# AquaFish CRSP Symposium on the effects of semi-intensive aquaculture on biodiversity in nearshore and inland waters at the 141st Annual Meeting of the American Fisheries Society

Seattle, Washington, USA
8 September 2011

Symposium Organizers: Hillary S. Egna and Jim Diana

**Proceedings**

Assembled by Stephanie Ichien
Edited by Hillary S. Egna
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# AQUAFISH CRSP SYMPOSIUM PROCEEDINGS

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**Disclaimers**



**Cover Photo**

On the day of the CRSP Biodiversity Symposium, invited speakers and organizers posed for a group picture. In front: Marc Verdegem and Hillary Egna. Standing from left to right: Bob Pomeroy, Claude Boyd, Mark Peterson, Felipe Cabello (front), Jim Diana, Thierry Chopin, Todd Slack, Ling Cao, Maria Portella, Konrad Dabrowski, and Wilfrido Contreras-Sanchez. Photo By Stephanie Ichien

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# INTRODUCTION

**Symposium Organizers**
Dr. Jim Diana and Dr. Hillary Egna
**Symposium Sponsor**
Aquaculture & Fisheries Collaborative Research Support Program

ABSTRACT
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.

# RESPONSIBLE AQUACULTURE BY 2050: VALUING LOCAL CONDITIONS AND HUMAN INNOVATIONS WILL BE KEY

This co-authored paper was developed collarboatively as a result of this symposium.

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Aquaculture is an ancient method of food production, with early examples stemming from 2500 B.C. in China, murals depicted on the pyramids in Egypt, and images from the Roman Empire. Like most food production systems, it has changed dramatically since its inception. However, unlike agriculture, most of its growth and intensification has occurred within the last 30 years. Aquaculture has grown 3 times faster than agriculture, at an amazing rate of 8.3% per year since 1970 (*1*). Aquaculture presently provides 45.6% of the world's seafood production, and it is estimated that by 2012, more than 50% of global consumption of seafood (including aquatic plants and animals) will originate from aquaculture.

While capture fishery yields remain stable or even decline, aquaculture yields continue to rise. World population has reached 7 billion and will continue to grow beyond 9 billion in 2050 (*2*). At current consumption rates, 50% more seafood will be needed by 2050 in order to provide comparable seafood consumption for this expanding population. Even this amount of increase will not dramatically affect overall food security, as about 5 billion additional tons of food will be needed by 2050 (*2*). Much of aquaculture expansion to date has followed the agricultural line of increased intensification and has been criticized widely for its role in damaging ecological systems (*3*). Some of these negative impacts include the introduction of exotic species, diseases, and parasites, as well as polluted effluents (*1*). The degree of environmental impact resulting from the aquaculture industry has been heavily debated and remains contentious (*4*).

As aquaculture production expands, it is paramount that we avoid mistakes made in the increased intensification of agriculture during the Green Revolution. Thus, understanding both the environmental impacts and mitigation measures (*5*) is important for designing responsible aquaculture production systems for tomorrow and transforming the Blue Revolution to a greener Turquoise Revolution (*6*).

The intensity of inputs passing through aquaculture systems varies. Extensive systems, which basically stock young organisms and allow them to grow naturally, are at one extreme, whereas very intensive systems with high stocking and feeding rates are at the other. Most of the concerns expressed about aquaculture have focused on shrimp and finfish cultured at the higher end of this continuum. However, less than 40% of aquaculture today is of an intensive nature (*7*); that is, occurs at a level mainly associated with real or perceived environmental, economic, or societal issues. As crops increase in value, low intensity systems have been continually updated until reaching high production intensity. Thus, aquaculture is in a continual state of change as new methods and technologies allow for higher rates of production per unit area. This continuum is important to recognize, and intensification is most likely to continue in the decades ahead. No ideal level of intensity is uniformly acceptable when all impact parameters are considered, hence the rising interest in employing life cycle assessment in order to fully understand the environmental performance of each production system (*8*). How intensity is managed and how an ecosystem approach is built into the management design are the most important factors affecting aquaculture's sustainability.

Given its current growth rate, increasing intensity, and higher environmental performance such as the use of zero water exchange or multi-trophic systems (*9,* see Fig. 1), aquaculture is evolving quickly into a new phase. With the target continually moving, we need to make decisions rapidly on which types of aquaculture systems and management practices to implement. Several organizations have been involved in trying to define best management practices (BMPs) for a range of cultivated aquatic species. Using realistic information from farmers, as well as from the research and policy community, these organizations attempt to make decisions on BMPs that should be part of future aquaculture programs.

We, as a collective group of authors, have studied diverse aquaculture species under a range of conditions and in a variety of countries for long periods of time. It is evident that there is no single method of growing a particular species in these countries; instead, there is a wide variety of techniques. It is also obvious that the current production systems are not always well managed, and much more food could be produced by simply improving management practices, regardless of the scale of aquaculture operations. This is not a dramatic revelation to aquaculture extension professionals in most countries, as they are already involved in outreach to producers in an attempt to improve management of aquaculture systems. Technology has been developed to a level where major improvements could be made by farmers simply adopting new production practices without increasing intensity of the aquaculture grow-out operation. Even low intensity farms can be improved in terms of management practices for both production efficiency and environmental performance (*10*).

One challenge in disseminating information about better management methods involves local decision making and human capital available. Within a country, most information is transferred on aquaculture technology by local communication among people who are in the process of growing the same crop. This farmer-to-farmer exchange far outweighs the effort dedicated by government outreach organizations or academic institutions, and the local dissemination of knowledge on production systems may be well integrated into new management technology or dominated by old technology. Since production methods rely on local environmental conditions, it would be impractical to have one common technology applied in all locations even within one country. Human capital, including the level of education, training, and innovation, combined with availability of local resources is what makes aquaculture succeed. These characteristics are also important determinants of the ecological efficiency of aquaculture. For example, local food sources for a particular organism may vary considerably, based on agriculture byproducts available, and feed is the major cost of most aquaculture systems.

Since local stakeholders are critical in the understanding of what leads to aquaculture success, they must be involved in policy and regulatory decisions. The collective action of farmer organizations can be an effective assistance mechanism, especially for small-scale producers, in overcoming the challenges and facing the opportunities offered through aquaculture (*11*). Well-defined individual or collective rights (property, access, human, labor) would act as incentives for private and public promoters of aquaculture development to plan their activities with a more secure and informed basis for decisions. Also, many small-scale actions taken individually (such as choosing a location to build ponds) can aggregate into larger actions with greater environmental impact.

Because success of aquaculture operations is dependent on local conditions, this presents a dilemma for management organizations and policy makers as they consider applying large-scale standards to the industry. This is complicated further by the fact that we cannot attribute environmental damages of aquaculture to intensity alone. Therefore, even promoting a particular level of intensity for aquaculture of a given species would be difficult. There are no silver bullets available to make aquaculture systems magically sustainable; instead, there are many practices that could, in combination, be more sustainable, profitable, and environmentally neutral. The key then is flexibility to allow for the best mix of local resources and human capital to fit aquaculture while reducing or eliminating negative environmental impacts, all based on a few guiding principles most often rooted in common sense.

This flexibility is important in another regard, i.e., the future of aquaculture production. About 40% of aquaculture currently occurs in coastal marine and brackish water. These areas are also locations where great uncertainty exists related to climate change, water levels, storm frequencies, and human population growth. Flexibility will be very important for aquaculture to adapt to future climate scenarios, not only in production systems and species, but also in capital investments in facilities, as many could be damaged or destroyed by the predicted rise in sea level as well as storm size and frequency.

The future of aquaculture should be bright, and its responsible growth is imperative for humans to secure their food supply. Many of the environmental impacts of aquaculture are being effectively addressed. For example, the reliance on fish meal in feeds has been reduced to 15% for many carnivorous species by replacement with plant-based protein or other feed sources (*12*), brought about by environmental and economic concerns. Another example is the development of biomitigative approaches, such as integrated multi-trophic aquaculture, which is based on co-cultivating in proximity organisms selected purposely at different trophic levels for their complementarity in ecosystem functions and services (*13*). As well, a number of risk-management measures are being applied, all aimed at enhancing the two lines of defense against pathogens: protection and prevention. These include effective biosecurity governance through national strategies and regulatory frameworks, compliance with international standards of aquatic animal health, vaccination, prudent use of veterinary medicines, effective on-farm biosecurity, and active disease surveillance (*14*). These changes have occurred largely as a result of farmers adapting to challenges from the environmental community as well as to their own production regimes and have often preceded government regulations. Current regulations must be amended at a faster pace to be relevant and efficient and not perceived as impediments to the evolution of practices.

Certification of aquaculture products, BMPs decided upon by groups of farmers and environmentalists, inter-disciplinary research and government involvement in outreach to design and implement more responsible aquaculture systems have combined to make major improvements in environmental performance. However, products from more sustainable aquaculture systems are poorly differentiated in the market, and consumers cannot easily make decisions on which products to buy. For many commodities, the future of terrestrial food production appears grim, based on limited land, water, and other resource inputs into agriculture, while the future looks promising for aquaculture. There are large areas of the ocean, as well as coastal and inland waters, still suitable for aquaculture production. However, expansion to these regions must be done using more sustainable practices in order to eliminate introduction of invasive species by aquaculture, as well as to provide an environment with good water quality, low incidence of diseases, and normal rates of sedimentation (*1*). For the ever-growing human population to be able to secure its food, it has no alternative but to change its business models to develop efficient food production systems that consumers will trust as being sustainable and providing healthy products.

By 2050, seafood will be predominantly sourced through aquaculture products. These may not be mainly finfish, as seaweeds, invertebrates, and their derived products will become an increasing part of our diets, especially in the western world. Will we be ready to evolve in our use of this planet's "last frontier" and finally deal with the concept of marine spatial planning in coastal and offshore waters where aquaculture operations will move in the future? Ultimately, it will come down to the basic question of societal acceptance.

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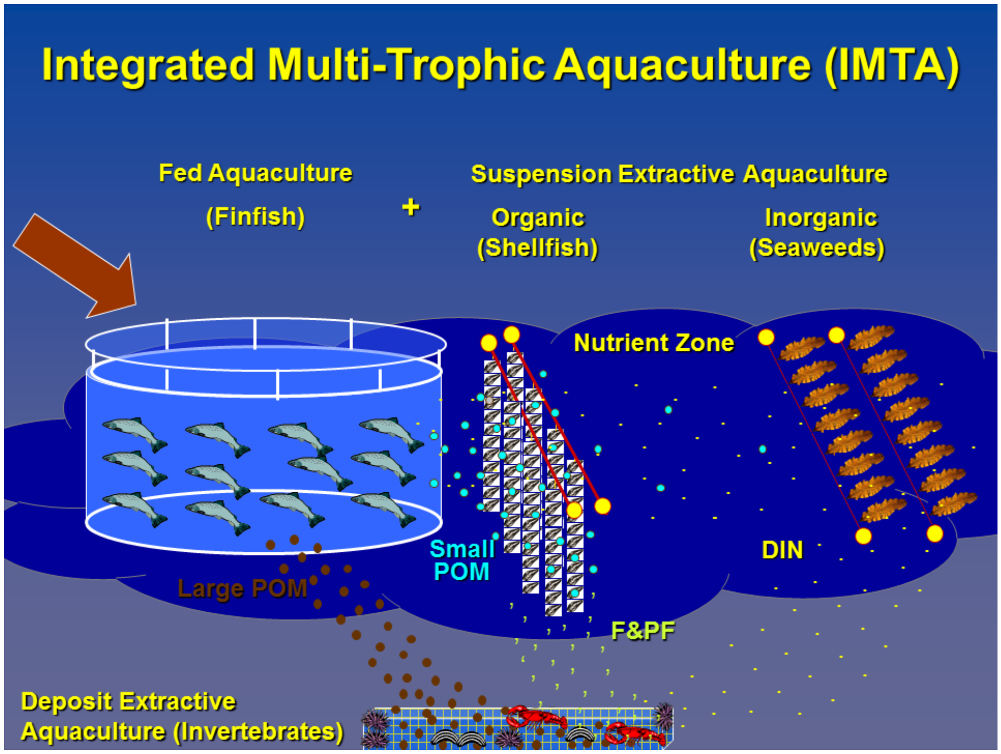
A.

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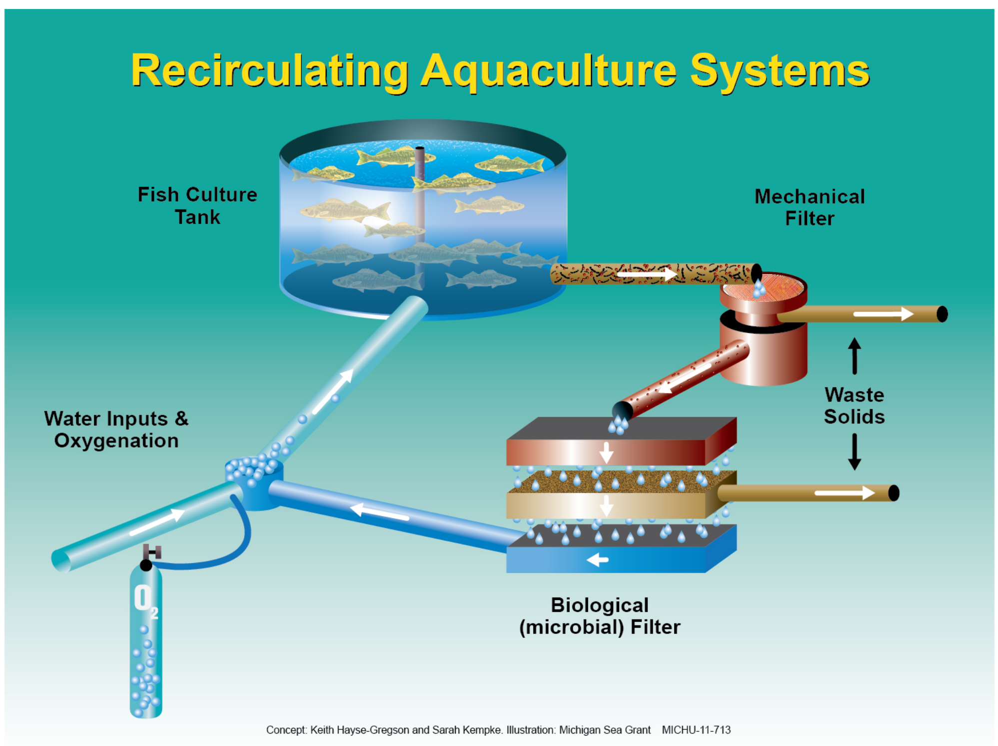


**Figure 1.** Two modern and responsible aquaculture systems: A. Integrated Multi-Trophic Aquaculture (IMTA) systems and B. Recirculating Aquaculture Systems (RAS).

# SYMPOSIUM AGENDA

**Moderators:** James Diana and Hillary Egna

1:15 PM

**The Effects of Semi-Intensive Aquaculture On Biodiversity In Nearshore and Inland Waters: An Overview**
James Diana, University of Michigan

1:30 PM

**Integrated Multi-Trophic Aquaculture (IMTA): Biodiversifying fed fish aquaculture with extractive seaweed and invertebrate aquaculture to provide both biomitigative services and diversified seafood production**
Thierry Chopin, University of New Brunswick; J. Andrew Cooper, Department of Fisheries and Oceans; Gregor Reid, University of New Brunswick; Shawn Robinson, Department of Fisheries and Oceans

1:45 PM

**Aquaculture Effluents and Eutrophication**
Claude Boyd, Auburn University

2:00 PM

**Transboundary and Emerging Diseases of Freshwater Farmed, Ornamental and Wild Fish**
Melba G. Bondad-Reantaso, PhD, Food and Agriculture Organization of the United Nations;Rohana P. Subasinghe, PhD, Food and Agriculture Organization of the United Nations;Hang'Ombe Bernard Mudenda, DVM, University of Zambia

2:15 PM

**Applying Environmental Footprint Concept for Biodiversity Conservation In Semi-Intensive Aquaculture**
Ling Cao, University of Michigan

2:30 PM

**Environmental Performance**
Marc Verdegem, Wageningen University; Ep H. Eding, Ing., Wageningen University

2:45 PM

**Antimicrobial Use In Aquaculture, Microbial Diversity and Antimicrobial Resistance**
Felipe Cabello, New York Medical College

Afternoon Break

3:30 PM

**Primary Questions of Nutritional Physiology That Would Combine the Whole Life Cycle In Culture of South American Pseudoplatystoma Destined for Conservation and Industrial Purposes**
Konrad Dabrowski, The Ohio State University;Maria Celia Portella, PhD, Sao Paulo State University; Murat Arslan, Ataturk University;Michal Wojno, The Ohio State University; Marcos A. Cestarolli, PRDTA Centro Leste/DDD/SAA

3:45 PM

**Social and Economic**
Robert Pomeroy, University of Connecticut-Avery Point; Madan Dey, University of Arkansas at Pine Bluff

4:00 PM

**Aquaculture for the Conservation of Native Fish Species In Southeastern Mexico**
Wilfrido Contreras Sanchez, Universidad Juárez Autónoma de Tabasco

4:15 PM

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

Mark S. Peterson, PhD, University of Southern Mississippi; William T. Slack, PhD, US Army ERDC

4:30 PM

**Tilapia and Aquaculture: a Review of Management Concerns**

William T. Slack, PhD, U.S. Army Engineer Research and Development Center; Mark S. Peterson, PhD, University of Southern Mississippi

4:45 PM

**The Effects of Geoduck Aquaculture Practices on Habitat and Trophic Dynamics of Nekton and Macroinvertebrates in Puget Sound**

P. Sean McDonald, PhD, University of Washington; Aaron Galloway, University of Washington; Jenny Price, University of Washington; Kate McPeek, University of Washington; Dave Armstrong, PhD, University of Washington; Glenn VanBlaricom, PhD, University of Washington

## THE EFFECTS OF SEMI-INTENSIVE AQUACULTURE ON BIODIVERSITY IN NEARSHORE AND INLAND WATERS: AN OVERVIEW

*James Diana, University of Michigan*

**Abstract**
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 fishmeal and transmission of disease, are much less common in semi-intensive aquaculture systems.

# Is semi-intensive aquaculture a valuable means of producing food? An evaluation of its effects of on biodiversity in near shore and inland waters

James S. Diana
University of Michigan

*Funding for this research was provided by the*

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## Positive Impacts on Biodiversity

1. Production of high quality food
2. Conservation aquaculture
3. Cleaning natural waters by filtering or consumption of natural materials
4. Reducing pressure on wild stocks
5. Replacing more damaging forms of employment with more sustainable aquaculture jobs.

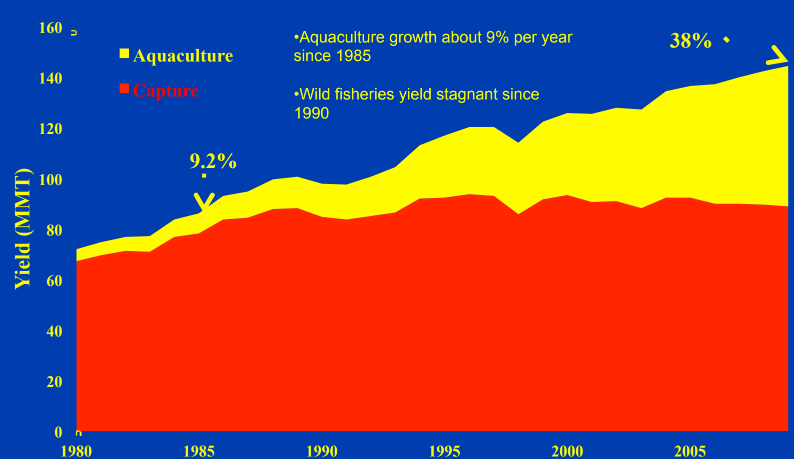
## Impacts that damage biodiversity

1. Escapement of invasive alien species
2. Eutrophication of receiving waters
3. Release of parasites and diseases into natural communities
4. Genetic alteration of natural stocks
5. Land conversion for pond construction
6. Release of antibiotics and drugs into receiving waters
7. Use of natural resources like water and fishmeal
8. Loss of benthic biodiversity from settling of sediments
9. Collection of larval fish from natural populations.

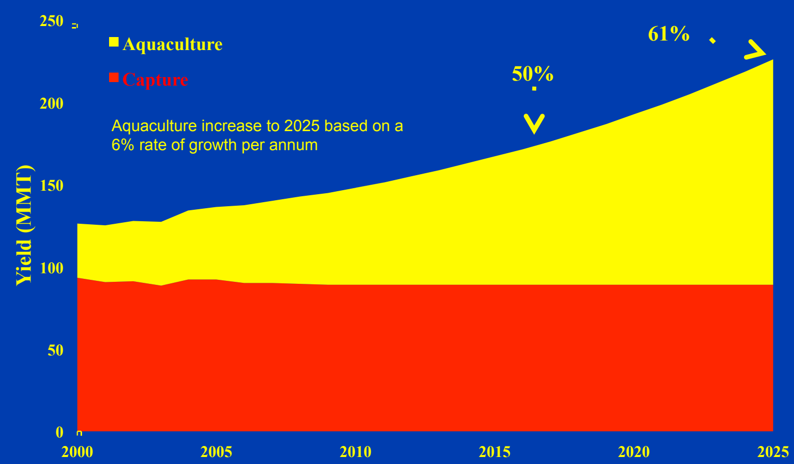
# Why aquaculture?

- Future potential - fastest growing food production system globally at about 9% increase per year since 1985
  - Can either exacerbate or reduce pressure on wild fisheries
- New technology - increasing number of new species and new innovations
- Future needs- FAO forecasted global increase in seafood consumption of 1.5 kg/person, along with population growth of 3 billion, while wild catches remain static at best
- Value to economy and social equity
  - Seafood generates much food and exports generate considerable income for developing countries
  - Jobs are dispersed and rural, promoting social stability and safe employment

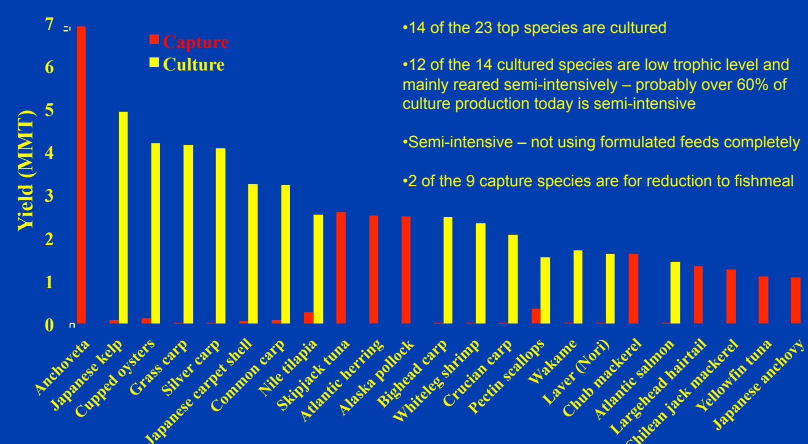
# Positive impacts – 1. Food production



# 1. Future Trends in Seafood Production

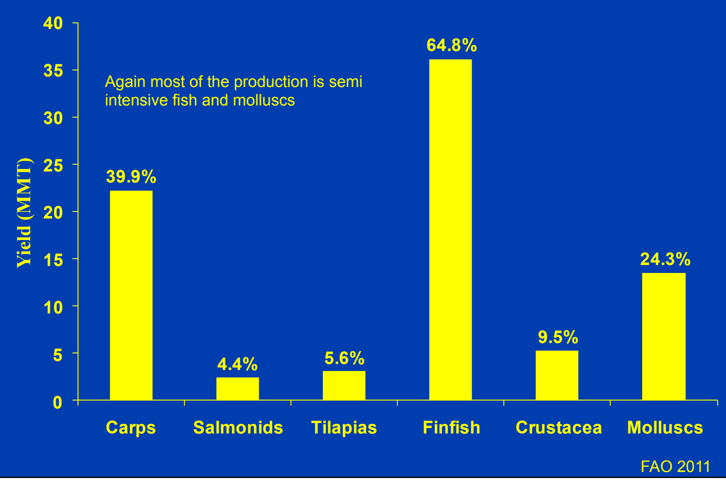



# 1. Top 23 Species Produced Globally

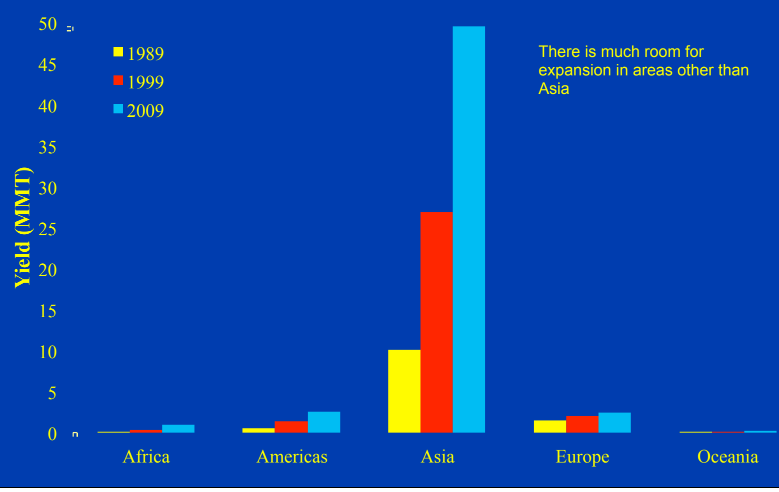



- 14 of the 23 top species are cultured
- 12 of the 14 cultured species are low trophic level and mainly reared semi-intensively – probably over 60% of culture production today is semi-intensive
- Semi-intensive – not using formulated feeds completely
- 2 of the 9 capture species are for reduction to fishmeal

# 1. Proportional culture of species in 2009




# 1. Changes in culture production (MMT)



## Positive impacts – 2. Restoration

- Commonly used in many areas for management of declining or endangered species
- Volunteer programs – crab bank, giant clams

Razorback sucker hatchery

Crab bank sites in Thailand

## Positive impacts – 3. Cleaning waters

- Seaweed and bivalve culture can remove nutrients and organisms from water systems
  - Used for aquaculture cleanup or human pollution

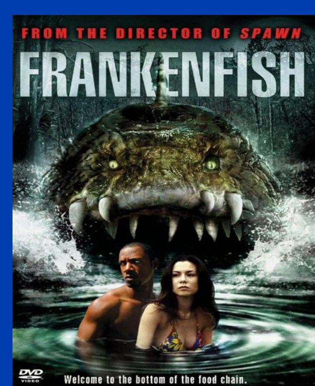
# Negative Impacts – 1. Invasive species

- Tilapia is poster child
- More than half of documented introductions were not result of aquaculture but natural stocking (Canonico et al. 2005)
- Many species also spread by aquarium trade and dumping


# Negative Impacts – 1. Invasive species

- Factors limiting escapee impacts
  - Most fish have been little domesticated; that is, they are essentially wild fish

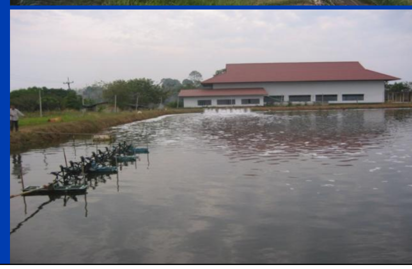
GMO Atlantic salmon




Mutant fish specially bred and inadvertently released by government scientists

## Negative Impacts – 1. Invasive species

- Escapement is inevitable with aquaculture species in almost any system
- Best avoidance is not culturing outside of native or common current range
  - Opposite of terrestrial trends

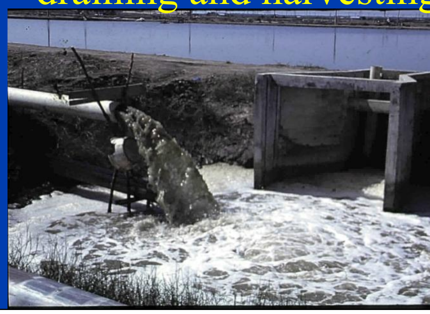


## Negative Impacts – 2. Effluents

- Common concern in cages/pens
  - In oligotrophic waters, actually seems to increase biodiversity
  - Major damages especially in freshwater cage culture
- We rely on the assimilative capacity of waters as an important ecosystem service

## Negative Impacts – 2. Effluents

- Effluents can also be a concern in ponds too, but mainly for intensive culture
- May be remediated by plant co-culture or by draining and harvesting techniques



## Negative Impacts – 3. Parasites

- Krkosek et al. 2007 - transmission of sea lice
  - "if outbreaks continue, then local extinction is certain, and a 99% collapse in pink salmon abundance is expected in 4 salmon generations" (by 2012)
- Predictions controversial, with other studies showing minimal mortality from sea lice
- Most likely will remain a problem in aquaculture
  - Again more common in dense, intensive culture systems

# Role of semi intensive aquaculture?

- Less damaging than intensive in most categories
- Definitely need all sorts of systems to produce food for the future
- All forms of aquaculture must adapt (and are adapting) to reduce damages from production
- We need to recognize this role in food production and better understand all systems, particularly small scale ones in the developing world

# Is Semi-Intensive Aquaculture a Valuable Means of Producing Food? An Evaluation of its Effects on Biodiversity in Near Shore and Inland Waters

James S. Diana
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**Abstract**
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. Over 60% of production today uses semi-intensive culture to produce organisms at a lower level of intensity with more natural systems like ponds. The ranked positive impacts of semi-intensive aquaculture on biodiversity include production of high quality food, supplementing reproduction in natural populations, cleaning natural waters by filtering or consumption of wastes, reducing pressure on wild stocks by providing alternative sources in the market, and replacing damaging employment with more sustainable aquaculture jobs. Negative impacts include escapement of alien species which become invasive; eutrophication of receiving waters, release of parasites and diseases into natural communities, escapement resulting in genetic alteration of native stocks, land conversion, release of drugs into receiving waters, use of water, loss of benthic biodiversity from settling of sediments, and collection of larval or juvenile fish from natural populations. Some of these impacts, especially use of fish meal and transmission of disease, are much less common in semi-intensive aquaculture systems. Aquaculture has an important role in current and future food production, and in most cases semi-intensive aquaculture provides a more sustainable solution to increased aquaculture production.

**Introduction**
Human population growth continues, and forecasts indicate a global population of about 8.9 billion in 2050 (Cohen 2003). This increase of nearly 3 billion since 2005 will require 70% more food production to feed the increased population as well as to adequately feed people who are currently underfed or eat nutritionally deficient diets (FAO 2009). While seafood is only responsible for a small fraction of today's caloric consumption, it is an important animal crop with high protein content and other nutritional advantages. Aquaculture is the only increasing sector for seafood production, and the fastest growing of all food commodities, with an average growth rate of nearly 9% since 1985 (Diana 2009). The role of aquaculture in feeding the hungry in the future is controversial, as some see aquaculture as a polluting and environmentally-degrading food production method (Naylor et al. 2000, Ford and Myers 2008), while others see it as an efficient, expanding, and important means to produce more food in a relatively sustainable manner (Costa-Pierce 2010). The purpose of this overview is to evaluate the positive and negative effects of semi-intensive aquaculture on biodiversity, as a lead in to the series of publications resulting from a symposium on the same topic held at the annual meeting of the American Fisheries Society in September 2011. The papers that follow will provide richer details on many of these effects.
Aquaculture systems vary in the types of containment used, effluent produced, and inputs required (Pillay 1993). Aquaculture has been categorized into extensive, semi-intensive, and intensive methods based on inputs and stocking densities, with intensive relying on formulated feeds and organisms stocked at high densities, semi-intensive relying on fertilizers or nutritionally incomplete fodders and organisms at moderate densities, and extensive relying on natural production and organisms at low density. The boundaries between these types are not clear, so here the focus will be on systems of lower intensity which do not use formulated diets at high input rates to completely feed the crop. Much of the criticism of aquaculture has been directed at very intensive systems like shrimp culture in ponds or salmon culture

in cages (Naylor et al. 1998), which are examples of the intensive methodology. Most global production in aquaculture comes from less intensive means, although direct statistics on proportions are lacking. Costa-Pierce (2010) estimated that only 40% of annual production was derived from aquaculture which used formulated feeds. Verdegem and Bosma (2009) estimated the global average aquaculture production in 2004 derived from ponds alone to be 25.3 million tonnes (MT), representing 56% of the 45.5 MT produced that year (FAO 2010a). They also estimated the average production levels for these ponds were from 3,000 kg/ha in freshwater to 7,530 kg/ha in brackish water in China, also indicative of mainly semi-intensive systems. Both of these estimates demonstrate that semi-intensive production is the most common method of aquaculture production today, probably accounting for over 60% of production. There remains additional controversy among proponents of aquaculture expansion on the best type of system that should be developed to meet future demands. If one bases best type on the degree of land use or production per unit area, then intensive systems should be developed for future needs (Marra 2005, Duarte et al. 2009). However, if one evaluates best type on effects of the system on receiving waters, or energy demand of the crop, then lower intensity systems should be developed (Diana 2009, Costa-Pierce 2010). I think both types of production will be necessary and important in the future, and the environmental performance of each can be improved as well. Many less intensive systems function much like artisanal fisheries for poor people in developing countries; they provide an opportunity to produce food mainly for their own consumption, and possibly for some income as well (Diana 2009, Hall et al. 2010). Thus, lower intensity systems have importance beyond the absolute quantity of crop produced, as they also help to solve some poverty and food security issues. The best means to help in poverty, food security, and the environment is to consider current systems utilized by small scale farmers and to do research and extension on those systems so that the most sustainable and profitable ones can be encouraged. Development projects have often failed because they do not consider the role of local people, along with the beliefs and social constraints that affect their adoption of new systems (Rogers 1995, Schwantes et al. 2009). A far better means of intervention is to consider the small-scale systems already in place in various locations (which are mainly semi-intensive), and to help adapt them for future use.

Numerous authors have evaluated aquaculture and its expansion and have produced rankings of various positive and negative effects of aquaculture on the environment and biodiversity (Egna et al. 1997, Boyd 2003, Boyd 2005 et al., Diana 2009, Duarte et al. 2009, Costa-Pierce 2010, FAO 2010b). These categories include both direct effects, like the release of invasive fish into natural waters or the eutrophication of waters, and indirect effects, like water and energy use or changes in the means of livelihood for local people. My ranking of the positive aspects of semi-intensive aquaculture on biodiversity includes: 1. Production of high quality food for future population growth and to help feed undernourished people; 2. Conservation aquaculture, which is mainly supplementing reproduction in natural populations where recruitment is limited; 3. Cleaning natural waters by filtering or consumption of natural materials done by cultured organisms, 4. Reducing pressure on wild stocks by providing alternative sources in the market; and 5. Replacing more damaging forms of employment with more sustainable aquaculture jobs. My ranking of the 9 negative effects that are important includes: 1. Escapement of alien species which become invasive; 2. Eutrophication of receiving waters from pond effluents; 3. Release of parasites and diseases into natural communities; 4. Escapement of native species resulting in genetic alteration of natural stocks; 5. Land conversion for pond construction; 6. Release of antibiotics or other drugs into receiving waters; 7. Use of natural resources like water and fishmeal; 8. Loss of benthic biodiversity from settling of sediments produced in the culture system; and 9. Collection of larval or juvenile fish from natural populations. The purpose of our symposium was to provide an unbiased evaluation of these various effects by examining wither the overall issue or case histories focused on some of these effects. My objective here is to use a review of the literature to briefly evaluate each of these potential effects of aquaculture.

**Positive Effects**

There have been numerous publications dealing with the negative effects of aquaculture, so I will start off with positive effects in order to develop a different train of thought. The first and most obvious effect of aquaculture is the production of high quality food. This seems obvious, yet many times we ignore that the increased production of food is not a luxury but a necessity. Semi-intensive aquaculture is a valuable means to use natural ecological processes to aid in food production, since it does not rely on formulated feeds but rather uses waste crops, other available fodder, and fertilizer to stimulate natural processes in ponds and produce a crop. Another form of this aquaculture is even more benign; that is, to use bivalves or seaweed in natural waters to not only grow a crop with minimum human inputs but also to improve water quality in the process. Both forms of aquaculture are quite common, and in terms of external energy input or food conversion, semi-intensive aquaculture performs similarly to chicken production and better than all other forms of meat production (Costa-Pierce 2010). This issue is often lost on concerned people – that aquaculture is a form of food production and should be compared to other forms, not to natural ecosystems and their functions (Diana 2009, Costa-Pierce 2010). Over 75% of seafood produced in developing countries is consumed locally, indicating that seafood fulfills a special role in expanding food security for the world's poor (Hall et al. 2010). As a food production system, increased aquaculture production should be encouraged to narrow the gap of protein need in the future. Of course, the most sustainable methods should be the focus of increased production whenever possible.

A second positive effect is conservation aquaculture, used in the reseeding of declining natural populations of aquatic organisms. This role has been recognized for hundreds of years, and many government agencies have used fish hatcheries to produce and stock fish into natural waters for various purposes. While much of this stocking has been done to improve sport fish or commercial fish production, some has focused on restoration of declining stocks (Costa-Pierce and Bridger 2002). Examples abound, including a recent one where tilapia Oreochromis niloticus are grown semi intensively in ponds, sahar Tor putitora used as predators to control tilapia reproduction, and sahar production split between some fish used as food and some to restock natural populations that are in decline (Shrestha et al. 2011). A more developed example is the culture of giant clams, which are used for consumption, for products made from the shells, and for restocking natural populations (Bell 1999). Throughout the world there are hatcheries geared to produce threatened and endangered species not as food but for reseeding populations. Since many of these species will not readily take to artificial feeds, they are often grown in semi-intensive systems, where natural foods or nutrients are promoted and used to increase production of the target organisms.

The third positive effect is the cleaning of waters that occurs by consumption of waste materials done by cultured organisms. Use of aquatic organisms to consume dense concentrations of phytoplankton, zooplankton, and suspended particles is a well known and ancient method, stemming back to polyculture techniques in ancient China, Polynesia, and other cultures (Costa-Pierce 2010). Examples of such systems in aquaculture ponds include polyculture of Chinese carps to reduce production of phytoplankton and zooplankton, improving the culture environment itself and also improving effluent water released from ponds during draining and harvest (Pillay 1993). Another more modern example is cage-cum-pond culture, where carnivorous fish are reared intensively in cages submersed in ponds, and filter feeding fish are reared semi-intensively in pond water where they consume waste feed as well as plankton produced by nutrients released from the cage culture, improving pond water and effluent quality (Yang Yi et al. 2003). Similar methods have been developed in marine systems, termed Integrated Multi Trophic Aquaculture, using seaweeds and bivalves to intercept nutrients and particles released from nearby intensive aquaculture cages, this time reducing the effluent effects of the cages on local water quality (Neori et al. 2004, Troell et al. 2009). These seaweed and bivalve crops may be contained in the cage operation itself or in nearby waters.

Beyond the improvement of aquaculture effluents, semi-intensive culture is also commonly used as a biomanipulation to remediate damages caused in natural systems by other human induced inputs of nutrients and materials. An improvement in water quality often occurs as a result of culturing bivalves and seaweeds in natural waters (Neori et al. 2004, Xiao et al. 2007, Sequeira et al. 2008). The use of bivalve culture as a habitat restoration method in polluted bays is common, and depending on the circumstances, can be a successful means to reduce pollution effects. For example, Sequeira et al. (2008) evaluated the filtering capacity of shellfish in reducing eutrophication of 4 bays, and found that filterers cleared from 5-45% of the bays' volumes daily. They also found strong competition between wild and cultured species, so the success of such biomanipulations may depend on the natural communities present in a bay. Xiao et al. (2007) found similar results in Chinese waters, while Miron et al. (2005) and Crawford et al. (2003) found minimal positive (but no negative) effects of shellfish culture in reducing productivity of other natural bays. Zhou et al. (2006) and Yang et al. (2006) both described the common method of seaweed culture in China, which takes advantage of rich nutrient supplies in coastal waters and results in significant removal of nutrients by seaweeds. These biomanipulations, while not always successful, are important because they not only improve habitat but also produce a useful crop for human consumption, animal feeds, or other uses.

The fourth positive effect of aquaculture on biodiversity is reducing pressure on wild stocks by providing alternative sources of that product in the market. This has long been expected in aquaculture systems, but seldom proven. In the 1980s, it was commonly believed that aquaculture could not compete with a wild fish crop, so that aquaculture only expanded into areas with small wild harvests or where harvests declined due to overfishing. However, in more recent years the development of aquaculture for common commercial species like Pacific salmon has changed this paradigm. Diana (2009) provided evidence that when cultured Atlantic salmon Salmo salar increased in production, wild fish harvests declined. This demonstrates replacing the wild crop in the marketplace with cultured fish, with a decline on harvest pressure for wild stocks and the potential for restoration of natural populations. For semi-intensive species, there are also a number of examples of replacement and expansion trends in wild and cultured species. For oysters, snakeskin gourami Trichogaster pectoralis, and Nile tilapia, wild harvest rates that had been increasing either stabilized or declined after aquaculture expansion produced larger crops of these species (Data from FAO 2010a). For the seaweed Gracilaria and for scallops, capture production continued to increase even after culture overtook capture as the main harvest method. Of course, this simple analysis does not evaluate whether the capture harvests are sustainable or whether the replacements in the market have enhanced wild populations by reducing pressure on these species, but it at least indicates that the markets are changing as a result of semi-intensive aquaculture.

The fifth positive role of aquaculture is replacing more damaging forms of employment with more sustainable aquaculture jobs. This is a double edge sword, as at times aquaculture interferes with local artisanal fishing, which can be sustainable employment, although artisanal fishing is also suffering greatly from overfishing and competition with offshore commercial fishing (Heck et al. 2007, Hall et al. 2010). But aquaculture employment in many parts of the world can be more lucrative (Schwantes et al. 2009), long-term, and safer than many other rural jobs for poor people (Pomeroy et al. 2006b). Pomeroy et al. (2007) presented a particularly troubling case of 'fish wars' which developed after overfishing resulted in low yields and much competition for capture fisheries in Southeast Asia. Replacement of capture fisheries by aquaculture, either in overexploited situations or in situations where exploitation is harming natural biodiversity, can result in net benefits to both the local community and to biodiversity. For example, Pomeroy et al. (2006b) evaluated the replacement of harmful fishing with aquaculture for coral reef species, and while he found many challenges to this conversion, conversions had occurred. Similarly, Pollnac et al. (2001) found that many fishers in poor communities in Vietnam wanted to convert to aquaculture as a means of better living, and this would also reduce fishing pressure on overfished stocks. Even beyond the fishing trades, small scale aquaculture provides a safer and less damaging income than slash and burn agriculture or many urban jobs, and as such can provide security to humans as well as less damaging activities than would exist without aquaculture. Examples of the use of aquaculture to enhance human job security and safe employment include the work of many NGOs like

Caritas in Bangladesh and Nepal to provide aquaculture training and outreach to help produce better and more sustainable livelihoods for the rural poor (Diana 2009). Costa-Perce (2010) showed that aquaculture not only provided jobs for people working on farms, but more employment was generated in processing and marketing the fish produced than in the original farming jobs.

**Negative Effects**

To provide balance in this evaluation, there are also a number of important negative impacts that semi-intensive aquaculture has had on biodiversity. Once again, it is important to put these into context, compared to other threats to biodiversity, particularly agriculture. The first and most important of these negative effects is escapement of alien species which become invasive. Many people consider Asian carps and tilapia to be prime examples of invasive aquatic species, and both were largely introduced throughout the world for aquaculture production. In fact, up to 90% of the yield for the 22 species of freshwater finfish that produce over 10,000 tons in aquaculture annually is from alien species, and 16% of global aquaculture production results from alien species used in production (DeSilva et al. 2009). DeSilva et al. (2009) evaluated the documented cases of harm from tilapia introductions, and acknowledged that many cases were not well documented as to the end result of alien species release into natural waters. There were 349 cases of known releases, 17 with adverse ecological impacts, 13 with beneficial, and the remainder with an unknown effect. While this could be used to extrapolate that one might use alien species in some areas, DeSilva et al. proposed that fresh introductions of alien species should not occur in aquaculture development, and indigenous species would be better candidates for aquaculture expansion into new locations. This strongly contradicts the common methods used in terrestrial agriculture, where few strains or species of animals were developed in domestication, and they are used nearly universally.

The case history of tilapia as an alien and invasive species is sobering, as many documented cases of damage have resulted from tilapia introductions. Aquaculture has played a role in this, although more than half of the documented introductions of tilapia were not the result of commercial aquaculture but of intentional stocking of tilapia in natural waters by governmental entities (Canonico et al. 2005). Peterson et al. (2005) determined that tilapia were the sixth most common species collected in their study in Mississippi watersheds. They also found that both aquaculture operations and power plant effluents were common contributors to the tilapia invasion, providing sources for recolonization and thermal refuges. While Peterson et al. (2005) did not quantify the reductions in other species in these receiving waters due to the spread of tilapia, there are numerous other studies that have documented changes in systems after expansion of tilapia, including loss of submerged aquatic vegetation and changes in the abundance and distribution of native fishes present (Eglund 2002, McCrary et al. 2005). Damages due to these introductions are difficult to quantify for cause, as often multiple human disturbances have occurred at the same time as the introduction. Also, initial introduction is not the only concern, as aquaculture facilities are linked to the spread of tilapia to new watersheds in a region as well as their continuance in those watersheds (DeSilva et al. 2009, Esselman 2009). My own belief is that we should follow the precautionary principle here and not introduce alien species for aquaculture purposes into areas unless they are already widely distributed in that area, and even then we should only complete new introductions with caution.

The second negative impact of semi-intensive aquaculture is eutrophication of receiving waters from farm effluents. This impact would include mainly effluents from ponds, as seaweed or mollusk culture in the nearshore environment rarely causes water quality problems at the densities cultured. It is obvious that intensive culture systems with high densities and high feeding rates have the largest potential to produce impacts from effluents (Naylor and Burke 2005, Diana 2009), but pond systems can have a similar effect even under semi-intensive conditions (Boyd 2003). Most ponds for semi-intensive aquaculture do not have regular exchange of water, because that would result in a loss of the nutrients used to drive production. However, most still discharge water during precipitation events or at harvest (Boyd 2003).

The discharge of nutrients, suspended solids, and other materials at harvest can be a major impact of aquaculture, and commonly results in the eutrophication of receiving water bodies (Trott and Alongi 2000, MacKinnon et al. 2002). While studies of intensive systems have shown clear and dramatic effects of effluents on biodiversity in receiving waters (see reviews in Naylor and Burke 2005, Islam 2005), I could find no empirical studies focused on semi-intensive systems as defined in this paper. The closest I came was Stephens and Farris (2005), who evaluated environmental conditions below catfish ponds (intensive in production) in the US. They found that these ponds did not have many significant effects on organisms or water quality below the outflow. While studies on semi-intensive aquaculture effluents may not have demonstrated biodiversity effects, there are numerous studies on eutrophication demonstrating significant losses of intolerant species and shifts in dominant species due to eutrophication (Agostinho et al. 2005, Gong and Xie 2011). There are also a number of studies evaluating how to remediate effluent effects for semi-intensive aquaculture through water treatment in ponds, drainage into settling ponds, and harvest methods (Lin and Yang Yi 2003, Boyd 2003). In spite of the lack of direct empirical work, governments are moving to regulate and enforce effluent standards in all forms of aquaculture (Boyd 2003). This is justified, given the general knowledge of eutrophication effects and the methods available to reduce the impact of pond effluents (Lin and Yang Yi 2003, Boyd 2003).

The third negative impact is release of parasites and diseases into natural communities. For intensive systems, this has been the subject of much debate in the salmon – sea lice issue (Krkosek et al. 2007, Brooks and Jones 2008, Diana 2009). One example of this issue for semi-intensive aquaculture is the spread of Koi herpes virus from the ornamental fish trade to common carp Cyprinus carpio aquaculture, then to wild carp populations (Bondad-Reantaso et al. 2005). It is fairly clear that if water from diseased aquaculture facilities is exchanged with natural waters, disease organisms will be introduced into natural waters, and their spread will depend on local conditions (Bondad-Reantaso et al. 2005). The disease problem in aquaculture has led to management developments like the use of specific pathogen free (SPF) organisms and antibiotics. Antibiotic release is a concern which will be covered later. SPF brood stock has revolutionized the shrimp industry, with the changeover from Penaeus monodon to Litopenaeus vannamei being largely driven by the availability of SPF broodstock of the latter species (Lightner 2005). SPF indicates organisms that have been reared in pathogen free conditions for certain diseases, so the starting point of brood stock is to produce young will also be pathogen free. However, these organisms are no more resistant to pathogens in the culture system than any other organisms, so clean culture is still required. So far the widespread use of SPF broodstock is limited to the shrimp industry, but SPF individuals of a variety of fish species have been used in many hatchery cases to replace diseased brood stock when a particular outbreak occurred (Amend 1976), and the development of SPF broodstock of other species could occur if disease outbreaks became major issues (Bondad-Reantaso 2007). Generally, diseases are more common in the high density, fed systems used for intensive culture, but the spread of disease in the carp example was from a semi-intensive system.

The fourth negative impact is escapement of native species resulting in genetic alteration of natural stocks, or the release of genetically modified organisms (GMO). To date, no species of GMO has been approved for aquaculture production, and the potential approval of Atlantic salmon would be for use in intensive systems, so I will not consider GMO effects. The genetic effects of escaped organisms on natural species have been emphasized in salmon culture, particularly Atlantic salmon (Fleming 2000). Similar concerns have been expressed for a variety of marine finfish (Youngson et al. 2001), salmonids (Hiundar et al. 1991), and clams (Kong and Li 2007), to name a few. This leads to a controversy that some culturists would prefer to see strong selection for faster growing and more disease resistant strains of aquatic species, while others prefer less domestication and use of native or sterile fish for culture purposes (Bartley et al. 2009). Most genetic selection for improved growth and food utilization has occurred in intensively produced fish (Hulata 2001), although the development of GIFT tilapia is an example of this process for semi-intensive culture (Ponzoni et al. 2005). This dilemma will continue for some time, and aquaculturists are currently both calling for culture of only locally existing organisms

(DeSilva 2009, Diana 2009) and others desiring better domestication, genetic selection, and even genetic modification (Hulata 2001, Bartley et al. 2009). Since escape is inevitable in all but the most intensely biosecure productions systems, I recommend using unmodified or sterile individuals for local culture, again citing the precautionary principle and numerous papers indicating negative genetic interactions between wild and cultured fishes.

The fifth negative effect is land conversion for pond construction. There is an obvious link between clearing of land for human purposes and loss of biodiversity, most commonly expressed in the species-area curve. In freshwater systems, virtually all semi-intensive aquaculture is done in ponds. With their lower level of production, these ponds take up much more space to produce the same crop compared to cages or intensive ponds. Land conversion for human food production is a global issue today, with over 25% of the earth's surface (33 million square km) cleared as grazing lands for meat production (Asner et al. 2004). In comparison, estimates of land cleared for pond culture (11,100,000 ha or 111,000 km2, Verdegem and Bosma 2009) is only about 0.3% of the land used in meat production. Comparing land clearing for these two purposes, even considering the difference in total meat or aquaculture production, can at least be estimated in simple calculations. Pond aquaculture production (mainly semi-intensive) was about 25.3 MMT in 2008 and meat production about 280 MMT, so the fraction of pond produced seafood to meat was 9%. However, given the production levels and land use for each pursuit, pond aquaculture produced 26 times more mass of crop than meat production on the same quantity of land. Such an analysis discounts the quality of the land converted for each conversion, which may be prime agricultural areas, coastal sites, or wetland habitats of value in the water cycle. Another land use issue in aquaculture is the construction and abandonment of ponds, especially in the case of marine or brackish water systems, where the soils are damaged and may not be immediately useful for other agricultural pursuits (Naylor et al. 1998). While pond abandonment is an issue (Barbier and Cox 2004), particularly in areas where animal diseases become established, the reuse of those ponds is also common and in the longer term most pond areas are reclaimed and used in aquaculture or other human pursuits (Clark 2003). Conversion of mangroves to ponds is a special problem here (Flaherty and Kamjanakesorn 1995). While the cases that have been made are mainly on shrimp aquaculture, comparable issues arise in milkfish culture, which is mostly done at a semi-intensive level (Kuhlmann et al. 2009). Overall, land conversion occurs in aquaculture, but not as extensively or any more damaging in general than land conversion for agriculture or urban growth, and both of those uses are currently converting much more land than aquaculture.

The sixth negative impact is release of antibiotics or other drugs into receiving waters. This has been a major concern in intensive culture, where studies of sediments near culture facilities often show elevated chemotherapy agents (Lalumera et al. 2004). Antibiotic use is an important issue in fed aquaculture, where it can be administered in feeds (Burridge et al. 2010). Its use in nonfed systems is much less but still present. Major concerns are for human health, but these materials also can have significant effects on fish and invertebrates as well (Cabello 2006). In many countries, antibiotics are banned or strictly limited for aquaculture production, but these guidelines are not often followed. It is a major impact of aquaculture, and agriculture for that matter, and is the target of a number of regulations and best practices. While there is strong opinion use of antibiotics in aquaculture should be avoided and regulated, this is not the case in all producing countries (Burridge et al. 2010). Such management techniques as improved sanitation in the culture system, improved water quality, and treatment of aquaculture discharges in settling ponds or other systems are all alternative methods of disease control which are very effective and should be used (Cabello 2006). Antibiotic application in aquaculture is a problem, and use of antibiotics should not be tolerated.

The seventh negative impact is use of natural resources like water and fishmeal. While the biggest issue in water use is related to the scarcity of water and its need for human quality of life (Radulovich 2011), there are also clear implications on biodiversity when water is removed from surface sources, especially in arid climates (Verdegem and Bosma 2009). Since semi-intensive systems generally do not use formulated feeds that have much fishmeal content, the lack of fishmeal use can be considered a benefit of lower intensity farming. However, water use remains a major natural resource sink in aquaculture that is important in lower intensity systems. Verdegem and Bosma (2009) did an excellent analysis of water use in pond aquaculture. The details of water use are system specific, and too complex to evaluate fairly here. It should suffice to say that water use in aquaculture is less than in agriculture on a per kg basis comparing fish and beef, but the actual ratio depends greatly on the quality of water discharged from the pond at harvest. Mariculture uses water only based on water needed for food ingredient production, but all cage culture is fed and often uses some water intensive crops as ingredients, which leads to water demand for feed production. Finally, brackish water culture also has high water demands, as the mixture of fresh and salt water means that none of the freshwater discharged can be returned to productive use, due to its salinity. Verdegem and Bosma (2009) evaluated options and determined that lower flushing rates and feeding rates, using feed ingredients with lower water demand, or not feeding at all but using fertilized systems instead resulted in better water use in aquaculture. This focuses the management effort directly on semi-intensive systems. Their final recommendations also included paying better attention to water quality in ponds so that returned water (either discharged or seeped into groundwater) would not pollute receiving waters, intensifying to produce more yield in the same quantity of water (without degrading water quality), and reducing dependence on grains in feed (feed the pond, not the fish). All of these should be components of well managed aquaculture systems for the future.

The eighth negative effect is loss of benthic biodiversity from settling of sediments produced in the culture system. Once again the main criticism for this effect has been related to net pen culture of salmonids (Brooks et al. 2003) as well as other fish cages (Dimitriadis and Koutsoubas 2011). However, sediments are a common constituent of pond discharges, and the settling of suspended sediments in natural waters results in loss of benthic organisms in areas where currents do not eliminate sediment accumulation (Longdill et al. 2007). Here again some perspective is in order. The major factor causing such settlement of sediments and anaerobic deep waters in coastal environments is land-based agriculture and overuse of nitrogen fertilizers (Rabalais et al. 2002). The area of dead zone in the Gulf of Mexico alone (20,700 km2 in 2001) exceeds any estimates of potential smothering caused by aquaculture. For a very liberal estimate of area of smothered sediments due to marine cage culture, one can use the estimates of total cage production (10MT annually, Islam 2005), production per unit area (10,000 T/ha, which is the moderate production estimate from Bostock et al. 2010) and an assumed fallout area of 1 ha/cage (assume the size of cage at 10x10m as well as an overly large fallout area of 100 x the cage area) to give a total benthic area smothered of 10,000 km2 for all global marine cage culture in 2004. This amounts to less than 50% of the area affected by the Gulf of Mexico hypoxic zone alone, and there are similar zones off most major rivers in the world, probably also due to agriculture (Rabalais et al. 2002). However, this low damage compared to agriculture does not excuse aquaculture to discharge sediments because it is not the major polluter. Earlier cited studies on bivalves (Crawford et al. 2003, Miron et al. 2005) demonstrated varying sediment accumulation below these culture systems, and studies of intensive fish production produced more dramatic effects (Brooks et al. 2003, Dimitriadis and Koutsoubas 2011). Like the case of nutrients in effluents, pond aquaculture should treat discharges with sediment basins and use the precautionary principle to base its future management efforts, and bivalve culture should reduce stocking densities in an area to reduce local sedimentation effects.

The final negative interaction is collection of larval or juvenile fish from natural populations resulting in recruitment failure. This method of seed production has a clear negative effect on biodiversity, and is particularly related to semi-intensive aquaculture because reproduction control and control of the entire life cycle is usually necessary for intensive culture. As aquaculture has progressed, methods have been developed to artificially produce young of most species under controlled conditions, making the need to wild seed collection relatively rare. This is not necessarily true for new or developing indigenous species, or in some developing countries (Primavera 2006), so the artificial production of seed should be a first priority in the culture of a new species.

