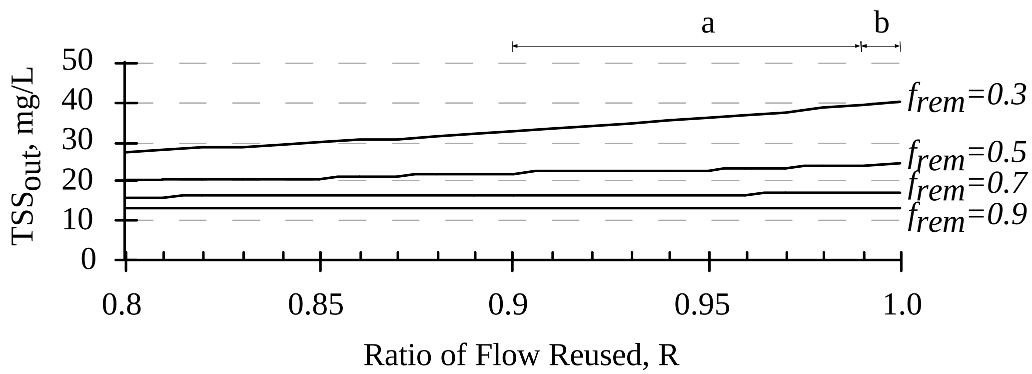

Figure 2. The TSS concentration leaving a fish culture tank (TSS_{out}) in a water reuse system (operating at steady state) is largely dependent upon the fraction TSS removed (f_{rem}) across the solids treatment unit and slightly dependent upon the ratio of flow reused (R). The letter designations (a) 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.

<u>Settling basins</u>. 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.

<u>Swirl settlers</u> 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 : 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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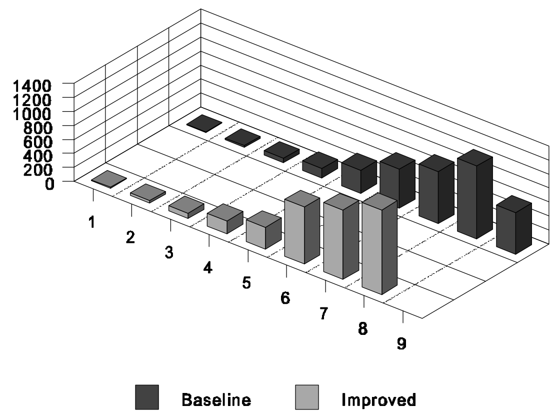
Start-up Month		**Month 9**	**Month 10**	**Month 11**	**Month 12**	**Total**
January		September	October	November	December	
Price/lb	$1.60	$1.40	$1.60	$1.80		
Revenue		$2,271	$5,973	$11,381	$15,374	$34,998
April		December	January	February	March	
Price/lb	$1.80	$1.80	$1.80	$1.70		
Revenue		$2,555	$7,679	$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?

<u>Swot Analysis</u>

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.

