# Shellfish Aquaculture and the Environment – An Industry Perspective

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## Introduction

Marine aquaculture has become an increasingly important contributor to global food production necessary to support an expanding world population estimated at 6 billion today and expected to grow to 8 billion by 2028 (US Census Bureau 2009). Global demand for seafood products alone is projected to increase by 70 percent in the next 30 years as harvests from traditional capture fisheries either remain stable or continue to decline. Currently, production of seafood from fish and shellfish production including aquaculture provide 15% of average annual animal protein consumption to 2.9 billion people (FAO 2008). At the same time, coastal marine ecosystems worldwide that support wild shellfisheries are threatened by pollution, habitat degradation, overharvesting and a growing dependence on common pool-resources among other concerns (Jackson et al. 2001; Lotze et al. 2006; Halpern et al. 2008; Beck et al. 2009; Smith et al. 2010), lending an increasingly important role for sustainably produced and managed intensive marine aquaculture to fill the widening gap in the world’s capacity for food production. The shift to increasingly intensive aquaculture operations where suitable coastal sites exist, coupled with either peak extraction or serial depletion of many fisheries stocks has stimulated discussion about how humans utilize and ultimately manage aquatic resources in the future (Pauley et al. 1998; Marra 2005). What remains clear is that marine aquaculture will likely continue to provide an increasingly significant share of fish and shellfish based resources (Costa-Pierce 2002), such that combined fish and shellfish aquaculture will in 2009 for the first time supply half of the world's seafood supply (FAO 2008). This is an important milestone for marine aquaculture in general as the world's attention for millennia has been on increasingly efficient extraction of marine resources without significant attention paid to effectively manage or replenish stocks until relatively recently, and mainly only in developed portions of the world (Worm et al. 2009).

Policy debate flourishes over the array of potential solutions necessary to maintain overall ocean health and the ability of near-shore marine ecosystems to remain resilient to climate change, pollution including excess nutrient runoff and other threats associated with anthropogenic inputs to near-shore habitats critical to marine plants and animals. Yet marine ecosystems are counted upon to provide the vast ecological and economic benefits to earth and its inhabitants. To that end marine aquaculture including shellfish culture has the potential to supply an increasingly valuable contribution of high quality protein-based foods for humans in cost-effective and sustainable sea-based production systems. Production from shellfish culture alone has greatly expanded. As seen in Figure 1, shellfish production through aquaculture has greatly increased (in particular for oysters and clams) with the majority produced in Asia (FAO 2008).