**The Future**

Considering all of the positive and negative impacts above, should humans continue to pursue semi-intensive aquaculture in the future? Such a decision requires a synthesis of all the positive and negative effects listed above, and the consideration of the need for food in the future. I believe that the answer to this question is a resounding yes. Because of the more limited alteration of water quality and the lack of using formulated feeds, semi-intensive aquaculture avoids many of the major pitfalls of intensive aquaculture. When compared to terrestrial agriculture, it produces protein rich food more efficiently in terms of energy inputs, food conversion, land area affected, and water use. While it does have significant negative impacts on biodiversity, many of those impacts can be improved upon with research and extension of new systems like the culture of sahar or indigenous species from the Amazon like Tambaqui Colossoma macroponum (Gomes and Silva 2009), particularly since Tambaqui are herbivorous and can feed on waste fruits and the like. For semi-intensive aquaculture to really flourish, more systems need to be developed using indigenous species of low trophic level that produce crops by natural processes that can be enhanced by management. In addition, we should expand the use of bivalves and seaweeds to remediate intensive aquaculture wastes as well as to remediate pollution in bays and other coastal waters. This relies on the produced bivalves and seaweed having a market so the crop can be sold and used in some way, such as animal feed, compost for land crops, or algal products that have commercial value. When that happens these are win-win situations, where pollution problems are cleaned up and a food crop is also produced.

In reality, the initial question of the value of semi-intensive aquaculture in the future is not one that we have the choice to make. We need to expand food availability over the next 40 years, and most likely need to increase all means of food production. Much of that production comes from small scale, local systems used in the developing world, and those systems are expanding. Aquaculture has a special role in local food security in many areas, and as such cannot be discarded because of environmental complaints issued mainly from rich, developed nations. We need to help developing countries expand their food production and income generating systems, and the best means of doing that is to consider their current systems and to do research and extension on those systems so that the most sustainable and profitable ones can be encouraged. Fitting of these systems into the social context of the area in question is of extreme importance; many development attempts have failed because they do not consider the role of people, their beliefs and their social constraints in adopting new systems. A far better means of intervention is to consider the systems already in place in various locations, and to help adapt them for future use. This should be a major research and development role of the developed world.

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# INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA): BIODIVERSIFYING FED FISH AQUACULTURE WITH EXTRACTIVE SEAWEED AND INVERTEBRATE AQUACULTURE TO PROVIDE BOTH BIOMITIGATIVE SERVICES AND DIVERSIFIED SEAFOOD PRODUCTION

*Thierry Chopin, University of New Brunswick; J. Andrew Cooper, Department of Fisheries and Oceans; Gregor Reid, University of New Brunswick; Shawn Robinson, Department of Fisheries and Oceans*

**Abstract**

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 CO2, 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.

Integrated Multi-Trophic Aquaculture:
environmental biomitigation and economic diversification of fed aquaculture by extractive aquaculture

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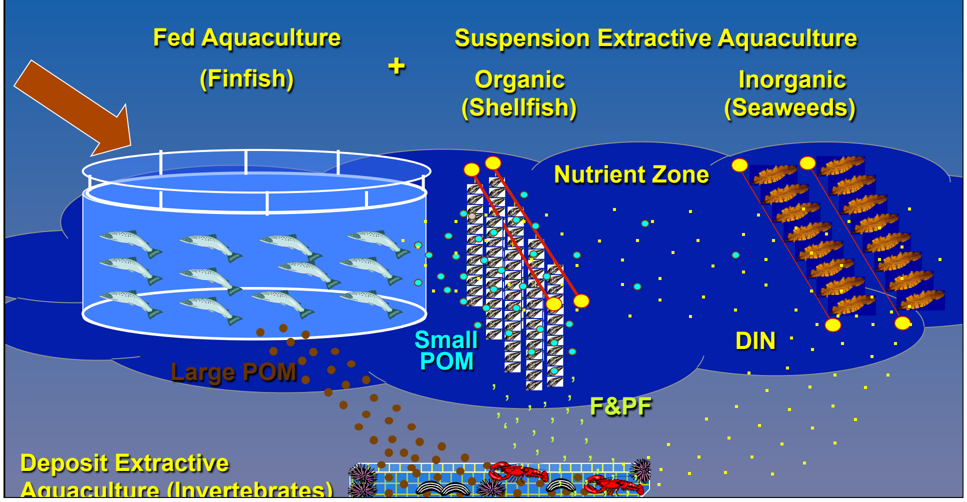
## Integrated Multi-Trophic Aquaculture (IMTA)



Based on a very simple principle:

**The solution to nutrification**

**is not dilution...**

**but extraction and conversion**

**through diversification**

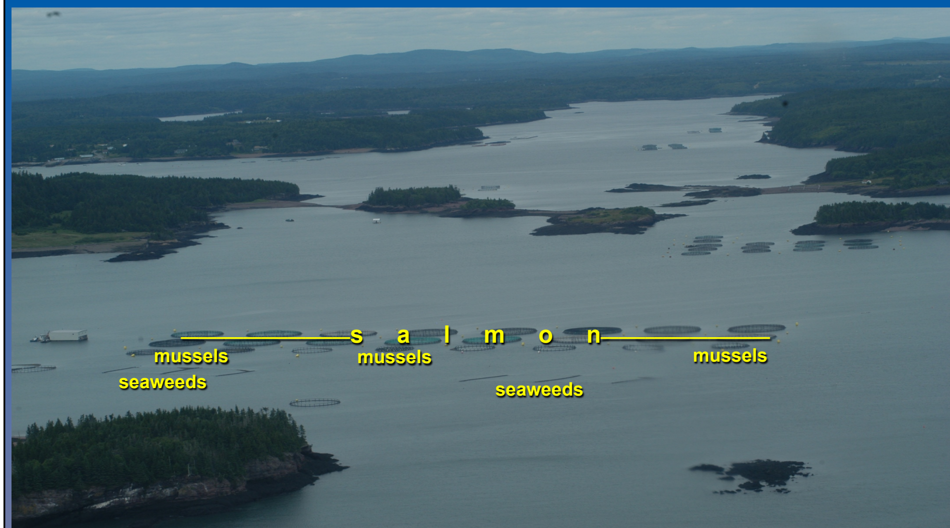
## The IMTA concept is extremely flexible

- IMTA is the central/overarching theme on which many variations can be developed.

- IMTA can be applied to open-water or land-based systems, marine or freshwater systems, and temperate or tropical systems.

- What is important is that the appropriate organisms are chosen at multiple trophic levels based on their complementary functions in the ecosystem, as well as for their economic value.

- Integration should be understood as cultivation in




## Fed component of IMTA: salmon

# Inorganic component of IMTA: seaweeds

- *Saccharina latissima*
  - previously *Laminaria saccharina*
  - *Saccharina* means sweet
  - similar to other *Saccharina* and *Laminaria* for the Oriental market
  - sold as "*kombu*"

- *Alaria esculenta*
  - *esculenta* means succulent
  - similar to *Undaria* for the Oriental market


From R&D to C
future NETS your east coast advantage!


Organic component of IMTA: mussels

Mussels: from

biofouling

to

value-added

co-cultured


## . Meat yield of IMTA mussels: 56 %

Meat yield of mussels you buy: 30-35 %

## . More omega-3 fatty acids in IMTA mussels

(particularly DHA and EPA)

## Positive impacts of aquaculture/IMTA

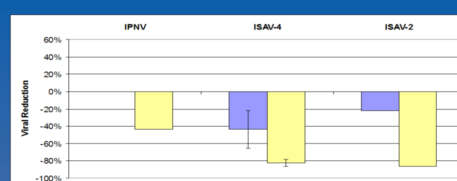
- Difficult to measure and to get a true picture because our monitoring protocols, performance measures and metrics are mostly designed to identify negative impacts, not positive ones.

- But under the right conditions, right assimilative capacities and right scales, aquaculture practices can increase environmental and economic productivity and biodiversity.

- Not surprisingly, it is a question of doing it in

## Species interactions – Disease controls

- In laboratory experiments, blue mussels are capable of inactivating the infectious salmon anemia virus (ISAV) and the infectious pancreatic necrosis virus (IPNV).



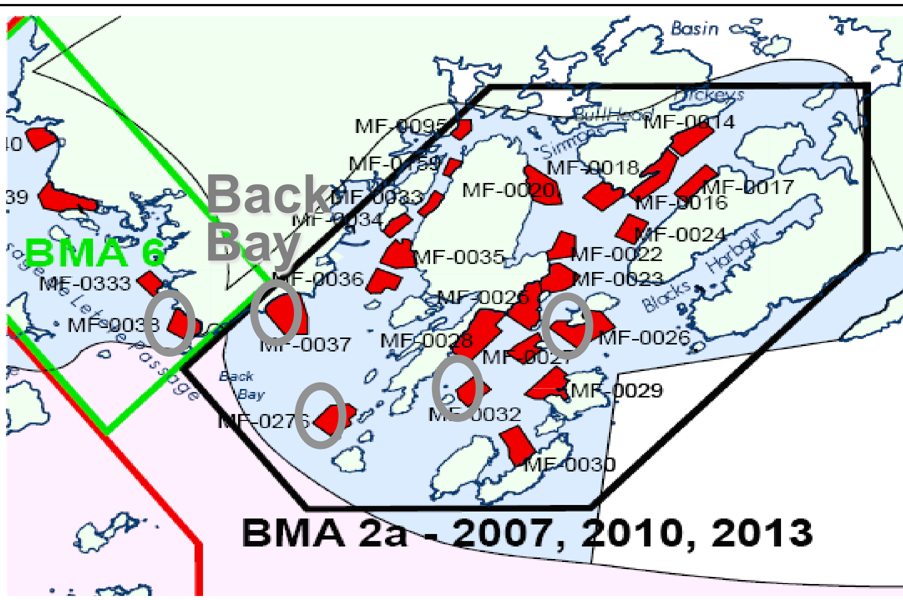

- Blue mussels, and other shellfish such as scallops, can consume copepodids, the planktonic and infectious stage of sea lice.

>>> Shellfish rafts could be strategically placed to serve as a kind of sanitary/biosecurity cordon around salmon cages to combat some diseases.

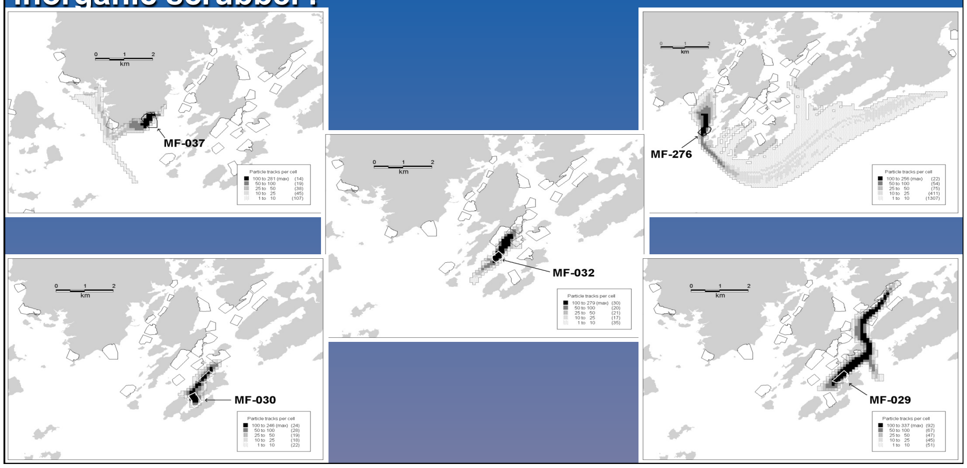
**A major rethinking will be needed regarding the definition of an "aquaculture farm".**

**>>> how does it work within an ecosystem?**

**>>> considering it in a broader context of Integrated Coastal Zone Management**

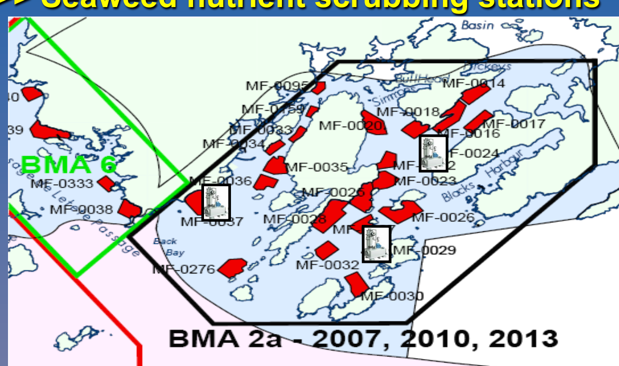


## Particle tracking: dissolved inorganic nutrients moved over longer distances than particulate organic matter >>> overlap between sites >>> does the site origin really matters for an inorganic scrubber?




## Nutrient sequestration at the Bay Management level

>>> Seaweed nutrient scrubbing stations  for nutrient trading credits



**The value of the biomitigative services provided by the extractive components of IMTA systems will have to be recognized and accounted for.**

**>>> Introducing the concept of "nutrient trading credits" (NTC), similar to carbon trading credits**

For examp … .4 billion

| Composition | NTC |
|---|---|
| 0.35% N | US$10-30 $kg^{-1}$ |
| 0.04% P | US$4 $kg^{-1}$ |
| 3.00% C | US$30 $t^{-1}$ |

**>>> biomitigative services: at least US$592.5 million to US$1.698 billion**
***i.e.*** **as much as 23% of their present commercial value.**

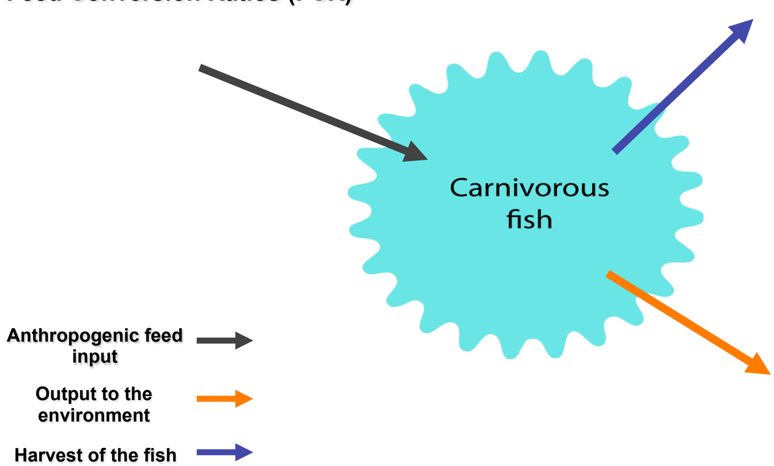
**Biomitigative services should represent financial incentive tools to encourage mono-aquaculturists to contemplate IMTA as a viable marine agronomy option to their current practices.**

**We should also give a value to:**

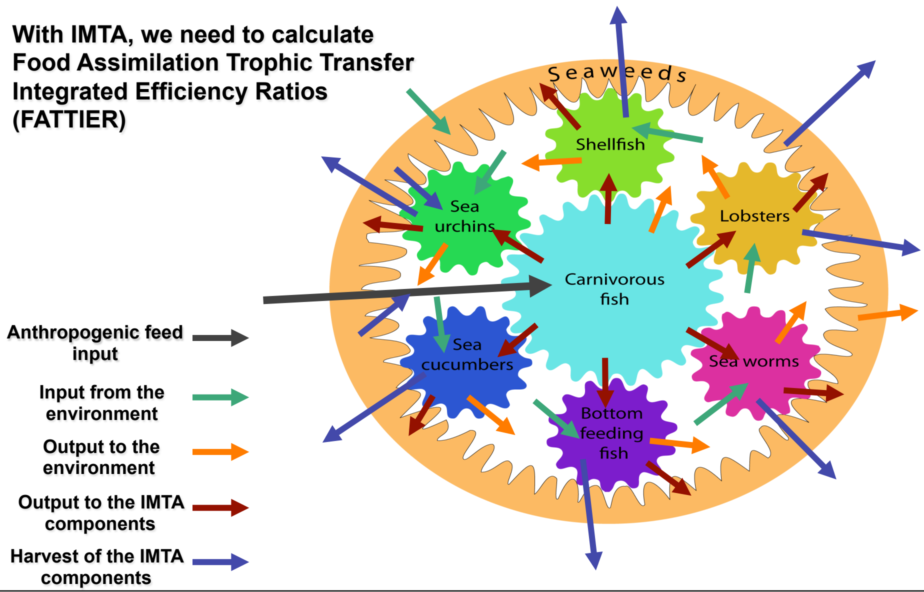
- **Recapturing feed and energy otherwise lost and their conversion into other commercial crops.**

Evolving aquaculture practices will require a shift toward understanding the workings of food production systems rather than focusing on monospecific technological solutions.

With monoculture, we calculate
Feed Conversion Ratios (FCR)



**With IMTA, we need to calculate Food Assimilation Trophic Transfer Integrated Efficiency Ratios (FATTIER)**




**Consumers' (and scientists') perceptions and attitudes will have to change, especially in the western world:**

**Wastes or nutrients?**

- **Nutrients are essential for life** (again, in moderation, *i.e.* within the assimilative capacity of the system).

- **Recycling is accepted on land and in**

**Biomitigative services should represent financial incentive tools to encourage mono-aquaculturists to contemplate IMTA as a viable marine agronomy option to their current practices.**

**We should also give a value to:**

- **Recapturing feed and energy otherwise lost and their conversion into other commercial crops.**
- **Reduction of risks through crop diversification.**

## Profitability – Net Present Value (NPV in US$)

**NPV calculated for a 10 year period at discounted rates of 5 and 10%**

**3 scenarios:**

- **optimistic** (20% probability): 5 successful harvests (11% mortality rate)
- **intermediate** (40% probability): 4 successful harvests (11% mortality rate)
  1 harvest (70% mortality rate)
- **pessimistic** (40% probability): 4 successful harvests (11% mortality rate)
  1 harvest completely destroyed (disease or winter chill)

| Operation | NPV | Optimistic | Intermediate | Pessimistic |
|---|---|---|---|---|
| Salmon monoculture | 5% | 8,146,477 | 2,664,112 | 50,848 |
| IMTA | 5% | 8,906,435 | 3,296,037 | 674,580 |
| Salmon monoculture | 10% | 6,885,181 | 2,391,135 | - 228,345 |
| IMTA | 10% | 7,508,913 | 3,014,866 | 403,579 |

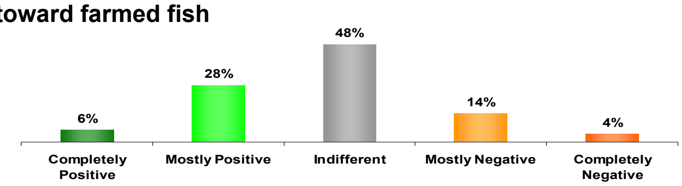
**Biomitigative services should represent financial incentive tools to encourage mono-aquaculturists to contemplate IMTA as a viable marine agronomy option to their current practices.**

**We should also give a value to:**

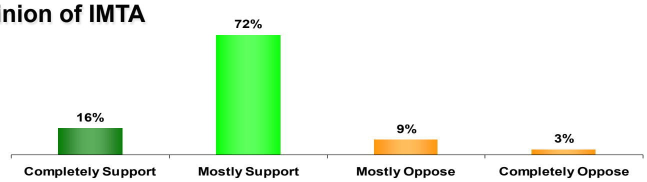
- Recapturing feed and energy otherwise lost and their conversion into other commercial crops.
- Reduction of risks through crop diversification.
- **Increase in aquaculture societal acceptability.**

## New York consumers are generally indifferent in their opinion of farmed fish and overwhelmingly support an IMTA approach

**Current attitude toward farmed fish**




**Consumer opinion of IMTA**



Biomitigative services should represent financial incentive tools to encourage mono-aquaculturists to contemplate IMTA as a viable marine agronomy option to their current practices.

**We should also give a value to:**

- Recapturing feed and energy otherwise lost and their conversion into other commercial crops.
- Reduction of risks through crop diversification.
- Increase in aquaculture societal acceptability.
- Differentiation and eco-certification of IMTA products which command premium market prices.

## Latest news: IMTA salmon goes commercial


Biomitigative services should represent financial incentive tools to encourage mono-aquaculturists to contemplate IMTA as a viable marine agronomy option to their current practices.

We should also give a value to:

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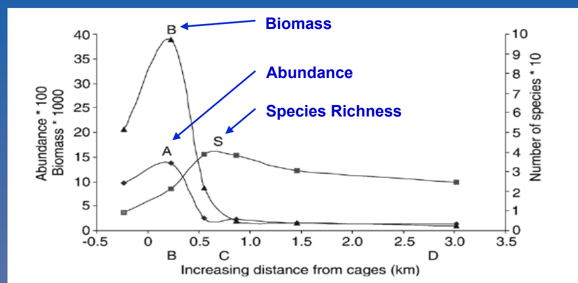
## Aquaculture, IMTA and biodiversity

A review by our group of 30 aquaculture benthic impact studies published since 2000 reveals that:

- 1/3 showed some evidence of increased biodiversity.
- 1/3 showed some evidence of increased abundance or biomass, but not necessarily biodiversity.
- 1/3 showed no increase in biodiversity.

## Infaunal community composition gradient away from fish cages in a fjord system in Norway




Kutti *et al.* (2007)

In environments where organic loading does not exceed the assimilative capacity of the benthos, biomass, abundance and species richness can be higher in locations closer to the farm than background levels.

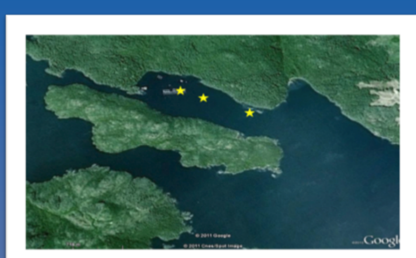
## Current CIMTAN project

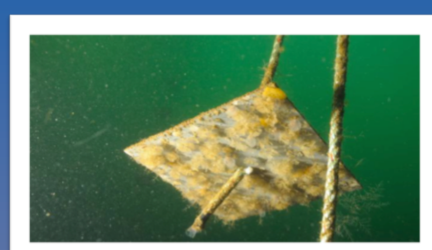
Quantifying nutrient and energy dispersal from open-water IMTA sites and the spatial scales of influence on "near field' and "far field" wild species

**Areas of investigation:**

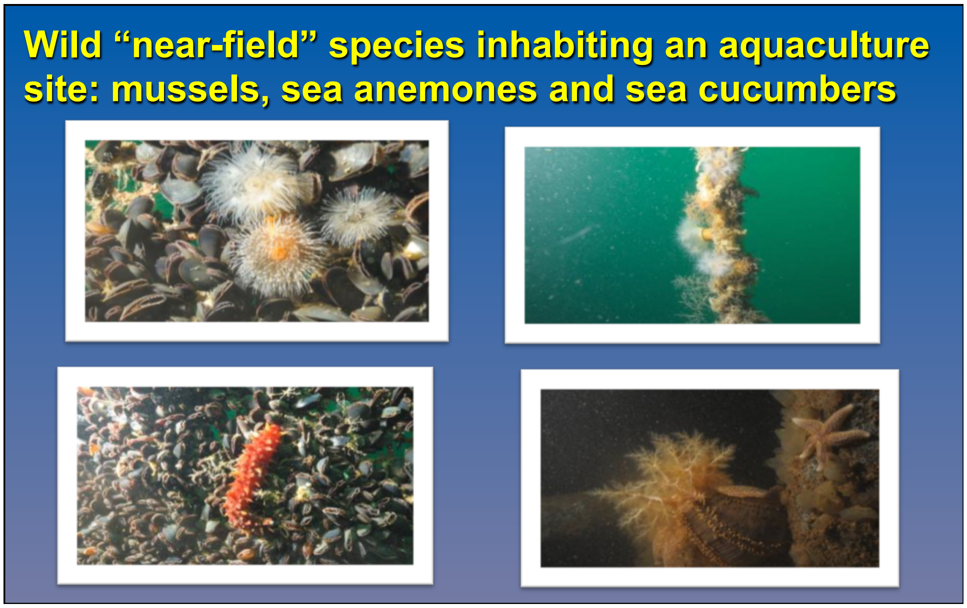
- Habitat availability: settlement, colonization.
- Nutrient loading: abundance, growth, biomass accumulation.
- Community: biodiversity, early colonization and community succession.
- Ecosystem functions: disease control, pests.

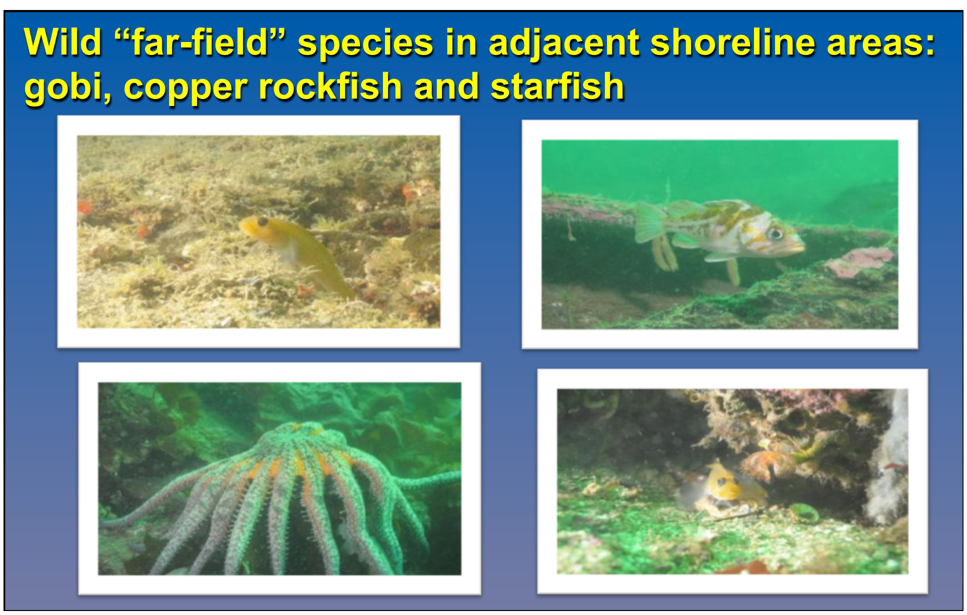

## Biocolonization PVC plates deployed at fixed distances

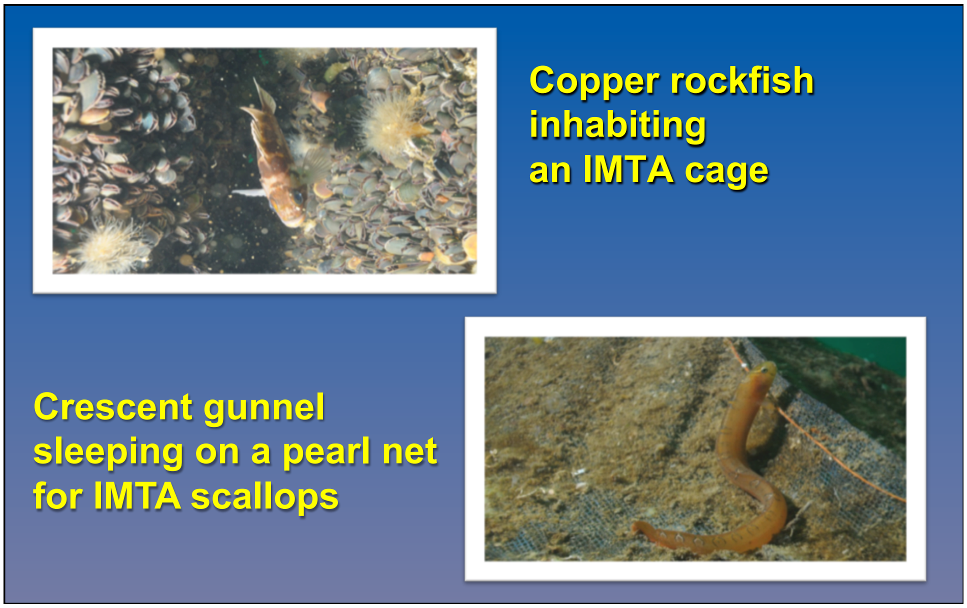




Early colonizing species, such as tunicates and hydrozoans, established after only 10 weeks


Wild "near-field" species inhabiting an aquaculture site: mussels, sea anemones and sea cucumbers


Wild "far-field" species in adjacent shoreline areas: gobi, copper rockfish and starfish


Copper rockfish
inhabiting
an IMTA cage
Crescent gunnel
sleeping on a pearl net
for IMTA scallops


INTEGRATED MULTI-TROPHIC AQUACULTURE
Bon appétit
and thank you!

# Aquaculture Effluents and Eutrophication

*Claude Boyd, Auburn University*

**Abstract**

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.

# Aquaculture Effluents and Water Pollution

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## Pollution Potential of Aquaculture Production Systems

| Type of system | Pollution potential |
|---|---|
| Propagules “planted” on artificial structures | Not considered a significant source. |
| Ponds, flow-thu units, cages, and pens | Discharge nutrients, solids and organic matter. Relative potential: Ponds < Flow-thru < cages and pens. |
| Intensive, water-recirculating facilities | Discharge a small volume of highly-concentrated effluent. However, comparatively few in use. |

| Pollution by Pond Aquaculture | |
|---|---|
| Type of culture | Pollution concern |
| Extensive ponds | Total suspended solids. |
| Chemically-fertilized and manured ponds | Total suspended solids and minor concerns about nutrients and organic matter. |
| Ponds with feeding, water exchange, and aeration | Nutrients, organic matter, and suspended solids. Concerns increase with increasing production intensity. |

## Direct Waste Load

Direct waste load consists of uneaten feed, feces, and metabolic wastes. Typical disposition of feed in system:

1,700 kg feed (1,530 kg DM) = 1,000 kg fish (250 kg DM)

230 kg DM in uneaten feed

195 kg DM in feces

855 kg metabolic wastes ($CO_2$, $NH_3$, etc.)

## Typical Direct Waste Loads to Culture Systems

| | Waste load (kg/1,000 kg fish or shrimp) | | |
|---|---|---|---|
| Species | C | N | P |
| Channel catfish | 951 | 88.4 | 13.0 |
| Blue tilapia | 707 | 59.4 | 10.0 |
| Rainbow trout | 408 | 45.4 | 10.8 |
| Pacific white shrimp | 603 | 55.4 | 14.8 |

## Effect of feed conversion ratio (FCR) on system loads of carbon, nitrogen, and phosphorus per tonne of production in channel catfish ponds.

| FCR | Carbon (kg/tonne) | Nitrogen (kg/tonne) | Phosphorus (kg/tonne) |
|---|---|---|---|
| 2.20 | 951 | 88.4 | 13.0 |
| 2.00 | 855 | 78.2 | 11.2 |
| 1.80 | 759 | 68 | 9.4 |
| 1.60 | 663 | 81.6 | 7.6 |

Feed composition: 48% C; 5.1% N; 0.9% P.
Fish composition: 10.5% C; 2.38% N; 0.68% P.

Effect of reducing concentration of crude protein (% N × 6.25) and phosphorus in feed at a feed conversion ratio of 1.8 on system waste loads of nitrogen and phosphorus.

| Feed crude protein (%) | Feed nitrogen (%) | System N load (kg/1,000 kg fish) | Feed phosphorus (%) | System P load (kg/ 1,000 kg fish) |
|---|---|---|---|---|
| 32 | 5.12 | 68.36 | 1.2 | 14.8 |
| 31 | 4.96 | 65.48 | 1.1 | 13.0 |
| 30 | 4.80 | 62.60 | 1.0 | 11.2 |
| 29 | 4.64 | 59.72 | 0.9 | 9.4 |
| 28 | 4.48 | 56.84 | 0.8 | 7.6 |

Fish composition: 38% N; 0.68% P.

## Fate of Waste

| System | Comment |
|---|---|
| Ponds | Much of waste is assimilated in the pond. (10-20% feed C; 10-40% feed N & P in effluent) |
| Flow-thru | Part of waste can sometimes be removed by sedimentation, but most is discharged. |
| Cages and pens | All waste goes into the water body containing the cages or pens. |

**Typical composition of pond overflow and initial draining effluent contrasted with that of average medium-strong domestic wastewater.**

| Variable | Pond effluent | Wastewater |
|---|---|---|
| pH | 7-9 | 6.5-8 |
| Dissolved oxygen | > 3 mg/L | < 1 mg/L |
| Total suspended solids | 30-120 mg/L | 210 mg/L |
| Total ammonia nitrogen | 0.3-3 mg/L | 25 mg/L |
| Total nitrogen | 2-6 mg/L | 40 mg/L |
| Total phosphorus | 0.1-0.5 mg/L | 7 mg/L |
| 5-d biochemical oxygen demand | 5-20 mg/L | 190 mg/L |

## Effluent Limitations

Simple concentration limits – avoids problems in mixing zone near outfall.

Pollutant load limits – can lead to reduction in pollution to a water body, but does not assure that assimilation capacity is not exceeded.

Delta-based limits – possibly superior to load limits, but no increase in a variable between inflow and outflow is unrealistic.

Best management practices (BMPs) – probably best approach, but verification difficult.  Can best be used to comply with concentration or load limits.

## BMPs for Pond Effluent Management

- Avoid excessive inflow from watersheds and erosion on watersheds.
- Capture rainfall to extent possible.
- Cease or reduce water exchange.
- Harvest without draining or reuse water.
- Use adequate aeration and position aerators to avoid erosion.
- Lime acidic waters.

## Feed BMPs

- Use good quality feed of appropriate pellet size.
- Store properly and use before expiration date.
- Spread feed over culture area.
- Feed no more than animals will eat.
- Feed several times per day for some species.
- Remove uneaten feed.
- Screen fish from ends of raceways and remove solids that accumulate.

## BMPs for Pond Effluent Management (cont.)

- Design, construct, and maintain ponds to minimize erosion.
- Use sedimentation pond to treat final draining effluent.
- Operate sedimentation ponds responsibly.
- Protect against erosion at farm outfalls.
- Don't discharge into stagnant areas.

## Sedimentation

Settling basins of 1-m depth can be designed with aid of the following equation:

$$V_{cs} = \frac{Q}{A}$$

$V_{cs}$ = critical settling velocity of smallest particle to be removed (m/sec);

Q = inflow ($m^3$/sec);

A = surface area ($m^2$).

## Eco-label Certification

- Several programs: Aquaculture Certification Council; World Wildlife Fund; EureGAP; Friends of the Sea; many organic programs; buyer programs.
- Eco-label certification programs impose various types of limitations on effluents.

## USEPA Effluent Rule

For most production systems, EPA did not specify effluent limitation guidelines. These were left to the states; EPA only suggested BMPs for concentrated aquatic animal production (CAAP) facilities.

**United States Environmental Protection Agency definitions of warmwater and coldwater concentrated aquatic animal production (CAAP) facilities.**

**Warmwater CAAP Facilities**

Includes ponds, raceways, or other similar structures which discharge at least 30 days per year but does not include:

- Closed ponds which discharge only during periods of excess runoff;
- Facilities which produce less than 45,454 harvest weight kilograms per year.

**Coldwater CAAP Facilities**

Includes ponds, raceways, or other similar structures which discharge at least 30 days per year but does not include:

- Facilities which produce less than 9,090 harvest weight kilograms per year;
- Facilities which feed less than 2,272 kg during calendar month of maximum feeding.

# Aquaculture Effluents and Water Pollution

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## Abstract

Aquaculture facilities discharge into natural waters. Their effluents are enriched with nitrogen, phosphorus, organic matter, and suspended solids because fertilizers and feed are used widely to enhance yields above those possible through natural productivity. Generally, 20 to 40% of nitrogen and phosphorus applied to ponds in feed is recovered in 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. 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 from effluents. In cage culture, nitrogen and phosphorus not recovered in fish at harvest enters the water body that contains the cages. Many countries have regulations for aquaculture effluents. These include limits on feed inputs, specifications for site selection, and effluent water quality standards. Aquaculture "eco-label" certification programs that are being established in response to consumer demand for "environmentally-friendly" products may include effluent standards. Compliance with effluent regulations and "eco-label" certification program standards usually require use of best management practices (BMPs) to limit discharge of nitrogen, phosphorus, organic matter, and suspended solids. Examples of 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 voluntarily adopt BMPs independently of regulations or participation in "eco-label" certification. Studies of environmental benefits of regulations, certification, and BMPs are few, but "responsible aquaculture" programs are gaining popularity with wholesalers, retailers, and consumers.

### Introduction

Aquaculture can cause negative environmental impacts most of which can adversely affect biodiversity. Some impacts can be avoided or minimized through rejecting wetlands and other ecologically-important areas as aquaculture sites, relying on farm-reared brood stock and seed stock from hatcheries, rearing native or endemic species, screening pumps to prevent entrainment of small aquatic animals, applying non-lethal predator control techniques, and minimizing chemical and antibiotic use for disease control. However, aquaculture effluents are enriched in nutrients, organic matter, and suspended solids (Naylor et al. 1998; Funge-Smith and Briggs 1998; Tucker and Hargreaves 2008). In addition, culture of marine species in inland ponds can result in saline discharges into surface and underground freshwater (Braaten and Flaherty 2001; Boyd et al. 2006; Pine and Boyd 2011).

The greatest threat of aquaculture to biodiversity likely is eutrophication, sedimentation, and salination in water bodies receiving discharges of production facilities. This chapter focuses on the pollution potential of land-based aquaculture and cage culture in inland waters with particular emphasis on pond aquaculture. Methods for reducing pollution loads from such facilities will be considered.

### Discharge Characteristics of Production Systems

Aquaculture production systems consist of three basic types. In Type 1 systems, propagules of the culture species are "planted" – often on artificial structures – at specific sites and the culture organisms rely upon natural sources of nutrients for growth, e.g., seaweed and bivalve aquaculture. Type 2 systems include ponds, raceways and other flow-through units, cages, and net pens to culture fish and crustaceans. These methodologies typically use fertilizers or feeds to allow greater production than would be possible naturally. Type 3 aquaculture systems comprise the new, highly-intensive, water-recirculating systems that often are located inside greenhouses.

Type 1 systems do not result in increased nutrient inputs. They are not considered to be sources of water pollution, but pollution of water bodies into which Type 1 systems are superimposed can negatively impact the production and quality of the culture species (Shumway et al. 2003; Boyd et al. 2005).

Type 3 systems, in spite of relying on internal water treatment and water recirculation, release effluents of considerable pollutional potential when filters are cleaned or dissolved solids concentration reduced by dilution with source water (Timmons et al. 2002). These systems may someday be commonplace, but they presently represent a minute fraction of global aquaculture production and will not be considered in this report.

The greatest concern over water pollution is directed at Type 2 aquaculture systems – particularly those that use feed to allow greater production than can be achieved naturally or with fertilization to increase natural food availability (Boyd et al. 2005). Although some heavily-manured aquaculture ponds may have high concentrations of nutrients in effluents (Boyd and Tucker 1998), and draining effluents from extensive fish ponds may have elevated concentrations of suspended solids (Banas et al. 2008), the present discussion will focus on feed-based, Type 2 aquaculture systems.

Culture units and methods of water use vary greatly in Type 2 aquaculture, but the most popular units are earthen ponds (Verdegem and Bosma 2009). Many ponds discharge only in response to large rainfall events or when drained for harvest. Ponds that receive stream or spring flow and those to which water exchange is applied discharge frequently or continuously. Of course, water reuse may be applied in pond aquaculture to conserve water and lessen discharge.

The level of production in ponds also varies greatly and depends upon feed input, water exchange rate, and amount of mechanical aeration used. The tendency is towards greater production, e.g., channel catfish (Ictalurus punctatus) production in ponds in the southern United States probably averaged less than 2,000 kg/ha in the early 1970s, but averages were 3,713 kg/ha in 2000 and 5,544 kg/ha in 2010 (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1016). Because all ponds potentially discharge, the tendency towards greater production intensity increases concern over water pollution.

Feed is almost always used in raceways and other flow-through systems as well as in cage and net pen culture. Water retention in these systems is brief compared with that of ponds, and at such facilities, wastes almost immediately enter public waters.

The direct waste load to a culture system from feeding consists of uneaten feed, feces, and metabolic wastes. Typically, about 80 to 90% of feed applied is eaten, and of this, 80 to 90% is absorbed across the intestine. Much of the absorbed material will become metabolic wastes; biomass of the culture species will contain only 10 to 20% of the dry matter added in feed (Boyd and Tucker 1998). The feed conversion ratio (FCR) is the feed input divided by net production. In a culture unit where FCR = 1.7, 1,700 kg feed (90% dry matter) yields 1,000 kg live fish (25% dry matter), the distribution of the added dry matter might be as follows: uneaten feed, 230 kg; feces, 195 kg; metabolic wastes, 855 kg; biomass, 250 kg. The uneaten feed and feces are solids of high organic matter content, but metabolic wastes are mainly carbon dioxide, water, ammonia, and phosphate.

The direct system load of individual feed elements may be estimated by subtracting the amount of an element in harvested biomass from the amount of this element added in the feed. System loads of carbon, nitrogen, and phosphorus for several common aquaculture species are presented (Table 1). Loads for carbon tended to decline as the FCR decreased and ranged from 408 to 951 kg/kg production. The greatest system loads for nitrogen were 90.4 kg/1,000 kg production for black tiger prawn (Penaeus monodon) and 88.4 kg/1,000 kg production for I. punctatus. Nitrogen loads were similar (45.4 to 59.4 kg/1,000 kg production) for the other species. Fish species had phosphorus system loads of 10.0 to 13.0 kg/1,000 kg production. Shrimp that have no bone – bone is made mainly of calcium phosphate – had greater system loads of phosphorus than did fish.

The environmental impacts of aquaculture wastes are assessed for the water bodies receiving the discharges from production facilities. Thus, any wastes assimilated in the culture system or removed by other means are prevented from entering the receiving water pond and do not contribute to the pollution load by an aquaculture facility. Water is retained in ponds for considerable time allowing natural processes to assimilate wastes (Boyd and Tucker 1998). The nutrients released when organic matter is decomposed stimulate additional organic matter synthesis by phytoplankton, but phytoplankton die and are oxidized (Boyd 1985; Boyd and Tucker 1998). Organic matter also settles to the pond bottom to become sediment (Steeby et al. 2004; Boyd et al. 2010). Ammonia nitrogen is oxidized to nitrate by nitrifying bacteria, and nitrate nitrogen that enters anaerobic zones in the pond bottom is denitrified to nitrogen gas that diffuses into the atmosphere (Hargreaves 1998). Ammonia also diffuses from pond water to the atmosphere (Weiler 1979; Gross et al. 2000). Phosphorus contained in solids settles to the bottom, and inorganic phosphorus is strongly adsorbed by pond soil. For example, about 60% of phosphorus applied to experimental ponds at Auburn University over a 22-year period could be accounted for by an increase in bottom soil phosphorus (Masuda and Boyd 1994), and 68% of phosphorus applied in feed to three, commercial shrimp (P. monodon) ponds in Madagascar during a single crop was bound in bottom soil (Boyd et al. 2006).

The percentages of elements applied to ponds in feed that are subsequently discharged in effluents range from 10 to 20% for carbon and from 10 to 40% for nitrogen and phosphorus (Avnimelech and Lacher 1979; Boyd 1985; Pengseng 2007; Schwartz and Boyd 1994; Gross et al. 1998; Gross et al. 2000). Overflow from ponds usually is of relatively good quality, but with higher concentrations of several key variables than typically found in receiving waters (Boyd 1978; Silapajarn and Boyd 2005; Soongsawang 2010). Pond overflow usually is within the following concentration ranges: pH, 7 to 9; dissolved oxygen, > 3 mg/L; total suspended solids, 30 to 120 mg/L; total ammonia nitrogen, 0.3 to 3 mg/L; total nitrogen, 2 to 6 mg/L; total phosphorus 0.1 to 0.5 mg/L; 5-d biochemical oxygen demand, 5 to 20 mg/L. Nevertheless, other than for total suspended solids, pond effluent is relatively mild in comparison to domestic wastewater. For example, Tchobanoglous et al. (2003) reported the average composition of medium-strong domestic wastewater as follows: pH of 6.5 to 8, < 1 mg/L dissolved oxygen, 210 mg/L total dissolved solids, 25 mg/L total ammonia nitrogen, 40 mg/L total nitrogen, 7 mg/L total phosphorus, and 190 mg/l 5-d biochemical oxygen demand.

Draining effluent at harvest has almost constant composition until near completion of draining. During the final stages of draining, crowding of frightened culture animals and operations to capture the animals resuspend sediment. Although pH and dissolved oxygen concentration remained about the same, other variables mentioned above increased in concentration in the final 25% of draining effluent (Boyd 1978; Schwartz and Boyd 1994; Teichert-Coddington et al. 1999; Soongsawang 2010). Nevertheless, with the possible exception of total suspended solids concentration, pond effluents are not highly polluted relative to domestic or other common wastewater sources.

In traditional pond aquaculture, only a small proportion of the pond area and volume is necessary for the culture species – most of the area and volume functions to assimilate waste. Production capacity is restricted by the amount of feed that may be applied without causing water quality to deteriorate below acceptable limits for the culture species (Boyd and Tucker 1998; Boyd et al. 2007). Production capacity is increased by liming acidic ponds to enhance microbial decomposition, applying mechanical aeration to supply supplemental dissolved oxygen for the culture species and to oxidize waste, and water exchange to flush wastes from ponds. Liming and mechanical aeration are beneficial in improving waste assimilation within ponds, but water exchange has the environmentally-undesirable effect of exporting more of the waste load to the outside environment.

Ponds may be lined with plastic to prevent aerator-induced erosion allowing more aeration and greater production. Production may be further intensified by dredging sediment during the crop to reduce oxygen demand within ponds. Moreover, it is common practice in shrimp farming in Asia to wash bottoms of empty ponds between crops with water from high pressure nozzles to remove sediment and reduce oxygen demand (Yuvanatemiya et al. in press ). If sediment removed from a pond by dredging or washing is discharged directly into natural waters, that part of the waste load is exported to the environment.

Pond aquaculture can be highly intensive. For example, the author has experience with a shrimp (Litopenaeus vannamei) farm in Indonesia where yields typically reach 12 to 15 tonne/ha per crop, and an Asian catfish (Pangasius hypohthalmus) farm in Vietnam produces 10,000 tonne/yr in 12 ha of ponds (Boyd et al. in press). In both cases, much of the waste load to the production systems is exported to the environment through water exchange and sediment removal during and between crops. The only way that such high production can be achieved without exporting a considerable waste load is to construct settling and waste treatment ponds on the farm – a practice that received widespread use.
There is research on development of pond systems that permit high production yet treat most of the waste within the pond, e.g., the partitioned aquaculture system (Brune et al. 2003), heterotrophic "floc" system (Browdy et al. 2009), and the split-pond system (Tucker and Kingsbury 2009). Nevertheless, these ponds will discharge after heavy rainfall and when drained for harvest.

In raceway culture, it is possible to screen the lower end of raceway units to exclude fish. This will prevent fish-induced turbulence and allow solids to settle so that they can be separated from the raceway effluent. The solids from the raceway can be concentrated again by sedimentation and applied to the land as a soil amendment (Fornshell and Hinshaw 2008). However, solids that do not settle and dissolved substances are flushed from the raceway into the receiving water. An alternative to raceways are intensive culture units in which water is exchanged with a treatment pond. The wastewater from the culture units is passed through a sedimentation basin and then to the treatment pond. Of course, when heavy rains occur, the treatment pond will discharge. Another variation in raceway culture involves the use of in-pond raceways. Raceways are constructed inside a pond, and a paddlewheel is used to force water through the raceway units. The pond serves as a treatment system for wastes from the raceways and can be used for culture of filter-feeding fish, but again, following heavy rains, the pond will discharge (Brown et al. 2011).

In cage culture, the total system waste load enters the water body containing the cages, and no effective method for capturing and removing these wastes has been devised. Usually, cage farms are located in reservoirs, lakes, or the sea, and the system load is equal to the environmental load. However, cages sometimes are installed in ponds on private property. The pond serves to treat the waste load, but effluent from the ponds will enter public water bodies.

In summary, all Type 2 aquaculture systems will discharge to the environment. The amount of waste discharged per unit of production varies greatly among systems, but concentrations of potential pollutions in aquaculture effluents typically will be greater than their concentrations in the receiving waters (Boyd and Tucker 1998). Efforts to reduce the pollution potential of aquaculture should focus on effective use of feed to reduce input of organic matter and nutrients and implementation of procedures for removing or treating wastes on the farm to lessen the amount discharged to the environment. Potential pollutants will not cause environmental degradation unless they are at high enough concentration to cause adverse impacts in the mixing zone where effluents enter the receiving water or if the load of pollutants exceeds the assimilative capacity of the receiving waters. Attention should be given to both concentrations and loads of pollutants that are discharged from aquaculture facilities.

**Best Management Practices**

There are several opportunities to lessen the pollution potential of aquaculture. An obvious way is to limit feed input and production at a facility. This approach may be needed to avoid pollution of a given body of water, but it does nothing to make aquaculture production procedures less polluting. Methods that can be used to lessen the pollution load per unit of production without limiting the amount of production are needed. This point is critical, because capture fisheries have reached or likely exceeded their sustainable limit, and aquaculture production must increase in the future if the growing human population is to continue to consume fisheries products at the current rate (Boyd 2009a).

More pollution is generated in the culture of some species than in the culture of others, and some culture methods appear to have a greater pollution potential than others. Thus, environmental advocacy groups tend to promote certain culture methods, e.g., ponds versus cages, and the consumption of particular species rather than others. However, the purpose of this report is to consider methods for reducing pollution, and no attempt will be made to encourage use of particular species or culture methods over others.

Aquaculture production consists of applying a number of practices, and a convenient way to promote pollution control techniques is to offer them as best management practices or BMPs (Boyd 2003). A BMP is a practice that is considered to be the best available method for preventing or lessening a specific negative impact (Hairston et al. 1995) – in this case, water pollution by aquaculture. Normally, a single BMP will not be sufficient to reduce pollution to an acceptable level; rather a suite of BMPs will be necessary.

**Feed Quality and Management**

Feed quality and feeding practices are key issues in pollution control, because feed is the primary source of nutrients and organic matter in aquaculture effluents. The objective should be to convert the maximum possible amounts of feed ingredients to aquaculture biomass, because this will conserve resources, reduce feed costs, and lessen the system waste load.

Several factors influence FCR as follows: the contribution of natural food organisms to production; the proportion of the feed that is consumed by the culture animals; the proportion of the nutrients in the consumed food that is absorbed across the intestine; the proportion of the absorbed nutrients that are contained in biomass at harvest. The importance of natural food to production declines as production level increases, but it seldom is possible to adjust FCR values for commercial farms to account for the role of natural food in production. The amount of feed eaten by the culture species declines if fish are stressed by disease or adverse environmental conditions. For example, fish eat and grow less as dissolved oxygen concentration declines (Collins 1984; Torrans 2005, 2008). The proportion of feed absorbed across the intestine is a function of feed digestibility, and the efficiency of conversion of absorbed nutrients to biomass depends upon how well the feed composition matches nutritional requirements. Moreover, the percentage of feed intake used for growth decreases when animals are stressed. This is illustrated by data from Wang et al. (1997) for effects of salinity on common carp (Cyprinus carpio); grown at 0.5 ppt salinity, carp converted 33.4% of their food energy intake to growth as compared to 10.4% at 8.5 ppt salinity. Assuming that environmental conditions are adequate and culture organisms are healthy, high FCR usually is caused by poor quality feed and overfeeding.

Lowering FCR will reduce feed cost and diminish the quantity of feeding wastes that enter the culture system per unit of production. For example, each 0.1-unit reduction in FCR lowers feed input by 100 kg/1,000 kg of production. Assuming that composition of culture animals is unaffected by FCR, the corresponding reduction in outputs in waste for carbon, nitrogen, and phosphorus in kilograms per 1,000 kg production would be equal to the percentage of each element in the feed (Table 2). And, in this example (Table 2), an improvement in FCR from 2.2 to 1.8 would lessen total system waste load by 20.2%, 23.1%, and 27.7% for carbon, nitrogen, and phosphorus, respectively. The reduction in carbon would be of particular importance in lessening the amount of organic waste entering the system, because it would result primarily from a smaller amount of uneaten feed.

In addition to lowering FCR, system loads of nitrogen and phosphorus can be lessened by using feed with adequate, but not excessive, nitrogen and phosphorus. For example, reducing the crude protein content of feed by 1% (0.16% reduction in nitrogen) at an FCR of 1.8 would lessen system nitrogen load by 2.88 kg/1,000 kg production (Table 3). The corresponding reductions in system phosphorus load caused by a 0.1% reduction in feed phosphorus concentration would be 1.8 kg/1,000 kg production (Table 3). Most feeds have similar organic carbon concentrations, and it likely is not feasible to change carbon concentration appreciably.

**A list of BMPs for feed quality and feeding follow:**

- Feed should be of good nutritional value but contain no more nitrogen and phosphorus than necessary to meet the nutritional needs of the culture species.
- Feed should be of pellet size appropriate for its use and not contain a large proportion of fines (unconsolidated feed ingredients too small to be consumed by the culture animals).
- Store feed by batch in a cool, dry place, and use each batch before its expiration date.
- Apply feed by spreading it over the culture area.
- Avoid feeding more feed than the animals can consume. For species that feed at the surface, use of floating pellets can greatly facilitate monitoring of feeding activity. Feeding trays can be used to monitor feeding activity of organisms that feed on the bottom.
- With some species, feed should be applied several times per day.
- Uneaten feed pellets in corners of production units should be removed manually.
- Screen fish from the downstream end of raceway units so that uneaten feed and feces will settle allowing them to be separated from the effluent.

**Effluent Management**

Overflow following rainfall events is a major cause of discharge from production facilities. Watershed ponds are formed by damming watercourses and capturing runoff. The ratio of pond watershed area to pond storage capacity determines overflow volume and hydraulic retention time (HRT) in watershed ponds (Yoo and Boyd 1994). The HRT is of interest in pollution control, because a long HRT favors natural assimilation of wastes within ponds to lessen the amount of waste discharged (Boyd and Tucker 1998).

Maps depicting annual runoff amounts across the United States are available, and a number of other procedures can be used to make more exact assessments of runoff from specific watersheds (Yoo and Boyd 1994). Runoff data and estimates of seepage and evaporation allow pond size to be matched with runoff supply to avoid excessive flushing. Many ponds, nevertheless, have a larger ratio of watershed area:storage volume than desirable. Runoff often may be diverted from the pond by ditches, terraces, or a combination thereof (Boyd et al. 2003).

Embankment ponds are formed by levees around the area in which to impound water from wells, streams, or other external sources. Such ponds receive little runoff, because watershed area consists only on tops and above water slopes of inner levees. In embankment ponds, maintaining water level 15 to 20 cm below the tops of overflow structures (Fig. 1) captures most rainwater entering ponds and avoids overflow (Boyd 1982; Cathcart et al. 1999). This procedure for managing pond water levels is commonly referred to as the drop-fill method (Tucker and Hargreaves 2006). The drop-fill method also is effective during drier parts of the year in avoiding overflow from watershed ponds following normal storms.

Excavated ponds are made by digging a hole in the ground, and they seldom overflow. These ponds are uncommon except for small-scale aquaculture in Asia in which feed seldom is used.

Reduction in water exchange also lessens the amount of effluent from ponds, and lengthens the HRT. Consider a pond that is 1.2 m deep and operated at an average water exchange rate of 10% of pond volume per day. Assuming that rainfall and evaporation are roughly equal during a 100-d crop, the total effluent resulting from water exchange would be 120,000 m3 per day and the HRT would be 10 d. However, if water exchange could be reduced to 2%, the amount of effluent would be only 24,000 m3 and the HRT would be 50 d.

In some types of aquaculture, animals can be harvested by seining and without draining ponds (Boyd et al. 2000). Where it is possible, this practice should be encouraged. If ponds are drained for harvest, the effluent changes in composition during draining. If ponds are drained from the bottom, the velocity and turbulence of water entering the discharge structure will resuspend sediment resulting in increased suspended solids until the area around the structure is swept clean (Hargreaves et al. 2005). However, regardless of whether ponds are drained from the surface or the bottom, effluent will become more elevated in suspended solids during the last 20 to 25% of drawdown because of the harvest activity and the movements of frightened fish or shrimp (Boyd 1978; Schwartz and Boyd 1994; Teichert-Coddington et al. 1999). It is sometimes possible to close the drain during the final stages of harvest, and remove animals by seining or dipping. The water can then be held for 1 or 2 d for sedimentation of solids and then released slowly to avoid resuspension of solids. Of course, final draining effluent could be passed through a sedimentation basin to remove suspended solids.

Water from a pond may be pumped to an adjacent pond during harvest operations and then returned after harvest. A reservoir also may be used to facilitate harvest without discharge of effluent to natural waters (Fig. 2).

In pond aquaculture systems, practices that encourage the assimilation of wastes should be applied. Use of adequate mechanical aeration is particularly important in oxidizing organic matter and ammonia. The feed BOD is the amount of dissolved oxygen required to oxidize the organic matter and nitrogen added in feed but not recovered in fish at harvest (Boyd 2009b). The feed BOD usually is about 1.2 kg oxygen/kg feed. The amount of aeration required to oxidize feeding waste and maintain dissolved oxygen concentration above 3 mg/L in a system without waste removal, e.g., a typical pond, is about 1 hp aeration for each 20 kg ha/d of feed input.

Erosion results from wave and wind action, rainfall erosion of pond embankments, erosion of inlet and outlet canals by water currents, aerator-generated water currents, and bioturbation. Suspended soil particles from erosion contribute to total suspended solids in effluents. Moreover, the water supplies for ponds may contain high concentrations of suspended solids.

If farms have control over watersheds, erosion on watersheds can be minimized by grading of steep, erosion-prone areas and installation of vegetative cover. Turbid runoff from specific areas may be diverted by terraces or ditches. However, where farms have no control over watersheds, the only option often is to use a sedimentation basin to remove solids from incoming water before transferring it to ponds. Farm infrastructure can be a source of erosion and suspended solids. Erosion control should begin at the farm design and construction stages. Side slopes of embankments and canals and bottom slopes of canals should be in accordance with soil properties. Guidelines for design of embankment slopes and sides of canals can be found in Yoo and Boyd (1994). It is particularly important to compact soil well at its optimum moisture content. The standard Proctor test may be used to ascertain the optimum moisture content for compaction, but the usual optimum moisture values are 6 to 10% for sand, 8 to 12% for mixtures of sand and silt, 11 to 15% for silt, and 13 to 21% for clay (Boyd 2008). Embankments should be planted with grass, and highly-vulnerable areas should be reinforced with rip-rap, gabion, geofabric, or other material.

