Evaluating the Relationship Between Semi-Intensive Aquaculture and Natural Biodiversity

Mitigating Negative Environmental Impacts/Activity/09MNE06UM

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The effects of aquaculture on biodiversity have been the subject of much examination, but most of the focus has been on two particular aquaculture systems: shrimp and salmon. However, these are not among the most common species grown in aquaculture, or the most common systems used. Many aquaculture systems use semi-intensive culture to produce fish at a lower level of intensity and use more natural systems, often in ponds or other containers. Semi-intensive aquaculture has a different potential impact than intensive aquaculture, and the specific impact in this area has not been well defined. The role of intensification in aquaculture and agriculture is the subject of much debate today, so this is a good time to consider the relationship between lower intensity aquaculture and biodiversity as a part of that debate. This symposium is proposed to identify and illustrate the main impacts of semi-intensive aquaculture on biodiversity, and to seek means of reducing these impacts of aquaculture expansion on organisms.

As a result of this symposium, a number of papers were prepared for the final publication. Originally we intended to do this in book form, but after some discussion with authors, publishers, and editors, we decided to publish them as a special edition of *Reviews in Aquaculture*. The decision on publishing venue delayed the completion of these reports beyond the planned date, but as of 15 December 2011, we have 7 of the manuscripts submitted to the journal and out for review, and there are 3 others that are still being edited. We also added one new plan for publication, which was to prepare a shorter version of the reports as a contribution from the group to *Science* or *Nature*. So far, we have drafted a version of this manuscript and it is in its second round of editing. That paper, which will be submitted to *Science* as a contribution to their Policy Forum, should be completed by January 15 and submitted then.

PAPERS PRESENTED

The Effects of Semi-Intensive Aquaculture on Biodiversity: In Nearshore And Inland Waters: An Overview

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The effects of aquaculture on biodiversity have been the subject of much examination, but most of the focus has been on shrimp and salmon. These are not among the most common species grown in aquaculture, nor the most common systems used. Many aquaculture systems use semi-intensive culture to produce fish at a lower level of intensity and use more natural systems, often in ponds or other containers. Positive impacts of aquaculture on biodiversity include cultured seafood reducing pressure on overexploited wild stocks, stocked organisms enhancing depleted stocks, increased production, and species diversity caused by aquaculture, and replacing more destructive resource uses with employment in aquaculture. Negative impacts of aquaculture include invasive species established by escapement from aquaculture, eutrophication from effluents, conversion of sensitive land, use of fishmeal, and transmission of diseases to wild fish. Some of these impacts, especially use of fish meal and transmission of disease, are much less common in semi-intensive aquaculture systems.

Integrated Multi-Trophic Aquaculture: Environmental Biomitigation and Economic Diversification of Fed Aquaculture by Extractive Aquaculture

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Integrated multi-trophic aquaculture (IMTA) seeks to engineer intensive fed aquaculture (e.g., finfish or shrimps) by biodiversifying it with extractive aquaculture of species utilizing the inorganic (e.g., seaweeds) and organic (e.g., suspension- and deposit-feeders) excess nutrients from fed aquaculture for their growth.

The combination fed/extractive aquaculture aims to biodiversify food production systems to provide both biomitigative services to the ecosystem and improved economic farm output through the co-cultivation of complementary species. Through IMTA, some of the food, nutrients and by-products considered “lost” from the fed component are recaptured and converted into harvestable and healthy seafood of commercial value, while biomitigation takes place (partial removal of nutrients and CO_2, supply of oxygen, and beneficial species interactions/controls). Some of the externalities of fed monoculture are internalized, hence increasing the overall sustainability, profitability and resilience of aquaculture farms.
A major rethinking is needed regarding the definition of an “aquaculture farm” (reinterpreting the notion of site-lease areas) and regarding how it works within an ecosystem, in a broader framework of Integrated Coastal Zone Management (ICZM). The economic values of the environmental/societal services of extractive species should be recognized and accounted for in the evaluation of the true value of these IMTA components. This would create economic incentives to encourage aquaculturists to further develop and implement IMTA. Seaweeds and invertebrates produced in IMTA systems should be considered as candidates for nutrient/carbon trading credits within the broader context of ecosystem goods and services.
Our research is also establishing appropriate performance measures regarding environmental mitigation by investigating the responses in wild species (microbial and higher trophic levels) inhabiting the surrounding environment to determine if they can be used as valid indicators of nutrient cycling for aquaculture operations. Measures of diversity, abundance, colonization rates and individual species health (e.g. growth, reproductive output, immune responses) are all potential indicators of how a farm may function with respect to nutrient loading. While organic loading has been associated with benthic impacts (e.g. anoxia and hydrogen sulfide release), there have also been occurrences of moderate enrichment, promoting localized increase in biodiversity and abundance of wild species, as a natural response to changes in nutrient availability and niche space utilization. Changes in the rates and conditions under which these influences occur have the potential to provide direction for aquaculture management and improved IMTA farm design. Long-term planning/zoning promoting biomitigative solutions, such as IMTA, should become an integral part of coastal regulatory and management frameworks.

