Design of an Emergency Aeration System for Intensive Aquaculture Raceway Systems

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This report summarizes the results of a Senior Design Project in the Biological Resources Engineering Department at the University of Maryland to design an emergency aeration system for intensive raceway production of trout. The system was tested by simulating both loading characteristics and fish respiration in a raceway, through a series of simulations using a deoxygenating slurry delivery system. The deoxygenating agents, sodium sulfite and cobalt chloride, in the slurry were delivered into a 2 m^3 holding tank as an impulse, step input and as a continuous input to simulate various test scenarios. The deoxygenating system was tested by monitoring dissolved oxygen concentrations in the holding tank for the three different inputs as a function of time. Several different aeration systems were designed and along with several commercial systems, subjected to the three loading scenarios. Dissolved oxygen levels were monitored for an extended period to ensure that the aeration system was able to maintain acceptable levels during a prolonged emergency scenario.

Development and Evaluation of a Feedback Control System for Dynamic Control of Dissolved Oxygen in Intensive Recirculating Aquaculture Systems

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Abstract

Over the past hundred years, agriculture productivity in the United States has reached record levels through mechanization, intensification, and automation. The short history of aquaculture has also seen a similar trend of increasing production levels in both open pond systems and indoors intensive recirculation systems. Improved monitoring and control of these production systems will yield a reduction in the risk of catastrophic losses and stress, in effluents and their potential environmental impact, in cost of production by maximizing yield per dollar of capital, and most importantly an overall improvement in product quality.

Low concentration of dissolved oxygen is the major variable limiting production in intensive aquaculture systems. With production densities approaching one pound of fish per gallon of water, supplemental oxygen is required to maintain optimal growing conditions. The high cost of on-site generation or transportation and storage of liquid oxygen makes it critical, for economic reasons, that pure oxygen be used in the most efficient manner possible. The ability to adjust oxygen concentration to meet constantly changing oxygen demand should have a significant impact on the overall economics of pure oxygen use. An improved understanding and control of dissolved oxygen in intensive systems will yield:

1) real time control of oxygen levels in the production tank,
2) elimination of high and low oxygen levels following feeding and other disturbances, thus reducing opportunities for stress induced diseases,
3) a quicker response to the faster changes in water quality as systems are pushed closer to their carrying capacity limits, and
4) automation of a critical process to reduce labor requirements and management responsibility.

This is one aspect of an overall research program to apply modern control system analysis to intensive aquaculture recirculating system, design and develop control algorithms and systems for optimizing water quality parameters and automate routine functions. This project developed a negative feedback control system for dissolved oxygen in intensive recirculating aquaculture systems. Control algorithms were developed and computer simulated for maintaining the dissolved oxygen levels in the

system at a specified set point, given a range of system loading and disturbances. System disturbances, influencing dissolved oxygen levels from baseline metabolism, include such dynamic changes as intensive feeding activity of the fish and stress response to some external stimuli. Several prototype control systems of varying design and cost were constructed from "off-the-shelf" components and installed on a research recirculation system at the Department of Biological Resources Engineering, UMCP. These systems were then evaluated based on their performance, i.e. ability to maintain a given oxygen set point under several fish stocking densities and system disturbances, and their overall economic savings compared to current systems used in the industry.

Growth of <u>Mercenaria</u> Seed Clams in a Recirculating Nursery System Utilizing Computer-Control and Fluidization Technology

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Commercial hatcheries have utilized a number of approaches for taking young seed clams (1 mm) and growing them through the nursery phase to a size suitable for field planting (10 mm). The current developmental design of the recirculating seed clam system implemented at the University of Georgia Shellfish Aquaculture Laboratory consists of six clear cylindrical upweller units (5 cm in diameter, 76 cm in height); a 400 L feed reservoir; a solids separator; a bead filter (0.03 m^3); and utilized during the summer a 0.375 kW (0.5 hp) chiller unit. A 0.075 kW (0.1 hp) magnetic drive centrifugal pump provided a system water flow rate of 40 Lpm. A high water flow velocity (3.6 $\pm$ 0.2 Lpm) was maintained in each of the upweller units to fluidize the seed mass. Fluidizing the seed mass allows for the high density culture of seed by providing a more uniform distribution of food, and transporting waste material away from the seed mass. Culture density in each upweller unit reached approximately 5.5 g whole wet weight clam per cm^2 and greatest biomass growth rates (0.06 d^{-1}) were observed when an effective daily ration of approximately 2% dry weight of algae per g whole wet weight of clam was provided. Feeding of the seed clams from an algal storage reservoir and backflushing of the system bead filter were computer-controlled.

Fish Health Management of Recirculating Systems

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Fish producers today have very limited choices for controlling fish disease problems. Many bacteria that infect fish are now resistant to the only two FDA approved antibiotics. A fish health prevention/maintenance program is presently recognized as a required management practice by fish producers to lessen the risk of diseases,. This management approach has become particularly critical for producers using recirculating systems. Fish health prevention/maintenance programs require many elements including quarantine procedures, examination and monitoring for fish pathogens, and prophylactic treatments for parasites. Developing fish health prevention protocols are necessary to reduce likelihood of bacterial and parasitic diseases.

The vital key in the prevention of disease outbreaks is water quality. It well known that recirculating systems water quality can go from good to bad very quickly. When this happens dreaded disease problems often appear and seem to never go a way. Monitoring and managing of water quality parameters on a daily schedule is necessary management practice for recirculating facilities.

The greatest disease problem facing tilapia producers is Streptococcus (Strep). Strep is a rapidly emerging disease in the aquaculture industry using recirculating systems. Since control of this problem is difficult (Requiring extra label use of antibiotics in many cases), a fish health management plan is needed for reducing this problem.

Fish (Tilapia especially) should be checked and monitored for Strep at recirculating facilities. CNA agar with 5% sheep blood can be used for isolating Strep from fish. This media is well suited for screening for gram positives such as Strep. The brain (nervous tissue) or the intestines are used as the inoculum from fish. Plates are incubated for no more than 96 hrs. Suspicious colonies are gram strained. Those colonies that are gram positive cocci in pairs or short chain are further screened using the catalase test. Strep is catalase negative while many other gram positive cocci such as Staphylococcus are catalase positive. The number of fish (60 fish in most cases) in samples should follow American Fisheries Society Fish Health Section Blue Book procedures for pathogen detection.

It is critical that producers have a quarantine procedure in place for new fish arrivals at their facilities. It is at this stage where fish are checked for potential diseases problems. Fish are examined for parasites and Strep before moving them to production tanks. Also fish should

be treated prophylactically for external parasites before moving regardless of parasite intensity of fish.

Once in production tanks, fish should be sampled two to three times during the course of production to monitor for parasites and for Strep. A planned management program adds to expense of the operation but is preferred to having to shut down completely and disinfect an entire system.

Since fish are going to be sacrificed for a Strep check, they should be also examined for parasites especially Gyrodactylus (Skin Flukes). Research indicates that Strep infections are more likely to occur when trauma occurs to the epidermis. A heavy infection of skin flukes attaching to skin could create such epidermal trauma. Prophylactic treatments for external parasites must be part of a management plan. When fish are moved or transferred to new tanks a standard practice should include treatment for external parasites.

When developing a production facility, a fish health management plan should be use in guiding its construction. A producer should have a production system that is easily treatable and manageable for diseases. A facility that uses a few large units would most likely have difficulty in treatment and management of a problem leading to a shut down for disinfecting the system, thus having no production for months. If a disease gets into a facility with many small units, individual systems can be isolated and disinfected without total facility shut down.

Application of Industrial Monitoring and Control for an Experimental Carbon Dioxide Stripper in a Recirculating Aquaculture System

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Personal computers and generic industrial control software and modular hardware are well suited for monitoring, data collection, and control in aquaculture applications. This mix of components was chosen for the following reasons: PC's provide cost advantages over PLC based solutions, industrial control software offers a rich feature set, and modular hardware provides flexibility for input and output signals. This strategy was used to organize data from multiple locations in a recirculating aquaculture system using an experimental carbon dioxide stripper.

A standard desktop 486/66 computer running Windows 95 with an available serial port for RS-232 communication was used for this application. As the computer was placed in an office environment rather than in the laboratory it did not need to be an industrial version. Personal computers are relatively inexpensive machines that can be used simultaneously with other applications such as word processing in non-critical process monitoring and control environments. Additional stability is gained by dedicating the machine to data acquisition and control.

The user interface must be operator-friendly to facilitate data monitoring, collection, and analysis. We used Genesis by Iconics, a PC based industrial software package with scripting features for control algorithms and a customizable user interface. For our application, the software was used to collect and display data for the user in the office. Monitored data are summarized in a main display with additional detail such as pulsed-bed biofilter status, CO2 scrubber status and tank status, being easily selected by pressing a button for the appropriate display. Historical trending is also displayed for review of trends in collected data. Data from a CO2 gas phase monitor is used to control a three stage-carbon dioxide scrubber coupled with a pure oxygen contactor. The monitor uses an infrared detector to generate an analog signal proportional to CO2 readings over the range of 0 to 10% by volume.