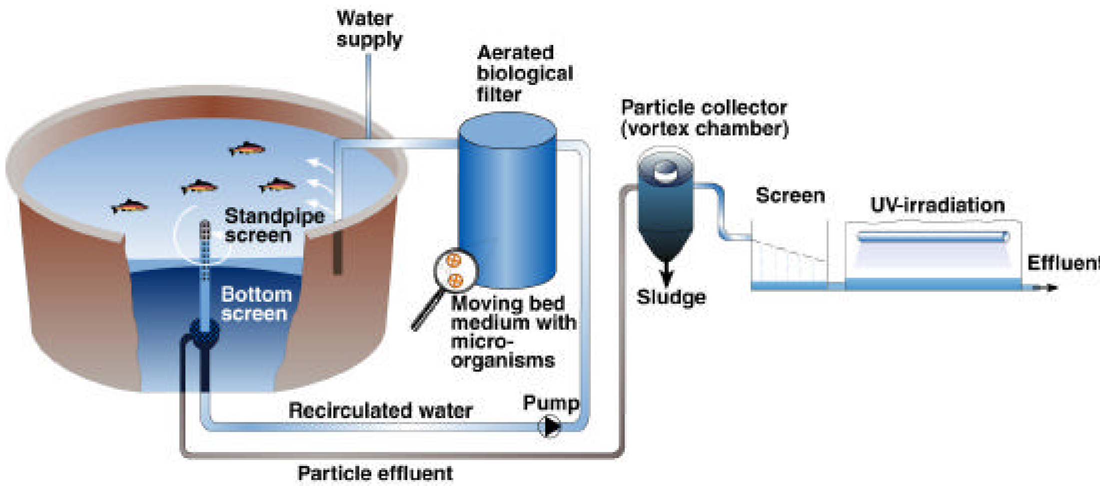

Figure 1. The recirculation system BIOFISH (Procean, P.O Box 1722, N-5024 Bergen, Norway).

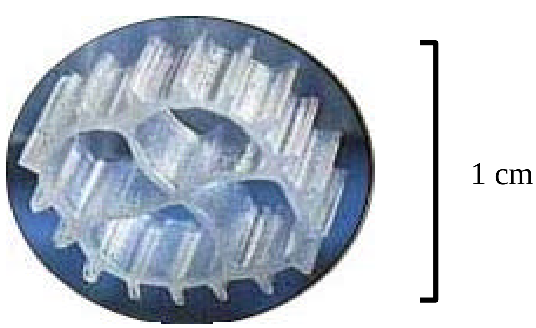

Figure 2. The KMT moving bed biofilter media (Kaldnes Miljöteknologi, P.O Box 2011, N-3103 Tönsberg, Norway).

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).

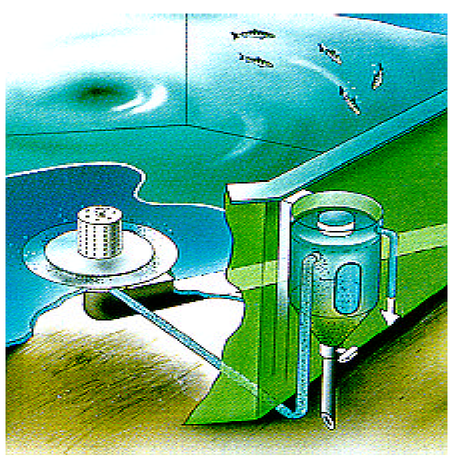

Figure 4. Schematic illustration of the ECO-TRAP connected to a swirl separator outside the fish tank. (Aqua Optima, Pir-Senteret, N-7005 Trondheim, Norway).

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.

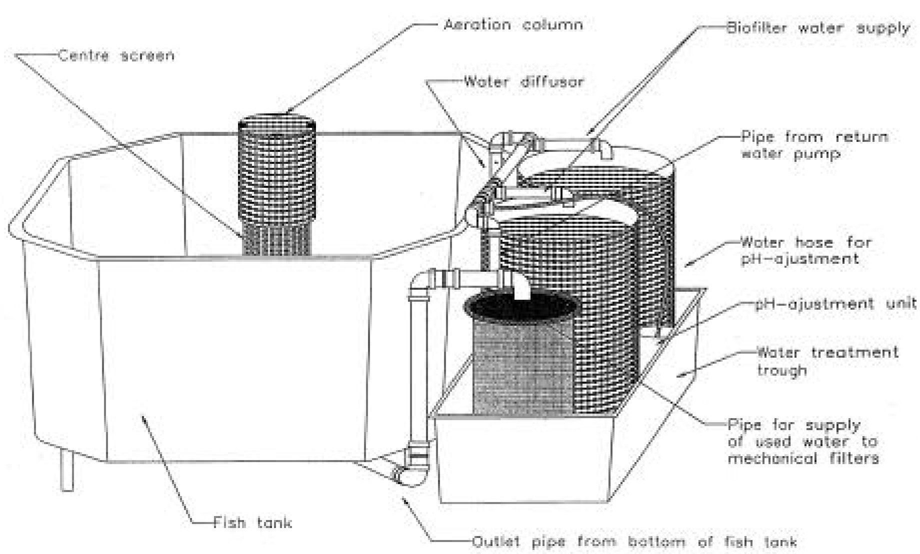

Figure 5. Schematic illustration of the recirculation system "Folkekaret" (Calcus, Tangen, N-7500 Stjördal, Norway).