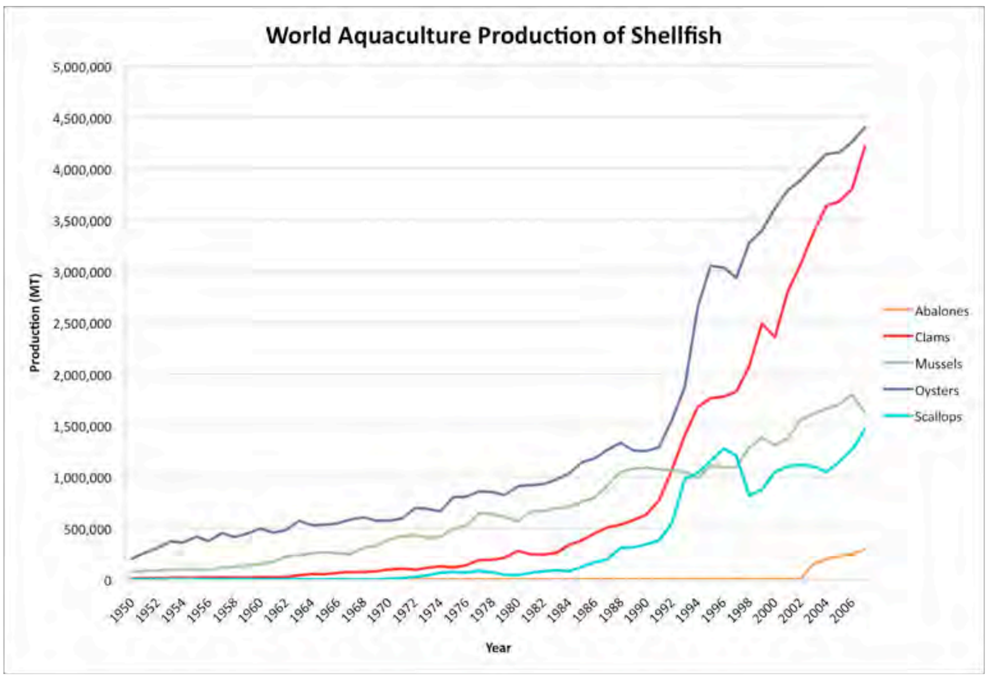


**Figure 1.** Shellfish aquaculture production for abalone, clams, mussels, oysters and scallops for years 1950-2006. Source: FAO Fisheries Department, Fishery Information, Data and Statistics Unit. Fishstat Plus: Universal software for fishery statistical time series. Version 2.3 2000.

An ecologically and economically sustainable shellfish industry large enough to materially supply growing populations with seafood depends upon four critical components. First, a viable industry depends on the maintenance of certified growing waters located in productive, sheltered waters with access to marine shorelines. Shellfish are best grown in areas that are free from pollution, rich in productivity and readily accessible by a trained work force. Second, a stable and predictable regulatory framework that is responsive to changes in industry practices remains an integral requirement for successful aquaculture. This includes industry participation in developing in concert with regulators environmental codes of practice (e.g. Best Management Practices) that remain flexible to changes in policy, scientific information, industry innovation and markets. Third, a strong infrastructure for processing, transport, marketing and sales of product and for monitoring pollutants and other factors that can affect shellfish quality and safety. Fourth, an educated public that embraces the quality and variety of seafood products produced through marine farming is critically important. Public awareness of ecological and regulatory issues affecting the marine environment is high and growing and it is largely incumbent on the marine farming sector to demonstrate its commitment to maintaining the biological integrity of the environments they utilize for farming shellfish.

Shellfish aquaculture has not historically been subject to the same level of public and regulatory scrutiny that intensive fish and shrimp culture operations have become accustomed. This view is changing. In the developed world public interest is often less on enabling food to be grown from seafarm based production and more on ensuring the public’s multiple-use of shorelines, the maintenance of the ecological integrity of coastal marine environments to the exclusion of other uses and the preservation of viewscapes. Attempts to increase utilization of marine and shoreline environments for shellfish aquaculture has resulted in both existing and proposed operations receiving greatly increased public scrutiny over the last 30 years. Much of the public opposition to shellfish farming has been expressed as either real or perceived impacts on the environment due to specific shellfish aquaculture and fishery operations. Recent reviews have focused on the suite of ecological effects associated with shellfish aquaculture for a variety of habitats (see Kaiser et al. 1998; Nizzoli et al. 2007; Dumbauld, et al. 2009) and a voluminous literature has developed describing species specific environmental and ecological interactions associated with shellfish aquaculture. Much of this work is summarized in this volume.

This chapter provides a perspective on the role the shellfish industry has in maintaining the environmental integrity of coastal environments suitable for shellfish aquaculture and associated commercial shellfisheries. First, the evolution of the shellfish industry in the US Pacific Northwest is described with specific reference to the advocacy and stewardship role shellfish growers have long held relative to the development and maintenance of marine water quality and land-use standards necessary to support a viable industry. The second section considers the variety of Best Management Practices (BMPs) that have been developed to help integrate culture practices with the best available science and other public concerns relative to environmental effects associated with shellfish aquaculture. Together, with a short discussion of third party sustainability certification efforts, a perspective is provided to suggest that the shellfish industry will continue to play an integral role into the future in helping shape public policy with regard to sustained multiple-use of near-shore marine environments.

## I Shellfish farmers and harvesters history of water quality protection and stewardship roles

### *a. shellfish growers as water quality advocates*

The shellfish industry has long been an advocate for protecting and restoring water quality. Simply speaking, clean water is the life-blood of the industry. This necessity is due to the historical practice in Europe, North America and Austral-Asia of consuming shellfish live - the case in particular for oysters and clams. This long tradition has the potential to increase the public health risk and subsequently requires the waters they are harvested from be exceptionally clean. In the United States public health controls for shellfish were initiated in 1925 with the creation of the National Shellfish Sanitation Program (NSSP)(NSSP 2007). This program's development was triggered by a large number of illnesses attributed to the consumption of raw oysters, clams and mussels in the late nineteenth century and early twentieth century. A large typhoid fever outbreak in 1924 with illnesses in New York, Chicago and Washington, D.C. linked to the consumption of sewage-contaminated oysters was the final impetus for the creation of the NSSP. Unable to assure consumers that their products were safe to eat, the shellfish industry joined with state and local public health officials to request the Surgeon General of the United States Public Health Service to develop necessary control measures to ensure a safe shellfish supply.

