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Integrated aquaculture systems for nutrient reduction in agricultural wastewater: potential and challenges*

Andrew M. LAZUR*[1] and Frank LETEUX*[2]

Abstract The integration of aquaculture with agriculture, such and fish production with poultry , has been practiced for hundreds of years and takes advantage of the nutrient output of one crop to increase pond primary productivity, subsequently, enhancing herbivorous fish production. Applying this integration concept for the purpose of reducing the environmental impact of agriculture via the nutrient extraction ability of various shellfish, plant and fish species, is however, a relatively new concept and is increasingly justified by nutrient discharge regulations and associated increasing effluent treatment costs. Agricultural operations, such as animal feedlots, are specific nutrient point sources in which integration with extraction aquaculture could reduce environmental impact. In addition to playing a key role in nutrient reduction, extraction aquaculture species can be an important source of income, critical to offsetting increasing nutrient treatment costs and increasing farm profitability. This paper will review current strategies to apply this concept in the field, present an overview of specific efforts in Florida and summarize the challenges of implementation of integrating production of various aquaculture species to reduce nutrients in agricultural wastewater.

Key words: Integration, aquaculture, agriculture, nutrient reduction

Agriculture has increasingly been identified as a major source of nitrogen and phosphorus contributing to eutrophication of numerous bodies of water worldwide. Traditional grain and vegetable row crop production with nitrogen and phosphorus based fertilizer applications, accounts for the majority of non-point nutrient sources in many watersheds including the Chesapeake Bay and Florida Everglades, USA (Boesch *et al.*, 2001; Sharpley, 2002; SFWMD, 2002a). The vastness of land dedicated to this type of agriculture presents a challenge for specific nutrient discharge treatment. However, progress in reducing nutrient runoff has been achieved with adoption of specific changes in production practices, or best management practices, such as no till seeding or planting winter cover crops to minimize soil erosion and enhance plant absorption of nutrients (Staver and Brinsfield, 1998; SFWMD, 2001a). Concentrated animal feeding operations (CAFO's) such as dairies, poultry houses, cattle and swine feedlots, and aquaculture, however, are finite point sources of nutrients, and therefore, specific nutrient capture or treatment systems could be more easily employed.

Numerous examples of aquaculture integrated with agricultural crop and animal production exist including fish culture with rice, fruit, ducks, chicken production and have been for hundreds of years in Asia (Beveridge and Little, 2002; Little and Edwards, 1998; Little

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*[1] University of Maryland Center for Environmental Sciences, Horn Point Laboratory, P.O. Box 775, Cambridge, MD 21613 USA
*[2] Florida Department of Agriculture and Consumer Services, Office of Agricultural Water Policy, 1203 Governor's Square Blvd., Suite 200 Tallahassee, FL 32301 USA
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and Satapornvanit, 1996). In these cases, the goal is to maximize food production by utilizing waste from one crop to enhance production of another, in effect increasing nutrient utilization, and consequently, and until recently unintentionally, reducing nutrient impacts. Aquaculture species such as clams, mussels, oysters, algae and macrophytic plants are relatively efficient in assimilating or extracting nitrogen and phosphorus from their environment. (Boyd, 1995; Jones et al., 2002; Lasalle and Posadas, 1997; Newell, 1988; Schwartz and Boyd, 1995). In addition, numerous studies have shown the benefits of applying polyculture or culture of numerous species to reduce the nutrient and suspended solid loading of aquaculture effluent (Drenner, *et al.*; Hopkins *et al.*, 1993; Jones *et al.*, 2002; Schwartz and Boyd, 1998). The field of aquaponics, integrating fish and plant production, whereby fish wastes are used as fertilizer for vegetable crops has demonstrated successful method of increasing nutrient utilization and improving farm income (Racocy, *et al.*, 1992; and Diver, 2000). Using this extraction attribute of aquatic species in conjunction with agricultural crops specifically to reduce nitrogen and phosphorus discharges, or aquaculture serving as environmental rededication, is still in the development phase with limited field applications and research.

