CRMC Working Group on Aquaculture Regulations

Subcommittee on Biology
Report on Biological Impacts of Aquaculture

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Preface

In its early deliberations, the CRMC Working Group on Aquaculture Regulations decided that a scientific review should be done to provide science-based information on the limits to aquaculture development in Rhode Island. Particular areas selected by the Working Group for consideration were: Water Quality, Diseases, Invasive Species, Physical Impacts of Aquaculture Gear, Essential Fish Habitat, and Carrying Capacity. We also wanted input on an Ecosystem Approach to Aquaculture. Members of the Working Group who volunteered to contribute to this effort took on the title "Subcommittee on Biology". The intent of the Subcommittee has been to broadly summarize the state of knowledge in the above areas and to bring forward recommendations to the full Working Group. The first draft of the report was presented in September 2007 and comments were received from the Working Group at the October 2007 meeting. The final report was approved by the full Working Group at the January 2008 meeting.

Executive Summary

A considerable amount of information exists from around the world on aquaculture operations and their relationship to the environment. Farming of fish in pens and shrimp in ponds can have significant detrimental environmental effects, usually restricted to the area right around the operation. Thus, any attempt to raise fish in Rhode Island's open waters will require extreme scrutiny. On the other hand, the shellfish aquaculture practiced in Rhode Island is most likely beneficial for the environment, for a number of reasons. Oysters filter phytoplankton from the water, thereby allowing light to penetrate deeper so that submerged aquatic vegetation (SAV) can grow from the bottom. In doing so, they also remove nutrients from the water and can help ease the eutrophication problems in Rhode Island's estuaries. Oyster operations also provide refuges for the juvenile stages of several species of popular fish. The physical presence of shellfish aquaculture in Rhode Island waters has an impact on the natural environment. The question is whether that impact is acceptable to ecosystem structure and function and, by extension, to a Rhode Island public that does not want to see our estuaries degraded. We have made our best attempt to answer that question, but the process of doing so has allowed us to identify areas for which more information is clearly needed. For example, does oyster aquaculture hinder or help the winter flounder populations? In the areas of disease and invasive species, we need to remain vigilant in our monitoring and to develop practices and technologies that will minimize damage to the existing shellfish industry from these factors. There has been no evidence that shellfish aquaculture (as practiced in Rhode Island) is having negative environmental impacts and little reason to believe that further modest growth will have negative impacts in the future. Even in states where shellfish aquaculture is far more widespread there is little evidence that the impacts have been anything other than positive.

From a biological and ecological perspective, the really critical question is: what is the maximum amount of shellfish aquaculture that can occur in a given water body without unacceptable ecological impact to that body of water? This amount is a calculable quantity called the <u>ecological carrying capacity</u>. Ultimately, we need to take an ecosystem approach and determine the real ecological carrying capacity for Narragansett Bay, the coastal ponds, and other Rhode Island waters. To fully define that capacity for each water body is a task that will require much more information and work than we are able to provide here. One of the recommendations is to seek funding to do that type of work. Meanwhile, we rely on work that was done in New Zealand to estimate carrying capacity for shellfish culture there. Adapting the New Zealand work to Point Judith Pond as a representative coastal pond, we calculate that the carrying capacity of the pond for shellfish aquaculture is approximately 5% of the pond's area. We recommend that number as our scientifically defensible best estimate for the moment, with the realization that better estimates could be available in the future with better data and site-specific modeling efforts.

Recommendations

1. Limit shellfish aquaculture to no more than 5% of the area of any water body until specific estimates for Rhode Island waters can be generated with site-specific data.

2. Seek funding to investigate the ecological carrying capacity of estuaries in Rhode Island for aquaculture and to investigate the interaction of shellfish aquaculture with native species.

3. Establish a single interdepartmental advisory board that would be in charge of providing recommendations for the regulation and management of infectious diseases in wild and cultured populations of aquatic organisms.

4. Provide funding and mechanisms for assistance in the form of disease monitoring for aquaculture and wild harvest industries, extension personnel and develop a rapid-response plan for the outbreak of disease.

5. Rhode Island should a) continue to participate in a region-wide Northeast ANS Panel, to ensure that regulations and management of ANS introductions are uniform throughout the region and that all states are in compliance with whatever strategies are in place, b) undertake an aggressive outreach and education program to teach the general public about the risks associated with the introductions of exotic species, and c) utilize the guidelines provided by the ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2004 if intentional introductions are proposed in the state.

6. In considerations of aquaculture siting, continue to provide special protection for eelgrass habitat and native species.

7. Encourage growers, researchers and regulators to conduct studies to determine optimal stocking densities to maximize growth and minimize potential negative impacts; specifically, to monitor a) water column dissolved oxygen and phytoplankton abundance, and b) sediments for excessive organic enrichment and benthic oxygen demand.

Chapter 1
Water Quality

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Summary
Water quality is technically defined by a suite of physical and chemical characteristics. In Rhode Island, the RI Department of Environmental Management enforces federal water quality regulations. High-density aquaculture, including finfish, shrimp and molluscan aquaculture operations, has been shown to have detrimental impacts on water quality in certain areas of the world. Shellfish aquaculture, as practiced in Rhode Island, has not been shown to have detrimental impacts and in fact can be beneficial to water quality by removing excess nutrients.

Components of Water Quality – Although we may think of "water quality" as a single concept (is it good or bad?), water quality is made up of several components, defined below. In an ecological or aquacultural context, these components all contribute to the suitability of the water for habitation by species of plants and animals. Thus, water quality is, in turn, one component of essential fish habitat (cf. Murphy and Wood report in this document). While a single water quality component may be enough to make the water unsuitable for a given species, many of the components of water quality are interrelated (e.g., dissolved oxygen saturation levels decrease with increasing temperature), so suitability is often a question of multiple components considered simultaneously. The following definitions or explanations of water quality components are taken from Avault (1996):

1. **Temperature** – no definition needed, but Rhode Island coastal waters are characterized by large annual fluctuations in temperature; thus we may have very different biological communities in winter vs. summer and many fish move inshore and offshore depending on season.
2. **Salinity** – the total concentration of dissolved solids in seawater, ranging from 0 psu (practical salinity units) for fresh water to about 35 psu in full seawater. Many organisms that live in estuaries can exist in a wide range of salinities due to the salinity fluctuations with the tides.
3. **Dissolved oxygen** – as the term implies, the quantity of oxygen gas that can be dissolved in water, usually reported as milligrams per liter (mg/L) or parts per million (ppm), and referred to as DO. Temperature and salinity both affect the amount of DO that water is capable of holding at saturation. Demands on oxygen in the water and sediments include those for animal and plant respiration as well as chemical reactions. Plants of course produce oxygen via photosynthesis.
4. **Free carbon dioxide** – analogous to dissolved oxygen, the amount of carbon dioxide gas dissolved in water, usually reported as ppm. Plants take up carbon dioxide during photosynthesis and it is quite rare that CO_2 levels rise high enough to affect organisms in the natural environment or even in an aquaculture setting, particularly in marine

aquaculture where seawater has a high buffering capacity due to the formation of carbonates from dissolved CO_2.

5. **Alkalinity** – the sum of exchangeable bases reacting to neutralize acid when acid is added to water. This is due primarily to bicarbonate, carbonate, and hydroxide ions and provides a buffering system to reduce fluctuations in pH. Because seawater has such high levels of these ions, alkalinity is much less of an issue in seawater than in freshwater.
6. **pH** – an index of hydrogen ion activity. A pH of 7 is neutral, lower than 7 is considered acidic, and higher than 7 is considered basic or alkaline. The pH of seawater is about 8.
7. **Ammonia** – Un-ionized ammonia (NH_3) is toxic to organisms in high enough concentrations, whereas ammonium (NH_4^+) is generally unable to cross tissue barriers. Ammonia is excreted by aquatic organisms, is a product of decomposition of organic matter, and may be discharged into waters from terrestrial sources. Bacteria in the environment transform ammonia into nitrite and then into nitrate. All of these may be used as nutrients by plants in the environment.
8. **Suspended and settleable solids** – particles of various sizes that remain suspended in water (usually fine particles, often referred to as turbidity) or settle out quickly (larger particles). These can be produced by aquaculture facilities as a result of feeding or production of fecal matter, and are also produced by organisms living naturally in the environment, by inputs from land-based runoff, etc.
9. **Hydrogen sulfide** – produced by the anaerobic decomposition of organic matter and normally found only in sediment (the "rotten egg" smell that one gets from digging in mud). It can be toxic to organisms.
10. **Heavy metals** – these are normally present in the environment and in organisms in very small quantities and are necessary for life; however, inputs to the environment from industrial source can often elevate them to toxic levels.
11. **Organic pollutants** – substances like pesticides, chlorinated hydrocarbons (e.g., PCB's), etc. result from anthropogenic inputs and can be quite toxic. Due to federal regulations, both organic pollutants and heavy metals are currently being added to the environment in very low, non-toxic quantities

<u>Regulation of water quality</u> – As a result of the Clean Water Act, the U.S. Environmental Protection Agency (EPA) has regulated discharges that could reduce water quality in U.S. fresh and salt waters. EPA issues Water Quality Criteria (WQC) that are based on an analysis of all the scientific studies conducted on a given pollutant, primarily heavy metals and organic pollutants. These are typically used in writing permits for discharges by industries and municipalities. EPA has also produced a WQC for dissolved oxygen that is used in the calculation of Total Maximum Daily Load (TMDL) of discharges, based on the concept that the decomposition of organic material discharged into the environment will use up dissolved oxygen. EPA has a long history of regulating discharges that are considered "point source", that is, coming from a single point, like the end of a discharge pipe. The regulation of non-point sources has been much more of a problem because the source is so diffuse and difficult to regulate (e.g., runoff of nutrients from farms). In Rhode Island, U.S. EPA has delegated regulation of water quality to RI DEM.

Background on water quality and marine aquaculture – The impacts of marine aquaculture on water quality have been well documented around the world and are generally local in nature, i.e., affecting the area quite close to the farm(s) (Gowen and Bradbury, 1987; Silvert, 2001). The culture of fish in net pens can have several adverse impacts. The fish crowded in pens take up oxygen at a rather high rate from water flowing through the pen (Silvert, 1992; Wildish et al., 1993). Because the organisms most affected by this are the fish themselves (i.e., they grow less when oxygen is sub-optimal), proper siting of pens in locations with good currents for adequate oxygen replacement becomes paramount (Lumb, 1989; Black and Truscott, 1994). Excess fish feed and fish feces that constitute settleable solids sink below the cage; if sufficient currents are not present, the material builds up below the cage and decomposition of this organic matter also consumes oxygen and results in ammonia production (Brown et al., 1987). In extreme cases, an anaerobic pile of decomposing matter below the pens can produce outgassing (eruption of bubbles) of hydrogen sulfide and methane into the water (Black et al., 1996). Again, the organisms that suffer most are the fish in the pens through which the bubbles pass on their way to the surface. Another major impact on impact of fish in pens is ammonia production (Aure and Stigebrandt, 1990; Silvert 2001). Fish excrete ammonia via their gills, which diffuses into the water. Even with minimal current flow, the amount of ammonia produced is rarely sufficient to have any toxic impacts on the fish or surrounding organisms, but does serve as a source of nutrients for algal blooms (Wildish et al. 1993). In recent decades, much suspicion has arisen regarding the contribution of fish farms to blooms of harmful (toxic) algae (Silvert, 2001). Finally, fish farmers use chemicals and/or antibiotics to treat diseases of fish in net pens (Grave et al., 1990; ICES, 1994). The use of antibiotics has declined substantially in recent years due to vaccination programs for fish, but chemicals are still used to treat sea lice in salmon, an external parasite (Black et al. 1997). Studies of this chemical usage have concluded that the concentrations involved are not likely to have an adverse impact on the surrounding environment (Davies et al., 1997, 1998; Burridge et al., 2000 a, b). Also, the nets used in the pens may contain heavy metals to ward off fouling organisms and these metals leach into the water when the nets are new; again, the concentrations of metal in the water are likely to not have an adverse impact on the environment (Balls, 1987).

Shrimp aquaculture mostly takes place in tropical coastal ponds and has also had several impacts on the environment (Clay, 2001). Because fresh water from wells is often used to control salinity in the ponds, release of water from the ponds can alter salinity in estuaries that receive the effluents. Those effluents typically also contain ammonia produced by the shrimp, suspended and settleable solids from the ponds, and any chemicals or antibiotics that may have been used in the ponds. The extent of damage done to the environment depends on the amount of effluent relative to the flushing rate of the estuary receiving the effluent. Over the last several decades, shrimp aquaculture progressed from a low-density operation with few organic inputs (like feed) to high-density culture with much added food, fertilization of the water and frequent water changes to counter the rapid build-up of ammonia (Browdy and Hopkins, 1995). Many efforts are currently underway to try to reduce the environmental impacts of shrimp culture (Hopkins et al., 1994, 1995; Clay, 2001).