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.

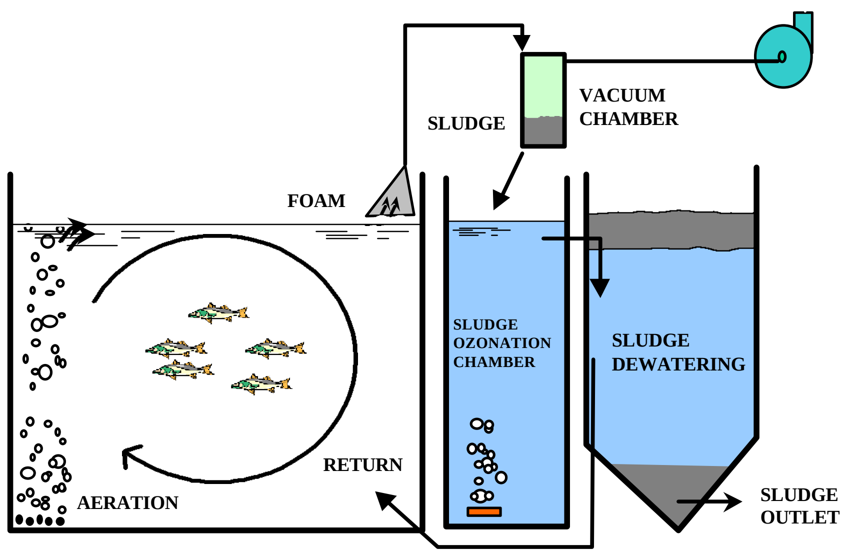

Figure 6. Schematic illustration of the SUNFISH recirculation system (PurAq, Fritznersgt 1, N-0264 Oslo, Norway).

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.

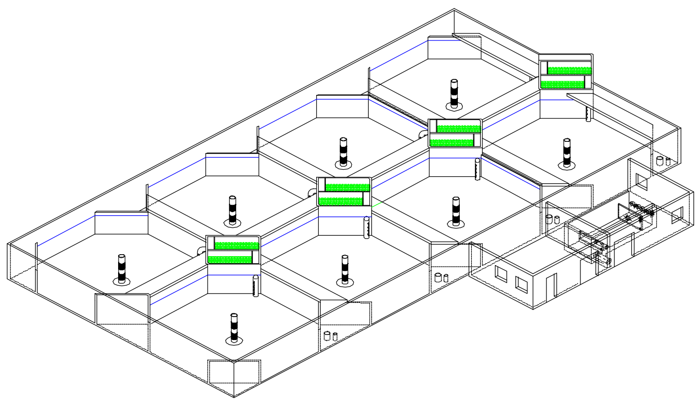

Figure 7. Overview of a halibut farm with flow splitting and moving bed biofilters, (approximately 1000 m^3 production volume, shelves not shown).

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.

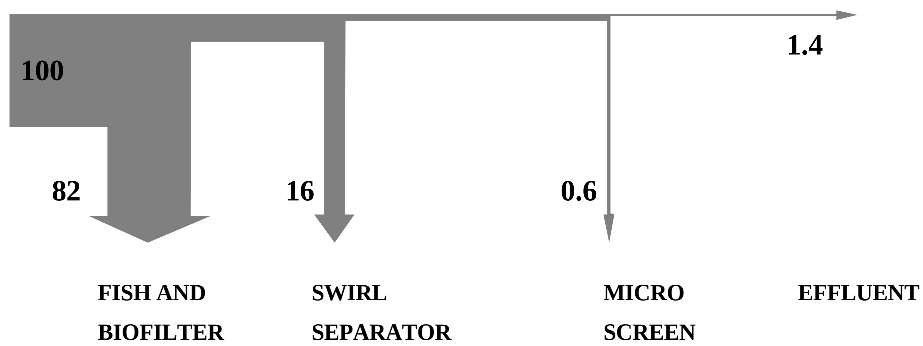

Figure 8. Example of a mass balance for SS in a BIOFISH tank with Atlantic salmon (125 g) and dry pellet feeding.

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.