Current nutrient loading and reduction strategies in Florida

In south Florida agriculture runoff has been identified as the major contributor of the eutrophication of the Everglades and its watershed including Lake Okeechobee, Florida's largest lake. Phosphorus is the key limiting nutrient in freshwater systems and increases in phosphorus loading play a major role to eutrophication of the Everglades. SFWMD (2002a) estimated the total phosphorus import to the Lake Okeechobee watershed is over 1,800 tons per year originating from the major uses of the watershed including: improved pasture (33 %); truck crops (32 %); dairy (27 %); and citrus (11 %).

Recent nutrient management strategies focusing on phosphorus reductions include establishment of total maximum daily loads (TMDL's) for industries and CAFOs including an effluent standard of 40 ppb phosphorus for farm discharges. The use of best management practices (BMP's) and the employment of best available technologies (BATs) for many of the agricultural commodities including, beef cattle, poultry, citrus, and dairy are being established to achieve the new discharge standard (SFWMD, 2002b). Attempts to reduce phosphorus loading on a large watershed scale in the Lake Okeechobee region include: establishment of artificial wetlands, large chemical treatment ponds (which pump and inject untreated water with limestone, iron, humic acid, alum or polymers to bind P prior to discharging water), soil treatments, limiting nutrient applications, confinement barn-based technology, on-farm storage or retention (permanent storage) ponds, and governmental buy out of dairies (SFWMD, 2001b). These methods are very often costly to construct and maintain, have specific site limitations, and in the case of chemical treatment ponds and wetlands, have only temporary benefits due to substrate saturation and siltation. Dairies, which often concentrate several hundred to nearly two thousand animals per barn or dairy facility, have been identified as major phosphorus importers to Lake Okeechobee.

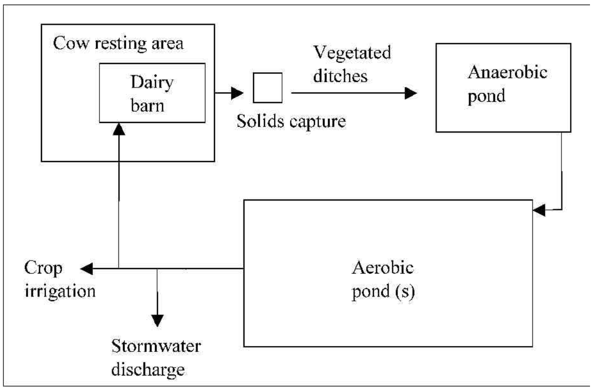

Fig. 1. Diagram of wastestream treatment and partial water re-use of a typical south Florida dairy

Using daily nutrient excretion estimates of Van Horn, *et al.* (1998) of 0.27-0.46 kg N and 0.05-0.068 kg P per dairy cow, total daily nutrient loading of barns in the Lake Okeechobee watershed are 81-828 kg and 15-122 kg of N and P respectively. They further show that solids collection, composting and crop irrigation of pond treated manure can capture significant levels of N and P and crops of bermudagrass hay and alfalfa periodically irrigated with dairy barn effluent resulted in 20-34 % and 22-49 % absorption of N and P respectively for the two crops.

Since the 1980's, the predominant method for treating CAFO wastes and effluent has been the use of individual or a series of lagoons or detention (temporary storage) ponds, both anaerobic and aerobic. The degree of nutrient reduction from ponds is highly variable and depends on many factors such as pre-pond solids capture, pond depth, surface area, oxygen concentrations, littoral area, plant species and hydraulic retention time. Increasing concern and government regulation of dairy effluent has prompted the necessity for additional or alternative nutrient reduction practices. Many dairies have increased the scale of treatment ponds and partially recycle water from the aerobic ponds for use as barn wash down water and for crop irrigation (Fig. 1). A waste treatment practice similar to the one depicted in Fig. 1 has resulted in reductions of 50 % and 76 % for N and P respectively with the majority of the remaining nitrogen being volatilized (Van Horn , *et al.*, 1998). The present challenge for this treatment practice is dealing with storm water discharge which is of special concern in the area due to low elevation and periodic hurricanes. New discharge requirements with a total maximum daily discharge (TDML) of 40 ppb phosphorus will mandate farms to treat storm induced off-site discharges as well, requiring additional treatment innovation and investment.