Molluscan aquaculture is quite benign compared to fish and shrimp culture. Because no organic inputs like feed are added (the mollusks filter their feed directly from the water), the impacts on the environment are much reduced, in terms of decomposition, etc. Mollusks concentrated on a farm still consume oxygen, produce carbon dioxide, and produce ammonia as an excretory product, so there is clearly some impact, the extent of which depends on flushing of water around the farm. In the 1980's, several studies of extremely concentrated mussel farms (e.g., 120,000 MT annual production in the Ria de Arosa in Spain) showed that the deposition of feces and pseudofeces directly under the farms could overwhelm the ability of the environment to assimilate and transform those natural wastes coming from the mussels (Dahlbäck and Gunnarsson, 1981; LaPointe et al., 1981;Tenore et al., 1982; Kaspar et al., 1985; Kautsky and Evans, 1987). The result was an anaerobic environment similar to those under fish net pens. There has been no corresponding demonstration of negative results for oyster or clam culture. The only known instance of chemical contamination resulting from molluscan culture is the use of a pesticide (carbaryl) by oyster farmers in Washington on the tidal flats to kill burrowing shrimp that can harm the oyster cultures (Simenstad and Fresh, 1995).

Molluscan culture is usually considered the most beneficial form of aquaculture for the environment, because mollusks filter material from the water. Much of that material is phytoplankton, which has used nutrients in the water to grow. Thus, in eutrophied estuaries, i.e., those characterized by excessive nutrients, molluscan aquaculture can be quite beneficial because the mollusks transform the organic (plant) production resulting from those nutrients into animal tissue that can be removed and consumed by humans. Using published data on filtering rates of various molluscan species, several authors (Newell, 1988; Rice, 2001, etc.) have calculated the amount of water that is filtered by a large population of mollusks, either naturally occurring or in aquaculture farms, and have shown the role that these mollusks can play in removing nutrients, especially nitrogen (N) from estuarine waters. By filtering phytoplankton from the water, mollusks increase the amount of light that reaches the bottom, providing increased opportunities for submerged aquatic vegetation to grow (Newell, 2004).

One can argue that much of the nitrogen that the mollusks take up is released back to the environment either as excreted ammonia or in the pseudofeces that are deposited on the bottom. Pietros and Rice (2003) studied oyster impacts on water column nitrogen levels and sedimentation rates using mesocosms at the University of Rhode Island. They found that, although oysters clearly excrete ammonia, ammonia levels in oyster tanks were not significantly higher than those in control tanks without oysters, suggesting that the ammonia is quickly taken up by phytoplankton as a nutrient source. They also found that oysters significantly increased rates of sedimentation to the bottoms of the tanks and altered the phytoplankton composition in the tanks (presumably because of selective feeding on one particular phytoplankton species). Newell (2004), in an excellent review article, pointed out that oysters are one of the mollusk species particularly useful in clearing phytoplankton from the water column because they continue to feed even when food concentrations are high and they presumably have enough food. The excess, undigested phytoplankton (along with other less digestible particulate matter) is incorporated into pseudofeces that sink more quickly to the bottom than would the phytoplankton particles themselves. The fate of the nutrients, especially the organic nitrogen, in the sediment depends to some degree on the amount of sedimentation in relation to the absorptive capacity of the benthic microbial community to break down the organic material. Under normal conditions, aerobic bacteria will decompose that material into ammonia, which enters the process of nitrification to be converted to nitrite and nitrate, which in turn can be used as nutrients for benthic algae, submerged aquatic vegetation, or phytoplankton (if resuspended into the water column). In addition, deposition of organic nitrogen to the sediments may increase denitrification. Denitrification is the process by which nitrate or nitrite is converted to nitrous oxide or free nitrogen (N_2). The process can be completed by either aerobic or anaerobic bacteria and production of free nitrogen in particular represents a way by which nitrogen can be fixed by plants or returned to the atmosphere as nitrogen gas. Newell et al. (2002) studied nutrient regeneration in a laboratory experiment using bivalve biodeposits and found that 17-24% of the sediment nitrogen was released to the atmosphere as nitrogen gas (in the absence of light) or that most of the nitrogen was fixed by benthic algae (in the presence of light); in either case, substantial amounts of nitrogen were not released back to the water column as nutrients for phytoplankton. On the other hand, if conditions are not normal (e.g., excessive amounts of organic material deposited if aquaculture densities are too high), anaerobic processes come into play once the deposited material exhausts the oxygen available for aerobic decomposition. In this case, the water above the sediments can become anoxic and ammonia, hydrogen sulfide and methane can be released into the water column. Again, the critical aspect is the rate of deposition of organic material to the sediments compared to the rate at which the bacteria there can process that material, in particular the nitrogen (cf. Rheault report on carrying capacity in this document).

Recommendation: A program should be developed to monitor DO, phytoplankton abundance and benthic oxygen demand to determine whether aquaculture farms are exceeding appropriate stocking densities.

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Chapter 2
Disease Considerations for the Rhode Island Aquaculture Plan

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Summary

Infectious diseases are a major threat to wild and cultured populations of marine organisms. Due to the potential catastrophic effect of diseases, and because disease does not distinguish between farmed and wild populations of marine organisms, several international, federal, and state agencies have established regulations geared to minimize the risk of the introduction of new pathogens to an area and the spread and impact of diseases in those areas where diseases are already present. In Rhode Island, regulations regarding the importation of shellfish are included in the Department of Environmental Management "Aquaculture of Marine Species in Rhode Island Waters" and the Coastal Resources Management Council (CRMC) aquaculture regulations. These regulations are routinely evaluated by the Rhode Island CRMC Biosecurity Board, an advisory group composed of representatives from state agencies, scientists and health specialists, extension agents, the aquaculture and fishing industries, and groups involved in restoration projects. The state uses available information on the distribution and prevalence of disease in bivalve populations, available through monitoring programs, to regulate the transfer of cultured shellfish within Rhode Island waters and to provide farmers with recommendations on how to best manage disease. Effective management should include monitoring programs, knowledge of the biology of the shellfish and their pathogens, awareness of the environmental conditions that trigger disease outbreaks, establishment of a plan outlining procedures on how to report and manage disease outbreaks, and access to the most recent tools available to manage disease, such as disease-resistant strains. Any plan regulating aquaculture in Rhode Island should include those elements.

Introduction – The impact of diseases on marine organisms

Infectious diseases are one of the major threats to wild and cultured populations of marine organisms. In examples relevant to the important role of oysters, hard clams, and lobsters in Rhode Island's fishery and aquaculture industries, the diseases commonly known as dermo, multinucleated sphere unknown (MSX), Juvenile Oyster Disease (JOD), quahog parasite unknown (QPX), have caused hundreds of millions of dollars in losses to the oyster and clam fishing and culture industries in the Atlantic Coast of the United States, including the Northeast (Ford & Tripp 1996). Recently, populations of lobsters in Rhode Island have been severely impacted by shell disease (Castro & Angell 2000).

Marine organisms and their pathogens constitute a complex and evolving ecosystem heavily influenced by natural and anthropogenic factors (Harvell et al. 1999b, Harvell et al. 2002). The vast majority of cultured marine organisms (like salmon, cod, tuna, oysters, and clams, just to name some favorites of US consumers) are raised in "open systems" (*i.e*. cages and netpens) placed in the marine environment, exposed to a complex and changing milieu of microorganisms, interacting with wild populations of marine organisms, and in environmental conditions that cannot be controlled. Disease outbreaks in cultured populations can spread to wild populations (Skall et al. 2005, Nowak 2007) and wild populations serve as reservoirs for aquaculture pathogens (Samuelsen et al. 2006). Furthermore, climate change now threatens to promote ecosystem instability and the emergence of new diseases that affect marine species (Harvell et al. 1999). Rising ocean temperatures are expected to expand the geographic range of familiar pathogens and cause more frequent outbreaks (Colwell 1996). Indeed, marine diseases already appear to be on the rise (Harvell et al. 1999).

Who is responsible for the management of diseases of aquatic organisms?

Due to the potential catastrophic effect of diseases, and because disease does not distinguish between farmed and wild populations of marine organisms, **several international, federal, and state agencies have established regulations geared to minimize the risk of the introduction of new pathogens to an area and the spread and impact of diseases in those areas where diseases are already present.** Most of these regulations target the aquaculture industries since wild populations are not under any effective control that would allow such activities.

Effective aquatic animal health management requires a cooperative effort between state and federal agencies, scientists and health specialists, extension agents, the aquaculture and fishing industries, and groups involved in restoration projects.

Effective aquatic animal health management requires a cooperative effort between all stakeholders (Atlantic States Marine Fisheries Commission 2002). ***State, Federal (USDA), and International (World Organization for Animal Health and the International Council for the Exploration of the Sea) agencies*** develop regulations and recommendations geared to minimize the introduction and impact of diseases on marine populations. In Rhode Island, the management of farmed fish (finfish and shellfish) populations is the responsibility of the Coastal Resources Management Council (CRMC). The management of wild and restored shellfish populations is overviewed by the Department of Environmental Management, Fish and Wildlife (RIDEM). The Rhode Island CRMC Biosecurity Board, lead by the Aquaculture Coordinator and composed of the state veterinarian, an aquatic animal health specialist, an aquaculture extension agent, and representatives of the fishing and aquaculture industries, as well as restoration groups, advises the CRMC on issues pertaining to disease and genetics as they concern the aquaculture industry. Decisions on how to manage farmed and wild fish populations are based on current scientific knowledge and information gathered by health specialists on disease distribution within the state. ***Health specialists*** are responsible for health certifications, disease diagnosis, and monitoring wild and cultured populations or marine organisms for disease. ***Farmers, fishermen, and other groups*** involved in the management of wild and restored populations of marine organisms ("user groups") are responsible for avoiding as much as possible disease outbreaks by following the guidelines and recommendations of agencies and health specialists. User groups should report *as soon as possible* any unusual levels of mortality to local extension agents or health specialists, so appropriate measures to control the disease and minimize its impact can be taken.

Aquatic Animal Health Management: Regulations and Recommendations

Box 1. Potential routes for introduction of diseases in the marine environment:

1. Introduction of a new pathogen due to:
    - Importation of infected bivalves from infected areas.
    - Transport by vectors (animals or objects that carry the pathogen but do not suffer the disease). Examples of vectors include boats coming from infected areas, transported either in ballast water or in hitchhikers in fouled hulls, bait used for fishing, waste from shucking houses, and dirty shells from recently dead shellfish to be used as cultch.
    - Transport by currents.
2. Introduction of a susceptible host in an area where the pathogen exists in low levels.
3. Changes in environmental conditions, leading to increased susceptibility in the hosts (due to stress) or increased virulence of the pathogen.

Transfer of marine organisms for aquaculture: Health certification programs

The most effective regulations and recommendations are those geared to prevent the introduction of pathogens in an area. Pathogens affecting aquatic organisms can be ***introduced*** in a new area by several means (Box 1). A major route for the introduction of pathogens in clean areas is the importation of organisms from infected areas. To minimize the risk of introduction of diseases by this route, the transport of shellfish for aquaculture between states and countries is highly regulated. The Agreement on the Application of the Sanitary and Phytosanitary Measures (SPS Agreement) of the World Trade Organization (WTO) has stimulated the application of risk analysis to international trade policy for animals and animal products. *A key principle of the SPS agreement is that there should be no restrictions (sanitary measures) on trade in animal and animal products, unless it is likely that the trade will result in disease spread with unacceptable consequences.* The World Organization for Animal Health (OIE at www.oie.int) regulates the international transport of cultured aquatic organisms. Member countries agree to report to the OIE the presence of certain diseases considered a threat to aquaculture. OIE establishes a disease-free certification process that facilitates the transport of shellfish from certified areas to any other areas. The organization considers epidemiological information and risk analysis to regulate the transfer of shellfish between countries and areas in which the reportable diseases are already present. Examples of issues considered in this risk analysis are the presence of strains of a pathogen with different levels of virulence and patterns of distribution, or differences in the relative levels of disease in the two areas.

In the United States, each state has rules regarding the ***importation from other states of marine organisms for aquaculture***. In Rhode Island, regulations regarding the importation of shellfish are included in the RI Department of Environmental Management "Aquaculture of Marine Species in Rhode Island Waters" regulations (Box 2). These regulations should be routinely evaluated to make sure that they take into account the most recent information about diseases.

Box 2. Rhode Island regulations regarding importation of shellfish for aquaculture

- The aquaculturist must notify the Aquaculture Coordinator at CRMC in writing of every shipment of animals for culture entering this state, at least five working days prior to entry into the state.
- Each shipment of seed must be accompanied by a certificate of disease inspection from a recognized laboratory appropriate to the species received.
- The Director of DEM, in consultation with the Biosecurity Board, may waive the requirement for a certificate of disease inspection, or set forth specific requirements governing shipments.
- The transfer of non-indigenous species is not allowed.

The state of Rhode Island uses available information on the distribution and prevalence of disease in bivalve populations to regulate the transfer of shellfish within Rhode Island waters (***intrastate transport of shellfish***). Since the risk of introducing disease agents increases with the amount of time that the organism to be transported has spent in coastal waters, the CRMC Biosecurity Board recommends that no adults are transported between the different bodies of water in Rhode Island (for example, between the coastal Ponds and Narragansett Bay). For example, the transport of seed oysters is considered on a case-by-case basis, using available information on disease prevalence and intensity. If no information about disease prevalence is available from the area of origin, and the seed shellfish is being moved to a different body of water, the Biosecurity Board may recommend that a sample of the shellfish to be moved be tested for relevant diseases.