The NSSP ensures that shellfish are harvested from waters that meet stringent water quality standards and that they are transported, handled and processed in a sanitary manner. Since the inception of the NSSP both shellfish harvesters and growers have been strong advocates for water quality.

Shellfish growers are arguably more ardent water quality advocates and resource stewards than wild harvesters with the key distinction being that shellfish growers own the shellfish they grow and either own or lease the land on which they farm. De Alessi (1996) explored this phenomenon in Washington State where shellfish growers typically either own or lease the tidelands they farm. De Alessi notes that "Oyster growers have had a profound effect on Willapa Bay and elsewhere in Washington………… Ownership ties oyster growers to a particular spot and gives them a vested interest in protecting the local environment; their livelihood depends on it."

In an effort to expand awareness and demand for clean marine waters, Taylor Shellfish Farms(TSF), Washington State's largest producer of farmed shellfish has joined efforts in other regions of the state and country to encourage shellfish gardening. Through sponsored seed and gear sales TSF provides shellfish seed, culture equipment, information and encouragement to shoreline residents to create shellfish gardens. In the process shoreline owners learn about the importance of ensuring their septic systems are functioning properly, controlling pet and domestic animal wastes and the fate of herbicides and pesticides placed onto lawns and gardens. Like commercial shellfish growers, private shellfish gardeners have become strong water quality advocates within their communities. Similarly, community shellfish gardens are springing up in the Pacific Northwest as they have elsewhere in the United States and for similar reasons commercial shellfish growers have encouraged and supported these publically managed ventures. Community shellfish gardens are usually managed by environmental non-governmental organizations and provide similar water quality education opportunities. In many cases, when the shellfish crops are sold a portion of the revenue is used for water quality related projects. In the Chesapeake Bay and elsewhere on the U.S. East Coast where nutrient pollution is a demonstrable problem shellfish gardening is encouraged for the ecological services shellfish provide through filtration activities and removal of excess nutrients at harvest.

Besides toxins, heavy metals and organic pollutants that can impact the safety of shellfish cultivated for human consumption, shellfish growers are also impacted directly by pollution that directly affects shellfish health. Molluscan shellfish and their larvae in particular have been long demonstrated to be highly vulnerable to degraded water quality. Impacts to the health of cultured shellfish crops also stimulate environmental advocacy by shellfish growers.

A classic example in Washington State illustrates the relationship between a viable shellfish industry and clean water. During the first half of the 20th century pulp and paper industries developed and thrived in the Pacific Northwest during a period that shellfish growers were focused on the culture of both native oysters (*Ostrea lurida*) and the introduced Pacific oyster (*Crassostrea gigas*). Untreated sulfite liquor effluent and other waste discharge from the pulp mills fouled bays and destroyed oyster beds in various parts of Puget Sound. Particularly hard hit were native oyster beds in southern Puget Sound and around Bellingham in northern Puget Sound. To protect their crops and tidelands oyster farmers responded by suing the pulp mills and lobbying the state legislature and Congress for laws and regulations to address regulations for pulp mill effluent. It was an unpopular fight in local communities as it generated conflicts among different sectors (e.g. timber producers, pulp and paper mills and shellfish producers) whose livelihoods collectively depended upon locally generated resources (Steele 1957). Oyster growers played an integral role in this dispute and as a group responded with programs designed to generate public awareness of the relationship between pulp mill effluent and declining oyster populations (Figure 2).

Significantly, continued shellfish industry lobbying of the state legislature in 1945 incited the creation of the Washington

Pollution Control Commission (now the Washington Department of Ecology). Water quality standards were established at that time along with a control board to enforce regulations.

