ISSN : 1410-5217
Acrredited : 83/Kep/Dikti/2009

Review

ALTERNATIVE PRACTICE FROM COASTAL POND TO RECIRCULATION AQUACULTURE SYSTEM

Ludi Parwadani Aji

Technical Implementation Unit for Marine Biotic Conservation, Research Centre for Oceanography,
Indonesian Institute of Science (LIPI), Biak – Papua

Received :October, 31, 2011 ; Accepted : January, 25, 2012

ABSTRACT

Coastal pond aquaculture used solar energy to produce oxygen via phytoplankton with their cultivation can be extensive such as the culture of low value cultured animals. Pond encompasses a larger culture area for juvenile or grow-out culture which is depending on their carrying capacity of the pond. There is no feeding and the amount of food available depends on pond management which can be increased by manuring. As well as in hatcheries that require a very well environmental control, Recirculation aquaculture systems (RAS) tend to occupy a small area to culture high value species at high densities. The key parameter affecting RAS is the biological filtration system that removes metabolic and other waste products. This contains bacteria which break down the ammonia and nitrite in the water. Moreover, the food from RAS is supplied externally from cultured or formulated feed. Recirculation systems offer the advantage over pond aquaculture of being able to control the environment and water quality parameters to optimise fish health. For production of commodity food fish that are low in price, pond aquaculture is better than recirculation system due to their lower overheads and production cost as the environment acts as a natural water reconditioning system compared to money spent on water recirculation technology. In developing countries, pond will still remain dominant due to the ease of culture and the low initial investments. While, in developed countries, the growing concern about environmentally friendly discharges, the high labour costs and the need for controlling niche markets will result in the adoption of recirculation technology and the production of high value species at high densities. In comparison to pond culture, RAS offered more control and independent from the environment influence.

Keywords: aquaculture; pond; recirculation system; environment

Correspondence: Phone +62-981-81112; E-mail: ludi_bio@yahoo.co.id

INTRODUCTION

The majority of the world's fish supplies from marine capture fisheries, therefore, natural marine fisheries in some areas are overexploited to satisfy the market demand. This condition has come to promote the development of marine aquaculture. According to the Food and Agriculture Organization (FAO) of The United Nations survey in 2010, aquaculture production (mollusk, crustacean and fish) in the world increased by nearly double from an estimate of 26 million tonnes in 1996 to around 55 million tonnes in 2009 and provide nearly 50% of the world fish food. Aquaculture systems can be classified under three aspects. The first aspect is the type of culture structure which can range from closed structures like recirculation tanks and raceways to semi closed structures like coastal ponds and open systems such as sea cages. The second is then amount of water exchange and the control of water flow into and out of the system. The levels of water exchange can be classified as static, open, semi closed or recirculating (fully closed). The last is the culture intensity (the number of aquatic organisms grown per unit area) that refers to the natural productivity needed to support a crop. The intensity of culture can be further subdivided into extensive, semi intensive and intensive (Apppleford, *et al.*, 2003).

Pond aquaculture has been established for centuries and is believed to have originated from China around 475 BC, by Fan Li, who wrote the book "The Classic of Fish Culture", describing the structure of ponds and the method

ISSN : 1410-5217
Acrredited : 83/Kep/Dikti/2009

of propagation used for cultivating fish (Rabanal, 1988). Coastal pond aquaculture use solar energy to produce oxygen via phytoplankton. Moreover, the microbial and algae communities in the coastal pond are useful to recycle nutrients and waste products into fish food (Anderson and Douglas, 1993). Coastal ponds cultivation can be extensive, semi intensive or intensive, as the case of the prawn farm in Australia and South East Asia (FAO, 2006).

Many land-based coastal aquaculture farms are located on salt marshes and mangroves (**Fig. 1**). Mangrove forests are being logged to the point of clear-felling for aquaculture, so, it cause an ecological changes in coastal areas and has consequences for people who living in coastal communities as they depend upon mangrove forests for a variety of benefits. For example, mangroves have provided many household necessities such as charcoal, construction materials, firewood, herbal plants for traditional medicines or ecological benefits such as acting as windbreaks, controlling shoreline sedimentation and providing a habitat for marine animals. Therefore, the destruction of coastal mangrove or marsh will lead to a general decline in wild stocks.

Fig. 1. Mangrove area that can be used for pond aquaculture (Photo: Ludi).