The exiting regulations for transport of shellfish only apply to aquaculture leases. However, the pathogens could also be introduced through transfer of wild stocks and restoration projects, as well as frozen and live products imported from other countries or states. The risks from aquaculture activities should be evaluated relative to risks of transfer by other vectors, both natural and anthropogenic. Furthermore, it is **strongly recommended** that the same guidelines and regulations used to avoid the introduction of pathogens through the transport of aquaculture product should be followed in the case of transfer of bivalves for **restoration projects** and **fisheries management**. This will ensure the health of wild and restored populations of shellfish in Rhode Island waters.

Development of a plan for disease management in aquaculture

The Atlantic States Marine Fisheries Commission, in the Guidance Relative to Development of Responsible Aquaculture Activities in Atlantic Coast States, recommends that farmers, in order to minimize diseases in their farms, develop a comprehensive plan to manage diseases in their farms. These plans can be site and species specific, and should be developed with the help of state agencies, extension agents, and health specialists. Information about procedures and guidelines regarding key aspects in health management should be provided to farmers, including:

- Basic concepts of disease (impact, causes, transmission, effect of the environment, etc)
- A list of the pathogens that constitute major the major threats to wild and cultured populations of marine organisms
- Transfer and transport guidelines, and the role of health certification programs
- Guidelines for site and stock selection (avoid sites exposed to conditions that trigger disease outbreaks, and stocks susceptible to disease)
- Guidelines for routine, frequent disease monitoring, including information on how to recognize disease, procedures for the confidential reporting of potential disease outbreaks and obtaining a rapid disease diagnosis, recommendations for management of the outbreaks, and guidelines for the proper disposal of diseased organisms.
- Safe operational protocols and best management practices (how to minimize stress, maintain water quality, provide proper nutrition, sanitize equipment to minimize spread of diseases, employ quarantine protocols, etc)

In Rhode Island, health specialists and the aquaculture extension specialist with funding from the Rhode Island Aquaculture Initiative are in the process of developing a brochure with guidelines for disease management in bivalve aquaculture farms. This brochure will be provided to all farmers. Furthermore, the USDA Natural Resources Conservation Services (NRCS) Environmental Quality Incentives Program (EQIP) is currently supporting an annual (2006 – 2009) disease monitoring program with participating farms for 3 years by the Aquatic Pathology Laboratory at URI, with the hope that farmers will see the benefits of disease monitoring and continue after the program is completed.

Monitoring of wild and cultured populations of key marine organisms and support of basic research on diseases of marine organisms.

To make wise management decisions and preserve valuable marine resources, the state must assemble accurate and timely data on the prevalence and intensity of disease in cultured and wild populations of key marine organisms. Health inspections and monitoring programs can minimize the potential for disease pathogens and parasites to be inadvertently introduced during production, transfer, or transport of animals and product. Data from monitoring programs should be available to all stakeholders nationwide, to foster communication between states and the development of fair and effective regulations and guidelines. Furthermore, the Atlantic States Marine Fisheries Commission recommends that disease research and local and regional collaboration in disease matters should be encouraged in all states (Atlantic States Marine Fisheries Commission 2002). Research is necessary to evaluate the geographic range and distribution of the pathogen, determine the environmental and host conditions that trigger disease outbreaks, develop accurate diagnostic tests and treatments, and determine the pathogenicity and virulence of the pathogen and the species of organisms at risk. This information is critical for risk analysis and the development of management plans.

Recommendations.

- **In Rhode Island, the regulation and management of infectious diseases of wild and cultured populations of finfish and shellfish is under the purview of several different agencies and sections within those agencies. For example, RIDEM manages wild populations of finfish and shellfish, while CRMC is in charge of managing cultured populations. The CRMC Biosecurity Board has no overview over wild or restored populations of marine organisms. We recommend the establishment of a single interdepartmental advisory board or expansion of the CRMC BioSecurity's Board purview that would be in charge of providing recommendations for the regulation and management of infectious diseases in wild and cultured populations of aquatic organisms. This advisory board should include representatives of all stakeholders, including state agencies, fishing and aquaculture industries, groups involved in restoration projects, scientists, health specialists, and a representative of the public at large.**

- **Consistent availability of funds for disease monitoring in wild and cultured populations of key species.**

- **Provide continuous assistance to farmers, through outreach programs, in the development and implementation of comprehensive plans for the management of disease.**

- **Establishment of a plan for reporting and rapid response (ensure privacy of people that report disease outbreaks, provision of emergency funds for rapid diagnosis, tools for rapid communication to stakeholders).**

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Chapter 3

Aquatic Nuisance Species and RI Aquaculture

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Summary

Aquatic nuisance species are a real risk to the shellfish aquaculture industry and wild harvest fisheries in Rhode Island. RI shellfish farmers are currently dealing with a wide variety of nonindigenous nuisance species that are increasing their workloads and decreasing their profits. While wild resources are under threat from a variety of introduced predators and competitors Therefore, it is in the best interest of local shellfish farmers and harvesters to minimize the risk for new introductions. Furthermore, with the advent of stringent regulations controlling the transport of shellfish, the actual risk of introducing a nuisance aquatic species from the importation of shellfish for aquaculture that are contaminated with exotic species is extremely remote. On the other hand, the risk to farmers from introductions via other means is real and growing as the number of other users of the aquatic environment and the mobility of these users increases. Therefore, it is in the best interest of all users of the aquatic environment to expand the oversight of practices that can result in the introduction of exotics into Rhode Island waters. The following recommendations will provide a better base of operations to reduce the risk of introductions of new aquatic nuisance species:

- A standard protocol of evaluating and permitting the movement of shellfish and all other aquatic species into and within the state when being moved for fishery management purposes, such that both aquaculturists and fisheries managers are held to the same standard,
- Increase the oversight and authority of the Biosecurity Board to include all restoration and importation activities.
- Initiate a educational campaign to raise public awareness of ANS issues in Rhode Island, and
- Curtail intentional introductions by utilizing a strategy similar to that recommended by the International Council for the Exploration of the Seas.

As found on the CRMC ANS Plan http://www.crmc.state.ri.us/projects/projectfiles/RIAIS_Plan_Draft.pdf aquatic nuisance species (ANS) are a group of organisms described as “nonindigenous species that threaten the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters. ANS include nonindigenous species that may occur in inland, estuarine and marine waters and that presently or potentially threaten ecological processes and natural resources. In addition to adversely affecting activities dependant on waters of the United States, ANS adversely affect individuals, including health effects.” To refine the definition, “nonindigenous species (NIS) are any species or other viable biological material that enters an ecosystem beyond its historic range, including any such organism transferred from one country into another. Nonindigenous species include both exotics and transplants. Synonyms for NIS include *introduced*, *foreign*, *exotic*, *alien*, *non-native*, *immigrant* and *transplants*.”

Not all nonindigenous species are considered nuisance species although it is inevitable that any new species introduced into an ecosystem will have some level of impact on that system. In many instances, our level of knowledge regarding the minutiae of ecosystem operations precludes determining the impact an introduced species may play on native species. Whereas those introduced organisms identified as nuisance species have easily observed and measured ecological effects that may affect a variety of general classes of adverse consequences, including environmental, economic and public health issues (Table 1). It should be noted that, in some instances, the introduced species might contribute to a positive benefit to one or more of the general classes of consequences. For example, the introduction of the Japanese oyster (*Crassostrea gigas*) on the west coast of the US as well as in Europe in the late 1800's has resulted in significant economic benefit to the shellfish industries in those areas (Davies et al., 2007). For the sake of this document, we will confine our discussion to identifying, preventing and/or managing the potential deleterious effects of the introduction of an exotic species.

Table 1 provides a list of the three classes of adverse impacts caused by aquatic nuisance species (From: http://www.anstaskforce.gov/ans.php):

Types of Aquatic-Nuisance-Species Impacts

Environmental Effects	**Economic Impacts**	**Public Health**
Predation	Industrial Water Users	Human Disease Risk
Parasitism	Municipal Water Supplies	e.g. cholera
Competition	Nuclear Power Plants	
Introduction of new pathogens	Commercial Fisheries	
Genetic	Recreational Fishing	
Habitat Alterations	Other Water Sports	

Exotic organisms can be accidentally introduced into a new environment via a variety of mechanisms. In surveying the current published materials about aquatic nuisance species, the predominant mechanisms by which new species are unintentionally introduced include transport during ship ballast water uptake and discharge, species attached to the hulls of ships as they traverse the oceans, unintentional introductions as species are contained in materials moved from site to site by commercial transport, aquaculture and the aquarium trade, and movement of materials as a component of tourism and recreational activities. In addition, there are numerous records of intentional introductions of exotic species for either economic or biological gain. For example, the U.S. Bureau of Commercial Fisheries (now NOAA Fisheries) intentionally introduced the European flat oyster (*Ostrea edulis*) into the waters of New England (Boothbay Harbor, ME) in 1949 in response to a lack of soft shell clams for harvest (Loosanoff 1955). It has since expanded its range from Nova Scotia through to Rhode Island.

Of late, the aquaculture industry has been severely criticized as a major player in the movement and introduction of aquatic nuisance species. For example, in 1993 the U.S. Office of Technology Assessment stated "unintentional introductions are currently one of the largest problems associated with aquaculture activities and warrant caution on the part of regulatory agencies and the fishing industries alike" (as cited in DeFur and Radar 1995). Naylor *et al.* (2001) focused an entire Policy Forum editorial in Science (a premier publication for research scientists), entitled *Aquaculture – a gateway for exotic species*, where the authors warned that the aquaculture industry was a "leading vector of aquatic invasive species worldwide". Based on their evaluation of aquaculture as a significant contributor to the ANS problem and on their judgment that "local and state regulations are inadequate", the authors argued that "a clear policy on exotic introductions is needed as aquaculture expands – one that includes scientific risk assessment for all nonnative introductions and single-agency oversight for the prevention, containment and monitoring of potentially harmful exotics."

Before delving into the world of prediction, prevention and/or management of ANS as they relate to aquaculture activities in Rhode Island, I would like to explore more deeply the role that aquaculture, more specifically shellfish aquaculture, has historically played in the movement of ANS in the United States. For this information lends considerable light on the current risks of ANS introductions in Rhode Island and other regions where shellfish aquaculture is conducted. Jim Carlton published a manuscript in 1992 that provided an end of the 20th century perspective on mollusk introductions in North America (Carlton 1992). Within that document, Carlton summarizes our current state of knowledge regarding 36 different nonindigenous species of mollusks that have been successfully introduced in North American waters. Of those 36, 16 species are North American species that had been moved to new locales within the continent while 20 were introductions from Europe or the Far East. Regionally, 30 species were introduced to the Pacific Coast, 8 to the Atlantic Coast, and 1 to the Gulf Coast. An interesting observation about these introductions and one that is never mentioned when discussing the risk of ANS introductions from aquaculture activities is the timeline of these introductions. Table 2 provides a summary of the information included in Carlton's work. Of the 46 species listed by Carlton, 23 were the direct result of fisheries and/or aquaculture activities while another 6 were intentionally introduced, presumably for fisheries and/or aquaculture reasons. The remaining introductions were the result of commercial and recreational transport processes. The obvious conclusion is that fisheries and aquaculture has contributed 50% to known exotic mollusk introductions in North America and therefore is currently a high risk for continued introductions.

However if one notes the timeline of introductions via fisheries and aquaculture, it is important to be aware that the bulk of the introductions occurred during a period of high intensity movement of oysters from both the Pacific rim and the Atlantic to the Pacific coast of North America, during an interval of the 1870's to 1930's. With the exception of an accidental introduction to the Pacific in 1981 (the Takinoshima shipworm that was actually introduced via wooden boxes that oysters were shipped in), the last documented introduction of an aquatic mollusk via fisheries and/or aquaculture activities was the European ovatella to the Pacific coast in 1965. This is compared to the more recent introductions, such as the zebra mussel in 1992 and the brown mussel in 1990, which were introduced via commercial ship traffic, either as fouling attached to the hull or in the ballast water. Why is this so?

Two oyster diseases have decimated eastern oyster populations throughout the Atlantic coast of North America. Dermo, caused by the protistan *Perkinsus marinus*, and MSX, caused by the protistan *Haplosporidium nelsonii*, have taken a heavy toll on commercial oyster fisheries and aquaculture since first discovered, dermo in the 1940's in the Gulf or Mexico and MSX in the 1950's in Delaware Bay. Since their discovery, both diseases have been spread across the Atlantic range of North America, presumably by way of the practice of moving juvenile and adult oysters associated with fisheries and aquaculture management. As our level of understanding regarding shellfish disease processes began to coalesce through the 1970's and 1980's, it clearly became evident that the mass movement of juvenile and adult oyster stocks was a primary mechanism for spreading oyster diseases and one that could be curtailed through effective regulatory oversight. This new knowledge resulted in the implementation of increasingly stringent control of shellfish movements, due to disease considerations.

By carefully controlling the movement of juvenile and adult shellfish for disease purposes, to the point where most shellfish can only be moved from site to site, even within a single state, as post-set spat directly from the hatchery or as seed certified as having no known shellfish diseases, state regulations since the 1980's have indirectly but significantly reduced the hazard of moving unwanted ancillary organisms with the shellfish seed. Therefore, shellfish aquaculture presents an extremely small risk for the introduction of aquatic nuisance species in Rhode Island waters at the present time.