Unfortunately, the pulp mills continued to pollute. A 1957 letter by oysterman Ed Gruble to the Seattle Post Intelligencer newspaper claiming that "Puget Sound has almost become a marine desert'………75 percent of the raw liquor still goes directly into Bellingham Bay, and the bay for a considerable distance from the pulp mill is black as ink." (cited from Gordon et al. 2001). Gruble and other oysterman testified repeatedly before Congress in Washington DC. These efforts by Washington's oystermen contributed to the enactment of the Clean Water Act (CWA) in 1972.

While the CWA was largely effective at stemming effects of point source pollution, shellfish growers continue to be plagued by nonpoint source pollution. Today, shellfish growers remain active both individually and through the Pacific Coast Shellfish Grower's Association (PCSGA) lobbying for more stringent storm-water and onsite sewage laws and regulations.

**b. Solutions to resolve use conflicts associated with shellfish culture development and maintenance with an emphasis on U.S. West Coast examples.**


**Figure 2.** Washington State shellfish growers were actively engaged in water quality initiatives in the 1950's. Pulp mill effluent and its effect on oysters was a galvanizing issue and helped focus oyster growers on threats to the marine environment. (Photos used with permission from David Steele from *The Immigrant Oyster (Ostrea gigas) Now Known As The Pacific Oyster*

Shorelines where shellfish are grown in the United States and around the world are also popular places to reside. Population growth in coastal counties has been dramatic. In the contiguous United States coastal counties are home to 53% of the nation's population, or more than 148 million people. By 2015 the coastal population in the United States is expected to reach 165 million people, or an average density of 327 people per square mile (NOAA 1998a; USDC 2001). Globally, approximately 37 percent of the world's population lives within 100 kilometers (62 miles) of the coastline and 50 percent reside within 200 kilometers (124 miles) (Cohen et al. 1997; Hinrichson 2001). The increased popularity of coastal living not only contributes to water quality problems but it also results in escalating conflicts over land use. The land use conflicts facing shellfish farmers are similar to those that terrestrial farmers and foresters experience as historic resource production areas are increasingly used for both housing and recreation. Conflicts arise when new residents unaccustomed to working waterfronts move to shorelines having historic shellfish operations or when changes occur in the species cultivated that result in the use of more intensive culture methods. Conflicts also arise when shellfish culturists expand to locate new operations adjacent to previously developed shorelines with other established water dependent uses.

Some common user conflicts include: aesthetic impacts, noise, lighting and hours of operations, physical interference with recreational or commercial fishing and recreational use of the shoreline.

Comprehensive land-use planning coupled with zoning can be useful to reduce use conflicts, preserve existing shellfish culture operations and provide opportunities for growth of the shellfish aquaculture industry. Together, land-use planning and zoning are critical tools used for addressing terrestrial land use conflicts. Unfortunately, these approaches have been almost universally underutilized when considering use conflicts in marine and shoreline environments. One consequence of this lack of planning and zoning for industrial uses of the marine environment is that both long-standing and new shellfish culture operations are often challenged by shoreline opponents, most usually during the permitting stage for any expanded farm operations or the establishment of new farms. Challenges to most farm operations usually result in significant delays and increased costs that have significantly impeded the growth of the shellfish industry in much of the developed world over the last 30 years.

As has been the case elsewhere, opposition to shellfish aquaculture development is often generated at the local or regional level and Federal support for shellfish aquaculture has been positive but generally limited by inadequate funding. In 1990 Congress created in Section 309 of the Coastal Zone Management Act a program of Coastal Zone Enhancement Grants to enhance state programs relative to eight national priorities. In 1996 Congress added aquaculture as a ninth priority. The act provides funding for the "Adoption of procedures and policies to evaluate and facilitate the siting of public and private aquaculture facilities in the coastal zone, which will enable States to formulate, administer, and implement strategic plans for marine aquaculture". Coastal zone management programs are encouraged by NOAA to use this funding to develop and enhance regulatory planning and intra-governmental coordination mechanisms to provide meaningful state participation in the management of aquaculture, to balance the uses of coastal and ocean resources, to coordinate with existing authorities and to minimize user conflicts. Unfortunately funding for this program has been limited and most states have opted to use what funding is available for priorities other than aquaculture.

In the U.S. Pacific Northwest where commercial shellfish culture has had a long, historical presence extensive new residential shoreline development has been intense. As a consequence use conflicts between shoreline owners and shellfish farmers have increased, especially in recent years as more intensive forms of shellfish culture have been adopted by the industry (Figure 3). Shellfish growers in Washington State have taken both proactive and reactive measures at the Federal, State and Local levels to address the conflicts.