The application uses modular Dutec® hardware for in-lab collection of data and control. The system uses a single RS-232 cable to send data to the office where the computer is located. It can be further expanded by using additional base units and the RS-422 or RS-485 communication protocols. The Dutec model used in this project consists of a base unit with 16 Analog or Digital signals and an expansion unit, allowing an additional 16 Digital I/O points. Individual modules were purchased according to the type of signal. The cost of this unit is leveraged most effectively when all 16 input/output locations are used.

Water level, dissolved oxygen, temperature, and flow rate are among the standard types of data collected. The flexibility of the Dutec base unit allowed us to purchase individual modules for each type of input or output provided which included DC digital inputs and outputs, AC analog voltage inputs, and AC analog current inputs.

As the electronics industry is constantly advancing, newer products offering additional features and simplicity of use continue to arrive on the market. This system will be able to adapt to changes in available products. Because a generic design was used, the sensors, the hardware, and software can be interchanged or replaced if necessary. At the same time, as configured, this system has adequate monitoring and control features for most aquaculture applications.

The Use of Commercial Probiotics in the Production of Marine Shrimp Under No Water Exchange

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Abstract

The effect of a commercial bacterial supplement (probiotics) on the high density production of *Penaeus setiferus* in an outdoor tank system with no water exchange was studied, using high (45%) and low (20%) protein diets and high aeration. At $\alpha = 0.05$, the 3 months study revealed no significant difference between tanks treated with the commercial bacterial supplement and those that were not, for the mean shrimp survival, shrimp final yield, and shrimp final weight. However, some differences were significant at $\alpha = 0.08$. The probiotics treatment had no effect on the nitrogen cycle in the tanks. The commercial bacterial supplement was further tested for its microbial activity on shrimp sludge. No major differences were noted in respiration and chemical oxygen demand (COD) of the treated and control sludge samples. However, at the end of the test, biological oxygen demand (BOD) in the treated sludge was lower than that of the untreated sludge. Thus, based on this work and other studies of probiotics' use in aquaculture, it appears that commercial bacterial supplements might have some advantage, but more studies are necessary to answer this issue unequivocally.

Introduction

The issue of using commercial bacterial supplements (in liquid or powder forms) to benefit aquaculture production systems is controversial (Jory, 1998). This work describes the potential of probiotics use in high-density *P. setiferus* production systems with no water exchange.

Results and Discussion

A commercial bacterial supplement (BioStart HB-1&HB-2) was added according to the manufacturer (AMS) instructions to 6 test tanks of *P. setiferus* grown in an outdoor high-density production system with no water exchange and with high aeration. Three of the tanks were fed with a high (45%) protein diet, and the other three were fed with low (20%) protein diet. The 6 control growout tanks were fed as above, but did not receive the probiotics supplement. The volume of each tank was 10 m^3 and each tank had a 15 cm layer of clay soil on the bottom. The 3 months study revealed no significant difference between tanks treated with the commercial bacterial supplement and those that were not, at both the 45% and 20% protein diets, for the mean shrimp survival, shrimp final yield, and shrimp final weight at $\alpha = 0.05$ (Table 1). At $\alpha = 0.08$, however, some significant differences were noted.

Table 1. Mean shrimp survival, final yield, and final weight of *P. setiferus* treated or untreated with a commercial bacterial supplement (BS) after 3 months in an outdoor tank system with no water exchange. Feeding was with a 45% or 20% protein diet.

Treatment	Survival* % $\pm$ STD	Final Yield* Kg/m^2	Final Weight** g $\pm$ STD
45% + BS	84.1 $\pm$ 19.67	0.380	9.03 $\pm$ 1.681[a]
45% - No BS	94.1 $\pm$ 4.14	0.482	10.24 $\pm$ 1.247[b]
20% + BS	72.5 $\pm$ 24.61	0.413	11.40 $\pm$ 1.458[c]
20% - No BS	85.9 $\pm$ 7.14	0.431	10.03 $\pm$ 1.040[d]

* There is no significant difference at $\alpha = 0.05$ between treatments in each of these columns.

** There is no significant difference at $\alpha = 0.05$ between treatments in this column, except between a and c (a<c). At $\alpha = 0.08$ there is a significant difference in this column between the following treatments: a and b (a<b) and c and d (c>d).

The levels of ammonia, nitrite and nitrate in the experimental tanks were followed with time. There were no striking differences in the pattern of ammonia, nitrite, and nitrate accumulation with time in the tanks that received the commercial bacterial supplement and the untreated controls. The build-up of ammonia and nitrite levels with time was, however, related to the protein level in the feed. As expected, the tanks fed with the 45% protein diet had significantly higher levels of ammonia and nitrite than those fed with the 20% protein diet. Accumulation and removal rates of ammonia and nitrite were not affected by the probiotics addition.

The commercial bacterial supplement was further tested for its microbial activity on shrimp sludge. Shrimp sludge was incubated in the lab with and without probiotics addition. No major differences were noted in the respiration and COD between the

treated and untreated sludge. However, at the end of the test, BOD in the treated sludge was lower than that of the untreated sludge (Table 2).

Table 2. The effect of a commercial bacterial supplement (BS) on shrimp sludge – a lab study.

Treatment	Respiration mg O_2/l/hr after 1 day	COD ppm t=0	COD ppm 2 days	COD reduction in 2 days	BOD ppm t=0	BOD ppm t=2	BOD reduction in 2 days
Control sludge	2.02	89	77	13%	4288	3520	18%
Sludge + BS	2.20	87	79	9%	3104	352	89%

Based on the present work and on other studies of probiotics' use in aquaculture (Jory 1998; Queiroz and Boyd, 1998), it appears that there is no clear benefit for adding such bacterial supplements. However, some of the differences that were noted, especially BOD removal and shrimp size with low protein feed, need to be studied further. Similarly, Queiroz and Boyd (1998) found higher yield of catfish (at $\alpha = 0.10$) with the addition of another commercial probiotics product. Better understanding of the reasons for such effects may lead to better probiotics products in the future.

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A Study of Selected Fish Feed Binders: Effect on Generated Waste Quantity and Quality

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Abstract

Aquacultural effluent and the potential for pollution from it are some of the most widely discussed problems both within and outside of the aquaculture industry. Recirculating aquacultural systems are intensely stocked with fish, feeding on high-protein feed, to obtain production values that offset the high capital and operating costs of such systems. In these systems, approximately 3% of the fish feed is discharged as ammonia and 30 to 60% as solid waste rich in organic matter content. Such a wastewater has a potential to degrade the receiving water quality quite significantly.

This paper presents the results obtained from a series of experiments, conducted at the University of Maryland (UMCP) with hybrid striped bass, on the study of the effect of selected binders on generated waste quality and quantity. It also compares the UMCP findings with those from similar studies at Cornell University, Illinois State University Normal, and Louisiana State University Baton Rouge, using trout, tilapia, and catfish, respectively. The main objective of the presented study was to determine the effect of adding binding supplements to fish feed on fish growth, culture water quality, and culture system filter performance.

At UMCP, initially nine preliminary diets, including a control, were tested and then four, including a control, were further investigated. Treatment diets for preliminary studies were prepared using carageenan, sodium alginate, wheat gluten, guar gum, nutra-binder, bentonite, lignin sulfonate, and Pel-Plus as supplemented binders in a basal feed. Preliminary trials used all binders at a relatively high percent (10%) of the feed. Wheat gluten or nutra-binder (NB) at 5%, lignin sulfonate (LS) at 3%, and bentonite (B) at 5% of the feed were the three binders that were used for more detailed tests (secondary trials) after preliminary trials.

At UMCP, hybrid striped bass showed poor acceptance of feeds containing 10% guar gum, sodium alginate, wheat gluten, or bentonite as binder material. Weekly measured water quality parameters and solids characteristics (particle size distribution) during the secondary trials were not significantly different among the four treatments at the 5% level of significance. Somewhat similar results were reported by investigators at the other universities.

Effect of Chemotherapeutants on Nitrification in Fluidized-Bed Biofilters in a Recycle Rainbow Trout Culture System

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Two commonly used fish therapeutants, formaldehyde and benzalkonium chloride (roccal), were evaluated for their effect on the nitrification efficiency of fluidized-bed biofilters. The therapeutants were added at conventional concentrations to two small-scale (2200 L) recirculating trout culture systems which each contained six fluidized bed biofilters operating in parallel. Biofilter efficiency was measured, before and after treatments, by determining ammonia and nitrite removal efficiencies at ambient conditions, and when challenged with a spike of ammonium chloride at a concentration four times that of the ambient TAN. Three formalin treatments in recycle mode ranging from 167-300 ppm had no significant effect on biofilter efficiency. Four roccal treatments from 1-2 ppm were conducted; three bath treatments and one recycle treatment. None of the roccal treatments had an immediate effect on ambient nitrification but a delayed drop in biofilter efficiency was observed after 3-5 days with no effect detectable after 7 days in all of the treatments. There was no catastrophic drop in nitrification efficiency caused by any of the treatments. In only one instance did roccal treatment have a deleterious effect on nitrification when the biofilters were challenged.