Aquaculture Effluents and Water Pollution

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Aquaculture facilities typically discharge into natural waters. Their effluents are enriched with nitrogen, phosphorus, organic matter, and suspended solids because fertilizers and feeds are used to enhance production above natural productivity. Generally, 20 to 40% of nitrogen and phosphorus applied to ponds in feed is recovered in harvested fish. In shrimp ponds, phosphorus recovery is 10 to 15%, but nitrogen recovery is about the same as in fish ponds. Bottom soils adsorb phosphorus, and denitrification and ammonia volatilization also occur in ponds. Usually, less than 30% of nitrogen and 10% of phosphorus applied to ponds exits in effluent. In raceway culture, nitrogen and phosphorus in uneaten feed and feces can be partially removed before effluents enter natural waters. However, in cage culture, nitrogen and phosphorus not recovered in fish at harvest enters the

water body. Large aquaculture facilities or clusters of many small ones contribute considerable amounts of nitrogen, phosphorus, and certain other potential pollutants to receiving waters.

Aquaculture facilities contribute particularly to eutrophication of natural water bodies. Eutrophication is undesirable for other water users, but it also can be harmful to aquaculture facilities such as cage farms and shrimp farms that use the same water body as water supply and effluent recipient. Many countries have imposed regulations on aquaculture effluents. These may include limits on feed inputs, specifications for site selection, and effluent water quality standards. Aquaculture “eco-label” certification programs are being established in response to consumer demand for “environmentally-friendly” products. These programs may include effluent standards that limit discharge of nitrogen and phosphorus. Compliance with effluent regulations and “eco-label” certification program standards usually require installation of best management practices (BMPs) to limit discharge of nitrogen and phosphorus. Some examples of these BMPs are use of high-quality feeds that have no more nitrogen and phosphorus than required, conservative feeding practices, use of adequate mechanical aeration to oxidize waste in ponds, and discharge of effluent through a sedimentation basin. Some large producers also are voluntarily adopting BMPs independently of regulations or participation in “eco-label” certification. Studies of the environmental benefits of regulations, certification, and BMPs are few, but "responsible aquaculture" programs seem to be gaining popularity with seafood purchasers and consumers.

Transboundary and Emerging Diseases Of Freshwater Farmed, Ornamental and Wild Fish

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Aquaculture offers a solution to many of the food and nutrition security issues facing the growing human population. It bridges the gap between stagnating yields from capture fisheries and an increasing demand for fish and fishery products. It also offers opportunities to reduce poverty, increase employment and community development and reduce overexploitation of natural aquatic resources, thus creating social and generational equity, particularly in developing countries. Increased focus on aquaculture as solution to the demand and supply gap of aquatic products in the future will undoubtedly increase transboundary movement of live aquatic animals and their products. This carries an increasing biosecurity risk, particularly associated with introduction and spread of pathogens.

Transboundary aquatic animal diseases are highly contagious with strong potential for rapid spread irrespective of national borders. They pose a significant threat to the aquaculture sector and have major social, economic and environmental implications. These include loss of important animal protein source in human diet; direct and indirect impacts on output, income and investment; increased operating costs; restrictions on trade; impacts on biodiversity; loss of market share or investment; loss of consumer confidence; and in some cases, collapse of the sector. Managing aquatic animal health and biosecurity in aquaculture is particularly challenging because of the great diversity of the sector in terms of species cultured, the range of culture environments, the nature of containment, the intensity of farming practices and the variety of culture and management systems.