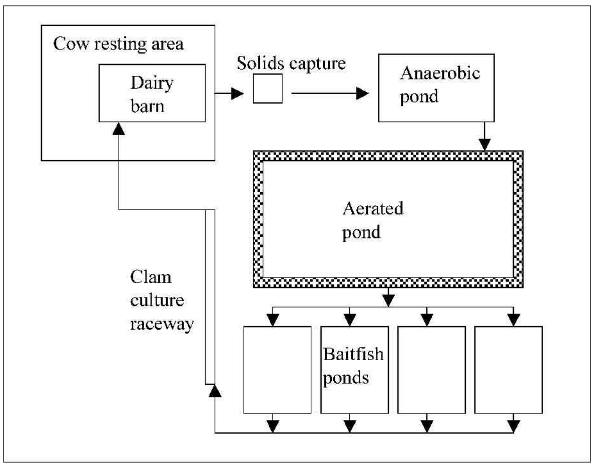

Fig. 2. Conceptual diagram of a integrated dairy - aquaculture operation with multi-stage water treatment and crop production. Shaded are in the aerobic pond depicts aquatic plant littoral zone.

The integrated dairy/aquaculture approach

One approach being developed for dairies in the Lake Okeechobee area involves incorporating culture of aquatic species such as Tilapia, paddlefish, baitfish (fish used as bait for recreational fishing), freshwater clams, and plants to provide additional nutrient assimilation, and in addition produce secondary crop income (Fig. 2). In this scenario, modifications to the water treatment ponds and ditches would be necessary as follows: 1) addition of more efficient solids removal equipment; 2) reshape pond bottom and slopes of anaerobic pond to facilitate removal of sludge accumulation in anaerobic pond; 3) renovate aerobic pond bottom to allow periodic fish harvesting; and 4) modify ditches and to enable culture and periodic harvest of the freshwater clam Corbicula fluminea.

With the modifications in place several phases of water treatment and nutrient reduction would occur:

Stage 1-Solids Collection:

Solids collection via use of a screen separator can remove 20-30 % of the organic matter from manure flushed with water that averages 72 % moisture and is comprised of 1-1.6 % N and 0.12-0.15 % P on a dry matter basis (Van Horn *et al.*, 1998). They also report an average of 45 kg of feces is defecated per cow daily. Taking into account the screen separator collection rate and the moisture and phosphorus content of organic matter, a reduction of approximately 25 % of the phosphorus or 0.004 kg P/cow is possible.

Stage 2-Anaerobic Pond:

Approximately 60 % of the nitrogen can be volatilized from an anaerobic pond via denitrification depending on hydraulic retention time. Phosphorus, however, is not removed by any organic mechanism within the anaerobic pond, but will accumulate into the bottom sludge. Phosphorus reduction estimated up to 50 % (Van Horn *et al.*, 1998) can occur when sludge is periodically collected and removed from the pond.

Stage 3-Aerobic Ponds:

Phosphorus absorption or removal can occur by several mechanisms within the aerated pond: fish harvest, macrophytic plant absorption, absorption by the pond sediment and phytoplankton. The aerobic ponds should receive intense mechanical aeration to enhance oxidation processes and to ensure adequate oxygen levels for the Tilapia stocked into the pond. The Tilapia serve as a forager on plankton and detritus, hence removing both nitrogen and phosphorus from the water. Harvesting Tialpia 2-3 times per year is possible and can be processed into a fish meal source for animal feeds. With a phosphorus and nitrogen content of Tilapia of 1.6 % and 2.7 % live weight respectively (Lovell, 1989) and using mean annual production of Tilapia of 1,600 kg/hectare/yr in cow manure fed ponds (Racocy and McGinty, 1989), an estimated 25.5 kg P and 43 kg N ha^{-1} y^{-1} removal is achieved.

In addition, the aerated pond has a littoral zone where aquatic plants can assimilate or extract additional phosphorus. Total export of P will depend on plant species and plant area. Common native emergent plant species which are effective in assimilating nutrients and have value in mitigation markets include: duck potato and arrowhead, *Sagittaria* spp., pickerelweed, *Pontederia* spp., and many shoreline grasses or rushes such as bulrush, Scirpus spp., and *Juncus* spp. Mitsch and Gosselink (2000) presented potential nutrient retention rates per area of marsh or wetland ranging from 3 -66 g N m^{-2} y^{-1} and 0.36-5.6 g P m^{-2} y^{-1}. In existing dairy operations, most of the aerobic ponds range from 4 -14 hectares in size and utilize 4 : 1 pond levee slopes, thus providing approximately 450 square meters of littoral zone per hectare of pond. Using nutrient retention rates suggested by Mitsch and Gooselink, nutrient retention would amount to 0.5-5.6 kg P ha^{-1} y^{-1} and 3-65 kg N ha^{-1} y^{-1}. Aquatic plants can also serve as an important secondary crop for sale in the restoration or mitigation markets.