Water Quality Limitation of Fixed Film Biofilters for Recirculating Aquaculture Systems

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The existing research, demonstration, and commercial recirculating aquaculture systems almost exclusively use fixed film biofilters for nitrification. The main advantage of this type of process is that the biofilm can maintain a relatively long cell detention time that accommodates the low growth rate of nitrifying bacteria. Due to the nature of the diffusion controlled process that occurs in a biofilter, the nitrification rate of a fixed film filter is directly related to ammonia concentration in the system. Based on biofilm theory, this paper presents a mathematical model for ammonia removal in a recirculating system, considering mass transfer through a biofilm, feeding rate, and volume and water exchange rates of the system.

Minimum concentration of substrate

A biofilm is a layer-like aggregation of microorganisms attached to a solid surface. Because the mass transfer in a fixed film process is diffusion controlled, there must be a minimum substrate concentration maintained in the bulk water to create a concentration gradient that drives the nutrient transport across the biofilm. In addition, a stable nitrifier population requires an adequate concentration of substrate. According to Rittmann and McCarty (1980), the minimum substrate concentration, S_{min} (g.m^{-3}), can be calculated as:

$$S_{min} = K_S \frac{b}{Yk - b}$$

Where, K_S= half-velocity coefficient (g.m^{-3}); b = specific bacterial decay (day^{-1}); Y= yield of bacterial mass per unit of substrate mass (g.g^{-1}); k= maximum specific rate of substrate use (g.g^{-1}.day^{-1}).

Substrate flux into a biofilm

The flux of substrate into a biofilm (or removal rate), J (g.m^{-2}.day^{-1}), can be estimated by the formula of Atkinson and Davis (1974):

$$J = \boldsymbol{\eta} \, k L_f X_f \frac{S_S}{K_S + S_S}$$

Where, η = the effectiveness factor; L_f = thickness of the steady-state biofilm (m); S_S = interfacial concentration of substrate (g.m^{-3}); X_f =bacterial density in biofilm (g.m^{-3}). A detailed description of this calculation can be found in Rittmann and McCarty (1980 and 1981).
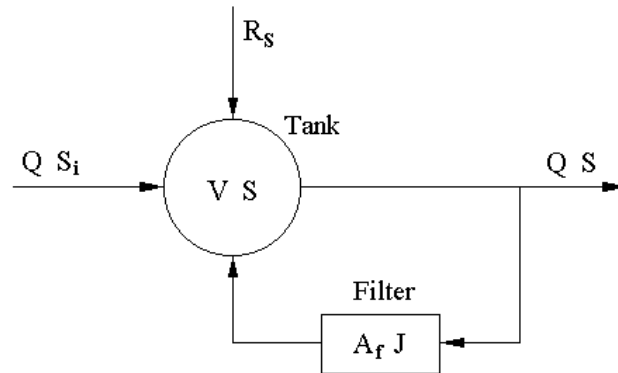
Recirculating aquaculture systems

Fig. 1 Substrate transfers in a recirculating aquaculture system.

For a recirculating aquaculture system (Fig. 1), the equation of substrate mass balance can be expressed as:

$$V\frac{dS}{dt} = R_S R_f W_f - A_f J - (S - S_i)Q$$

Where, A_f = biofilm area (m^2); Q = water exchange rate ($m^3.day^{-1}$); R_f =daily fish feeding rate (g feed (g fish)$^{-1}.day^{-1}$); R_S = the ratio of substrate production to feed mass (g ammonia (g feed)$^{-1}$); S = substrate concentration ($g.m^{-3}$); S_i = substrate concentration of inflow water ($g.m^{-3}$); t = time (day); V = water volume (m^{-3}); W_f = total fish weight (kg).

Simulation and discussion

The ammonia nitrification process is simulated here since it's important for recirculating aquaculture. The relationship between ammonia concentration and removal rate for different values of biofilm parameters is indicated in Fig. 2. Due to energetic and kinetic constraints, a minimum concentration is needed to support a steady-state biofilm. Below the minimum concentration, biofilm growth occurs at a negative rate and the monolayer of bacteria gradually disappears. As a result, no steady-state-biofilm will exist, and substrate flux will be zero. When ammonia concentration is above the minimum level, but not very high, the relationship between ammonia concentration and removal rate is approximately linear (Fig. 2).

For recirculating aquaculture, simulation is carried out for a system with a 20 m^3 water tank and a PBF-10 filter (Aquaculture System Technologies, LLC, 1996). The biofilm area of the filter is about 370 m^2. It is assumed that the ammonia concentration of the inflow and the initial water bulk are zero, the daily fish feeding rate is 2.5%, and the ratio of ammonia production to feed mass is 3%. The values of the biofilm parameters are assumed to be the same as curve 2 in Fig. 2. Thus the minimum ammonia concentration is 0.286 $g.m^{-3}$, and the relationships between ammonia concentration, removal rate, and

fish biomass can be determined (Figs. 3 and 4). It is clear that different minimum amounts of fish mass must be maintained for different water exchange rates, to keep the ammonia concentration above the minimum level. Otherwise, the ammonia removal rate will be zero (Fig. 4) and the biofilm will be destroyed. When fish mass is more than the limit, both ammonia concentration and its removal rate have an approximately linear relationship with fish mass (Figs. 3 and 4).

This paper gives the initial results of the water quality limits of fixed film biofilters used for recirculating aquaculture systems. Note that BOD_5 interaction has not been considered, and the kinetic parameters used in the simulation are based on non-aquaculture wastewater. Additionally, further studies are needed, especially on experiments for parameter calibration, model validation, and effective application.
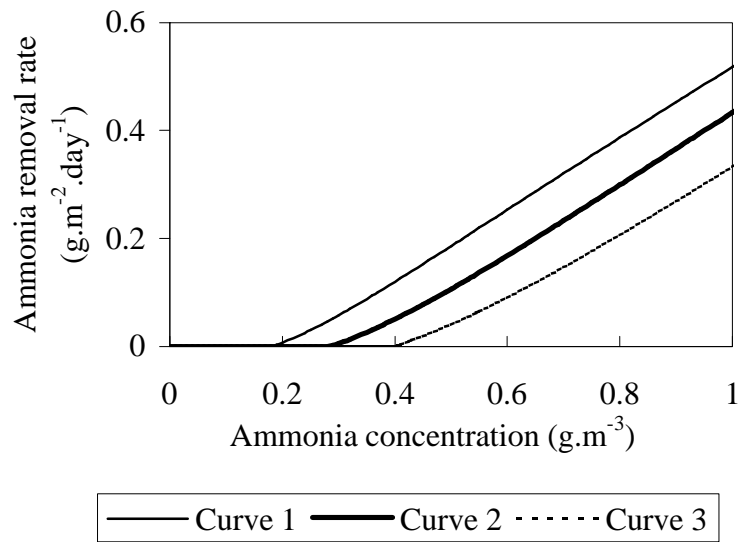

Fig. 2 Relationship between ammonia concentration and removal rate.

Curve 1: K_S=2 g.m^{-3}, k=2.0 g.g^{-1}.day^{-1}, Y=0.3 g.g^{-1}, S_{min}=0.182 g.m^{-3} ;
Curve 2: K_S=2 g.m^{-3}, k=2.0 g.g^{-1}.day^{-1}, Y=0.2 g.g^{-1}, S_{min}=0.286 g.m^{-3} ;
Curve 3: K_S=2 g.m^{-3}, k=1.5 g.g^{-1}.day^{-1}, Y=0.2 g.g^{-1}, S_{min}=0.40 g.m^{-3} .
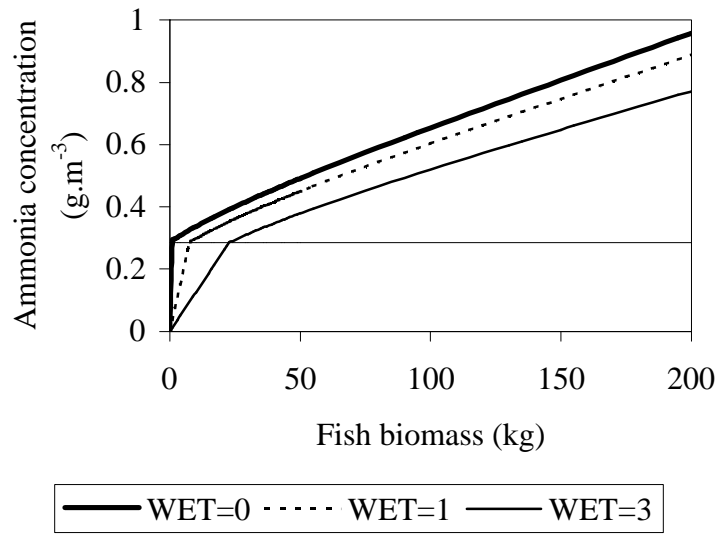
Fig. 3 Computed result of ammonia concentration vs fish mass. WER is water exchange times of the total water volume per day.
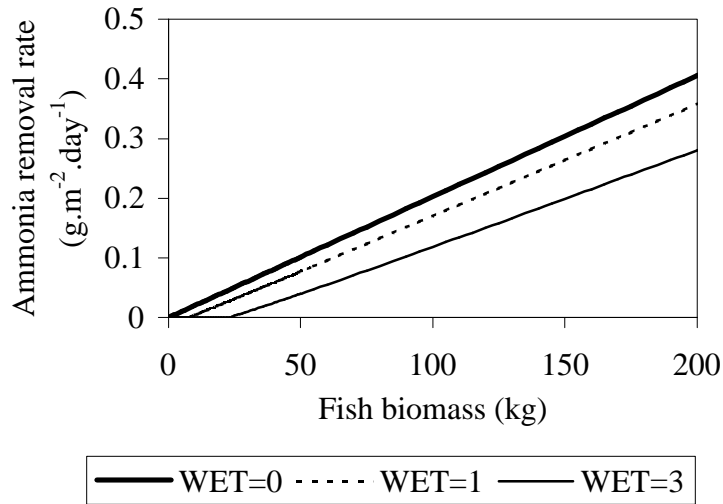

Fig. 4 Computed result of ammonia removal rate vs fish mass.