**Figure 3.** Intensive geoduck farming operations on intertidal beaches in close proximity to upland property owners have generated resource use conflicts in Washington State. (Photo Credit: Jon Rowley)

Washington State's primary law for land use planning is the Growth Management Act (GMA). One of the main goals of GMA is to identify and preserve commercial resources including timber, agricultural and mineral resource lands. Shellfish growers have made the case recently that commercial shellfish tidelands are also resource lands that are deserving of protection under the Act. This measure was omitted when the law was passed and the growers have proposed legislation to rectify this problem and hope to bring commercially valuable shellfish tidelands under the umbrella of the GMA. If successful, use conflicts should diminish over time as purchasers of shoreline property are notified that the tidelands adjacent are zoned for commercial shellfish culture and what types of activities might be expected on those lands. Water quality should improve as well as counties adopt more stringent septic and storm water regulations to protect tidelands zoned for commercial shellfish culture.

At the local level, Washington's Shoreline Management Act (SMA) regulates shoreline development through the implementation of Shoreline Master Programs (SMPs). To ensure that policies and regulations are both supportive and reasonable and that irresponsible growth doesn't place their livelihoods in jeopardy shellfish growers have again made a conscious effort to participate with local planning commissions, conservation districts and service on boards of non-governmental organizations and other entities who share a common agenda of protecting water quality and conserving resource lands.

Outreach and education by shellfish growers is also effective at reducing user conflicts. A number of farms and grower organizations provide information through websites, videos and flyers, host or sponsor tours, shellfish festivals and receptions that inform the public and policy makers about the industry. Growers regularly contribute time, funding and product to assist fundraisers for local not-for-profit civic or environmental organizations.

Several salmonid fishes in the Pacific Northwest listed in recent decades as threatened or endangered under the Endangered Species Act occupy habitat for a part of their life cycle that overlaps intertidal shellfish beds. The Magnuson Stevens Act subsequently mandated that Essential Fish Habitat (EFH) for federally managed fish species be identified and protected. While shellfish beds can provide critical and essential fish habitat by themselves, the activities associated with shellfish farming can potentially have adverse impacts on fishes utilizing shellfish beds for habitat. For these specific reasons the PCSGA pursued the development and implementation of Best Management Practices (BMP) in the mid 1990's. BMPs or Environmental Codes of Practice (ECOP) as they are sometimes called have helped circumvent the need for formal regulations and provided growers with a "social license" to operate where they have been successfully developed and implemented. Formal regulations and use conflicts emerge where growers have not developed or have failed to adequately implement BMPs. The section following further describes how BMPs have specifically helped integrate regulatory reform with shellfish farming practices.

In March 2007 in an effort to improve consistency of federal permitting of shellfish culture, the U.S. Army Corps of Engineers established a new programmatic permit. Nationwide Permit 48 covers all existing shellfish farms prior to March 12, 2007. This permit requires consultation by the National Marine Fisheries Service and U.S. Fish and Wildlife Service as well as Clean Water Act certification and approval by states that it is consistent with the Coastal Zone Management programs before farms are technically covered. BMPs under development and knowledge of the science about environmental effects have proven beneficial in the NWP 48 consultation process with NOAA, USFWS and the Army Corps.

Farm equipment and debris lost from shellfish culture operations either during storms or from simple carelessness is a growing problem for growers. Materials escaping the confines of marine farms and subsequently deposited on public and private beaches significantly erodes public perception of shellfish aquaculture. Growers recognize this as an issue and regularly patrol their shorelines in the vicinity of their farms to pick up loose materials (Figure 4). Growers are also seeking better means to secure culture equipment, reduce the amount of plastics used and employ recyclable and biodegradable materials. In the

Pacific Northwest growers organize geographically broad and coordinated beach clean-ups twice a year. In southern Puget Sound, a large group of companies and representatives from local tribes participate in collecting debris from over one hundred miles of beach during these tightly coordinated clean-up events and all materials coming from aquaculture sources are sorted and quantified by type and area of origin. This information is used to identify and work with specific growers to stop the proliferation of debris at the source. Self-policing of practices that do not serve the industry's collective benefit has proved to be an important tool for reducing use conflicts.