Phosphorus readily binds with soil particles and accumulates in aerobic pond bottom muds. Pond sediment becomes saturated with phosphorus, which can be released into the water when the bottom sediments become anaerobic (Newell, 2003). The long-term P removal by the pond sediment will vary on several factors including degree of oxygenation, pH, soil type and plant absorption, but would be insignificant compared to other sources of P removal mechanisms in the aerobic pond.

Phytoplankton are efficient utilizers of phosphorus. Nurdogan and Oswald (1995) report 10-30 % absorption of phosphorus by microalgae in high-rate holding ponds and studies by UNEP (1999) show a 30-50 % uptake of P by microalgae in the aerobic pond portion of a waste stabilization pond system. The phosphorus uptake of microalgae is significant and appreciably greater than the potential from fish harvesting and marcrophytic plants in the perimeter littoral zone.

Stage 4-Baitfish Ponds:

Within the baitfish production ponds, species such as golden shiner, *Notemigonus crysoleucas* and bull minnow, *Fundulus* spp. feed on phytoplankton and zooplankton, and with harvesting further N and P assimilation and export from the system is achieved. Expected annual production of golden shiners using the wild spawn method (low fish yield culture practice where broodfish and offspring are raised in same pond) and with no commercial feed added is 110-330 kg ha^{-1} (Stone *et al.*, 1997).

Phosphorus removal rates from harvesting baitifsh would be expected to range from 1.8-5.3 kg ha^{-1} y^{-1}. In addition, the baitfish ponds proposed to be 4 hectares in size each would have similar littoral zone area and nutrient absorption as the aerobic pond on a per hectare basis. As in the aerated pond stage, phtoplankton would be present in the baitfish ponds and, therefore would be a major means of P uptake. In addition, incorporating the minor stocking (1-20 fish/ha) of paddlefish, *Polydon spathula*, an efficient zooplankton consumer, contributes to nutrient reduction benefit and also offers high value for its meat and roe. Paddlefish cultured in a 5 hectare reservior within a 200 hectare cattle watershed have been shown to survive for over 15 years and reach up to 36 kg (Kahrs, J., personal communication, 2002).

Stage 5-Clam Culture:

The final phase of water treatment prior to returning to the barn for wash down purposes, is clam culture within modified ditches or earthen raceways to facilitate periodic clam harvest. The species considered to be a good candidate for the integrated system in Florida is the Asian clam, *Corbicula fluminea*, due to its abundance throughout Florida freshwater bodies, tolerance to various water quality, high standing densities of up to 4,000 adults m^{-2}, relative high shell growth rate and rapid population recovery (McMahon, 1999). In addition, this species of clam has been observed to be a major feeder of phytoplankton, reducing plankton concentrations by 20-75 % in certain areas of the Potomac River (Cohen *et al.*, 1984). Unlike the fish culture portion of this integrated dairy/aquaculture system, in which extensive production data exists, the effectiveness and applicability of *Corbicula* as the final phase of water treatment within this integrated setting remains unproven. Current studies at the University of Florida Department of Fisheries and Aquatic Sciences are investigating some fundamental questions on *Corbicula* prior to incorporation into the dairy/aquaculture system. These include: substrate suitability, growth and filtering rates in a raceway environment, phosphorous uptake, shell and tissue P concentrations, and recommended water flow and clam stocking rates. Preliminary results show reasonable clam growth, but also a partial die off occurred which may be due to high water temperatures as observed with *Corbicula* in many natural environments (McMahon, 1999).