Aquaculture Engineering Design of Tilapia Breeding System in a Freshwater Recirculating System

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Abstract

Production of male tilapia individuals using hormone has become increasingly popular in the aquaculture industry and its effect on human health has not been known. Tilapia male individual grows faster compared to females. Tilapia fry supply in the Philippines is mainly dependent from hatcheries in fishponds, cages and fishpens in lakes and reservoirs. With the rapid expanding growout production system, degradation of the natural bodies of water and the absence of management policies will pose a problem for many aquaculture operations. There is therefore a need to design tilapia breading system that is environment friendly and poses no problems on consumers in the design and construction of pilot tilapia breeding system in a freshwater recirculating system in Cabuyao, Laguna, Philippines.

The breeding system is composed of male compartment, female compartment, fry compartment and fry collector with a total area of $154m^2$. Five hundred (500) female (*Oreochromis niloticus*) and one hundred (100) male (O.areus) tilapia breeders were stocked in their respective compartment to evaluate the system performance in the production of male tilapia fry. The average recorded hybrid fry production in five (5) months was 29,008 per month. Based on five hundred (500) female breeders used, the average production rate was 58 fry/female/mo ranging from 37.4 to 74.2 fry/female/month. The production per unit area of the system equivalent to 188.4 fry/m^2/mo ranging from 121.5 to 241.0 fry/ m^2/mo. The percentage of hybrid male production based on random sampling (n=300) from first batch progeny grown in growout rearing tank for three (3) months was 91%.
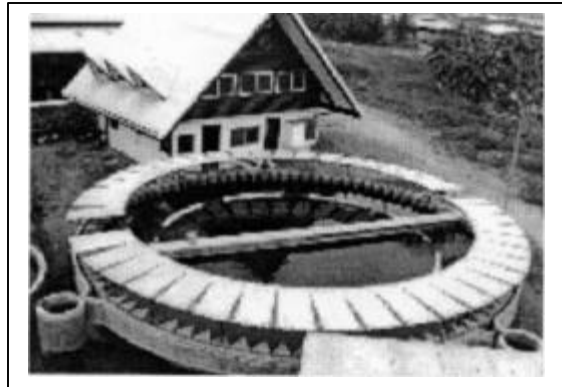
System redesigning and re-engineering using alternative source of energy could be considered potential household backyard fry production component to supply the fry requirement of the industry. Further design improvement and development of the system for cost effective and efficient fry collection to minimize handling should be given emphasis.

Keywords: tilapia, breeding system, aquaculture engineering, and recirculating system

Performance of a Prototype Zeolite Recirculating Aquaculture System

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Abstract

A prototype demonstration recirculation aquaculture system (RAS), using a natural zeolite to remove ammonia, successfully supported and grew coho salmon (*Oncorhynchus kisutch)* for a period of one year.

The system has a total water volume of 4.0 m^3 (4000 l) distributed over two 1.3 m^3 volume circular rearing tanks, one 1.0 m^3 volume settling tank and a 0.4 m^3 volume zeolite column. Less than 5% of the water volume was replaced daily.

The rearing tanks are equipped with a split drain system. Solids are removed using one third of the 120 lpm recirculating flow, and are discharged via a central bottom drain into the settling tank.   From there, the solid free water is pumped through the zeolite while injected with high purity oxygen and ozone.

Two thirds of the flow exits the tanks by way of a central standpipe, located at mid-depth. This flow is pumped to the top of a 2.0 m tall oxygen/ozone enhanced packed column for oxygenation and degassing of carbon dioxide. Adding ozone to the column retards biofouling of the packing media.

Temperature and dissolved oxygen were monitored continuously, total ammonia nitrogen and pH were recorded daily, total alkalinity and carbon dioxide were measured occasionally. Temperatures were maintained at an average of 12.0^{0}C, dissolved oxygen near or slightly above saturation. Because the normal pH of the water is 7.8, initially the pH was adjusted to maintain un-ionized ammonia at recommended concentrations. However it was soon noticed the salmon tolerated higher concentrations and pH adjustments were discontinued. Despite high ambient un-ionized ammonia concentrations of up to 0.35 mg/l, fish showed no signs of ammonia toxicity (gill hyperplasia) but ceased feeding at concentrations in excess of 0.20 mg/l.

The pH ranged from 7.8 to 8.0 most of the time and carbon dioxide registered from 30 to 35 mg/l. Total alkalinity increased, over time, from 300 mg/l to up to 1000 mg/l. Both calcium and sodium concentrations increased as a result of zeolite regeneration with a solution of NaCl and NaOH.

Ozone prevented biofouling of the zeolite and simultaneously disinfected the recirculation flow. Water clarity, most of the time, approached drinking water quality. Neither fungal nor bacterial infections were observed, even on fish with eroded snouts.

Fish growth was normal, feed conversion averaged one. The system was designed to support a maximum biomass of 208 kg (80 kg/m3), it maxed out at a biomass of 260 kg of 60 g fish and a daily feed input of 2.8 kg. This biomass represented a rearing density of 100 kg/m^3 (6.25 lbs/ft^3), a loading of 2.2 kg/lpm (18 lbs/gpm). Zeolite was regenerated with a 2.0 percent salt solution elevated to a pH of 11.5 to 12.5 with sodium hydroxide, allowing degassing of the ammonia.

Zeolite columns were regularly regenerated after feeding 10 kg of food. By that time the ambient total ammonia nitrogen concentration was at 20 mg/l, un-ionized ammonia between 0.25 and 0.35 mg/l.

Bacterial floc routinely obstructed rearing tank discharge plumbing and became especially bothersome once daily feed exceeded 1.5 kg. Some improvements were made in design to simplify clean-out, and routine maintenance readily controlled the floc.

The system's design and operating parameters were applied to estimate the costs of large systems. To construct a similar system at commercial scale costs approximately $3.00 per pound annual production capacity. Production costs (utilities, feed, chemicals, annual labor) for a coldwater species range from $1.50 to $1.75 per pound.

The results obtained thus far with the coho salmon are very encouraging and further studies are warranted.

An Integrated Recirculating System for the Production of Oysters and Shrimp

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Aquatic animal production can be increased beyond what has been achieved without requiring additional water resources or causing additional environmental impact. In traditional culture the carrying capacity of a production system is ultimately limited by the accumulation of toxic metabolites such as NH_3 and CO_2 in the water. To increase the carrying capacity of a traditional aquaculture production system beyond its normal limit, specific waste treatment processes must be added to remove the limiting metabolites. Temperate zone re-circulating aquaculture production systems are examples of what can be done to increase the carrying capacity of an aquaculture system. However, these waste treatment measures add costs to the production, and commercially successful examples are rare. Two recent developments, the Partitioned Aquaculture System being developed at the Clemson University and the Integrated Recirculating Systems being developed at the University of Hawaii, are both noteworthy since they have gone beyond the present day waste management technology and demonstrated that cost competitiveness is possible for integrated recirculating systems.

The University of Hawaii Integrated Recirculating Oyster/Shrimp Production Systems is based upon a simple concept. In an oyster/shrimp system, the excess nutrients in the shrimp tank can be used to produce marine algae, such as *Chaetoceros* sp. The algal water is then pumped to a fluidized packed oyster column where oysters are suspended individually in a stream of high velocity water from the shrimp tank. The oyster feed on the algae, thereby eliminating oyster food cost while reducing the excessive nutrient load caused by the incomplete utilization of the shrimp feed. After the algae has been removed by the oysters, the water is returned to the shrimp tank to be reused. Up to 95% of sustained water reuse has been achieved. The normal range of water reuse is 80% to 90%. The system rests on two patents: The first is the Fluidized Bed technology, and the second is a pending patent application on the controlled production of marine algae in an open system. The ability to control the algal species is important to the success of the system, since it must be the right food for the oysters. By controlling the nutrient input to the tank, and by making sure there are sufficient oysters to remove algae continuously, a desired dominate algal species in the system can be maintained.

A venture capital group has licensed the patents from the University of Hawaii and created the Kona Bay Oyster & Shrimp Company in 1997. The company has begun its operation and is expected to reach full production in late 1998. Flat-bottomed, twenty-eight foot diameter round shrimp tanks with center drains are used. Circular water

motion is maintained in the tanks to remove all settleable solid. The oyster columns, 18 inches in diameter and 6 feet in height, can contain about 3,000 55-gram size American Cup oysters.