Local policy development for aquatic nuisance species falls under the auspices of the Northeast ANS Panel, a component of the Aquatic Nuisance Species Task Force. The ANS Task Force is an intergovernmental organization dedicated to preventing and controlling aquatic nuisance species, and implementing the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990. The various NANPCA mandates were expanded later with the passage of the National Invasive Species Act (NISA) in 1996. The Task Force consists of 10 Federal agency representatives and 12 Ex-officio members, and is co-chaired by the U.S. Fish and Wildlife Service and National

Table 2: A summary of the mollusk species introduced into North America (modified from Carlton 1992).

Species	Common name	Location of Introduction	Mechanism	Time of first reported observation
Clanculus ater	top snail	Pacific	Ballast	1964
Cecina manchurica	Manchurian cecina	Pacific	Fisheries/Aquaculture	early1960's
Littorina littorea	common periwinkle	Atlantic	Ballast/Intentional	pre-1840's
		Pacific	Fisheries/Aquaculture	1968
Tectarius muricatus	beaded periwinkle	Atlantic/Gulf	unknown	1986
Truncatella subcylindrica	looping snail	Atlantic	Ballast	1880
Barillaria attramentaria	Japanese false cerith	Pacific	Fisheries/Aquaculture	1920's
Sabia conica	hoof snail	Pacific	Ballast	1940
Crepidula covexa	convex slipper snail	Pacific	Fisheries/Aquaculture	1898
Crepidula fornicata	Atlantic slipper snail	Pacific	Fisheries/Aquaculture	1898
Crepidula plana	white slipper snail	Pacific	Fisheries/Aquaculture	1901
Cerastostoma inornatum	Japanese oyster drill	Pacific	Fisheries/Aquaculture	1924
Urosalpinx cinerea	Atlantic oyster drill	Pacific	Fisheries/Aquaculture	1890
Busycotypicus canaliculata	channeled whelk	Pacific	Fisheries/Aquaculture	1938
Ilyanassa obsoleta	eastern mudsnail	Pacific	Fisheries/Aquaculture	1907
Nassarius fraterculus	Japanese nassa	Pacific	Fisheries/Aquaculture	1959
Ovatella mysotis	European ovatella	Atlantic	Ballast	1851
		Pacific	Fisheries/Aquaculture	1965
Siphonaria pectinata	striped false limpet	Atlantic	Ship fouling	pre-1800's
Mytilus galloprovincialis	European mussel	Pacific	Ship fouling	1880's
Musculista senhousia	Asian date mussel	Pacific	Fisheries/Aquaculture	1941
Geukensia demissa	ribbed mussel	Pacific	Fisheries/Aquaculture	1894
Perna perna	edible brown mussel	Gulf	Ballast	1990
Mytella charruana	charru mussel	Atlantic	Ballast	1986
Patinopectin yessoensis	Japanese sea scallop	Pacific	Intentional	1984
Anomia chinensis	Chinese jingle	Pacific	Fisheries/Aquaculture	1924
Crassostrea gigas	Pacific oyster	Pacific	Fisheries/Aquaculture	1914
Crassostrea virginica	eastern oyster	Pacific	Fisheries/Aquaculture	1917
Ostrea edulis	edible oyster	Atlantic	Intentional	1949
Rangia cuneata	Atlantic rangia	Atlantic	Ballast/Fish./Aquac.	1955
Macoma balthica	Baltic macoma	Pacific	Fisheries/Aquaculture	1800's
Theora lubrica	Asian semele	Pacific	Ballast	1968
Dreissena polymorpha	zebra mussel	Atlantic	Ballast	1992
Mytiliopsis leucophaeata	dark false mussel	Atlantic	Ballast	1937
Trapezium liratum	Japanese trapezium	Pacific	Fisheries/Aquaculture	1947
Corbicula fluminea	Asian clam	Pac./Atl.	Intentional	1920's
Venerupis philippinarum	Japanese littleneck	Pacific	Intentional	1936
Gemma gemma	amethyst gem clam	Pacific	Fisheries/Aquaculture	1893
Mercenaria mercenaria	quahog	Pacific	Intentional	1967
Petricola pholadiformis	false angelwing	Pacific	Fisheries/Aquaculture	1927
Mya arenaria	soft shell clams	Pacific	Fisheries/Aquaculture	1911
Pommocorbula amurensis	Amur River corbula	Pacific	Ballast	1986
Lyrodus pedicellatus	blacktip shipworm	Pacific	Ship fouling	1871
Lyrodus takanoshimensis	Takanoshima shipworm	Pacific	Fisheries/Aquaculture	1981
Teredo barrschii	Barusch shipworm	Atlantic	Ship fouling	1971
Teredo novalis	naval shipworm	Pacific	Ship fouling	1913
Teredo furcifera	deep cleft shipworm	Atlantic	Ship fouling	1974
Laturnula limicola		Pacific	Ballast	1963

Oceanic and Atmospheric Administration. The Task force coordinates governmental efforts dealing with ANS in the U.S. with those of the private sector and other North American interests via regional panels and issue specific committees and work groups.

The ANS Task Force encourages state and interstate planning entities to develop management plans describing detection and monitoring efforts of aquatic nuisance species, prevention efforts to stop their introduction and spread, and control efforts to reduce their impacts. Management plan approval by the Aquatic Nuisance Species Task Force is required to obtain funding under Section 1204 of the Aquatic Nuisance Species Prevention and Control Act. Regardless of financial incentives, plans are a valuable and effective tool for identifying and addressing ANS problems and concerns in a climate of many jurisdictions and other interested entities. Rhode Island has recently developed a State ANS Management Plan, following guidelines published by the National Task Force (http://www.anstaskforce.gov/stateplans.php). In RI, The CRMC has taken the lead in the development of the RI plan and Kevin Cute (RI-CRMC) oversees the process. The RI Aquatic Invasive Species Management Plan was approved at the state level this fall and has been sent along for federal approval as of 28 September 2007 (http://www.anstaskforce.gov/State%20Plans/RI_SMP_Draft.pdf).

In the RI state management plan, there are currently guidelines or practices being implemented to protect state natural resources for ANS invasions. Protection of natural and important aquatic resources comes in the form of prevention, eradication and management. Eradication has only been successful in a very small subset of nuisance species introductions and cannot realistically be considered an option for dealing with ANS introductions in Rhode Island. Therefore, the effort that should be expended needs to focus on prevention followed by management in the event that prevention wasn't successful.

The current mechanism for the control of the movement of juvenile and adult shellfish is a state-managed effort at both the interstate and intrastate levels. In Rhode Island, there currently are two management agencies that oversee shellfish movement (with potential hitchhikers), depending on the fate of the seed. Shellfish and other species being moved for aquaculture purposes are overseen by the RI Coastal Resources Management Council's Aquaculture Coordinator, in consultation with the Biosecurity Advisory Board – an advisory board established to review proposed aquatic species movements into and out of Rhode Island. Farmed shellfish can only be moved into and around the state with permission of the CRMC. A process dictated through the state receiving the seed regulates shellfish seed being exported from RI.

With shellfish and other species being moved for fisheries management purposes, the process of control within RI is less well defined. To my knowledge, there is no formal process for requesting permission to move aquatic species within the RI Department of Environmental Management's Marine Fisheries Section. In surveying and searching the RI governmental websites, The Northeast ANS Panel only found well-presented regulations describing the process to move aquaculture shellfish in RI (see Appendix 1;

http://www.northeastans.org/docs/ri-laws.pdf) but no equivalent descriptions for non-aquaculture marine aquatic species movements**.**

Recommendation: RIDEM should establish a formal process, including better use of the RI Biosecurity Board, for permitting the movement of aquatic species (for restoration or enhancement) within state waters as soon as possible.

Prevention of introductions, over and above the regulatory tools listed above, falls on all users of the aquatic environment. Anyone can introduced a nuisance species in local waters, from the shellfish farmer to the 8 year-old child tired of their saltwater aquarium! On the other hand, in those instances where an ANS is introduced at a location outside of state boundaries, the chances of actually preventing range expansion across the state line is unrealistic.

Recommendation: **Rhode Island should continue participation in the region-wide Northeast ANS Panel, to ensure that regulations and management of ANS introductions are uniform throughout the region and that all states are in compliance with whatever strategies are in place.**

See: http://www.crmc.state.ri.us/projects/projectfiles/RIAIS_Plan_Draft.pdf

Recommendation: Rhode Island should undertake an aggressive outreach and education program to teach the general public about the risks associated with the introductions of exotic species.

One strategy that has been adopted for preventing the spread of ANS and judged as relatively successful is the use of a HACCP-type of effort (Gunderson & Kinnunen, 2004). Hazard Analysis Critical Control Point (HACCP) management came from the food handling industry where food-processing methods were analyzed to determine the level of risk associated with each step in the handling process. At those stages where there is a real risk to introduce a human health hazard, methods are designed and implemented to monitor and control the critical control point such that the hazard is not manifested. This HACCP analysis and management strategy has been targeted to the baitfish industry in the mid-west to protect receiving waters from the inadvertent introduction of nuisance species from baitfish aquaculture operations. While not directly transferable from baitfish distribution to shellfish distribution, the strategy may have some useful components for application. In the event that an ANS control program may be needed in Rhode Island, this would be an interesting model to pursue. For more information, please visit http://www.haccp-nrm.org/.

Once an ANS has been established within RI waters, the management of the impact of the species on aquatic farmers currently lies within the responsibilities of the farmer. There currently are a number of ANS that have been introduced in the northeast that cause severe economic impacts on shellfish farmers, including those listed in Table 3. Traditional methods to control nuisance species include mechanical cleaning, air/sun drying, brine/freshwater treatment, biological control, and antifouling coatings. Research is currently being conducted on a number of these species to determine best methods to control and mitigate their impacts. As this information is forthcoming, it is dispersed to the local shellfish farmers through an active outreach program. The same process needs to be expanded to restoration and wild fisheries programs as well. In addition, Rhode Island growers are in constant communication with each other as well as other participants in the industry throughout the U.S. Significant information is transferred between growers as they share strategies and information to optimize their growing methods.

Table 3: a list of some common aquatic nuisance species that are impacting shellfish farmers in RI as either active predators or fouling organisms (not including pathogens).

Species name	**common name**
Coelenterate	
Diadumene lineata	orange-striped anemone
Bryozoa	
Membranipora membrancea	lacy crust bryozoan
Mollusks	
Urosalpinx cinerea	oyster drill
Crustaceans	
Carcinus maenas	Green crab
Hemigrapsus sanguineus	Asian shore crab
??*Eriocheir sinensis*	Chinese mitten crab??
Hemichordata	
Styella clava	club tunicate
Botryllus schloserri	star tunicate
Botrylloides violaceus	orange sheath tunicate
Didemnum spp.	pancake batter tunicate
Algae	
Codium tomentosoides	oyster catcher
Grateloupia turuturu	red algae

In some instances, there have been proposals to intentionally introduce exotic aquatic animals into specific ecosystems for a variety of reasons, including economics, biological control of other exotic species, and etc. For example, there is a current proposal pending to introduce the Asian oyster (*Crassostrea ariakensis*) into Chesapeake Bay (Maryland and Virginia) to replace a native oyster (*Crassostrea virginica*) population that has been decimated by the diseases MSX and dermo and other stressors. Normally, these proposed introductions are subjected to an extensive review process to assess the associated benefits and risks of such an introduction before a decision is made. The most common process for evaluating intentional introductions, and one that is being used to evaluate the *C. ariakensis* introduction, has been developed by the International Council for the Exploration of the Seas (ICES), namely the ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2004. This document gives recommended procedures and practices to reduce the risks of detrimental effects from the intentional introduction and transfer of marine (including brackish water) organisms. The Code is aimed at a broad audience since it applies to both public (commercial and governmental) and private (including scientific) interests. In short, any persons engaged in activities that could lead to the intentional or accidental release of exotic species should be aware of the procedures covered by the Code of Practice (http://www.ices.dk/reports/general/2004/ ICESCOP2004.pdf. There currently is not a realistic expectation or need for local shellfish farmers to propose the introduction of an exotic species. While it is not necessary for RI shellfish farmers to propose the introduction of an exotic species, they have a vested interest in protecting the environment within which they conduct their business. Therefore, it is in the best interest of all coastal users to carefully evaluate any proposed introductions of exotic species.

Recommendation: Rhode Island should utilize the guidelines provided by the ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2004 if intentional introductions are proposed in the state.

In conclusion, aquatic nuisance species are a problem for all users of the coastal environment, in that they can be detrimental to native ecosystems. Aquatic farmers in Rhode Island are acutely aware of the impacts of nuisance species and have much to lose when new species get introduced into state waters. Therefore, an aggressive program to prevent the introduction of exotic species is a necessary component to the management of our marine resources.

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Appendix 1: Summary of Rhode Island ANS Laws
(retrieved from: http://www.northeastans.org/docs/ri-laws.pdf)

RI statutes: http://www.rilin.state.ri.us/scripts/search/search.asp

RI statutes: Introduction & Possession of Fish and Other Animals:

1) Stocking of streams and ponds: No one shall stock or liberate into any Rhode Island fresh water pond or stream any fish species without a DEM permit. R.I. Gen. Laws § 20-11-6 (2003).

2) Penalties: Any person who violates §§ 20-11-6 or 20-11-10 shall be guilty of a violation. The penalty for each violation is a $100 fine. R.I. Gen. Laws § 20-11-20 (2003).

Control of Invasive Plants:

1) Injurious substances: With a DEM permit and under DEM regulations, a person may use certain chemicals to eradicate plants and to control fish populations. R.I. Gen. Laws § 20-11-10 (2003).