Aerators should be installed at least 1 m beyond the inside toes of embankments, and they should not impinge water currents against embankment. Aerators also should be in water of at least 1 m depth. Areas that are susceptible to aerator erosion should be reinforced with stone or geofabric.

Resuspension of sediment from empty ponds by rainfall can be a source of suspended solids. Pond drains should be closed after harvest to avoid discharge after rainfall events while ponds are empty. Effluent from washing pond bottoms with high-pressure streams of water is particularly concentrated in suspended solids and should be held in a sedimentation basin before release to the environment.

Sedimentation basins detain water to provide time for suspended solids to settle from effluent before final discharge to natural waters. The HRT needed for removal of particles of a specific size by sedimentation can be estimated using the Stoke's Law equation (Boyd 1995). The settling velocity of particles depends upon several factors, but particle diameter and particle density are the most important. Settling velocities of fine sand, silt, and clay size particles are 2.3 × 10-3, 9 × 10-5, and 9 × 10-7 m/sec, respectively. The critical settling velocity is the minimum settling velocity necessary for a particle to settle before flowing out of a sedimentation basin (Fig. 3). The critical settling velocity is related to settling pond inflow rate and areas:

$$V_{cs} = \frac{Q}{A}$$

where Vcs = critical settling velocity (m/sec), Q = inflow (m3/sec), and A = surface area (m2). If it is desired to remove the particles with critical settling velocities of < 9 × 10-5 m/sec from a discharge 0.11 m3/sec, a 1 m deep settling basin would need an area of 1,222 m2 to provide sufficient HRT for sedimentation. However, settling basins should be larger than the minimum size by at least 50% to allow sediment storage and maintain sufficient HRT.

Sand and coarse silt particles can be removed effectively by sedimentation, but a long HRT is necessary to remove clay particles. For example, it would require a 122,222 m2 settling basin to remove clay particles (Vcs = 9 × 10-7 m/sec) from a discharge of 0.11 m3/sec. Organic particles and particularly plankton have a low particle density relative to mineral particles. Thus, organic matter usually cannot be removed effectively from pond effluents by sedimentation (Boyd and Queiroz 2001b; Ozbay and Boyd 2003). However, as mentioned earlier, uneaten feed and feces can be removed from trout raceways by sedimentation.

There are guidelines for effective operation of settling basins. Effluent should enter at the surface on one side and exit at the surface on the opposite side (Fig. 3). A baffle can be installed in a basin to prevent the effluent from passing directly from the inflow point to the outflow point. Mechanical aerators or other devices that mix water should not be placed in settling basins for the turbulence they create will inhibit sedimentation. If aeration of final discharge is required, it should be done in a separate basin.
Settling basins will fill with solids over time, and sediment removal is occasionally necessary to maintain HRT. Sediment removal will resuspend solids, and it is desirable to construct dual settling basins so that one may be operated while the other is being cleaned. Sediment removed from settling basins or

production ponds can cause environmental degradation. Sediment piles create an ecological nuisance by disrupting or destroying natural vegetation, and rainfall erosion of sediment piles can lead to turbid runoff. Sediment from ponds with saline water has a salt burden, and salt leached by rainfall can lead to salination of soils, surface water, and groundwater (Boyd et al. 1994).

Sediment removed from settling basins, ponds, or canals should be confined in a bunded area with enough storage volume to avoid overflow after rains. After solids resuspended by rainfall have resettled, standing water can be left to evaporate or slowly drained away with care to avoid resuspension of solids.

Sediment usually consists of sand and silt particles, and it is not of good quality for repairing erosion damage to farm earthwork or for new construction. However, it can be used for earth fill, and non-saline sediment may be spread over agricultural land and incorporated into the soil.

Inland ponds in freshwater areas that are filled with saline water or coastal ponds that are constructed above a freshwater aquifer are particularly likely to cause salination. Such ponds probably should be lined with plastic membranes, but at least, they should not be constructed on highly-permeable soil (Boyd et al. 2006). Because ponds will likely seep regardless of precautions taken to prevent seepage loss, they should be constructed as far as possible from freshwater streams (Pine and Boyd 2011). A lined ditch with bottom elevation deeper than pond bottoms can capture lateral seepage from ponds and avoid salination of nearby surface soils. Water reuse should be practiced for inland, saline water aquaculture. When such farms must discharge water, the water should be discharged slowly to avoid large spikes in salinity of the receiving water body.

**BMPs for pond effluent management will be summarized:**

- Watersheds for ponds should not be excessively large in relation to pond storage capacity.
- If the watershed is too large, a portion of the runoff should be diverted by terraces or ditches where possible.
- Ponds should be operated to retain as much direct precipitation and storm runoff as feasible.
- Water exchange should be reduced or ceased.
- Water reuse by harvesting without draining or by water transfer among ponds or among ponds and a reservoir should be practiced.
- Use adequate aeration to avoid dissolved oxygen concentration below 3 mg/L in ponds for warmwater species and 5 mg/L for coldwater species.
- Apply liming materials to acidic ponds to maintain total alkalinity of 40 mg/L or more.
- For new facilities, expansions, or renovations, design earthwork slopes in accordance with soil properties and compact embankments well.
- Establish grass cover on earthwork and reinforce erosion-prone areas with rip-rap, gabion, or geofabric.
- Control erosion on watersheds where possible.
- Install aerators so that resulting water currents do not impinge on embankments or bottoms to cause erosion and resuspend solids.
- Where water supply is highly turbid, provide a sedimentation area for incoming water.
- Treat highly-turbid effluents by sedimentation before final discharge into public waters.
- Construct sedimentation basins with adequate hydraulic retention time to remove coarse soil particles, and operate basins according to procedures that facilitate sedimentation.

- Dispose of sediment from sedimentation basins in a responsible way.
- Do not discharge effluent into stagnant areas.
- Protect areas around outfalls from erosion.
- Do not site ponds for saline-water aquaculture on sandy or other highly-permeable soils in freshwater areas, or line pond bottoms to avoid infiltration.

When it is necessary to release saline effluent into freshwater, discharge slowly to avoid a spike in salinity of receiving stream.

**Site inland, saline water ponds as far as possible from freshwater streams.**
Although fertilized ponds are not usually considered a serious source of pollution, animal manures, other organic materials, and chemical fertilizers should not be applied in amounts that exceed the assimilative capacity of ponds leading to water quality deterioration. The BMPs for effluent management mentioned above also can be used in ponds to which feed is not applied.

**Government Regulations**
Many governments have made regulations for aquaculture; aquaculture regulations for 47 countries have been posted on the website for the FAO Department of Fisheries (http://www.fao.org/fishery/statistics/software/fishstat/en), and most country-level regulations include restrictions on aquaculture effluents. The most common restriction is water quality concentration limits for effluents, but there also may be limits on pollutant loads, allowable increases in pollutant concentrations, mandated use of BMPs, or some combination of these measures.

**Simple concentration limits**
The most common variables and corresponding concentration limits used in aquaculture effluent discharge permits are as follows: pH, 6-8.5; dissolved oxygen, ≥ 5.0 mg/L; temperature, ≤ 5oC above ambient; total nitrogen, 2 to 10 mg/L (depending upon quality of receiving water); total phosphorus, 0.2 to 0.5 mg/L (depending upon quality of receiving water); TSS, ≤ 20 to 50 mg/L (depending upon quality of receiving water); BOD5, ≤ 20 to 50 mg/L; salinity, ≤ 500 mg/L when discharged into freshwater (Boyd et al. 2007).

Simple concentration limits can reduce the amount of a pollutant discharged by a facility, but without restrictions on discharge volume, a facility could reduce effluent concentrations enough to comply with standards by increasing water inflow to dilute pollutants without lessening the total amounts of pollutants discharged in effluent. The major benefit of simple concentration limits is to avoid negative impacts of pollutants in the area around the wastewater outfall where the effluent mixes with the receiving water and where coarse suspended solids particles settle. The effluent to which simple concentration limits have been applied could still cause eutrophication and other pollution problems in the receiving water body.

**Pollutant loads**
The load of a pollutant is calculated from concentration and volume, e.g., an effluent containing 20 mg/L BOD5 discharged at 1,000 m3/d has a daily BOD5 load of 20 kg/d (20 g/m3 × 1,000 m3/d × 10-3 kg/g). The pollutant load is important because the receiving water has a finite capacity to assimilate wastes and maintain acceptable water quality (Beveridge 1984; Ward 2006; Ward et al. 1999). In the United States, there is an undergoing effort to determine the permissible, total maximum daily loads (TMDLs) of pollutants for streams and other water bodies, and some other nations are making similar efforts. Nevertheless, there are few places in the world where the assimilative capacities of water bodies that receive aquaculture effluents are known. Arbitrary assignment of a load limit can cause an aquaculture facility to reduce its pollution load, but this does not assure that the facility will not cause a pollution problem in the receiving water body.

Even if TMDLs (or assimilative capacity) of water bodies are known, aquaculture seldom is the only source of pollutants. To effectively use TMDLs or assimilative capacity, all waste load sources must be evaluated. If the combined load of one or more pollutants is excessive (exceeds the TMDL or assimilative capacity), the permissible, total waste loads of those pollutants should be allocated among the different sources. A highly concentrated effluent that is discharged at low volume may have acceptable daily loads of pollutants. However, to avoid negative impacts near the wastewater outfall, simple concentration limits usually are included with the load restrictions.

**Delta-based standards**

The practice of restricting concentrations of pollutants to a specific level of increase, e.g., a percentage of the ambient concentration of variables that exist in the receiving water is possibly superior to arbitrary load limits where the assimilative capacity is unknown. However, restricting concentrations of pollutants in aquaculture effluents to the same concentrations found in inflow or to the concentrations in the receiving water is not realistically achievable except possibly for TSS concentration. There are facilities with highly-turbid water sources that discharge a lower concentration of TSS than received in inflow (Wahab et al. 2003). This results because solids settle out in the production units. Settleable solids also can be effectively removed by sedimentation. However, concentration of nutrients, BOD5, and TDS typically increase in production units and cannot be removed effectively by sedimentation. More advanced wastewater treatment techniques usually are not cost-effective for treating aquaculture effluents.

**BMPs**

The United States Environmental Protection Agency (USEPA) developed an aquaculture effluent rule, but for most types of aquaculture, effluent limitation guidelines were not established for most culture systems (Federal Register 2004). The main reasoning seemed to be that aquaculture effluents do not appear to cause a serious pollution load to waters of the United States, and affordable treatment technology is not available. Facilities were classified as concentrated aquatic animal production (CAAP) facilities based on specifications listed in Table 4, and CAAP facilities must obtain a National Pollutant Discharge Elimination System (NPDES) permit, but usually without effluent standards. Most facilities apparently would not be required to apply BMPs, but BMPs were recommended.

The effectiveness of aquaculture BMPs has not been thoroughly evaluated, but they are based on sound scientific principles and usually thought to provide benefits in reducing pollution. A recent study was conducted of applications of a suite of BMPs in channel catfish ponds in Mississippi: use of reduced protein content feed (28% versus 32%); limiting daily feed input (110 kg/ha versus ad libitum feeding); moderate stocking rate (18,500 fish/ha versus 24,700 fish/ha); drop-fill water management versus refilling according to manager's judgment (Tucker and Hargreaves 2006). Fish production was not significantly different ($P > 0.05$) between treatment – 6,425 kg/ha in BMP ponds versus 6,250 kg/ha in non-BMP ponds. The BMP ponds had 50% less overflow after rains and used 60% less groundwater for maintaining water levels than did the non-BMP ponds. Moreover, phosphorus discharge in effluent from BMP ponds was only 30% of that from non-BMP ponds. This study certainly suggests that BMPs are effective, but additional studies of other species and a wider range of BMPs are needed.

**Aquaculture Eco-labeling Programs**

An important component of effects to improve the sustainability of aquaculture has been the development of voluntary BMP programs, buyer purchasing policies or standards, and certification standards for eco-label products. Organic certification programs for aquaculture also have an environmental component. These programs have been promoted as providing the consumer with a greater level of assuring that a particular aquaculture product has been produced by environmentally- and socially-responsible procedures. Voluntary BMP programs are not verifiable, but buyer programs and certification programs require producers to apply specific BMPs or to comply with verifiable standards. Prevention of water pollution and protection of biodiversity are major objectives in responsible aquaculture programs.

There is much hope for aquaculture certification within environmental advocacy circles. The Marine Aquaculture Task Force (2007) stated that "eco-labeling and certification have potential to significantly improve the sustainability of aquaculture production practices." Aquaculture certification is making an impact in the market. Boyd and McNevin (2011) reported that about 1,400,000 tonne of aquaculture products are currently certified annually. The largest part of the certified products is shrimp, but certification is extending to tilapia, Pangasius spp., channel catfish, and a variety of other species.

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Table 1. System loads of carbon, nitrogen, and phosphorus for six aquaculture species. Source: Modified from Boyd and Queiroz (2001a) and Boyd et al. (2007).

| | | | | | | | | Waste load | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed (%) | | | Typical | Whole body composition (%) | | | (kg/1,000 kg fish) | | | (% of feed input) | | |
| Species | C | N | P | FCR | C | N | P | C | N | P | C | N | P |
| Channel catfish *Ictalurus punctatus* | 48 | 5.1 | 0.9 | 2.2 | 10.5 | 2.38 | 0.68 | 951 | 88.4 | 13.0 | 90 | 79 | 66 |
| Blue tilapia *Oreochromis aureus* | 48 | 4.8 | 1.0 | 1.7 | 10.9 | 2.22 | 0.70 | 707 | 59.4 | 10.0 | 87 | 73 | 59 |
| Atlantic salmon *Salomo salar* | 48 | 7.0 | 1.3 | 1.1 | 12.0 | 2.96 | 0.40 | 408 | 47.4 | 10.3 | 77 | 62 | 72 |
| Rainbow trout *Oncozhynchus mykus* | 48 | 6.4 | 1.3 | 1.1 | 12.0 | 2.50 | 0.35 | 408 | 45.4 | 10.8 | 77 | 65 | 75 |
| Pacific white shrimp *Litopenaeus vannamei* | 48 | 5.6 | 1.2 | 1.5 | 11.7 | 2.86 | 0.32 | 603 | 55.4 | 14.8 | 84 | 66 | 82 |
| Black tiger prawn *Penaeus monodon* | 48 | 6.7 | 1.5 | 1.8 | 12.4 | 3.02 | 0.25 | 740 | 90.4 | 24.5 | 86 | 75 | 91 |

Table 2. Effects of feed conversion ratio (FCR) on system loads of carbon, nitrogen, and phosphorus per tonne of production in channel catfish ponds.

| FCR | Carbon (kg/tonne) | Nitrogen (kg/tonne) | Phosphorus (kg/tonne) |
|---|---|---|---|
| 2.20 | 951 | 88.4 | 13.0 |
| 2.10 | 903 | 83.3 | 12.1 |
| 2.00 | 855 | 78.2 | 11.2 |
| 1.90 | 797 | 73.1 | 10.3 |
| 1.80 | 759 | 68 | 9.4 |
| 1.70 | 711 | 62.9 | 8.5 |
| 1.60 | 663 | 81.6 | 7.6 |
| 1.5 | 615 | 76.5 | 6.7 |

Feed composition: 48% C; 5.1% N; 0.9% P.

Fish composition: 10.5% C; 2.38% N; 0.68% P.

Table 3. Effect of reducing concentration of crude protein (%N × 6.25) and phosphorus in feed at a feed conversion ratio of 1.8 on system waste loads of nitrogen and phosphorus.

| Feed crude protein (%) | Feed nitrogen (%) | System N load (kg/1,000 kg fish) | Feed phosphorus (%) | System P load (kg/1,000 kg fish) |
|---|---|---|---|---|
| 32 | 5.12 | 68.36 | 1.2 | 14.8 |
| 31 | 4.96 | 65.48 | 1.1 | 13.0 |
| 30 | 4.80 | 62.60 | 1.0 | 11.2 |
| 29 | 4.64 | 59.72 | 0.9 | 9.4 |
| 28 | 4.48 | 56.84 | 0.8 | 7.6 |

Fish composition: 38% N; 0.68% P.

Table 4. United States Environmental Protection Agency definitions of warmwater and coldwater concentrated aquatic animal production (CAAP) facilities.

| |
|---|
| Warmwater CAAP Facilities |
| Includes ponds, raceways, or other similar structures which discharge at least 30 days per year but does not include:<br>• Closed ponds which discharge only during periods of excess runoff<br>• Facilities which produce less than 45,454 harvest weight kilograms per year |
| Coldwater CAAP Facilities |
| Includes ponds, raceways, or other similar structures which discharge at least 30 days per year but does not include:<br>• Facilities which produce less than 9,090 harvest weight kilograms per year<br>• Facilities which feed less than 2,272 kg during month of maximum feeding |

Figure 1. Photograph illustrating the drop-fill method for water replacement. When water is added to restore evaporation and seepage losses, the water level is not increased to the level of the overflow intake to provide capacity to store rainfall and runoff.

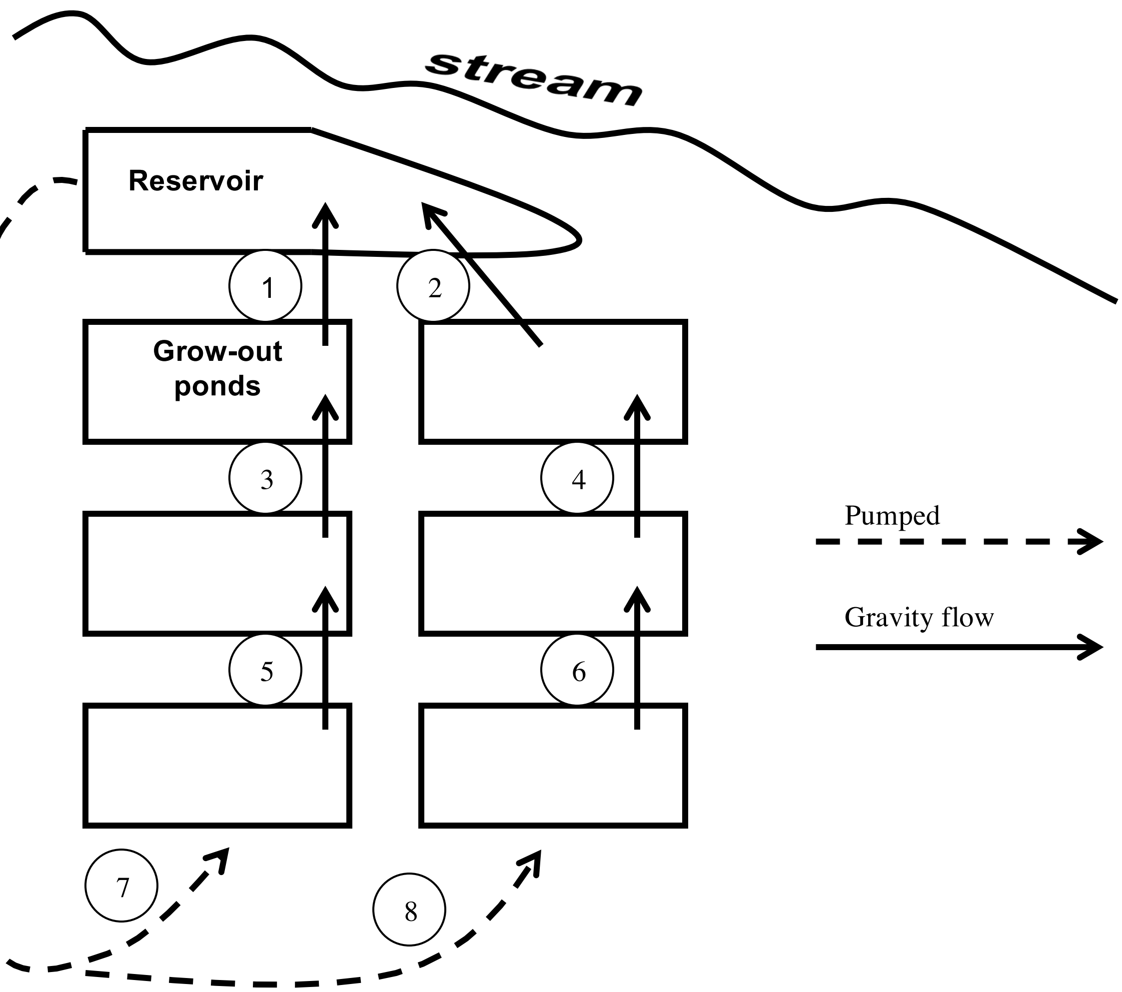


Figure 2. Use of reservoir to avoid discharge when ponds are drained for harvest.

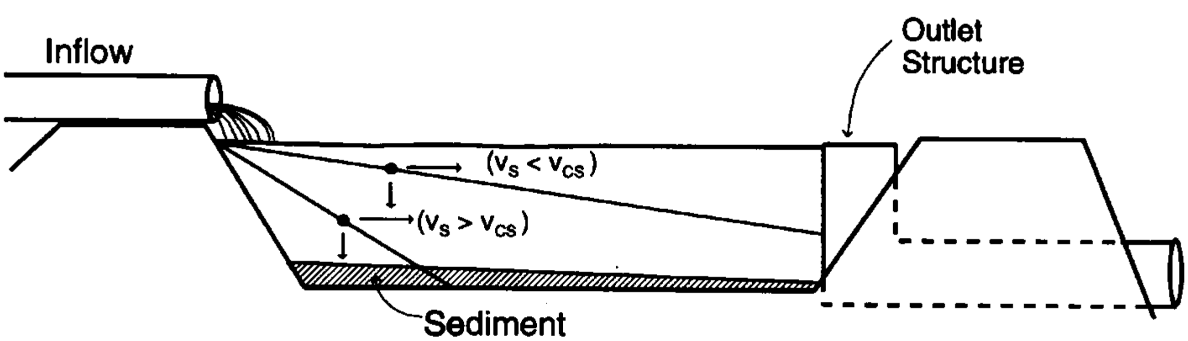


Figure 3. A sedimentation basin.

## TRANSBOUNDARY AND EMERGING DISEASES OF FRESHWATER FARMED, ORNAMENTAL AND WILD FISH

*Melba G. Bondad-Reantaso, PhD, Food and Agriculture Organization of the United Nations;Rohana P. Subasinghe, PhD, Food and Agriculture Organization of the United Nations;Hang'Ombe Bernard Mudenda, DVM, University of Zambia*

**Abstract**

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.

Food and Agriculture Organization of the United Nations

*Seattle, Washington,*
*8 September 2011*

# Transboundary and Emerging Freshwater Finfish Diseases In Farmed, Ornamental and Wild Fish

**Melba G. Bondad-Reantaso, Rohana P. Subasinghe and Hang'Ombe Bernard Mudenda**

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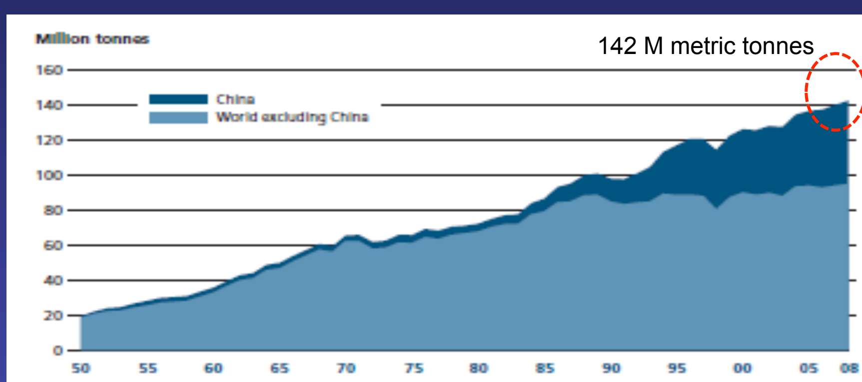
- Prof J. S. Diana
- Ms B. Diana
- Drs Angus Cameron and Agus Sunarto

## Outline

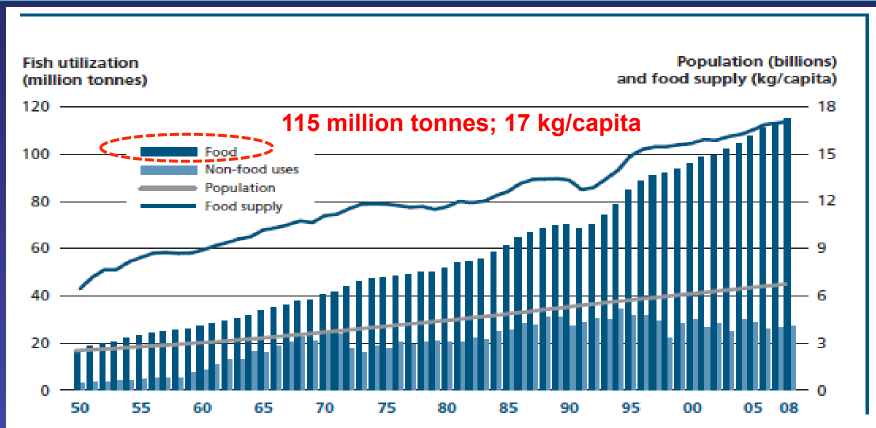
- **World fish production, aquaculture production**
- Fish disease as contraint to aquaculture development
- Transboundary aquatic animal diseases (TAADs)
  - – epizootic ulcerative syndrome (EUS)
  - – koi herpesvirus (KHV)
- Lessons learned from investigation of TAADs
- Future outlook and few last thoughts

## World capture fisheries and aquaculture production (2008)




(Source: FAO SOFIA 2010)

## World fish utilization and food supply

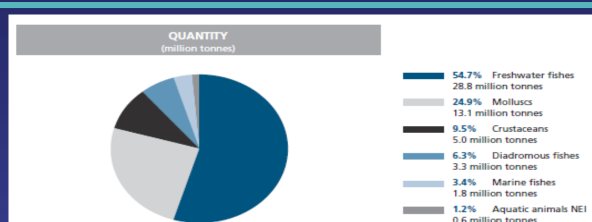


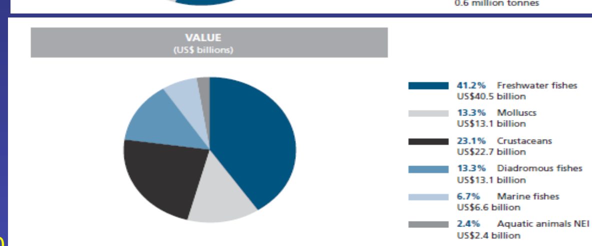

(Source: FAO SOFIA 2010)

## World aquaculture production: major species group in 2008

54.7% freshwater fishes
28.2 million tonnes

41.2 % freshwater fishes
USD 40.5 Billion




Source: FAO SOFIA 2010

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## What are TAADs?

highly contagious/transmissible **(infectious!)**

potential for very rapid spread irrespective of national borders **(no passport!)**

cause serious socio-economic consequences **(high risk and high impact!)**

OIE lists more than 30 aquatic pathogens/diseases which fit established criteria for listed diseases in terms of consequence, spread and diagnosis **(important to trade!)**

## Reasons for international trade in live aquatic animals (Arthur, 2004)

**live food market (seafood restaurants):** from producing countries to consuming countries

**aquaculture development or sustainment:** shipment of all stages (gametes, fertilized eggs, fry, fingerlings, spat, broodstocks)

**ornamental fish trade**

- 2 000 species moved annually, 10 M ornamental marine fish (70-100 MT) imported globally; 1993-1997 value of ornamental fish imports to EU = Euro 67 B; highly unregulated; involves high amount of transhipment

**other reasons** (development of capture and sport fisheries, use of bait and as biological control agent, research, development assistance)

Different goals and pathways - ***Involve different***

## Factors contributing to the current disease problems in aquaculture

intensification of aquaculture throug broodstock, post-larvae, fry and

global distribution of shrimp diseases

KHV

development and expansion of the ornamental fish trade

misunderstanding n free (SPF) stocks

exemplified by Taura syndrome, IMNV of SPF *Litopenaeus stylirostris*

slow awareness on emerging disea

KHV in Indonesia and EUS incursion in Africa

inadequate or poorly implemented biosecurity measures

exemplified by *Kudoa amamiensis*

unanticipated negative interactions between cultured and wild fish p

pilchard mortalities and feeding with live or fresh food as pathway

# 2 examples of TAADs

- Example 1: National spread of KHV: case of Indonesia: ornamental to cultured to wild fish populations
- Example 2: International spread of epizootic ulcerative syndrome (EUS) and emergence in southern Africa 10 years after the last major outbreak in Asia

# Koi herpes virus (KHV)

Koi carp (high value ornamental fish – one piece can cost as high as USD 100 000)
Common carp – an important food fish

## March 2002

## April 2002

## June 2002

## August 2002

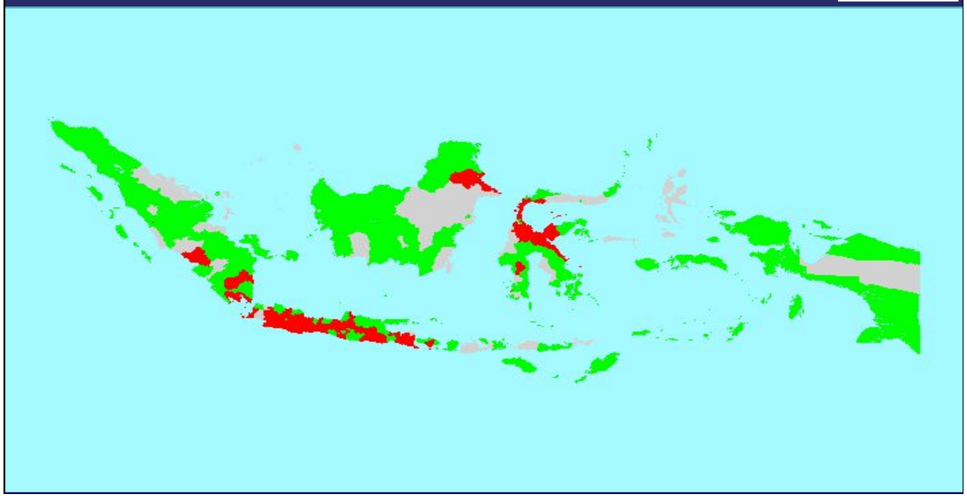
## September 2002

## November 2002

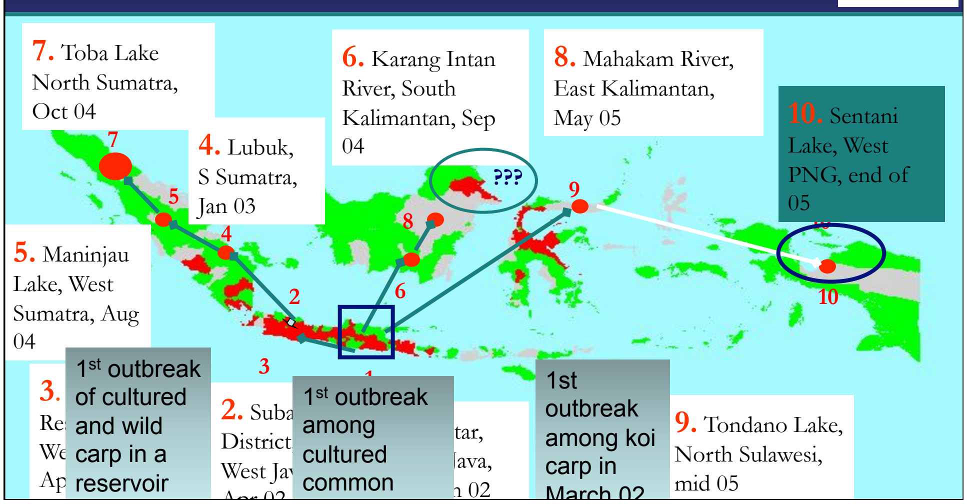
## December 2002

## January 2003

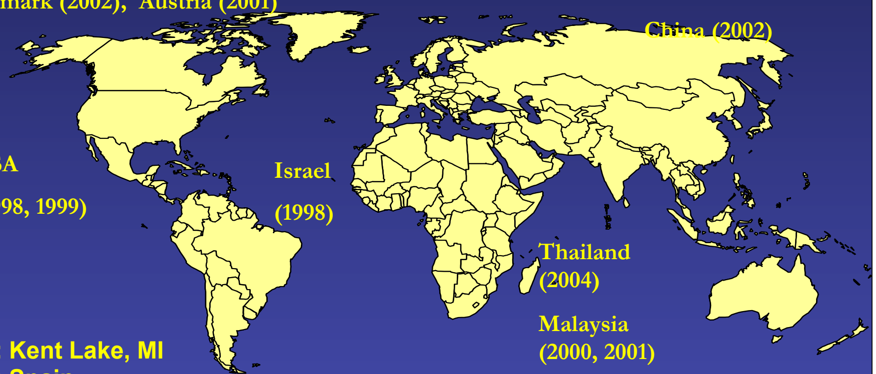
## February 2003



## Episodes of 10 Major Outbreaks



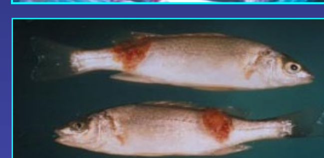
# Global distribution of KHV

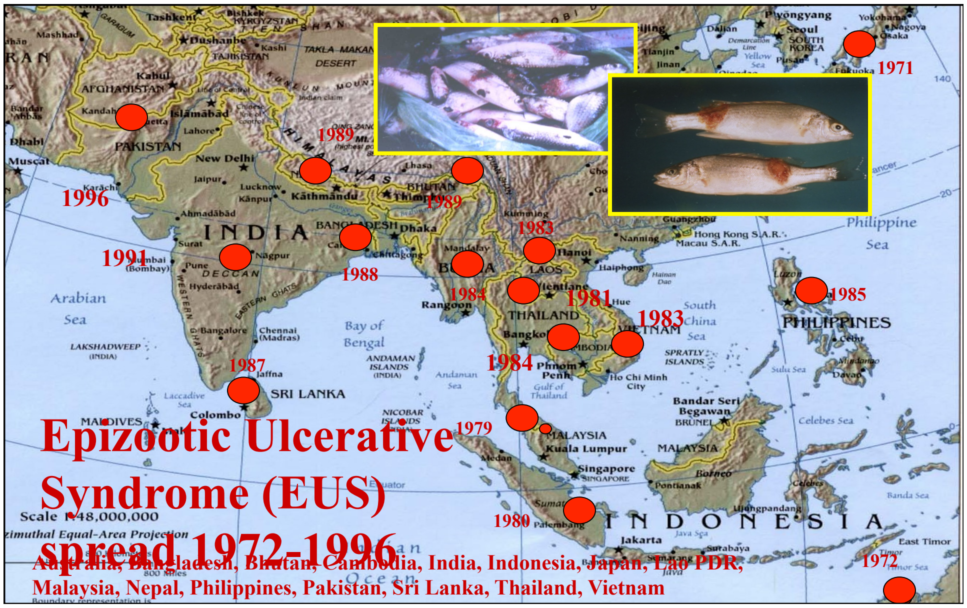



# EUS: international spread and emergence after 10 years in southern Africa

Baldock *et al.*, 2005; FAO, 2007/2008

- 1971 first described in Japan as an *Aphanomyces* (fungal) infection (Egusa and Masuda, 1971): mycotic granulomatosis (MG)
- 1972 epizootic cutaneous ulcerative syndrome in estuarine fishes in Australia: red spot disease (RSD)
- since 1978 USA: ulcerative menhaden disease (UM)
- 1986: major outbreaks since 1985 in Asia
  - Epizootic ulcerative syndrome (EUS)
- 2002 (Australia, Diseases in Asian Aquaculture V)
  - Epizootic granulomatous aphanomycosis

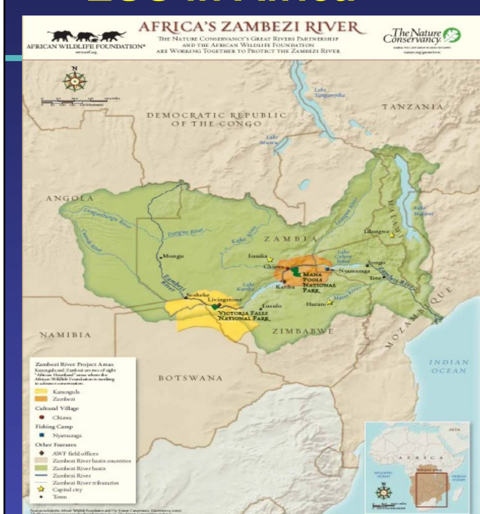





# Epizootic Ulcerative Syndrome (EUS) spread 1972-1996

Australia, Bangladesh, Bhutan, Cambodia, India, Indonesia, Japan, Lao PDR, Malaysia, Nepal, Philippines, Pakistan, Sri Lanka, Thailand, Vietnam

# EUS in Africa



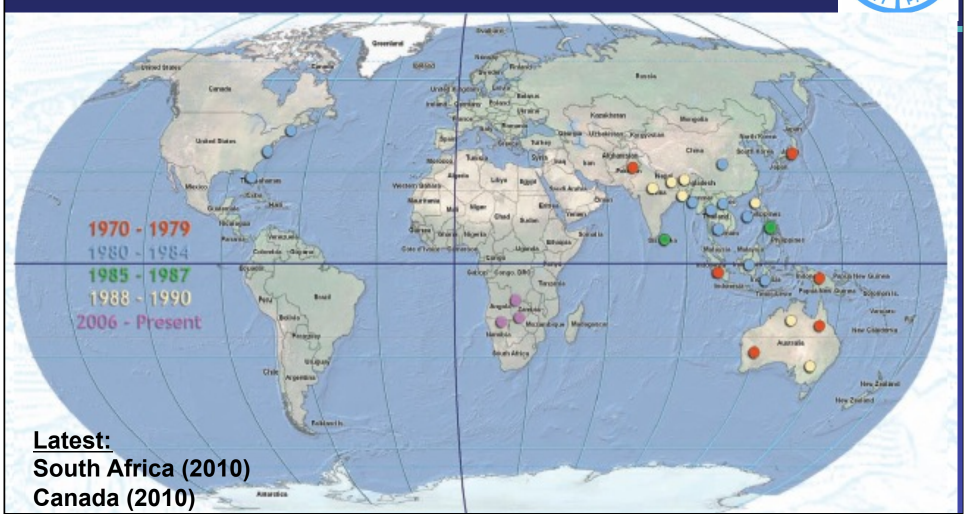

- Zambezi River is the 4th longest river in Africa
- River flows through Angola, Zambia, Namibia, Botswana, Malawi, Zimbabwe and Mozambique
- 32 million people inhabiting the river valley; 80 percent dependant on agriculture; heavily fished
- River is important for local livelihood, riverine fish for food and nutrition, recreational angling
- Home to more than 200 fish species

## EUS incursion in southern Africa


Site (lower tip of the balloon, Kasane, Chobe River, Botswana) sampled and confirmed as EUS positive during the May 2007 Task Force outbreak investigation (courtesy of F. Corsin).


Showing the EUS-confirmed (red balloons), EUS-suspected (yellow balloons) and EUS-negative (blue balloons) as reported during the follow-up surveillance activities conducted in 2007 and 2008 (courtesy of F. Corsin)

## Where is EUS now?




**Latest:**
**South Africa (2010)**
**Canada (2010)**

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## Lessons learned from KHV and EUS outbreak investigations

- Important: Emergency response, surveillance, reporting/notification
- Essential: Knowledge base and capacity: diagnostics, epidemiology, biosecurity, risk analysis
- Required: Investments in biosecurity and aquatic animal health infrastructure, human capacity, regulatory frameworks and partnerships
- Consider: Biodiversity and health of native fish populations

## Biodiversity and health of native fish populations

- **<u>Possible extinction of species may be one of the effect of EUS on native populations</u>**
- Continuous occurrence of EUS on an annual basis may have negative effect on the population of affected and susceptible wild species
- Eastern United States, outbreaks of ulcerative menhaden disease (UM, now known as EUS) in the 1980s had a significant impact on the productivity of the estuarine fisheries (Noga *et al*., 1988)
- In Asia, reports of reduction in production from aquaculture (Subasinghe, 1997) and catches or landings from capture

## Biodiversity and health of native fish populations

- Interactions between wild and cultured fish populations are important concerns for aquaculturists, AAH and NR conservation specialists
- Disease is a result of the complex interaction between the host, the pathogen and the environment (Snieszko, 1974)
- Certain essential criteria in order for a disease to spread from either cultured fish or vice-versa:
  - presence of pathogen in both fish and water source;
  - presence of susceptible host;
  - viability in terms of number and longevity of pathogen in the

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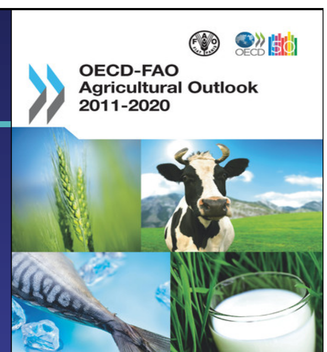
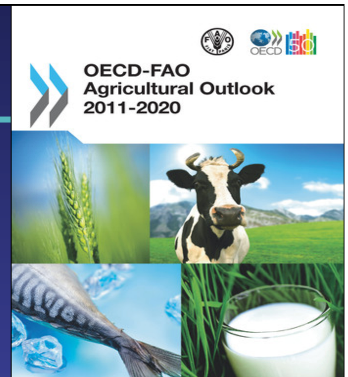
## Growth of fisheries based on aquaculture

- The **fisheries sector**, which is covered for the **first time in this Outlook**, is projected to **increase its global production by 1.3% annually to 2020**, slower than over the previous decade due to a lower rate of growth of aquaculture (2.8% against 5.6% for 2001-2010) and a reduced or stagnant fish capture sector.




**17th edition and the 7th co-edition prepared jointly with the FAO.**
**• World market trends for biofuels, cereals, oilseeds, sugar, meats, dairy products and, for the first time, the fisheries sector over the 2011-20 period.**
**•An evaluation of recent developments, key issues and uncertainties in those commodity**

## Growth of fisheries based on aquaculture




- **By 2015**, **aquaculture is projected to surpass capture fisheries** as the most important source of fish for human consumption, and **by 2020** should represent about **45% of total fishery production (including non-food uses)**.
- Compared to the 2008-2010 period, average capture **fish prices** are expected to be about **20% higher by 2020** in nominal terms compared with a **50% increase for aquaculture species**

- The projections are the result of close co-operation with national experts in OECD and non-OECD countries.
- A jointly developed modelling system, based on the OECD's AGLINK and on the FAO's COSIMO models, facilitates consistency in the

## A few last thoughts…..

Freshwater aquaculture is a significant contributor to the total "food fish" production and it will continue to do so in the future.

TAADs will continue to threaten the sector unless appropriate and effective biosecurity measures are put in place

Government and private sectors will be faced with more costs in terms of production losses and efforts to contain and eradicate them, funds which would have been better spent in preventing their entry into the system, in the first place.

Eradication programmes, extremely difficult and costly, may be unlikely for both EUS and KHV, in view of wild populations already affected

Focussing efforts on prevention, appropriate pre-border and border controls, good husbandry practices and maintaining a

## Benefits of improved biosecurity…..

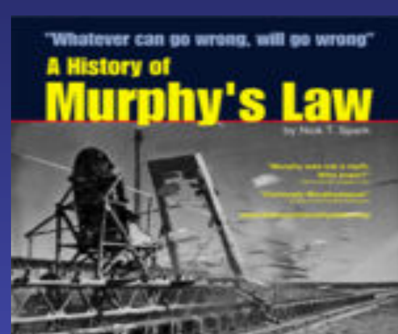
Safeguards animal and human health, protects biodiversity, promotes environmental sustainability and enhances food safety.

Stimulates increased market supply and private investments as it enables farmers to produce healthy products which can be highly competitive in the market and it makes a country a responsible trading partner.

Enables developing countries to grow more food efficiently, increase their incomes and thus improve their resilience, reduce their vulnerability and enhances their capacity to effectively respond to the

## Thank you

Whatever can go wrong, will go wrong – *in any given situation, if you give them a chance...*



## Thank you

*“Left to themselves, things tend to go from bad to worse.”*

*Corollary to Murphy’s Law*

With respect to aquatic health management

*“An ounce of prevention is worth a pound of cure...”*

# Transboundary and Emerging Freshwater Finfish Diseases In Farmed, Ornamental and Wild Fish

Melba G. Bondad-Reantaso, PhD[1], Rohana P. Subasinghe, PhD[1] and Hang'Ombe Bernard Mudenda, DVM[2],

([1])Fisheries and Aquaculture Department, Food and Agriculture Organization of the United Nations, Rome, Italy, (2) Paraclinicals Department, University of Zambia, Lusaka, Zambia

**Abstract**
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.

Keywords: Aquaculture Biosecurity, Disease and Freshwater Fishes

**Introduction**
Aquaculture, the farming of finfish, crustaceans, molluscs, and aquatic plants, had expanded tremendously since it was first introduced 2 300 years ago by Fan Li, a scholar-statesman from China. With an average global annual growth rate of 7.0 percent (1970-2006) and contributing 47 percent of world aquatic food production, aquaculture has gained recognition as the fastest growing food production sector in the world (FAO, 2009). The sector is highly diverse in terms of species cultured (over 360 species), culture systems (e.g. cages, pens, bottom/pole/rack/raft/long-line, tanks, raceways, irrigated or flow through systems, monoculture/polyculture systems, integrated farming systems), culture

environment (freshwater, brackishwater, marine; inland, coastal and oceanic; temperate and tropical); type of operation and scale (e.g. small-scale backyard ponds and hatcheries to commercial scale operations); intensity of practice (e.g. extensive, semi-intensive, intensive); and type of management (family to corporate ownership).

In terms of production volume, freshwater aquaculture contributed 60 percent to the total "food fish" production in 2008; with the rest coming from marine or brackishwater aquaculture. In terms of value, the contribution to the total value of "food fish" by freshwater aquaculture is 56 percent, a little lower than its share in volume (FAO FishStat, 2008). Included in the top-25 cultured freshwater species or species group for 2007 are, for example, the cyprinids, the tilapias (*Oreochromis* spp.), catfishes [e.g. Pangas catfish (*Pangasius pangasius* Hamilton, 1822), channel catfish (*Ictalurus punctatus* Rafinesque, 1818)], crustaceans [(whiteleg shrimp *Litopenaeus vannamei* Boone, 1931), Chinese mitten crab (*Eriocheir sinensis* H. Milne-Edwards, 1853), red swamp crawfish (*Procambarus clarkia* Girard, 1852), giant river prawn (*Macrobrachium rosenbergii* De Man, 1879)], trout (*Oncorhynchus mykiss* Walbaum, 1792), snakehead (*Channa striata* Bloch, 1783), eel (*Anguilla* spp.), and others. Included in the cyprinid group are silver carp (*Hypopthalmichthys molitrix* Richardson, 1845), grass carp (*Ctenopharyngodon idella* Cuvier and Valenciennes, 1844), common carp (*Cyprinus carpio* Linnaeus, 1758), bighead carp (*Hypopthalmichthys nobilis* Richardson, 1845), crucian carp (*Carassius carassius* Linnaeus, 1758), mrigal carp (*Cirrhinus mrigala* Hamilton, 1822), and black carp (*Mylopharyngodon piceus* Richardson, 1846).

In order to, at least maintain the current level of per capita consumption of aquatic food over the coming decades, under the circumstance of stagnant capture fishery production and increasing global population, it is important that aquaculture production is steadily increased. Since freshwater fish production will continue to play a significant role in meeting the global demand for aquatic food in the coming decades, threats posed by health (pathogen) risks to aquaculture should be minimised. In this regard, epizootic ulcerative syndrome (EUS) and koi herpesvirus (KHV) are considered as two emerging and re-emerging freshwater fish diseases which require attention in the coming years. Threats posed by EUS and KHV to freshwater farmed, ornamental and wild populations and freshwater resources are explored in this paper.

**Fish diseases as significant constraint to aquaculture development**

The current trend towards intensification and diversification of the aquaculture sector, like other farming sectors, has increased the likelihood of major disease problems occurring. Information on serious impacts of aquatic animal diseases to the aquaculture sector and to the farming communities dependent on it for their livelihood are growing (Bondad-Reantaso *et al*., 2005). Transboundary aquatic animal diseases (TAADs) are highly contagious diseases with strong potential for very rapid spread irrespective of national borders. TAADs are limiting the development and sustainability of the sector through direct losses (in many cases, in a scale of millions of US$), increased operating costs, closure of aquaculture operations, unemployment; and indirectly, through restrictions on trade and potential negative impacts on biodiversity. In addition to these, there are cases of undiagnosed, emerging and re-emerging pathogens. Thus, disease is now a primary constraint to the culture of many aquatic species, impeding both economic and social development in many countries. Bondad-Reantaso *et al.* (2005) reviewed the variety of multi-faceted and highly interconnected factors causing the current disease situation in aquaculture. These include the following: (i) increased globalization of trade in live aquatic animals and their products; (ii) the intensification of aquaculture through the translocation of broodstock and seed; (iii) development and expansion of the ornamental fish trade; (iv) enhancement of marine and coastal areas through stocking aquatic animals raised in hatcheries (Bartley *et al*., 2007); (v) misunderstanding and misuse of specific pathogen free (SPF) stocks (e.g. shrimps); (vi) unanticipated negative interactions between cultured and wild fish populations (Olivier, 2002); (vii) poor or lack of effective biosecurity measures and slow awareness on emerging diseases; (viii) climate change; and (ix) other human-mediated movements of aquaculture commodities. The emergence of EUS and KHV exemplify many of the above attributes (i.e., i, ii, iii, vii, viii and ix).

**Epizootic ulcerative syndrome (EUS) and its emergence in southern Africa**
**Description of disease**: EUS, an infection with a fungal oomycete known as *Aphanomyces invadans* (Index of Fungi, 1997) or *A. piscicida* (Hatai, 1980), is a serious finfish disease which has swept across Japan, Australia, many countries in Asia and the United States of America (USA), since the first outbreaks were reported in the early 1970s, causing significant loss of income to fishers and fish farmers. EUS has been given several names during the last three decades: (i) mycotic granulomatosis (MG): in Japan, first described in 1971 as an *Aphanomyces* (fungal) infection (Egusa & Masuda, 1971); (ii) red spot disease (RSD): in Australia, since 1972, an epizootic cutaneous ulcerative syndrome in estuarine fishes (McKenzie & Hall, 1976); (iii) EUS: in 1986, given by an FAO Expert Consultation on Ulcerative Fish Disease (FAO, 1986) concerning similar conditions with dermal ulcerations and mortalities which have occurred throughout southeast and south Asia; (iv) ulcerative mycosis (UM): in the USA, similar ulcerative lesions (Noga & Dykstra, 1986) affecting estuarine fishes since 1978; and (v) epizootic granulomatous aphanomycosis (EGA) and ulcerative aphanomycosis: two new names proposed, in 2000, by an Expert Consultation on EUS, a special session of the Fifth Symposium on Diseases in Asian Aquaculture held in Gold Coast, Australia where 36 EUS experts from Australia, India, Japan, the Philippines, Sri Lanka, Thailand, and the USA re-examined the causal factors, case definition and nomenclature of EUS and proposed the above two new names (Baldock *et al.,* 2002).

**Susceptible host species**: Farmed and wild fish worldwide are affected, with natural infection, confirmed by histopathology, for about 76 finfish species [e.g. barbs, breams, catfish, gouramy, eel, mullet, pike, tigerfish, tilapias, seabass, snakehead]. Few fish species such as common carp, Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) and milkfish (*Chanos chanos* Forsskal, 1775) appear to be resistant (OIE, 2009; FAO, 2009).

**Geographical distribution:** Since it was first reported in Japan in 1971, followed by subsequent reports from Australia (1972), the USA (1978), south and southeast Asia (1986), and most recently from southern Africa (2007), EUS now affects 24 countries in 4 continents [southern Africa, Asia, Australia and North America] (OIE, 2009; FAO, 2009). In most cases, e.g. many countries in Asia (e.g. Bangladesh, Cambodia, India, Nepal, Philippines, Thailand, Vietnam), Australia and Japan have reported EUS among wild fish populations (Baldock *et al*., 2005; several references in Lilley *et al*., 1998).

**Environmental and other risk factors:** In Asian outbreaks, shipping movements, ballast water, fish migrations, ocean currents have been reported as potential pathways for pathogen movement (Morgan, 2001); rainfall has been associated with outbreaks, for example, in Australia (Virgona, 1992), India (Vishwanath, 1997), and the Philippines (Bondad-Reantaso *et al*., 1992). EUS outbreaks in wild estuarine populations (e.g. Australia and the Philippines) have been reported as associated with acidified run-off water from acid sulphate soil areas (Callinan *et al*. 1995, 1997). In the Philippines, EUS outbreaks occur during periods of low temperature between 18–22°C and after heavy rainfall (Bondad-Reantaso *et al*., 1992) – conditions which favour fungal sporulation (Lumanlan *et al*., 1997). A diverse group of biotic (e.g. parasites, bacteria, virus) and abiotic agents/factors (e.g. acid water) are likely to be involved in initiating skin lesions in freshwater and estuarine fish species and which are subsequently colonized by the fungal pathogen. A specific determinant is unlikely associated with EUS outbreaks; most probably, environmental determinants vary from outbreak to outbreak depending on the agent initiating the non-specific lesions, the aquatic environment at the site and the population at risk. For EUS to occur, a combination of causal factors must ultimately lead to exposure of the dermis, attachment to it by *A. invadans/piscicida*, and subsequent invasion by the fungus.

**Emergence in southern Africa**: The emergence of EUS in southern Africa was first reported by Andrew *et al.* (2008) based on a preliminary investigation and by FAO (2009) from the outcomes of an international disease investigation task force; both were in response to a request for technical assistance from the government of Botswana launched in 2007. The investigations confirmed the occurrence of EUS in Botswana in 2007 among wild fish populations. FAO (2009) provided further confirmation of EUS in Namibia and Zambia based on a targeted EUS surveillance that was put in place as part of the FAO Technical Cooperation Programme [TCP] (TCP/RAF/3111 "Assistance to combat EUS in the Chobe-Zambezi River system) and confirmed by histopathology that about 27 species of natural freshwater fish in the Chobe-Zambezi river system were affected by EUS from the three countries in the region. Many of these species are very important to both capture fisheries and aquaculture sectors. FAO (2009) reported also that two additional countries (Angola and Zimbabwe) have collected fish samples with suspected EUS-like lesions but still subject to confirmation. The initial occurrence of EUS in the region in late 2006 affected wild freshwater fish populations and continues to do so in Zambia and Namibia. Only two cases were reported of EUS affecting cultured fish in Namibia.

**Disease impacts:** A compilation of available estimates of losses due to EUS, made by FAO (2009), includes the following: (i) US$ 100 million in Thailand (1983-1991 period); (ii) US$ 4.8 million in Bangladesh during 1988-1989; (iii) US$ 235 000 in Indonesia during 1980-1987; (iv) US$ 300 000 in Pakistan in 1996; and (v) US$ 700 000 annually in Eastern Australia.

The occurrence of EUS in the Chobe-Zambezi river system has huge implications, not only in terms of potential negative impact to biodiversity but more importantly, the negative impact to the livelihoods and the food and nutritional security of communities dependent on fishing and aquaculture and the freshwater river resource in the affected region. The Zambezi River, the fourth longest river in Africa flowing through Angola, Zambia, and along the borders of Namibia, Botswana, Zambia and Zimbabwe to Mozambique, is home to more than two hundred fish species, some of which are endemic to the river. Important species include cichlids which are fished heavily for food, as well as catfish, tigerfish, yellowfish and other large species. There are an estimated 32 million people inhabiting the Zambezi river valley of which 80 percent are dependent on agriculture and the upper river's flood plains provide good agricultural land. The river, important for local livelihoods and nutrition, is being fished extensively by surrounding communities; people travel long distances to fish for food. Recreational angling is also a significant activity in some parts of the river. In Zambia and Namibia, for example, there are several safari lodges which cater for tourists targeting tigerfish and other predatory fish species.

The impact of EUS in Zambia, which affects only wild fish populations, is alarming. Since the preliminary EUS surveillance carried out in 2007, it appears that EUS has since moved to other areas, with the disease moving upstream. Based on outcomes of 2009 surveillance, the disease has spread affecting almost the entire upper Zambezi river system. By October 2009, EUS was detected in Lake Itezhitezhi on the Kafue River, an entirely new river system which drains its waters in the Zambezi River. The Western Province of Zambia, with a population of over 850 000, is solely dependent on subsistence fishing, one of the poorest regions of Zambia, with 18 percent HIV/AIDs prevalence and where more than 85 percent of the population are living in villages along the Zambezi River. Over 2000 villages are affected because of EUS.

In most of the countries currently affected by EUS, the governments' decision to ban fishing during the EUS season negatively impacted the livelihood and food fish source of the communities dependent on subsistence fishing.

The African region is home to a wide variety of indigenous and endemic species; at least 3 200 freshwater species having been reported (FishBase, 2004). Dozens of them have been evaluated as good aquaculture candidates, the most important are the tilapias and catfishes (Brummett, 2007). Both of these species are susceptible to EUS. Thus, there is a high risk of EUS being spread, within the African continent, from one river or lake system to another which presumably have the same or closely-related fish fauna, through several pathways such as movement of fish species for aquaculture, angling and the ornamental trade as well as natural upstream and downstream movement of fish.

**Control and prevention**: No protective vaccine or effective chemotherapeutant is available and control of EUS in natural water bodies impossible.