This paper shows the design steps for such a system.

Design and Construction of a Commercial Biosecure, Closed, Recirculating Shrimp Production System

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Production losses from disease (i.e. viruses) have had a serious negative economic impact on marine shrimp farming world-wide. The need for specific-pathogen-free (SPF) broodstock that are either geographically or environmentally isolated from common diseases has become a priority. The latter is more difficult to accomplish because of possible sources of contamination from influent sea water, shared facilities and shared personnel. The establishment of commercial, environmentally isolated broodstock also necessitates the use of totally, closed recirculating water filtration systems to contain the costs of water replacement due to declining pH and nitrate accumulation.

A commercial biosecure facility composed of 4-100 mt raceway systems has been designed and constructed. The system is composed of 4-3.3 m W X 33 m L X 1.3 m D concrete raceways housed in greenhouses. Each raceway has a central concrete partition and a 1.6 m deep settling basin at one end. All effluent water is drawn from a screen standpipe located in the middle of the settling basin. Filtered water is returned to the surface of the raceways along the central partition at 1-2 m intervals. In addition, a cleaning system consisting of notched 5 cm polyvinyl chloride (PVC) pipe located along the lateral walls and medial partition suspends uneaten feed and particulates off the bottom. Two of the raceways have a combination upflow bead (2.2 m^3)/fluidized sand (1.44 m^3) biofilter system supplied with water from a 2-1 hp pumps (200 lpm). The other two raceways have a reciprocating biofilter (8.9 m^3) supplied by an airlift pump (500 lpm). All four raceways have protein skimmers and activated charcoal filters. The tanks and filters were all new construction and artificial sea salts were used to establish and maintain the salinity (5-25 ppt). Each raceway was designed to produce >100 shrimp m^{-2} for a total of 40,000 biosecure adult broodstock. In addition, the raceways were used to acclimate 5.5 X 10^6 postlarvae before they were stocked into production ponds.

Procedure for Analyzing the Technical and Economic Risk of a Recirculating Aquaculture System

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Since the economic results of investing in an aquaculture enterprise are unknown at the time the investment decision is made, it is advisable to analyze the uncertainty and risk of such an investment. This is particularly true when the potential aquaculture enterprise includes a recirculating system. Recirculating systems require large capital expenditures for building and equipment which give rise to high fixed costs and high operating leverage. If the investment is financed with a combination of debt and equity, the investors have both operating leverage and financial leverage, and increases in either tend to increase business risk. In addition, a recirculating aquaculture system is subject to technical failures which can result in critical death losses of fish.

One method of analyzing the risk of a potential investment is to simulate outcomes on paper prior to committing funds to physical facilities. The accuracy and usefulness of the simulation depends, of course, on the accuracy of underlying assumptions and the comprehensiveness of the model of the firm which is being simulated. Data collected from established recirculating systems contributes to the accuracy of underlying assumptions, and computer software allows simulation of fairly complex models of an aquaculture enterprise.

A spreadsheet was developed based upon the commercial-scale recirculating system in operation at Illinois State University. It contained information pertaining to revenue, capital costs, and operating costs including feed costs, feed conversion ratios, and fish growth rates. Output cells in the spreadsheet included net income, net present value, modified internal rate of return, breakeven volume measured in dollars of sales, and breakeven volume measured in kilograms sold. Estimates of probability density functions for various sources of technical and economic risk and uncertainty were derived from best available information and incorporated into the spreadsheet. A commercial risk analysis software which was based upon the Latin Hypercube sampling technique was used to quantify the impacts of various sources of risk and uncertainty on profitability and acceptability of the investment. Sources of risk and uncertainty were ranked from most important to least important based upon standardized beta coefficients which were generated by the risk analysis software.

Modeled sources of risk and uncertainty related to physical structures were annual repair and maintenance expenditures and salvage value. Information on salvage value was critical to computation of net present value and modified internal rate of return. Modeled

sources of risk and uncertainty related to fish growth were stocking weight of fingerlings, survival rate, and average daily rate of gain. Other modeled sources of risk and uncertainty included per unit feed cost and feed conversion ratio; per unit prices of LP gas, water, oxygen, and electricity; the hourly labor wage rate; and the price of fingerlings.

Based upon the assumption that 46,800 fingerlings weighing approximately 20 g would be stocked each year, a simulation based upon 1000 iterations generated the following results for output cells:

Output	Mean	Standard deviation
Net profit after taxes (annual)	$15,430	$5,554
Net present value (WACC = 14%)	($25,633)	$19,536
Modified internal rate of return	10.0%	0.3%
Breakeven volume – dollar sales	$88,309	$4,127.87
Breakeven volume – kilograms sold	21,145	1,665

The net present value (NPV) and modified internal rate of return (MIRR) analyses were based upon a five-year planning horizon. Results indicated that under the assumptions utilized, the investment could be expected to generate a 10 percent rate of return after taxes. The minimum MIRR generated by the simulation was –1.5 percent, and the maximum value generated was 18.6 percent.

Sensitivity analysis was utilized to determine which sources of risk and uncertainty had the strongest impacts on output values. The five most important sources of variation for net profit after taxes, NPV, and MIRR, were price per kg of fish at harvest, average daily rate of gain, feed conversion ratio, survival rate, and cost of feed per kg. The five most important sources of variation for breakeven volume measured in dollars of sales were feed conversion ratio, price per kg of fish at harvest, hourly labor wage rate, cost of feed per kg, and fish survival rate. The five most important sources of variation for breakeven volume measured in kg of sales were price per kg of fish at harvest, feed conversion ratio, hourly labor wage rate, cost of feed per kg, and fish survival rate.

With slight modifications, the spreadsheet can be used to analyze recirculating aquaculture systems of different scale and technical makeup. Although the analysis described above did not include a true bioeconomic model, it is possible to incorporate such information into a spreadsheet at the cost of greater complexity.

The Effect of Biological Air Purifying System With Aquatic Animal-Plant Integrated Greenhouse

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Abstract

Two different types of the joint greenhouses for aquatic animal-plant integrated system were developed at the Agricultural Bioenvironment Engineering Institute of Zhejiang Agricultural University in China. The joint greenhouses form mutual compensation system for exchange CO_2 and O_2 between the aquatic-animal housing and plant-growing greenhouse. The CO_2 from aquatic-animal housing can be used as a nutrient resource for the vegetable or flower inside the greenhouse, the plant photosynthesis product O_2 will purify and improve the air quality inside the animal housing. One of these is the back to back' interaction greenhouses (Fig1),
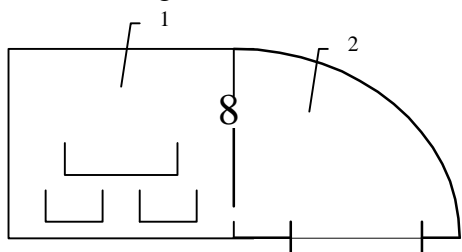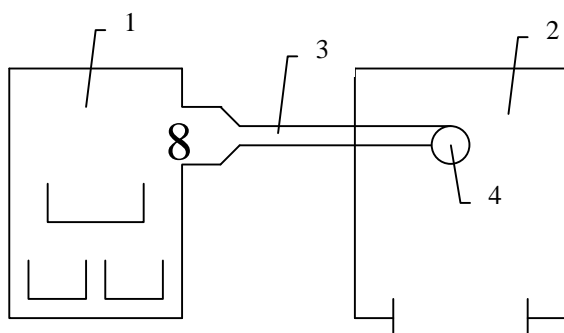
1. aquactic-animal housing
2. plant greenhouse

Fig. 1 Back to back interaction greenhouses system**.**

Dynamic variations of CO_2 concentration related to operating time was measured and measured with LI 6200 portable photosynthesis system.

Another type of interaction greenhouses is connected with pipe (Fig. 2)

1. aquactic-animal housing
2. plant greenhouse
3. Conecting pipe
4. Pipe with holes

[1]Fig. 2   The interaction greenhouses system with pipe connecting

Dynamic variation of CO_2 concentration was measured too and the simulated equation of CO_2 variation of aquatic-animal housing is as follows:

$$C_1 = 807 + 260e^{-\frac{t}{5000}}$$

C_1: The CO_2 concentration variation related to time of aquatic-animal housing

The simulated equation of plant greenhouse is as follows:

C2: The CO_2 concentration variation related to time of plant greenhouse

$$C_1 = 681 + 358e^{-\frac{t}{5000}} - 632e^{-\frac{t}{1366}}$$

The data indicates that when the ventilation system for air exchange is operating, for the back to back' interaction greenhouse system, the mean value of concentration of CO_2 inside plant greenhouse increase from 320ppm to 780ppm after half hour and the mean value of concentration for CO_2 inside aquatic-animal housing decrease from 1100ppm to 800ppm. For the interaction greenhouses system with pipe connecting, the mean value of concentration of CO_2 inside plant greenhouse increase from 360ppm to 780ppm and the mean value of concentration for CO_2 inside aquatic-animal housing decrease form 1100ppm to 700ppm after one hour, the measure results indicated that the hole position of the distribution pipe is one of the important factors of CO_2 concentration equality, this paper proposed some principles of air exchange system design.