As described above, there are several uses for the coastal marsh and mangrove areas. Both coastal marsh and mangrove areas are productive where higher plants grow on the mud and have greater use to man. They can control erosion and serve as buffer areas to prevent flood damage. Their ecosystems have been described as constituting a reservoir, feeding ground, refuge, nursery and spawning area for many animals such as crabs, shrimps, clams, mussels, oysters, fish and etc. Therefore, an alternative way to practice Recirculation Aquaculture Systems (RAS) may be fostered to reduce the impacts of coastal aquaculture to the environment. RAS are a relatively new technology with about 30 years of development, designed for growing a wide variety of aquatic species (Timmons, *et. al*, 2001). RAS recycled water by passing it through filters that remove metabolic and other waste products. In comparison to pond culture, RAS offer more control and independence from the external environment (Kazmierczak and Caffey, 1995).

This paper will give a general overview of similarities and differences between coastal pond and Recirculation Aquaculture Systems. This will be carried out through the examination of the scale and characteristics of each system. It will also consider the main factors limiting and affecting production, feeding regime, as well as

ISSN : 1410-5217
Acrredited : 83/Kep/Dikti/2009

issues which require good management practices such as water quality, harvesting and environmental impacts. As a result, the advantages and potential of each system in the future could be better understood.

System Characteristics and Scale

Coastal pond aquaculture generally encompasses a larger culture area which is generally for juvenile or grow-out culture and requires large quantities of water. The cultured species can be of high value but culture tends to gets more extensive when the market value of species is lower. Coastal pond aquaculture is depending on their carrying capacity. The key factor affecting pond carrying capacity is nutrient cycling, which involves processes such as nitrogen and phosphorus cycle brought about by bacteria, and is essential for primary production by aquatic organism (Lucas and Southgate, 2003). Successful culture involves proper management of phosphorus, carbon, and nitrogen ratio to control the composition and abundance of algae species. In the nitrogen cycle, cultured organisms produce nitrogenous wastes such as ammonia which can be toxic (**Fig. 2**). Through bacterial activity, ammonia and nitrite are metabolised to be transformed to become nitrate which is relatively non-toxic and act as a nutrient source for phytoplankton (Moll, 1986).

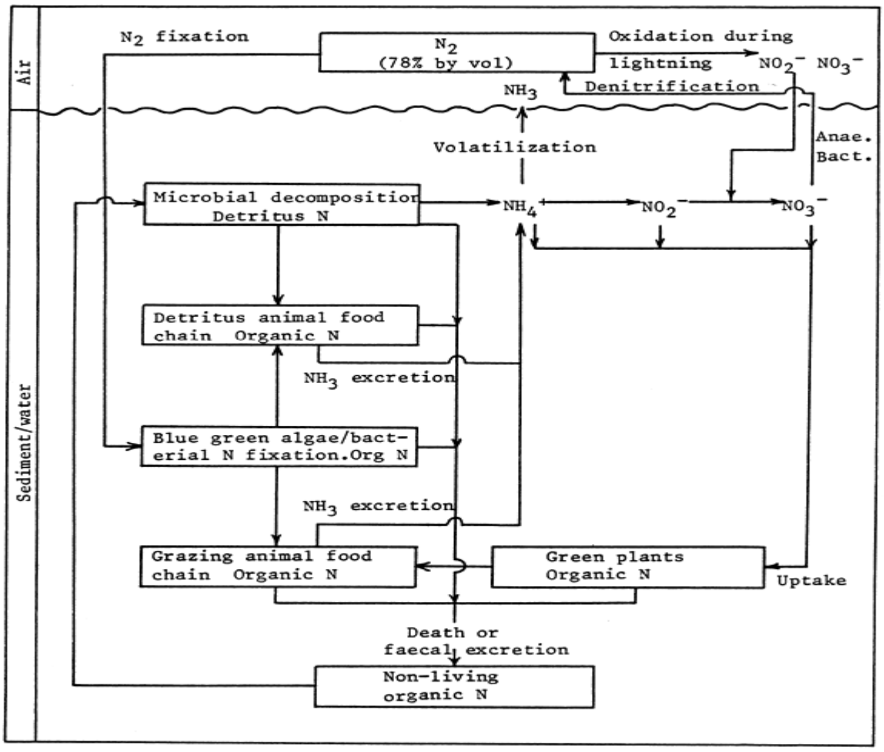

Fig. 2. Nitrogen cycle in ponds (Source: FAO, 2006).