**Koi herpesvirus (KHV) and its emergence in Asia**

**Description of disease**: Koi herpesvirus (KHV) (Hedrick *et al*., 2000) and carp nephritis and gill necrosis virus (CNGV) (Ronen *et al.*, 2003) are the two published disease names used to refer to mass mortalities specifically affecting koi (*Cyprinus carpio* Linnaeus, 1758) and common carp. The aetiological agent belongs to the family Herpesviridae (Hedrick *et al*., 2000). Mortalities are associated with aquaculture, ornamental and wild fish populations (Bondad-Reantaso *et al*., 2005).

**Susceptible host species**: KHV infects only koi and common carp and hybrids of these varieties (OIE, 2009). An outbreak of what is now known as KHV, which occurred in August 1996, in a private farm in England, revealed that other fish species grown in polyculture such as tilapia (*Oreochromis* sp.), goldfish (*Carassius auratus auratus* Linnaeus, 1758), sturgeon (*Acipenser* sp.) and orfe (*Leuciscus idus* Linnaeus, 1758) did not show any symptoms of the disease (Barnes, 2004). Bretzinger *et al*. (1999) on their account of the first outbreak in 1997 and 1998 in Germany, reported that goldfish or sturgeon held together with infected koi were unaffected. In cohabitation trials using diseased koi with Japanese and European koi carps and German mirror carp at temperature of 23ºC, all fish except, Euro koi, died with heavy signs of disease. Tinman and Bejerano (1999) reported that goldfish within the same ponds which experienced KHV outbreak in Israel in 1998-1999 was completely asymptomatic to the disease. Observations from the Indonesia outbreaks in 2002 (NACA/ACIAR, 2002) indicated that KHV is highly host specific, as although common carp is polycultured with tilapia (*Oreochromis* sp.) and gourami (*Anabas* sp.) in Blitar, East Java and a double-cage system culture of carp and tilapia is utilized in Cirrata Lake, common carp was the only species affected during the suspected KHV outbreak in those locations in Indonesia. Ronen *et al.* (2003) reported that tilapia (*Oreochromis* sp.), silver perch (*Bidyanus bidyanus* Mitchell, 1838), silver carp, goldfish, and grass carp were completely asymptomatic following long-term co-habitation with diseased fish. In the USA, experimental infection with filtered material from infected fish showed that only koi and common carp were affected; while goldfish, fathead minnows (*Phimephales* sp.)and golder shiners (*Notemigonus* sp.) were not. Koi herpes virus is very specific to koi and common carp; wild populations of common carp in Indonesia, Japan and the United Kingdom have been affected.

**Geographical distribution:** KHV has a broad geographic distribution affecting most of koi and carp producing regions and wild populations as well. The disease, now known as KHV, appears to have occurred as early as 1996 in England (Barnes, 2004) and in 1997 in Germany (Bretzinger *et al*., 1999; Hoffman *et al.*, 2004); in Asia, in 2000 in Malaysia (Gilad *et al*., 2003), other countries affected are China (2002), Taiwan, People's Republic of China (2002), Indonesia (2002) and Japan (2003) (Bondad-Reantaso, unpublished report). It is now known to occur in, or has been recorded in fish imported into, at least 22 different countries (OIE, 2009; Way, 2009). In Europe, this includes Austria, Belgium, Denmark, France, Italy, Luxembourg, The Netherlands, Poland, Switzerland and the United Kingdom; elsewhere, KHV has been reported also in South Africa and the United States of America.

Prior to 2007, KHV was not listed by the World Animal Health Organisation (OIE) in its Aquatic Animal Health Code. Despite this, at least two countries (i.e. Indonesia and Japan, in June, 2002 and November, 2003, respectively) have provided emergency notification to the OIE on the occurrence of this disease. After its listing in January 2007, more reports are forthcoming, adding to the long list of countries which are KHV-positive. New records from the World Animal Health Information Database (WAHID, http://www.oie.int/wahis/public.php?page=home) for 2008 include that of Slovenia, Canada, Hong Kong China and Sweden (2009).

**Environmental and other risk factors:** A number of risk factors play a role in disease development. These include water temperature (between 16-25°C), viral infectivity, fish size/age, population density and stress factors (OIE, 2009).

**Emergence in Asia:** A detailed account of the emergence of KHV in Indonesia, which first occurred in East Java in 2002, was reported by Bondad-Reantaso, Sunarto and Subasinghe (2007) including the findings and major achievements of the an International Emergency Disease Control Task Force organized by the Network of Aquaculture Centres in Asia and the Pacific (NACA) and the subsequent emergency technical assistance by FAO to the government of Indonesia. The NACA Task Force did not confirm the exact aetiology of the observed mortalities in 2002, but reported a very close analogy with KHV outbreaks (NACA/ACIAR, 2002).

The subsequent work under the FAO project TCP/INS/2905 "Health management in freshwater aquaculture in Indonesia" confirmed that the 2002 outbreak was indeed caused by KHV, based on a more detailed epidemiological survey and diagnostic assessment of subsequent disease outbreaks (Sunarto *et al*., 2005). The FAO project (Bondad-Reantaso, Sunarto & Subasinghe, 2007) also determined the extent of spread of the disease with documented episodes of 10 major KHV outbreaks in Indonesia, identified risk areas and conducted a retrospective analysis of the origin of KHV in Indonesia. The first episode demonstrated the spread from the first outbreak in Blitar in East Java from infected koi carp to aquacultured common carp and its eventual spread to other natural bodies such as lakes and rivers in the islands of Java and Sumatra. Retrospective analysis based on quarantine records in Surabaya revealed that koi carps were imported from China through Hong Kong to Blitar, the center for koi production in Indonesia. Subsequently, some of these Blitar koi were transferred to Bandung in East Java which immediately experienced an outbreak. Outbreaks occurred in neighbouring Subang – a major centre for common carp production - in March-April, 2002. As infected fish were being moved from Subang, KHV spread further to the Cirrata Reservoir affecting both cultured and wild carps. A Ministerial Decree issued in June, 2002, restricting live fish movement, did not stop KHV from spreading to the island of Sumatra. By end of 2005, there were unconfirmed reports of KHV occurrence in Sentani Lake in the West Papua Province and which was later confirmed as KHV.

A detailed account of KHV outbreaks in Japan was provided by Iida *et al. (*2005). Mass mortality of net-pen cultured common carp at Lake Kasumigaura, Ibaraki Prefecture, Japan, reportedly began in October 2003. This was confirmed to be caused by KHV. Massive losses in excess of 10 000 carp occurred in the rivers and a lake in the western part of Japan in Okayama Prefecture during late May to mid-July 2003. This was also confirmed as KHV based on historical freezer-stored samples of diseased fish, indicating that KHV was introduced to Japan prior to the outbreaks in Lake Kasumigaura.

Following the outbreaks in Indonesia (2002) and Japan (2003), KHV spread further to other Asian countries (e.g. Singapore, Thailand). The emergence of KHV in Indonesia and Japan, both involved wild carp populations.

**Disease impacts:** Losses from Israeli outbreaks (1998 and 1999) were estimated at US$ 4 million worth of high quality koi intended for export and more than 600 metric tonnes of common carp (Tinman and Bejerano, 1999). In Indonesia, the loss revenue of the sector and the socio-economic impact to the rural farming communities as of July 2003 have been so far estimated at US$ 5.5 million (= 50 billion rupiah, 1 US$ = 9 000 Indonesia Rupiah) (NACA/ACIAR, 2002). As of December 2003, losses were US$ 15 M; total fish mortality reached 80-95% (Sunarto and Rukyani, 2004). Losses in two major lakes (Lake Kasumigaura and Lake Kitaura) in Japan were estimated at 150 M yen (approximately US$ 1.4 million).

Almost 1200 tonnes of common carp equivalent to one fourth of the annual production from Lake Kasumigaura, the largest single production area in Japan producing more than one half of the total annual aquaculture production of food carp in Japan, were lost (Sano, 2004; Iida *et al*., 2005)). By the end of 2003, KHV-infected common and colored carp were reported in 23 prefectures (Pro-Med News, November 4, 2003). In Derbyshire, England, one farm alone during an outbreak in 1996, lost 17 tonnes of koi and carp stocks (Barnes, 2004). Barnes (2004) also suggested that the impact of KHV on the market was the creation of two separate koi markets: (a) a cheaper market also known as the 'annual' koi market where purchasers are less interested in the long-term survival of these koi; and (b) the more expensive 'pet' and show type koi (nishikigoi) market, where the longevity is more important. He further indicated that it is the more expensive koi market that is really threatened by KHV. The expressed concern of Gilad *et al.* (2003) concerning the potential spread of the virus from ornamental and farmed fish to wild cyprinid fish has already happened as KHV has already been detected among wild carp in England (Way, 2004), Indonesia and Japan.

Common carp is an important cultured food fish and ranks 3rd among the top 25 freshwater producing species with a recorded global production of 2.8 M tonnes in 2007. It is also an important species for recreational angling; while koi carp is a high value ornamental fish (sometimes costing USD 150 000.00/fish or even more depending on the quality).

The KHV event is an exception case in the history of aquatic animal disease incursion. At the regional/international levels, three major conferences on KHV were convened, i.e. (i) the International Workshop on KHV, London, UK, February, 2004 (OATA/CEFAS); (ii) the International Conference on KHV, Yokohama, Japan, March, 2004 (Fisheries Agency of Japan); and (iii) the Expert Workshop on Emergency Preparedness and Response to Aquatic Animal Diseases in Asia, Indonesia, September, 2004 (FAO). KHV became such a high profile disease that it called for three major conferences on the same subject within a year – this was unprecedented.

**Control and prevention.** No protective vaccine or effective chemotherapeutant is available and control of KHV in natural water bodies impossible. Biosecurity measures at farm level and border controls may reduce the introduction and spread of KHV.

**Lessons learned from investigation of EUS and KHV outbreaks**

There are important lessons that can be learned from emergency investigations of outbreaks of KHV in Indonesia and EUS in southern Africa. These are:

**Emergency response, surveillance and reporting/notification.** The Emergency Disease Investigation Task Force formed by NACA (for KHV) and FAO (for EUS) was a rapid coordinated effort and a critical quick action that triggered a chain of events for an immediate investigation of the outbreak; both garnered strong support from development aid/scientific groups. These events included preliminary diagnosis, establishment of a case definition, implementation of specific actions and control measures at national level, and early warning for neighbouring countries. In both cases, the initial findings became the basis for emergency technical assistance from FAO. Both investigations strongly recommended to direct efforts at improving surveillance and reporting of the disease. Subsequently, Hong Kong SAR, Japan, Thailand, Singapore and Philippines immediately initiated a surveillance programme for KHV (Bondad-Reantaso *et al*., 2007). Under an FAO project assistance, an active surveillance for EUS was implemented by the seven countries bordering the Chobe-Zambezi river system (FAO, 2009). As EUS and KHV are OIE-listed diseases, OIE members are required to make an outbreak report/notification to OIE. Both the NACA and FAO Task Forces were an *ad hoc* action and nevertheless could very well serve as a model. There needs to be, however, some institutionalized mechanism in terms of an expert group, funding and other required resources to deal with aquatic animal disease emergencies.

**Knowledge base and capacity building: diagnostics, epidemiology, biosecurity, risk analysis.** The emergence or re-emergence of diseases is generally a phenomenon of pathogen transfer and incursion. As discussed earlier, pathogen incursion is a consequence of movement, likely associated with movement of host species. In the case of EUS and KHV, the hosts are susceptible freshwater fish. Trans-boundary pathogen transfer is a serious biosecurity breach and the problem can only be addressed by improving policy and regulatory frameworks of countries, by building national capacities on diagnostics, risk assessments, early warning, contingency plans to disease emergencies, etc. Research towards better understanding of disease, better health management and dissemination of information on biosecurity, risks of diseases to production and biodiversity and socio-economic impacts are of paramount importance. Since all potential harms and associated pathways cannot always be known and precisely predicted *a priori*, the use of risk analysis is a valuable decision-making tool which help identify, assess, manage, mitigate and communicate risks.

Prompt and correct diagnosis of any disease incursion can help quickly draw control measures to prevent further spread or apply appropriate treatment where possible. In many developing countries, diagnostic capacities are still lacking thus presenting problems during disease epizootics. A case in point is the emergence of EUS in southern Africa. Since it is a known disease and it was not difficult to confirm because of available diagnostic and confirmatory tests, information about the disease was readily available that was immediately shared with responsible authorities especially concerning actions to prevent further spread, treatment, public health aspects, etc. If it was an 'unknown disease', there would have been more complication as lack of accurate information can lead to speculations, may cause further panic from consuming public and potentially continued losses. Farmers or fishermen who are not familiar with biosecurity measures which need to be done during a disease outbreak may also serve as pathways for further spread of disease through such actions as trading infected fish, throwing infected fish back into the water system (instead of proper disposal). In any disease emergency, speed of response, can make a lot of difference. Building capacity on epidemiology is also becoming an essential requirement especially when dealing with diseases epizootics. In the absence of a confirmatory diagnosis, an epidemiologist can provide important guidance on possible intervention based on an understanding of the risk factors, pathways and affected populations. Risk analysis is a decision-making tool that responsible authorities can use when deciding whether to approve the introduction of a species or not, when deciding what risk management measures (e.g. (i) pre-border measures such certification of production source, list of approved species, list of approved exporting countries, on-site inspection of exporting facilities, etc. and (2) post-border measures such as restrictions on use of imported species, monitoring programmes, contingency planning) can be put in placed based on an assessment of the level of risk (Arthur *et al*., 2008). . Species that are susceptible to both EUS and KHV are important aquaculture and ornamental species and since trading or movement of aquatic species is now recognised as important pathway for the introduction and spread of these pathogens, risk analysis will be a useful decision-making tool. Risk analysis can also be used when determining the potential risk posed by KHV-vaccinated carps. The ornamental sector, in particular, is not well-regulated thus posing further risks. Outbreaks in some cases occur from fish coming from an ornamental fish trade show, thus quarantine of incoming fish is an important biosecurity measure. All the above, including good surveillance programmes, are important aspects of biosecurity which will reduce the risk of diseases being introduced or spread into new areas or reintroduced into previously affected areas or zones. Diagnosis, epidemiology and risk analysis are parts of a large number of components of an aquatic animal health strategy and they cannot function effectively unless the other components have been developed and the means to implement them are in place.

**Investments in biosecurity and aquatic animal health infrastructure, human capacity, regulatory frameworks and partnerships.** Meeting development and sustainability objectives requires that aquatic food produced from aquaculture must be safe and wholesome to the consuming public. Effective, coordinated, proactive and sufficient biosecurity systems that improve aquatic animal and human health, food safety and environmental and biodiversity protection must be in place. Knowledge, science and technology when used within effective regulatory frameworks with sufficient resources for enforcement play an essential role. More investments are therefore needed in biosecurity and aquatic animal health frameworks for controlling risks; and public and private sector partnerships for identifying, monitoring and evaluating risks. Of particular importance is dealing with ‘unknowns’; therefore effective regional and international cooperation and putting emergency preparedness with advanced financial planning as a core function of an appropriately-mandated institution is highly desired. Such continued efforts are important for reducing the risks that EUS and KHV pose for freshwater fish production, aquatic biodiversity, and their potential emergence to new geographical locations, especially in developing countries.

**Biodiversity and health of native fish populations**.
Among the 5 potential impacts of aquatic animal diseases on wild populations and biodiversity, summarised by Arthur and Subasinghe (2002), possible extinction of species may be one of the effect of EUS on native populations. Continuous occurrence of EUS on an annual basis may have negative effect on the population of affected and susceptible wild species. Noga *et al.* (1988) reported that in the eastern United States, outbreaks of ulcerative mycosis (UM) in the 1980s had a significant impact on the productivity of the estuarine fisheries. It is now known that the invasive *Aphanomyces* involved in those outbreaks is the EUS fungal pathogen (Blazer *et al.* 1999; Baldock *et al.*, 2005). In Asia, there were reports of reduction in production from aquaculture (Subasinghe, 1997) and catches or landings from capture fisheries during serious EUS outbreaks (Das, 1994; Callinan *et al*., 1999). EUS is not the only case of a pathogenic fungus having negative impact on biodiversity; another aquatic fungal pathogen, *Aphanomyces astaci* Schikora, 1906, devastated the European crayfish populations (OIE, 2009).

Interactions between wild and cultured fish populations are important concerns for both aquaculturists and natural resource conservation officers. Snieszko (1974) defined disease is a result of the complex interaction between the host, the pathogen and the environment. Olivier (2002) listed certain essential criteria in order for a disease to spread from either cultured fish or vice-versa. These include: presence of pathogen in both fish and water source; presence of susceptible host; viability in terms of number and longevity of pathogen in the environment; viable infection route. Both EUS and KHV fulfil all the above criteria, thus both cultured and wild fish populations are now carriers of fungal propagules which may explain the wide distribution of these two pathogens. Once a pathogen or disease agent is introduced and becomes established into the natural environment, there is little or no possibility for either treatment or eradication. The consequences of ‘‘trickle’’ infections from wild to cultured populations have predictable consequences due to accessible hosts under cultured conditions; however, the consequences of culture-borne transmission to wild stocks are harder to predict (Subasinghe *et al*., 2001).

**Future outlook**
Aquaculture offers a solution to many of the food security issues facing the growing human population. It bridges the gap between stagnating yields from many 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. The current and future dependence on farmed fish presents an ideal opportunity for the aquaculture sector to contribute to its own food security, poverty reduction and economic development with, under appropriate management, minimum impact on the environment and maximum societal benefit. However, future aquaculture development will require the trade of aquatic animals and products within and between countries. This trade carries with it attendant biosecurity risks associated with the introduction or spread of pathogens. Unless appropriately managed, these risks can seriously hinder the economic and societal benefits of aquaculture, and as well may potentially have deleterious environmental impacts.

EUS currently prevails in southern Africa in most of the countries bordering the Zambezi River. There are about 32 million people in the communities surrounding the Zambezi River, of which 80 percent are dependent on agricultural resources including those who are dependant on Zambezi fishery resources. EUS poses a significant risk to these livelihoods and food supply. A concerted action is therefore required to strengthen the capacity of southern African countries to effectively respond to aquatic animal emergencies.

Since a large number of people, particularly belonging to many vulnerable rural poor communities in the Zambezi basin, are dependent on the river fisheries resources for their livelihoods, any concerted action to improve biosecurity in the region should be considered within the broader river fisheries management framework and aquaculture development strategies. Improving biosecurity must be addressed within a framework where beneficiaries (fishers and fish farmers) are also included. However, our current understanding and the knowledge of the river fishery resources and the dependency of people on these resources are still inadequate. Therefore, there is an urgent need to look at the Zambezi basin resources, understand its contribution to the livelihoods of communities surrounding the river basin, and incorporate a management strategy into the proposed biosecurity programme for southern Africa.

Intra-regional trade and shared waters mean that a coordinated and cooperative approach to aquatic biosecurity is essential. Harmonization of national policies and regulatory frameworks on aquatic biosecurity is paramount. Impacts on livelihoods of fishers and farmers caused by EUS need to be better understood, and practical coping strategies identified and supported.

The situation regarding KHV is somewhat different. Currently, the disease does not occur at an epizootic level in any country. As movement of ornamental fish is an important pathway for pathogen spread, stringent biosecurity controls on the ornamental fish movement will be necessary to reduce the risks. As KHV is now an OIE- and EU-listed disease; improving biosecurity will be essential and of significance for trading of susceptible species between both EU Member States and third countries.

As pointed out earlier, EUS and KHV incursions provide clear evidence of biosecurity breach. Further development of aquaculture, therefore, brings new challenges to biosecurity. There is tremendous benefits that can be gained with improved biosecurity. Biosecurity safeguards animal and human health, protects biodiversity, promotes environmental sustainability and enhances food safety. It can also stimulate increased market supply and private investments as it enables farmers to produce healthy products which can be highly competitive in the market and it makes a country a responsible trading partner. The current global crisis on food prices has now given pressure to both governments and the international community to ensure an adequate supply of food for a growing population. Biosecurity enables developing countries to grow more food efficiently, increase their incomes and thus improve their resilience, reduce their vulnerability and enhances their capacity to effectively respond to the impacts of higher food prices as well as other food production risks.

**Conclusions**

Freshwater aquaculture is a significant contributor to the total "food fish" production and it will continue to do so in the future. However, the risks of TAADs will continue to threaten the sector and unless appropriate and effective biosecurity measures are put in place, TAADS will continue to threaten the sector and both the government and private sectors will be faced with more costs in terms of production losses and efforts to contain and eradicate them, funds which would have been better spent in preventing their entry into the system, in the first place. Focussing efforts on prevention, appropriate pre-border and border controls, good husbandry practices and maintaining a healthy environment are still the key to managing risks from diseases. Since eradication programme, which in many instances are extremely difficult and costly, may be unlikely for both EUS and KHV, in view of wild populations already affected, applying appropriate biosecurity measures will reduce the risks of negatively impacting biodiversity.

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# Applying Environmental Footprint Concept for Biodiversity Conservation In Semi-Intensive Aquaculture

*Ling Cao, University of Michigan*

**Abstract**

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.

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# "Cradle to Grave"

## Applying Life Cycle Thinking towards Sustainability in Aquaculture


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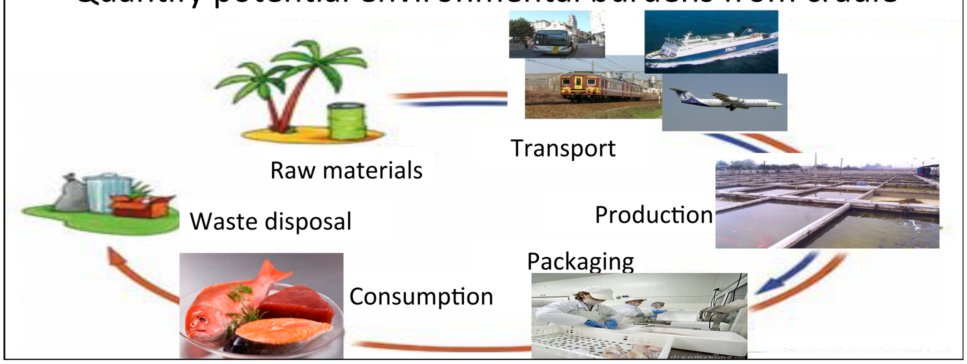
## Outline

1. Life Cycle Assessment (LCA)
2. Applying LCA to Aquaculture
3. Modeling Biodiversity Loss in LCA
4. Using LCA for Certification and Eco-labeling
5. Shortcomings of LCA
6. Research Outlook

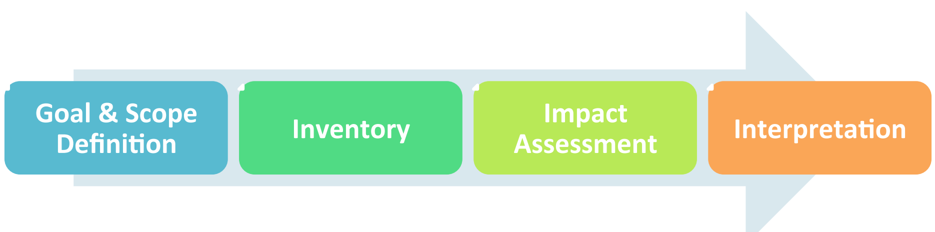
## Life cycle assessment (LCA)

- Most popular analytical tool using life cycle thinking
- Quantify potential environmental burdens from cradle






- LCA has four main phases:



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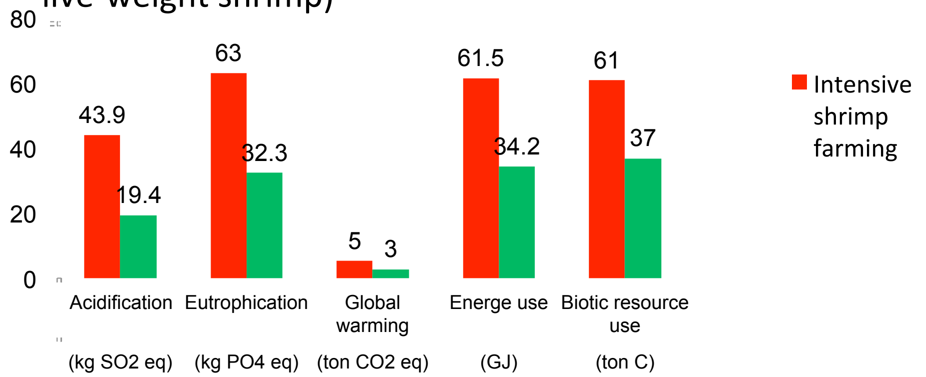
## 2. Application of LCA in Aquaculture

- **Intensive vs. Semi-intensive** (Functional unit: 1 tonne of live-weight shrimp)

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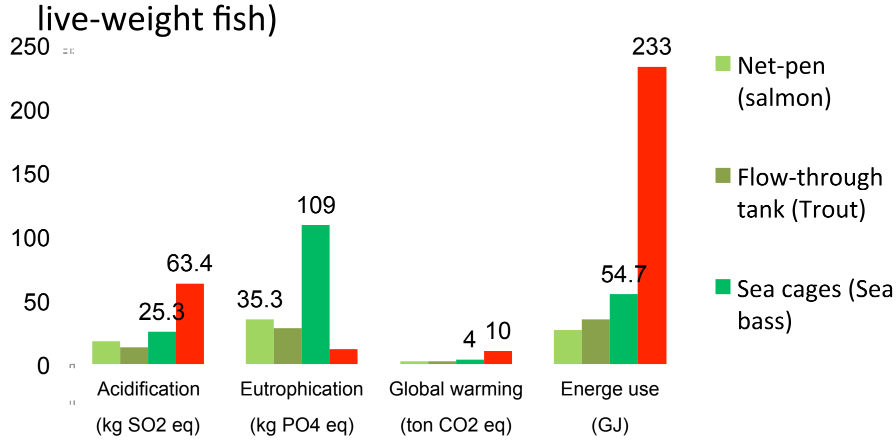
## 2. Application of LCA in Aquaculture

- **Open vs. Closed systems** (Functional unit: 1 tonne of live-weight fish)



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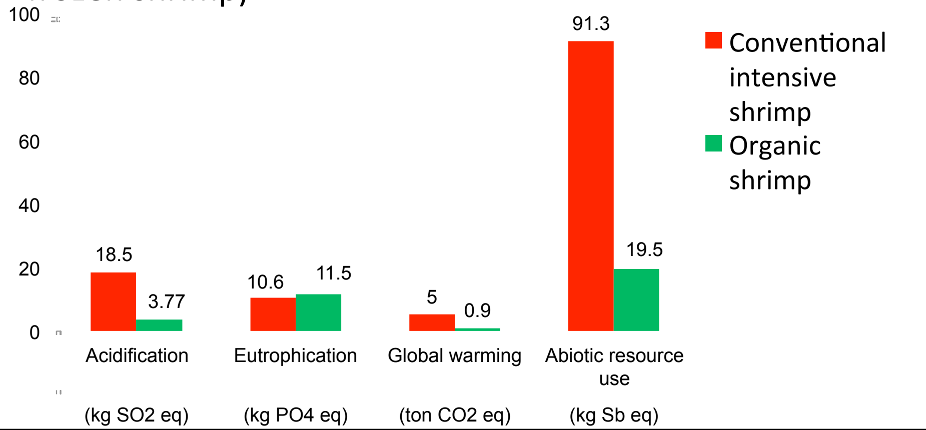
## 2. Application of LCA in Aquaculture

- **Conventional vs. Organic** (Functional unit: 1 tonne of frozen shrimp)

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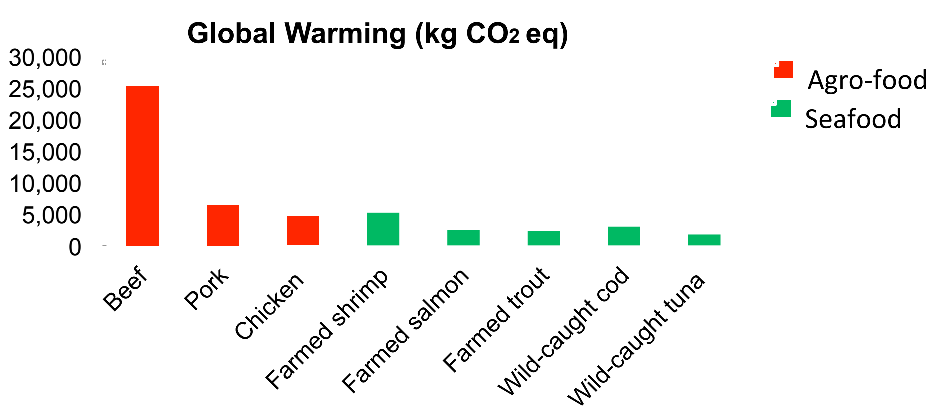
## 2. Application of LCA in Aquaculture

- **Agro-food vs. Seafood**



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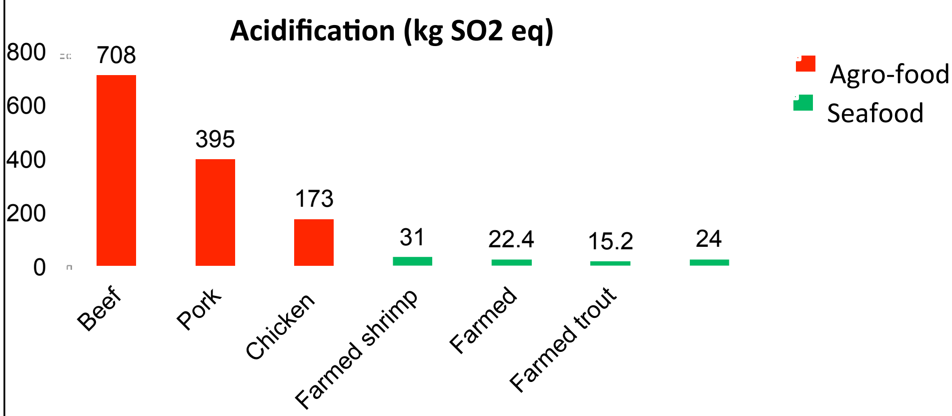
## 2. Application of LCA in Aquaculture

- **Agro-food vs. Seafood**

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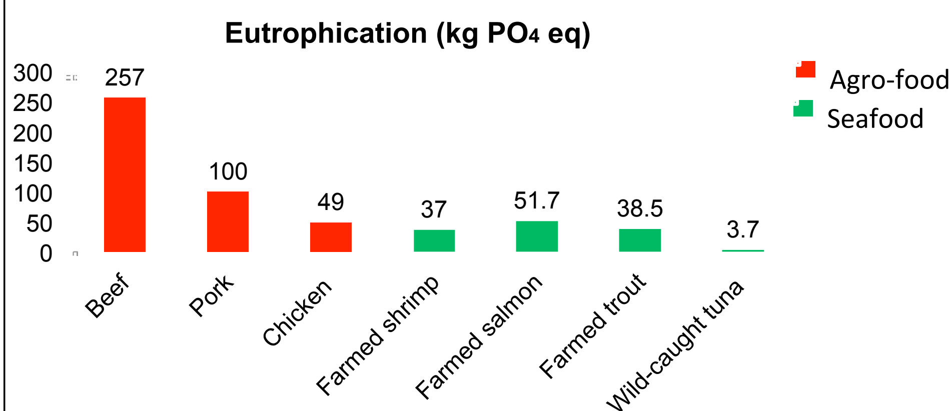
## 2. Application of LCA in Aquaculture

- **Agro-food vs. Seafood**



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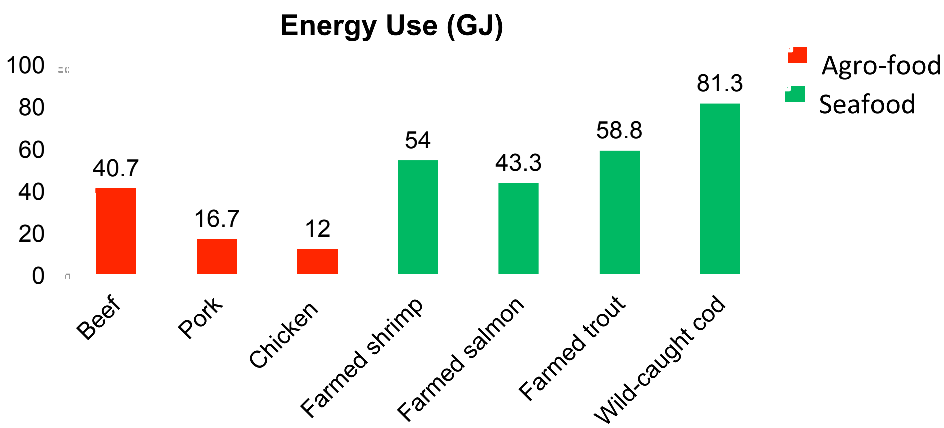
## 2. Application of LCA in Aquaculture

- **Agro-food vs. Seafood**

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## 3. Modeling Biodiversity loss

- Majority causes of biodiversity loss
- Five direct indicators (MA, 2005)
  1) Habitat change
  2) Climate change
  3) Pollution
  4) Invasive species
  5) Overexploitation
- Three represented in LCA
- **Invasive species** & **overexploitation** still completely missing!!!

## 4. LCA for Certification & Eco-labeling

- Few standards use life cycle thinking
- Current standards may overlook some key procedures and environmental issues
- LCA can help!!


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## 5. Shortcomings of LCA

- CANNOT quantify local ecological and socio-economic impacts
- Limited impact categories specific to aquaculture
- Limited background data for aquaculture

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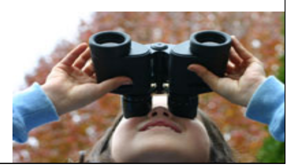
## 6. Research Outlook

- Learn from agricultural LCAs & develop impact categories for seafood production
- Integrate the missing indicators of biodiversity
- Integrate socio-economic impact categories
- Validate novel indicators



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# Thanks for your attention!

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## Appendix

- Examples of impact categories

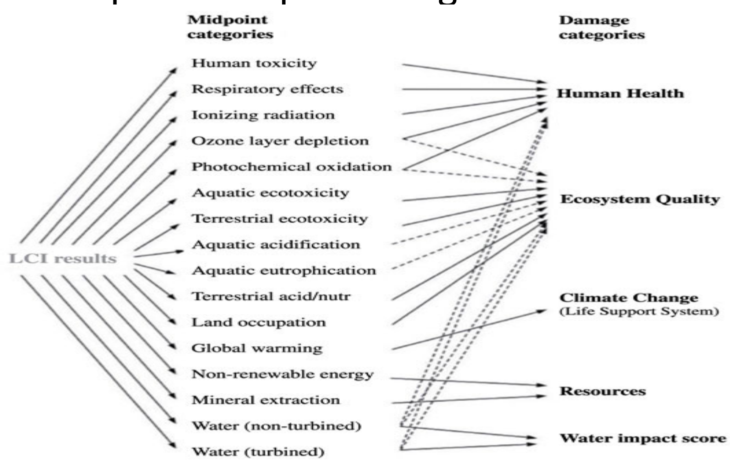


**Table 1.** Impact categories commonly used in LCA of aquaculture production systems (adapted from Owens 1996; Pelletier *et al*., 2007)

| Impact category | Characterization factor | Category indicator | Equivalency unit | Interpretation | Spatial | Temporal |
|---|---|---|---|---|---|---|
| Climate change | GWP | $CO_2$ | kg $CO_2$ eq | Atmosphere absorption of infrared radiation | Global | Decades/Centuries |
| Eutrophication | EP | $PO_4$ | kg $PO_4$ eq | Nutrient enrichment | Regional/local | Years |
| Acidification | AP | $SO_2$ | kg $SO_2$ eq | Acid deposition | Regional | Years |
| Energy use | EUP | MJ | MJ | Depletion of non-renewable energy resource | Regional/local | Centuries |
| Biotic resource depletion | BDP | NPP | kg C | Depletion of renewable resources | Regional/local | Years |
| Abiotic resource depletion | ADP | Sb | kg Sb eq | Depletion of non-renewable resources | Local | Centuries |
| Ecotoxicity | Ecotoxicity potential | 1, 4 DB | kg 1, 4 DB eq | Toxic to flora, fauna and humans | Local | Hours/Days/Years |
| Ozone depletion | ODP | CFC | kg CFC eq | Stratospheric ozone breakdown | Global | Decades/Centuries |
| Photochemical | POP | $C_2H_4$ | kg $C_2H_4$ eq | Photochemical | Regional/local | Hours/Days |

# Applying Life Cycle Thinking towards Sustainability in Aquaculture

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**Abstract**
As an alternative food source to wild fisheries, aquaculture shows a great potential to meet the growing demand for seafood and feed the world. The expansion of aquaculture is achieved by system intensification, which has drawn vast criticisms of aquaculture over its sustainability and negative influence on the environment and human livelihoods. Life cycle assessment (LCA) has become the leading tool for identifying key environmental impacts of seafood production systems. It can evaluate sustainability of diverse aquaculture systems quantitatively from a cradle-to-end perspective. By assessing environmental performance, it presents a best basis for system improvement in terms of sustainability and development of certification or eco-labeling criteria. Ongoing efforts tend to integrate local ecological and socio-economic impacts into the LCA framework. LCA has great potential in assisting decision making for more sustainable seafood production and consumption. This article reviews recent application of LCA in aquaculture, compares environmental performance of different aquaculture production systems, explores the potential of including biodiversity issues into LCA analysis and the potential of LCA in setting criteria for certification and eco-labeling.

**Keywords**: Environmental impacts; Life cycle assessment; Aquaculture; Sustainability; Biodiversity; Certification; Eco-labeling

**Introduction**
As an alternative food source to wild fisheries, aquaculture shows a great potential to meet the growing demand for seafood and feed the world (Pauly *et al.*, 2002). Global production of aquaculture including fish, molluscs, crustaceans and aquatic plants has increased from less than 700,000 tonnes in 1950 to nearly 70 million tonnes by 2008 which accounts for 50% of the world's fish supply (FAO, 2010). Most production occurs in Asia, which contributes 89% by volume and 79% by value to world aquaculture production. China is the leading producer, accounting for 48% of world aquaculture total in 2008 (Bostock *et al.*, 2010). Aquaculture has already become the most rapidly increasing food production sector with an average annual growth rate of 6.9% since 1970 (Bostock *et al.*, 2010), and will continue to grow at a significant rate (Diana, 2009). Modern aquaculture is highly diverse, encompassing a great variety of production systems, technologies and more than 310 different farmed species recorded by FAO in 2008 (Pelletier and Tyedmers, 2008; Bostock *et al.*, 2010). Freshwater aquaculture is dominated by carps, tilapia and catfish. Coastal aquaculture primarily comprises salmon, shrimp, oyster, scallop and mussels (Bostock *et al.*, 2010). Production systems range from traditional low intensity such as extensive and semi-intensive to highly intensive systems with different farming technologies. Closed recirculating and organic systems have emerged as newly developed alternatives to conventional systems.

The expansion of aquaculture is achieved by system intensification, which has drawn vast criticisms of aquaculture over its sustainability and negative influence on the environment and human livelihoods. These criticisms include pressure on natural resources such as water, energy and feed, eutrophication caused by effluents, depletion of biodiversity, conversion of sensitive land, introduction of invasive species, genetic alteration of and disease transmission to wild stocks (Diana, 2009), as well as food insecurity. Increasing attention to environmental responsibility of aquaculture underscores the urgent need to understand the environmental footprints of different production systems in order to better manage them to promote more sustainable aquaculture.

Many assessment tools have been developed recently to evaluate environmental impacts of production systems, including risk analysis, ecological footprint, energy analysis and life cycle assessment (LCA). LCA allows comprehensive assessment of relevant environmental impacts along the whole life cycle of a product. It allows one to compile the relative inputs and outputs in an overall process and calculate the possible associated impacts based on a functional unit. Those impacts which cannot be directly measured are calculated by models. Life cycle modeling comprises of four steps, including goal definition and scope, inventory, impact analysis and interpretation (ISO, 2003). In the goal definition and scope phase, one should define system boundary and functional unit for studied systems. In the inventory phase, inputs and outputs associated with studied systems should be quantified and the results are used to calculated environmental impacts in the impact analysis phase. LCA has already become the leading tool for identifying and comparing the environmental impacts of different food production systems (Pelletier and Tyedmers, 2008).

Currently, there are no objective methods to evaluate sustainability of aquaculture in a quantitative and fair way (Diana, 2009). LCA can be used to make such an evaluation in quantifiable terms that are clear indicators of sustainability. In aquaculture, the system boundary is often from cradle to farm gate with the focus on the farm management. Post-farm stages including processing, sale, consumption and waste disposal are less affected by aquaculture practices and thus usually excluded from analysis. LCA relates the driving forces to the consequently environmental pressures and impacts. This can be used to inform environmental problems and track hotspots which significantly contribute to overall impacts in aquaculture. LCA also enables analysis of system eco-efficiency and can make suggestions for system/activity improvement, as well as predict environmental outcomes if one activity is changed.

Although LCA has been widely applied in industrial and agricultural products (Roy *et al.*, 2009; de Vries and de Boer, 2010), LCA-styled studies for seafood production systems have been launched for less than a decade. To date, LCA of wild-caught seafood include Swedish cod (Ziegler *et al.*, 2003), Danish fish products (Thrane, 2004a), Spanish tuna (Hospido and Tyedmers, 2005), and Norwegian cod (Ellingsen and Aanondsen 2006). Aquaculture LCAs mainly focus on intensive farming systems (Iribarren *et al.*, 2010) or species with high economic value, including salmon farming (Ellingsen and Aanondsen, 2006; Ayer and Tyedmers, 2009; Pelletier *et al.*, 2009), shrimp farming (Mungkung *et al.*, 2006; Cao *et al.*, 2011), rainbow trout culture (Grönroos *et al.*, 2006; Aubin *et al.*, 2009; d'Orbcastel *et al.*, 2009), sea bass and turbot culture (Aubin *et al.*, 2009), tilapia farming (Pelletier and Tyedmers, 2010), and mussel culture (Iribarren *et al.*, 2010). There is a growing trend in the use of LCA to study sustainability of seafood production systems (Pelletier *et al.*, 2007).

This article reviews recent application of LCA in aquaculture, compares environmental performance of different aquaculture production systems, explores the potential of including biodiversity and socio-economic issues into LCA analysis and the potential of LCA in setting criteria for certification and eco-labeling. Our goal is to provide informative information to decision makers, producers, researchers, certification and consumer awareness programs, and other stakeholders who seek to promote more sustainable seafood production and consumption.

**Assessing sustainability of aquaculture through LCA**

We found 10 aquaculture-based LCA studies from peer-reviewed journals or conference proceedings in the recent five years. To compare LCA results among selected studies, the functional unit is recalculated to be the same in each scenario. Of all studies reviewed, impact categories commonly used are presented in Table 1 with detailed characteristics. Among them, global warming, eutrophication, and acidification and energy use have been employed with highest frequency. Only global warming and ozone depletion have global effects that may affect the entire planet. The rest of impact categories only manifest regionally on a scale from 100-1000 km or locally to the immediate vicinity (Thrane, 2004a). However, LCA is still underdeveloped for assessing local ecological (biodiversity loss, habitat loss, and land use etc.) and socio-economic impacts (social welfare etc.) (Cao *et al*., 2011).

**Table 1.** Impact categories commonly used in LCA of aquaculture production systems (adapted from Owens 1996; Pelletier, Ayer et al. 2007)

| Impact category | Characterization factor | Category indicator | Equivalency unit | Interpretation | Spatial | Temporal |
|---|---|---|---|---|---|---|
| Climate change | GWP | $CO_2$ | kg $CO_2$ eq | Atmosphere absorption of infrared radiation | Global | Decades/Centuries |
| Eutrophication | EP | $PO_4$ | kg $PO_4$ eq | Nutrient enrichment | Regional/local | Years |
| Acidification | AP | $SO_2$ | kg $SO_2$ eq | Acid deposition | Regional | Years |
| Energy use | EUP | MJ | MJ | Depletion of non-renewable energy resource | Regional/local | Centuries |
| Biotic resource depletion | BDP | NPP | kg C | Depletion of renewable resources | Regional/local | Years |
| Abiotic resource depletion | ADP | Sb | kg Sb eq | Depletion of non-renewable resources | Local | Centuries |
| Ecotoxicity | Ecotoxicity potential | 1, 4 DB | kg 1, 4 DB eq | Toxic to flora, fauna and humans | Local | Hours/Days/Years |
| Ozone depletion | ODP | CFC | kg CFC eq | Stratospheric ozone breakdown | Global | Decades/Centuries |
| Photochemical oxidant | POP | $C_2H_4$ | kg $C_2H_4$ eq | Photochemical smog | Regional/local | Hours/Days |

**Note**: Characterization factors: GWP = Global warming potential; EP = Eutrophication potential; AP = Acidification potential; EUP = Energy use potential; BDP = Biotic depletion potential; ADP = Abiotic resource depletion potential; ODP = Ozone depletion potential; POP = Photochemical oxidant potential. Category indicators: $CO_2$ = Carbon dioxide; $PO_4$ = Phosphate; $SO_2$ = Sulphur dioxide; MJ = Mega Joules; NPP = Net primary productivity; Sb = Antimony; 1, 4 DB = 1,4 Dichlorobenzene; CFC = Chlorofluorocarbon; C = Carbon.

Numerous impact assessment methodologies have been developed, such as CML 2000, Eco-indicater 99 and IMPACT 2002+. Each method has a different focus and own special impact categories which might lead to different results. There is no single methodology that comprehensively covers all environmental issues from seafood production. Differences in system boundaries, functional units, and impact assessment methodologies adopted would make comparisons of different production systems more subjective (Cao *et al*., 2011). In spite of this, comparisons of different systems or products can still be informative. Any of system changes or shift would require further evaluation of environmental performance and profitability to assure more sustainable production.

*Intensive vs. semi-intensive vs. extensive systems*

Traditional aquaculture can be classified mainly by stocking density, feeding management and capital investment. There is a trend towards growing more aquatic crops per area unit in recent years. Extensive systems with lowest unit production have been replaced by semi-intensive and intensive systems gradually. Aquaculture mostly takes place in both semi-intensive and intensive systems in developing countries, while remains intensive in developed countries (Diana, 2009). Semi-intensive is considered a way of remedying environmental problems associated with intensive farming systems. But do semi-intensive aquaculture at a lower level of intensity and using more natural systems truly result in a significant reduction in environmental impacts, especially taking its lower productivity into account? If yes, semi-intensive aquaculture definitely should be promoted to conserve biodiversity and environment while still producing enough food. There is very limited published data on comparison of extensive, semi-intensive and intensive systems.

The most common types of shrimp farms in China are semi-intensive and intensive. Criticism of intensification of shrimp farming systems has been focus on high material and energy inputs, and more effluent discharge, which might largely increase environmental burdens. Our published work indicates that, although with higher unit production, intensive shrimp farming systems have almost twice higher environmental impacts than semi-intensive farming in all studied impact categories (Table 2) (Cao *et al.*, 2011). This is due to higher electricity use, feed inputs, and concentrations of nutrients in effluents. Based on higher land footprint, intensive systems might outperform semi-intensive systems in land modification (Cao *et al.*, 2011). It can be concluded that semi-intensive shrimp aquaculture is environmentally friendlier than intensive farming systems in China. By comparing the two shrimp aquaculture systems with extensive mussel culture in Spain (Iribarren *et al.*, 2010), extensive mussel culture outperformed the other two systems in acidification, eutrophication and global warming. This is probably because mussel culture requires much less inputs than shrimp culture. The result is probably not true for all extensive farming systems due to lower unit yield. Energy and feed dependence are usually positively correlated with system intensity (Pelletier and Tyedmers, 2007). Aqua-plants such as seaweed culture at a lower intensity usually require least material and energy inputs. They would be much less environmental damaging compared to fish aquaculture.

**Table 2** Life cycle impacts (cradle to farm-gate) associated with 1 tonne of live-weight product.

| System | Acd. (kg $SO_2$ eq) | Eut. (kg $PO_4$ eq) | GW (kg $CO_2$ eq) | CEU (GJ) | BRU (kg C) | References |
|---|---|---|---|---|---|---|
| Chinese intensive shrimp | 43.9 | 63 | 5,280 | 61.5 | 60,700 | Cao et al., 2011 |
| Chinese semi-intensive shrimp | 19.4 | 32.3 | 2,750 | 34.2 | 36,800 | Cao et al., 2011 |
| Spanish extensive mussel | 4.72 | 0.4 | 472 | - | - | Iribarren *et al.*, 2010 |

Note: Acd. = acidification; Eut. = eutrophication; GW = Global warming; CEU = Cumulative energy use; BRU = biotic resource use.

*Open flow-through vs. closed recirculating systems*

The majority of fish farms especially in the developing countries are outdoor flow-through systems which discharge effluents directly to receiving water bodies without treatment. A number of environmental impacts have been recognized for this form of aquaculture. The impacts include: eutrophication and change of fauna in the receiving water bodies; escapement of aquatic crops and their potential ecological and genetic alteration; transfer or spread of disease and parasites to wild stocks; release of chemical hazards to receiving waters (Diana, 2009). Research is ongoing to develop alternatives with an emphasis on closed recirculating systems which may reduce or eliminate these impacts. By isolating the culture environment from surrounding ecosystem, closed recirculating systems are designed to grow fish at high densities with zero discharge of effluents. Water is treated to remove toxic wastes and then reused. Reusing water gives farmers better control over the environment, reduces water consumption and effluent discharge (Bostock *et al.*, 2010). Notable advantages of recirculating systems also include less fish escapes and improved waste management.

Several studies employed LCA to compare the environmental performance of open and closed recirculating systems (Aubin *et al.*, 2009; Ayer and Tyedmers, 2009; d'Orbcastel *et al.*, 2009; Pelletier and Tyedmers, 2010). They desired to determine how the life cycle environmental impacts would change if shift to closed recirculating systems (Table 3). Overall, the closed recirculating systems outperformed open systems in eutrophication emission and biodiversity reservation but all other environmental impact categories such as global warming and energy use were substantially worse. This was due to greater energy and material requirements for the recirculating system and lower unit production. Other than that, relatively high capital costs would be another barrier for closed recirculating systems to be widely employed and promoted.

**Table 3.** Life cycle impacts (cradle to farm-gate) associated with 1 tonne of live-weight fish produced

| **Systems & Species** | **Location** | **Acd. (kg $SO_2$ eq)** | **Eut. (kg $PO_4$ eq)** | **GW (kg $CO_2$ eq)** | **CEU (GJ)** | **BRU (kg C)** | **ABD (kg Sb eq)** | **HT (kg 1,4 DB eq)** | **MT (kg 1,4 DB eq)** | **Ref.** |
|---|---|---|---|---|---|---|---|---|---|---|
| Net-pen (salmon) | Canada | 17.9 | 35.3 | 2,070 | 26.9 | - | 12.1 | 639 | 822,000 | Ayer and Tyedmers, 2009 |
| Net-Pen (tilapia) | Indonesia | 20.2 | 47.8 | 1,520 | 18.2 | 2,760 | - | - | - | Pelletier and Tyedmers, 2010 |
| Sea cages (Sea bass) | Greece | 25.3 | 109 | 3,600 | 54.7 | 71,400 | - | - | - | Aubin et al., 2009 |
| Bag (salmon) | Canada | 18 | 31.9 | 2,250 | 37.3 | - | 13.9 | 840 | 574,000 | Ayer and Tyedmers, 2009 |
| Flow-through earthen pond (tilapia) | Indonesia | 23.8 | 45.7 | 2,100 | 26.5 | 2,700 | - | - | - | Pelletier and Tyedmers, 2010 |
| Flow-through tank (Trout) | France | 13.4 | 28.5 | 2,020 | 34.9 | 28,000 | - | - | - | d'Orbcastel et al., 2009 |
| Flow-through raceway (Trout) | France | 19.2 | 65.9 | 2,750 | 78.2 | 62,200 | - | - | - | Aubin *et al.*, 2009 |
| Flow-through tank (salmon) | Canada | 33.3 | 31 | 5,410 | 132 | - | 38.1 | 2,580 | 3,840,000 | Ayer and Tyedmers, 2009 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Recirculating tank (Trout) | France | 13.1 | 21.1 | 2,040 | 63.2 | 28,100 | - | - | - | d'Orbcastel et al., 2009 |
| Recirculating tank (Arctic char) | Canada | 63.4 | 11.6 | 10,300 | 233 | - | 72.5 | 54,400 | 6,510,000 | Ayer and Tyedmers, 2009 |
| Recirculating (Turbot) | France | 48.3 | 77 | 6,020 | 291 | 60,900 | - | - | - | Aubin *et al.*, 2009 |

Notes: Acd. = acidification; Eut. = eutrophication; GW = Global warming; CEU = Cumulative energy use; ABD = abiotic depletion; HT = human toxicity; MT = marine toxicity.

*Conventional vs. organic systems*

A growing number of consumers place emphasis on seafood safety issues, animal welfare and environmental concerns. Organic aquaculture is becoming increasingly important as consumers become more environmentally aware and demand for more secure seafood. Organic aquaculture is considered as one of the most promising alternatives for reducing environmental burdens associated with intensive farming. It is defined as an overall system of farm management and food production that combines best environmental practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards and a production method in line with the preference of certain consumers for products produced using natural substances and processes (EU, 2007). Organic aquaculture is described to be superior to conventional farming in that it relies largely on own internal resources and thus consume less external materials and energy. Prohibition on use of chemicals in organic farming markedly reduces ecotoxicity potentials and also conserves biodiversity. Organic products usually have great market opportunities and stable prices in exported markets. Despite the rapid growth of organic agriculture production, organic aquaculture is newly developed and still in its early stage (Mente *et al.*, 2011). This is due to diversification of cultured species, obstacles of implement some organic practices such as complete chemicals prohibition and fishmeal substitution, as well as lack of unified certification standards and criteria (Mente *et al.*, 2011). Moreover, some organic farming systems have lower yield and their requirements to adopt organic practices such as using organic feed ingredients may reduce farm eco-efficiency and cause more environmental problems. The question arises whether organic farming is really less environmental damaging once lower yields and all changes in practices are considered. LCA can be used to answer this question and provide basis for certification and eco-labeling of aquaculture to indicate the environmentally-friendlier product/system.

Mungkung conducted an LCA study for shrimp farming in Thailand and compared life cycle impacts of conventional intensive, organic as well as other transitional systems (Table 4) (Mungkung, 2005). Organic shrimp farms in Thailand are characterized by operation at lower stocking density with best available organic inputs and complete elimination of chemicals and antibiotics. Conventional intensive systems are managed at high stocking rate and high inputs aiming for high productivity. Overall, the conventional intensive farm showed the highest impacts for all impact categories, except for eutrophication which was highest for the organic farm. The significantly higher impacts from conventional intensive farm were caused by high energy inputs, feed use, and chemicals use. Organic system in her study was identified as the most environmentally sustainable practice.

**Table 4.** Life cycle impacts associated with 1 tonne of conventional and organic products

| **Product** | **Acd. (kg $SO_2$ eq)** | **Eut. (kg $PO_4$ eq)** | **GW (kg $CO_2$ eq)** | **ABD (kg Sb eq)** | **MT (kg 1,4 DB eq)** | **BRU (kg C)** | **EU (GJ)** | **References** |
|---|---|---|---|---|---|---|---|---|
| Conventional | 18.5 | 10.6 | 5,210 | 91.3 | 475,000 | - | - | Mungkung, |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| intensive shrimp | | | | | | | | 2005 |
| Organic shrimp | 3.77 | 11.5 | 901 | 19.5 | 61,300 | - | - | |
| Conventional salmon feed | 12.6 | 5.3 | 1,400 | - | 60,700 | 10,600 | 18.1 | Pelletier and Tyedmers, 2007 |
| Partial-organic salmon feed | 11.8 | 4.9 | 1,250 | - | 61,100 | 10,600 | 17.1 | |
| All-organic salmon feed | 24.6 | 6.7 | 1,810 | - | 63,300 | 45,100 | 26.9 | |
| All-organic salmon feed with substitutions | 6.9 | 2.3 | 690 | - | 47,600 | 6,300 | 9.86 | |

Notes: Acd. = acidification; Eut. = eutrophication; GW = global warming; CEU = Cumulative energy use; ABD = abiotic depletion; MT = marine toxicity; BRU = biotic resource use; EU = energy use.

However, Pelletier and Tyedmers (2007) studied organic salmon farming and concluded that use of organic crop ingredients and fisheries byproducts failed to reduce the environmental impacts of feed production for all impact categories considered in their study. They indicated that compliance of current organic standards in salmon farming would rather result in markedly higher environmental burdens with respect to energy use, global warming, ecotoxicity, acidification, eutrophication and biotic resource use. They suggested that substitution of animal-derived ingredients with plant-based ingredients in the fish feed could probably solve this dilemma. But more research and case studies are needed to test if the substitution satisfies the nutrition requirement of fish and doesn’t harm fish growth. Some species with high economic value such as shrimp and salmon require higher protein level in the feed. Substitution of animal-based protein with plant protein may result in lower growth rate. Pelletier and Tyedmers (2007) also pointed out that impacts on land use would be greater in organic systems due to lower yields. Optimizing organic farming to achieve higher yields could solve this problem.

*Mono vs. polyculture systems*

As one of integrated systems, polyculture is developed as an alternative model to counter the problems such as disease vulnerability and low feed efficiency caused by monocultures. Polyculture systems have higher levels of biodiversity and usually gain more economic profits. But is polyculture superior to monoculture in terms of environmental sustainability?

Based on a published LCA study on polyculture (Baruthio *et al.*, 2009), we compare potential impacts per tonne of all products from polyculture with prawn as the main species, prawn from polyculture, and shrimp from monoculture (Table 5). Results show that polyculture performs better in terms of global warming and energy use, but not in terms of acidification and eutrofication compared to shrimp monoculture. With a focus on prawn only from polyculture by employing economic allocation, impacts per tonne of prawn from polyculture are higher than per tonne of mono-cultured shrimp. Comparative results indicate that polyculture system fails to be more environmentally sustainable than monoculture system in this case.

