Title

Preparing for a Deep Blue Revolution: The Development of Aquaculture in the US Exclusive Economic Zone

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PREPARING FOR A DEEP BLUE REVOLUTION: THE DEVELOPMENT OF AQUACULTURE IN THE US EXCLUSIVE ECONOMIC ZONE

by

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EXECUTIVE SUMMARY

PREPARING FOR A DEEP BLUE REVOLUTION: THE DEVELOPMENT OF AQUACULTURE IN THE US EXCLUSIVE ECONOMIC ZONE

by Lorraine Anglin

Chairperson of the Supervisory Committee: Dr. Enric Sala
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Globally, humans are harvesting the majority of capture fisheries at or above maximum sustainable yield, yet the demand for seafood is ever growing, a trend that cannot be met by the apparent plateau or possible decline of capture fisheries. Aquaculture appears to be an essential part of the solution, although it has become an increasingly controversial form of food production due to human health concerns and negative environmental impacts, as it has developed into a viable industry over the past 20 years. The US Department of Commerce is currently drafting legislation for the purpose of creating a streamlined permitting process for offshore aquaculture facilities in the US exclusive economic zone (EEZ). The objective of the legislation, referred to as the National Offshore Aquaculture Act of 2005, is to increase current US aquaculture production from a $1 billion per year industry to $5 billion annually by the year 2025. However, permitting aquaculture facilities in federal waters may have negative impacts on marine biodiversity in regards to increased disease transmission to wild stocks, pollution, escaped exotic or genetically modified species, as well as interference with natural marine mammal behavior and protected species. The purpose of this review is to evaluate the sustainability and feasibility of the US plan to intensity aquaculture efforts in the US EEZ through current case studies and interviews of industry experts and scientists, and to produce recommendations for a future policy framework based on the impacts to marine biodiversity.

Given the many uncertainties, the Department of Commerce should consider the following limits to offshore aquaculture projects: 1) No aquaculture activities producing non-native species should be permitted in federal waters to protect wild species that may be at risk of hybridizing or losing habitat to non-endemic escapees; 2) A moratorium on genetically modified species should remain until their safety can be proven in land locked closures over several generations; 3) Antibiotics and pesticides should only be administered to fish in quarantine by a veterinarian, and mandatory reporting of therapeutic types and quantities used by offshore aquaculture farms will assist in public awareness and project transparency; 4) Pens should not be sited in areas that overlap with marine mammal activities that will cause disruption, stress, or disease to these animals in compliance with the Marine Mammal Protection Act; 5) Identify areas that will be restricted from offshore aquaculture activities that may pose additional stress to protected species or recovering wild fish stocks. Aquaculture exclusion zones should be determined in collaboration with fisheries management councils, and abide by the protections afforded by the Endangered Species Act.

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I would like to give a special thanks to my family and friends for their support and most importantly my second family: Andy Balendy, Greg Wells, Fernanda Mazzillo, Morgan Richie, and Amy Broulik.

OBJECTIVES

The purpose of this review is to evaluate the sustainability and feasibility of the US plan to intensity aquaculture efforts in the US EEZ through current case studies and interviews of industry experts and scientists, and to produce recommendations for a future policy framework based on the impacts to marine biodiversity. This report addresses the growing demand for aquaculture, the current problems associated with near shore aquaculture, and the US policy to develop offshore aquaculture in federal waters.

INTRODUCTION

Humans are at a critical juncture with the oceans. Globally, we are harvesting the majority of capture fisheries at or above maximum sustainable yield, yet the demand for seafood is ever growing, a trend that cannot be met by the apparent plateau or possible decline of capture fisheries at 90-110 mmt per year (Figure 1). Increased demand for seafood is the result of a growing human population that requires additional sources of protein, primarily in Asia, Africa, and South America, as well as increased per capita demand globally due to increased incomes and improvements in transportation and distribution of seafood.

The recognized global solution for protein and seafood demand is aquaculture, an industry that has blossomed at a rate of 11% a year, making it the fastest growing food sector (FAO, 2003). Aquaculture has been hailed as the "blue revolution" that will produce food security on a scale similar to the green revolution of the previous century (Diouf, 2003; The Economist, 2003). Currently, 38.9% of all food-quality seafood is farmed, a percentage projected to exceed wild capture fisheries by 2030 (FAO, 2003). It is clear that aquaculture is here to stay, but how we proceed with our national and global policies on aquaculture will determine the sustainability of our natural capital in ocean resources.