The measure results indicated that the interaction greenhouses of aquatic-animal plant integrated system is an efficient method for purifying air in aquatic-animal housing, and it is used for not only purifying air, but also water recycling and economizing energy.

Integrating Hydroponic Plant Production with Recirculating System Aquaculture: Some Factors to Consider

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Abstract

Aquaponics, the integration of hydroponic plant production with recirculating fish culture systems, is gaining in popularity among hobbyists and receiving attention in the commercial sector. Although the number of commercial operations is still small, at least two large suppliers of aquaculture and/or hydroponic equipment have introduced aquaponic systems in their catalogs and many schools are beginning to include aquaponics as a learning tool in their science curricula. With such high interest, aquaponics appears to be on the threshold of increased technological development and greater application.

Growing plants with fish requires some modification of the design criteria and operational procedures of standard recirculating aquaculture systems. Properly-designed aquaponic systems emphasize plant production, which receives about 90% of the culture area and generates 65-70% of the revenues. Raising and marketing plants require skills that may be unfamiliar to aquaculturists. Other factors to consider in adopting aquaponic technology involve:

Aeration. Plant roots require DO levels that are comparable those required by fish. DO levels should remain high throughout the hydroponic component and throughout the each mass of densely packed roots. Formation of anaerobic zones will cause root death. Rapid water exchange, intermittent dewatering or induced turbulence are used to ensure adequate root aeration.

Solids removal. Rapid removal of settleable and suspended solids from an aquaponic system reduces mineralization, which may decrease some dissolved nutrients to levels that limit plant growth. Aquaponic systems vary from daily or weekly removal of solids to no solids removal at all in some configurations.

Biofiltration. In a properly-designed aquaponic system with a high ratio of plant growing area to surface area for fish production, the hydroponic component should provide sufficient biofiltration, through direct ammonia uptake by the plants and nitrification on the submerged surface areas, so that a separate biofilter is not required. This is an important economic justification for integrating hydroponic plant production in a recirculating aquaculture system. Hydroponic technique. The hydroponic methods that are generally used in aquaponic systems are raft culture, nutrient film technique and ebb and flow systems with either gravel or sand

substrates. Each method requires special design considerations and has advantages or disadvantages depending on the plant crop being cultured.

Suitable fish species. Tilapia are the most common species cultured in aquaponic systems. Not all fish species are suitable. For example, hybrid stripped bass cannot tolerate the elevated levels of potassium, produced through supplementation, that are desirable for rapid plant growth.

Planting densities. It is essential that plants be given adequate space for robust growth. If plant densities are too high, plants will elongate, reducing market value, and lack of air circulation and moisture buildup will foster disease and pests outbreaks.

Stocking rates. Since aquaponic systems emphasize plant production and the fish rearing component is relatively small compared to the plants, stocking fish at extremely high densities and using pure oxygen systems are not practical or cost effective. Fish should be stocked at less than 100/cubic meter to increase individual growth rates, lower feed conversion and promote health.

Water source and exchange. The nutrients or contaminants in source water can impact plant growth and should be assessed. Water exchange should be minimized to maximize nutrient retention time in the system.

Base and nutrient addition. Potassium and calcium bases will neutralize acidity as well as supplement essential plant nutrients that are low in fish waste.

Nutrient and gas recovery. Hydroponic plants can not only recover waste nutrients from fish but also carbon dioxide that is sparged from the culture water and contained by a greenhouse.

Nitrate control. A partially anaerobic solids zone can be used to regulate nitrate levels by adjusting the cleaning frequency. High nitrate levels favor vegetative growth in plants while low nitrate levels promote fruiting.

pH. pH should be maintained at 7.0 for optimum nutrient availability while maintaining adequate nitrification.

Temperature. The optimum temperature is 24C for vegetable production and 30C for tilapia production. If possible, the temperature should be adjusted to favor plant production.

Solar radiation. Commercial hydroponic plants grow best in intense sunlight and should not be shaded. Low wintertime solar radiation in temperate regions will prolong plant production cycles.

Pest and disease control. The need for pest and disease control will be reduced by providing growing conditions that minimize stress. Biological control methods are appropriate for

aquaponic systems. Pesticides and antibiotics should not be used.

Monitoring. At prescribed stocking, planting and feeding rates, aquaponic systems require a minimum amount of monitoring. Only pH is monitored on a regular basis.

Management and labor. Aquaponic systems should be designed for ease of management and should minimize labor requirements. For profitability it is important to reduce operating expenses.

Ground Limestone as a Biofilter Media for Hybrid Stripped Bass Culture

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A pilot study was conducted to evaluate ground limestone as a biofilter media in a recirculation system containing hybrid striped bass. Two replicated biofilter configurations were used. Each system consisted of a rearing tank (122 cm diameter, 67 cm deep), settling tank (102 cm square, 21 cm deep), biofilter and re-oxygenation column (76 cm height, 15 cm diameter) containing Koch rings. The biofilter type and media consisted of either a pulsed bed near buoyancy plastic bead filter or a pulsed bed ground limestone filter. In the pulsed bed limestone and plastic bead filters, 3 kg of media were placed in each column (16 cm diameter, 260 cm height) with two columns per system. A timer-relay-ball valve assembly directed 22.7 l/min of water flow through each column at 30 s intervals. The intermittent flow expanded and mixed the bed during the 30 s of flow, shearing excess microbial growth. Estimated surface area per square meter of each material was, near buoyancy beads, 960 m^2/m^3 and limestone, 4000 m^2/m^3. Temperature was set at 23 C, water hardness adjusted to 150 ppm with calcium chloride and pH maintained above 6.5 by the addition of saturated lime solution. Each unit was stocked with 24 kg of hybrid striped bass averaging 397 g/fish. Fish were hand fed commercial feed twice daily to satiation.   The effect of limestone on rearing unit pH and alkalinity was measured independently from ammonia removal rates to avoid any effect pH change may have on ammonia removal rates. During this period lime dosing was shut off. Ammonia removal rate based on a surface area basis was higher for the pulsed bead filter. When ammonia removal rate was calculated as per unit of bed volume, ammonia removal rate was higher for the limestone filter and the efficiency of ammonia removal was also higher with the limestone biofilter. Biological oxygen demand (BOD) measured in the rearing unit was similar between the two filter types.   Suspended solids were higher in the limestone treatment. In addition to providing surface area for nitrifying organisms, limestone increased both pH and alkalinity of the water (Table 1). Use of limestone as a biofilter media resulted in less saturated lime solution used to maintain rearing water pH. After 2 months of operation, the limestone bed height had dropped by half and new limestone was added to return bed volume to original depth. Limestone media provided a reasonable nitrification rate and improved both pH and alkalinity but the rearing tank water remained cloudy or milky throughout the study. This turbidity was not due to the addition of lime to control pH. After three months, fish mortality (1-2 fish/day) was observed only in tanks with limestone filters. Microscopic inspection of the gill tissue from dead fish revealed small imbedded limestone fragments. In addition, it was discovered that limestone silt had trapped organic matter at a low point in the system and the trapped material became anaerobic. In summary, limestone supported reasonable nitrification rates, elevated pH and increased alkalinity of the water. The disadvantages include higher suspended solids,

gill irritation and a propensity of limestone silt to trap organic material resulting noxious undesirable by-products. Limestone has potential as a biological filter media if suspended limestone is removed and care is taken to avoid anaerobic pockets within the system.

Table 1. Biofilter ammonia removal and rearing tank water chemistry.

Measurement	Plastic Bead	Limestone
NH_4 removal rate, g/m^2 day (surface area)	0.41	0.30
NH_4 removal rate, g/m^3 day (bed volume)	0.39	1.47
NH_4 removal efficiency %	29.3	35.0
Rearing tank NH_4, ppm	0.38	0.46
Rearing tank BOD, ppm	4.02	4.26
Rearing tank Suspended Solids, ppm	2.4	6.0
Water pH and alkalinity with no base addition (CaOH)		
Rearing tank pH	5.6	6.2
Rearing tank alkalinity, ppm	27.9	49.0

Evaluation of an Aerated Floating Plastic Media Biofilter Within a Recirculating System Used to Produce Food-Size Yellow Perch

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A moving bed biofilter consisting of aerated floating plastic media (Purac Engineering, Inc.) was installed within a recirculating system used to produce food-size yellow perch. The ridged tubular media is 7-8 mm long, 10 mm in diameter, and provides roughly 98% void space as a loose-packed bed. The manufacturer reports that the media has roughly 333 m^2/m^3 of surface area when filling 67% of reactor volume. For the present study, about 4.25 m^3 (150 ft^3) of "unwetted" media was divided into two equal portions and added to the two biofilter vessels (each 3.66 m diameter and 1.22 m sidewall depth). Each biofilter was operated at 0.95 m (3.1 ft) water depth. About 40.5 L/s (640gpm) of water flow and 20.4 L/s (43 cfm) of diffused air was split between the two biofilters, producing a volumetric gas:liquid ration of 0.5:1. The water flow was first filtered through a single drum filter (Hydrotech) operated with 40 µm sieve panels before entering the two biofilters.