Fish Propagation and Aquaculture:

1) Procedures for Approval [to Conduct Aquaculture]: Upon submission of a permit to conduct aquaculture to the CRMC, the director of the Department of

Environmental Management (DEM) shall determine, *inter alia*, if the proposed aquaculture activities are likely to adversely affect the vitality of Rhode Island's native fisheries. R.I. Gen. Laws §20-10-5 (2003).

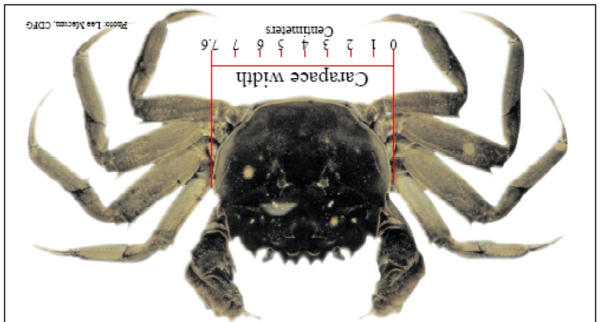
2) Permits and Licenses for the Taking, Possession, Sale, Importation, and Transportation of Species Used in Aquaculture: The DEM director has the authority to grant permits and licenses regarding the possession, taking, importation, sale, and transportation of aquaculture plants and animals. The director may issue regulations regarding the same. R.I. Gen. Laws § 20-10-12(a) (2003).

3) Permits and Licenses for the Taking, Possession, Sale, Importation, and Transportation of Species Used in Aquaculture: Anyone who possesses, takes, imports, sells, or transports aquaculture plants or animals without a permit is guilty of a misdemeanor. The person may be imprisoned for a maximum of one year, or fined a maximum of $500, or both. R.I. Gen. Laws § 20-10-12(b) (2003).

4) Introduction of non-indigenous species is prohibited unless protocols are in place to ensure that no accidental releases into the state's waters can occur. These protocols will be reviewed by the CRMC Bio-Security Board before any permit is issued. Any proposed modifications to the permitted operation will be reviewed by the Bio-Security Board before an assent modification can be issued. The issuance of a permit under these stipulations can be revoked if a release of non-indigenous species takes place during the term of the assent. (RI-CRMC Program Section 300.11 – Aquaculture regulations)

Appendix 2: the newest threat to shellfish farmers in Rhode Island.

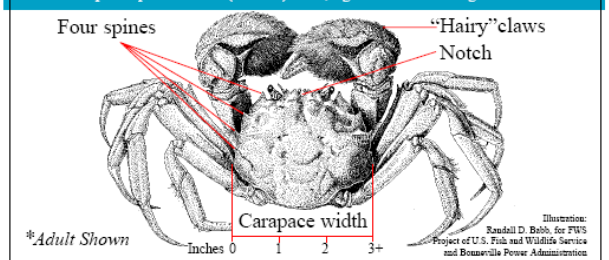
http://www.crmc.ri.gov/news/2007_0601_mittencrabs.html



Mitten Crab WATCH

How to Identify a Mitten Crab

- Only crab in fresh waters of North America
- Claws equal in size and “hairy” (juveniles may not have“hairy”claws)
- Four lateral carapace spines (last one smaller); notch between eyes
- Carapace up to 4 inches (100mm) wide; light brown to olive green in color



The Mitten Crab

Mitten crabs may pose a serious threat to the freshwater, estuarine and marine ecosystems and economy of the West Coast. First discovered in San Francisco Bay in 1992, they spread to the Sacramento and San Joaquin rivers where massive migrations clog fish screens and hamper water delivery. One mitten crab was found in the Columbia River in 1997. Mitten crab burrows weaken levees and increase bank erosion. They can eat salmon, trout, and sturgeon eggs and may threaten successful spawning. Juvenile crabs also damage rice fields. These crabs can carry the oriental lung fluke, a threat to human health. Native to Asia, mitten crabs live in freshwater but migrate to saltwater to reproduce and are easy to identify because they have hairy claws (other identification traits on back of card). Often, recreational anglers or commercial fishermen are the first to discover the mitten crab because they commonly steal bait from anglers or are caught in commercial nets.

Your help is vital to report new sightings and to prevent their spread.
***If you catch a mitten crab*,**

- Do not throw it back alive!
- Preserve it in rubbing alcohol or freeze it.
- Note the precise location where the crab was found.
- Contact your local natural resource management agency:

In Alaska, call the Fish and Wildlife Service (907- 262-9863); in British Columbia, call Fisheries and Oceans (604-666-6529); in Washington, call the WA Department of Fish and Wildlife (360-902-2200); in Oregon, call the OR Invasive Species Hotline (866-468-2337, toll free); in California, call the CA Mitten Crab Hotline (888-321-8913, toll free).

REMINDER: ***Know the rules!***
Mitten crab specimens are needed to confirm sightings, but many jurisdictions have different possession and transport rules. Contact your local natural resources agency for instructions. Never transport live mitten crab.

2001 Pacific States Marine Fisheries Commission

Chapter 4
Physical Impacts of Aquaculture Gear

Perry Raso
Matunuck Oyster Farm

Summary
Properly managed aquaculture operations are a productive use of the coastal zone. Coastal planning is necessary to avoid undesirable ecological impacts resulting from all aspects of coastal development, including aquaculture operations. This section identifies ecological impacts of aquaculture gear and harvesting methods for consideration during the planning of commercial aquaculture operations in Rhode Island.

On-Bottom Structures:
Cages, trays and racks are commonly used grow-out gear for aquaculturists in Rhode Island. These structures, which vary in dimension, are placed directly on the seabed and usually hold sturdy plastic mesh bags containing oysters (see Pillay and Kutty 2005 for further detail regarding these grow-out methods). There are three potential impacts of these sorts of structures; 1) physical modification of water flow or local hydrography, 2) addition of vertical structure and substratum, 3) organic enrichment of local sediment. These impacts can be both positive and negative, usually depending on the intensity and scope of the project.

On-bottom cages, racks and bags used for shellfish grow-out increase species diversity in the vicinity of farms (Kaiser et al. 1998) as new sub-stratum is provided for epibiota to settle and grow. Introduction of structures used for shellfish grow-out also affect local hydrography as most water flows around submerged gear (Boyd and Heasman 1998). Reduced flow through gear can lead to the accumulation of silt and organic matter under and near gear that can result in anoxic patches of seabed.

Norling and Katusky (2007) found the abundance and biomass of associated flora and fauna were higher near mussel beds because mussel biodeposition and nutrient regeneration supplied limiting resources and increased carrying capacity. Species complexity and biodiversity increased and community metabolism in mussel patches depends on mussel biodeposition for 24 to 31% of its energy demand. Mallet et al (2006) found that there was no indication of organic enrichment in the sediment due to cultivation in oyster tables used in Eastern Canada. Macrofauna biomass, abundance and number of species, in areas where oyster tables were maintained, increased or had similar values compared to control sites. A study performed in Rhode Island comparing total organic carbon (TOC) within, near and away from aquaculture leases in Rhode Island showed that TOC levels were not significantly higher in the 16 shellfish grow-out leases sampled (Raso and Rice 2000). In fact TOC levels were higher in locations away from leased areas which is likely due to aquaculturist's selection of sites with a sandier, firmer substrate.

However others have documented negative impacts when deposition rates exceed the assimilation capacity of the local environment. Nugues et al. (1996) investigated environmental changes at an oyster farm in England and found that the abundance of macrofauna decreased by nearly one half directly beneath grow-out gear, while water currents were significantly reduced trough the farm. Sedimentation rates and the organic content of the sediment under the grow-out gear were increased. These changes were confined to the area immediately beneath the grow-out gear. Castel et al (1989) found that densely stocked oysters caused elevated organic carbon levels in local sediments from feces and pseudofeces of shellfish, combined with reduced flow under gear.

At lower stocking densities (which are optimal for increased growth rates) the effects of shellfish grow-out gear on benthic fauna are relatively benign and highly localized (Kaiser et al. 1998). However, these environmental effects are increased as the carrying capacity of the grow-out area is approached (Castel 1989).

Recommendation: Encourage growers and researchers to conduct studies to determine optimal stocking densities to maximize growth and minimize potential negative impacts.

Predator Netting:
Predator netting is used to protect juvenile northern quahogs (*Mercenaria mercenaria*) from gulls, crabs, gastropods and starfish after bottom planting (see Pillay and Kutty 2005 for further detail regarding the use of predator netting). The use of predator netting can lead to an increase in sedimentation and increased organic content of the sediment (Spencer et al. 1997). Sedimentation occurs as netting becomes fouled with algae and hydrographic conditions are altered. The fouling alga on the netting attracts grazers such as littorinid snails and other epifaunal species. Spencer et al. (1997) found that post-harvested sites seemed to be restored after 3 months, however; differences in the benthic community were apparent for 6 months post harvest. An alternative method to predator netting is the use of plastic grow-out bags placed directly on the sediment. This more labor-intensive alternative method of northern quahog grow-out has shown to have no detectable effects on the benthic invertebrate community (Mojica and Nelson 1993). Another method used for grow-out of clam species is adding gravel and shell material to decrease predation on juvenile clams. This method creates a new sediment structure and results in a longer lasting change to the local biota (this method has not been used on a commercial scale in Rhode Island).

Suspended Rope Culture:
Large numbers of blue mussel (*Mytilus edulis*) larvae set on rocks and other substrate in coastal bays and inlets. Frayed rope suspended in the water column is a common and effective method to obtain seed from this abundant source of natural mussel set (see Pillay and Kutty 2005 for further detail regarding rope culture methods).

The complex surface area provided by suspended mussels offer habitat for over 100 different species (Tenore and Gonzalez 1976). A large biomass of cultured mussels and fouling organisms suspended from lines attached to buoys or rafts has a major effect on phytoplanktonic, benthic and hydrographic conditions within the immediate area of cultivation (Kaiser et al. 1998). Suspended rope culture in high current waters does not promote accumulation of pseudofeces that allows for favorable increase in macrofaunal biomass (Rodhouse and Roden 1987) in the vicinity of the culture operation. However, areas with low diversity (usually due to pollution) and decreased flow rates demonstrate organic sedimentation under long lines to be up to two times of that found in adjacent uncultivated areas (Dahlbäck and Gunnarsson 1981).

Bottom Culture:
Broadcast seeding oysters on the seabed for grow-out is a method that is increasing in popularity among aquaculturists in Rhode Island. Field planting the oysters on the seabed reduces costs associated with grow-out of oysters, as increased gear costs and maintenance requirements (labor) are reduced as the oysters mature. Harvest of the bottom planted oysters is carried out via bull raking, the use of SCUBA and, most commonly, dredging.

Direct mortality of non-target species and destruction of habitat from mechanical harvesting techniques (dredging) is well documented. Studies on commercial scale dredging for wild harvested shellfish demonstrates the negative ecological impacts of dredging such as reduced species abundance and numbers as well as prolonged recovery of fauna. While the impacts of dredging for wild harvest shellfish are well documented, the impacts of dredging for seeded oysters on aquaculture leases is not. Wild harvested areas are likely to have an increased abundance of structure and habitat as compared to areas that are permitted for bottom culture in Rhode Island.

In order to assess the impacts of bottom planting and dredging of oysters, the natural productivity of the area prior to seeding must be considered. In Rhode Island, naturally productive areas are not permitted for aquaculture. By seeding these unproductive areas with oysters, structure and habitat is created for commercially important species as well as their prey. Howell et al. (1999) investigated nursery areas of winter flounder in shallow embayments in Connecticut to determine if there are areas that yield higher abundances, he found that winter flounder prefer a shell/mud matrix to any other habitat type. Visel (1988) reporting on the impacts of distributing shell stock on the seabed on populations of wild oysters in Connecticut found that increased shell stock promoted settlement of oysters. In more recent study by DeAlteris et al. (2004) found that higher abundances of winter flounder were found on shellfish gear than nearby eelgrass beds in a coastal pond in southern Rhode Island.

Aquaculturists that bottom seed aquaculture leases in Rhode Island stagger their crop through out the year, therefore only a portion of the leased area is being harvested (dredged) while the majority of the lease area is planted with small seed stock and is not disturbed for months at a time. This seasonal nature of harvesting/dredging for seeded shellfish within permitted aquaculture leases allows for juvenile oysters to mature and also allows for recovery of benthic communities. The amount of time that harvested areas require in order to fully recover depends on the amount of disturbance experienced and the time of year of the disturbance in relation to larval recruitment patterns of non-target species disrupted (Kaiser et al. 1998). There is no doubt that dredging causes some mortality of non-target species. What is not known is whether the habitat improvements created by acres of seed oysters planted on otherwise barren bottom compensates for the localized harvest activities.

The East Coast Shellfish Growers Association (ECSGA) has secured a grant from the United States Department of Commerce to investigate the environmental impacts of dredging seeded shellfish. The results of that study should be incorporated into this section when they are available.

Submerged Aquatic Vegetation (SAV):
Submerged aquatic vegetation (SAV) serves as an important habitat for fish and crabs as well as a food source for waterfowl (Wilkins 1982). Aquaculture gear placed on top of SAV can kill or exclude growth of SAV, however; the presence of shellfish may promote SAV growth due to increased water quality and improved sediment nutrition (Hershener and Woods 1997). A recent study by Wisehart et al. (2006) investigated the interactions between oyster aquaculture and eelgrass recruitment. The results showed higher eel grass seedling densities in eel grass growing in dredged beds compared to eel grass under long lines or in eel grass beds suggesting that ground culture practices may positively affect eelgrass recruitment.