This presentation focusses on two transboundary and emerging/re-emerging freshwater fish diseases, epizootic ulcerative syndrome (EUS) and koi herpesvirus (KHV), which require focussed attention in the coming years to protect a major freshwater aquaculture sector from biosecurity emergencies. Freshwater aquaculture is the major contributor to “food fish” production; susceptible hosts to EUS and KHV rank amongst the world’s most important aquaculture species. These diseases are also important to the ornamental fish industry. The threats posed by EUS and KHV to freshwater farmed, ornamental and wild fish and freshwater resources are explored in this paper. Institutional responses and biosecurity measures to protect and prevent, two major lines of defence, against pathogen aggression, are also explored in this paper.

Applying Environmental Footprint Concept for Biodiversity Conservation in Semi-Intensive Aquaculture

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Aquaculture is of great importance worldwide, serving as an alternative source to traditional food production systems and helping supply the expansion of human population. Increase of global aquaculture production is achieved by intensification of farming systems, including increased farm size, material inputs, energy demands, and effluent discharge. The intensification has generated global concerns over its negative environmental impacts on the environment, aquatic ecosystems and human livelihoods in coastal areas. The negative effects of intensive aquaculture on biodiversity have been the subject of much recent debate. The debate is over whether semi-intensive aquaculture at a lower level of intensity and using more natural systems should be promoted to conserve biodiversity while still producing enough food. Thus, evaluation of environmental performance on different semi-intensive aquaculture systems is highly demanded. This overview examines impacts of semi-intensive aquaculture systems on biodiversity conservation from an environmental footprint perspective.

Environmental Performance

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In aquatic systems, as soon as feeds or wastes enter the water column, in situ mineralization occurs. The fraction of the produced wastes that is discharged depends on farm type, culture density, feed composition and water renewal rate. The effects of these factors on waste discharge are reviewed. All possible combinations of these factors result in large differences in the type and amount of waste products discharged to neighboring surface waters from aquaculture operations. Few farms discharge directly to a sewage system or operate an on-farm water purification system to deal with the discharged nutrients. Using a fraction of the otherwise discharged waste as an input for other cultures is possible, but also rarely practiced. In farms applying recirculating aquaculture system (RAS) technology and relying on nitrification and denitrification, nearly all wastes produced on-farm are mineralized, resulting in a stabilized sludge which represents on a dry weight basis 4 to 8% of the feed input. The semi-closed nature of RAS farms also minimizes the possible introduction and dissemination of diseases and parasites and the use of disinfectants and antibiotics. A small water exchange also reduces opportunities for culture animals to escape. With the exception of some extensive production systems, pond, cage or raceway operations discharge more nutrients and use more water per kg fish produced than RAS. The challenge is to make all future aquaculture farms equally efficient as RAS in dealing with waste discharge. This can be done by making aquaculture operations either more or less intensive. Each approach has its advantages and disadvantages and is reviewed in terms of water use, nutrient utilization and discharge, and energy use.

Antimicrobial Use In Aquaculture And Microbial Diversity

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Antimicrobials are widely used in salmon aquaculture. This use in the aquatic environment can potentially decrease bacterial diversity by eliminating susceptible organisms and simultaneously selecting for resistant ones. These effects and the emergence of antimicrobial resistant bacteria are directly linked and proportional to the amounts of antibiotic used in a particular geographical location. Studies of salmon aquaculture in Chile strongly indicate that the amounts of some antimicrobials, including tetracyclines, quinolones, and florfenicol, used in this industry are larger than those used in human medicine and other veterinary activities. This use in salmon aquaculture makes it the most important current and future selective pressure on the development of antimicrobial resistance in this country. Studies of sediments from salmon aquaculture-impacted and non-impacted sites indicate that these sediments appear to contain sufficient amounts of antimicrobials to exert selective pressure upon the bacteria contained in them.