On the other hand, Recirculation Aquaculture Systems (RAS) have not been widely adopted commercially as of their high production costs such as labour, electricity and feed. Therefore, they must rely on economic productivity per unit volume of space for profitability. This requires a good knowledge of economics. For example, increasing production may lower production costs (Rawlinson and Forster, 2000) in the growing of murray cod. However, due to market prices model shows that a 20 ton per annum production may not maximise profit compared to a 10 ton per annum farm. Economics also dictate that recirculation farms tend to occupy a small area to culture high value species at high density (Ionno *et al.*, 2006).

Key parameter affecting RAS is the biological filtration system. This biofiltration system contained bacteria which break down the ammonia and nitrite in the water to the success of the RAS. Since in, the whole system grows

 ISSN : 1410-5217
Acrredited : 83/Kep/Dikti/2009

two types of organisms i.e., bacteria and the culture species, so if the biological filter efficiency falls, time to harvest becoming longer, net returns decreases, and higher stocking levels may result in economic failure (Rawlinson and Forster, 2000).

Feeding

The level of feeding increases from extensive to intensive systems. In extensive coastal ponds, there is no feeding and the amount of food available depends on pond management which can be increased by manuring. Bacteria, at the bottom of the food web, can decompose the manure into nitrates which act as a nutrient source for phytoplankton. Phytoplankton carry out photosynthesis are a source of food for zooplankton which in turn become food for fish. In general, higher species diversity of algae indicates a greater variety of food (Gal, *et al.,* 2003). However, pond fertilization to improve phytoplankton growth can result in rapid bloom. It causes oxygen depletion that can have results in the death of fish. Furthermore, blue green algae can out-compete other algae under rich nutrient conditions resulting in production of geosmin (a musty odour compound) which when absorbed by fish can causes off-flavour taste (Thomson, *et al.,* 2006).

As coastal ponds increase in intensity, there is introduction of artificial feeds. Prawns in semi intensive system are fed three times a day on 50% protein feed. For warm water fishes, fishmeal containing 25% protein is supplementary fed with food conversion ratio around 2.5-3.5. Food conversion ratio is affected by the physical environment. Higher temperatures can increase metabolic rate and food consumption of cultured species. Size of fish also affect food conversion ratio. Smaller fishes have higher food conversion ratio due to higher metabolic rate per unit body weight (Schroeder, 1973).

Since all food in the RAS is supplied externally as cultured or formulated feed, therefore, food conversion ratio is a very important factor affecting productivity. Food manufactured using extrusion has been demonstrated to have higher digestibility than that from pelleted processing. Digestible energy in identical feed can also vary depend on the type of cultured species. Size of fish and temperature has the same effect on fish in recirculation system as that of pond systems. Under-feeding can result in poor fish growth, while over-feeding results in the production of waste and accumulation of undigested food causing poor water quality (Thomson, *et al.,* 2006).

Water Quality Management

There are some levels of water quality restraints in coastal pond aquaculture. They involve site selection and managing water quality deteriorations caused by management inputs. The quality of source water should be the main factor affecting site selection (**Fig. 3**). For example, if ponds are built on acidic soils, liming the pond may be required. Highly polluted water source can also have serious effects on production causing disease and mortality to cultured organisms (Golez and Kyuma, 1997). Thus, site selection plays an important role in minimising this effect.

The other factor affecting water quality in ponds is the water quality deteriorations caused by management input to enhance production such as organic fertilization and feeds. This greater nutrient source can result in phytoplankton blooms, dissolved oxygen depletion and production of toxic metabolites (Naylor, *et al.,* 2000). Management methods would include continuous aeration using a paddlewheel and water exchange. This would involve predictive techniques to deduce minimum DO values during the night and at dawn. Continuous aeration can remove thermal stratification in ponds and maintain aerobic conditions throughout the coastal pond. It can also result in more oxygen diffusion into ponds, so, preventing phytoplankton die offs (Golez and Kyuma, 1997). Another effective method involves controlling the amount of fertilization and feed to prevent excessive algae growth. A current method is to keep particulate matter in suspension at shrimp pond. This facilitated nitrification of waste products by bacteria. As long as the system is aerated, pond conditions can be kept suitable for shrimp to live (Subasinghe, *et al.,* 2003).