Summary of opportunities and challenges of integrated systems

The nutrient assimilation or reduction capability and production potential of all components within the integrated concept except the *Corbicula* stage have individually been demonstrated in the field. Using the mean P uptake values reported for stages 1 - 4 : 25 %, 50 % 20 %, and 40 % respectively, a 99 % total uptake may be possible without including the less significant removal by the Tilapia and baitfish harvesting as well as the littoral zone contributions. The *Corbicula* culture component would serve as the final P removal or polishing stage providing additional P removal. Proper sizing of each stage to the total P input or loading, would be necessary to prevent phosphorus being removed at high enough rates to starve subsequent stages of either P or P induced phytoplankton. Reviewing the uptake efficiencies, one could suggest that perhaps improvements on stages 1 , 2 and the contribution of phytoplankton together can accomplish P reduction goals. However, the fish, macrophytic plants and clams serve two important roles: 1) consumption of phytoplankton and subsequent removal of the P bound in the plankton via periodic harvesting; and 2) provide economic value to potentially pay for the treatment system. Pilot field studies are a essential tool to validate nutrient removal contributions of each stage and provide critical information in sizing the system, identifying optimum combinations of stages, and cost-benefit data.

The fundamental concept of sustainable animal production integration is maturing and being considered in many areas to improve sustainability of intensive animal production. Fedler and Parker (1994) present a similar multistage wastewater treatment scenario for swine or cattle production. In their system concept, fish, algae, duckweed, Lemma spp., and macrophytic plants are used to filter nutrients and, energy recovery, in the form of methane is incorporated. Parker and Fedler (1996) also note the increased potential for energy production through use of advanced facultative pond incorporated into an integrated wastewater treatment system and further suggest the many environmental and economic benefits of an integrated feedlot system.

The integrated concept is relatively simple in design, is applicable to a variety of type and scale of animal operations, and offers farmers the potential for increased farm income through sales of high value aquaculture crops. Incorporating a phosphorus reduction approach within the existing dairy barn treatment operations in south Florida offers cost savings and is more attractive to farmers compared to either new treatment systems or "regulatory relief" technologies, such as chemical treatment, that offers P reduction without any secondary crop income potential. Utilizing an aquaculture production component, does however, present challenges, especially the need for aquaculture training and experience, and detailed market information. In most cases, as was indicated by dairy farmers in the Lake Okeechobee area, demands on the farmers' time is currently too great to take on the additional time for training or production management responsibilities. Therefore, integrated operations would need to hire experienced individuals or contract with an aquaculture service company to manage the aquaculture component. An additional, and essential consideration is identification of market opportunities for the aquaculture products. The relatively large volume of fish and aquatic plants potentially generated by this system would be best accommodated through wholesale type markets rather than retail which require greater time due to smaller volumes and distances between customers. Thorough research on market outlets and their needs such as species preferences, product sizes, frequency of supply, volumes, seasonality of demand and pricing information is critical to evaluating the economic benefit of the aquaculture component and in the decision making process of investment.

The advantage of application in areas like south Florida are: 1) a long growing season of 10—11 months enabling efficient filtration capability of aquatic species nearly year-round; 2) the close proximity to high value markets and established distribution for baitfish (Adams *et al.*, 1998; Lazur, 1995), and aquatic plants; and 3) access to infrastructure and outlets using farm biosoilids such as, manure for compost, organic fertilizer, or bio energy production, and Tilapia and possibly clam shells for generation of animal feed products. Adapting this technology to cooler climates would result in reduced filtration efficiencies of aquatic species due to dormancy periods, which would increase the need for manure storage during winter months. However, the nutrient reduction benefit of wastewater treatment of an integrated system, despite the reduced growing season, may be highly significant and be more environmentally and economically justifiable than other options.

The culture of brackish water or marine aquatic algal and shellfish species with a joint goal of food production and nutrient reduction is expanding rapidly and Costa-Pierce, (2002) states many estuary based examples worldwide. Neori *et al.* (2000) studied a land-based marine recirculating polyculture system incorporating gilthead sea bream, *Sparus aurata*, Japanese abalone, *Halotis discus hannai*, and two seaweed species (as biofilters), *Ulva lactuca* and *Gracilaria conferta*. In their system, nutrients from the fish wastes were fed to the seaweed which was then fed to the abalone. They found that *Gracilaria* performance was poor, but the sea bream, *Ulva*, and abalone experienced good growth and the system converted 23 % of the nitrogen into fish and abalone flesh and an additional 10.3 % into seaweed exported from system. Based on their study, a component ratio of 0.6: 1 : 2 m^2 of abalone: fish: seaweed respectively is recommended. With this ratio, they estimate that 27% of the nitrogen would be converted to fish and abalone flesh with much of the remaining nitrogen in the form of ammonia and DON and would be recycled into the seaweed biofilters.