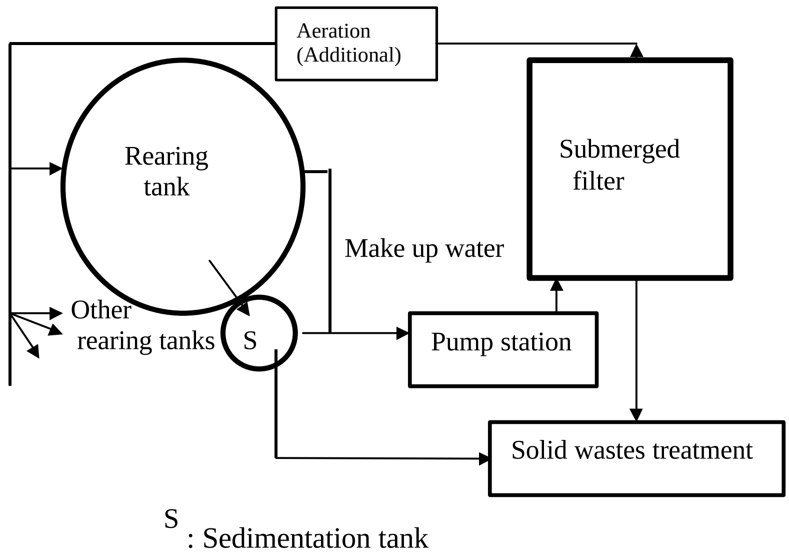

Figure 1. Diagram showing the path of the flow in the Intensive Bio-production Korean System (IBK System) to grow tilapia in Korea.

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.

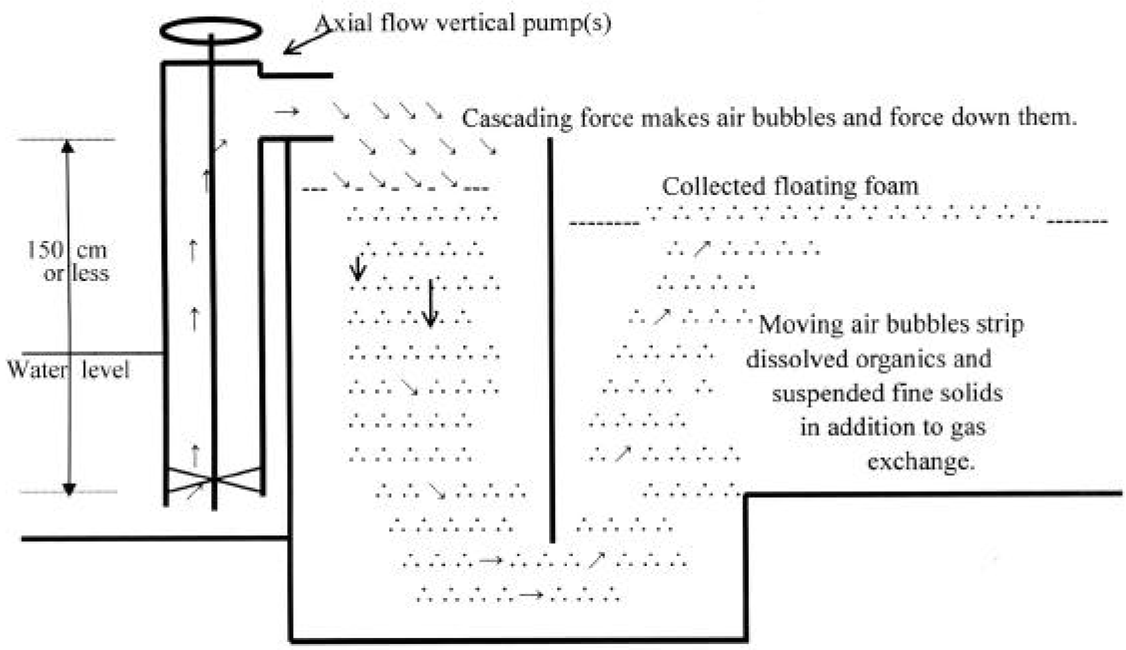

Figure 2. Diagram showing the sectional view of pumping station. The pumping station serves for aeration, carbon dioxide removing of carbon dioxide, dissolved organic matter and fine suspended solids in addition to water moving.

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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