**Figure 4.** Shellfish growers in Washington State lead volunteer efforts for annual beach cleanup activities to collect wayward or discarded aquaculture derived and other debris  from beaches in Puget Sound. (Photo Credit: William Dewey).

The Coastal Zone Management Act (CZMA) is due for reauthorization. At the federal level growers are engaged to ensure that when the CZMA is reauthorized it includes incentives and/or requirements for aquaculture planning for state waters and the preservation of working waterfronts. There is increased pressure as well for expanding domestic aquaculture production, developing ocean energy alternatives (wind, wave, current, thermal) and expansion of offshore oil production in the U.S. Exclusive Economic Zone (EEZ). The potential for increased user conflicts over completing uses has resulted in policy makers to increasingly utilize marine spatial planning as a tool to identify synergies among user groups and avoid conflicts between proposed uses. In 2009 the Obama Administration formed an Interagency Ocean Policy Task Force to develop recommendations for effective coastal and marine spatial planning. In March 2010, Washington's Governor Gregoire signed a bill into law establishing a process to conduct marine spatial planning for the State's marine waters. Shellfish growers in the US Pacific Northwest believe these efforts will help address the user conflicts which are negatively impacting their businesses.

The history of the shellfish industry as advocates for clean water and land land-use policy as it relates to shellfish aquaculture in the US Pacific Northwest serves as a lens through which to view user conflicts elsewhere. The lessons learned in

Washington State are similar to those in other parts of the developed world where conflicts over resources are both common and increasing. As the public expands into rural areas for first and second home development and increased recreational opportunities, traditional rural economies based on resource extraction and farming are often targeted for reform and greater regulation. To combat these trends the shellfish industry has adopted the tactics described above to better engage the public. These efforts have a record of mixed success and are largely viewed as stopgap measures to enable marine farming to continue to the extent possible. It is likely that increased BMP development and implementation coupled with a greater emphasis on marine zoning will be necessary in the future to accommodate growth in the shellfish aquaculture industry.

## II Best Management Practices (BMPs), the shellfish industry and the role of available research

### a. Description, development and implementation of Best Management Practices for shellfish aquaculture

As described earlier a BMP is a tool defining and/or prescribing types of activities or operations to meet some type of production, environmental or engineering goal. BMPs describe methods or techniques found to be the most effective and practical means in achieving an objective while making the optimum use of natural and human resources. When referencing environmental goals BMPs are often used synonymously with Environmental Codes of Practice (ECOP). BMPs and ECOPs are typically created by industry members, often in concert with non-governmental organizations and regulatory agencies. Coincident with the expanded application of marine environmental policies and regulations coupled with recognition of the role BMPs have in helping conserve and manage aquatic resources, the development and incorporation of BMPs by the shellfish aquaculture industry is increasing. Well-designed BMPs offer guidance to both the industry and regulatory agencies for a broad range of practices including regulatory compliance, training, farm siting, planting and harvesting, pest, predator and disease control, waste management, vessel/vehicle operations and shipping/packaging. BMPs are often tailored to apply to industry specific harvest, processing and production practices to ensure shellfish products meet public health and safety standards. These practices are typically covered under Hazard Analysis and Critical Control Points (HAACP) protocols, usually administered by State government public health agencies in concert with the USFDA through the Interstate Shellfish Sanitation Conference (ISSC). The ISSC was formed in 1982 to help foster and promote shellfish sanitation through the cooperation of state and federal control agencies, the shellfish industry, and the academic community. The program has been generally successful in bringing agencies and the industry together to help resolve problems relating to shellfish health and sanitation.

Table 1 offers a list of representative BMP programs in North America, Europe and Australia/New Zealand. These BMPs offer examples of both voluntary and compulsory standards that provide growers, processors, regulators and consumers with a uniform set of guidelines to ensure sustainable and environmentally sensitive farm practices. In some cases growers complying with all or most of the BMPs receive recognition through their governing organization or industry group. Additional information on environmental standards applied at the national level is available on fact sheets at the UNFAO Fisheries and Aquaculture Department, National Aquaculture Legislation Overview (NALO) web site: http://www.fao.org/fishery/nalo/search/en.