Applying marine species in integrated agriculture/aquaculture presents greater challenges given that CAFO's utilize freshwater and many operations are located inland. Those operations located near marine environments would require mixing the freshwater effluent with the marine water source in order to provide salinities required for the desired marine organisms. Recycling the treated water containing high salinities may not be acceptable in some applications, but may fit the dairy model and wash down use described within this paper.

The methods and potential combinations of components of integrating agricultural systems for nutrient reduction are numerous. The one concept presented here bases the nutrient reduction potential on a collection of observations and data for individual systems components. Field tests or demonstration projects are essential next steps and would provide valuable data in determining individual component and whole system nutrient reduction efficiencies, component compatibility, recommended nutrient input to component sizing, system costs and economic viability.

References

Adams C. M., Lazur A. M., Zajicek P., and Zimet D. J., 1998: An assessment of the market for live marine baitfish in Florida, Florida Department of Agriculture Bureau of Seafood and Aquaculture, 40pp.

Beveridge M. C. M. and Little D. C., 2002: The history of aquaculture in traditional societies, in "Ecological aquaculture" (ed. by Costa-Pierce B.A.), Blackwell Publishing, Oxford, pp. 3 -29.

Boesch D. F., Brinsfield R. B., and Magnien R. E., 2001: Chesapeake Bay eutrophication: scientific understanding, ecosystem restoration, and challenges for agriculture. *Journal of Environmental Quality*, **30**, 303-320.

Boyd C. E., 1995: Water quality in ponds for aquaculture, Alabama Agricultural Experiment Station, 482pp.

Cohen R. R. H., Dresler P. V., Phillips E. P., and Cory R.L., 1984: The effect of the Asian clam, *Corbicula fluminea*, on phytoplankton of the Potomac River, Maryland. *Limnology* and *Oceanography*, **29**(**1**), 170−180.

Costa-Pierce B. A., 2002: Ecology as the paradigm for the future of aquaculture, in " Ecological aquaculture" (ed. by Costa-Pierce B. A.), Blackwell Publishing, Oxford, pp. 339-372.

Diver S., 2000: Aquaponics- integration of hydroponics with aquaculture, Appropriate Technology Transfer for Rural Areas, 16pp.

Drenner R., Day D., Basham S., and Durward Smith J., 1997: Ecologica water treatment system for removal of phosphorus and nitrogen from polluted water. *Ecological Applications*, **7**(**2**), 381-390.

Fedler C. B. and Parker N. C., 1994: Waste treatment system alternatives integrating product development, in "Proceedings Great Plains Animal Waste Conference on Confined Animal Production and Water Quality" (eds. by Storm D. E. and Casey K. F.), Great Plains Agricultural Council Publ., National Cattlemen's Assoc., Englewood, Colorado, No.151, pp.219-225.

Hopkins J. S., Hamilton I. I. R. D., Sandifer, P. A., and Browdy C. L., 1993: The production of bivalve mollusks in intensive shrimp ponds and their effect on shrimp production and water quality. *World Aquaculture*, **24**, 74-77.

Lasalle M. W. and Posadas B. C., 1997: Use of constructed wetlands to improve water quality in finfish pond culture, Final report, Coastal Research and Extension Center, Mississippi Agricultural Experiment Station., 32pp.

Lazur A. M., 1994: Northwest Florida golden shiner market survey. in Florida Bait

Marketing Survey, Florida Dept. of Agriculture Bureau of Seafood and Aquaculture Publication, 6pp.

Little D. C. and Edwards P., 1998: Alternatives strategies for livestock-fish integration with emphasis on Asia, Aquaculture and Aquatic Resource Management, Asian Institute of Technology, 18pp.

Little D. C. and Satapornvanit K., 1996: Poultry and fish production- a framework for their integration in Asia, Aquaculture and Aquatic Resource Management, Asian Institute of Technology.