Recommendation: Maintain the prohibition on leasing areas within established eelgrass meadows.

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Chapter 5
Essential Fish Habitat (EFH) and Aquaculture

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Save the Bay

Summary

The effects of aquaculture on EFH are varied and depend upon a number of interacting factors that include the type of species cultured, scale and intensity of operation, features of the physical environment, and culture and harvest methods employed. Careful consideration of these can effectively minimize impacts on EFH that might occur. In order to minimize impacts on EFH, protection of existing spawning and reproductive grounds is necessary. Aquaculture facilities should be limited or restricted in areas where they would be destructive to natural EFH.

Definition of Essential Fish Habitat

As defined by Congress in the Magnuson-Stevens Fishery Conservation and Management Act and reauthorized by the Sustainable Fisheries Act (1996), Essential Fish Habitat (EFH) consists of "those waters and substrate necessary for fish to spawn, breed, forage and grow to maturity" (USDOC, 1997). The term "fish" in this definition includes marine, estuarine, and anadromous finfish, mollusks, and crustaceans. EFH includes all the physical features of the environment to which fish have adapted and are necessary for the long-term survival of populations. Some of these features include temperature, nutrients, and salinity of the water column and substrate such as sand, rocky reefs, or vegetation.

The concept of EFH was adopted with the intention of protecting habitat for those species of fish that are managed through federal law in effort to ensure healthy and sustainable fisheries. The Sustainable Fisheries Act of 1996 requires the eight regional fisheries management councils to describe and identify EFH and activities that may adversely affect fish habitat. An adverse affect is any impact that reduces the quality or quantity of EFH and may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of or injury to benthic organisms, prey species and their habitat, and other ecosystem components. Adverse effects to EFH may result from actions occurring within or outside of EFH and may include site-specific or habitat-wide impacts.

This legislation has enabled federal agencies to assess whether there are any potential impacts on EFH associated with activities in the marine and estuarine environments. One such activity is the operation of aquaculture facilities. Within the United States there is a variety of aquaculture operations that differ depending on the species being raised, the geographical location such as shallow estuaries or coastal waters, types of gear used, and the harvesting practices employed to retrieve the product for market. A variety of effects associated with aquaculture on EFH have been described ranging from harmful to beneficial and are dependent upon the type of operation.

EFH and aquaculture in Rhode Island

In Rhode Island, aquaculture practices are carried out exclusively to raise shellfish with oysters comprising most of the product followed by quahogs (CRMC, 2006). Oysters are typically raised on leases within the shallow estuarine environments of Narragansett Bay and the salt ponds. Oysters are either raised in cages placed on the substratum or directly on bottom sediments within the boundaries of the lease. Once oysters reach market size they are removed from cages or collected by various means.

Farms are maintained within estuarine environments that are important habitat for many species of fish. Approximately 75% of the commercial fish and shellfish species of the United States depend on estuaries at some stage in their life cycles (Chambers, 1992). In Rhode Island, EFH has been identified within coastal estuaries for several species of commercially and recreationally important fish such as winter flounder, black sea bass, scup, bluefish, striped bass and menhaden that typically use these areas as nursery habitat. Features identified as EFH include a broad array of habitats such as sediments composed of sand, mud or covered with shell, hard bottom such as rocks, and submerged aquatic vegetation (SAV) such as eelgrass. With expansion of aquaculture in Rhode Island over recent years, the environmental impacts have become a concern. In particular, whether there are any effects associated with aquaculture on EFH.

The potential for negative effects on habitat associated with aquaculture undoubtedly exist however the intensity and magnitude differ between the types of aquaculture systems, organisms cultivated, and the characteristics of the local environment. The possible effects relevant to fish habitat can be grouped into the following sources; (1) addition of physical structure to the environment (2) addition of organisms and therefore biological activity (3) husbandry activities.

The obvious impact on the local environment is the alteration of habitat associated with the addition of gear that essentially converts a sediment type habitat into one with structure. Structural features are well known to harbor greater densities and diversity of fish compared with featureless substrate (Orth et al., 1984). With the addition of aquaculture gear species that prefer sandy or mud substrate would be replaced by species that prefer structure. Tallman and Forrester (2007) and Dealteris et al. (2004) both concluded that oyster grow-out cages serve as quality habitat for species of fish that typically associate with hard bottom habitat. Dealteris et al. (2004) demonstrated that oyster cages harbored significantly greater abundances and diversity of species than shallow non-vegetated seabed. Likewise, Tallman and Forrester (2007) showed that equal or greater densities of species such as scup and black sea bass were found near oyster grow-out cages than natural rock reefs. Whether the gear results in the production of additional fish biomass or the concentration of existing biomass depends on the factors that limit local fish abundance.

Conversely, species associated with substrate composed of sediments could be displaced by aquaculture gear or activities associated with the operation. It is well documented that winter flounder utilize sediments within shallow estuarine environments during all life stages including eggs which are found clung to algal mats or firm bottom (Howell et. al, 1999; Crawford, 1990). Specific sites that serve as persistent spawning habitat year after year have been identified within Point Judith Pond (Crawford and Carey, 1985). One such area consisted of a submerged gravel bar located in the north end of the pond. Placement of aquaculture farms in such locations could conceivably reduce the availability of suitable habitat for egg production. Howell et al. (1999) found a correlation between abundance of young of the year winter flounder and sediment type with no consistent pattern with other environmental variables. Thus, it appears that juvenile winter flounder have strong associations with particular types of substratum and any alterations could affect habitat suitability.

Recommendation: Maintain the policy of not leasing of known spawning areas and protected essential fish habitats such as established eelgrass beds.

There is no documented evidence in the literature indicating that oyster grow out cages serve as suitable habitat for winter flounder. However, an association with oyster beds has been suggested (Castonguay and Visel, 1988). Based on anecdotal accounts from several individuals, Castonguay and Visel (1988) reported that high abundances of winter flounder have been observed to occur on natural and cultivated oyster beds. Farms where oysters are cultivated directly on substratum could potentially serve as suitable habitat, however methods used to retrieve the oysters such as dredging could counteract the benefits.

Of considerable concern regarding environmental impacts of aquaculture is the potential for hypoxic or anoxic conditions to develop as a result of decaying organic material such as feces, pseudofeces, and feed that accumulates around sites. Low oxygen conditions would compromise the water quality necessary for many species of fish to survive and effectively decrease the availability of suitable habitat. Concomitant with depletion of oxygen levels are changes in community structure to species tolerant of these conditions. Not all aquaculture operations have such an effect on the local environment and whether these conditions develop and the severity of the impact associated with the organic load introduced is dependent upon several factors including the type of species cultured, the scale of culture, physical conditions and culture method.

Most studies examining organic enrichment associated with aquaculture have concluded that the effects from finfish aquaculture are more pronounced that that caused by shellfish culture (Crawford et al., 2003). The key difference is the addition of an external food source for finfish which when unconsumed collects underneath pens, whereas food is readily available in the water column for shellfish. Studies measuring the effects of organic enrichment of sediments around shellfish aquaculture sites have produced varying results ranging from no evidence of increased organic content (Bastien-Daigle et al., 2007; Crawford et al., 2003; Mallet et al., 2006) to the production of extensive bacterial mats, oxygen depletion and shifts in the benthic community to opportunistic species tolerant of low oxygen (Barranguet et al., 1994; Mattsson and Linden, 1983; Dahlback and Gunnarson, 1981).

The scale or intensity of aquaculture operations appears to be a significant causal factor as to the extent of organic enrichment. In Sweden and South Africa severe impacts from organic enrichment associated with the culture of mussels were observed at farms with an annual production of 24 kg m^{-2} and 175 kg m^{-2}, respectively (Dahlback and Gunnarson, 1981; Stenton-Dozey et al., 2001). In comparison, at sites with no observable impacts on benthic sediment chemistry produced annually 3 kg m^{-2} of mussels in Prince Edward Island (Canada), 0.8 kg m^{-2} of oysters in northern New Brunswick, and 8 kg m-2 of oysters in St. Simon Bay, New Brunswick (Mallet et al., 2006). In Rhode Island the estimates range from 3-5 t/acre = 0.67-1.12 kg/m2

Accumulation of organic matter in the vicinity of aquaculture sites is regulated in part by the physical features of the area. Water flow directly affects the transport and erosion of biodeposits (Widdows et al., 1998). Areas that are shallow with slow currents are more likely to experience problems associated with eutrophication, as organic matter will accumulate under the equipment (Mattson and Linden, 1983). Conversely, strong currents and deep water will facilitate the dispersal of biodeposits to other areas. Chamberlain et al. (2001) attributed differences in the levels of organic enrichment to differences in current patterns between sites within an estuary located in Ireland. Other factors such as the frequency of storm generated wind and waves can act to re-suspend and redistribute organic material from the sediments, further mitigating the affects of organic enrichment.

Recommendation: Encourage growers, researchers and regulators to monitor sediments for excessive organic enrichment and possible impacts on water column oxygen concentrations.

The types of equipment used and the techniques employed in aquaculture also contribute to the amount of organic matter accumulating near farms. Finfish are typically raised in large pens that are anchored to the substratum but able to float and move with the tides. In the culture of shellfish there are a variety of techniques and equipment that can be classified as either suspended, off-bottom, or bottom culture (Bastien-Dagle et al., 2007). Suspended culture is conducted in the water column or at the surface where the structures which are typically bags, ropes, trays or cages suspended from longlines, are anchored but free to float or move with the tides. With off-bottom culture the equipment consisting of bags, tables, or trestles are fixed in place on the substrate and do not move with the tides, whereas bottom culture is conducted directly on or in the substrate. Structures provide a complex surface area on which epifauna and algal communities can develop. Accumulation of these organisms and algae on the substratum when they die can further increase levels of organic enrichment and elevate the demand for oxygen. The method and types of gear used therefore differ in the amount of structure available to other organisms and consequently the levels of organic matter introduced. For example, Murray et al. (2007) observed significantly greater macrofaunal densities associated with rope-grown mussels compared with mussels cultured on the substratum. The practices employed while harvesting the cultured product will also determine the amount of organic material introduced, i.e. whether nets and gear are cleaned of biofouling organisms on vessels or on land, and then transferred to landfills.

It has been suggested that water quality within estuarine systems could be improved by increasing the abundance of shellfish. This hypothesis is based on the supposition that shellfish could remove a significant fraction of particulate bound nutrients from the water column through filter feeding, thereby mitigating the effects of eutrophication. Using an empirical model, Haamer (1996) estimated that mussel farms covering 1% - 2.4% of a Swedish fjord could reduce dissolved inorganic nitrogen concentrations in the surface water by 20% and lower biological oxygen demand in the deep basin waters by 26%. An increase in oyster biomass in the Chesapeake Bay was projected to reduce chlorophyll, increase deep-water dissolved oxygen, increase biomass of submerged aquatic vegetation, and remove nitrogen (Cerco and Noel, 2007). Oyster restoration was not suggested as a solution to eutrophication but was recommended as one of many small steps that can help address the problem.

Submerged aquatic vegetation (SAV) such as eelgrass has been identified as EFH for numerous species of finfish and its importance as nursery habitat within shallow estuaries is well documented. In addition to its value as a refuge for juvenile fish, SAV is paramount in the cycling of nutrients, acts to reduce turbidity by trapping particles suspended in the water column, and acts to stabilize the substratum mitigating erosion (Caffrey and Kemp, 1990; Ward et al., 1984). Over several decades, eelgrass beds along the U.S. Atlantic Coast have been declining for many reasons such as disease, eutrophication, and removal associated with shoreline development, boat anchors, and moorings (Orth et al., 2006). Because of its importance in maintaining ecosystem integrity numerous restoration programs have been implemented with modest success. The value of transplanted eelgrass beds as adequate habitat is suspect and may not provide the same benefits as natural meadows. Therefore the protection of existing SAV is a high priority for environmental agencies.

Since many aquaculture operations (in other states) are sited in the same locations as SAV their impact has been investigated. For obvious reasons placement of gear directly on SAV results in damage to the vegetation through direct impact from the gear. Operations that are suspended above SAV have also been shown to have a negative impact on SAV. Rumrill and Poulton (2004) examined the spatial cover of eelgrass and shoot densities underneath suspended oyster lines and found a positive correlation with the spacing between lines. Other studies have suggested that introducing shellfish could benefit SAV. Through the removal of phytoplankton and suspended inorganic particles from the water column by means of filter feeding, bivalves maintain water clarity providing sufficient light for photosynthesis (Porter et. al, 2004). Declines in oyster abundance within Chesapeake Bay contributed in part to the decline in eelgrass because of the loss of this filtering process (Newell and Koch, 2004). Cerco and Noel (2007) incorporated an oyster module into a model used to examine eutrophication issues in

Chesapeake Bay to demonstrate an increase in SAV abundance with an increase in oyster abundance. An example of this link between bivalves and SAV occurred in the tributaries of the Potomac River. Dramatic increases in the abundance of non-native Asiatic clams, *Corbicula fluminea*, during the early 1980'sufficiently reduced turbidity and increased light penetration allowing SAV to become reestablished (Cohen et al. 1984).