**Table 5**. Life cycle impacts associated with 1 tonne of products

| **System** | **Country** | **Acd. (kg $SO_2$ eq)** | **Eut. (kg $PO_4$ eq)** | **GW (kg $CO_2$ eq)** | **CEU (GJ)** | **References** |
|---|---|---|---|---|---|---|
| Shrimp (monoculture, average value) | China | 32 | 48 | 4,020 | 48 | Cao et al., 2011 |
| All products (prawn, tilapia, milkfish, crab) | Philippines | 34 | 129 | 3,550 | 46 | Baruthio et al., 2009 |
| Prawn (from Polyculture and | Philippines | 48 | 172 | 5,110 | 67 | Baruthio et |

| | | |
|---|---|---|
| calculated by economic allocation) | | al., 2009 |

Notes: Acd. = acidification; Eut. = eutrophication; GW = global warming; CEU = Cumulative energy use.

*Global scale comparison*

Ongoing efforts have been devoted to manage environmental performance of food production from local through regional and global scales. Pelletier *et al.* (2009) presented a global-scale comparison of farmed salmon using LCA (Table 6). They evaluated environmental burdens associated with salmon farming in Norway, the UK, Canada, and Chile. They found that impacts were lowest per unit production for Norwegian production in most impact categories, and highest for UK farmed salmon. These were mainly due to differences in feed composition and feed utilization rate among regions. Greater biotic resource use in Norway and the UK results from higher inclusion rates of fish- based inputs such as fish meals and oils derived from high tropic level species. Sometimes, different electricity generating files among regions might be another pivotal environmental performance driver. Electricity generating mix of most developing countries is still coal-dominated. If electricity mix could be changed toward less carbon intensive energy production such as hydro, natural gas or nuclear power, the impact on global warming would be reduced significantly.

**Table 6**. Life cycle impacts (cradle to farm-gate) associated with 1 tonne of live-weight salmon produced (Pelletier *et al.*, 2009).

| Countries | Acd. (kg $SO_2$ eq) | Eut. (kg $PO_4$ eq) | GW (kg $CO_2$ eq) | CEU (GJ) | BRU (kg C) |
|---|---|---|---|---|---|
| Norway (Salmon) | 17.1 | 41.0 | 1,790 | 26.2 | 111,000 |
| UK (Salmon) | 29.7 | 62.7 | 3,270 | 47.9 | 137,000 |
| Chile (Salmon) | 20.4 | 51.3 | 2,300 | 33.2 | 56,600 |
| Canada (Salmon) | 28.1 | 74.9 | 2,370 | 31.2 | 18,400 |

Note: Acd. = acidification; Eut. = eutrophication; GW = global warming; CEU = cumulative energy use; BRU = biotic resource use.

**Life cycle comparison of agri-food and seafood**

Seafood is an alternative protein source to agricultural livestock products. Although LCA are initially designed for land-based industrial applications, application of this methodology to seafood products is a recent phenomenon compared to agri-food products. Thus, it would be interesting to use well studied agri-food products for bench-marking when assessing environmental impacts of seafood production. Comparison of environmental performance of agriculture and aquaculture products would also be in demand for certification and eco-labeling to guide purchasing decisions for more sustainable consumption. Several studies have been conducted to rank the environmental performance of different agri- and aqua- food products (Ellingsen and Aanondsen, 2006; Williams *et al.*, 2006; Mungkong and Gheewala, 2007; Ellingsen *et al.*, 2009; Cao *et al.*, 2011).

Results from several recent studies are summarized and compared in Table 7. Average value is used for products from the same region. Based on current listing, agri-food products except chicken are usually more $CO_2$-intensive and perform worse in acidification and eutrophication than seafood products from both capture fisheries and aquaculture. Beef is most $CO_2$-intensive and generates highest impacts in acidification and eutrophication. Beef production also uses more land than aquaculture-based seafood. It seems that wild-caught seafood, followed by farmed seafood, is more energy-intensive than agri-food. Wild-caught seafood also has the highest impact on land use.

However, due to differences in system boundaries, functional units, and impact assessment methodologies adopted, comparisons and interpretation could be subjective and should be done with care (Mungkong and Gheewala, 2007; Cao *et al.*, 2011). Mungkong and Gheewala (2007) proposed to address the issue of different function unit by using normalization of the nutrients gained per kg of product consumed with the daily nutritional values required. Comparison of different food products with different value chains will be very complicate and resource demanding. Thus, it is necessary to develop a unified impact assessment methodology to get a true basis for comparison in the future studies (Ellingsen *et al.*, 2009).

**Table 7.** Environmental impact comparison of different food products per tonne of product

| **Products** | **Location** | **GW (kg $CO_2$ eq)** | **Acd. (kg $SO_2$ eq)** | **Eut. (kg $PO_4$ eq)** | **CEU (GJ)** | **Land ($1000m^2$)** | **References** |
|---|---|---|---|---|---|---|---|
| Beef | UK | 25,300 | 708 | 257 | 40.7 | 38.5 | Williams et al., 2006 |
| Pork | UK | 6,360 | 395 | 100 | 16.7 | 7.4 | Williams et al., 2006 |
| Chicken | UK | 4,570 | 173 | 49 | 12 | 6.4 | Williams et al., 2006 |
| Farmed shrimp (average) | Asia | 5,250 | 31 | 37 | 54 | 2.2 | Mungkung, 2005; Cao et al., 2011 |
| Farmed salmon (average) | Europe | 2,450 | 22.4 | 51.7 | 43.3 | 6 | Ellingsen and Aanondsen, 2006; Pelletier et al., 2009 |
| Farmed trout (average) | France | 2,270 | 15.2 | 38.5 | 58.8 | - | Aubin et al., 2009; d'Orbcastel et al., 2009 |
| Wild-caught cod (average) | Europe | 3,000 | - | - | 81.3 | 1,390 | Ellingsen and Aanondsen, 2006; Mungkong and Gheewala, 2007 |
| Wild-caught tuna | Spain | 1,800 | 24 | 3.7 | - | - | Hospido and Tyedmers, 2005 |

Note: GW = global warming; Acd. = acidification; Eut. = eutrophication; CEU = cumulative energy use.

**Modeling biodiversity loss in LCA**

Biodiversity loss is perhaps currently the most serious environmental problem. Global biodiversity is suffering a sharp decline and continuing at an alarming rate (Curran *et al.*, 2011). The major causes of aquatic biodiversity loss are invasive species, habitat loss, pollution, and exploitation associated with aquaculture (Diana, 2009). Each aquaculture system now in use has rarely positive but mostly negative impacts on aquatic biodiversity. None of them is truly sustainable from a biodiversity perspective (Diana, 2009). Impacts arise from resource consumption, land modification, and waste generation. Diana (2009) listed five most important effects of aquaculture on biodiversity, including escapement of aquatic crops and their invasive potentials, effluent effects on water quality, conversion of sensitive land, inefficient resource use, and spread of disease and parasite. Therefore, it is essential to assess biodiversity loss caused by aquaculture and examine the driving forces behind for better protection of aquatic biodiversity and system optimization. Biodiversity loss should also be included as one of the most important impact indicators of sustainability.

Five direct drivers of biodiversity loss have been identified by the Millennium Ecosystem Assessment in 2005 (MA, 2005). They are habitat change, climate change, invasive species, pollution, and overexploitation of wild populations. Although the development and inclusion of biodiversity in LCA has been ongoing for more than a decade, many methodologies in LCA are still in their infancy (Curran *et al.*, 2011). To date, three of five drivers of biodiversity loss have been employed in LCA to some degree, including habitat change, climate change and pollution. They have been developed into impact categories of land use, water use, global warming, eutrophication, acidification and ecotoxity. However, land use in

LCA fails to reflect its impacts on biodiversity. New method for evaluating the impacts on biodiversity from land use in agricultural LCA has been proposed with a focus on species richness (Schmidt, 2008). Two drivers including invasive species and overexploitation are still completely missing in the LCA framework (Curran *et al.*, 2011). A number of complete or ongoing studies are attempting to include them quantitatively on the functional unit basis or qualitatively into an expanded LCA framework (Pelletier *et al.*, 2007; Jeanneret, 2008; Alkemade *et al.*, 2009). Many novel impact categories have been developed but not yet scrutinized. Pelletier and colleagues (2007) also suggested impact categories reported in agricultural LCAs might be references for impact category development for seafood. To meaningfully characterize biodiversity in LCA, Curran *et al.* (2011) offered two recommendations for future research. First, the methodological shortcomings should be addressed. Then, data representative of distribution of global biodiversity and its pressures should be acquired. Integrating the missing drivers and impact factors of biodiversity could further enhance the credibility of sustainability assessment in LCA (Curran *et al.*, 2011).

**Using LCA for certification and eco-labeling**

Certification and eco-labeling systems for aquaculture are used to identify sustainable seafood products based on their relative environmental performance. They are a form of sustainability measurement which integrates environmental concerns into aquaculture sector and intend to direct consumers for more sustainable food consumption. At present, certified and eco-labeled food products represent one of the fasted growing food markets, with an growth rate at 20%-25% per annum (Pelletier and Tyedmers, 2008). The rapid development of certification and eco-labeling systems stimulates increasing recognition of the need to standardize criteria to provide producers with clear guidelines and reduce consumers' confusion (Pelletier and Tyedmers, 2008). There are now many certification initiatives and consumer awareness programs focusing on food safety, animal welfare, environmental protection and social risk assessment standards. However, few of them are life-cycle based and fully cover all relevant environmental issues. Developing robust measures of sustainability and its assessment tools have been highlighted by the World Wildlife Fund (WWF) aquaculture dialogues (Bostock *et al.,* 2010). LCA is one of the key approaches which can provide a relatively comprehensive measure of the sustainability in the seafood sector to inform certification and eco-labeling criteria. It helps to identify key environmental impacts in the product life cycle which can be used as certification or eco-labeling criteria (Mungkung *et al.*, 2006). Mungkung and colleagues (2006) identified abiotic depletion, global warming and eutrophication as key environmental impacts for shrimp aquaculture which could be covered by eco-labeling criteria. Other important impacts including depletion of wild broodstock, impacts of trawling on marine biodiversity and the choice of suitable farm sites could not be quantified by traditional LCA. They can be included as 'hurdle criteria' and qualitatively described in the expanded LCA.

Use of LCA for setting certification and eco-labeling criteria is still very much limited, since socio-economic impact categories are still under development in the LCA framework. Methodologies for the integration of social and economic sustainability through a life cycle approach are still in their early stages. There are increasing efforts working on the integration of social and economic aspects into the LCA framework (Kruse *et al.*, 2009). For instance, life cycle costing is developed and often employed to address economic issues. Guidelines for social life cycle assessment have also been developed to address social issues. However, practical applications of social life cycle assessment are very limited. Future research need to test the relevance, practicability and validity of the indicators presented in social life cycle assessment.

**Conclusions**

An increasing number of LCA studies of aquaculture have been published. This indicates that LCA is an appropriate means and will become a mainstream tool to evaluate global and local environmental impacts of seafood production systems. As a systematic approach, LCA can evaluate sustainability of aquaculture systems quantitatively from a cradle-to-end perspective. By assessing system performance, it presents a best basis for system improvement in terms of environmental sustainability and development of certification or eco-labeling criteria. However, LCA still could not quantify local ecological and socio-economic impacts, which limits its ability and future popularizing. More efforts should be given to adapt the tool to aquaculture applications, as well as integration of current missing (such as biodiversity) or immature (such as socio-economic) impact categories for more comprehensive evaluations of system/product sustainability. Overall, LCA is a useful tool and has great potential in assisting decision making for more sustainable seafood production and consumption.

Comparative LCA studies indicate that farming systems with relatively lower intensity and use more natural systems would be more environmentally friendly. Semi-intensive farming outperforms intensive farming systems. Closed recirculating systems outperforms open systems in eutrophication emission and biodiversity reservation but all other environmental impact categories such as global warming and energy use were substantially worse. Polyculture appears not superior to monoculture in terms of environmental sustainability. Currently there is no farming system or seafood product really environmentally sustainable. Organic farming with low intensity seems to be the most promising system if animal-derived ingredients are substituted with plant-based ingredients in the feed. By comparing captured and farmed seafood with agri-food products, agri-food products except chicken are usually more $CO_2$-intensive and perform worse in acidification and eutrophication than seafood products. Beef is most $CO_2$-intensive and generates highest impacts in acidification and eutrophication. Wild-caught seafood is more energy-intensive than farmed seafood and agri-food. More comparative studies are needed to benchmark different aquaculture production systems and their seafood products to promote developing more sustainable aquaculture production systems. Due to differences in system boundaries, functional units, and impact assessment methodologies adopted, comparisons and interpretation should be done with care.

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# ENVIRONMENTAL PERFORMANCE

*Marc Verdegem, Wageningen University; Ep H. Eding, Ing., Wageningen University*

**Abstract**

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 neighbouring 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.

# Environmental performance (of fed aquaculture)

Marc C.J. Verdegem & Ep. H. Eding

"WAGENINGEN AQUACULTURE"

## Fed aquaculture

- Finfish
- Crustaceans

## Extractive aquaculture

- Algae/seaweeds
- Molluscs

**Marine aquaculture: net extractive**

## Nutrient loading

(Eding et al., 2006)

**1 kg formulated feed**

| feed utilization | DM |
|---|---|
| Input | |
| feed | 900 |
| Output | |
| spilled feed | - |
| fecal loss | 315 |
| settleable | 180 |
| non-settleable | 135 |
| non fecal loss | 360 |
| oxygen consumption | |
| gain (growth) | 225 |

**European eel**

Environmental nutrient loading



## Nutrient loading

(Eding et al., 2006)

**1 kg formulated feed**

| feed utilization | N |
|---|---|
| Input | |
| feed | 77 |
| Output | |
| spilled feed | - |
| fecal loss | 23 |
| settleable | 17 |
| non-settleable | 6 |
| non fecal loss | 41 |
| oxygen consumption | |
| gain (growth) | 13 |

**European eel**

Environmental nutrient loading

## Nutrient loading

(Eding et al., 2006)

**1 kg formulated feed**

| feed utilization | COD |
|---|---|
| Input | |
| feed | 1260 |
| Output | |
| spilled feed | - |
| fecal loss | 441 |
| settleable | 252 |
| non-settleable | 189 |
| non fecal loss | 50 |
| oxygen consumption | 409 |
| gain (growth) | 360 |

**European eel**

Environmental nutrient loading



## Flow through systems

(Foy and Rosell, 1991)

$$\textit{Nutrient loading} = \text{amount fed} - \text{weight gain}$$

$$Nutrient_i\ loading = (kg\ feed * F_i) - G_i$$

**Trout raceways: measured loading as % of estimated loading:**

- **N: 89%**
- **P: 102%**

## Nutrient loading fed aquaculture

**World aquaculture production 2008**

| Species group | Total tonne |
|---|---|
| Plantae aquaticae | 15 781 159 |
| Mollusca | 13 114 194 |
| Pisces | 33 824 303 |
| Crustacea | 5 009 993 |
| Invertebrata aquatica | 305 461 |
| Amphibia, reptilia | 313 833 |
| Total | 68 348 943 |

(FAO, 2010)

**39 million MT**

**30% protein diet**

**FCR 1.5; 1%P**

**Nutrient loading:** 1.7 million MT **N**

0.46 million MT **P**



## Anthropogenic N and P loading

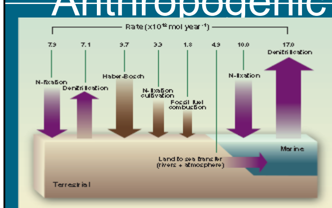



Fig. 4. Rates of nitrogen flux in the modern nitrogen cycle depend on the efficiency of the transformations between reservoirs. Arrow size reflects relative size of the flux. The dark brown arrows represent anthropogenic inputs (25, 45, 46, 52, 53, 68, 69).

(Canfield et al. 2010)

**N**

**Global: 205 * $10^6$ MT**

**Aquac.: 1.7 * $10^6$ MT**

**0.86% (0.37%)**

**P**

**Global: 17.3 * $10^6$ MT**

**Aquac.: 0.46 * $10^6$ MT**

**2.7%**

(FAO, 2008; Filippelli, 2008)

## Aquaculture production systems

- Ponds:
  - > 85% global fed aquaculture production
- Cages & flow-through
  - 15%
- RAS
  - 0.1 – 0.2 % global aquaculture production



## Maximum and minimum discharge of loading

### Flow-through (cage; raceway)

- 100% discharge
- **Traceable impact** = maximum dispersion area = 12 – 18 time farm size (Alongi et al., 2009)
- **Share loading**; consider all nutrient inputs to ecosystem; dispersion modelling (Cai and Sun, 2007) ➔ Maximum nutrient loading

nt

### RAS

- 4-6% discharge
- Discharge is P fertilizer
- expensive

**Link to extractive aquaculture**

## Ponds: discharge of COD, BOD

- Stagnant, non aerated
  - Non-aerated: biomass (1000 – 5000 kg/ha) ➔
    25 – 25% COD input is discharged
  - Aerated: biomass (5000 – 25000 kg/ha) ➔
    5 -10% COD input is discharged
- Water exchange
  - 15% volume per day: PP 4-6 g C $m^{-2}$ $d^{-1}$; 20 MT ➔
    1000 – 1500 % COD input is discharged
  - Less biomass ➔ ratio ↑

(Verdegem and Bosma, 2009)



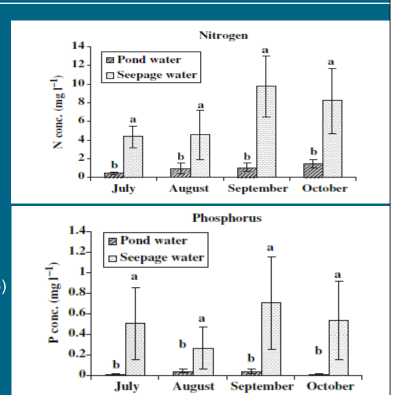
## Ponds: seepage

**Extensive pond: 2000 kg/year; FCR 1.5**

- **N-loss: 28 % of N input**
- **P-loss: 44 % of P input**

**Mobility to aquifers is low** (Kunwar et al., 2006)

- **Uptake by plants**
- **Immobilization by soil bacteria**



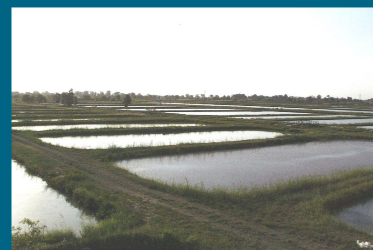

(Muendo et al. 2005)

## **Ponds:** tidal water exchange

(Hussenot et al. 1998 & 2003)

### Atlantic coast Europe:

- Sea bass
- Sea bream
- Turbot



### "Downstream water treatment"

- Algal ponds: diatoms (+silicon & phosphorous)
- Oysters (*Crassostrea gigas)* harvest algae:
  - 100 % in winter
  - 92 % in summer
  - Not during spawning season

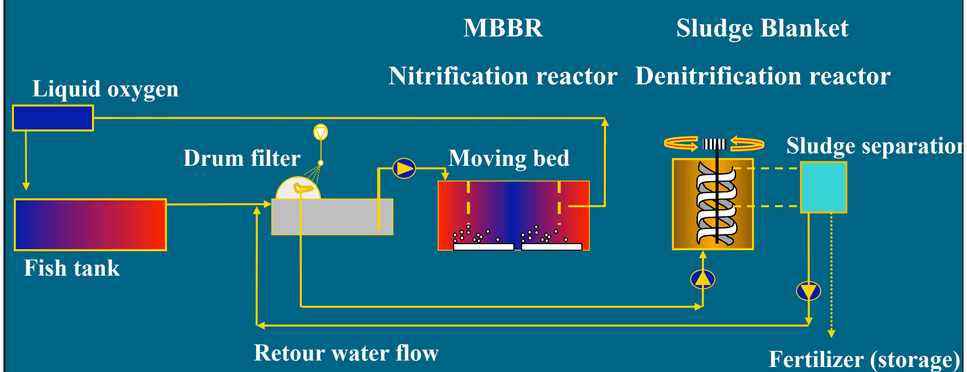
| Treatment | TSS | Chl | TAN | DOM | PO4 |
|---|---|---|---|---|---|
| Retention lagoon | +++ | 0/-- | 0/+ | 0 | + |
| Foam fractionation | + | + | + | +++ | + |
| Microalgae reactor | - | --- | +++ | 0/- | ++ |
| Bivalve filter | ++ | +++ | 0/- | - | 0 |



## RAS: water consumption

- Water re-use: 1 – 50 $m^3$ kg $feed^{-1}$
- RAS: 0.1 – 1.0 $m^3$ kg $feed^{-1}$
- ~~Next generation RAS: <~~ 0.1 $m^3$ kg $feed^{-1}$
- ... Zero discharge RAS
  - Minimum sludge 40 – 60 g DM kg $feed^{-1}$
  - N ➔ $N_2$
  - Sludge rich in P, Cd, ....

# RAS: next generation




## 300 MT Tilapia farm

Son en Breugel, The Netherlands

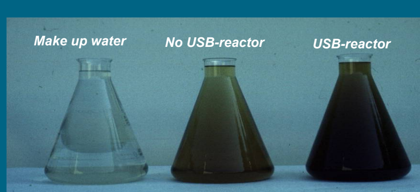


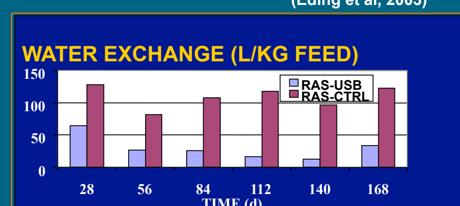
# RAS: Effect of USB-reactor

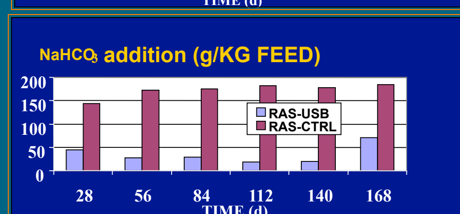
(Eding et al, 2003)

African catfish

- Normal RAS (RAS-CTRL)
- Next generation (RAS-USB)



## Challenges: pond aquaculture

(Bosma & Verdegem, 2011)
(Verdegem & Bosma, 2009)

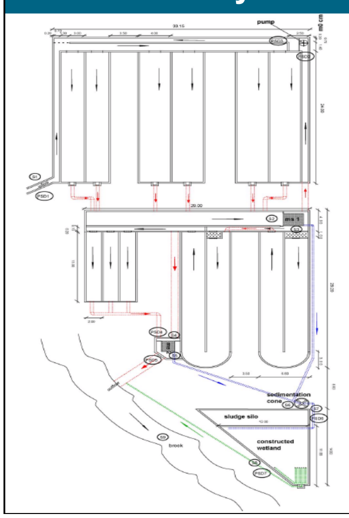
- Low water flow ➔ dilute effluents
- Efficient water treatment: ↑ concentration effluent > 20 times
- ➔ intensify pond aquaculture
- ➔ increase water re-use

- Exchange flow:
  - (artificial) wetland



## Water re-use system: trout

(Sindilariu et al. 2009)




Trout farm:

- Screen filters
- Pure oxygen on sec. water use
- Sludge collection ➔ fertilizer
- Wetland for dissolved and small particulate matter

Water returning to river is a slightly enriched:

- 0.57 mg/l TSS
- 1.08 mg/l $BOD_5$
- 0.03 mg/l TP

treatment costs 0.2 US$ $kg^{-1}$

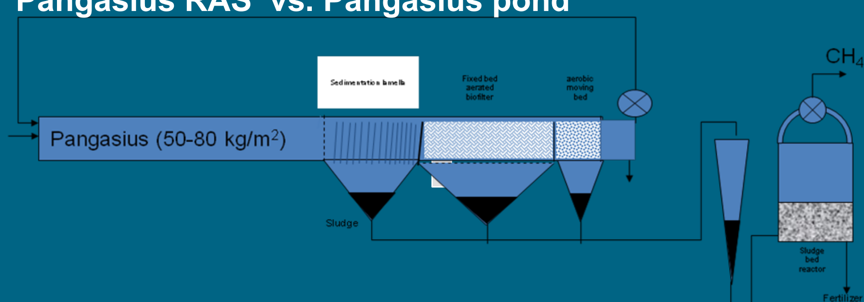
# **Outdoor RAS:** trout farm Denmark


Courtesy Per Bovbjerg Pedersen



# Water re-use in tropics and semi-tropics

**Pangasius RAS vs. Pangasius pond**



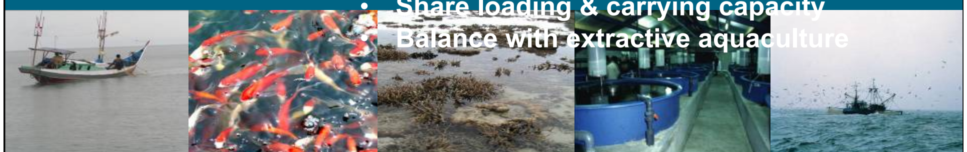

**Compare sustainability indicators**

Globally: not major player

# Minimum pollution aquaculture

- RAS
  - 0.1 – 0.2% global aquaculture production
  - Adapt technologies to outdoor systems
- Pond cultures:
  - Evolve to water re-use systems
- Cages & flow-through
  - Share loading & carrying capacity
  - Balance with extractive aquaculture





## ANTIMICROBIAL USE IN AQUACULTURE, MICROBIAL DIVERSITY AND ANTIMICROBIAL RESISTANCE

*Felipe Cabello, New York Medical College*

**Abstract**
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.

Funded by the Lentfest Ocean Program/Pew Charitable Trusts

# Antimicrobial Use in Aquaculture and Microbial Diversity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**Funding:** Lenfest Ocean Program/Pew Charitable Trust;
John Simon Guggenheim Foundation

# Aquaculture

**Extensive:** **i.** low degree of control; **ii.** low costs, low technology, low production; **iii.** high dependence on climate and water quality

**Intensive:** **i.** high degree of control; **ii.** high costs, high technology, high production; and **iii**. independence of climate and water quality

**Semi Intensive:** **i.** some degree of control; **ii.** natural foods, fertilizers; and **iii.** some technology

**Integrated:** shared resources

**Antimicrobials are used in all of them**

FAO, 2008

**Negative impacts of semi-intensive aquaculture on biodiversity**

Escapement alien species

Eutrophication

Introduction of infections agents and parasites

Escapement of native species

Land conversion

**Release chemotherapeutants, antimicrobials**

Use of natural resources

Loss of benthic biodiversity

Recruitment failure

Diana et al. 2011

**Prevalence of resistance (expressed as percentages) in *Enterococcus* spp. Isolated from integrated chicken-fish farms (int) and control fish farms (con)**

| Species | CHL | | CIP | | ERY | | GEN | | OTC | | STR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | int | con | int | con | int | con | int | con | int | con | int | con |
| *E. durans/hirae* (13/0)[a] | 0 | – | 0 | – | 92 | – | 0 | – | 92 | – | 82 | – |
| *E. faecalis* (50/9) | 20 | 0 | 32 | 0 | 100 | 11 | 21 | 0 | 62 | 11 | 88 | 67 |
| *E. faecium* (140/23) | 0 | 0 | 3 | 17 | 92 | 65 | 1 | 0 | 79 | 44 | 67 | 48 |

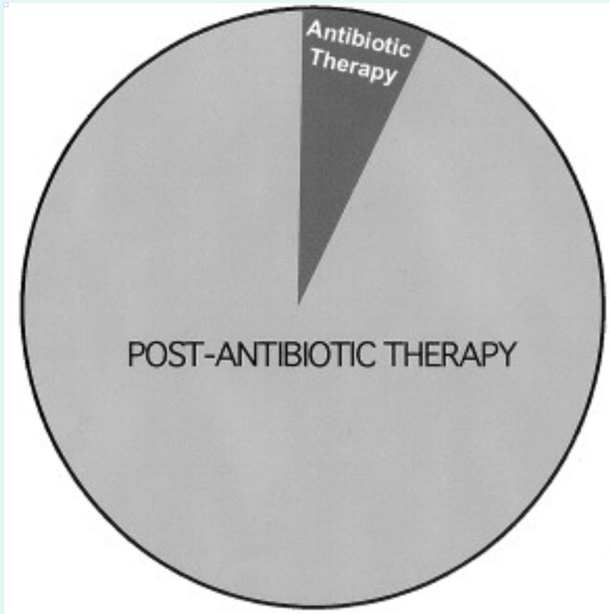
a. Number of isolates from integrated/control farms.

## Decrease of biodiversity

Petersen and Dalsgaard (2003), *Environmental Microbiology,* 5, 395-402

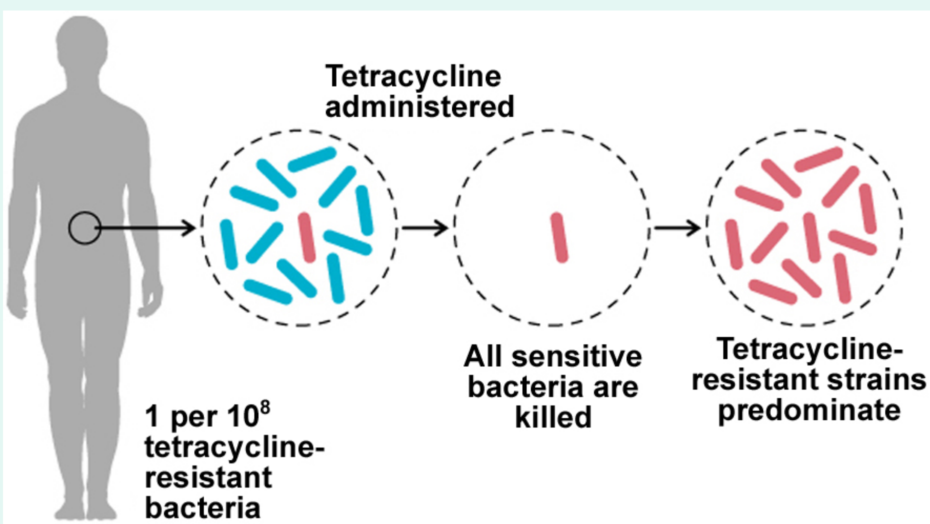
# Some Properties and Problems of Antimicrobials

## Antimicrobial effects



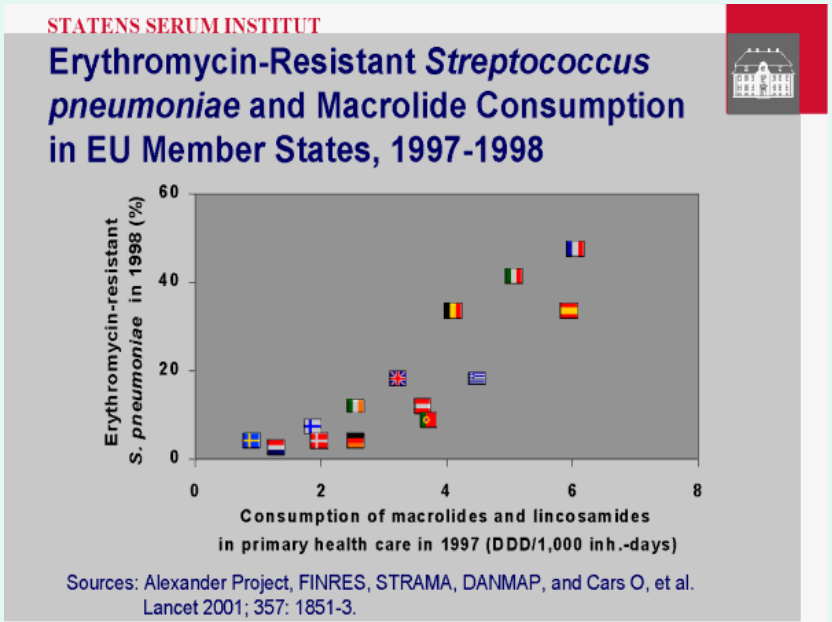

Levy, Clin. Infect. Dis. 33(Suppl. 3), S124, 2001

## Antimicrobial effects



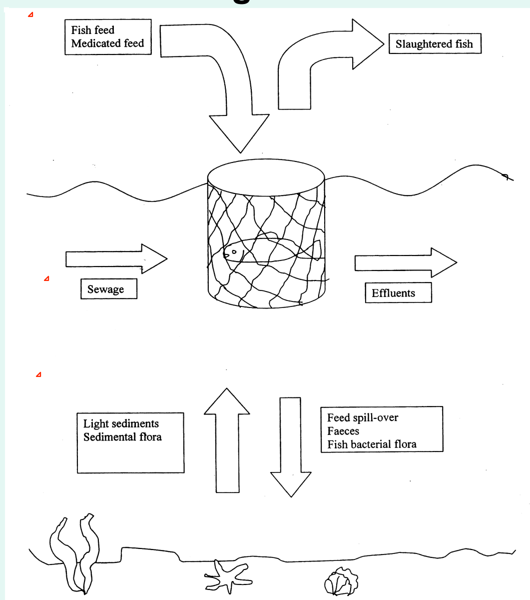

Decrease of biodiversity

## Antimicrobial effects




# Problems of the Use of Antimicrobials in Aquaculture

## Management and environmental factors in aquaculture that contribute to the spread of drug-resistant bacteria and their genetic factors




*Antimicrobial Resistance in Bacterial of Aniimal Origin.* ASM Press, 2006, p. 233

## SELECTION DENSITY

**Amount of Antibiotic**

***per***

**Individual**

***per***

**Geographic Area**

Levy, Clin. Infect. Dis. 33(Suppl. 3), S124, 2001

## Classes of chemical compounds used in Atlantic salmon aquaculture, quantities used in 2007 and quantities applied relative to production

| Country | Salmon production (metric ton)[a] | Therapeutant type | kg (active ingredient) used | kg therapeutant/ metric ton produced |
|---|---|---|---|---|
| Norway | 821,997 | Antibiotics | 649 | 0.0008 |
| | | Anti-louse | 132 | 0.00016 |
| Chile | 330,791 | Antibiotics | 385,600 | 1.17 |
| | | Anti-louse | 600.1 | 0.00018 |
| UK | 132,528 | Antibiotics | 1,553 | 0.0117 |
| | | Anti-louse | 194.8 | 0.0015 |
| Canada (includes data from Maine, USA) | 121,370[b] | Antibiotics | 21,330[c] | 0.175 |
| | | Anti-louse | 19.8 | 0.00016 |

[a] Data accessed at FAO (April 2010) ( http://www.fao.org/fi/website/FIRetrieveAction.do?dom=collection&xml=global-aquaculture-production.xml&xp_nav=1).

[b] Data accessed at http://www.dfo-mpo.gc.ca/communic/statistics/aqua/index_e.htm (October 2009) and New Brunswick Salmon growers Association (personal communication 2009).

[c] Government of British Columbia (October 2009) (http://www.al.gov.bc.ca/ahc/fish_health/antibiotics.htm and New Brunswick Salmon Growers Association (personal communication).

L. Burridge et al., *Aquaculture* (2010) 306, 18

## $IC_{50}$ and $LC_{50}$ values of OTC and FLO to *Tetraselmis chuii* and *Artemia parthenogenetica*, respectively

| | *Tetraselmis chuii* | | *Artemia parthenogenetica* | |
|---|---|---|---|---|
| | $IC_{50}$ (72 h) (mg/l) | $IC_{50}$ (96 h) (mg/l) | $LC_{50}$ (24 h) (mg/l) | $LC_{50}$ (48 h) (mg/l) |
| Oxytetracycline | 13.16 (10.24 – 18.89) | 11.18 (8.39 – 15.84) | 870.47 (778.83 – 983.66) | 805.99 (650.71 – 1129.81) |
| Florfenicol | 11.31 ( 7.95 – 17.02) | 6.06 (4.38 – 8.40) | >889 – | >889 – |

95% confidence limits are within brackets.

C.S.Gonçalves Ferreira et al., *Ecotoxicol. Environ. Safety* (2007), 67, 455

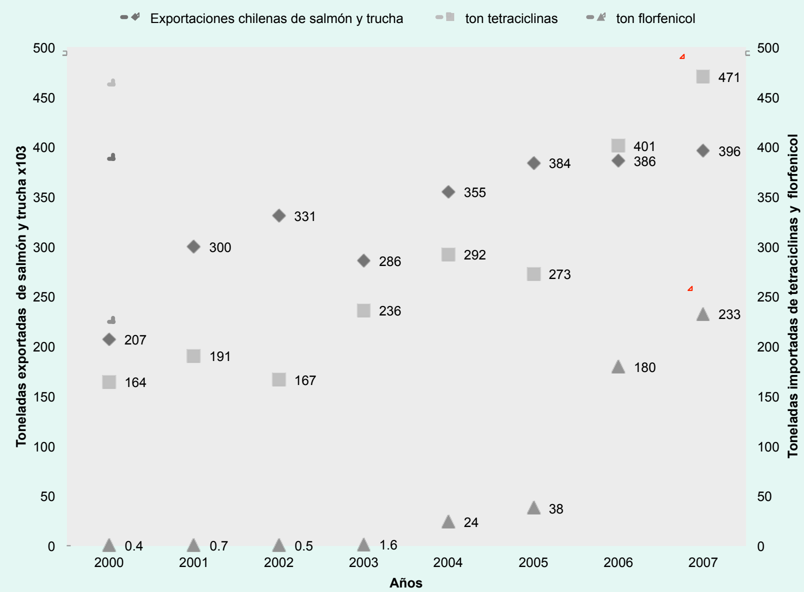
# Antibiotic Use in Salmon Aquaculture in Chile and its Effects

## Estimates of antibiotic use in salmon aquaculture in Chile

| Source | Amount | Year |
|---|---|---|
| Bravo *et al*. | 119.9 mt | 2002 |
| | 134.1 mt | |
| 2003 | | |
| Economics | 385 mt | |
| 2007 | | |
| Ministry, Chile | 322 mt | 2008 |
| Marine Harvest, Chile | 732 g/mt salmon | 2007 |
| | 560 g/mt salmon | 2008 |
| Norway | 0.02 g/mt salmon | 2007 |
| | 0.07 g/mt salmon | 2008 |

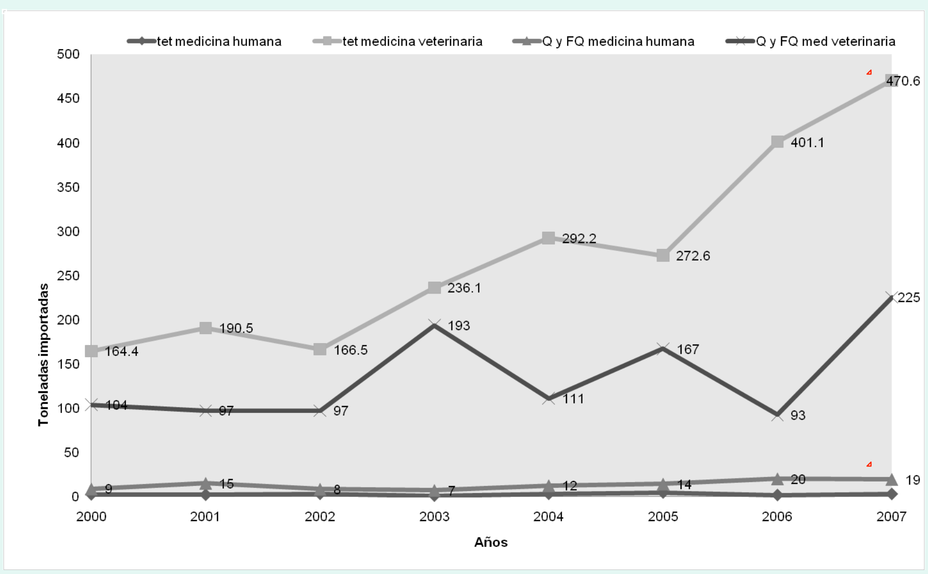
Bravo et al, 2005, Ministerio de Economia, Chile, 2008, Marine Harvest, 2008

## Metric tons of salmon and trout exported, and metric tons of imported tetracyclines and florfenicol for use in veterinary medicine in Chile during 2000 to 2007



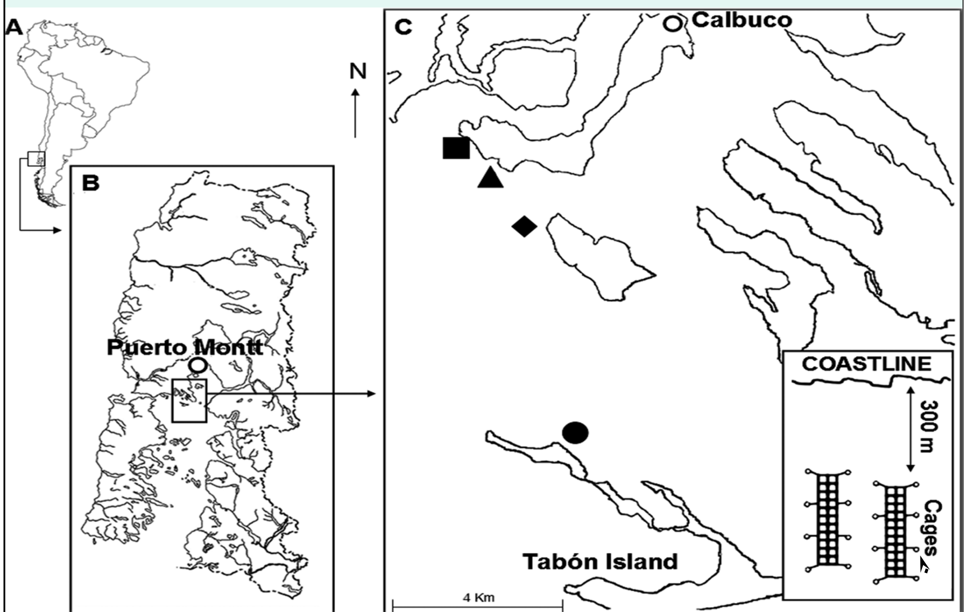

Millanao *et al.*, 2010

## Metric tons of tetracyclines (tet), quinolones (Q) and fluoroquinolones (FQ) imported for use in human medicine and veterinary medicine in Chile during the period 2000 - 2007

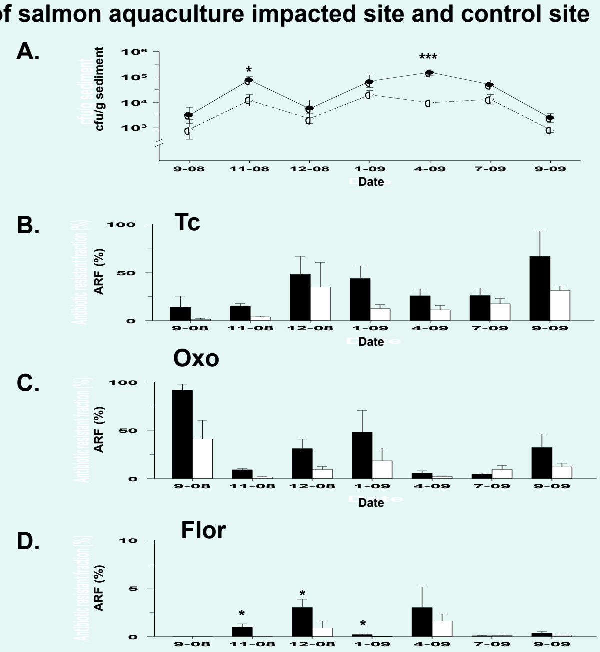



Millanao *et al.*, 2010

## Geographical location of the study

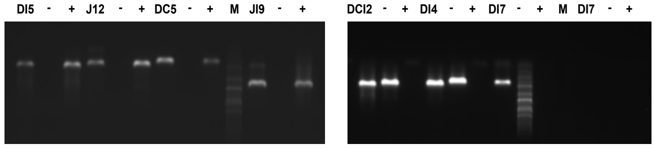



## Cultivable bacteria and antibiotic resistance bacteria in the sediment of salmon aquaculture impacted site and control site



# Detection by PCR of quinolone resistance genes *qnr* in bacteria of the marine sediment

Bacterial isolates and controls




Antibiotic resistance genes

**Antibiotic resistance genes present in marine sediment bacteria from aquaculture and control sites in Chile**

| Site | No. of Strains | Antibiotic resistance genes to: Tetracycline | | | Quinolones | | | | | | | | Florfeni-col | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *tetA* | *tetB* | *tetK* | *qnrA* | *qnrB* | *qnrC* | *qnrD* | *qnrS* | *qepA* | *oqxA* | *aac* (6') *Ib-cr* | *florR* | *Int1* |
| Aquaculture | 24 | 4 | 5 | 5 | 2 | 1 | 0 | 0 | 3 | 0 | 3 | 4 | 4 | 3 |
| Control | 24 | 4 | 5 | 4 | 2 | 1 | 0 | 0 | 5 | 0 | 3 | 1 | 2 | 1 |

# Conclusions

- Salmon aquaculture increases the number of cultivable bacteria in the sediments under the salmon cages, altering biodiversity.
- Use of antimicrobials in salmon aquaculture increases the frequency of antimicrobial resistant bacteria to tetracyclines, florfenicol and quinolones in the marine sediment under the cages, decreasing biodiversity .
- Marine bacteria from the sediment, contain plasmid mediated quinolone resistance genes, tetracycline resistance and florfenicol resistance genes, that confer a potential selective advantage to these bacteria in the presence of antimicrobials
- More studies will be needed to ascertain the relevance of the antimicrobial resistance bacteria generated by salmon aquaculture for marine microbial diversity, fish and human health
- Sustainable semi intensive and intensive aquaculture should improve hygienic and biosafety standards, increase the use of vaccines and probiotics and decrease the use of antimicrobials

## Total antibiotic use (kg active ingredient) in Canada and Chile

| Total antibiotics | 2006 | 2007 | 2008* |
|---|---|---|---|
| Canada[a] | 13,522 | 21,330 | 5,093 |
| Chile | NA | 385,600 | 325,600 |

[a]Data for the provinces of British Columbia and New Brunswick or for *British Columbia only. Data are not available for other Canadian provinces.

L. Burridge et al., *Aquaculture* (2010) 306, 11

## Prevalence of resistance (expressed as percentages) in *Enterococcus* spp. Isolated from integrated chicken-fish farms (int) and control fish farms (con)

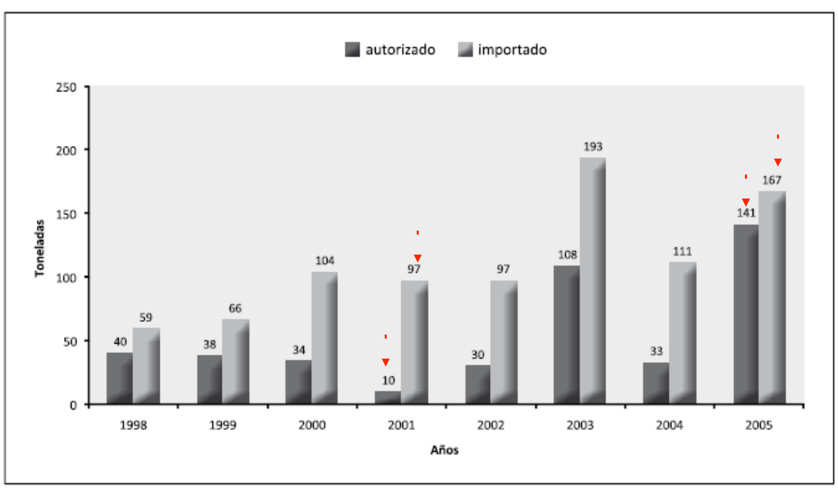
| Species | CHL | | CIP | | ERY | | GEN | | OTC | | STR | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | int | con | int | con | int | con | int | con | int | con | int | con |
| *E. durans/hirae* (13/0)[a] | 0 | – | 0 | – | 92 | – | 0 | – | 92 | – | 82 | – |
| *E. faecalis* (50/9) | 20 | 0 | 32 | 0 | 100 | 11 | 21 | 0 | 62 | 11 | 88 | 67 |
| *E. faecium* (140/23) | 0 | 0 | 3 | 17 | 92 | 65 | 1 | 0 | 79 | 44 | 67 | 48 |

a. Number of isolates from integrated/control farms.

## Decrease of biodiversity

Petersen and Dalsgaard (2003), *Environmental Microbiology,* 5, 395-402

## Undetected use of antimicrobials in aquaculture




Millanao *et al*, 2011

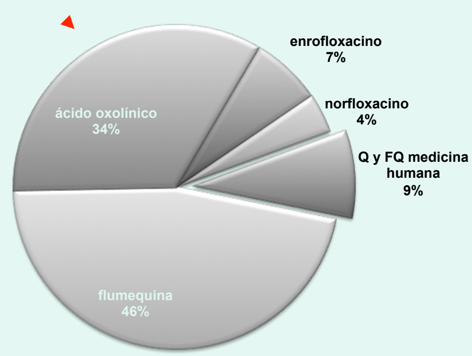
## Antibacterial activity in the control sediment and in those treated with oxytetracycline (OTC), oxolinic acid (OXA), and flumequine (FLU) during the experiment

| | Inhibition zone (mm) | | |
|---|---|---|---|
| Day | OTC | OXA | FLU |
| 1 | 14 | 23 | 23 |
| 7 | 14 | 25 | 23 |
| 25 | 0 | 18 | 18 |
| 80 | 0 | 22 | 20 |
| 185 | 0 | 16 | 15 |

NOTE: No antibacterial activity was measured in the control sediment on any of the sampling dates. Antibacterial activity was measured as the diameter of the inhibition zones.

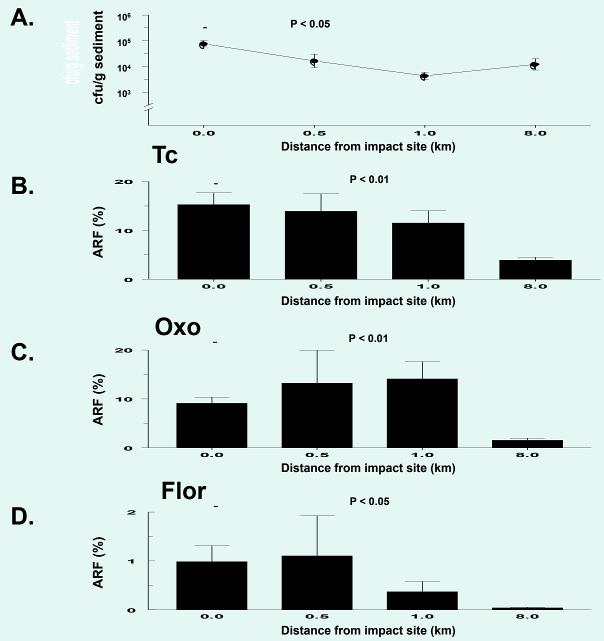
Hansen, Lunestad, and Samuelsen, *Can. J. Microbiol.* (1993), 39, 1310

## Percent distribution of 1193 tons of quinolones y fluorquinolones used in human medicine and veterinary medicine in Chile during the períod 2000 - 2007




Millanao *et al.*, 2010

## Cultivable bacteria and antibiotic resistance bacteria in the sediment at variable distances of a salmon aquaculture impacted site



# Primary Questions of Nutritional Physiology That Would Combine the Whole Life Cycle In Culture of South American Pseudoplatystoma Destined for Conservation and Industrial Purposes

*Konrad Dabrowski, The Ohio State University; Maria Celia Portella, PhD, Sao Paulo State University; Murat Arslan, Ataturk University; Michal Wojno, The Ohio State University; Marcos A. Cestarolli, PRDTA Centro Leste/DDD/SAA*

**Abstract**

The genus Pseudoplatystoma contains 8 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, 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.

**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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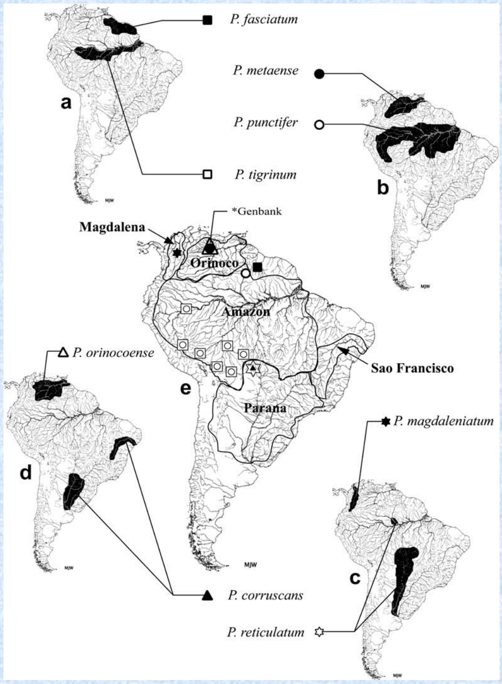
Fisheries Institute, PRDTA-Centro Leste/DDD/SAA, Pirassununga, Brazil

# Plan of presentation

1. Biogeography and phylogeny of the genus *Pseudoplatystoma spp.*
2. Growth in captivity and reproduction
3. Embryonic development
4. Larval development and sensory system
5. Differentiation of digestive tract and digestive enzymes in early ontogeny
6. Formulation of semi-purified diets and juvenile growth
7. Nutritional requirement – protein/lipid
8. Future studies with the second generation in captivity – domestication versus conservation/stocking programs
9. Conclusions

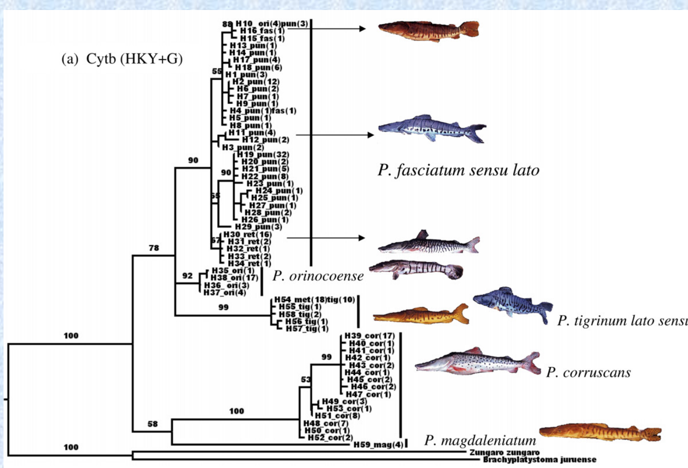


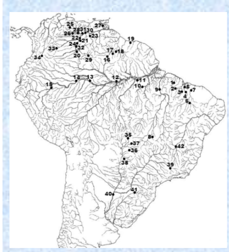

**Distribution areas of neotropical catfish *Pseudoplatystoma* in the major hydrological basins of S. America**

Torrico et al. 2009. Molecular Phylogen. Evol. 51:588

## Molecular systematics of *Pseuoplatystoma spp.*

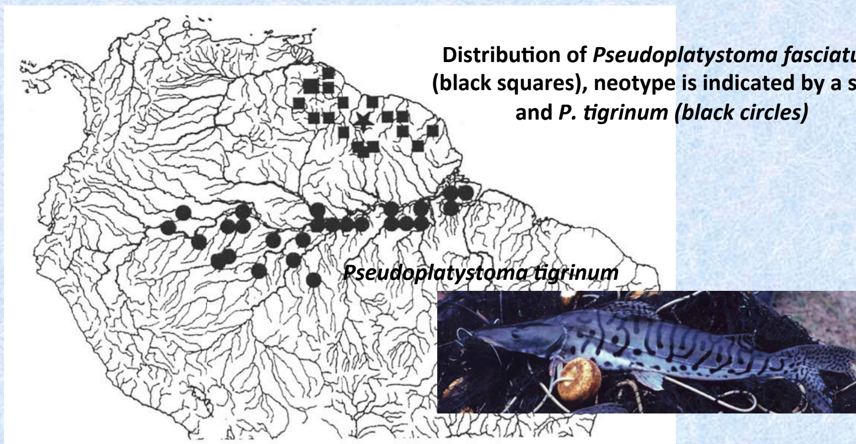
(Carvalho-Costa et al. 2011. Molecular Phylogenet. Evol. 59: 177)



Sampling sites and distribution

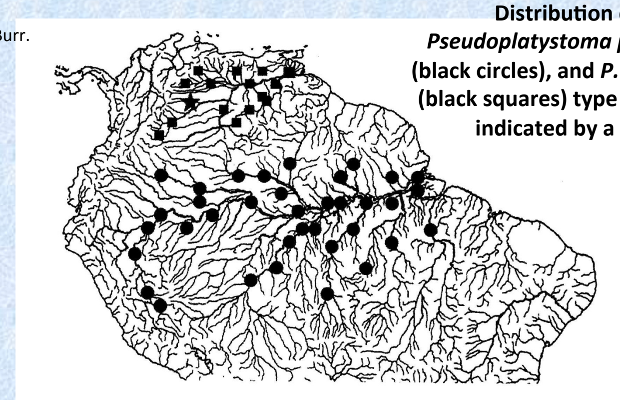
***Pseudoplatystoma fasciatum*** **(Linnaeus, 1776) INHS 48973, 516 mm SL**




From: Buitrago-Suarez and Burr, 2007. *Zootaxa* 1512:1-38.

***Pseudoplatystoma punctifer***
**from Amazon River, near Iquitos, Peru, June 1994**

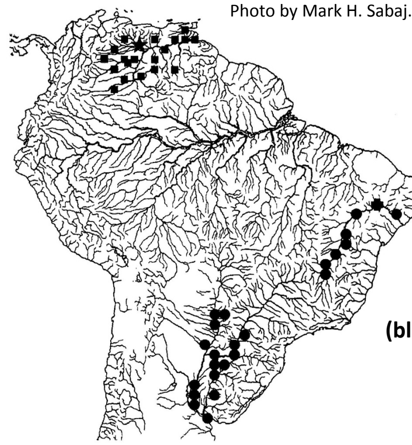
Photo by Brooks M. Burr.




From: Buitrago-Suarez and Burr, 2007. *Zootaxa* 1512:1-38.

***Pseudoplatystoma orinocoense*** **(black squares),**
**holotype is indicated by a star**
**San Bartolo River (Orinoco River), Venezuela, January 1986**

Photo by Mark H. Sabaj.