Molecular analysis of bacteria isolated from these sediments has revealed that their genomes contain a variety of antimicrobial resistance genes coding for resistance to tetracycline, quinolones and florfenicol. These resistant bacteria can be selected in vitro, and probably in situ, by the presence of residues of antimicrobials in the sediments. The occurrence of some of these genes in genetic elements such as integrons, coupled to the presence of residual antibiotics in the sediment, also indicate that the potential exists for dissemination of these resistance determinants among bacterial populations by horizontal gene tranfer. This potential ability is consistent with information indicating that bacteria from aquatic environments and terrestrial environments including human pathogens share antibiotic resistance determinants and the mobile genetic elements harboring them.
In summary, injudicious use of antimicrobials in aquaculture decreases bacterial diversity, selects for bacteria resistant to these antimicrobials and is associated with potentially negative impacts on piscine and human health.

Primary Questions Of Nutritional Physiology That Would Combine The Whole Life Cycle In Culture Of South American Pseudoplatystoma Destined For Conservation And Industrial Purposes

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The genus Pseudoplatystoma contains eight species of catfishes, and they belong to largest migratory species in South America. These species have been decimated in the wild due to overfishing and environmental changes affecting their reproduction. They attract commercial interests, both for industrial culture and ornamental trade. We summarize the current understanding of the nutrition related physiology of these species, identify shortcomings and suggest further research. Examination of the olfactory system in early ontogeny suggests that larvae are nocturnal and are guided by their sensory system in feeding. We have concluded that larval catfish grown solely on Artemia naupli outperform fish offered formulated diets and live Tubifex, although cannibalism was lower in fish fed purified dipeptide based diets. To evaluate the protein and lipid requirement of Pseudoplatystoma, nine semi-purified casein-gelatin-lecithin based diets containing three levels of protein (40-50%) and three levels of lipid (12-20%) were tested. Juvenile fish were fed at a restricted-readjusted feeding rate for 8 weeks. The diets resulted in an average body weight increase of 21.2 ± 2.9 fold. The feed conversion ratio was affected by the dietary lipid level. At the 40% protein level, increasing the level of dietary lipid had a positive effect on final weight (protein sparing effects). Whole body protein and moisture contents were affected by the dietary level of lipid. Ash content was not affected by the dietary protein/lipid levels whereas several mineral levels, Na, K, B, and Mn were affected. Whole body lipid content positively correlated with the level of dietary lipid. Fatty acid composition of the whole body was affected by the dietary lipid level in the case of both neutral and phospholipids. Polyunsaturated fatty acids increased with increasing levels of dietary lipid while saturated fatty acids decreased. Our preliminary results suggest that surubim can utilize a high level of dietary lipid, and the optimum protein/lipid ratio might be close to 45/16%. We also used a stable isotope labeled amino acid (15N) to examine differences in the protein turnover ratio among groups fed diets with distinct levels of proteins/lipids. Studies on effect of broodstock feeding were inconclusive as a protein level in the range of 28 to 40% did not appear to affect gonad maturation. No viability of eggs was examined as a result of the variability in the composition of the diets. We ultimately discuss the implications of these findings for further expansion of the management programs, aquaculture and aquarium trade.

The Social and Economic Impacts of Semi-Intensive Aquaculture on Biodiversity

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As aquaculture has become more intensive, so have its impacts on the environment and biodiversity. There is growing concern and debate about the impacts of intensive aquaculture on biodiversity. As a

result, semi-intensive aquaculture is being considered as an alternative since it will have different and lesser potential impacts than intensive aquaculture and use more natural systems. The biophysical impacts of aquaculture on biodiversity have been examined but there is only limited understanding of the social and economic impacts, especially in a shift from intensive to semi-intensive aquaculture systems. Aquaculture can provide improvements in quality of life through employment and income; however it can also have negative impacts as a result of environmental damage, changes in property ownership patterns, displacement of traditional users, and economic losses. This paper will examine the social and economic impacts of moving from intensive to semi-intensive aquaculture systems, especially in developing countries. Recommendations will be presented on how to minimize social and economic disruptions from lower intensity aquaculture and on biodiversity.