In summary, the there are many possible effects of aquaculture on EFH, which depend upon a number of interacting physical factors which need careful consideration in order to minimize detrimental impacts on EFH. In regards to aquaculture in Rhode Island, there are currently no marine finfish aquaculture farms being operated, however due to the greater potential of environmental impact all of the issues should be carefully considered if the interest of such an operation ever arises in the future. The impacts on EFH due to the aquaculture of shellfish have been shown to be quite variable but if conducted properly can have little or no negative effect on the surrounding environment and could possibly be beneficial. **In order to minimize negative impacts on EFH recommendations include the protection of existing beds of eelgrass.** Aquaculture facilities should be limited or restricted in areas where they would be replacing or deterring natural eelgrass beds from growing. Sites should be selected in areas with adequate water flow to alleviate the effects of biodeposition. **Given the current status of local populations, demersal nature of their eggs and evidence for spawning site fidelity winter flounder spawning and nursery habitats should be protected.** And lastly, in the planning and development of aquaculture on a system wide level, consideration of the overall magnitude or scale of operations to is necessary to address large scale effects on EFH.

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Chapter 6
Carrying Capacity

Robert B. Rheault
Moonstone Oysters

The term "carrying capacity" has been used with varying definitions to describe the quantity of something that can be added to an ecosystem before some undesirable impact occurs. Small-scale shellfish aquaculture has been shown to have ecological benefits, but at some point too much of a good thing invariably has negative consequences. Where to draw that line can be a subjective question that depends on which specific consequences are of concern.

In the simplest of terms carrying capacity is determined by the amount of shellfish in a given body of water in relation to the flushing or exchange rate of the water in that basin. When the combined filtration capacity of a population of shellfish consumes an excessive proportion of the phytoplankton in that system before tidal flushing (and the natural reproduction of the phytoplankton in that system) can replenish that plankton, then the shellfish start to dominate the energy flow in that system (Dame and Prins 1998).

When a basin has large populations of filter feeding shellfish and small tidal flux (a long residence time), then the shellfish can dominate the energy flow of the system at the expense of zooplankton (and the fish that feed on the zooplankton). Deep basins with a small tidal flux will have a longer residence time and will not be able to support large shellfish populations. Conversely, shallow basins with relatively large tidal amplitude will be able to support much larger shellfish populations. Higher nutrient levels and moderate water temperatures will speed up the reproduction rate of the phytoplankton and such systems will support more secondary consumers (both shellfish and zooplankton) (Small and Prins 1993).

Dame (1996) compared eleven different water bodies around the world with differing circulation patterns and shellfish populations. For example Narragansett Bay was described as a "well balanced estuary" where 30% of the primary production was consumed by shellfish. Dame estimated that the population of clams in the Bay was capable of filtering the entire volume of the Bay in 25 days. The estimated residence time of the Bay was estimated at 27 days.

The question for resource managers becomes: What is the appropriate proportion of an ecosystem's primary production that should go to shellfish as opposed to zooplankton? There is no simple objective answer to this question. When the biomass of shellfish are able to clear the volume of a basin faster than the water is replenished by tidal action there is the possibility that the shellfish will regulate the concentration and character of the primary production at the expense of the planktonic food web (Dame 1996).

A number of different carrying capacity definitions have evolved and it is important to define these terms before we can discuss the issue in depth.

Definitions: (from Inglis et al. (2000))

i) **physical carrying capacity** — the total area of marine farms that can be accommodated in the available physical space.

ii) **ecosystem carrying capacity** - maximum standing stock that can be supported by a given ecosystem for a given period of time (sometimes referred to as assimilative capacity) (Kuiper)

iii) **production carrying capacity** — the stocking density of bivalves at which harvests are maximized. The "optimized" level of production of the target species. (review by Kaiser and Beadman (2002)) Well-developed models, many good examples.

iv) **ecological carrying capacity** — the stocking or farm density above which unacceptable ecological impacts begin to manifest. From a practical standpoint this process begins with the definition of components of interest (e.g., species or habitats) and acceptable levels of change for each of these (McKindsey et al. 2006b). (no activity is without some level of impact) Also consider positive ecosystem impacts. Few well developed models or examples where this approach has been employed.

v) **social carrying capacity** — the level of farm development that causes unacceptable social impacts.

Introduction:

There has been a great deal of speculation about potential environmental impacts of shellfish aquaculture. Intensive shellfish aquaculture has been implicated in altered nutrient dynamics, changes in phytoplankton populations and energy flows as well as enhanced sedimentation and benthic organic content (review by Cranford et al. 2003).

The feeding activity of bivalve filter feeders results in the packaging of fine suspended material into larger feces and pseudofeces that rapidly settle to the seabed. These activities divert primary production and energy flow from planktonic to benthic food webs (Cranford et al. 2003). Dense bivalve populations (either natural or cultured) may exert a strong influence on suspended particulate matter in some coastal systems through their combined capacity to clear particles from the surrounding water (Dame 1996). Bivalve aquaculture has the potential to alter energy flow at the coastal ecosystem scale, however these sorts of impacts are seldom observed except in extreme cases of intensive bivalve cultivation over large areas (Cranford et al. 2003).

The consumption and deposition of suspended particulate matter by bivalves, as well as the excretion of dissolved nutrients, can play a significant role in controlling the amounts and forms of nitrogen in coastal systems and the rate of nitrogen cycling (reviewed by Dame 1996). The transformation and translocation of nutrients and organic matter by bivalves can exert a controlling influence on nitrogen concentrations in some coastal regions (Dame et al. 1991) and may provide a means of retaining nutrients in coastal areas, where nutrients are recycled within detrital food chains, rather than being more rapidly exported (Jordan and Valiela 1982). Benthic nutrient mineralization can increase at culture sites as a result of the increased organic matter sedimentation, speeding up the rate of nitrogen cycling (Dahlback and Gunnarsson 1981; Kaspar et al. 1985; Grant et al. 1995). These processes can also increase the rate of denitrification (Newell et al. 2002) resulting in lowered nitrogen concentrations. The ammonia excreted from dense bivalve populations may have a significant effect on phytoplankton production (Dame 1996). Bivalve aquaculture may also result in significant nutrient export from coastal systems, as nutrients stored in the cultured biomass are harvested and the nutrients are no longer available to the marine food web (Kaspar et al. 1985).

While all of these impacts on nutrient dynamics have been described as potential impacts, the actual impacts of intensive bivalve culture on coastal nutrient dynamics are poorly understood and difficult to predict. Increasingly, scientists have resorted to numerical modeling of carrying capacity in an attempt to quantify the relationship between different levels of shellfish farming and its environmental effects. Models vary greatly in complexity from simple ratios of flushing rates to filtration clearance rates to simplified 2-D box models and more complex 3-D finite element models with hydrodynamics driving the model, sometimes incorporating complex feedback loops.

Some of the factors that need consideration in the more complex models include
- hydrodynamics (tides, currents, stratification)
- sunlight
- internal sources and sinks (phytoplankton, detritus pool, sediments)
- Food supply and ingestion rates: phytoplankton, detritus, carbon
- Available nutrients (N, P, Si) atmospheric and anthropogenic inputs
- Feedback mechanisms – remineralization, accelerated nutrient cycling
- Competition between cultured stock and wild stock and/or zooplankton
- Population dynamics – growth rates, seasonal changes in rates
- Culture methods, species,

Review of ecological carrying capacity (excerpted from McKindsey et al. 2006)
Increasing evidence shows that the intensive culture of bivalves may have considerable influences on the benthic environment (Kaiser et al., 1998) as well as the concentration and composition of suspended particles and phytoplankton. To date, most research on the environmental effects of aquaculture has focused on benthic processes as they relate to increased deposition of organic matter (Carroll et al., 2003). This focus on benthic processes also ignores the influence of bivalve culture on water-column processes and the organisms that live in association with the bivalves growing in culture.

Most work to date has concentrated on near-field effects (benthic impacts), as opposed to far-field effects (impacts on nutrient cycling and plankton populations). Far-field effects are rarely discussed except to note “negative” effects, largely ignoring potentially “positive” ones (see, for example, Gibbs, 2004). A more holistic approach is needed to determine the influence of bivalve aquaculture on the environment and the ecological carrying capacity of the environment for bivalve culture.

There is a growing body of evidence showing that, similar to artificial reefs, the abundance of fish and macroinvertebrates associated with shellfish farming is substantially enhanced. (Costa-Pierce and Bridger, 2002; Olin, 2002; Davenport et al., 2003, DeAlteris et al. 2004, Tallman et al. 2007). Tenore and González (1976) found that the three-dimensional physical structure provided by mussel rafts provided habitat and food resources that enhance secondary productivity in this estuary while (Chesney and Iglesias, 1979) documented an increased abundance and productivity of macroinvertebrate and fish species. The production of epibiota (e.g., crabs, starfish) on structures in bivalve aquaculture should also be considered in the context of determining the total productivity associated with bivalve aquaculture. The biomass and diversity of such epibiota may be substantial (Tenore and González, 1976; Carbines, 1993; Kilpatrick, 2002) and contributes considerably to the total productivity of the site.

At this time, two main classes of research are being advanced to determine the ecological carrying capacity of ecosystems for bivalve culture. The first of these uses the output from spatially explicit hydrodynamic-dependent particle tracking models to predict organic flux to the bottom. A quantitative relationship between organic flux and a benthic community descriptor is developed and then used to predict the influence of different levels of bivalve culture on benthic community structure (Henderson et al., 2001). Management decisions regarding stocking densities can then be made based on predicted environmental outcomes.

There are a number of problems with this approach, not all of which are unique in a bivalve culture context. First, it is rare to have accurate three-dimensional hydrographic models for every site and development of such models can be costly. Second, the resuspension component of deposition models has not yet been fully developed for bivalve aquaculture. Third, there is some controversy over the validity of the commonly used infaunal trophic index (Word, 1979a,b). Other indices may be more appropriate, although these also need to be validated. Fourth, the model has yet to be fully validated so under certain environmental regimes.

Furthermore, models developed for suspended culture systems are probably not appropriate for bottom culture sites and they do not consider other aspects of bivalve aquaculture, such as dredging for spat and harvesting. Finally, this approach considers only the benthic component and thus its utility in determining the ecological carrying capacity for the entire ecosystem within an area is not known.

The second approach to determining ecological carrying capacity uses mass-balance/food web models. Early conceptual mass balance models involved examining the influence of bivalve culture as a part of the ecosystem (Tenore et al., 1982). More recent work has used ECOPATH (Christensen and Pauly, 1992) to determine the trophic functioning of areas that include bivalve culture in sites around the world (Wolff, 1994, Lin et al., 1999, Stenton-Dozey and Shannon, 2000, Wolff et al., 2000, and Brando et al., 2004). These models differ considerably in complexity and the number of trophic groups considered. Predictably, the presence of bivalve culture promotes short energy pathways with high trophic efficiency and may considerably accelerate nutrient and energy cycling.

As with the benthic deposition model, the mass balance approach also has limitations. First, the models are typically steady-state, ignoring seasonal and temporal variation. Second, the mass balance model (ECOPATH) is not spatially explicit and therefore the model may not be used to differentiate between near-field and far-field effects. Third, many biological variables (life history values, interactions, etc.) are poorly understood. Fourth, most applications of ECOPATH (with ECOSIM) do not adequately address uncertainty in data inputs and model structure (Plaganyi and Butterworth, 2004). And finally, this method, typically only considers the growout phase of shellfish culture; ignoring the potential impacts of activities such as seeding and harvest.

In sum, most of the potential measures of ecological carrying capacity consider only a single or a restrained number of ecosystem components (Broekhuizen et al., 2002). As we learn more about the functioning of marine ecosystems it is likely that our understanding of the factors affecting ecological carrying capacity will evolve, and we need to develop a flexible approach to allow for these changes.

Knowledge gaps and research needs for ecological carrying capacity studies:

– Studies must be done to better understand the environmental interactions (positive and negative) of various types of bivalve culture including all farming activities from seed collection to ongrowing, harvesting and processing.
– Existing models must be made spatially explicit.
– Temporal and seasonal variation must be built into existing models.
– Models must be validated in a number of locations.
Appropriate management tools, such as Fuzzy Expert Systems, must be developed to aid in decision-making.

Where do we stand in Rhode Island? - Estimates of Filtration Capacity

Since numerical modeling is expensive, time consuming and relies on extensive knowledge about the interdependence of all of the major elements of a given ecosystem, it is tempting to make some crude “back of the envelope calculations” to see whether “significant” impacts are “likely” to occur at a given level of production.

For instance we can calculate the combined filtration capacity of a given biomass of bivalves. This number can then be compared with the tidal flux of a given body of water and a subjective judgment can be made to assess whether such filtration impacts are acceptable.

Such an exercise was done for the largest oyster farm in the state (Spatco, Ltd.). It was estimated that the combined filtration capacity of the oysters on the site cleared approximately 10 to 40 million gallons each day.
Estimates of oyster filtration rates vary widely from 50 to 240 liters per day per gram tissue dry weight (typical weight for a market size oyster ~2gdw) (Haven and Morales Alamo 1970). Using these estimates and estimates of the numbers and sizes of oysters held on Spatco’s leases in Point Judith Pond it has been estimated that these animals filter

between 0.36 to 1.8% of the total pond volume each day. (see attached spreadsheet) This translates to clearance times of 55 to 275 days.