**TABLE 1 HERE**

Environmental BMPs developed for the shellfish industry address measures to reduce or minimize, or mitigate the effects of culture practices on aquatic and terrestrial resources and interactions with other users of marine resources. A common thread in environmental BMPs is the application of methods to comply with existing environmental norms and standards typically applied to land-based farms. Because shellfish farms occupy aquatic habitats where the water is in common public ownership, the detail and complexity of BMPs developed for aquatic uses tend to markedly exceed those associated with land-based operations. Key elements in environmental BMPs guiding shellfish culture are mainly related to culture practices (species and type of culture method, and associated activities) and farm site and size of the operation. Examples of environmental BMPs are listed in Table 2.

**TABLE 2 HERE**

Shellfish aquaculture is predominantly a near-shore practice utilizing intertidal bedlands and shallow coastal waters. The presence of shellfish and other structure creates habitat that is functionally similar to macroalgae and sea grass (Dumbauld et al. 2009) and culture practices involving the placement and transfer of seeded shell, culture in bags on or off the bottom, mechanical or hand harvest and other activities may have specific environmental benefits relative to the enhancement and restoration potential of the farm or culture site. Different grow out methods have unique environmental effects and varying resource requirements. For example bottom-cultured oysters require no external inputs other than seeding and crop tending whereas oysters grown in bag-on-bottom, longline or suspended systems require the use of more material intensive containment or support systems. However ground culture may be dependent on larger vessels for bed planting and harvest and can require more active predator and pest control. Culture practice BMPs and ECOPs are generally prescriptive and typically directed to specific culture methods and addressing measures to avoid adverse impacts. For example, the Environmental Management System Code of Practice for the British Columbia Shellfish Growers Association recommends “Any modification of tenure substrate (e.g. removal of rocks, gravelling) should be conducted in compliance with an approved management plan and should be planned to minimize impacts on other naturally occurring wildlife and fish habitat.”

The extent and intensity of farmed areas are controlled both by the availability of growing space and the carrying capacity of the water body to sustainability support both cultivated shellfish and the other aquatic organisms found in or moving through the culture area. Expansion of existing shellfish farms and creation of new farms is subject to varying levels of government and public oversight, ranging from minimal involvement and permitting requirements in areas with a history of shellfish culture to an extensive public process, the need for multiple permits and highly prescriptive permitting conditions. Unfortunately, as was discussed earlier, this process can overshadow important siting criteria related to the environmental suitability of farming areas, the economic and cultural values of the farming practice and the need to protect water bodies certified or suited for shellfish farming from adverse land use practices. BMPs created by regulatory agencies are typically directed at these siting issues(Table 1).

The question of system carrying capacity has been the subject of a large body of research focusing on the capability of the culture environment to support a given biomass and the effects of varying culture density or biomass on a fixed rate of aquatic production (Ferreira et al. 2007a; Ferreira, et al. 2007b, 2008; Sequeira, et al. 2008). BMPs to address carrying capacity are in place for several shellfish species as is the development of models to assess interactive carrying capacity (Ferreira et al. 2007b). In addition, the use of bivalve shellfish culture to reduce water column nutrients and help remediate land-based nutrient inputs is a potentially important application for BMPs that address specific culture practices. This may be especially relevant when considering, for example the expansion of shellfish farming specifically for ecosystem benefits derived from nutrient reduction (Gren et al. 2009).

**b. Efforts to establish a program for sustainability certification and third party accountability.**

The limitation of current shellfish BMPs is that they are either prepared by grower/processor groups in response to or at the request of regulatory agencies or other stakeholders or are generated by government agencies as specific regulatory or management tools. Over the last 10 years, however several third party resource certification programs have been developed, largely focused on environmental sustainability in land-based and aquatic applications. Aquatic certifications to date have been mainly directed towards wild-harvest capture fisheries, an example being the Marine Stewardship Council (MSC) certification for wild-caught Alaska salmon. However, several organizations are currently engaged in the development of certification and inspection standards for bivalve aquaculture at both regional and international levels.