'000 Tons

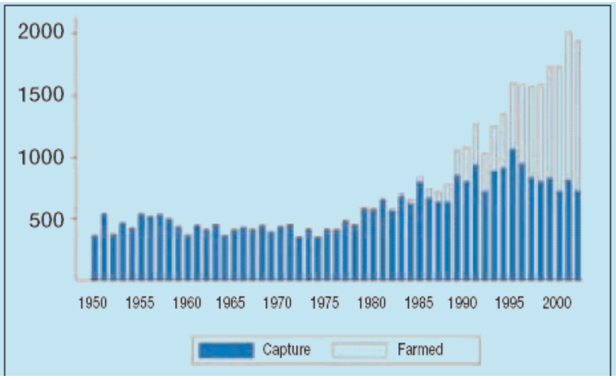


Figure 1. Plateau of capture fisheries vs. aquaculture
Source: FAO, 2003.

Aquaculture has become an increasingly controversial form of food production as it has developed into a viable industry over the past 20 years. The most prominent reoccurring aquaculture issues in the media relate to human health and the environment, and this has been particularly true of the farmed salmon industry that grew rapidly in areas such as Norway, Scotland, Canada, and Chile. The learning curve for farming fish has left a sour taste in the mouth of consumers from increased levels of PCB's, dioxins, and flame retardants in salmon flesh to concerns about antibiotics, pesticides, and chemical colorings, which prompted several warnings about the dangers of eating farmed salmon. The environmental issues for aquaculture, reviewed here, have broader implications and are more difficult to solve than the human health concerns.

AQUATIC FARMING METHODS

Many different forms of fish production fall under the umbrella of aquaculture. The majority of farmed fish are herbivorous carp raised in freshwater ponds across China, providing a productive and affordable protein source for millions (Weber, 2003; FAO, 2003). Unlike land-locked ponds, the farming of marine organisms *in situ*, referred to as mariculture or marine aquaculture, are open systems exposed to the surrounding marine environment. In respect to the dynamic nature of the ocean, certain farming practices can have broad environmental impacts. This is not to say that all land based farms are closed systems, in fact many fresh water ponds are drained into nearby rivers to harvest the fish contents. Marine aquaculture encompasses hatchery production and stock replenishment of wild species, as well as farming marine organisms for commercial purposes starting with brood stock, or the capture of wild juveniles for "fattening" or ranching, as it is also known.

Intensive aquaculture is a specific classification for marine finfish or anadromous fish, such as salmon that are completely dependent on receiving specialized feed diets (Figure 2). Organisms that require some feed in addition to what they are able to extract from the water are classified as semi-intensive aquaculture, such as coastal shrimp farms that enhance growth rates by adding fish meal or nutrients to the water. Herbivorous filter-feeding shellfish such as oysters, clams, and mussels do not require additional feed and are therefore classified as extensive aquaculture. The majority of nutrient pollution comes from the accumulation of uneaten feed and fish wastes in intensive aquaculture or semi-intensive shrimp farms, whereas the filtering nature of bivalves can have the opposite effect on eutrophic waters. Therefore, environmental groups and governments pay little attention to near shore farming of herbivorous shellfish as it does not have a negative impact on water quality.

Figure 2. Intensive aquaculture. Salmon pens off
Chiloe Island, Southern Chile. Photo: Larry Gault, 2004.

Integrated fish farming, or polyculture, is a culture method that combines different species for farming in the same ecosystem (Figure 3). In ponds, this is ideally a closed-loop system. Carp, for example, can be raised synergistically with rice by feeding on the crustaceans, insects, and worms that thrive in rice paddies. The carp, in turn, fertilize the rice and the rice farmer is able to harvest fish and rice from the same area of land. More complex systems involve wastes from livestock and added compost to fertilize the plants that a variety of fish feed upon. In the marine environment algae or shellfish have been shown to partially remediate nutrient laden waters surrounding finfish farms in integrated farming experiments. However, optimum growth conditions for shellfish and finfish may not exactly coincide as shellfish prefer shallow, silt filled bays or lagoons and finfish need stronger currents to keep conditions from becoming anoxic; in addition, most integrated algal efforts have been abandoned due to the small benefits associated with the larger labor intensive maintenance (Troell et al., 1997).