***Pseudoplatystoma corruscans***
**(Spix & Agassiz, 1820) neotype, MCP 14071, 700 mm. Scale 15 cm.**

**Distribution of**
***Pseudoplatystoma corruscans***
**(black circles) neotype is indicated by a cross**

From: Buitrago-Suarez and Burr, 2007. *Zootaxa* 1512:1-38.

## *Pseudoplatystoma reticulatum* and *P. corruscans*

**from Parana River, near Esquina, Argentina, April 2005**

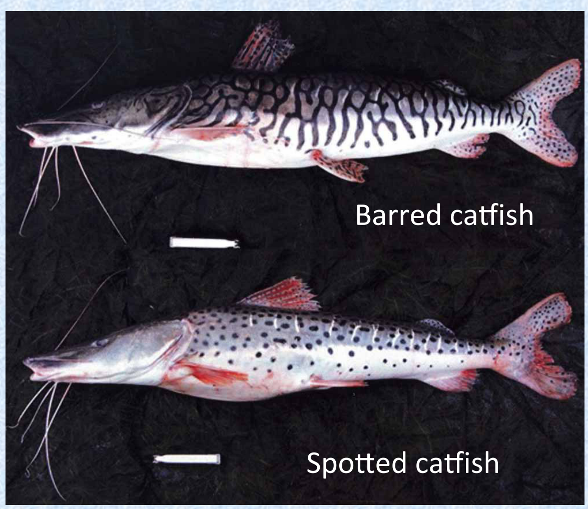



Photo by Mark H. Sabaj.

From: Buitrago-Suarez and Burr, 2007. *Zootaxa* 1512:1-38.

# Reproduction

Hormonal injection

Ovulation

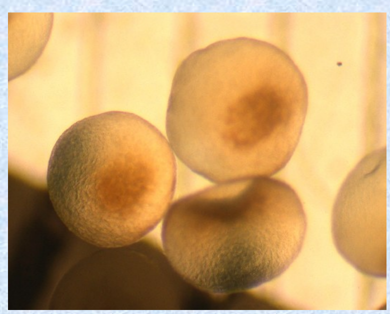
Fertilization

Incubation

**Brazil**
Romagosa E., 2010. Journal of Appl. Ichthyol. 26: 806
**USA**
Dabrowski, K . et al. 2009. J. World Aqua.Soc. 39: 174
**Bolivia**
Nunez, J. et al. 2008. Aquacult. Res. 39: 764

## Surubim propagation at OSU, Columbus, Ohio, February 2006

**Catheterization of females to receive oocytes for maturity (GVB) evaluation**



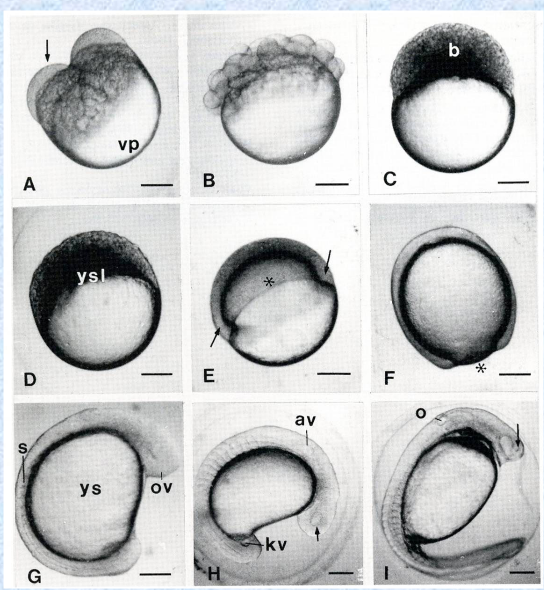
**Serra fixation to visualize germ vesicle migration toward micropyle in surubim unfertilized eggs**

## The first spawning of S. American catfish in North America, Columbus, Ohio, 7:45 am February 15, 2006

## Surubim *P. corruscans* embryogenesis at 23-25$^{o}$C

(Cardoso, Godinho H. 1995. Aquat.Liv.Res. 8: 343)

**Scale 0.2 mm**




**Hours** Embryonic stages

**1** A - Blastodisc with two cells

**1.5** B – Blastodisc with 32 blastomeres

**2.5** C - Prominents blastomers (morula)

**4** D – Flattened blastomers with yolk syncytial layer (ysl)

**5.5** E – elongated blastodisc, ½ epiboly

**6** F – closure of blastopore

**7.5** G – optic vesicles, somites and yolk sac

**11.5** H- auditory vesicle, Kupffer's vesicle, optic cup (arrow)

**14.5** I – prior to hatching, otoliths

**19** Hatching

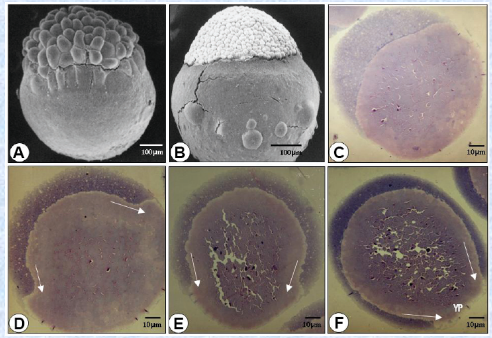
## Embryonic development

Optimum conditions: water temperature 24-28$^{o}$C

*Pseudoplatystoma* **spp. hybrids embryogenesis**

Late blastula, gastrula and closing of blastopore in hybrid of *P. corruscans* (female) and *P. fasciatum* (male).
Hybrids accept food better, grow faster and are less stressed by handling.

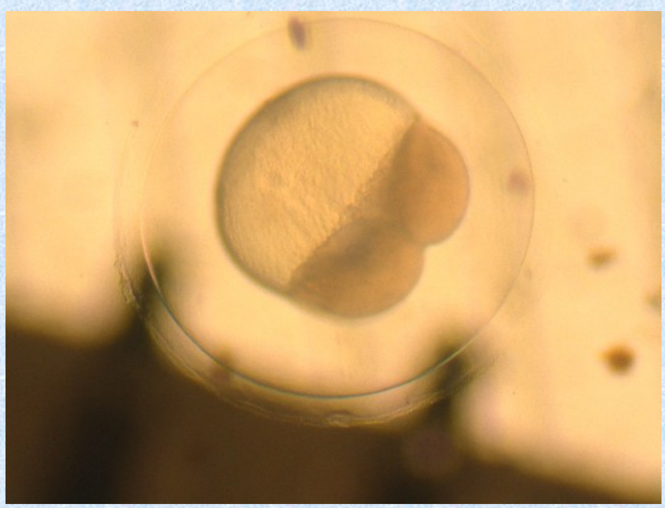
(Faustino et al. 2010. Int.J.Dev. Biol. 54: 723)



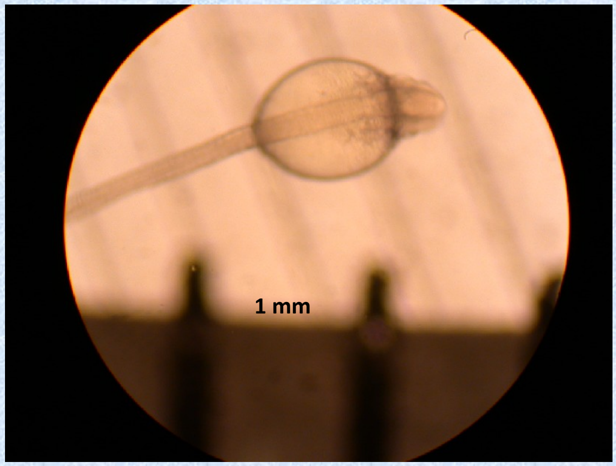

A. Morula
B. Early gastrula

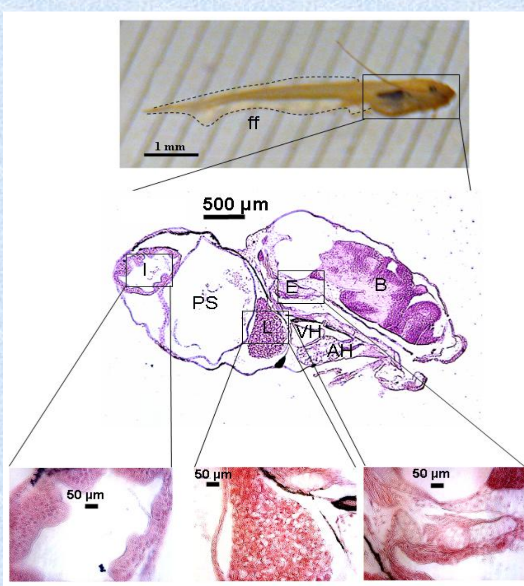
F. End of epiboly (closing of blastopore)

## Two-cell blastula of surubim, 60 min after fertilization at 27$^{o}$C



**Newly hatched surubim larvae, 14 h after fertilization (3.5 mm total length)**

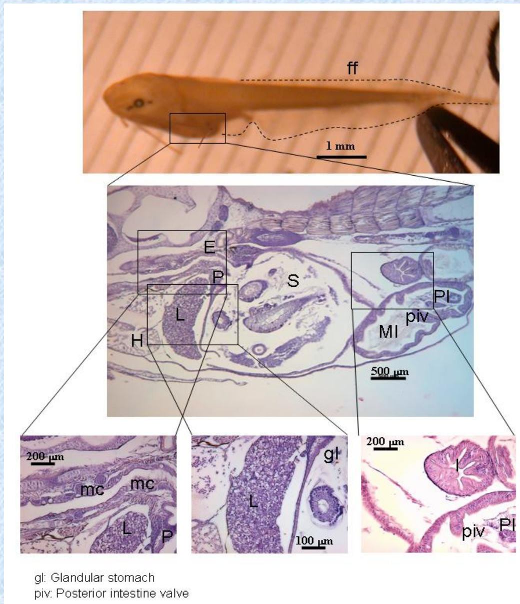



**Surubim larva with weak feeding activity after 9 days from hatching (5.5 mm TL)**

Development of esophagus (E), presumptive stomach (PS), intestine (I), and pancreas (P). Brain (B).

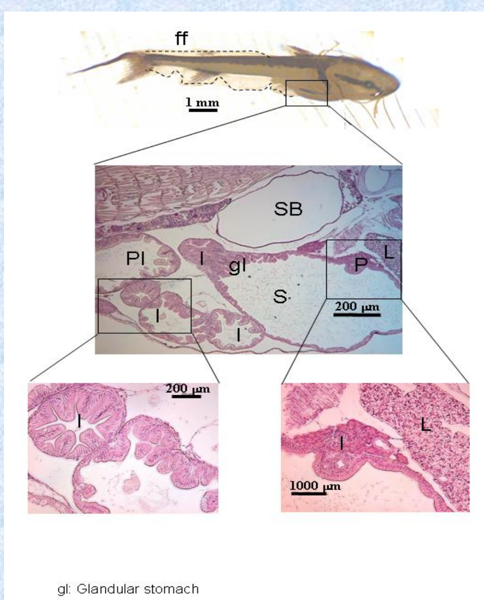
## Surubim metamorphosis from larva to juvenile Stage of 9 mm (9 day old) – Experiment in Columbus, OH




Fish were fed with live *Artemia* nauplii

Larval fin fold (ff), esophagus (E), differentiated stomach (S) with glandular part (gl), posterior intestine valve (piv) elongated intestine (I), enlarged pancreas (P). Liver (L) and heart H).

## Surubin juveniles raised at OSU, Columbus




Surubim – 13 mm TL, 24

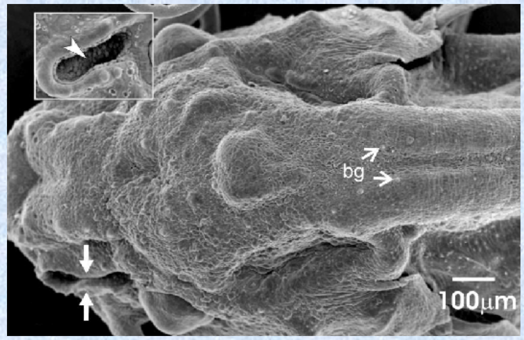
Differentiated stomach (S), 3-4 loops of intestine (I), enlarged pancreas (P) and liver (L)

Arslan, Dabrowski, Portella 2009. J .Appl. Ichthyol. 40:

## Olfactory organ of spotted surubim *P. corruscans* from the Amazon River

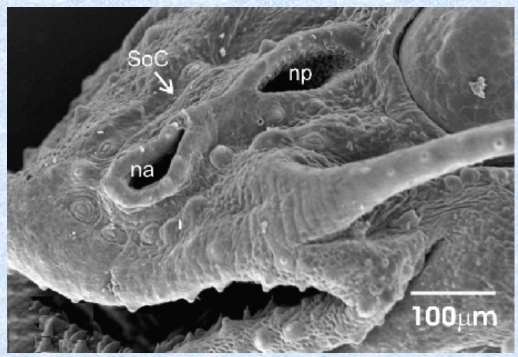
**183 hpf (8 dph) 7.99 mm TL**

**Dorsal view of the head. Bg = extra oral gustatory buds. Arrow = edge of the olfactory pit, in "eight-like shape". Insert = mechanocilia in the edges of the olfactory indentation**




**232 hpf (10 dph) 9.0 mm TL**

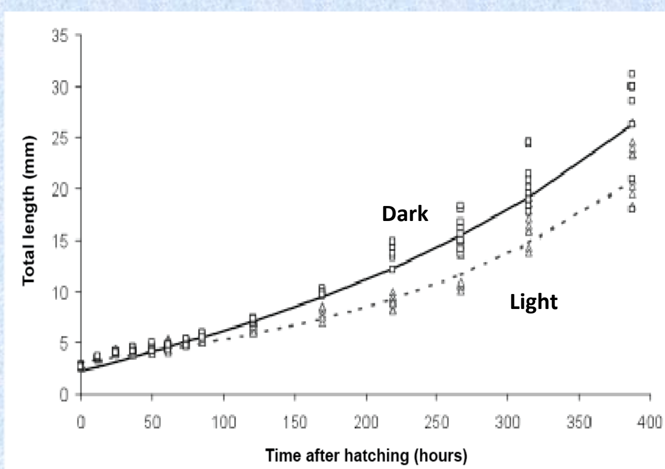
**Lateral view. SoC = supra orbital canal with two neuromasts. Na = anterior nostril and Np = posterior nostril.**




(Cestarolli and Portella, 2005)

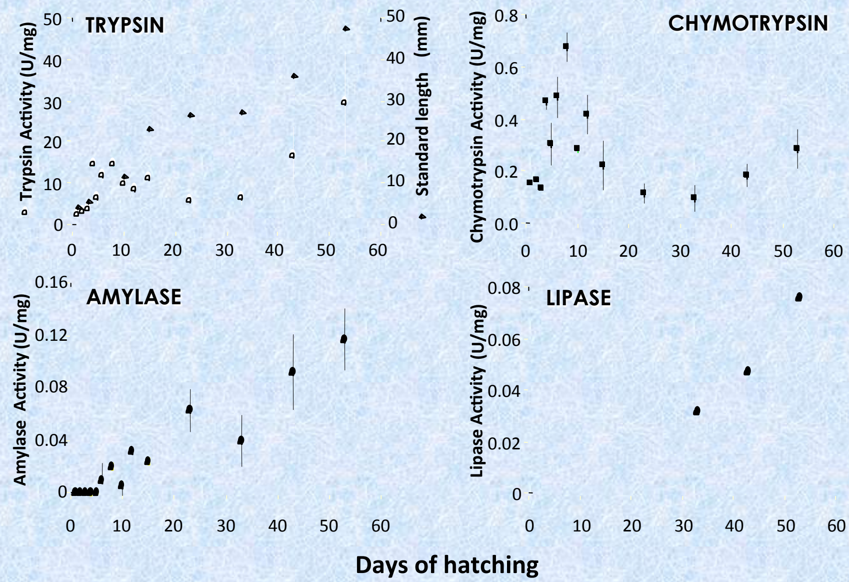
## Growth of spotted surubim *P. corruscans* larvae/juveniles during the first 16 days in dark (squares) or light (triangles).

(Cestarolli and Portella, 2005)

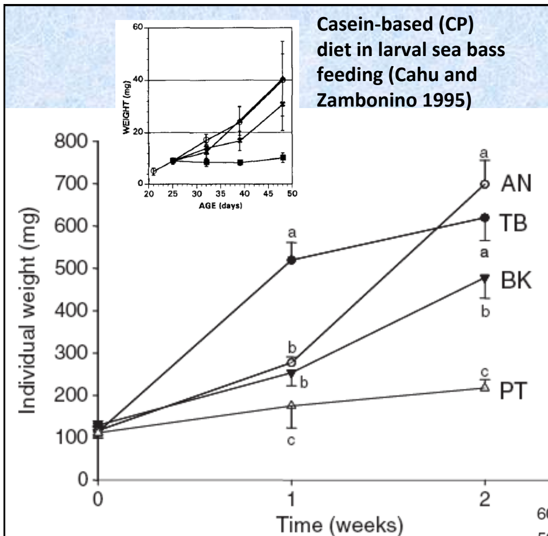


## Surubim digestive enzymes during early ontogeny

(Portella 2008)




Two weeks of feeding of surubim (the first week on live *Artemia* nauplii, the second week on live adult *Artemia*)

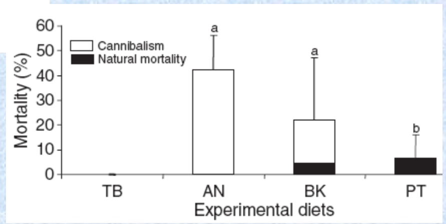



Casein-based (CP) diet in larval sea bass feeding (Cahu and Zambonino 1995)

## Growth and cannibalism-related mortality in juvenile barred surubim (*P. fasciatum*)

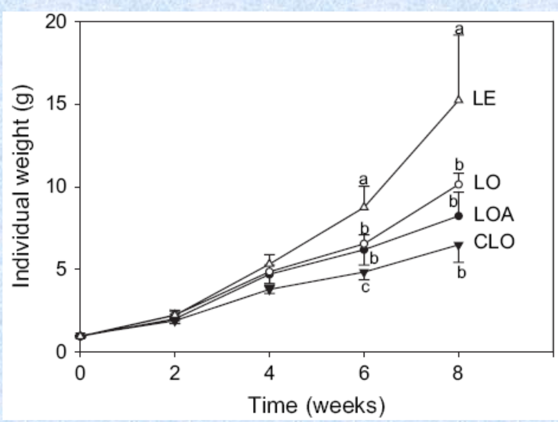
(Arslan, Dabrowski, Portella 2009. J.Appl.Ichthytol.25:73)

TB – live tubificid worms
AN – AgloNorse, Stavanger, Norway
BK – ByoKyowa, Tokyo, Japan
PT - Dipeptide-based purified diet (KD)




## Semi-purified (casein-gelatin based) diets for juvenile surubim – the effect of lipid/lipid class/ fatty acids

(Arslan et al. 2009. JWAS 39:51) (Protein 64%, lipid 14%)




**Fatty acids in liver lipids of surubim**

| | LOA | EPA | DHA |
|---|---|---|---|
| **CLO** | **2.4** | **5.7** | **14.9** |
| **LOA** | **8. 5** | **0.2** | **5.8** |
| **LO** | **5.8** | **2.0** | **8.3** |
| **LE** | **13.6** | **0.7** | **9.4** |

CLO – cod liver oil  LOA – oleic acid  LO - Linseed oil  LE – soybean lecithin

**PROTEIN - LIPID DIETARY OPTIMUM IN JUVENILE SURUBIM *Pseudoplatystoma* sp.**

(Arslan et al. 2011. Aquaculture Res., submitted)

**Constant dark environment**

**Experimental design – surubim (*Pseudoplatystoma* sp.)**

**Initial weight: 1.0 ± 0.1 g**

**Semi-closed recirculating-water system**

**3 aquaria (40-L) per dietary treatment**
**(2 aquaria for 40/12, 45/16, and 50/20)**

**18 fish per aquarium**

**Feeding rate: 5%, 4 times a day**
**Restricted-readjusted feeding**
**(every 3 days and after every 2 weeks)**

**Duration: 8 weeks**

**Temperature: 26.5 – 28.5oC**

**Photoperiod: Constant dark (aquariums covered with black plastic)**

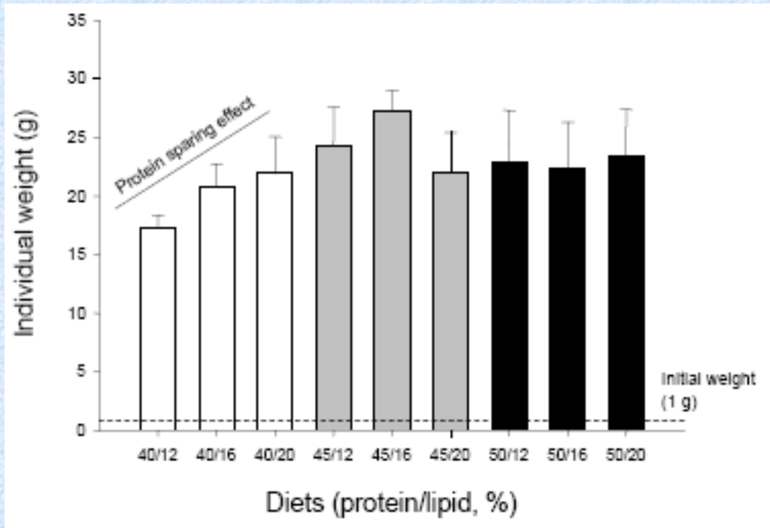
Constant dark environment

## Composition (%) of the experimental diets

| | 40/12 | 40/16 | 40/20 | 45/12 | 45/16 | 45/20 | 50/12 | 50/16 | 50/20 |
|---|---|---|---|---|---|---|---|---|---|
| Casein | 30.0 | 30.0 | 30.0 | 35.0 | 35.0 | 35.0 | 39.5 | 39.5 | 39.5 |
| Gelatin | 6.00 | 6.00 | 6.00 | 7.00 | 7.00 | 7.00 | 7.90 | 7.90 | 7.90 |
| Dextrin | 32.25 | 31.25 | 27.25 | 29.51 | 25.51 | 21.51 | 24.34 | 20.34 | 16.34 |
| CPSP[a] | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Lecithin | 10.0 | 13.3 | 16.7 | 10.0 | 13.3 | 16.7 | 10.0 | 13.3 | 16.7 |
| Cod liver oil | 2.00 | 2.70 | 3.30 | 2.00 | 2.70 | 3.30 | 2.00 | 2.70 | 3.30 |
| Vitamin mix | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| Mineral mix | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Phosphitan C | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| CMCb | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| L-Arginine | 0.50 | 0.50 | 0.50 | 0.42 | 0.42 | 0.42 | 0.36 | 0.36 | 0.36 |
| L-Methionine | 0.40 | 0.40 | 0.40 | 0.34 | 0.34 | 0.34 | 0.28 | 0.28 | 0.28 |
| L-Lysine | 0.80 | 0.80 | 0.80 | 0.68 | 0.68 | 0.68 | 0.57 | 0.57 | 0.57 |
| Choline chloride | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

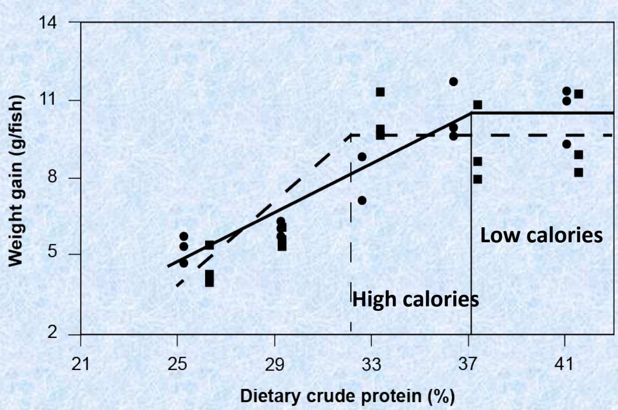
[a]Soluble fish protein concentrate (Sopropeche, France) bCarboxymethylcellulose

## Individual final weight of surubim fed diet with different levels of protein and lipid (Arslan et al. 2011. Aquacult. Res. submitted)




## Protein requirement of jundia *(Rhamdia quelen)* at two levels of energy provided by carbohydrates

(Meyer and Fracalossi, 2004. Aquaculture 240: 331)

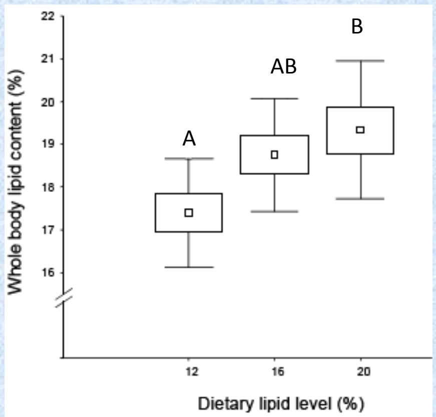


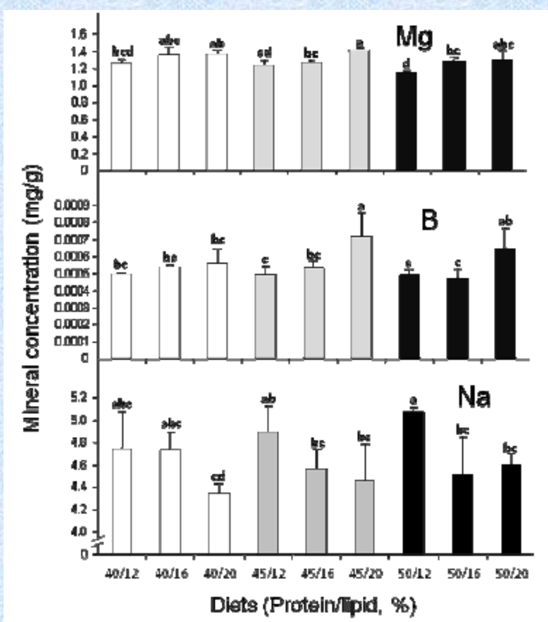

1. Diets were very low in lipids, 3.8-6.0%

2. Dextrin was the energy source used to replace protein at low energy (22.4-34.1%) and high energy (31.2-43.0%) diets

3. Weight gain relatively small, 5-6 fold during 90 days of feeding

**Relationship between dietary lipid level and whole body lipid content of surubim** (Arslan et al. 2011. Aquacult. Res. submitted)

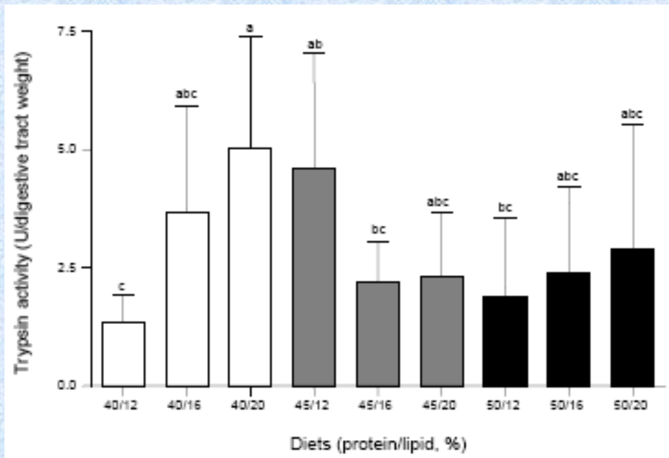



Na, Mg and B concentration of surubim fed diet with different levels of protein and lipid (Arslan et al. 2011. Aquacult. Res. submitted)

**Trypsin activity of digestive tract of juvenile surubim fed diets with different levels of protein and lipid for 8 weeks**

(Arslan et al. 2011. Aquacult. Res. submitted)




**Progenies of surubim (one female x 2 males) obtained via University of Wisconsin**

(Lima L.C. and Malison J. 2007. JWAS 37: 89)

## Conclusions

1. *Pseudoplatystoma* hybrids are well suited for intensive rearing in captivity (aquaculture purposes).

2. The major shortcoming of the early life stages was mortality due to inadequate starter feeds and cannibalism.

3. Nutritional requirements can be further addressed using semi-purified diets formulated in the present CRSP studies.

4. Vitamin requirements and broodstock nutrition are critical areas of further research.

5. Further studies must address the suitability of intensively reared juveniles for stocking programs, as well as survival in the wild of pure species.

6. Hybrids (sterile triploids) should be the subject of further studies in respect to domestication for aquaculture purposes.


## Acknowledgments

AQUA FISH
COLLABORATIVE RESEARCH
SUPPORT PROGRAM

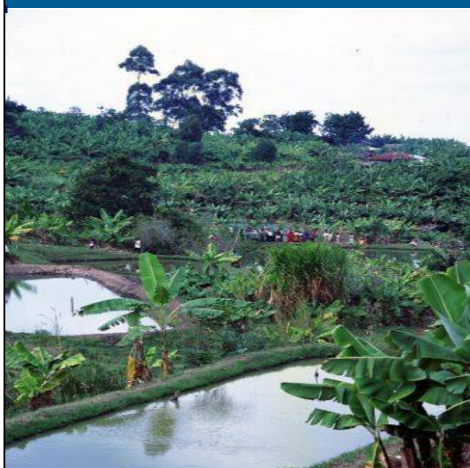
# THE SOCIAL AND ECONOMIC IMPACTS OF SEMI-INTENSIVE AQUACULTURE ON BIODIVERSITY

*Robert Pomeroy, University of Connecticut-Avery Point; Madan Dey, University of Arkansas at Pine Bluff*

**Abstract**

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.

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



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## Outline

- Introduction
- The social and economic impacts of aquaculture on biodiversity
- The social and economic impacts on biodiversity of moving from intensive to semi-intensive aquaculture systems
- Conclusions and recommendations

## Introduction

- There is only limited understanding of the social and economic impacts of aquaculture on biodiversity
- Especially the impacts of the shift from intensive to semi-intensive systems
- The purposes of this paper are twofold: (1) to identify and discuss the social and economic impacts of aquaculture on biodiversity, and (2) to examine the social and economic impacts on biodiversity of moving from intensive to semi-intensive systems.

## Social and economic impacts of aquaculture on biodiversity

- Biodiversity provides numerous ecosystem services (ES)
- MEA describes five major categories of ES:
  - Provisioning services
  - Regulating services
  - Cultural services
  - Supporting services
  - Preserving services

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Social resilience
    - Diversify HH economic activities
    - Create entrepreneurial opportunities
    - Limit opportunities – reduces economic activities, affects food supply, inequalities in wealth
    - More social resiliency is eroded, more poor engage in non-sustainable activities

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Habitat loss and modification
    - Loss of essential ES (mangroves, wetlands)
    - Displacement of communities
    - May replace destructive land use practices

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Food security
    - Depletion of capture fish stocks and biodiversity
    - Lower prices may cause shift to higher value species that are less sustainable
    - Reduction of genetic stock
    - Effluents and waste can increase local production and species diversity

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Human health issues
    - Red tide, pollution, persistence of chemicals in edible tissues

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Human rights abuses, social disruption, conflicts and violence
    - Pollution, access, salination, encroachment, decline in catch, employment and lack of, resource competition

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Resource ownership
    - Privatization of public lands and waterways
    - Lack of property title and displacement
    - Access

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Rural communities
    - Stimulate development, employment and economic activity
    - Often benefits elites
    - Can cause migration and unemployment
    - Increases vulnerability due to specialization

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Economic diversification
    - Greater integration of other HH economic enterprises to reduce risk and maximize income
    - Can also increase specialization

## Social and economic impacts of aquaculture on biodiversity

- There will be a variety of social and economic impacts from aquaculture on these ES:
  - Fresh water availability
    - Supply and quality

## Social and economic impacts on biodiversity of semi-intensive systems

There are fundamental economic and social differences between extensive/semi-intensive and intensive systems of aquaculture production.

## Social and economic impacts on biodiversity of semi-intensive systems

- Profitability, cost effectiveness, factor shares, and investment requirements:
  - An analysis of freshwater and brackish water fish culture in selected Asian countries was undertaken

## Social and economic impacts on biodiversity of semi-intensive systems

Factor shares and investment needs in brackish water aquaculture technologies in selected Asian countries

| *Country* | Species | Culture System | Intensity | Factor Shares (%) Seed | Factor Shares (%) Feed | Factor Shares (%) Labor | Investment Requirement (US$/ha) |
|---|---|---|---|---|---|---|---|
| Bangladesh | Shrimp | Pond mono | E | 40 | 2 | 47 | 863 |
| | Shrimp | Shrimp-rice | E | 36 | 2 | 35 | 812 |
| India | Shrimp | Pond mono | IE | 24 | 20 | 10 | 3,497 |
| Indonesia | Shrimp | Pond mono | E | 32 | 12 | 24 | 1,550 |
| Malaysia | Shrimp | Pond mono | I | 10 | 49 | 6 | 43,362 |
| Philippines | Prawn | Pond mono | SI | 7 | 44 | 5 | 10,194 |
| Thailand | Shrimp | Pond mono | SI | 14 | - | 16 | 802 |
| Viet Nam | Shrimp | Pond mono | E | 24 | 10 | 15 | 932 |
| Viet Nam | Shrimp | Pond mono | SI | 8 | 32 | 6 | 6,763 |
| Viet Nam | Shrimp | Pond mono | I | 8 | 62 | 7 | 10,763 |

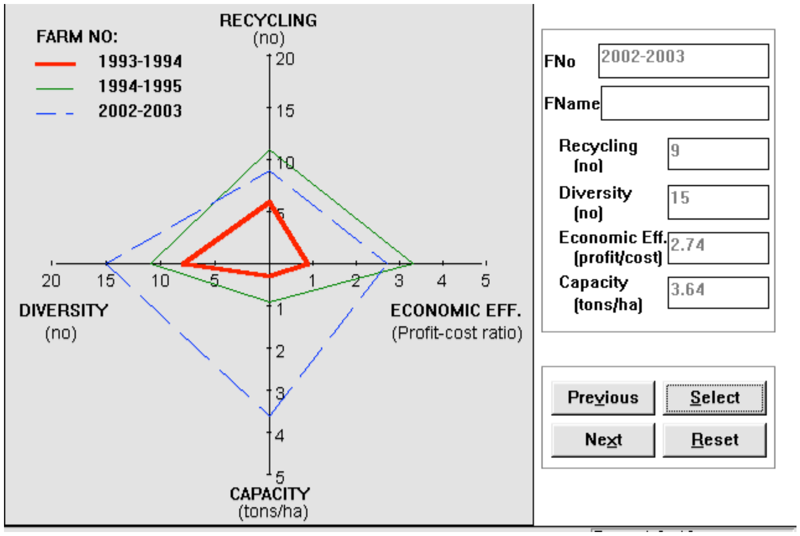
## Social and economic impacts on biodiversity of semi-intensive systems

- Profitability, cost effectiveness, factor shares, and investment requirements:
  - Today's production costs in intensive or high input semi-intensive aquaculture systems are often too high to be a sustainable economic activity (high feed cost, high labor costs, high land costs)
  - The price of feed, which contributes most of the cost of intensive aquaculture operation, has increased three to four times over the last few years.
  - Some fish farmers in Asia are moving from intensive to semi-intensive farming (for example, pangus farming in Bangladesh).

## Social and economic impacts on biodiversity of semi-intensive systems

- Impact of semi-intensive integrated aquaculture-agriculture on biodiversity and sustainability (IAA):
  - Various studies (including Dey et al. 2007; Dey et al. 2010, Jahan and Pemsl, 2011) reveal that semi-intensive aquaculture integrated with other components of farming activities (such as cereal, vegetables, livestock) is a sustainable practice and does improve farm biodiversity
  - In Malawi, results indicate that semi-intensive IAA farmers have increased enterprise diversity, recycling flows among enterprises, the overall biomass production, as well as improved economic performance, even though results might vary over time

## Social and economic impacts on biodiversity of semi-intensive systems: Impact of IAA in Malawi (Dey et al. 2007)




## Social and economic impacts on biodiversity of semi-intensive systems

- Impact of semi-intensive integrated aquaculture-agriculture on biodiversity and sustainability (IAA):
  - Semi-intensive integrated fishponds act as on-farm mini-reservoirs that store nutrient-loaded water, enable the cultivation of vegetables on the pond dikes or in the pond vicinity
  - Adoption of IAA has a positive impact on the sustainability of farming systems through resource recycling and use of pond water and nutrients for growing agricultural crops
  - Community-based extensive fish culture in the Bangladesh floodplain was found to enhance abundance of non-stocked fish species by about 10 to 20%.

## Social and economic impacts on biodiversity of semi-intensive systems

- Impact of semi-intensive system on food security:
  - Nutritional inputs in semi-intensive production can be on-farm by-products; even when off-farm fertilizers and supplementary feeds are purchased, they are cheaper than formulated feed used in intensive systems
  - Most of the semi-intensive aquaculture systems, particularly those practiced in freshwater environments, are polyculture in nature
  - Recent studies in Bangladesh (Jahan and Pemsl, 2011) and Malawi (Dey et al. 2007) show that integrated agriculture-aquaculture (IAA) systems improve nutrition and food security

## Conclusions and recommendations

- Integrated agriculture-aquaculture farming systems contribute to conservation of biodiversity
- A balanced strategy with judicious use of on-farm by-products and relatively cheap off-farm inputs is required to increase fish production to levels attractive to the farmer, thus addressing both social and environmental aspects of sustainability
- Products coming from extensive and semi-intensive culture are poorly differentiated by the majority of consumers from intensive farming products
- The recognition of non-market benefits to extensive culture does not ensure improved economic viability of production
- The road of subsidizing production for non-market services to the environment has been proven to be a difficult path to improve sustainability

## Conclusions and recommendations

- The search for internal incentives such as product value-adding or income diversification may be more efficient
  - One is differentiation of products
  - Another is consideration of diversity of complementary activities to generate income such as added-value
- Stakeholder involvement in aquaculture policy making, planning and management can lead to more realistic and effective policies and plans as well as improve their implementation
- Well defined basic rights (property, human, labor) of individuals and the welfare of the public should take precedence over that of interest groups

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

(Draft 080111)

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**Introduction**

Aquaculture can be broadly classified as extensive, having no feed or fertilizer inputs and relying on natural food produced in the water body; semi-intensive, having some supplemental feed and/or fertilizers; and intensive, largely relying on nutritionally complete concentrate feed and fertilizers (Dey et al. 2000, Edwards, 1993). The pressure to use resources more efficiently, to increase competitiveness and to respond to market forces is resulting in some areas in trends toward intensification of aquaculture production. These are associated with more sophisticated farm management, shift to monoculture of high-value species, and the targeting of more affluent consumers.

The rapid growth of aquaculture in recent years, especially the trend towards intensification, has raised many questions about its environmental sustainability and impact of biodiversity. A variety of biophysical impacts of aquaculture (especially intensive systems) on biodiversity and ecosystem services has been identified and examined (Beardmore et al 1997; Diana 2009). These impacts are sometimes positive, sometimes neutral and usually negative. Impacts may be direct (e.g. genetic alteration of existing fish stocks) or indirect (e.g. loss of habitat). These impacts include:

1. Habitat loss and modification such as mangroves and wetlands;
2. Fresh water availability;
3. Pollution of local water resulting in effluents, eutrophication of water bodies, and changes in the fauna of receiving waters;
4. Escapement of aquatic crops and their potential hazard as invasive species;
5. Intensive collection of wild seed;
6. Collection of wild fish for feed and fish meal and possible overexploitation of fish stocks;
7. Disease and parasite transfer from captive to wild stocks;
8. Genetic alteration of existing stocks from escaped stocks;
9. Predator mortality caused by, for example, killing birds near aquaculture facilities;
10. Effects of antibiotics and other chemical treatments.

As a result of the concern and debate about the impacts of intensive aquaculture development on biodiversity, semi-intensive aquaculture is being considered as an alternative since it will have different and potentially fewer impacts on biodiversity. While the biophysical impacts of aquaculture on biodiversity have been examined, there is only limited understanding of the social and economic impacts of aquaculture on biodiversity, and especially the impacts of the shift from intensive to semi-intensive systems. The purposes of this paper are twofold: (1) to identify and discuss the social and economic impacts of aquaculture on biodiversity, and (2) to examine the social and economic impacts on biodiversity of moving from intensive to semi-intensive systems. Recommendations will be made on how to minimize social and economic impacts from moving to a lower intensity aquaculture system and on biodiversity.

**The Social and Economic Impacts of Aquaculture on Biodiversity**

Biodiversity provides numerous ecosystem services that are crucial to human well-being at present and in the future. Ecosystem services are the ecosystem processes or functions that have value to individuals or society. The Millennium Ecosystem Assessment described five major categories of ecosystem services:

1. **Provisioning services** are: The products obtained from ecosystems, including, for example, genetic resources, food and fiber, and fresh water.
2. **Regulating services** are: The benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water, and some human diseases.
3. **Cultural services** are: The non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g., knowledge systems, social relations, and aesthetic values.
4. **Supporting services** are: Ecosystem services that are necessary for the production of all other ecosystem services. Some examples include biomass production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, crop pollination, water cycling, and provisioning of habitat.
5. **Preserving services** are: The maintenance of genetic and species diversity, accounting for uncertainty, protection of options.

There will be a variety of social and economic impacts from aquaculture on these ecosystem services:

**Social Resilience**. Aquaculture development has the potential to increase or reduce social resilience of rural communities (Bailey 2008). Social resilience is promoted by aquaculture development to the extent that the generation of entrepreneurial opportunity and employment for local residents (Bailey 2008): (1) does not disrupt culturally accepted gender divisions of labor; (2) creates greater diversity of economic activities in the local economy; (3) increases the local availability of food; (4) minimizes user conflicts; and (5) does not increase inequalities of wealth, income, and power. Aquaculture can also contribute positively to social resilience by diversifying the portfolio of household economic activities and making fuller use of available resources (e.g., labor, management skill, water, agricultural wastes). Aquaculture development, which is scale-appropriate for the host community and region, creates opportunity for entrepreneurial development among local residents, with potential ripple effects across the entire local economy.

Conversely, aquaculture development that limits opportunities for local residents, reduces the diversity of local economic activities, adversely affects the local supply of food, generates user group conflict and increases inequalities of wealth income and power will tend to reduce social resilience. Adger (2000) observed that construction of shrimp ponds in Vietnam decreased social resilience by reducing the availability of mangrove, which provided a wide array of important resources to people living in coastal communities. Shrimp farming generated profits, but these were highly variable and not widely distributed among the population. The owner of the shrimp farm benefited from “enclosure” of the mangrove “commons”, but most local residents lost access to a source of food, building materials, and firewood. This loss of access resulted in reduced social resilience, according to Adger.

People who are at the margins of society are likely to take what actions they find necessary to survive, even if those actions involve degradation of the biophysical environment. The more social resiliency is eroded, the more likely desperate people will engage in short-term survival behavior that is injurious to biodiversity and ecosystem services.

Most small-scale aquaculture activities involve family labor, allowing for fuller utilization of available human resources within the household. Where producers hire workers, the impact on social resilience with a community will depend on how such workers are recruited and compensated. Some producers hire local residents so that others in the community benefit from the enterprise. In other cases, producers prefer to hire outsiders, in which case few benefits accrue to the local community (Muluk and Bailey, 1996).

**Habitat loss and modification**. Probably the most significant and apparent social and economic impacts of aquaculture on provisioning, regulating and supporting services is habitat loss and modification such as mangroves and wetlands. Loss of essential ecosystem services generated by mangroves, for example, include the provisioning services of seafood; the supporting services for fish/crustacean nurseries and wildlife habitat; and the regulating services for coastal protection, flood control, sediment trapping and water treatment (Be et al 1999). Mangrove forests have also provided a sustainable and renewable resource of firewood, timber, pulp, and charcoal for local communities. Shrimp ponds, for example, are often profitable only temporarily as they are subject to disease and to downward shifts in the shrimp market. When the market falls, ponds are abandoned. A return to traditional fishing is not always possible because the lost mangroves no longer serve as nursery areas which are critical for the recruitment of many wild fish stocks. Unemployment prospects cannot always balance short-term gains. Large-scale mangrove conversion for shrimp and fish farming have displaced rural communities that depended on the mangrove resources for their livelihood.

Considering forest products and fisheries, as well as social benefits of coastal protection, shoreline stabilization and carbon sequestration, Sathirathai (1997) concluded that mangrove conversion to commercial shrimp farms in Surat Thani, Thailand was economically viable only for private persons but not for society as a whole. Further analysis of this mangrove system revealed that the intact forest had a total economic value 70% higher than when converted to a shrimp farm ($60,000 ha versus $16,700 ha).

On the positive side, destructive land use practices, such as slash and burn agriculture, may be replaced by more sustainable practices, such as aquaculture in ponds which may generate income, reduce poverty, and improved human health.

Food security. Food security and biodiversity, resulting from maintenance of provisioning and preserving services, can be negatively affected by modern intensive aquaculture practices such as the use of small size fish and trash fish for fish feed. The uses of small size/trash fish are diverse and include: (1) human consumption (e.g. fresh, dried); (2) direct feed (e.g. livestock, high value species aquaculture); (3) fish meal production (e.g. poultry, aquaculture); and (4) value-added products (e.g. fish sauce) (FAO-APFIC 2005). There is increasing demand in the Asian region for small size/trash fish for both aquaculture and animal feeds. There is also increasing conflict between the use of small size/trash fish for feed and for human consumption. The impact is greater on the poor and needy as the market price of the potentially food grade fish is raised due to increasing market demands for them as fish feed (Funge-Smith et al. 2005). The other negative impact of certain aquaculture practices on food security is the depletion of wild stock because of poor practices in collecting wild seed and broodstock for culture (Beardmore et al. 1997).

Due to the expansion of both scale and efficiency of aquaculture there has been a downward trend in the unit price of many locally consumed food fish species including cyprinids and tilapia, as has been the case in China (FAO 2007). Such downward trend in prices, while beneficial to the consumers in the short term also has its downside. The reduced unit value may not necessarily be attributable to lower production costs but may be due to increased supply. This would mean lower profit margins and would make small-scale operations less viable. When this happens, there will be a greater impetus to shift to high-value species that can return a substantially higher profit margin. This appears to be the case in China where there has been a surge in the production of high-value freshwater species such as mandarin fish, mitten-handed river crabs (Eriocheir sinenses), river prawns (Macrobrachium spp.) and even the Pacific white shrimp (Penaeus vannamei). In the Philippines most of the cage and pen grown milkfish are produced by large-scale operators who make up for the low margin by expanding into larger volume production.

Tisdell (2002) found that aquaculture development can impact negatively on wild stocks thereby shifting the supply curve of the capture fishery, or raising the demand for the fish species subject both to aquaculture and capture. Such development can threaten wild stocks and their biodiversity. While aquaculture development could in principle have no impact on the biodiversity of wild stocks or even raise aquatic biodiversity overall, its impact in the long-term probably will be one of reducing aquatic diversity both in the wild and overall. The development of aquaculture may fail to save a captured fish species from extinction. Given the experience with the long-term genetic consequences of agriculture, it seems highly likely that as aquaculture develops and expands, this will tend to reduce wild genetic stock. In addition, although genetic diversity within aquaculture may initially rise, in the very long-term, it might be expected to decline after peaking. However, the later development of aquaculture compared to agriculture, especially compared to livestock husbandry, may result in some differences in the evolving extent of animal diversity in aquaculture. The institutional arrangements affecting aquaculture's development today, particularly globalization factors, are quite different to those surrounding the earlier development of livestock husbandry. So some differences in patterns of global genetic development in aquaculture and in livestock production might be anticipated.

Aquaculture development can have a positive impact on food security as effluents and waste from aquaculture can increase local production, abundance and diversity of species (FAO 2007).

**Human health issues**. Aquaculture, which uses water from the river, estuary, or coastal areas, is prone to external pollution (thus impacting regulating services) and the produce (fish, prawns) can be a human health risk if consumed. Red-tide outbreaks have increasingly occurred in areas where shellfish is cultured (Primavera 2006). Risk to humans stems from the persistence of chemicals in edible tissues which can result in development of antibiotic resistance and accumulation of residues. A study done by the national university of Malaysia on a tiger prawn project which uses water from the Inanam River estuary in Sabah is a case in point. Light industries (workshops, etc), pig and poultry farms located near the estuary are sources of pollution. The water of the Inanam River and prawn ponds was monitored. Dissolved cobalt and lead were found to be higher than the recommended values of 0.05 mg/l. Suspended solids were found to be higher than the maximum value recommended (40 mg/l) by the World Health Organization (FAO 2007).

**Human rights abuses, social disruption, conflicts and violence**. Aquaculture development can generate conflicts between competing uses and users of land and water resources (Bailey 2008). Upstream and downstream water users affect or are affected by aquaculture, generating conflicts which can disrupt the social fabric of communities if not carefully managed. Conflicts have been known to arise because of the pollution of water resources, blocking of access to the coastal resources and navigation by aquaculture installations, salination of crop lands, encroachment, and decline in fish catch due to various aquaculture impacts including fish kills that also affect the wild fisheries and may lead to a reduction in biodiversity. Many rural communities enjoy the employment opportunities possible with aquaculture, but conflicts often develop within these communities when traditional employment clashes with the aquaculture industry. These conflicts include violence between crop farmers and shrimp growers, between coastal fishers and shrimp growers, between artisanal fishers and cage and pen culturists, and even between those that want to raise fish in communal village tanks and those that only want the tank for water, and between small farmers and the bigger farmers. Major social conflicts can also arise because of competition for water at the small-scale level, such as in sub-Saharan Africa between tobacco farmers and fish farmers.

**Resource ownership**. Aquaculture development can lead to privatization of public lands and waterways. Local fishing communities often do not hold title to coastal wetlands, and have at times been displaced by shrimp consortia that have acquired leases along tropical shorelines. Resource ownership is often complex or ambiguous in prime aquaculture locations because property rights are unclear. Mangrove conversion into shrimp ponds was a widespread problem during the 1980s in Southeast Asia and Latin America. Mangroves typically are public lands only loosely managed by governments, and conversion to shrimp ponds is the clearest example in the literature of aquaculture development representing a threat to resilience of local social systems. The growth of Ecuador's shrimp mariculture industry was possible in part because of the lack of restrictions placed on mariculture entrepreneurs. Prospective shrimp farmers privatized communal lands by building ponds on them, thus denying access to important sources of livelihood to resource poor groups. In another case in Ecuador, access to traditional resources was physically blocked by shrimp ponds. A large pond was constructed between the town and its agricultural fields (Epler 1992).

**Rural communities**. Aquaculture development takes place in a social, economic, and political context which can either increase or reduce vulnerability to rural communities (Bailey 2008). Aquaculture development has been credited with stimulating the development of the rural communities in which they are located by direct employment of residents, and the generation of greater economic activity with the establishment of support services. Aquaculture development brings with it an infusion of cash to areas which may not merit consideration for other types of industry. Wages for local labor become part of the local economy as they are used to pay for local goods and services. Commercial-scale investment also spurs the government to provide or improve the infrastructure of an isolated area in the form of roads, bridges and often electricity.

However, this rural development often involves and benefits the elite. The elite often appropriate natural resources and aquaculture projects. The appropriation of land in rural communities can cause rural unemployment and urban migration as aquaculture development does not require a large amount of labor and people put off their land or who no longer having access to coastal areas may become unemployed and migrate to urban areas looking for jobs. It may also put more pressure on the resources impacting biodiversity.

Specialization, such as aquaculture development, tends to increase vulnerability within resource dependent communities. These communities tend to be vulnerable to externally driven changes, including external control over the resource, changing government policies that affect resource availability, market valuations, or competition from other producers (Freudenburg, 1992). These forms of vulnerability affect the resilience of communities dependent upon natural resources.

Rural ommunities divided by ethnic or class boundaries, and societies without adequate governance structures which provide clear policies and assurances of stability provide inhospitable settings for success even when the biophysical conditions are favorable. Where monopolistic or oligopolistic markets exist, or corrupt political systems set policies and issue permits, producers can be vulnerable to forces beyond their control. (Bailey 2008)

**Economic diversification**

Aquaculture may allow for greater integration of other household economic enterprises (Burbridge et al. 2001). Water from ponds can be used for limited irrigation needs while crop residues and animal wastes can be used to fertilize ponds for production of carps, tilapias, or other appropriate species. This diversification can minimize risks while maximizing income opportunities. The introduction of aquaculture may fit into an adaptive strategy which is central to the resilience of rural economies. The introduction of aquaculture production systems which require increasing technical sophistication and investment of financial and human capital would tend to promote specialization rather than diversification of enterprises.

**Fresh water availability**. Where aquaculture depends on groundwater, such use may conflict with others both in terms of supply and quality impacting the delivery of ecosystem services. Saltwater intrusion is a common problem in coastal areas where shrimp farmers pump freshwater from coastal aquifers to control salinities. Pumping large volumes of underground water to achieve brackish water salinity in the 1980s to mid-1990s led to the lowering of groundwater levels, emptying of aquifers, land subsidence and salinization of adjacent land and waterways in Taiwan and Southeast Asia (Primavera 2006). Even when fresh water is no longer pumped from aquifers, the discharge of salt water from shrimp farms located behind mangroves still causes salinization in adjoining rice and other agricultural lands (Dierberg et al 1996). The development of low salinity shrimp farming in Thailand paved the way for industry expansion into rice paddies and other inland sites (Flaherty et al 2000).

**The Social and Economic Impacts on Biodiversity of Moving from Intensive to Semi-intensive Aquaculture Systems**

There are fundamental economic and social differences between extensive/semi-intensive and intensive systems of aquaculture production.

**3.1 Profitability, cost effectiveness, factor shares, and investment requirements**

Costs and returns of freshwater aquaculture production in selected Asian countries are presented in Table 1. The data is grouped by species, then by intensity level and gross cost. An important indicator is cost-effectiveness, measured here by the ratio of the gross margin to variable cost, i.e., the net income that one dollar of current outlay is expected to earn within one production cycle. If cost-effectiveness is low, one needs a larger outlay to hit the same gross margin, which may be a problem if there are limits to expansion, e.g., due to credit constraints.

As expected, as intensity increases, costs, as well as revenue, rises (though the pattern may be obscured by differences across countries). Profitability also exhibits a tendency to rise with intensity, but the pattern is much less obvious. It is noteworthy that cost-effectiveness appears to be unrelated to intensity; if at all, increasing intensity seems to be associated with lower cost-effectiveness. What is evident is that extensive systems perform relatively poorly in terms of profitability and cost-effectiveness. However, moderate increases in intensity can make a big difference in profitability and cost-effectiveness, though this improvement does not necessarily continue with increasing level of intensity. In India, carp polyculture in ponds with low inputs had the highest return per dollar of operating capital, while ponds with high inputs had the lowest. In Thailand, though snakehead culture had one of the highest gross margins, cost-effectiveness was among the lowest.

Costs and returns data for brackishwater fish culture in the selected Asian countries are presented in Table 2, which is grouped and ordered in the same way as Table 1. Similar patterns are observed as in freshwater culture, although cost, returns, and profits are on a higher level, given the higher unit value of brackishwater species. It is noteworthy that extensive shrimp culture in Thailand is highly cost-effective and semi-intensive culture even more so, but cost-effectiveness is mediocre for intensive systems (despite higher gross margins). Across species, extensive, improved extensive and semi-intensive monoculture of shrimp in India appears to be a good performer in terms of both gross margin and cost-effectiveness. Improved extensive mud crab farming in the Philippines also had reasonably high gross margins and cost-effectiveness. Overall, the data suggest that the technologies which were more profitable and cost-effective were extensive and semi-intensive. Such technologies involve lower operating costs and appear to be more affordable from the viewpoint of resource-poor farmers.

Over the last several years, some farmers in Bangladesh have been converting their rice land to fish ponds for intensive aquaculture. These capital intensive fish farmers are not very cost-effective, even less than some of the semi-intensive farms (Table 3). Some of these intensive farmers have started limiting fish culture to only one growing season (for about 6-7 months) and then cultivating rice during the dry season in those fish ponds.

Table 4 presents factor shares (i.e., percentages in gross return) for the major inputs in freshwater aquaculture. Aquaculture intensity would a priori be positively associated with capital intensity, an expectation that is met by the tabulation. Note that high capital intensity implies a greater investment need; hence, the large required outlays for fixed and working capital raise entry barriers for the poor. A notable exception is the case of Indonesia, where extensive and semi-intensive pond monocultures of tilapia and catfish were associated with very low use of labor and high use of feed and seed. The other exception was the labor-intensive pond monoculture of carp and tilapia in Philippines.

Intensive culture systems are also associated with a higher proportion of feed cost in the total cost. This is illustrated by intensive and semi-intensive pond polyculture of carp and pond monoculture of prawn in China, intensive floating cage culture of tilapia in Malaysia, intensive freshwater prawn monoculture in Philippines, and intensive pond monoculture of snakehead, river cage culture of tilapia, and semi-intensive freshwater pond monoculture of prawn in Thailand (Table 4). The technologies which had a higher share of labor in the production cost were extensive/improved extensive pond polyculture of carp in Bangladesh, duck-fish culture in India, extensive pen culture of crab in lake in China, and semi-intensive pond monoculture of carp and fish-paddy culture in Viet Nam.

Table 5 shows factor shares in the brackishwater aquaculture technologies in nine Asian countries. In all cases, the species was shrimp/prawn and the culture system was pond monoculture. Irrespective of the intensity of culture, seed constituted a major share in the total production cost, except for semi-intensive and intensive shrimp/prawn culture in Viet Nam and in the Philippines where seed constituted a relatively lesser share in the total cost of production. Moreover, intensive cultures were also associated with higher use of feed inputs, as for intensive and semi-intensive shrimp/prawn culture in Malaysia, Viet Nam, and Philippines. In contrast, extensive cultures tend to be labor-intensive, as for extensive pond monoculture and shrimp-rice culture in Bangladesh, and extensive pond monoculture of shrimp in Indonesia and Viet Nam.