Lovell T., 1989: Nutrition and feeding of fish, Van Nostrnad Reinhold, New York, 260pp.

Jones A. B., Preston, N. P., and Dennison W. C., 2002: The efficiency and condition of oysters and macroalgae used as biological filters of shrimp pond effluent. *Aquaculture Research*, **33**, 1-19.

McMahon R. F., 1999: Invasive characteristif the freshwater bivalve *Corbicula* fluminea, in "Nonindigenous freshwater organisms, vectors, biology and impacts" (eds. by Claudi R. and Leach J. H.), CRC Press, LLC, pp.315-342.

Mitsch W. J. and Gosselink J. G. 200: Wetlands (3rd ed.). John Wiley & Sons, Inc. Canada.

Noeri, A., Shpigel M., and Ben-Erza B., 2000: A sustainable integrated system for culture of fish, seaweed and abalone. *Aquaculture*, **186**, 279-291.

Newell R. I. E., 1988: Ecological changes in Chesapeake Bay: Are they the result of overharvesting the Eastern oyster (Crassostrea virginica)? in "Understanding the Estuary: Advances in Chesapeake Bay Research" (eds. by . Lynch M. P. and Krome E. C.), Chesapeake Research Consortium Publication 129 (CBP/TRS 24/88), Gloucester Point, VA., pp. 536-546.

Newell R. I. E., 2004: Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: a review. *J. shellfish Res.*, **23**(**1**)

Nurdogan Y. and Oswald W. J. 1995: Enhanced nutrient removal in high-rate ponds. *Water Science and Technology*, **31**(**12**), 33-43.

Parker N. C. and Fedler C. B., 1996: Production of energy, aquaculture products and cattle from an integrated feedlot system, Second National Workshop Constructed Wetlands for Animal Waste Management, Ft. Worth, Texas, pp.15-18,

Racocy J. E., Losordo T. M., and Masser M. P. 1992: Recirculating aquaculture tanks production systems, integrating fish and plant culture, Southern Regional Aquaculture Center Publication, No.454, 8pp.

Racocy J. E. and McGinty A. S. 1989: Pond culture of Tilapia, Southern Regional Aquaculture Center Publication, No.280, 4pp.

Schwartz M. F. and Boyd C. E., 1995: Constructed wetlands for treatment of channel catfish pond effluents. *Progressive Fish Culturist*, **57**, 255-266.

Schwartz M. F. and Boyd C. E., 1998: Characterization and management of effluents from aquaculture ponds in the Southeastern United States, SRAC Final Project Report, Southern Regional Aquaculture Center, No.600, 42pp.

Sharpley A. N., 2000: Agriculture and phosphorus management: the Chesapeake Bay, Lewis Publishers, Boca Raton, 229pp.

SFWMD., 2001a: Everglades best management practices program, South Florida Water Management District, 51pp.

SFWMD., 2001b: Natural resource analysis of Lake Okeechobee phosphorus management strategies, Contract C－11677. Hazen and Sawyer Environmental Engineers and Scientists, 98pp.

SFWMD., 2002a: Lake Okeechobee Annual Report, South Florida Water Management District, 17pp.

SFWMD., 2002b: Evaluation of alternatives for the dairy best available technologies in the Okeechobee Basin, Soil and Water Engineering Technology Inc., 14pp.

Staver K. W. and Brinsfield R. B., 1998: Using cereal grain winter cover crops to reduce ground water nitrate contamination in the mid-Atlantic coastal plain. *Journal of Soil* *and Water Conservation*, **53**, 230-240.

Stone N., Parl E., Dorman L., and Thomforde H., 1997: Baitfish culture in Arkansas, Arkansas Cooperative Extension Program, Publication, No. MP386.

United Nations Environmental Programme (UNEP)., 1999: Planning and management of lakes and reservoirs: an integrated approach to eutrophication, International Environment Technology Centre, Technical Publication Series, 11.

Van Horn H. H., Newton G. L., Nordstedt R. A., French E. C., Kidder G., Graetz D. A., and Chambliss C. F. ,1998: Dairy manure management: strategies for recycling nutrients to recover fertilizer value and avoid environmental pollution, Circular 1016, University of Florida Department of Dairy and Poultry Sciences.