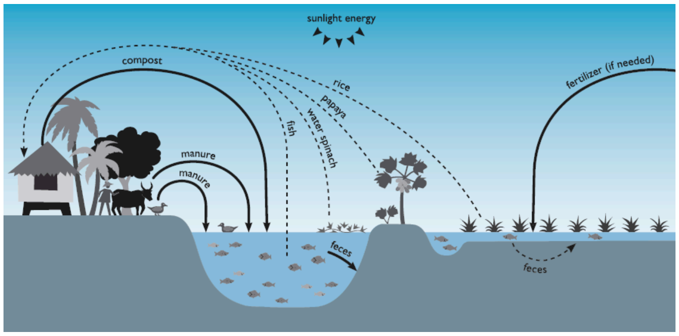


Figure 3. Integrated fish farming
Source: FAO, Fisheries technical paper, 407.

A variety of marine algae are grown for Asian food markets, or for use in nutritional supplements, such as *spirulina* grown in large land-locked tanks in warm climates such as Hawaii. Algae can also be used to grow astaxanthin, a fish coloring agent, by extracting the compound from an astaxanthin-producing microalga.

One of the most profitable forms of aquaculture is tuna farming. Scientists in Japan have been successful at completing the tuna lifecycle from fertilization to adult in culture, however this is still a relatively new advancement and the technology is not yet commercially available (P Sylvia, 2005, personal communication). Tuna ranching involves capturing wild schools of tuna, and transporting them in specially designed nets back to near shore waters where they are kept in pens and fattened daily on locally caught, or imported small pelagic fish. The intensive feeding allows them to grow quite rapidly, and the valuable meat catches extremely high prices on the sashimi market when harvested correctly.

The US is far behind the international mariculture industry and currently produces mostly catfish, placing the country eleventh for culture production, while third in global consumption. Regardless of the neophyte status, the US may soon be the leader in offshore mariculture as it is a relatively new venture globally, albeit with plenty of foreign backed investment and experience.

CURRENT ENVIRONMENTAL PROBLEMS ASSOCIATED WITH INTENSIVE NEAR SHORE AQUACULTURE

Water Quality:

Finfish pens have typically been sited near shore in protected areas that provide easy access for feeding, harvesting and pen maintenance. However, the carrying capacity of salmonids and marine finfish is quickly exceeded in the tight quarters of fish pens, a problem amplified by slow flushing rates or multiple pens in close proximity. Organic nitrogen and phosphorus discharges have the greatest impact on the surrounding marine ecosystem, and stem from the accumulation of fish feces and excess feed that falls to the bottom. Nordic salmon pen discharges of nitrogen are equivalent to the amount of nitrogen in untreated sewage produced by 3.9 million people, whereas the phosphorus is equivalent to the sewage outfall of 1.7 million (Naylor et al., 1998). Globally, farmed salmon wastes have the equivalent discharge of tens of millions of people (OSPAR, 2001). These levels of organic waste disposal are not currently tolerated by US coastal cities, and therefore, in addition to Environmental Protection Agency regulations, nutrient discharges from aquaculture facilities will need to be addressed by coastal zone management.

Sixty to ninety percent of the nitrogen waste from finfish farming is in the form of soluble ammonia, while the uneaten feed contributes carbon and nitrogen from the protein, carbohydrate, and fat components. Several studies have shown that high eutrophication of the surrounding water leads to alterations of the benthic ecology (Danovaro et al., 2003). Bacteria that facilitate the decomposition of these compounds decrease the amount of available oxygen in the immediate area, in combination with the mixing of the epibenthic layer, leads to anoxic surface sediments. Anoxic conditions change the amount and type of macrofauna in the immediate area; therefore the changes in local macrofauna are a common measure of fish farm impacts.

Microbial ecology:

Bacteria play an important role in the productivity of the entire ocean ecosystem at the biogeochemical level. Dissolved organic matter (DOM) can only be utilized by bacteria, which support part of the primary productivity feeding chain from protozoa to phytoplankton and zooplankton, the food base for all fish. Therefore, a dramatic increase in certain nutrients will change the structure of the microbial community and the ratio of microbes in the microbial loop to the plankton in the grazing chain (Azam, 1998).

At this time it is not clear how these changes at the molecular and microbial level will affect the base of the entire marine food web (Figure 4), yet many detrimental scenarios can be imagined under large scale shifts in energy utility and availability. Site specific changes have been monitored and show changes in the benthic communities below fish pens, including increased bacterial growth of up to ten times that of control sites (Rosa et al., 2001). Identification of the microbes shows a change in the species and enumeration of bacteria, often a shift from gram positive bacteria to mostly gram negative, antibiotic resistant bacteria (Danovaro et al., 2003).