Aquaculture For The Conservation Of Native Fish Species In Southeastern Mexico

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Populations of native species of fish have been severely depleted in Southeastern Mexico, particularly in the State of Tabasco where the consumption of fish is culturally a tradition. Exploitation is intensive in those species with high values in the market; snooks, tropical gars and native cichlids are highly appreciated in the region, increasing the fishing pressure as human population rises. Tabasco is located in a very large floodplain and human activities – such as cattle ranching and agricultural practices- have turned vast areas of wetlands into ranches or farming land. This loss of environments for feeding, spawning, or hiding have also impacted fish populations. In Mexico, aquaculture has focused mainly in the production of introduced species, been tilapias, carps, rainbow trout, and shrimps the main species cultivated. In our region tilapia and shrimp culture are the center of attention. However, in our laboratory, since 1985, we initiated studies regarding the biology and ecology of native species aiming to generate enough information in order to propose aquacultural practices. To date, we have generated the complete technological package for tropical gar (Atractosteus tropicus) culture. Regarding the freshwater cichlids castarrica (Cichlasoma urophthalmus), tenguayaca (Petenia splendida), and paleta (Vieja synspilla), we have partly generated the culture cycle in captivty, but more research is needed for culture systems and diets. Our latest incursions are with three species of snooks, (Centropomus undecimalis, C. parallelus, and C. Poeyi). So far, we have successfully induced spawning, but feeding of the larvae is still a problem. Few experiments regarding growth have been implemented and more research is needed regarding this group of fishes. In our laboratory we produce a small amount of juveniles of tropical gar (200,000) and native cichlids (300,000) per year. Most of them are used for grow-out, but part of the production is used for re-stoking in areas where populations have been depleted. Genetic variability is taking into account by using broodstock from different areas of the region. With the native cichlids, we have compared reproductive performance and growth in captivity using lots from four different areas. Our extension efforts have focused on technology transfer using workshops and direct training in the field, regarding larval production and growth of gars and cichlids. Many local farmers prefer the use of native species in their farms, but research is needed to significantly improve the culture of these fish in order to compete with tilapias.

Understanding the Basic Biology and Ecology of Invasive Nile Tilapia: The Role It Plays in Sustainable Aquatic Biodiversity

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Sustainable aquatic biodiversity is a complex process of understanding species physiological and behavioral capabilities, how these species respond to a non-native environment and its fauna, the economics associated with aquaculture, and social and philosophical realities. Herein we review our experience with an established population of Nile tilapia (Oreochromis niloticus) in coastal Mississippi. We set our review in context with other aquaculture, ballast water and aquarium trade introductions, some of which have trivial influences whereas other have significant influences on coastal and freshwater environments and native fauna. We argue that development of a complete understanding of the basic biology of aquaculture species is imperative to proactively protect aquatic biodiversity. To have real "responsible" aquaculture requires tradeoffs between establishment of appropriate best management practices to protect the environment and its native fauna balanced with the economics of industry growth.

Tilapia And Aquaculture: A Review Of Management Concerns

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The demand for seafood coupled with the decline of fisheries species worldwide due, in part, to overfishing and habitat degradation has resulted in an increase in land-based and offshore aquaculture facilities. Globally, tilapia are very important aquaculture species with China, Philippines, Taiwan, Indonesia, and Thailand responsible for nearly 76% of the total worldwide production. The United States is a major importer of tilapia products and within the United States, tilapia production has continued to grow since the early 1990s with Oreochromis aureus, O. mossambicus, O. niloticus, and various hybrid combinations of the three being the primary aquaculture forms. Thus the potential for the introduction and establishment of feral populations of tilapia has increased following this growth in aquaculture interests. Wild-caught individuals of the primary aquaculture forms have been documented in 27 states (USGS NAS) with populations established in 14. Similarly, commercial tilapia production has been reported in 20 states (2007 Census of Agriculture; American Tilapia Association, Fitzsimmons pers. comm.) with 10 of those (AZ, CA, CO, FL, ID, LA, MS, NC, PA and TX) also having established populations of feral tilapia. Six states (AL, AR, MA, NM, NY, and WI) have reports of wild-caught tilapia but no established populations and the remaining four states (IA, MN, MO, and VA) have no reports of wild-caught tilapia. National management recommendations and policies for regulating many non-native taxa exist; however in the case of tilapia and their ties to aquaculture, permitting requirements, and regulatory jurisdiction varies among states such that unified management policies are unattainable. Several states have imposed special restrictions on tilapia aquaculture facilities to minimize the potential of escape (screened effluent, sterilized effluent, culture ponds encircled by levees) while others force accountability for releases through monetary means (insurance bonding). There are few if any requirements in place to provide protection against natural disasters (flooding, hurricanes) although emergency management plans are advocated by nearly all regional and national policy advocates.