ISSN : 1410-5217
Acrredited : 83/Kep/Dikti/2009

Fig. 3. Site selection for opening pond may cause destruction of coastal area (Photo: Ludi).

The success of a commercial aquaculture business depends on providing the optimum environment for rapid growth. RAS offers the advantage over coastal pond aquaculture of being able to control the environment and water quality parameters to optimise fish health. Some parameters are crucial to RAS i.e., pH, temperature, suspended solids, and concentrations of nitrogenous compounds such as ammonia, nitrite, nitrate, dissolved oxygen (DO), carbon dioxide (CO_2) and alkalinity (Timmons, *et al*., 2001). For instance, the optimum pH range for biofilter bacteria in RAS is around 7 to 8. The pH tends to decline as bacterial nitrification produces acids and consumes alkalinity and as CO_2 is generated by microorganisms and cultured animals. Water reacts with CO_2 to form carbonic acid that resulted to the decreasing of pH value, so, nitrifying bacteria will not be able to remove wastes of toxic nitrogen. Therefore, adding alkaline buffers is needed to maintain the optimum pH range. Moreover, continuously supplying adequate amounts of DO is essential as nitrifying bacteria become inefficient at DO concentration below 2 ppm. Generally, DO have to be maintained above 5 ppm for optimum cultured animals growth (Losordo, 1998).

All the water quality parameters are interrelated and interact with each other. For example, poikothermic fish will adopt the same body temperature as the environment. As temperature increases, metabolic rate increases, so fish consume more oxygen and produce more carbon dioxide, and excrete more ammonia. Whereas, high levels of ammonia can stress fish.

Waste and Harvesting

Effluent from coastal aquaculture ponds can result in sedimentation, eutrophication and environmental perturbations. Best management practices are that pond effluents must be treated prior to discharge into common waterways. Typical pond aquaculture systems have settlement ponds to allow solids to settle. The ponds also contain photoautotrophic algae to control inorganic nitrogen build up (Ebeling, *et al.*, 2006).

Harvesting in ponds require draining of fish ponds. Complete draining allows for harvest, and draining and drying allows for oxidation of organic sediment, resulting in minerals that are more readily released into the ponds when the water is refilled. For fish harvesting, this method is impractical, as complete draining of the ponds causes stress to the harvest fish. Seining is normally carried out before draining. However, seining tends to disturb the sediment layer on the ground, and

ISSN : 1410-5217
Acrredited : 83/Kep/Dikti/2009

draining immediately after will cause a huge sediment load which is discharged in effluent water. Therefore, best management practices are that ponds should be allowed to settle after harvesting for a few days before draining (Boyd and Queiroz, 2001).

The key to managing waste in a recirculation system is the biological and mechanical filters. Drum filters can be used as mechanical filters that mainly remove suspended solid particles while biological filter contains nitrifying bacterial may be used to convert toxic ammonia and nitrites to become a relatively harmless nitrate (Chen, *et al.,* 2006). The total ammonium nitrogen (TAN) concentration is often the key limiting water quality parameter in RAS, therefore its removal by means of biological filtration is crucial. Most of this ammonia and urea came from gills excretion. Biological filters can successfully perform the conversion, yet the set up time is long with around 40 days (Perfettini and Bianchi, 1990).

Suspended solids are a particularly a tricky problem in aquaculture. They can clog biofilters and reduce its efficiency. They can also going through mineralation processes to produce ammonia which is toxic to fish. It is the first limiting parameter to aquaculture production as recycling rate increases (Timmons, *et al.*, 2001). Mechanical filtration can remove most of the suspended particles but fine particle removal requires line media or screen, increasing the cost of removal due to frequent backwashing or pressure losses (Chen and Malone, 1991).

Predation

Predation is one of the problems that affected the productivity in Pond culture system, so, aquafarmer have to have several methods to prevent predation. Several predators that commonly found in coastal pond area are birds, mammals, Piscivorous fishes, amphibians and reptiles (Timmons, *et al.,* 2001). The shallow waters of ponds provide ideal conditions for some bird to prey on cultured species as they can drive fish by flapping their wings and then prey on them. Bird can be prevented to enter pond by placing large mesh nets over and side the ponds. For preventing piscivorous fishes can be used physical methods like the screening of inflow water. Filtering the water input to culture system may be achieved by passing water through netting or fine meshed screen. Netting and screens must be cleaned periodically as they tend to become blocked (Lucas and Southgate, 2003).