The World Wildlife Fund (WWF) has been working since 2007 to create a suite of global environmental certification standards under the umbrella of the Bivalve Aquaculture) Dialogue (originally called the Mollusc Dialogue with a goal "... to create performance-based standards that will minimize the key social and environmental issues associated with bivalve farming.” The Bivalve Aquaculture Dialogue identified key environmental and social issues related to bivalve production as follows: “1) Ecosystem integrity: habitat interactions and ecological community structure modifications; 2) Genetics: gene transfer to wild populations, inbreeding, and escapes; 3) Biosecurity: deliberate or inadvertent introduction of new exotic species, pests, and pathogens; 4) Disease and pest management: transfer of disease and pests to and from the wild, within the wild, and within aquaculture systems; loading of pathogens; and the use of chemicals for preventing and controlling diseases and pests; 5) Farm maintenance: management and disposal of debris (e.g., nets and bags), chemicals, and organic waste; processing of wastes; treatment of effluent; and maintenance of equipment; 6) Multi-user cooperation: location, development, and aesthetics of aquaculture sites; and public access to aquaculture sites.” When the standards are finalized, it is proposed to give them to a new organization, the Aquaculture Stewardship Council, to be co-founded by WWF. This organization will be responsible for working with independent, third party entities to certify farms that are in compliance with the standards (WWF 2009a and b).

A new program on the U.S. West Coast is in the process of developing farm and crop specific certifications based on terrestrial farming practices to certify both environmentally appropriate and employment friendly shellfish production practices. This certification program, managed by the Portland, Oregon based Food Alliance (www.foodalliance.org) develops inspection criteria and guidance for farms, food handlers, processors and distributors based on a set of certification standards. Environmentally specific standards include: 1) Ensure the health and humane treatment of animals; 2) No use of non-therapeutic antibiotics; 3) No genetically modified animals; 4) management procedures to reduce pesticide use and toxicity; 5) Protect soil and water quality; 6) Protect and enhance aquatic and wildlife habitat; and 7) Continuously improve management practices. To assess whether an operation meets the Food Alliance standards, independent third-party inspectors use the evaluation criteria to assess whether and how desired management outcomes are being achieved. The benefit to the bivalve shellfish producer and provider is that environmental certification provides independent verification of marketing claims for social and environmental responsibility, can differentiate and add value to products and can protect and enhance branded shellfish products.

Efforts to develop certification standards should consider the scale and how widely adopted a program will become if implemented. Namely, should certification programs that address only local or regional considerations be developed as opposed to programs that are designed from the outset to consider a broader geographical range that includes the variability in domestic and international shellfish farm operations, food handlers, processors, distributors and markets for shellfish? This is an important distinction. The former approach may have significant value at the local or regional level and may satisfy local producers, buyers and consumers but can lead to a proliferation of standards and practices that are piecemeal in both development and implementation, vary in scale and application and may not be readily duplicated on regional and greater scales. The latter approach, while difficult to implement could potentially offer greater uniformity of standards, better industry buy-in and may incorporate a far greater range of national and international participants. Both approaches are likely important to pursue as the shellfish industry in many parts of the world grapples with increased public scrutiny and intensified interest in better defining the environmental and social costs of food production.

**Conclusion**

Shellfish aquaculture worldwide is growing, especially in regions where shellfish resources form an integral component of the human diet and an important means for producing biologically efficient, sustainable sources of high quality food coupled with economic vitality for coastal areas that are increasingly impacted by human development. Overall, the contribution of global supplies of shellfish to fisheries products have grown from 3.9% of total production (by weight) in 1970 to about 36% in 2006; on a per capita basis, global production supplied by aquaculture increased from 0.7 kg per capita in 1970 to 7.8 kg per capita in 2006, a eleven-fold increase over 36 years (FAO 2008). Shellfish growers in developed countries where use conflicts are well established are increasingly turning to BMP's and Environmental Codes of Practice to respond to public concerns and help ensure sustainable production into the future.

Appropriately sited and managed, shellfish aquaculture will likely continue to supply increasing quantities of high quality seafood utilizing increasingly domesticated stocks to enable sustainable coastal development economic opportunity and better food security (Marra 2005). The long-term stewardship role provided by the shellfish industry to help safeguard water quality and other environmental standards relating to land-use and non-point pollution in the Pacific Northwest over the last century offer important lessons for the public. As BMPs and certification standards are coupled with a better understanding of the environmental costs and benefits of shellfish aquaculture it is likely that increasingly sustainable shellfish culture practices will provide food, increased ecosystem benefits for the public at large while contributing to the safeguarding of a viable shellfish industry into the future.

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