The alkalinity of the system was maintained at or above 60 mg/L (as calcium carbonate) by addition of sodium hydroxide.

The water pH and TSS concentration were taken at least once per week. Ammonia, nitrite, oxygen, and carbon dioxide concentrations were measured before and after each biofilter three times a week. This data was used to determine the ammonia, nitrite, and carbon dioxide removal rates and efficiencies across the moving bed biofilter. The arial and volumetric nitrification rate of the media are reported and compared to rates reported for other aquaculture biofilter types.

Prediction and NMR Determination of Fluid Film Thickness and Velocity Distribution in Nitrifying Trickling Filters

Valdis Krumins

Biological trickling filters are a common means of removing nutrients from recirculating aquaculture systems. Design of trickling filters is currently based on rules-of-thumb or empirical loading curves. More rigorous design requires accurate descriptions of such parameters as wetted area, mass transport into and out of the biofilm, and shear forces on the film. These parameters are functions of fluid flow rates; therefore, knowing the distribution of flow rates would enable one to model these phenomena for the entire filter. Such models could then be used to optimize several aspects of trickling filter design, including packing media and irrigation rates.

In this work, nuclear magnetic resonance (NMR) is used to image miniature nitrifying trickling filters. The NMR images show the location of biofilm, packing media, and water, and also display the velocity of any flow. Therefore, they can be used to compute the distribution of flow rates and to observe any changes in flow patterns caused by the presence of an active biofilm.

In addition, a probability density function (PDF) of local flow rates is independently developed using only the irrigation rate, packing material properties, and fluid properties as inputs. Preliminary results show good agreement between the NMR images and the theoretically determined PDF.

The Chilean Aquaculture Industry and the Role Played By the Universidad Catolica Del Norte in Its Development

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Introduction

The explosive growth of the aquaculture industry in Chile over the past decade would not have been possible if the country did not have good natural conditions with extensive coastal areas, lakes and rivers that provide optimal environmental conditions for farming, and also the existence of technicians and professionals able to meet the industry demands. Also, the existence of high quality fishmeal produced in Chile provides enough feed production to support the aquaculture activities.

The present work presents a brief description of the most important aspects of the species farmed in the country and the role played by the Universidad Católica del Norte in its development.

Farming of Endemic Species

Scallop farming.
In 1983 Trench et al. and in 1984 Disalvo et al. published the main data and technique culture about scallop farming, used until now. With the development of the "Centro de Acuacultura e Investigaciones Marinas" , a donation from the Japan International Cooperation Agency (JICA) to the Universidad Católica del Norte in 1985 began the development at commercial scale of scallops, and the hatchery techniques, natural larvae collection and ongrowing systems were then established (Illanes, 1988; DiSalvo, 1988).

There are currently 27 companies operating with investments of more than US$40 million that produced 8264 t in 1995 (SERNAP, 1995), this production placing Chile as the third scallop producer in the world. The average nominal price over the past 5 years has been US$13.3 per kg increasing to US$ 14.9 per kg in the case of fresh chilled scallops (Anonymous, 1997).

Seaweed Farming
Main seaweed farmed is *Gracilaria* spp., and there are 268 authorized seaweed farming concessions, with a 75% of them located in the south and 12% in the north of Chile.

The regular FOB prices were for dry seaweed US$1.9 per kg, but at present due to the unstable Asian markets and a strong decrease in the prices stopped all the exportation and only a few farms continue operating, to supply the local demand only.

Farming of Exotic Species

Salmon and trout farming
The introduction of salmonid species in Chile with the idea of running ocean-ranching began between 1905 and 1910 with the importation of 400.000 eggs of *Salmo salar, Salmo trutta* and *Oncorhynchus mykiss*. Between 1924 and 1930 200.000 eggs of *Oncorhynchus tschawytscha,* 114.000 eggs of *O.nerka*, and 225.000 eggs of *O. kisutch* were introduced. Only in 1979 the first cage culture system was established and in 1986 it reached a production level of 900 t (Uribe, 1988), and 141.400 t in 1995 (Anonymous, 1997). Due to the location of the Universidad Católica del Norte in northern Chile, no research has been done in salmonids, that are grown in southern Chile.

There are currently 90 companies in Chile oriented to salmon and trout farming, which have approximately 361 farming authorized concessions, and the salmonids produced are exported to Japan (59.6%), USA (29.8%) and the European Community (6.3%).

Red abalone farming
The red abalone *Haliotis rufesces* was introduced by Universidad Católica del Norte (UCN) and Fundación Chile from California in the'80. There are at least 4 abalone ongrowing farming centers and three hatcheries, one of them belonging to the UCN.

Due to the Chilean Aquaculture and Fisheries Law, this species must be cultured in inland tank systems in northern Chile, but in the South its culture in long-lines systems was permitted.

Japanese abalone
This species was introduced by Universidad Católica del Norte and JICA at the end of the '80, and after six years of an important amount of research in artificial feed, aquaculture engineering, cost analysis, and other bioengineering factors, the UCN and JICA designed hatchery facilities with a production capacity of 500.000 seed per year, and all this seed will be ongrowing by a national corporation with an investment capital of US$1.000.000.

Oyster Farming
The first assay of Pacific Oyster (*Crassostrea gigas*) culture was made in 1978 by the Universidad Católica del Norte and Fundación Chile, with 20.000 seeds (2 at 5 mm) imported from Moss Landing (California, USA) (Hauer, 1988). From that starting point it has moved geographically to the South of Chile, where more than 94% of the total production is located (Anonymous, 1997).

There are 15 companies (individuals and trade unions) authorized to farm oysters, with a production of 1.130 t in 1995. Prices for fresh-chilled oysters have shown a rising trend reaching US$ 6.9 per kg in 1995 and US$ 5.97 per kg for frozen oyster (SERNAP, 1995).

One of the main problems in oyster farming is the impossibility of natural breeding because of the low temperature of the Chilean seawater, therefore, its production is highly dependent on the existence of two hatcheries located in Coquimbo area, which can produce the required seeds.

Australian prawn farming
The Australian prawn *Cherax tenuimanus* was introduced at the end of 80 decade by UCN and national business people, and reactivate this activity just this year through National Grant, that permit the development of a model farm and hatchery facility with the idea of start a new interesting aquacultural business.

Potential Species in Study at UCN

From 1986 the UCN was studying the biological aspects of three local species with a great potential for national and international markets, and they are:

Chilean flounder: (*Paralichtys* sp.) until now the UCN has achieved spawning in captivity and culture of larvae descending from these broodstock. Right now the UCN will be increasing the laboratory capacity to pilot scale with an initial production of 3.000 juveniles for 1998 and 10.000 juveniles for 1999. During this program studies on hatchery and nursery facilities, transport , and sea cage design systems will be carried out.

Chilean river prawn: *Cryphiops caementarius* is the only Paleomonidae specie in Chile, and since 1983 the UCN was studying adequate technology to develop a hatchery and ongrowing facility system (Rivera et al., 1983). Only last year Morales (1997) defined the hatchery techniques to reach the postlarval stages in only 45 days. With these results the possibility to continue building new ongrowing earth ponds will be open, because up to this discovery the only source for prawn seeds were the rivers, which provide limited supplies.

Sea urchin farming: the UCN has currently developed the technology for farming and stocking the local edible sea urchin (*Loxechinus albus*), with a larval phase of 20 days and survival rates over 30%, then they are cultured on policarbonate plates in race-way tanks of 10 t until 4 mm, then they are relocated in baskest hanging from long-line systems and ongrowimg there during 8 months (20 mm), and then they are ready for stocking natural areas (Guisado et al., 1988).

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Determination of the Primary Ammonia Removal Design Criteria for Biological Filters

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Abstract

Ammonia is one of the primary waste materials produced by aquatic species, which is toxic even in low concentrations. Therefore, recirculating aquaculture systems must have some means for ammonia removal. Thus, systems commonly employ nitrifying biological filters to convert ammonia to nitrite and thence to nitrate which is itself non-toxic even in high concentrations. This research investigated whether the ammonia inflow concentration or the ammonia loading rate to the biofilter was the more important biofilter design parameter. Five ammonia inflow concentrations and ammonia loading rates ranging from 0.5 – 8.57 mg NH_4/L and 109 – 2456 mg NH_4/L per filter per day were applied to each of five identical biodrums through a series of ten tests. Total ammonia removal and nitrite levels were monitored in each of the filters. Ammonia inflow concentrations, ammonia loading rates, temperature pH, dissolved oxygen levels and flow rates to the filters were measured and controlled by a semi-automated, synthetic wastewater system. Regression analysis yielded a relationship of ammonia removal versus ammonia inflow concentration and ammonia loading rate ($R^2 = 0.93$), implying that the interplay of both parameters is necessary in predicting biofilter performance. Percentage ammonia removed was inversely and linearly proportional to loading rate. Increase in flow rate, hence loading rate, under low ammonia concentration in the system, increased mass ammonia removal.