For other predator such as mammals, turtles, water rat and snake can be controlled by trapping and killing, provision of anti-predation fencing and nets. The other method to avoid predation can be achieved effectively by drying out the ponds and using chemical treatments of water remaining. All benthic species and algae must be removed and cement structure should be cleaned in dry out period (Lucas and Southgate, 2003). While, predation in fully recirculating tanks is not an important issues and it can be eliminated.

Advantages of both aquaculture practice

Coastal pond aquaculture will still exists and continue to increase, as it is a low technology with low cost investment for fish production and suitable for poorer farmers in developing countries. For production of commodity food fish that are low in price, pond aquaculture is better than recirculation system due to their lower overheads and production cost as the environment acts as a natural water reconditioning system compared to money spent on water recirculation technology (Malone, 2002). The possibility of integrated agri-aquaculture also offers an extremely attractive supplementary income for agricultural farmers. Furthermore, pond systems that contain a large variety of plankton species will provide a varied diet of nutrients and trace elements for culture organisms that artificial feeds may not be able to adequately supply.

Nevertheless, Recirculation Aquaculture System offers a high level of control of the rearing environment. This can offer several advantages including water and heat conservation, waste management controls and fish health controls. Growing fish in recirculation tanks allows observation of fish behaviour and therefore better stock management can be accomplished. Requiring only a small area, there is site flexibility, and farms are able to be located at the outskirts of big cities, reducing transport costs and ensuring that the product reaches the market in the freshest conditions. Total environmental control

ISSN : 1410-5217
Acrredited : 83/Kep/Dikti/2009

also means that fish can be cultured at high density, and photoperiod or temperature manipulations are able to be carried out such that stock is available all year around (Ebeling, *et al.,* 2006). Furthermore, development areas such as genetics, molecular studies, mutagenesis, teratogens evaluation, transgenics production, endocrine disruption and vertebrate development require a reliable supply of these organisms in optimal condition, and this can be controlled in recirculation systems (Gutierrez -Wing and Malone, 2006).

CONCLUDING REMARKS

Aquaculture will continue to grow as fisheries gets depleted and populations continue to grow, fuelling high demand for higher quality proteins available in fish. In spite of their differences in stocking density, feeding and water quality management; both pond and recirculation aquaculture supply the human demand for aquatic protein. Coastal pond and recirculation technology will continue to grow. In developing countries, pond will still remain dominant due to the ease of culture and the low initial investments. However, coastal pond aquaculture has several negative impacts to environment. In developed countries, the growing concern about environmental discharges, the high labour costs and the need for controlling niche markets will result in the adoption of recirculation technology and the production of high value species at high densities. Modern technology will be rapidly adopted in recirculation systems, as control of the system makes it possible to do all kinds of manipulations to improve the system. Integrated mariculture and polyculture will also continue to develop as farmers realise the benefits and the requirements for aquaculture to be environmentally friendly to ensure sustainability.

REFERENCE

Anderson, R.O. and T. Douglas. 1993. Strategies and tactics for management of fertilized hatchery ponds, Food product press, New York, USA, 262pp

Appleford, P.A., J. Lucas, and P.C. Southgate. 2003. General principles. In: Aquaculture: Farming aquatic animals and plants, Blackwell publishing, Oxford, UK, 502pp

Boyd, C.E. and J. Queiroz. 2001. Feasibility of retention structures, settling basins, and best management practices in effluent regulation for Alabama channel catfish farming, *Rev. Fish. Sci,* 9: 43– 67

Chen, S. and R.F. Malone. 1991. Suspended solids control in recirculating aquacultural systems. In: Engineering Aspects of Intensive Aquaculture, Proceedings from the Aquaculture Symposium, Cornell University, Ithaca, NY. Northeast Regional Agricultural Engineering Service, NRAES, 49: 170-l 86

Chen, S., J. Ling, and J.P. Blancheton. 2006. Nitrification kinetics of biofilm as affected by water quality factors. *Aquacul. Eng*. 34: 179–197.