Tables 1 to 5 reveal that today's production costs in intensive or high input semi-intensive aquaculture systems are often too high to be a sustainable economic activity (high feed cost, high labor costs, high land costs). The price of feed, which contributes most of the cost of intensive aquaculture operation, has increased three to four times over the last few years.

**3.2 Impact of semi-intensive integrated aquaculture-agriculture on biodiversity and sustainability**

Various studies (including Dey et al. 2007; Dey et al. 2010, Jahan and Pemsl, 2011) reveal that semi-intensive aquaculture integrated with other components of farming activities (such as cereal, vegetables, livestock) is a sustainable practice and does improve farm biodiversity. Dey et al. 2007 have analyzed the effect of integrated aquaculture-agriculture (IAA) technologies on the sustainability of natural resource use in Malawi using the following four sustainability indicators: a) diversity (number of species/enterprises maintained and utilized in the farming systems, i.e. managed biodiversity or agrodiversity; b) recycling (number of movements of biological output or byproduct/waste from one natural resource enterprise to another within the farming system); c) capacity - product biomass yield in tons per hectare; and d) Economic performance ( profit-cost ratio). Results indicate that semi-intensive IAA farmers have increased enterprise diversity, recycling flows among enterprises, the overall biomass production, as well as improved economic performance, even though results might vary over time (Dey et al. 2007). Semi-intensive integrated fishponds act as on-farm mini-reservoirs that store nutrient-loaded water, enable the cultivation of vegetables on the pond dikes or in the pond vicinity. Often, ponds are constructed in locations adjacent to streams, or farmer groups organize small and simple irrigation/conveyance systems to have year-round access to water. Although the primary motivation for establishing the water supply and holding facilities was that of fish culture, the complementary production of fish and vegetables, or use of the water for other (agricultural) activities can increase household income and overall sustainability of the farming system. However, issues of finiteness and fragility of the water sources need to be considered in up-scaling and adopting irrigation by larger numbers of farmers.

Brummett and Costa-Pierce (2002) found that adoption of IAA has a positive impact on the sustainability of farming systems through resource recycling and use of pond water and nutrients for growing agricultural crops. Jahan and Pemsl (2011) show that semi-intensive IAA technology offers Bangladeshi farmers economic improvements while reducing the adverse environmental impacts of farming. Phong et al. (2010) found similar results in the Mekong delta of Vietnam. Sheriff et al. (2010) reveal that community-based extensive fish culture in the Bangladesh floodplain enhances abundance of non-stocked fish species by about 10 to 20%. A very recent survey by Dey et al (2011) found similar results for semi-intensive community-based fish culture in floodplains in eastern Bangladesh. With an average yield of about 4300 kg/ha stocked fish, famers still get about 70 kg/ha non-stocked fish of 16 different species.

**Impact of semi-intensive system on food security**

Semi-intensive aquaculture has relevance for food security. Nutritional inputs in semi-intensive production can be on-farm by-products; even when off-farm fertilizers and supplementary feeds are purchased, they are cheaper than formulated feed used in intensive systems. Low cost inputs are affordable to poorer farmers and because the cost of production is low, the fish can be sold at a reasonable and affordable price to poor consumers. In contrast, fish cultured intensively can be marketed profitably only at a relatively high price because of the high production cost which puts them beyond the purchasing power of most consumers.

Most of the semi-intensive aquaculture systems, particularly those practiced in freshwater environments, are polyculture in nature. Many farmers in Bangladesh culture low-value herbivorous and/or omnivorous freshwater finfish in inland rural communities, within semi-intensive or extensive farming systems, that use moderate to low levels of production inputs, and supply large quantities of affordable fish for domestic markets and home consumption (Prein and Ahmed,2000; Jahan, Ahmed and Belton, 2010). Recent studies in Bangladesh (Jahan and Pemsl, 2011) and Malawi (Dey et al. 2007) show that integrated agriculture-aquaculture (IAA) systems improve nutrition and food security, both within IAA farm households and in non-IAA households in the community. These effects are direct, through within-household consumption and dietary improvement, but also indirect, through sale of fish produce and purchase of other food items (often at lower unit value than the sold fish). Several studies conducted in Bangladesh and other Asian developing countries show that semi-intensive polyculture of finfish with small indigenous species reduces vitamin A and mineral deficiencies among poor households (Ross, et al. 2007)

**Conclusions and Recommendations to Minimize the Social and Economic Impacts of Aquaculture on Biodiversity**

The positive social and economic impacts of aquaculture are well known and include increased social resilience, provision of rural livelihoods, better income and new or alternative employment, additional income from integrated systems, food security and better nutrition, and development of rural areas, the latter is also seen as a means to arrest urban migration. Negative impacts of aquaculture arise due to the constant need to produce more by expanding the production area or by increasing the unit productivity. Under such circumstances conflicts arise that stem from competition for common resources as well as denial to some groups of access to resources; social inequities when benefits from aquaculture are not equitably shared; from us of common resources by aquaculture operations; and damage caused to the ecosystem by aquaculture and the cost of mitigating the damage or restoring the ecosystem.

When interest in aquaculture shifts to generate cash with development of the economy, the use of on-farm resources alone is insufficient. This is particularly true where opportunity costs of labor through alternative activities to aquaculture are high. This lesson was learned through over a decade's involvement by AIT and collaborating national institutions in the promotion of aquaculture, starting in Northeast Thailand, and extending to Cambodia, Lao PDR, and Vietnam over the last five years. Dependence of extensive/semi-intensive aquaculture on natural processes also limits their productivity, implying a low compatibility with intense economic activity

There are aquaculture systems that contribute to conservation of biodiversity. The most well-known are integrated agriculture- aquaculture farming systems. A balanced strategy with judicious use of on-farm by-products and relatively cheap off-farm inputs is required to increase fish production to levels attractive to the farmer, thus addressing both social and environmental aspects of sustainability.

Products coming from extensive and semi-intensive culture are also poorly differentiated by the majority of consumers from intensive farming products. The simple recognition of non-market benefits associated to extensive aquaculture such as the maintenance of wetland functionalities, landscape structure or sentinel of coastal ecosystem integrity does not ensure improved economic viability of these productions. The road of subsidizing production for non-market services to the environment has been proven to be a difficult path to improve sustainability. The search for internal incentives such as product value-adding or income diversification may be more efficient. There are many options for that. One is in the differentiation of products based on collective action to build niche markets offering premiums to products from extensive and semi-intensive aquaculture. The other is to consider the diversity of complementary activities than can be developed to generate income in the form of added-value to the product or in the form of other activities benefiting of the environment and image of extensive and semi-intensive aquaculture

The adoption of better management practices would avoid or mitigate the impacts of aquaculture. Such practices should be enforced by legislation or adopted on a voluntary basis. Compliance with regulations and adoption of better management practices would necessarily entail cost to aquaculture. The aquaculturist should be required to internalize the costs of negative impacts on the environment from the aquaculture operation. Clay (2004) reports that better management practices can pay for themselves and he advocates support for small farmers to make the transition into better management practices, rather than leaving this to the market alone, through government subsidies in the short term.

Stakeholder involvement in aquaculture policy making, planning and management can lead to more realistic and effective policies and plans as well as improve their implementation. Stakeholder involvement makes it easier to develop and implement realistic aquaculture policies and plans, new initiatives can be embedded into existing legitimate local institutions, there is less opposition and greater political support, and local capacities are developed and political interference is minimized.

Well defined basic rights (property, human, labor) of individuals and the welfare of the public should take precedence over that of interest groups (Bailly and Willmann 2001). Clear rights defining access rights and limitations to various types of activities, and recognizing basic individual rights such as access to shore or water with specific properties would help private and public promoters of aquaculture development plan their activities with more security and a more informed basis for decisions. Well-defined individual or collective rights act as incentive where those who have rights, either on the side of the aquaculture promoter or on the part of another interested party, can use them for persuasion or can claim them in front of jurisdiction capable of enforcement.

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Table 1. Costs and Returns of Freshwater Fish Production in Selected Asian Countries(US$/ha/cycle), 2004/05 prices (adapted from Dey et al. 2008).

| Species | Intensity | Country | Culture System | Yield (kg) | Gross Return | Gross Cost | Variable Cost | Gross Margin | Gross Margin/ Variable Cost |
|---|---|---|---|---|---|---|---|---|---|
| Carp | E | Indonesia | Pond mono | 1,205 | 1,268 | 880 | 880 | 388 | 0.44 |
| Carp | IE | Bangladesh | Pond poly | 2,161 | 2,091 | 1,060 | 964 | 1,127 | 1.17 |
| Carp | SI | India | Low input | 2,500 | 1,592 | 890 | 678 | 914 | 1.35 |
| Carp | SI | Viet Nam | Pond mono | 3,647 | 2,374 | 976 | 976 | 1,398 | 1.43 |
| Carp | SI | Thailand | Pond poly | 4,280 | 2,527 | 1,336 | 1,229 | 1,298 | 1.06 |
| Carp | SI | Indonesia | Cage mono | 2,525 | 2,182 | 1,742 | 1,742 | 440 | 0.25 |
| Carp | SI | India | High input | 12,500 | 7,961 | 6,504 | 6,292 | 1,669 | 0.27 |
| Carp | SI | China | Pond poly | 12,708 | 13,791 | 10,381 | 9,446 | 4,352 | 0.46 |
| Carp | I | China | Pond poly | 19,748 | 11,207 | 6,780 | 6,170 | 5,043 | 0.82 |
| Catfish | SI | Indonesia | Pond mono | 2,136 | 1,538 | 1,355 | 1,290 | 248 | 0.19 |
| Crab | E | China | Pen lake | 417 | 4,798 | 2,821 | 2,595 | 2,205 | 0.85 |
| FW prawn | SI | Thailand | Pond mono | 4,000 | 11,818 | 9,409 | 8,468 | 3,350 | 0.40 |
| Mandarin | SI | China | Pond mono | 6,750 | 28,992 | 13,657 | 12,428 | 16,578 | 1.33 |
| Prawn | SI | India | Pond mono | 1,500 | 6,369 | 3,423 | 3,211 | 3,158 | 0.98 |
| Prawn | SI | China | Pond mono | 2,097 | 6,118 | 4,399 | 3,519 | 2,602 | 0.74 |
| Snakehead | I | Thailand | Pond mono | 60,450 | 74,440 | 69,958 | 67,859 | 6,580 | 0.10 |
| Tilapia | E | Bangladesh | Cage mono | 383 | 314 | 147 | 122 | 192 | 1.57 |
| Tilapia | E | Indonesia | Pond mono | 1,180 | 566 | 355 | 338 | 228 | 0.68 |
| Tilapia | E | Philippines | Case mono | 540 | 648 | 462 | 297 | 351 | 1.18 |
| Tilapia | SI | Bangladesh | Pond mono | 4,050 | 1,863 | 667 | 453 | 1,410 | 3.11 |
| Tilapia | SI | China | Pond mono | 5,860 | 7,819 | 4,372 | 3,974 | 3,848 | 0.97 |
| Tilapia | I | Thailand | River cage | 4,382 | 3,650 | 2,997 | 2,936 | 713 | 0.24 |
| Tilapia | I | Philippines | Pond mono | 10,800 | 9,564 | 3,731 | 3,109 | 6,455 | 2.08 |
| Tilapia/catfish | I | Malaysia | Floating cage | 5,303 | 6,003 | 9,069 | 5,301 | 702 | 0.13 |

Notes: 1. Area is measured in hectare for pond and 100 m2 for cage. 2. E - extensive, IE - improved extensive, SI - semi-intensive, I - intensive, FW – freshwater.

Table 2. Costs and Returns of Brackishwater Fish Culture in Selected Asian Countries (US$/ha/cycle), in 2004/05 prices

| Species | Country | Inten-sity | Culture System | Yield (kg) | Price (US$/kg) | Gross Return | Gross Cost | Variable Cost | Gross Margin | Gross Margin/ Variable Cost |
|---|---|---|---|---|---|---|---|---|---|---|
| Shrimp | Thailand | E | Pond mono | 104 | 4.68 | 487 | 184 | 103 | 384 | 3.74 |
| Shrimp | Bangladesh | E | Pond mono | 250 | 6.27 | 1,567 | 1,051 | 876 | 691 | 0.79 |
| Shrimp | Viet Nam | E | Pond mono | 500 | 3.57 | 1,785 | 1,215 | 1,013 | 772 | 0.76 |
| Shrimp | Indonesia | E | Pond mono | 650 | 4.71 | 3,062 | 1,860 | 1,550 | 1,512 | 0.98 |
| Prawn | Philippines | E | Pond mono | 450 | 5.12 | 2,303 | 2,046 | 1,356 | 946 | 0.70 |
| Shrimp | India | E | Pond mono | 1,000 | 5.94 | 5,944 | 2,238 | 1,865 | 4,080 | 2.19 |
| Shrimp | India | IE | Pond mono | 2,000 | 5.94 | 11,889 | 5,095 | 4,246 | 7,643 | 1.80 |
| Shrimp | Thailand | SI | Pond mono | 356 | 5.90 | 2,100 | 401 | 256 | 1,843 | 7.19 |
| Shrimp | Viet Nam | SI | Pond mono | 2,000 | 5.36 | 10,710 | 9,233 | 7,694 | 3,016 | 0.39 |
| Shrimp | India | SI | Pond mono | 4,000 | 5.94 | 23,778 | 11,889 | 9,907 | 13,870 | 1.40 |
| Prawn | Philippines | SI | Pond mono | 2,700 | 5.51 | 14,878 | 19,341 | 10,192 | 4,686 | 0.46 |
| Shrimp | Thailand | I | Pond mono | 2,116 | 5.29 | 11,200 | 10,122 | 8,401 | 2,799 | 0.33 |
| Shrimp | Viet Nam | I | Pond mono | 4,000 | 5.36 | 21,420 | 12,916 | 10,763 | 10,656 | 0.99 |
| Prawn | Philippines | I | Pond mono | 7,020 | 5.41 | 37,992 | 47,614 | 25,703 | 12,290 | 0.48 |
| Shrimp | Malaysia | I | Pond mono | 11,894 | 7.37 | 87,650 | 56,078 | 46,732 | 40,919 | 0.88 |
| Milkfish | Indonesia | IE | Pond mono | 1,138 | 0.95 | 1,083 | 1,062 | 885 | 198 | 0.22 |
| Mud crab | Philippines | IE | Pond mono | 1,050 | 3.94 | 4,133 | 3,222 | 1,694 | 2,438 | 1.44 |

Notes: 1. E - extensive, IE - improved extensive, SI - semi-intensive, I - intensive
2. Shrimp/prawn cycle is biannual; milkfish is typically triannual; mud crab is biannual.
Source: adopted from Dey et al. (2008)

Table 3: Cost and Return of Intensive Fish Farming in Muktagacha, Bangladesh, 2011( US $/ha)

| Cost and return | Pangas based Farming | Climbing Perch based Farming |
|---|---|---|
| Cost ( US $/ha) | | |
| Land-related | | |
| Ditch making and dyke preparation | 365 | 81 |
| Lease value or land rent | 257 | 342 |
| Input | | |
| Fingerling | 2119 | 1554 |
| Feed | 20129 | 10122 |
| Fertilizer | 149 | 158 |
| Irrigation | 517 | 179 |
| Labor cost | 3030 | 158 |
| Management-related | | |
| Management | 385 | 208 |
| Guarding | 45 | |
| Harvest- and Post-harvest-related | | |
| Fish harvesting | 479 | 236 |
| Transport and marketing | 6 | 6 |
| Total Cost ( US $/ha) | 27481 | 13042 |
| Total Variable Cost | 26429 | 12411 |
| Yield (Kg/ha) | 41946 | 10480 |
| Gross Return ( US $/ha) | 36936 | 24501 |
| Net return (US $/ha) | 9455 | 11459 |
| Gross Margin ( US $/ha) | 10507 | 12090 |
| Gross Margin/variable cost | 0.398 | 0.974 |

Source: Field survey

Table 4. Factor Shares and Investment Needs in Freshwater Aquaculture Technologies in the Selected Asian Countries

| Country | Species | Culture System | Intensity | Factor Shares (%) | | | Investment Requirement (US$/ha/100 m2) |
|---|---|---|---|---|---|---|---|
| | | | | Seed | Feed | Labor | |
| Bangladesh | Carp | Pond poly | IE | 27 | 20 | 30 | 1,108 |
| China | Carp | Pond poly | SI | 24 | 49 | 9 | 6,780 |
| | | | I | 28 | 46 | 8 | 10,380 |
| | Prawn | Pond mono | SI | 20 | 68 | 9 | 3,000 |
| | Crab | Pen lake | E | 29 | 32 | 18 | 1,000 |
| India | Carp | Pond poly | SI (LI) | 8 | 14 | 10 | 949 |
| | | | SI (HI) | 7 | 7 | 10 | 6,369 |
| | Prawn | Pond mono | SI | 10 | 20 | 10 | 3,397 |
| | Carp | Duck-fish | SI | 6 | 16 | 24 | 1,303 |
| Indonesia | Tilapia | Pond mono | E | 35 | 58 | 6 | 352 |
| | Catfish | Pond mono | SI | 24 | 70 | 5 | 1,075 |
| Malaysia | Tilapia | Floating cage | I | 10 | 79 | 7 | 6,764 |
| Philippines | Carp | Pond mono | I | 28 | 4 | 68 | 2,125 |
| | Tilapia | Pond mono | I | 19 | 23 | 55 | 3,109 |
| | FW Prawn | Pond mono | I | 24 | 53 | 12 | 4,074 |
| Thailand | Carp | Pond poly | SI | 19 | 32 | 16 | 1,435 |
| | Snakehead | Pond mono | I | 5 | 69 | 12 | 29,845 |
| | FW Prawn | Pond mono | SI | 19 | 49 | 7 | 4,270 |
| | Tilapia | River cage | I | 17 | 73 | 2 | 2,997 |
| Viet Nam | Carp | Pond mono | SI | 25 | 28 | 24 | 976 |
| | Carp | Fish-paddy | SI | 20 | - | 40 | 712 |

Source: Adopted from Dey et al. (2008)

Table 5. Factor Shares and Investment Needs in Brackishwater Aquaculture Technologies in the Selected Countries

| Country | Species | Culture System | Intensity | Factor Shares (%) | | | Investment Requirement (US$/ha) |
|---|---|---|---|---|---|---|---|
| | | | | Seed | Feed | Labor | |
| Bangladesh | Shrimp | Pond mono | E | 40 | 2 | 47 | 863 |
| | Shrimp | Shrimp-rice | E | 36 | 2 | 35 | 812 |
| India | Shrimp | Pond mono | IE | 24 | 20 | 10 | 3,497 |
| Indonesia | Shrimp | Pond mono | E | 32 | 12 | 24 | 1,550 |
| Malaysia | Shrimp | Pond mono | I | 10 | 49 | 6 | 43,362 |
| Philippines | Prawn | Pond mono | SI | 7 | 44 | 5 | 10,194 |
| Thailand | Shrimp | Pond mono | SI | 14 | - | 16 | 802 |
| Viet Nam | Shrimp | Pond mono | E | 24 | 10 | 15 | 932 |
| Viet Nam | Shrimp | Pond mono | SI | 8 | 32 | 6 | 6,763 |
| Viet Nam | Shrimp | Pond mono | I | 8 | 62 | 7 | 10,763 |

Source: Adopted from Dey et al. (2008).

# AQUACULTURE FOR THE CONSERVATION OF NATIVE FISH SPECIES IN SOUTHEASTERN MEXICO

*Wilfrido Contreras Sanchez, Universidad Juárez Autónoma de Tabasco*

**Abstract**

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.

Aquaculture for the Conservation of Native Fish Species In Southeastern Mexico

Contreras-Sánchez, W.M.*

Tropical Aquaculture Laboratory
Biological Sciences Diviion
UJAT

Projects funded by

UJAT

AQUAFISH COLLABORATIVE RESEARCH SUPPORT PROGRAM

CONACYT

COMISION NACIONAL DE AREAS NATURALES PROTEGIDAS

Native species we work with

Tenguayaca
*Petenia*

Paletas
*Cichlasoma spp*

Castarrica
*Cichlasoma urophthalmus*

Snooks *Centropomus spp*

Tropical Gar
*Atractosteus tropicus*

MAIN GOAL:

To develop technological packages to culture native species for:

1) Production of fingerlings for restocking depleted or extirpated populations.

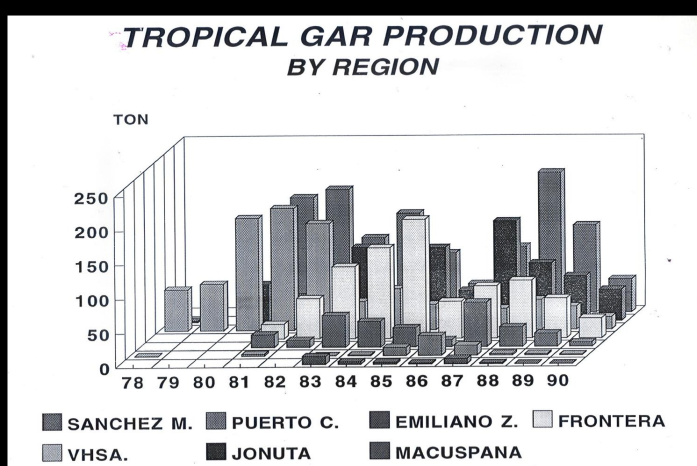
2) Commercial production to replace tilapia in farms.

Diverge pressure from wild populations allowing them to recover from overfishing

Main Distribution:
Central America: Southestern Mexico, Guatemala, Nicaragua, El Salvador and Costa Rica

•Value:
Ecological
Economic
Cultural

## Historic capture volumes




Marquez & Contreras (1990)

## Incorporation of native cichlids

**Tenguayaca**
*Petenia splendida*

**Castarrica**
*Cichlasoma urophthalmus*

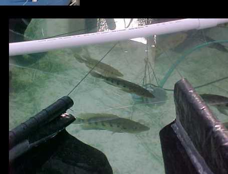
**Paletas**
*Cichlasoma spp*

## Incorporation of native cichlids

**Reproducción**

Spawning

Systems



Fry production

## Native cichlids culture

<u>Masculinization</u>

Excellent results with:
Castarricas
Tenguayaca

<u>Grow-out</u>

Grow-rates (masculinized vs not masculinized)
Systems
Diets

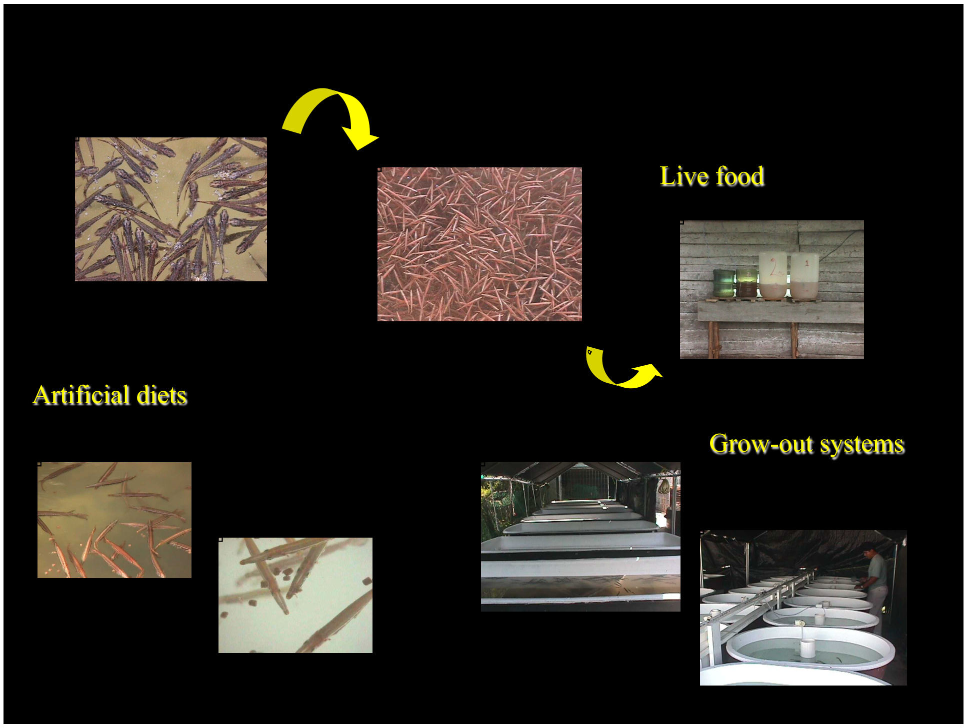
## Tropical gar culture

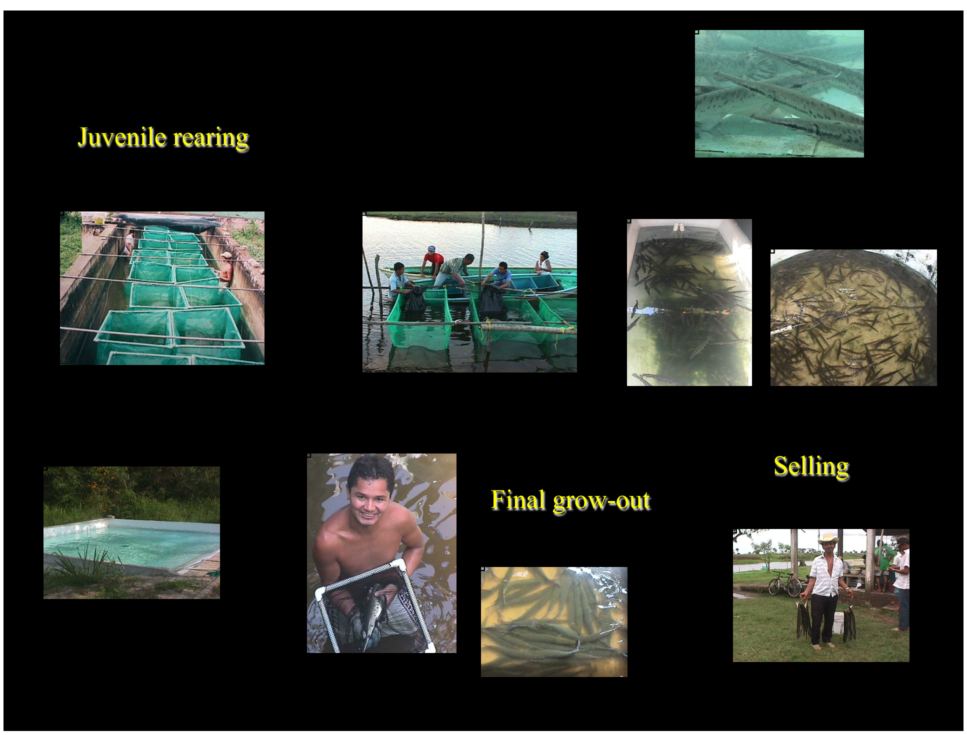
<u>Spawing induction</u>

Broodstock selection

Spawning

Larval culture


Live food
Artificial diets
Grow-out systems


Juvenile rearing
Selling
Final grow-out

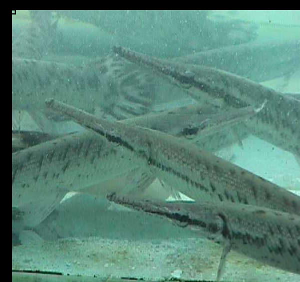

Training on gar culture
Training in situ


Grow-out in Circular Tanks


Full cycle culture
Technological package


Extension

Fingerling and juvenile production for restocking



SNOOKS
Distribution: Atlantic coast, Florida to Brazil
Gulf of Mexico: important commercial and sport fisheries

Snooks *Centropomus spp*

Snooks are well known as "marine species"
In southeastern Mexico snooks also inhabit Coastal lagoons, rivers, freshwater lagoons and wetlands

•Mexico: Very important fishery

•Migrations unknown

## METHODS

Marine Aquaculture Laboratory

Jalapita, Centla
Tabasco, México

•Broodstock capture:

2.5 - 3 " nets
3 to 10 km from the coast

At the beach
Beach sein

Collects between 4 - 6 AM

•Health evaluation
•Recovery in seawater (35ppm)
•Freshwater baths (to eliminate parasites)
•Bactericide baths (if needed)

Acclimation
Live fish
Fresh or frozen fish (pieces)

## Facilities

•***Experiment1: GnRH-a Injeccions:***

•**Methods:** Álvarez-Lajonchere
Hernández (2001)
Hernández-Vidal (2002)

•Intra-ovarian biopsy prior to treatments
Weight, Total Length.

•Injections with 0, 75 or 150 µg/kg for females and 50 µg/kg for males.

•Female to male ratios; 1:2.

**Experimental design: Complete Random block**
***Three treatments***
***Four pseudo-replications (through time)***

**Average weight and Length**

Females 252 - 540 g
26 - 35 cm

Males 155 - 305 g
25 - 33 cm

•**RECIRCULATION SYSTEMS**

2000 L Tanks connected to a sand filter

plástico de 30 L para colectar los huevos con una malla de 400 µ

•**EGG COLLECTORS**

Each tank had an egg collector made of 400 µ mesh placed inside a 30 L plastic tank

**EXPERIMENT 2: USE OF GnRH-a implants**

**Experimental design:**
**Complete Random block**
***Three treatments***
***Four pseudo-replications (through time)***

**Treatments: 0. 100 y 200 µg/female and 100 µg/male**

•**Implant elaboration:**
**Cocoa butter**
**Cholesterol**
**+ GnRH-a**

**Average weight and Length**

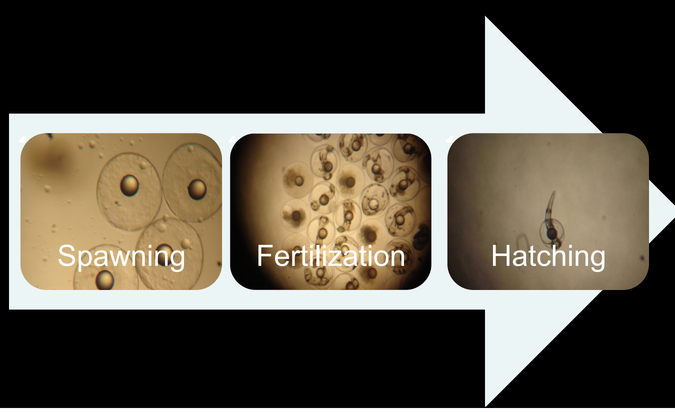
**Females 266 - 460 g**
**31 - 38 cm**

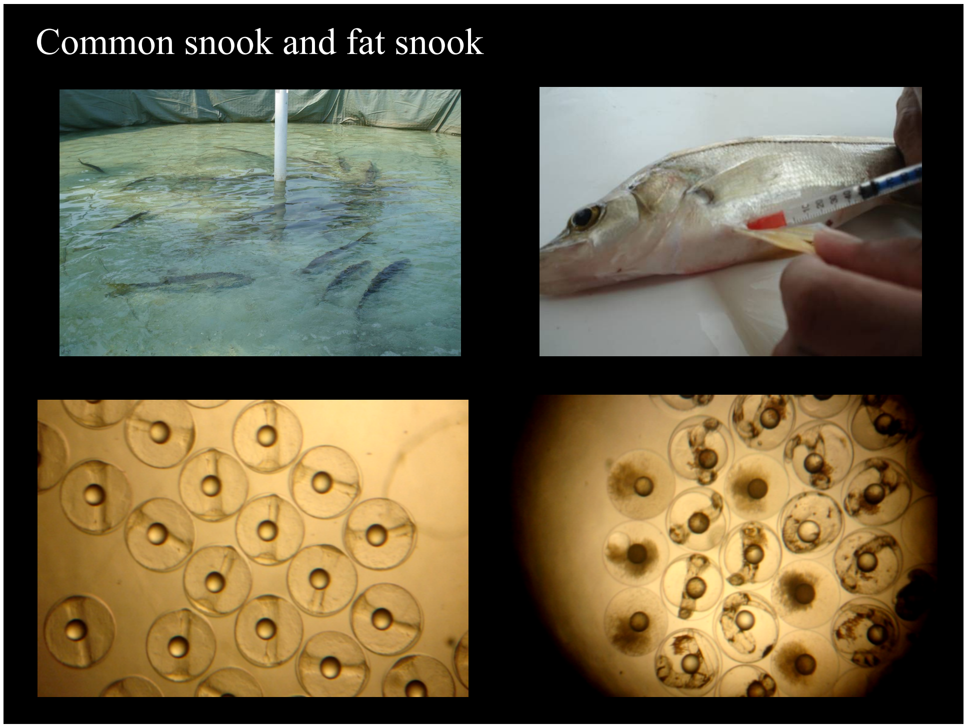
**Males 144 - 288 g**
**26 - 32 cm**

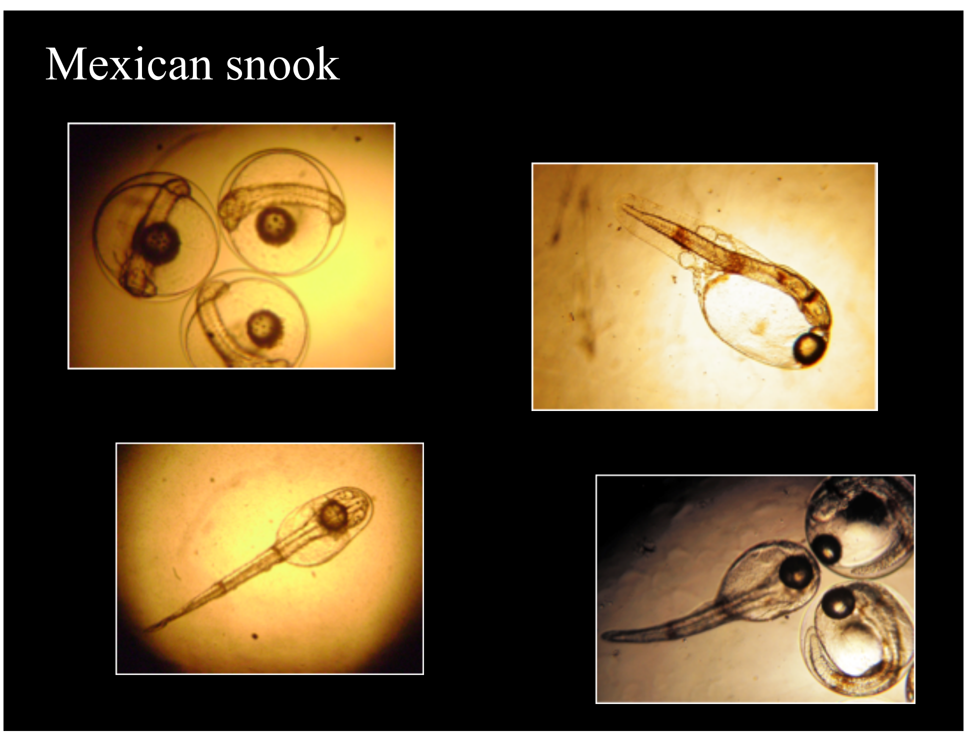
# *Results*

Implants
Spawning
Hatching
Larval Length

T0 10 20 30 40 50 60 70 Hours




Common snook and fat snook


Mexican snook

# Live food laboratory

UNIVERSIDAD JUAREZ AUTONOMA DE TABASCO
DIVISION ACADEMICA DE CIENCIAS BIOLOGICAS
LABORATORIO DE ACUACULTURA

Dr. Wilfrido M. Contreras Sánchez
Dr. C. Alfonso Alvarez González
MC. Gabriel Márquez Couturier
MC. Ulises Hernández Vidal
MC. Salomón Páramo Delgadillo
MC. Arlette Hernández Franyuti

Wilfrido

Gabriel

Salomón

Ulises

Alfonso

Arlette

*Funding for this research was provided by the*

AQUAFISH
COLLABORATIVE RESEARCH SUPPORT PROGRAM

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OSU Oregon State UNIVERSITY

AQUAFISH COLLABORATIVE RESEARCH SUPPORT PROGRAM

The AquaFish CRSP is funded in part by United States Agency for International Development (USAID) Cooperative Agreement No. EPP-A-00-06-00012-00 and by US and Host Country partners.

## UNDERSTANDING THE BASIC BIOLOGY AND ECOLOGY OF INVASIVE NILE TILAPIA: THE ROLE IT PLAYS IN SUSTAINABLE AQUATIC BIODIVERSITY

*Mark S. Peterson, PhD, University of Southern Mississippi; William T. Slack, PhD, US Army ERDC*

**Abstract**

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.

Understanding the basic biology & ecology of invasive Nile tilapia (*Oreochromis niloticus*): the role it plays in sustainable aquatic biodiversity

Mark S. Peterson & William T. Slack[1]

Department of Coastal Sciences,
The University of Southern Mississippi, Ocean Springs, MS

[1]U.S. Army ERDC, Waterways Experiment Station EE-A,
Vicksburg, MS

THE UNIVERSITY OF SOUTHERN MISSISSIPPI
GULF COAST RESEARCH LABORATORY
Coastal Ecosystems Group

ERDC
Engineer Research and Development Center

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SHORT PAPERS AND NOTES

An Opinion on the Effects of Cichlid Releases in North America

8. Good table qualities (??)," as reported on p. XXXVI of the Report of the United States Fish Commission for 1873–1874 and 1874–1875. The parenthetical in-

SCIENCE'S COMPASS • POLICY FORUM

POLICY FORUM: ECOLOGY

Aquaculture—A Gateway for Exotic Species

Rosamond L. Naylor*, Susan L. Williams, Donald R. Strong

clude the Japanese oyster drill (10), turbellarian flatworm (10), Asian eelgrass (12), and highly invasive seaweeds (13). One of these seaweeds, *Codium fragile*, is known as the "oyster thief" because it overgrows and smothers oyster beds (13).

**Introduced Carp for Biological Control**
Channel catfish (*Ictalurus punctatus*) are the most widely farmed fish in the United

Review

Cell PRESS

Invasive species, ecosystem services and human well-being

Liba Pejchar[1] and Harold A. Mooney[2]

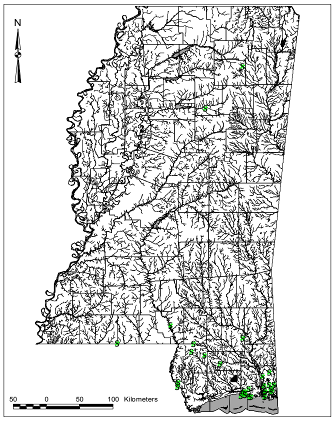
[1] Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO 80523, USA
[2] Department of Biology, Stanford University, Stanford, CA 94305, USA

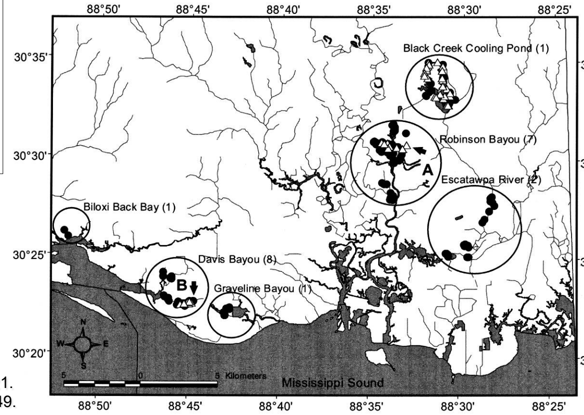
Human Domination of Earth's Ecosystems

Peter M. Vitousek, Harold A. Mooney, Jane Lubchenco, Jerry M. Melillo

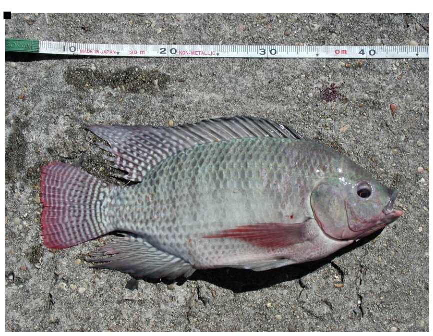
# Objectives

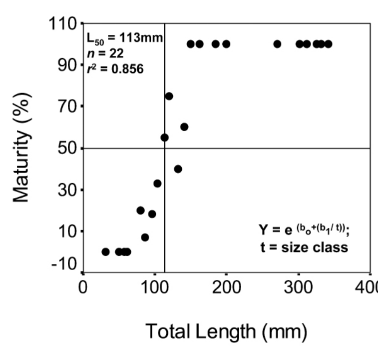
- Review Nile tilapia studies
- Briefly look at other invasive species
- Discuss knowledge pre- vs post-introduction
- Natural & anthropogenic impacts – Invasional Meltdown & Novel Ecosystem issues
- Need for standardized invasive network for management prior to permitting

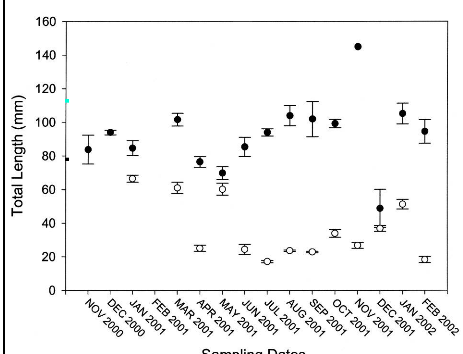


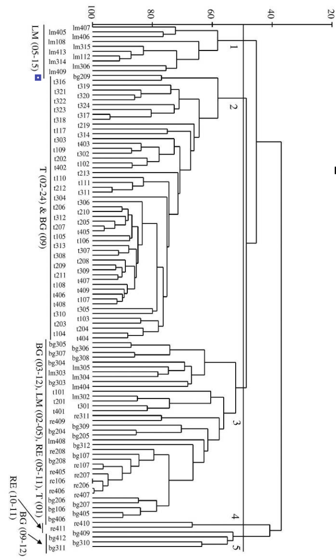




Grammer *et al.* (in rev) *AI*
Schofield *et al.* 2011. *MFR* 62:439-449.
Schofield *et al.* 2007. *SEFC*, *Proc.* 49:9-15.
McDonald *et al.* 2007. *JFE* 22(3):461-468.
Peterson *et al.* 2006. *EBF* 76:283-301.
Peterson *et al.* 2005. *Wetlands* 25(1):112-121.
Peterson *et al.* 2004. *Copeia* 2004(4):842-849.





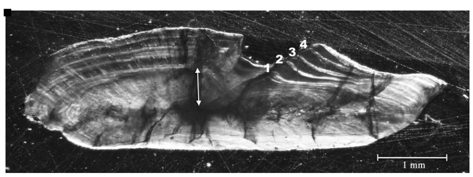
## 2-way ANOSIM & pairwise comparisons

Moderate size class effect (gR = 0.457, p = 0.1%).
Strong species effect (gR = 0.876, p = 0.1%).
No season effect (gR = 0.026, p = 24.3%).

Pairwise comparisons: larger values = more distinct



| | BG | LMB | NT |
|---|---|---|---|
| LMB | 0.620 | | |
| NT | 0.957 | 0.956 | |
| RE | 0.423 | 0.683 | 0.953 |

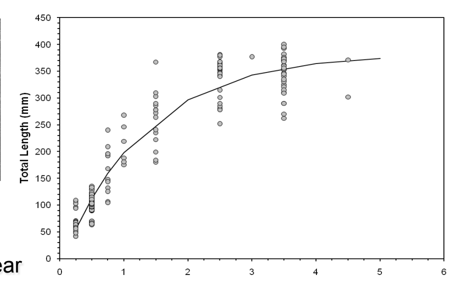


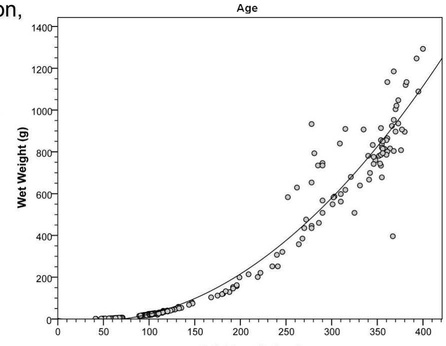

Grammer *et al.* (in review). *Aquatic Invasions*.

## Take home message:

It is clear some fish overwinter & Nile tilapia appear to maintain native life history patterns (reproduction, bowers, age-length, growth, diet) in invaded environments in Mississippi.

Knowledge of the basic biology of NT would have helped prior to aquaculture permitting.




TL-WW & Age-TL relationships identical to NT in Africa

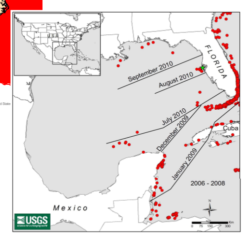
## Aquarium trade –more known from non-native environment

RioGrande, *Herichthyes cyanoguttatus*

courtesy Florida Caribbean Science Center/U.S. Geological Survey

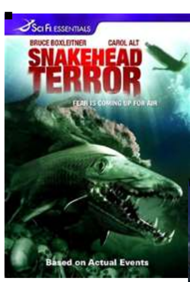
Mayan, *Cichlosoma uropthalmus*

Lionfish, *Pterois volitans/miles*

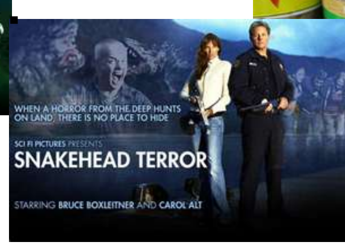




Recent report from
TX Flower Gardens!

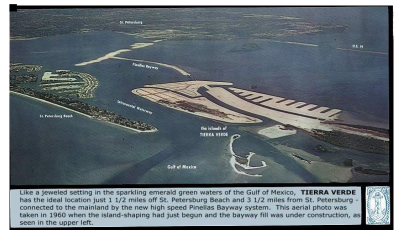
## Aquarium trade/live fish – more known from native environments

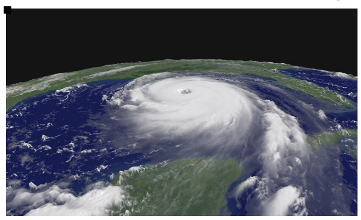








## Climate change, natural disasters, & human alterations

Global climate change & emergent properties (+, -) Human disturbances

(-) (-) (+) (+)

Native species (-) Direct Non-native species

(-) Indirect (+) (+)

Invasional meltdown

Assemblage composition matrix

# Conclusions

We argue that understanding the basic biology of aquaculture species is imperative to protect aquatic biodiversity. Actual invasive species management & permitting occur at state (local) levels & thus this knowledge must be required to proactively manage the permitting process prior to intentional introductions or permitting species which could potentially impact native biodiversity if they escape.

This requires a worldwide annotated data and research network that is standardized & continuously updated with literature on introduction vectors, impacts (+, -, 0), & literature on basic biology & ecology. Managers can query this single database prior to decisions on permit applications relative to the regional environment.

http://www.issg.org/database (Invasive Species Specialist Group)
http://fishbase.org (Fish Base)
http://www.gisp.org (Global Invasive Species Programme)
http://invasivespecies.nbii.gov/dbases.html (National Biological Information Infrastructure)
http://globallast.imo.org/ (GloBallast Partnerships)
http://www.iucn.org/marine (IUCN Global Marine Programme)
http://www.biodiv.org (The Convention on Biological Diversity)

Managing 'Novel Ecosystems' (Hobbs *et al.* 2006, 2009, 2011).

To have real 'responsible' aquaculture requires tradeoffs between establishment of appropriate best management practices to protect the environment & its native fauna balanced with the economics of industry growth.

# Acknowledgments

Early funding provided through MDWFP Project F-129 during 2000-2002 to MSP and WTS & the USGS Invasive Species Program & USFWS (Region 4) to P. Schofield.

Special thanks: M.A. Dugo, N. Brown-Peterson, C. Woodley, C. Vervaeke, G. Grammer, J. McDonald, J. Finley, J. Brookins, B. Lezina, M. Partyka, J.D. Williams, D. Bowles, R. Scott, G. Scott, G. Robertson, D. Riecke, B. Hubbard, J. Reynolds, M. Lowe, P. Schofield, & L. Nico.

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AQUAFISH Collaborative Research Support Program

# Understanding the basic biology and ecology of invasive Nile tilapia: The role it plays in sustainable aquatic biodiversity

Mark S. Peterson and William T. Slack1

Department of Coastal Sciences, The University of Southern Mississippi, 703 East Beach Drive, Ocean Springs, MS 39564 and 1U.S. Army ERDC, Waterways Experiment Station EE-A, 3909 Halls Ferry Road, Vicksburg, MS 39180

Running Head: Biodiversity and responsible aquaculture

**Abstract**
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.

**General overview of cichlid invasions**
Much of the historical and legal issues of non-native introductions of cichlids to the Americas can be found in Courtenay (1997), with a more recent treatment by Canonico et al. (2005), Diana (2009) and Canonico-Hyde (2011), and reviews on worldwide implications (Casal 2006; Molnar et al. 2008; Vitule et al. 2009; Cucheroosset and Olden 2011). However, offshore and land-based aquaculture activities are increasing as the need for protein increases worldwide (Naylor et al. 2000, Stickney 2002; Costa-Pierce 2003) and many facilities include members of the family Cichlidae (Beveridge and McAndrew 2000). Although cichlids are recognized as having the potential to alter aquatic communities into which they are introduced (McKaye 1995; Courtenay 1997; Leal-Flórez et al. 2008), and while there is considerable evidence that invasive species do spread and establish in many ecosystems (Canonico et al. 2005; Canonico-Hyde 2011; Cucherousset and Olden 2011), little quantitative or experimental data are available until recently (see below) that truly support this suggestion.

Clearly cichlids are tolerant of variable environmental conditions such as temperature and salinity (Trewavas 1983; Wilson et al. 2009; IUCN 2009) and can colonize and establish in fresh water and saline environments. For example, when living near brackish saline systems (near isosmoticity; salinity of 10–15), tilapiine cichlids have a lower energetic cost of osmoregulation (Febry and Lutz 1987), have significantly reduced oxygen consumption rates (Farmer and Beamish 1969), and can tolerate lower temperatures (Beamish 1970; Zale and Gregory 1989, Avella et al. 1993; Schofield et al. 2011). Furthermore, tilapiine cichlids are trophic generalists (Zale and Gregory 1990; Dempster et al. 1993; Traxler and Murphy 1995; Peterson et al. 2006), and their reproductive biology is characterized by short generation time, multiple clutches, and extended breeding seasons (Naylor et al. 2000; Stickney 2002; Peterson et al. 2004). All of these adaptations allow successful colonization into non-native environments.
Some large-scale ecosystem changes have been driven by introductions and subsequent interactions among native and non-native species. For example, Nile perch (Lates niloticus), Nile tilapia (Oreochromis niloticus) and two other cichlids were introduced into Lake Victoria, Africa in the 1950s

and early 1960s (Ogutu-Ohwayo 2001). Now, the former two species dominate the fish fauna because Nile perch is a piscivore and has almost eliminated the native haplochromine cichlids of the lake whereas Nile tilapia is a herbivore that outcompetes the native and two non-native cichlids. Similarly, the introduced blackchin tilapia (Sarotherodon melanotheron) represented 90% of the biomass and occurred in over 80% of all collections in an impounded mangrove habitat in Florida due to their ability to survive the altered mangrove conditions (Faunce and Paperno 1999). Crutchfield (1995) indicated that redbelly tilapia (Tilapia zilli) became the fourth most abundant species in a power plant reservoir in North Carolina within three years after introduction. Foraging by this species eliminated all submerged and floating macrophytes in the reservoir within a two-year period and this coincided with significant declines in native fishes.

Finally, biogeographic barriers which historically restricted dispersal of biota are increasingly being circumvented by human actions, resulting in increased faunal homogenization at the expense of native uniqueness (Cohen and Carlton 1998; Rahel 2007; Molnar et al. 2008). Typically, displacement of native species is by a small set of cosmopolitan non-native fauna that have been widely introduced through human actions, bringing sameness to formerly unique ecosystems (McKinney and Lockwood 1999; Rahel 2002; Vitule et al. 2009).

**Scope of review: why study basic biology of cichlids in non-native environments?**
Species used in aquaculture are generally extremely plastic in their ability to deal with environmental variation (Ricciardi and Rasmussen 1998; Batjakas 1999; Stickney et al. 2002), thus making them an excellent subject for aquaculture. However, these capabilities also make them excellent invaders (Peterson et al. 2005; Canonico et al. 2005) and thus it is important to fully understand the biology and ecology of non-native fishes being used for aquaculture in order to select species for production that would have the least negative impact to native ecosystems in case they escape. Identifying and understanding the scale of potential threats associated with escapes would facilitate the development and regulation of special permitting requirements. Casal (2006) and Crowl et al. (2008) noted that a missing component of aquaculture and other introduction vectors and their management is the lack of a worldwide tracking system for these introductions (see IUCN 2009 for list of seven invasive online databases). Furthermore, Molnar et al. (2008) quantified local, regional and national invasive species databases but indicated there is little integration and standardization of these databases to make them globally useful for tracking and managing invasive species from all vectors. Actual invasive species management & permitting occur at state (local) levels and thus this knowledge must be required to proactively manage the permitting process prior to intentional introductions or permitting species which could potentially impact native biodiversity if they escape. Thus, development of a standardized and integrated database would allow resource managers quick and accurate access to species-specific biological data on potential threats to native ecosystem and their fauna and documented negative impacts prior to permitting as well as managing existing facilities. The importance of available species-specific biological data in native and non-native environments is only becoming clear now as we elucidate the basic biology and ecology of Nile tilapia in Mississippi. For example, when we started our research, all we knew was that Nile tilapia was widely used and an adaptive aquaculture species (Costa-Pierce 2003; Casal et al. 2006), and that brackish marshes along the northern Gulf of Mexico are among the least studied regions of the U.S. in terms of introductions (Ruiz et al. 2000; Carlton 2001). As you will see below, Nile tilapia is clearly not a fresh water cichlid (Fryer and Iles 1972), but a species that is capable of survival, growth and reproduction in environments ranging up to a salinity of 30-35 and can thus move across the brackish bays in the north-central Gulf of Mexico extending their range and potential impacts to native fishes and their habitats.

**Case study of Nile tilapia in Mississippi**
At the start of our research on Nile tilapia in coastal Mississippi watersheds, the literature suggested that this species would not survive winter temperatures in our region (McBay 1961; Crittenden 1962) and

regionally (Shafland and Pestrak 1982) and was also not a threat to move into downstream more saline, estuarine waters. These data lead to a general lack of concern by regional resource agencies regarding establishment of Nile tilapia in coastal watershed following incidental release and/or escape from aquaculture facilities. The opportunity to study this species from 2000 to 2002 in the Pascagoula and Escatawpa river systems and Simmons Bayou (Figure 1; Peterson et al. 2005), however, suggests otherwise. Nile tilapia ranged from 4.53 to 430.00 mm TL in the Pascagoula and Escatawpa River systems, whereas in Simmons Bayou fish were 12.09 to 400.00 mm TL (Peterson et al. 2005). It was clear that Nile tilapia was surviving winter conditions based on their size distributions (Figure 2) and published data on size-age relationships (Trewavas 1983). Supporting evidence of total lengths across dates at the Pascagoula River effluent station not differing (Figure 2) also suggested the persistence of Nile tilapia in that system. In contrast, fish lengths were significantly smaller 1.55 km downstream in late spring and summer compared to other months, suggesting a spawning location as well (Figure 2). Recent research supports this hypothesis with otolith-based ages of fish 41.3 - 400.0 mm TL (1.34 - 1,293 g WW) from the Pascagoula River and an adjacent power plant cooling reservoir in coastal Mississippi indicate they reach ages up to 4+ years old (Figure 3; Grammer et al. in review). Our data also indicates they spawn all year in the Pascagoula River with fish as small as 79.9 mm TL carried eggs, and the size at 50% maturity was 113 mm TL (Figure 4; Peterson et al. 2004).

We also quantified the diet of the Nile tilapia, bluegill (Lepomis macrochirus), redear sunfish (Lepomis microlophus), and largemouth bass (Micropterus salmoides) and determined diets were separated (Figure 5) based on prey consumption: bluegill and redear sunfish fed on chironomids and insects; largemouth bass consumed fish and insects; and Nile tilapia fed most often on sediment resources such as nematodes, rotifers, bryozoans and hydrozoans. Nile tilapia had the highest frequency of mud, sand and detritus in their stomachs, suggesting they fed directly on bottom sediments. These data and the fact that Nile tilapia have a 1.3–7.6 times longer intestine on average than its body length, support our contention that this non-native species feeds at the base of the food web and any impacts will be at these lower trophic levels. Finally, we found that the Nile tilapia has the appropriate materials for building bowers, can establish active breeding leks, and distributes along thermal gradients within a power plant cooling pond (McDonald et al. 2007).

All of these attributes and biological metrics we measured for Nile tilapia in coastal Mississippi are nearly identical to those reported from the native African environments (Trewavas 1983; Lowe-McConnell 1987), which indicate they are flourishing in this non-native environment. Data of this type are vital to future modeling efforts on the invasion of non-native fishes into coastal watersheds, which may be particularly important given the predicted changes in coastal landscapes due to global climate change and sea-level rise.

Recent work on quantifying the adaptive capabilities of Nile tilapia relative to temperature and salinity suggests that it withstood acute transfer from fresh water up to a salinity of 20 and survived gradual transfer up to 60 at typical summertime (30°C) temperatures (Schofield et al. 2011). However, cold temperature (14°C) reduced survival of the fish in waters above a salinity of 10 and increased incidence of disease in freshwater controls. Although fish were able to equilibrate to saline waters in warm temperatures, reproductive metrics were reduced at salinities above 30. In general, Nile tilapia increased in mass in salinities ≤ 30 at summer temperatures but lost mass during summer temperatures when salinities were ≥ 40, and at winter temperatures regardless of salinity. These whole-animal, integrated responses suggest that Nile tilapia can successfully invade coastal areas of Mississippi beyond their current range subject to two caveats: (1) wintertime survival depends on finding thermal refugia, and (2) reproduction is hampered in regions where salinities are above 30. Clearly, a detailed database on physiological and behavioral capabilities of Nile tilapia would have initially been extremely useful to us and would have allowed us to examine effects of Nile tilapia on native environments and their fauna more closely.