These filtration rate estimates are probably high because they do not account for refiltration of water that has already been filtered by upstream animals held in dense concentrations. Whether this represents a "significant percentage" is an entirely different question. To answer this we need to evaluate food webs and energy flows to various trophic levels and we should take into account the fact that, like many coastal estuaries, Point Judith Pond suffers from excessive phytoplankton concentrations caused by excessive nitrogen inputs, to the point that eelgrass is not receiving adequate sunlight (Newell and Koch 2004).

Unfortunately we do not have good estimates for the biomass of wild filter-feeding shellfish in the pond, so we cannot make an accurate estimate of the combined clearance capacity (wild and cultured shellfish). Judging from the extremely high chlorophyll concentrations observed in the pond during the summer months (often as high as 10 μgChl/L (Rheault 1995) it is probably safe to assume that the combined clearance time (Dame 1996) is nowhere near the residence time in this pond.

Where do we stand in Rhode Island? - Extrapolation to Other Models of Ecological Carrying Capacity

Another crude approach to estimating carrying capacity is to extrapolate from other numerical models and see if they can be adapted to our situation. This is how the much-discussed "5 percent" number was developed.

Jiang and Gibbs (2005) recently attempted to determine the carrying capacity of a large bay in New Zealand for mussel culture using a mass-balance approach and the ECOPATH model. The question that the model attempted to answer was: What level of green mussel aquaculture could be supported in their system before impacts to the energy flow and trophic dynamics would become apparent? Their model predicts that the production carrying capacity of the bay was 310 tons per km^2per year, and the ecological carrying capacity of the area was 65 tons per km^2 per year. Below this lower level their model predicts no significant changes in energy fluxes within the system's food web.

If we assume that all of the elements of their model are directly applicable to our system (a big assumption for reasons I will go into below) and extrapolate the 65 ton/km^2 number to Point Judith Pond and use stocking densities typical of Rhode Island farms, we come up with an estimate of 5% of the total area of the pond that could be used for shellfish culture without seeing significant changes in the energy fluxes in our system. (see attached table for the calculation).

To apply this particular model to Point Judith Pond in Rhode Island requires that we ignore several obvious differences. First, the bay in New Zealand that they were modeling is about the size of the entire state of Rhode Island (4500km^2). There are no doubt significant differences between the two ecosystems, the food web dynamics and the energy flows. The New Zealand bay supports a finfish fishery with annual landings

Filtration Capacity of Spatco's Peak Annual Oyster Biomass

size	number	filtration rate	**Low rate est.**	
	count	liters/day	liters/day	cubic meter/d
4-6 inch	150,000	100	15,000,000	15,000
2-4 inch	1,000,000	25	25,000,000	25,000
1-2 inch	3,200,000	2	6,400,000	6,400
		total filtered	46,400,000	46,400

size	number	filtration rate	**high rate est.**	
	count	liters/day	liters/day	cubic meter/d
4-6 inch	150,000	480	72,000,000	72,000
2-4 inch	1,000,000	120	120,000,000	120,000
1-2 inch	3,200,000	12	38,400,000	38,400
		total filtered	230,400,000	230,400

Area of Point Judith Pond

1,574	acres =	6,369,978	square meters	at low rate est.	at high rate est
total volume - assume avg. depth 2m				percent filtered	percent filtered
12,739,956	cu meter total volume			0.36%	1.81%
tidal prism - assume avg. 1m tide					
6,369,978	cu meter per tide			0.73%	3.62%
Clearance time				275 days	55 days

Predicted Ecological Carrying Capacity - The 5% Solution
(that biomass of cultured shellfish that could be added w/o significant impact)
from Jiang and Gibbs (2005) Aquaculture v244:171-185

Using a linear food web model based on a 4500km2 bay in New Zealand
Authors predict that 65 tons per year could be harvested annually from each km2
without "significantly changing the major energy fluxes or structure of the food web"

Area of Point Judith Pond = 1574 acres = 6.37 km2
65 tons/km2 x 6.37 km2 = 414 tons per year is theoretical max biomass for the pond
at an average production biomass of 5 tons per acre = 82.8 acres needed to produce 414 tons
82.8 / 1574 = 5.3%

of 6000 tons, an aquaculturally enhanced scallop fishery that lands an average of 42 tons per year and an additional 500 tons of other wild shellfish species.

Lastly, and perhaps most significantly, the standing stock of phytoplankton in Point Judith Pond is much higher (Chl-a concentrations of 10 _g/l are not uncommon) (Rheault 1995) than that of the open water conditions of the New Zealand model. And since nutrient levels are likely to be much higher in shallow eutrophic waters we can predict that phytoplankton doubling times should be faster as well. Both of these suggest that Point Judith Pond should be able to support greater stocks of both bivalves and planktonic filter feeders (Dame and Prins 1993).

Recommendation: Attempt to secure funding to develop models that will allow us to accurately predict the ecological carrying capacity of typical aquaculture sites in Rhode Island.

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Chapter 7
An ecosystem approach to marine aquaculture
Summary of the FAO Working Group on an Ecosystem Approach to Aquaculture

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At an FAO Workshop on an ecosystem approach to aquaculture (EAA) in Mallorca, Spain in 2007, an EAA was defined as:

"a strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems".

Principles, Key Issues and Scales

Soto (2007) developed the following three principles and key issues of an EAA at the different scales defined below:

PRINCIPLE 1: *Aquaculture should be developed in the context of ecosystem functions and services (including biodiversity) with no degradation of these beyond their resilience capacity.*

The key issue is to define or estimate resilience capacity or the limits to "acceptable environmental change". States Soto (2007), "In the case of biodiversity, local declines may be acceptable (e.g. below fish cages) as long as such losses can be compensated and restored, at least at the water body scale, in order to preserve ecosystem function and services. For example, after a cage farm operation is halted it is expected that the relevant biodiversity recovers. Many environmental impact assessments touch on these issues and yet the tools to address them are either not well developed or used; a promising one is that offered by risk assessment. Relevant questions remain: How much biodiversity are we willing to loose?; at what scale levels?; at what costs?; and how are costs balanced with the benefits from aquaculture? On the other hand, aquaculture impacts need to be seen in context by comparing them with those from other food producing sectors such as agriculture and livestock farming. Most terrestrial food producing systems, especially intensive ones, have been achieved after drastically transforming the landscape (e.g. clearing native forests and grasslands for agriculture with permanent impacts on the original biodiversity); but we historically grew used to those impacts, while intensive aquaculture is a rather new development worldwide. Efforts need to be made in order to permanently monitor aquaculture effects on biodiversity to make sure that such effects do not result in serious/significant losses of ecosystem functions and services. In this respect real values of ecosystem goods and services should be integrated into micro- and macro-environmental accounting."

PRINCIPLE 2: *Aquaculture should improve human-well being and equity for all stakeholders.*

Key Issues

This principle ensures that aquaculture provides equal opportunities for development; and that the benefits from aquaculture are properly shared, while the activity does not result in any detriment for any society, especially for the poor. It ensures both food security and safety as key components of societal well-being.

PRINCIPLE 3: *Aquaculture should be developed in the context of other sectors, policies and goals.*

Key Issues

This principle recognizes the important interactions between aquaculture and the larger ecosystem, in particular, the influence of the surrounding natural and social environments on aquaculture. Aquaculture does not take place in isolation, and, in most cases is not the only human activity impacting on water bodies, which worldwide are more heavily impacted by agriculture, industrial activities, trash and sewage wastes. This principle also acknowledges the opportunity of coupling aquaculture activities with other producing sectors in order to promote materials and energy recycling.

Spatial Scales

There are three physical scales of interest in this review regarding the planning for and assessment progress towards an ecosystem approach to aquaculture: farm, water body/watershed/aquaculture zone/regional, and global. This breakdown is artificial, since issues at each scale are overlapping, and there are many important similarities among different scales.

Farm Scale: Planning and Assessment

Planning for the farm scale is easily defined physically and could, for example, be few meters beyond the boundaries of farming structures. However the increasing size and intensity of some farms (e.g. large scale shrimp farming or salmon farming) could affect a whole water body or watershed. Most planning for an EAA has been conducted at this scale.

Assessment of an EAA at the farm scale entails an evaluation of planning and implementation of economic, ecological, and social programs that account for the wider ecosystem and social impacts of farm-level aquaculture developments, including impact assessments, use of better management practices, and use of restoration, remediation, and mitigation methods. Proper site selection, production intensity levels, use of species (exotic vs. native), use of appropriate farming systems and technologies, and the social-economic impacts at the farm level are considered.

Regional Scale: Coastal Water Body/Aquaculture Zone: Planning and Assessment

Planning and assessment of progress towards an EAA for the water body scale will address circumscribed coastal/marine areas as well as impacts on aquaculture zones/regions and watersheds. Coastal/marine aquaculture can also have impacts on inland watersheds.

Planning for an EAA at aquaculture zone/regional level is more relevant to social/economic and political issues, but there may be some common and very relevant ecosystem issues; for example, diseases, seed and feeds trade, climatic and landscape conditions, etc. In practical terms many management issues are similar at the watershed and aquaculture zone/region.

Assessment of an EAA at this scale will address technical issues of farm interactions and densities, etc., as well, assessment of aquaculture's inclusion as a part of governance frameworks, e.g. as a part of, or separate from, an overall framework of other natural resource systems such as fisheries and forestry, integrated coastal zone management or integrated land-water resource management planning and implementation. Assessment would consider regional issues such as escapees, disease transmission, contamination to/from aquaculture, and user competition/conflicts for land and water use. Social considerations at the regional scale would be, for example: aquaculture's role in rural development, comprehensive planning for the beneficial multiplier effects of aquaculture on jobs and the regional economy, and considerations of aquaculture's impacts on indigenous communities.

A regional ecosystem approach to aquaculture also needs to consider the governance of aquaculture developments, including existing scenarios and alternatives for human development. While an EAA should be the responsibility of a lead aquaculture agency, its full implementation will require government to consider alternative methods of governance and use innovative approaches so that agencies responsible for managing activities impacting aquatic ecosystems (e.g. capture fisheries, coastal zone development, watershed management organizations, agriculture, forestry, industrial developments) can regularly communicate, cooperate, and collaborate. The design of aquaculture management zones could be a relevant tool, particularly when the benefits of integrated aquaculture, polyculture, or integrated aquaculture–fisheries initiatives are being considered.

Global: Planning and Assessment

Planning for an EAA at a global scale considers impacts of the global aquaculture industry for some commodity products (e.g. salmon and shrimp), and industrial progress on ecosystem (natural and social ecosystem) issues of global relevance.

Assessment of progress towards an EAA entails evaluation of issues such as availability of agriculture and fisheries feedstocks for aquaculture feeds, and the broader ecosystem, economic and social impacts of aquaculture on fisheries and agriculture resources, and society's infrastructure. Applications of tools such as lifecycle assessments of aquaculture commodities are useful at this level. Other relevant issues include markets and marketing, social sustainability (social capital, goods and social opportunities, and the application of innovative social enterprise management guidelines and tools in the aquaculture industry.

Needs for a Tighter Coupling of Aquaculture Science, Policy and Management for a Widespread Adoption of an EAA

An EAA will require a much tighter coupling of science, policy, and management. Aquaculture has intimate connections not only with capture fisheries, but also with agriculture, markets, and marine policy and regulatory environments. Accelerated production of aquatic proteins cannot be evaluated in a vacuum separate from other types of land-based animal agriculture or ocean-based capture fisheries since these food systems use similar (and sometimes competing) inputs and outputs, face similar policy and regulatory environments and markets, and have to deal with common consumers and decision-makers. More holistic planning perspectives are needed to ensure the survival and plan the future of traditional coastal fishing and aquaculture communities, and to link aquaculture science, industry, and society in order to design effective policies, practices and technologies to address the many challenges ahead.

Aquaculture is not a uniform "industry" or a standard set of practices easy to classify—or label—and regulate. There is a wide diversity of systems and species that can be classified in many different ways. For example, the integration of aquaculture, agriculture and animal husbandry on small farms in Asia creates definable aquaculture ecosystem types that closely resemble natural ecosystems having their own structure, closely-coupled nutrient recycling pathways, and ecological management strategies.

Aquaculture should be pro-active, promote and develop itself as the world's most ecologically integrated industry, and adopting this new strategy—that of a community-based, sustainable, ecological aquaculture industry that produces ecologically and socially certified produce—adopting input management strategies and codes of better practices. In this regards, the recent international guidelines developed for shrimp farming are a major advance (FAO/NACA/UNEP/WB/WWF, 2006).

In the 21st century, aquaculture developers will need to spend as much time on the technological advances coming to the field as they do in designing ecological approaches to aquaculture development that clearly exhibits stewardship of the environment. For aquaculture development to proceed to the point where it will be recognized worldwide as the most efficient contributor to new protein production—clear, unambiguous linkages between aquaculture and the environment must be created, fostered, and communicated—and the complementary roles of aquaculture in contributing to environmental sustainability, rehabilitation and enhancement must be developed and clearly articulated to a highly concerned, increasingly educated and involved public.

An ecological approach to aquaculture brings modern sustainability, ecological methods and systems thinking to aquaculture, incorporating social, economic, and planning for its wider social and environmental contexts in fisheries and coastal zone management. Ecological aquaculture will create new opportunities for a more diverse group of professionals and entrepreneurs to get involved in aquaculture since new advances will be needed not only in treatment technologies, production management and feed technologies; but also in energy technologies, information management, public information and outreach, community facilitation and networking.

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