Ebeling, J.M., M.B. Timmons and J.J. Bisogni. 2006. Engineering analysis of the stoichiometry of photoautotrophic, autotrophic, and heterotrophic removal of ammonia nitrogen in aquaculture systems, *Aquaculture,* 257: 346–358

FAO. 2006. State of world aquaculture 2006, Food and agriculture organisation of the United Nations, FAO Fisheries Technical Paper No. 500, Rome, 2006

FAO. 2010. Statistical query result capture: quantity. Food and Agriculture Organization of The United Nations, USA, viewed 5 August 2010, http://www.fao.org/fishery/aquaculture

Gal, D., P. Szabo, F. Pekar, and L. Varadi. 2003 Experiments on the nutrient removal and retention of a pond recirculation system, *Hydrobiologia*, 506–509: 767–772

Golez, N.V. and K. Kyuma. 1997. Influence of pyrite oxidation and soil acidification on some essential nutrient elements, *Aquacul. Eng,* 16: 107 –124.

ISSN : 1410-5217
Acrredited : 83/Kep/Dikti/2009

Gutierrez-Wing, M.T. and R.F. Malone. 2006. Biological filters in aquaculture: Trends and research directions for freshwater and marine applications. *Aquacul. Eng*., 34: 163–171

Ionno, P.N.D, G.L. Wines, P.L. Jones. and R.O. Collins. 2006. A bioeconomic evaluation of a commercial scale recirculating finfish grow-out system — An Australian perspective. *Aquaculture*, 259: 315–327

Kazmierczak Jr., R.F. and R.H. Caffey. 1995. Management ability and the economics of recirculating aquaculture production systems, *Mar. Res. Econ.,* 10: 187–209

Losordo, T.M., P.M. Msser, and J. Rakocy. 1998. Recirculating aquculture tank production systems: An overview of critical considerations. Southern Regional Aquaculture Center Publication No 41. United States.

Lucas, J.S., P.C. Southgate. 2003. Aquaculture farming aquatic animals and plants. Blackwell Publishing, Oxford.

Malone, R.F. 2002. Engineering for a responsible aquaculture with focus on growout facilities for commodity finfish. In: Creswell, R.L. and Flos, R. (Eds.), Perspectives on Responsible Aquaculture for the New Millennium, World Aquaculture Society, Baton Rouge, LA, USA/The European Aquaculture Society, Oostende, Belgium, pp. 94–111.

Moll, R. 1986. Biological principles of pond culture: bacteria and nutrient cycling. In: Lannan, J.E., Smitherman, R.O. and Tchobanoglous, G., 1986(Eds). Principles and practices of pond aquaculture, Oregon state university press, USA, pp. 1-7

Naylor, R. L., R.J. Goldburg, J.H. Primavera, N. Kautsky, M.C.M. Beveridge, J. Clay, C. Folks, J. Lubchenco, H. Mooney, and M. Troell. 2000. Effect of aquaculture on world fish supplies, Nature, 405:1017–1024

Perfettini, J. and M. Bianchi. 1990. The comparison of two simple protocols designed to initiate and stimulate ammonia oxidation in closed aquaculture systems. *Aquaculture.* 88: 179–188.

Rabanal, H.R. 1988. History of aquaculture, ASEAN/UNDP/FAO Regional Small-Scale Coastal Fisheries Development Project, ASEAN/SF/88/Tech. 7, Manila, Philippines

Rawlinson, P. and A. Forster. 2000. The Economics of Recirculation Aquaculture, Fisheries Victoria paper presented at IIFET Conference

Schroeder, G.L. 1973. Factors affecting feed conversion ratio in fish ponds. *Bamidgeh* 25:104-113

Subasinghe, R.P., D. Curry, S.E. McGladdery, and D. Bartley. 2003. Recent Technological Innovations in Aquaculture in: Review of the state of world aquaculture, FAO fisheries circular 886 (revision 2): 59-74

Thomson, K.R., L.S. Metts, L.A. Muzinic, S. Dasgupta, C.D. Webster. 2006. Effects of feeding practical diets containing different protein levels, with or without fish meal, on growth, survival, body composition and processing traits of male and female Australian red claw crayfish (*Cherax quadricarinatus*) grown in ponds. *Aqua. Nut.* 12: 227-238.

Timmons, M.B., J.M. Ebeling, F.W. Wheaton, S.T. Summerfelt, and B.J. Vinci. 2001. Recirculation aquaculture systems, Northeastern Regional aquaculture centre, New York, USA, 650pp