**Supporting evidence in other cichlids**

A similar situation based on an accidental aquarium release has been occurring for about 20 years in the Greater New Orleans Metropolitan Area (GNOMA) with the Rio Grande cichlid (Herichthyes cyanoguttatus) (Fuentes and Cashner 2002; O'Connell et al. 2002). High densities of this cichlid have been showing up mainly in altered (canals) areas of the GNOMA, with lower density outside the city in more natural habitats. Additionally, the Rio Grande cichlid is not restricted by salinity but recent research has indicated that aggression by native centrarchids (L. macrochirus and Lepomis miniatus (redspotted sunfish) may restrict their establishment and growth in natural areas (Lorenz and O'Connell 2008; Lorenz et al. 2011).

Presence of non-native tilapia species can have severe consequences on native fish fauna, as introduced Oreochromis spp. can literally occupy all available habitat with their spawning sites (McKaye et al. 1995), thus interfering with spawning by native nest-building species. Martin et al. (2010) through mesocosm experiments quantified that Nile tilapia displaced native redspotted sunfish from their preferred habitat through aggression, and when largemouth bass were also present with both species, the redspotted sunfish survivorship decreased. They suggested, if unchecked, Nile tilapia and other aggressive aquaculture species could have negative effects on native fish food webs. Finally, Doupe et al. (2009) experimentally quantified significant reductions in egg production by over 70% and egg fertilization by over 30% in native Australian rainbowfish (Melanotaenia splendida splendida) when breeding groups of Mozambique tilapia (Oreochromis mossambicus) were present.

Finally, a review of survey data in southern Florida (Trexler et al. 2000) noted, in the absence of experimental data, little impact of invasives on native fishes could be revealed. However, nest predation by the Mayan cichlid (Cichlasoma urophthalmus) and walking catfish (Clarias batrachus) on native centrarchids was observed and may contribute to decreases in centrarchid reproduction and changes in population dynamics (Trexler et al. 2000). Future research by Kobza et al. (2004) noted high abundances of black acara (Cichlosoma bimaculatus), walking catfish, and the Mayan cichlid in deep solution holes in Everglades National Park, Florida with a reduction of native fishes, but only after extended periods of low rainfall. They speculated that predation pressure on native fishes was greater during extended dry seasons.

**Other non-cichlid introduction vectors**

In addition to aquaculture releases, ballast water (NRC 1996), aquarium releases and live-food markets are important vectors of introductions worldwide (Crowl et al. 2008; Molnar et al. 2008). The latter two vectors are relevant to our discussion. For example, after a presumed aquarium release (Ruiz-Carus et al. 2006; Morris and Whitfield 2009), lionfish (Pterois miles/volitans complex) have now spread and become established in many near-shore and coral reef environments along the Western Atlantic, Caribbean Sea, and Gulf of Mexico (Whitfield et al. 2007; Schofield 2009, 2010). Impacts range from foraging on many life-stages of reef fishes, a decrease recovery of the snapper/grouper complex along southeastern U.S. coast (Morris and Whitfield 2009) and a phase shift to algal dominated communities at mesophotic depth on coral reefs (Lesser and Slattery 2011) have been indicated. Ruis-Carus et al. (2006) noted there was little biological or ecological data from their native range (see Donaldson et al. In press) available during the early invasion period to assist management but later studies on the species within the non-native environments suggest these species are well adapted ecologically and reproductively (Morris and Whitfield 2009; Morris et al. 2011) to survive, proliferate and expand in the Western Atlantic region.

In contract, snakeheads (Family Channidae) are also introduced from the aquarium trade and/or live-fish market (Courtney and Williams 2004; Nico et al. 2011), but unlike lionfish, there was considerable data available from their native range because of aquaculture, aquarium trade, and live-food market industries in Asia. These data have allowed managers and policy makers the ability to quickly make informed decisions on future permitting and identify threats to native fauna and their habitats.

## Conclusions

It appears that the closer scientists examine invasive species activities and potential impacts to ecosystems and their fauna, whether from aquaculture, ballast water or the aquarium trade (Molnar et al. 2008; Crowl et al. 2008; Strecker et al. 2011), modifications become apparent. For example, the recent experimental work on aggression of invasive species toward native species and subsequent quantified reduced growth, reproduction and the potential for modified food webs (e.g., Lorenz and O'Connell 2008; Doupé et al. 2009; Martin et al. 2010; Lorenz et al. 2011), suggests that some impacts may be subtle but have long-term consequences. These interactions can be acute or subtle but continue over time to produce long-term modifications, like influencing future year-class strength of the native species, which do not show up until invasive populations have fully established and the impact to natives only then becomes obvious. Reversal of the trend typically is not possible or is not cost effective (Cucherousset and Olden 2011). Recent work on the adaptive capabilities of invasive species illustrates the need to study these species, by way of laboratory and field experiments, such that we fully understand their ability to tolerate and proliferate under various environmental conditions. For many species, there are limited biological data available from their native environments and much of what we understand stems from recent research in non-native environments as invasive species begin to establish, spread, and influence native species and their habitats (Canonico et al. 2005; Brown et al. 2007; García-Berthou 2007). For example, recent studies on the African jewelfish (Hemichromis letourneuxi) indicate a wide tolerance to low oxygen concentration, as quantified by the frequency of aquatic surface respiration, compared to the native warmouth (Lepomis gulosus) and the dollar sunfish (L. marginatus). African jewelfish was significantly more tolerant to low oxygen than the two native, co-occuring centrarchids (Schofield et al. 2007). Furthermore, laboratory experiments on cold tolerance indicated the species exhibited loss of equilibrium between 10.8-12.5°C and death at 9.1-13.3°C. However, field caging studies in the Everglades National Park during two cold snaps (wherein the air temperature plunged to 0°C) revealed fish died in shallow water marshes but survived in deeper canals and solution holes where the temperature decline was attenuated (Schofield et al. 2009). These data illustrate that environmental tolerances are more complex and that geographic distribution and expansion based on laboratory determined temperature isoclines are not realistic because refugia (e.g., canals) exist that bolster the species survival in what would otherwise be an inhospitable environment. Finally, Langston et al. (2010) evaluated salinity tolerance of African jewelfish and determined that it had excellent survival from salinities between 0-50 under chronic conditions, but at a salinity of 60, only 25% survived with a mean survival time of only 12 days. Fish grew well between salinities 0-50. Above a salinity of 60, mortality was 100%. In contrast, direct transfer from freshwater to salinities between 5 and 35 for seven days and then a return to freshwater revealed survival was 100% up to a salinity of 20 but only 56% survived when transferred to a salinity of 25, and zero survival in higher salinities. Although this study evaluated survival in salinites up to 60, most coastal ecosystems rarely experience salinites above 35. Thus, salinity is not expected to restrict the dispersal in coastal waterways by the African jewelfish.

It is typical when a species becomes problematic, a risk assessment is required (e.g., Nico et al. 2005); however, many such risk assessments are completed well after the species has been introduced, begins to spread geographically, or often only after establishment has already occurred. These documents are extremely useful as a citation where all biological data are reviewed and management recommendations are made but are still reactive instead of proactive in terms of providing sufficient data to regulators, managers, and those charged with permitting aquaculture facilities. Responsible aquaculture practices should require a detailed review of available data and subsequent study on biological aspects not in the literature to evaluate these adaptive capabilities of potentially invasive species. Risk assessment procedures also should not be influenced by political interference (Simberloff 2005) of the rules and regulations established to protect native fishes and their environments. This is vital as "it is paramount that we not continue to approach non-indigenous organisms with the current naivety. The philosophy that allows the escape or release of non-indigenous taxa into our present landscape, justified by the belief that species will not survive or become established, is fallible" (Peterson et al. 2005). Much of the aquaculture philosophy revolves around the economic portion of the economic/human population growth/fish conservation conflict (Limburg et al. 2011). This conflict drives current thought and discussion at national and international levels (Limburg et al. 2011) relative to required changes that would produce 'responsible' aquaculture practices necessary for a sustainable environment upon which humans depend. This is particularly important because aquaculturists worldwide continue to produce strains which are hybrids of many tolerant species like GIFT (Rindha 2008) which are bred to be salt tolerant for aquaculture in brackish waters.

Issues of invasion success from all vectors can be modified or exacerbated by habitat modifications (Peterson and Lowe 2009), the recognition of rising global temperatures (McCarty 2001; Crowl et al. 2008) that have lead to poleward range species extensions (McCarty 2001; Perry et al. 2005; Hickling et al. 2006; Foldrie et al. 2010) thus enabling invasive species to flourish in new environments (Rahel and Olden 2008), interactions among multiple invading species (Griffen et al. 2011) and consequences of the 'invasional meltdown' hypothesis (Ricciardi 2000; Figure 6). Thus, we must strive to not allow ecosystems to be as greatly modified by invasive species as in San Francisco Bay (Cohen and Carlton 1998; Carlton 2001) and Tampa Bay (Nico and Fuller 1999) as we are only recently beginning to focus on structure and function of these novel or emerging ecosystems (Milton 2003; Hobbs et al. 2006, 2009).

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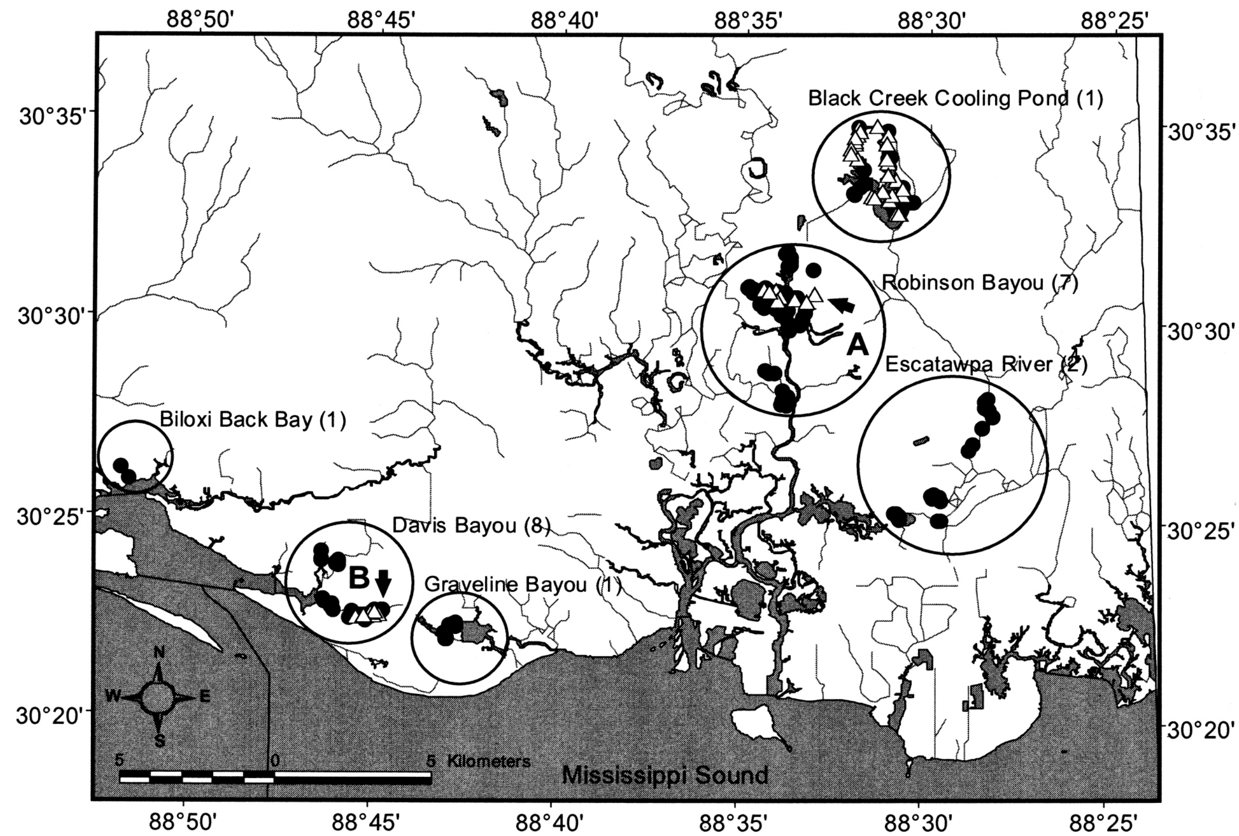


Figure 1. General map of stations and areas where 280 collections were made in coastal Mississippi. Solid circles represent sampled areas where Nile tilapia was not present; triangles represent areas where Nile tilapia was present. The arrows in circles A and B refer to the location of the aquaculture facilities (from Peterson et al. 2005 with permission from Wetlands Editor-in-Chief).

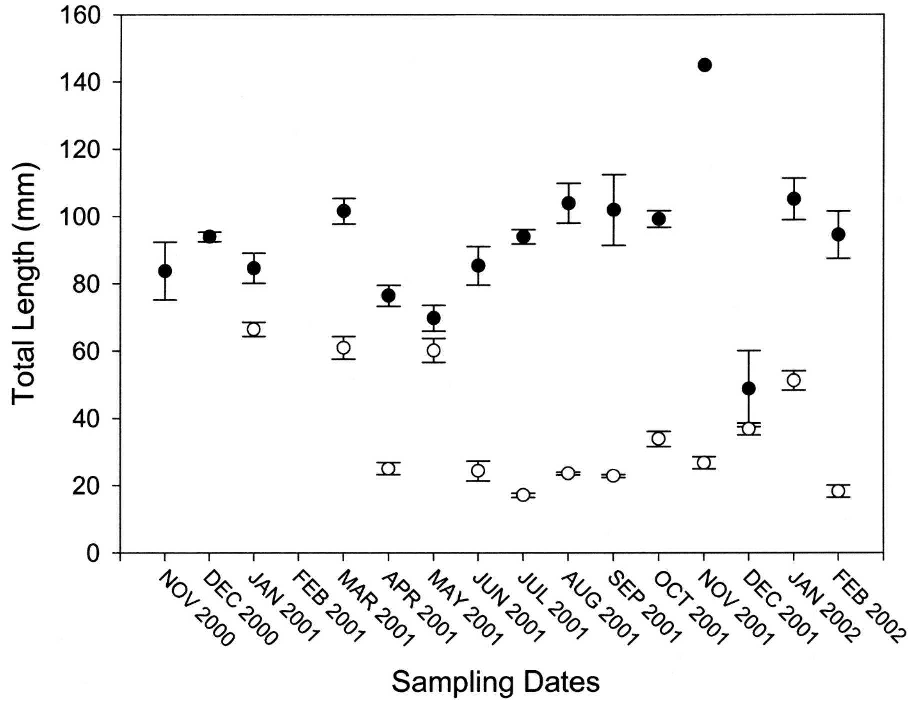


Figure 2. Plot of Oreochromis niloticus total lengths (mean ± se) for the Pascagoula River effluent station (solid circle, n = 604) and the 1.55 km downstream station (open circle, n = 2964) (both within circle A of Figure 1) by collection date. No collections were made in February 2001 (from Peterson et al. 2005 with permission from Wetlands Editor-in-Chief).

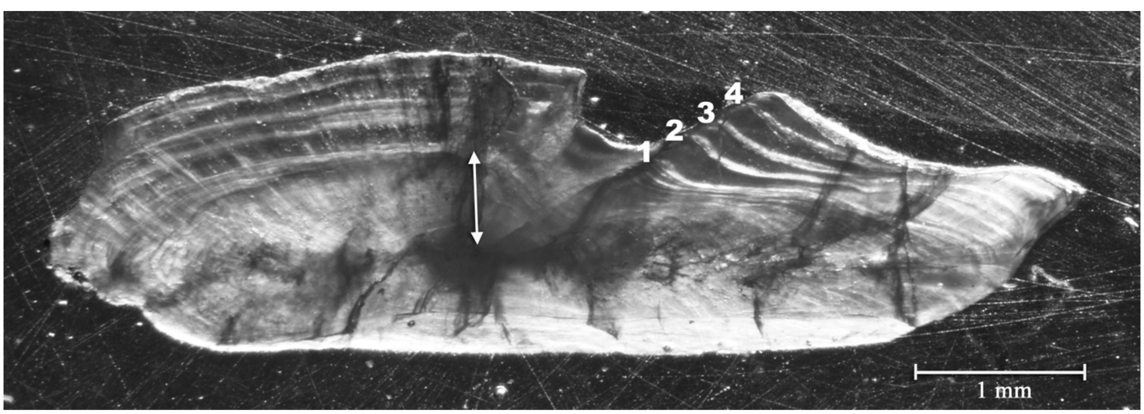


Figure 3. Arrow depicts the sulcal groove length (SGL) of an adult Nile tilapia (371 mmTL; 1021 g WW; SGL = 0.575 mm, 4 + yrs by annuli count). This measurement was used to calculate SGL ranges for YOY Nile tilapia. (Grammer et al. in review).

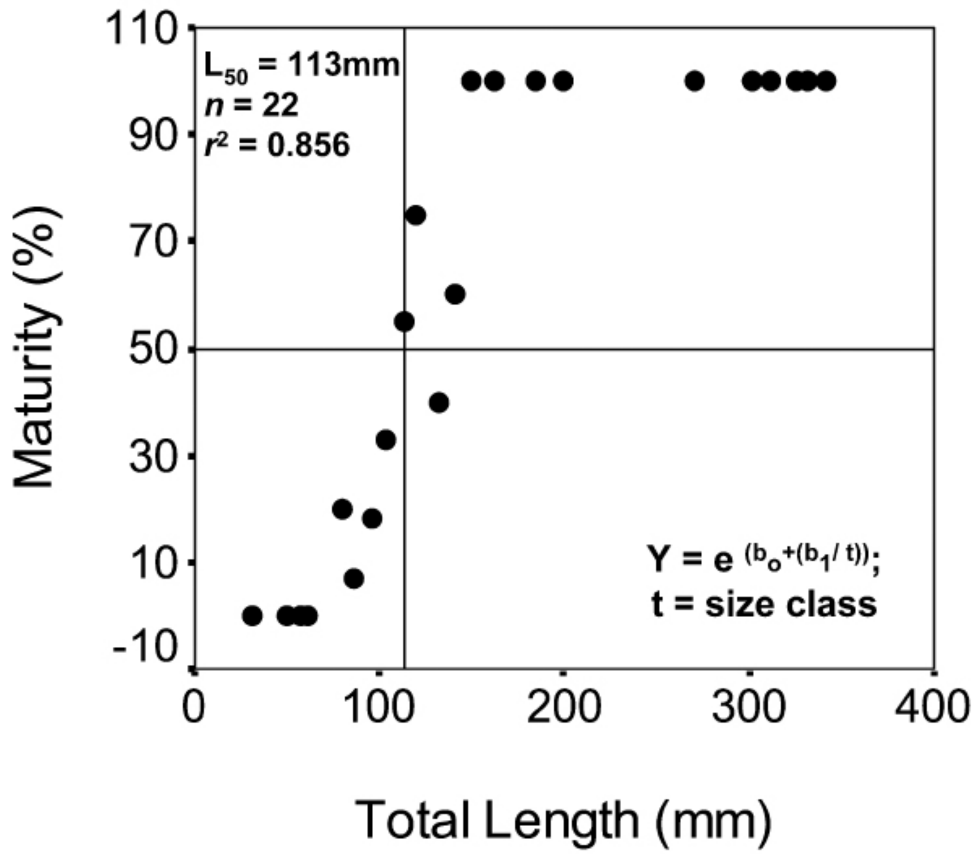


Figure 4. Plot of percentages of mature female Oreochromis niloticus (those with oocytes ≥ 1 mm diameter) by 10 mm TL size class. The TL where 50% of the individuals are mature (L50) equals 113 mm TL. (Peterson et al. 2004 with permission of Copeia).

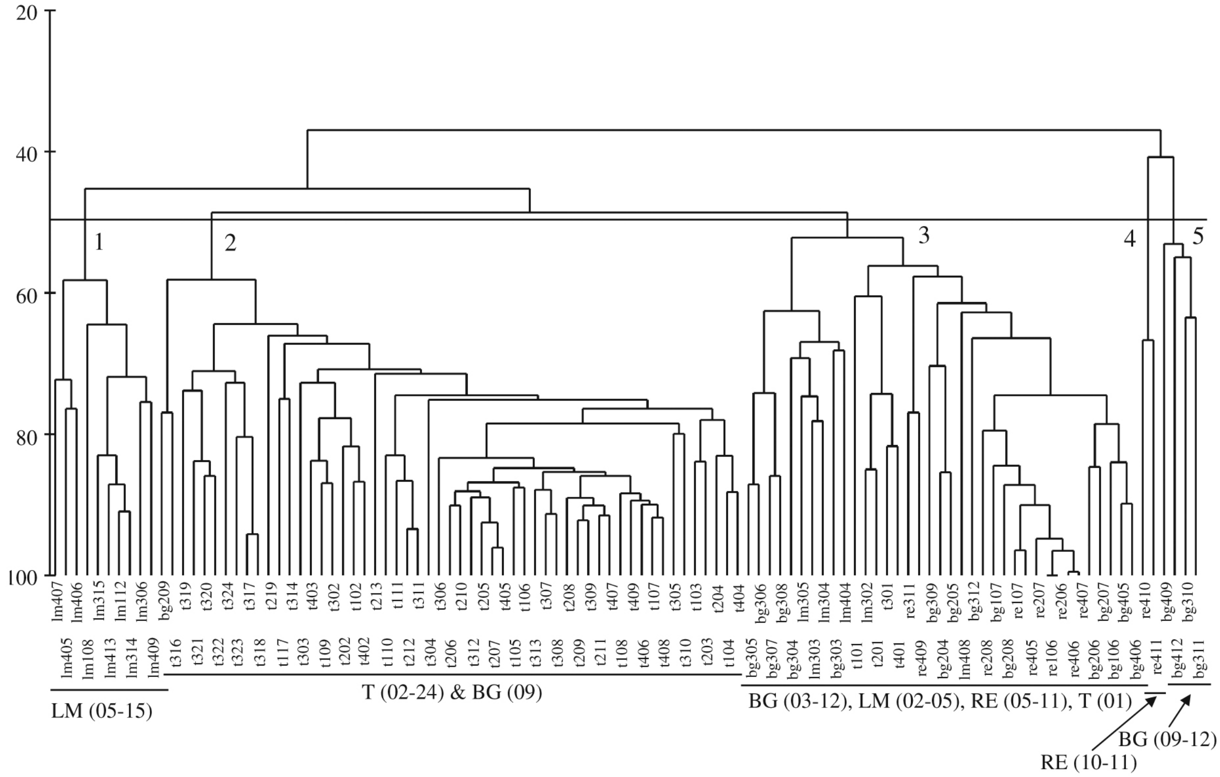


Figure 5. Plot of cluster analysis dendrogram based on Bray–Curtis similarity and group-average linkage of square root transformed species, season, and size class mean frequency of occurrence diet data. The solid horizontal line is the 50% similarity level allowing visualization of five upper level groupings labeled 1–5 on top of the figure. The codes at the bottom of the dendrogram reflect season and size class codes for the group of species below the horizontal line. For example, 310 = season 3 (spring) and size class 10 (131.01–150 mm TL). Season codes are 1 = fall, 2 = winter, 3 = spring, and 4 = summer. LM = largemouth bass, T = Nile tilapia, BG = bluegill, RE = redear sunfish. (Peterson et al. 2006).

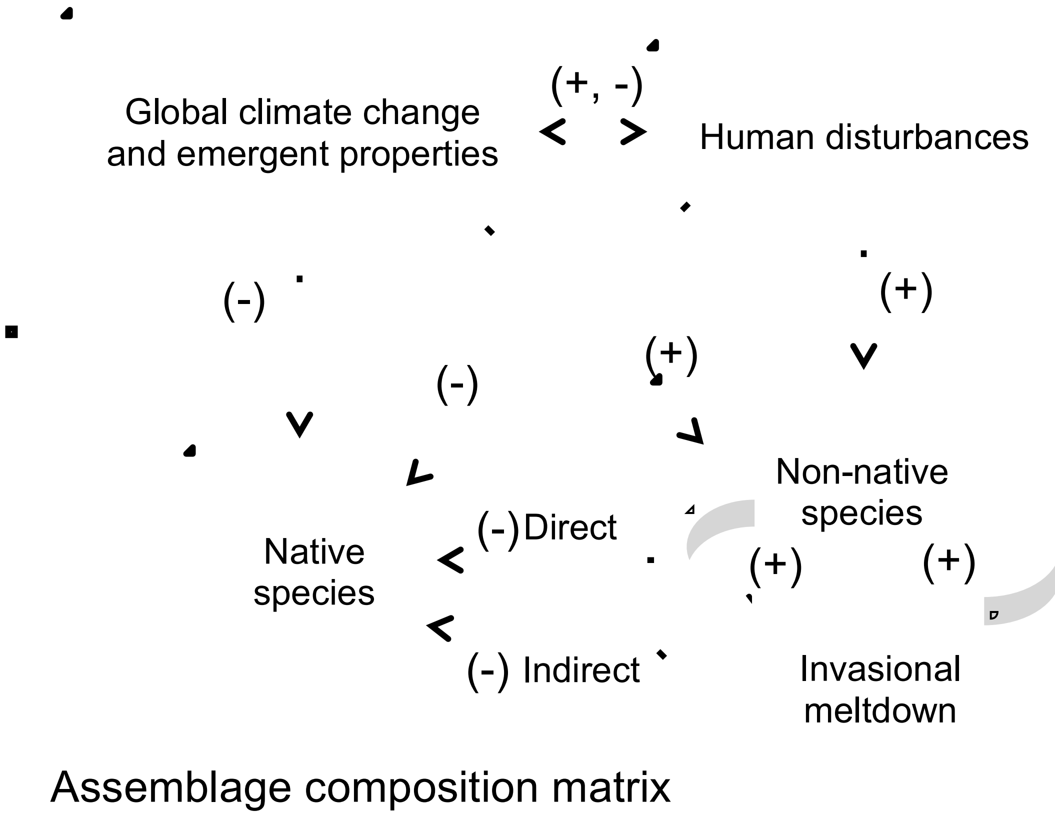


Figure 6. Conceptual model illustrating the potential linkages and impacts of global climate change and human disturbances on native and non-native species. Positive (+) and negative (-) impacts are denoted with each directional arrow. The resultant assemblage of aquatic organisms can vary spatially and temporally and will depend, in part, on whether the assemblage is observed early or late in the time sequence of invasion.

## TILAPIA AND AQUACULTURE: A REVIEW OF MANAGEMENT CONCERNS

*William T. Slack, PhD, U.S. Army Engineer Research and Development Center; Mark S. Peterson, PhD, University of Southern Mississippi*

**Abstract**

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 1990's 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.

# Tilapia and aquaculture: a review of management concerns

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# Basic Points

- Globally, tilapia are very important aquaculture species.
- 76% of the total worldwide production -- China, Philippines, Taiwan, Indonesia and Thailand.
- Within the United States, tilapia production has continued to grow since the early 1990's.
- Primary aquaculture forms -- *Oreochromis aureus*, *O. mossambicus*, *O. niloticus* (various hybrid combinations).

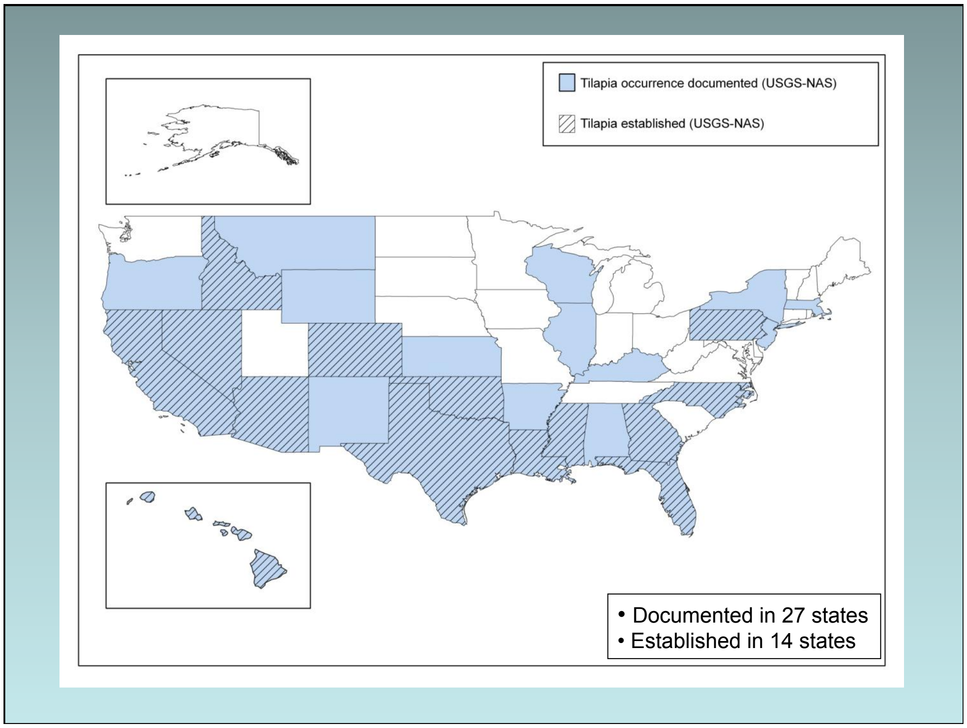
Objectives

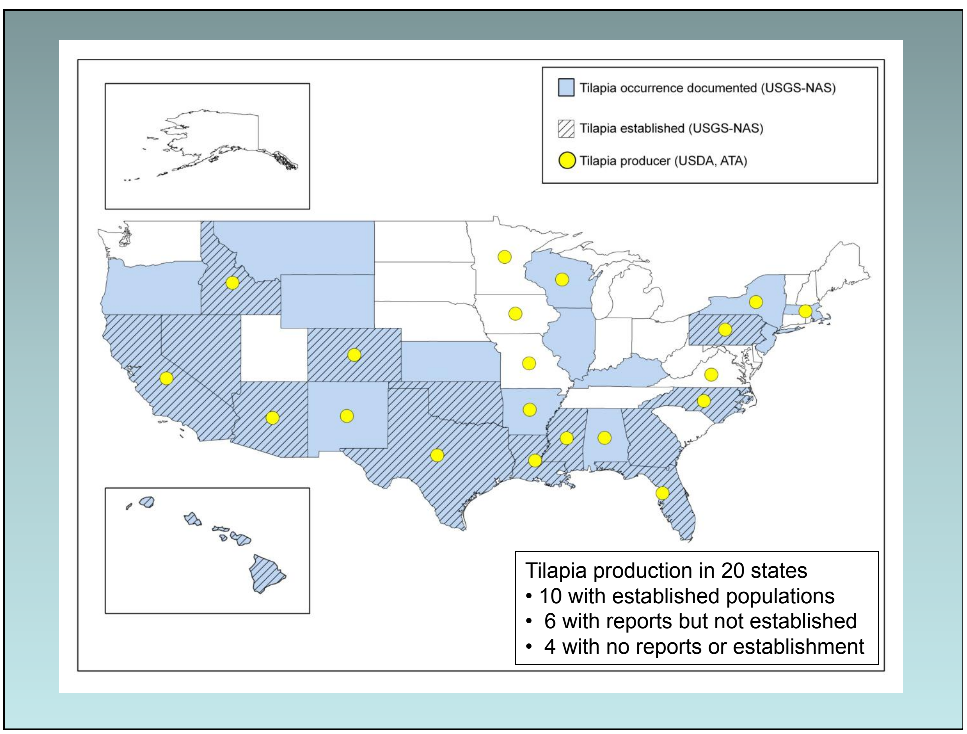
- Provide an overview of regulations regarding aquaculture and tilapia.
- Highlight management concerns.

Starting point -- Courtenay (1997) (Table 1)

- permit required to export non-indigenous species
- permit required to introduce non-indigenous fishes
- has restricted and/or prohibited list of fishes
- restricts tilapia

Courtenay, W.R., Jr. 1997. Tilapias as non-indigenous species in the Americas: environmental, regulatory and legal issues. Pages 18-33 in B.A. Costa-Pierce and J.E. Rakocy, eds. Tilapia Aquaculture in the Americas, Vol. 1. World Aquaculture Society, Baton Rouge, Louisiana, United States.

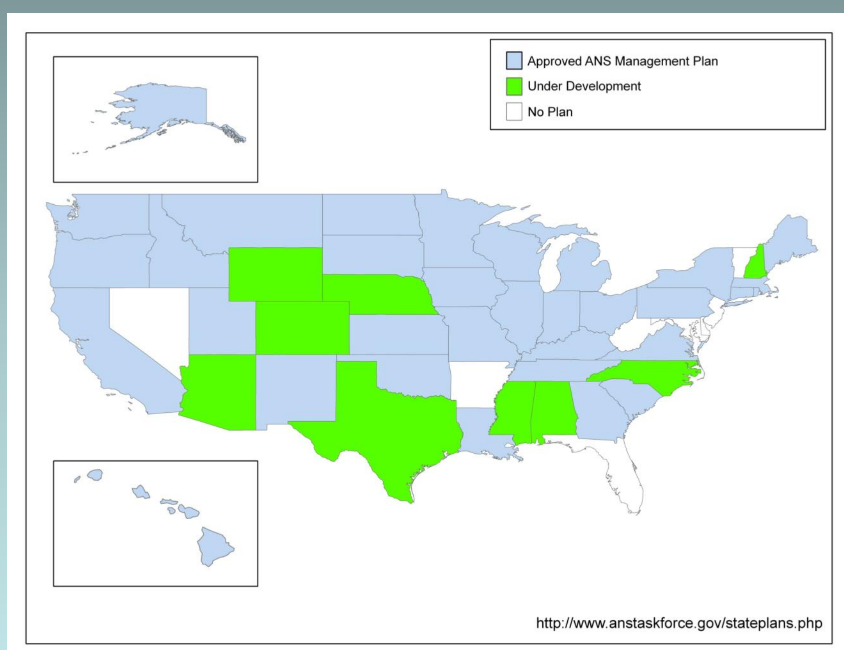

Tilapia occurrence documented (USGS-NAS)
Tilapia established (USGS-NAS)
• Documented in 27 states
• Established in 14 states

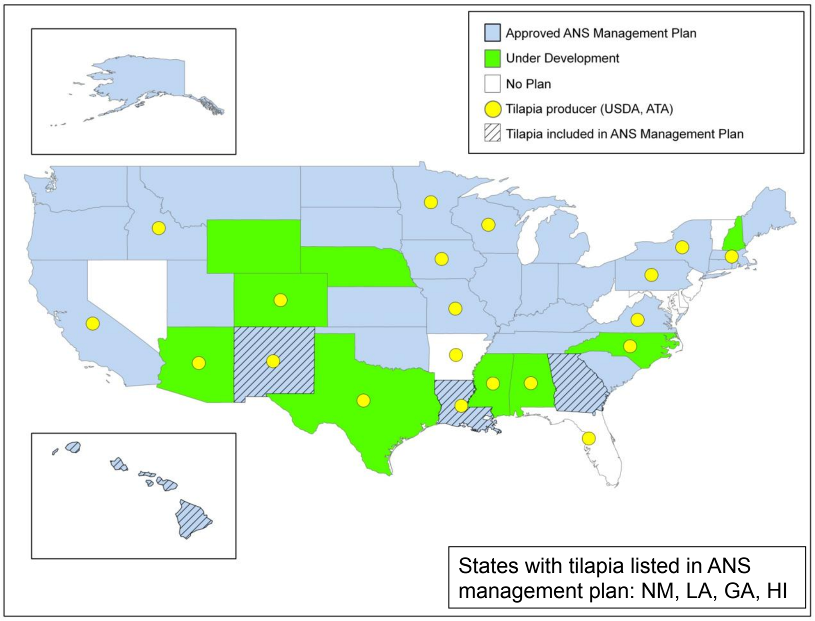

Tilapia occurrence documented (USGS-NAS)
Tilapia established (USGS-NAS)
Tilapia producer (USDA, ATA)
Tilapia production in 20 states
• 10 with established populations
• 6 with reports but not established
• 4 with no reports or establishment

# ANS Framework

- Lacey Act (1948 amendment)
  - provisions noted for injurious species
- Executive Order 11987 (Carter, 1977)
  - restrict introductions into federal land or waters; never implemented
- Non-indigenous Aquatic Nuisance Prevention and Control Act (NANPCA) (1990)
  - National Aquatic Nuisance Species Task Force
  - state and federal ANS management plans
- National Invasive Species Act (1996)
  - expanded NANPCA mandates
- Invasive Species Executive Order 13112 (Clinton, 1999)
  - formulated and empowered National Invasive Species Council

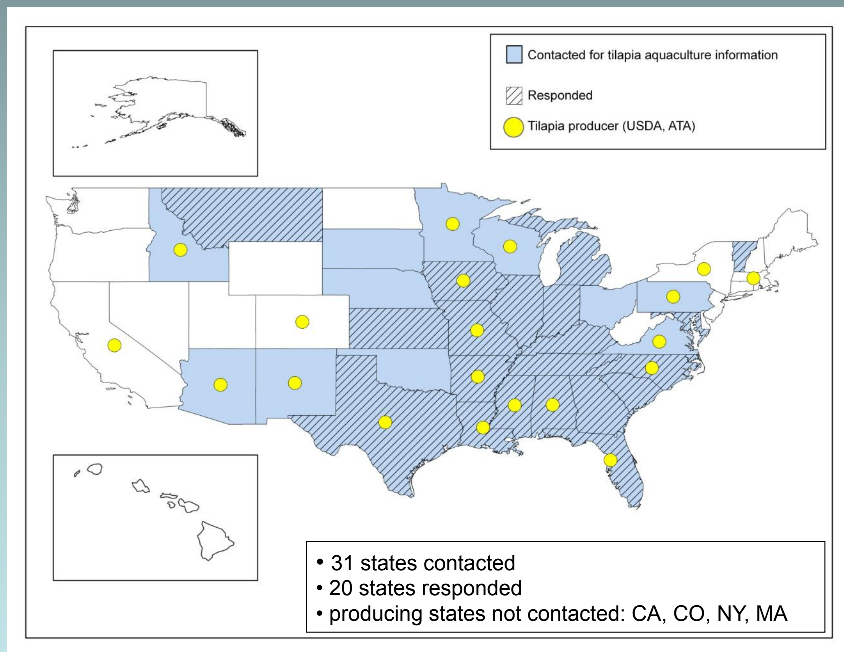
- Coordinate federal government agencies with private sector to prevent, control and manage non-indigenous aquatic species.
- States play the prominent role in regulatory authority for ANS.
- Gaps in state and federal regulations and enforcement authority creates a serious threat for national biodiversity as it relates to impacts from ANS (OTA-F-565, 1993).






# Aquaculture Survey

- Courtenay (1997) (Table 1)
    - permit required to export non-indigenous species
    - permit required to introduce non-indigenous fishes
    - has restricted and/or prohibited list of fishes
    - restricts tilapia
- Design -- informal email request for information
- Request
    - "…any information relating to specific regulations required by each state for facilities permitted to culture tilapia. For example, Mississippi (MDAC) requires effluent from aquaculture facilities be equipped with 1000 micron mesh screen to reduce the risk of escapement."
    - Special restrictions for tilapia aquaculture facilities?




# Survey Findings

Of the 20 states that responded:

•2 – no restrictions

•18 – some type of restriction placed on tilapia aquaculture facilities (e.g., approved list for aquaculture, permit required, facility restrictions)

- 7 – aquaculture activities are regulated but requirements were not specified (e.g., fuzzy language, bmp, biosecurity measures) or permitting dealt with on a case-by-case basis with no specifics noted in correspondence

- 11 – included specific requirements related to tank, pond and/or facility construction

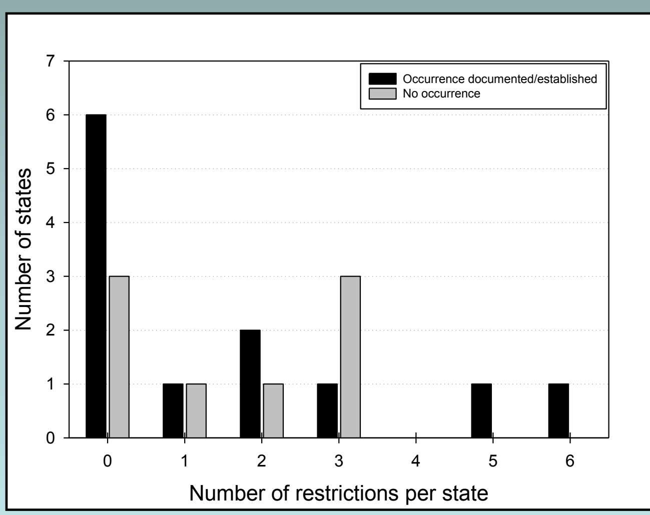
# Survey Findings

- Holding Requirements
  - (1) Levee/berm may be required around ponds and/or buildings
  - (4) Flood zone requirements (e.g., elevation specific-100 year floodplain, non-tidal areas)
  - (2) Indoor culture only
  - (4) Closed system only
    ** assumed pond culture allowed if other types were not designated (5)

- Facility Requirement
  - (9) Barriers/screens required to prevent escape including predation by birds and mammals
  - (7) Wastewater treatment specified (e.g., filtration, municipal treatment facility, discharge did not leave facility, cannot release effluent into public waters)
  - (1) Disease management screening (e.g., importation)
  - (2) Emergency plans for disaster (e.g., chlorination, desiccation)
  - (2) Liability insurance/bonding/agency reimbursement in case of release

- 12 states were specific in noting that it is unlawful to release or stock non-indigenous species in public waters

# Survey Findings




Documented in 12
Established in 6
Production in 7
Total: 19 restrictions
Mean: 1.58 per state
Range: 0-6

No tilapia in 8
Production in 2
Total: 12 restrictions
Mean: 1.5 per state
Range: 0-3

# Survey Findings

Louisiana (6) and Texas (5) were the most specific in their regulations regarding tilapia aquaculture, at least in terms of requirements for permitting and possession. Consider as templates for the development of guidelines for permitting recommendations.

** Regardless of geographic perspective, it is still somewhat alarming that some states continue to follow the perspective that winter water temperatures are too cold and thus escapees would be unable to overwinter and therefore threat of establishment is considered extremely low to non-existent.

# Recommendations

- Minimum:
  - Require integration of barriers on individual tanks, ponds and/or facility to reduce risk of escapement.
  - Incorporate wastewater treatment to prevent release of eggs, disease and/or fish from facility.
- Additional requirements:
  - Prohibit permitting in flood zones (i.e., coastal tidal zones, hurricane prone areas).
  - Require emergency management plans.
  - Require bonding/insurance for restitution in the case of release (force accountability for releases).
- Integrate use of global databases into the permitting process which includes management guidelines on basic fish biology, threats and potential of establishment if released (risk analysis) (*sensu* Canonico-Hyde, 2011; Casal, 2006; Molnar et al., 2008;Peterson and Slack, 2011 [AFS symposium]).
- Responsible aquaculture

Canonico-Hyde, G. 2011. Tilapias in aquaculture: the need for invasion science in decision making to protect and sustain biodiversity. Sustainable Fisheries: Multi-Level Approaches to a Global Problem, American Fisheries Society: 113-124.
Casal, C. M. V. 2006. Global documentation of fish introductions: the growing crisis and recommendations for action. Biological Invasions 8(1): 3-11.
Molnar, J. L., R. L. Gamboa, D. Revenga and M.D. Spalding. 2008. Assessing the global threat of invasive species to marine biodiversity. Frontiers of Ecology and the Environment 6(9): 485-492.

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ERDC Fish Ecology Team

USM – GCRL collaborators

## The Effects of Geoduck Aquaculture Practices on Habitat and Trophic Dynamics of Nekton and Macroinvertebrates in Puget Sound

*P. Sean McDonald, PhD, University of Washington; Aaron Galloway, University of Washington; Jenny Price, University of Washington; Kate McPeek, University of Washington; Dave Armstrong, PhD, University of Washington; Glenn VanBlaricom, PhD, University of Washington*

**Abstract**
Habitat complexity is known to enhance diversity and abundance by ameliorating interactions among competitors, by sustaining predator and prey populations, and by enhancing settlement processes and food deposition. Epibenthic structure may also provide refuge and foraging habitat for mobile macrofauna. In estuaries and nearshore areas, organisms undertake intertidal migrations to access littoral habitats at high tide. Previous studies have found higher abundances of fish and mobile invertebrates in littoral habitats characterized by structure relative to unstructured habitats. However, the trophic implications of these patterns have rarely been addressed.

In Washington State, commercial culture of geoduck clams (Panopea generosa) involves large-scale out-planting of juveniles to littoral habitats and installation of PVC tubes and netting to exclude predators and increase early survival. Nets typically consist of either small plastic mesh caps stretched over the opening of individual tubes or large continuous covers over entire plots. Placement of predator exclusion structures may affect a number of ecological processes that result in altered diversity and abundance of associated flora and fauna. Such disturbances can modify predation pressure and alter trophic relationships with consequences cascading through local food webs. We examined whether structures associated with this nascent aquaculture method affect patterns of use by mobile macofauna and modify trophic dynamics.

We summarized observations of mobile macofauna made during regular SCUBA surveys of aquaculture areas and reference beaches at three sites. These data indicate that structures attract mobile predators that feed on associated biota but exclude others that rely on soft-bottom benthic prey. Additionally, we synthesized several small studies of the food habits of Pacific staghorn sculpin (Leptocottus armatus) collected from geoduck aquaculture areas and adjacent reference beaches. Seines were used to capture fish on flooding and ebbing tides within structured and unstructured areas, and individuals from each of two size categories were retained and preserved. In the laboratory we extracted and identified gut content; prey were separated into broad taxonomic categories and common items were identified to the lowest taxonomic level. Comparisons were done using MANOVA for major prey types, followed by rank-transformed ANOVA for individual prey categories. Multidimensional scaling (MDS) was used to reveal shifts in diet among habitats. We found evidence that introduced structures alter predator-prey relationships from those found in unstructured littoral habitats and affect energetic tradeoffs for foraging predators. Our results highlight linkages within communities modified by the addition of epibenthic structure that should be considered in tideland management and conservation.

## AFS 2011

THE EFFECTS OF GEODUCK AQUACULTURE PRACTICES ON HABITAT AND TROPHIC DYNAMICS OF NEKTON AND MACROINVERTEBRATES IN PUGET SOUND

P.S. McDonald*, K. Armintrout, A.E.E. Galloway, J.L. Price, K. McPeek, D.A. Armstrong, and G.R. VanBlaricom

September 8, 2011

## Introduction

### Habitat complexity

- Natural complexity begets diversity
  - Enhances recruitment
  - Retains food, cycles nutrients, buffers physical stress
  - Mitigates predator/prey
- Aquaculture structure
  - Alters complexity
  - Effects on diversity and abundance highly variable

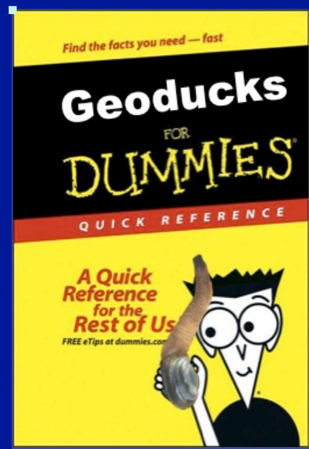


Photo credit: P. McDonald (upper); Wikipedia (lower)

# Introduction

## Geoduck aquaculture

- Native species
- Soft substrate; CA – AK
- Geoduck industry in WA
  - –$80 million market
  - –Major employer
- Heated debate
  - –Growers, NGOs & property owners





# Introduction

## Geoduck aquaculture

- Native species
- Soft substrate; CA – AK
- Geoduck industry in WA
  - –$80 million market
  - –Major employer
- Heated debate
  - –Growers, NGOs & property owners


Opposed property owners


Public meeting

Photo credit: Nogeoduckfarm.com (upper); Kitsap Sun (lower)

# Introduction

## Geoduck aquaculture

- Year 1: Planting
  - Placement of anti-predator structures
  - Out-planting of juveniles
- Years 2-5: Grow out
  - Removal/replacement of anti-predator structures
- Years 5-7: Harvest
  - Liquefaction of sediment
  - Extraction of geoducks

Photo credit: P. McDonald

# Introduction

## Geoduck aquaculture

- Year 1: Planting
  - Placement of anti-predator structures
  - Out-planting of juveniles
- Infauna study
  - Ongoing SG project
- Novel habitat created
  - Observed changes in epiflora/epifauna and macroinvertebrates



Photo credit: P. McDonald

# Questions

1) Does geoduck aquaculture affect patterns of habitat use by fish and macroinvertebrates?

2) Does geoduck aquaculture affect trophic dynamics and energetics of foraging predators?

# Study sites

**Study sites**

- Culture & reference plot
  - Similar habitat characteristics
- Macrofauna surveys (▲)
  - Monthly/bi-monthly sampling
- Diet study (●)
  - Synoptic gut sampling
- Trophic link study (■)
  - Mark-recapture
  - Stable isotope analyses

# Macrofauna survey - methods

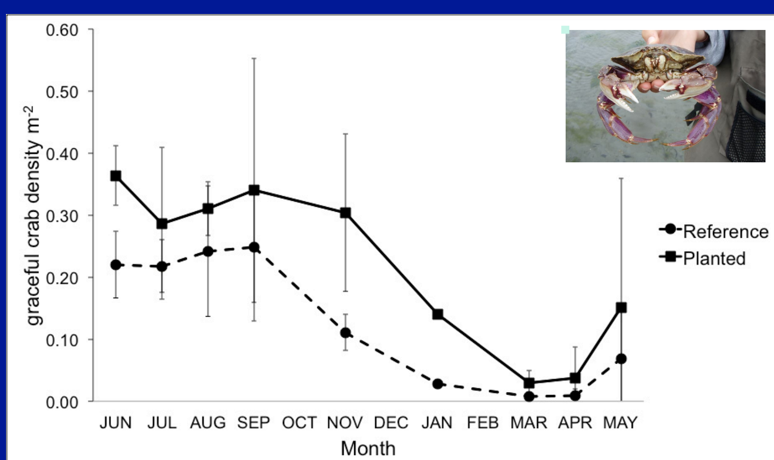
**SCUBA at high tide**

- 45-m transects
  - Planted and reference
  - Summer: monthly/ Winter: bi-monthly
- Metric Underwater Transect Tool (MUTT)
- Variables recorded:
  - Species ID, #, size
  - Habitat photos



Photo credit: G. Jensen (upper); J. Eggers (lower)

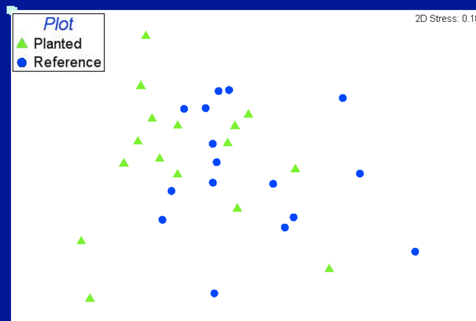
# Macrofauna survey - results



# Macrofauna survey - results

## Multivariate Analysis

- ANOSIM
  - No site effect
  - Aquaculture effect (Global R=0.24; p<0.001)




- SIMPER

| | |
|---|---|
| graceful crab: | 19.49% |
| shiner perch: | 16.29% |
| kelp crab: | 11.41% |
| blackeyed hermit: | 10.56% |
| Speckled sanddab: | 8.68% |

- Habitat associations

# Macrofauna survey - results

## Multivariate Analysis

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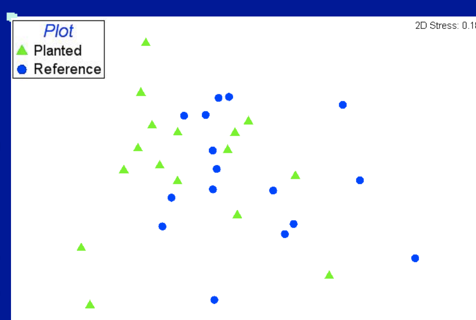


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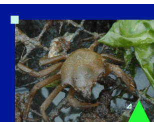

- Habitat associations

Photo credit: L. Thomson (left, middle); P. McDonald (right)

# Macrofauna survey - results

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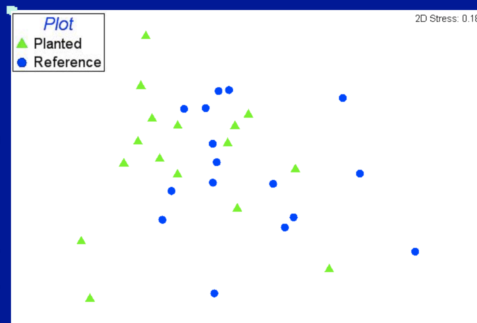


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- Habitat associations

Photo credit: L. Thomson (left, middle)

# Diet study - methods

## Staghorn sculpin

- Ubiquitous predator
  - Coasts, estuaries, brackish waters
- Broad diet
- Affects commercially important species
  - Dungeness crab (Armstrong et al. 1994)
- Variety of habitats

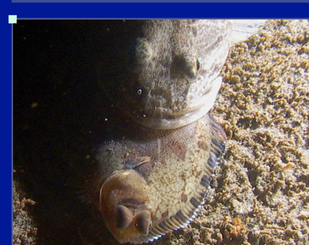



Photo credit: M.Gieselman (upper) & R. Anderson (lower)

# Diet study - methods

## Food habits

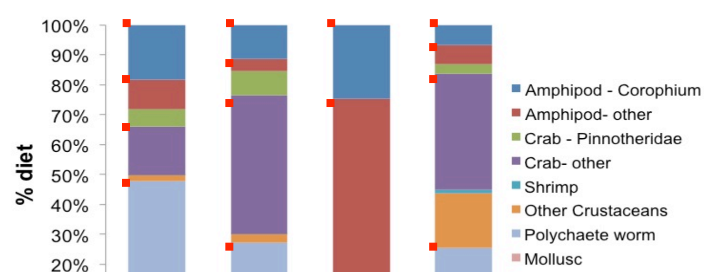
- Field collection
  - 10 m Pole seine
  - Planted and reference
  - Small (70-90 mm TL) and large (90-110 mm TL)
- Lab extraction
  - ID to lowest taxon & weighed
  - Multivariate analysis



Photo credit: K. Larson (upper); P. McDonald (lower)

# Diet study - results

## Diet data




# Diet study - results

## Multivariate Analysis

- ANOSIM
  - Site effect (Global R=0.12; p<0.001)
  - Aquaculture effect (Global R=0.13; p<0.001)
- Variability in aquaculture diet
- SIMPER

| | |
|---|---|
| amph-*Corophium*: | 22.14% |
| amph-other: | 17.82% |
| Crab-other: | 14.59% |
| polychaetes: | 11.71% |

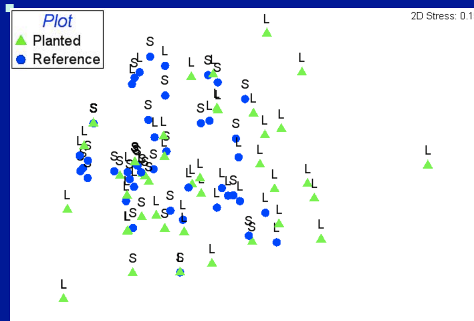



Photo credit: M. Clapp (left); L. Harris (right)

# Diet study - results

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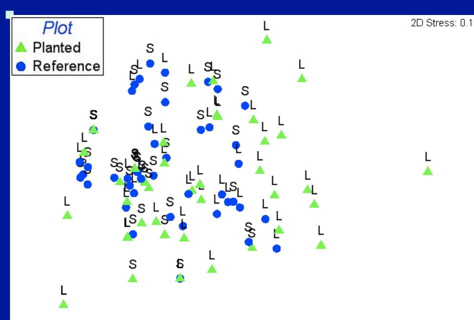



Photo credit: L. Thomson (left, middle); P. McDonald (right)

# Trophic study - methods

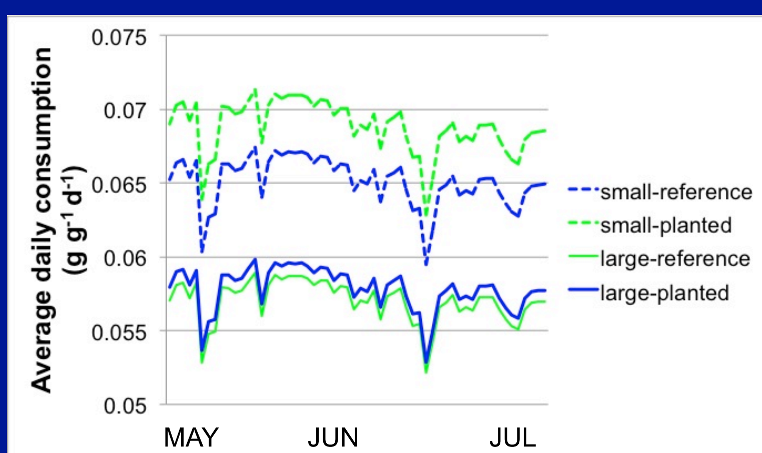
**Predator-prey links**

- Infauna/epifauna prey abundance
- Mark-recapture
  - Site fidelity
  - Growth data
- Stable isotope analyses and bioenergetics models



Photo credit: P. McDonald (upper); K. McPeek (lower)

# Bioenergetics- results



## Summary

- Geoduck aquaculture affects fish and macroinvertebrate diversity and abundance.
  - Typical pattern favors structure-associated species
- Diets of fish captured in aquaculture habitat reflect "structure-specific" prey types.
- There is some evidence that fish experience trade-offs between prey quality vs. quantity or quality vs. refuge.

## Implications

- "Semi-intensive" bivalve aquaculture affects diversity of fish and macroinvertebrate community
- Results will inform managers concerned with permitting future geoduck aquaculture sites
- Trophic relationships should be considered, particularly where aquaculture is expanding.

# Acknowledgements


- Funding Source
  - WA State Legislature
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  - Kent Kingman
  - Tom Bloomfield
  - Steve Bloomfield
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  - Jeff Fisher
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