In-Situ Passive Waste Removal in Circular Fish Culture Tanks

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A new approach to removing solid waste from recirculating aquaculture tanks was demonstrated, that incorporated part of the culture tank as the settling basin. Tank modifications included a dual standpipe design with an orifice to control discharge and the addition of a false bottom plate to form a quiescent area for solids settling. Three false bottoms and one control (no false bottom) unit were designed and tested in a 1 m^3 circular domed bottom fiberglass tank. The hypothesis that the standpipe/false bottom modifications would remove more waste from the water column than the standpipe modifications alone was tested. The hydraulic characteristics of the tank were determined using tracer studies. A completely mixed flow was present with only one of the false bottom designs, while the other three designs approached completely mixed flow. In addition, the effect of the false bottom designs on the velocity profile of the tank was analyzed. Results of the solids analysis indicated that this method of solids filtration is commensurate with other solid filtration units currently used in production scale recirculation systems. However the benefit from using the false bottoms in terms of solids removal (the reduced floor space) was outweighed by the extra amount of labor needed to maintain the tank and reduced tank circulation. Based on all the results, the control tank design is suitable for production if used as a primary filter for solids removal.

A Prototype Tilapia/Hydroponic Greenhouse Recirculating Production System for Institutional Application

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A recirculating tank production system was designed and tested during 1996 and 1997 under greenhouse conditions for the dual purpose of producing fish and plants for human consumption, principally for application in correctional institutions. Overall size of the rectangular tank was 7.3 m long by 2.4 m wide by 1.5 m tall with a total water capacity of approximately 18,190 l in the entire system. The tank was divided into three sections: a fish growing section (approx. 13,650 l), a sump area, and a biofilter area - each approximately 2,270 l. The fish growth area was subdivided using 2 inch diameter plastic mesh material into a primary area (9,100 l) and a secondary area (4,550 l). Water circulation was provided by 5-two inch airlift pumps located between the sump area and the biofilter. Water flowed by gravity from the biofilter, through the grow tank, and through the sump area, returning to the air lift pumps. The circulation rate was approximately 475 lpm.

Similar tank systems were installed in greenhouses located in Blacksburg and Petersburg, Virginia in 1996. The first season of testing was May - November and included mechanical aspects of tank system physical functions, water use and water quality monitoring, fish production and management, and use of effluents for irrigation and plant production. Prior to the 1997 season, several engineering design changes were made to the tank systems, as well as biological management changes for fish and plant production.

Application goals for this greenhouse recirculating system were to produce a crop of food fish every 5 to 6 months and to reuse the effluent water for both irrigation and nutrient inputs into greenhouse vegetable crops. Tilapia was used in theses tests, while vegetables tested included tomatoes and lettuce. Lettuce was grown using a nutrient film technique system over the fish tanks.

Fish Production

Nine hundred tilapia, average weight 45 g, were stocked in the primary production area during May, 1997. Fish were fed frequently by hand and with automatic (belt) feeders. Water temperature, dissolved oxygen, and pH were monitored twice daily. Approximately 2.35 kgs of sodium bicarbonate was added weekly to maintain alkalinity and pH levels in the system. Routine maintenance involved weekly sump flushes. Fish harvests were made during October. For 1997 the combined production data from Virginia Tech and VSU was: fish survival was 92% with an average size 439 g. Total fish harvested was approximately 340

kgs with an additional harvest of 700 fish that averaged 124 g each from the secondary growth area.

Effluent Uses

After 2 months of operation, approximately 3,500 l of water had been released and replaced with new water to maintain water quality levels for fish production. Tank water was tested for plant application as a nutrient source. Lettuce grown using tank effluent performed similarly to control lettuce until it reached 110 g size, when signs of nutrient deficiencies were indicated. Nutrients in the effluent water were inadequate at the fish densities tested for commercial vegetable hydroponic systems.

The Speedy Text to Identify Optimal Growth Temperature for Aquatic-Animals

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Abstract

The optimal growth temperature for aquatic animals, such as soft-shell turtles is affected by natural environment or experimental conditions. When water temperature is controlled above 24°C~25°C, the soft-shell turtles look very active. However, if the temperature falls below 20°C, the food intake of soft-shell turtles is significantly reduced. The heating facilities are widely applied to cultivate soft-shell turtles to dispel the hibernation period and the turtles will gain weight all year long. We have studied effect of water temperature on turtle's heart rate. The aim of this study is to provide certain scientific guidelines for fast cultivation of soft-shell turtle by investigating effects of water temperature on its physiological mechanism.

Experiments were performed in the ponds of the Agricultural Bio-environment Engineering Institute, Zhejiang Agricultural University. The experimental subjects were healthy adult soft-shell turtles. Their weight varied in the range of 226~280g (253g on average). Heart rate was taken by pH-38 ECG recorder. Water bath was applied to control water temperature, recording electrodes were well attached to four legs of turtle. To simulate temperature change in Zhejiang Province, the test temperature was controlled between 5~35°C and measurement was taken every 5°C.

In order to find consistent experimental conditions, Turtle was used to characterize an adaptive process of heart rate to the change of water temperature.

Experiment data show that the heart rate was constant after the turtle was kept in water for 40 minutes with the temperature unchanged. The heart rate was measured as a subject had been kept in one chosen temperature for 40 minutes.

The variation of heart rate as a function of temperature is plotted in Figure 1.
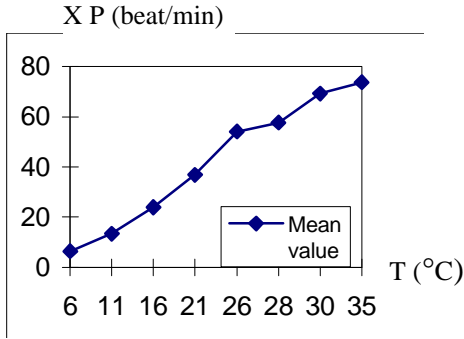
X P (beat/min)

Fig. 1 The relationship between the mean value of heart rate and the water temperature

The results provide the clear evidence of that the heart rate of turtle is linearly proportional to water temperature:

$P=-16.429+2.737T$ (P>0)

$R^2=0.9812$

P: heart rate (beat/min)

T: water temperature (°C)

Mean value:

$$\overline{X}=\frac{\Sigma_{Xi}}{n}$$

The relationship between the sum of square and temperature is showed in fig 2.

The relationship between the coefficient of variation and temperature is shown in fig 3.
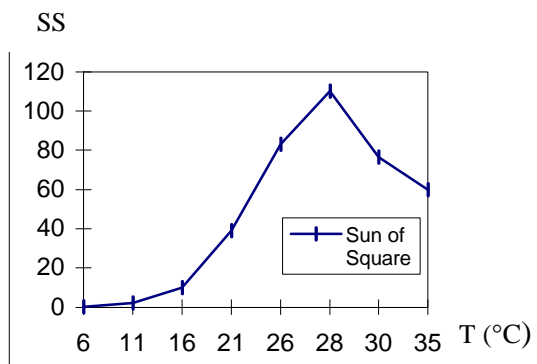

Fig. 2   The relationship between the sum of square and water
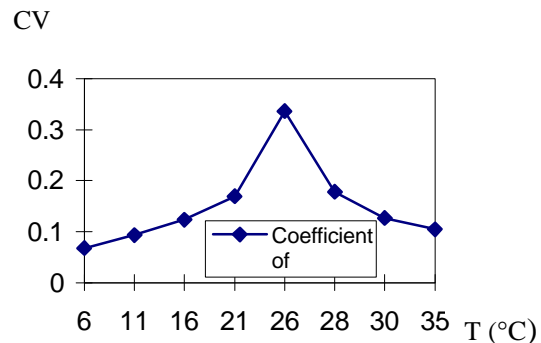
SS—Sum of Square

$SS=\Sigma(Xi-X)^2$

Fig. 3   The relationship between the coefficient of variation and water temperature

CV—Coefficient of Variation

$$CV=\frac{\Sigma\ (Xi\ -\ \overline{X}\ )}{\overline{X}}$$

Through statistical analysis the heart rate of aquatic-animal is closely indicates a protective mechanism for animals to adjust their breath, digestion, and metabolism to the change of environment.

Nevertheless, the data indicates that heart rates have the largest variation as the temperature falls between 26°C to 30°C. Many experiments suggest that this temperature range is optimal for soft-shell turtle growth in the sense of large food intake, rapid weight gain. In this optimal growth temperature range, the heart rate variation of soft-shell turtle

is not only affected by physiological mechanism, but also its behavior such as food intake and activity. That is a part of the reason to comply with the large variation of results in that temperature range, the conclusion is as follows:

Heart rate is linearly proportional to the temperature:

$$P=-16.492+2.737T \ (P>0)$$

In the optimal growth range (26°C ~30°C), relationship of heart rate and temperature presents large variations. Similar to homoiothermous animals, heart rate is affected by animal behavior in the optimal growth temperature.

To identify the optimal growth temperature for other types of poikilothermal animals, our study suggested measure heart rate as a function of temperature. The temperature that shows large variation may serve as the best cultivated range. Heart rate-temperature measurement will provide a quantitative method to quickly identify the optimal growth range for poikilothermal animals.