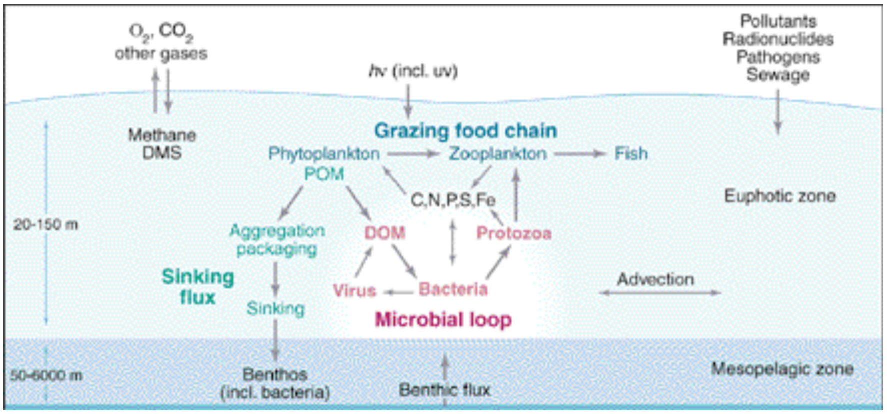


Figure 4. The microbial loop
Source: Azam, 1998.

Disease and antibiotic use:

Antibiotics are used in agriculture to maintain healthy animals in close quarters, and while it may be common practice to use antibiotics in land based animal feeds, the transmissibility of the ocean environment cannot permit this type of prophylactic use as it quickly spreads antibiotic resistant microbes.

Intensive aquaculture creates an environment for high transmission rates of disease and parasites that can be transmitted to passing wild stocks, from escaped fish to wild stocks, or be inoculated into pens from wild fish (Esmark et al., 2005). The importation of foreign microbes to the marine environment also poses many risks. Tuna farms in the Mediterranean, for example, are requiring importation of small pelagic feed fish, which introduces new bacteria and viruses without precaution to impacts on other species (WWF, 2005).

Currently, there are five drugs approved for use in US aquaculture by the Food & Drug Administration (FDA), including oxytetracycline HCL (Terramycin 10), sulfamerazine, and a combination drug containing sulfadimethozine and ormetoprim (Romet-30) (Goldburg & Naylor, 2001). These three antibiotics are most commonly used for salmon farming to treat vibriosis, furunculosis, or bacterial kidney disease, but are also prescribed to humans and veterinary animals. The risk of transmission of antibiotic resistance to bacteria that infect humans is not fully known, nor is the residence time of the antibiotics in the marine environment, including any associated secondary effects (Herwig et al., 1997). However, transferable drug resistance has been demonstrated from bacteria collected in marine sediments below fish farms in Norway to non-fish bacteria (Sandaa et al., 1992).

Pesticides:

Past organophosphate pesticide poisoning has caused major fish fatalities in Norway, with the product Dichlorvos, a chemical considered to be carcinogenic that has been found in fish flesh from farms all over the world (Horsberg, Hoy & Nafstad, 1989). The impact of pesticides on the marine ecology can be quite devastating killing most other mollusks in the area and residing in sediments below pens creating mini dead-zones. SLICE™ is the commercial name for emamectin benzoate, a pesticide used in feed, and therefore classified as a drug in salmon farming, to treat sea lice (*Lepeophteirus salmonis* and *Caligus elongates*). Near shore sites have shown that the combination of low oxygen and high chemicals increases opportunistic and pathogenic bacteria that no longer have to compete with the natural microbiota. Some farms have used such high dosages of pesticides that sea lice have become resistant as well. Fallowing net pen areas every few production cycles can reduce the number of sea lice out breaks, which involves removing all fish from a site and letting the bottom sediments and surrounding water recover to a more natural state over a substantial amount of time (usually two years in salmon farming). Sea lice attach to juvenile and adult salmon creating wounds that leave the fish susceptible to additional infections, and in the case of juvenile salmon, sea lice out-breaks can lead to mass mortalities. In general, these harmful environmental impacts are also detrimental to the farmed fish, and for the sake of profitability, are in the best interest of the farmer to reduce or eliminate as outbreaks are transmissible both from and to wild or farmed salmon.

Antifoulants:

Antifoulants prevent or greatly reduce the growth of marine organisms through metals, such as copper, and are most commonly used in marine paint for boats. Salmon farming has been responsible for the excessive use of antifoulants that have been detected in sediments at levels over 20 times the recommended safety limits (SEPA, 1998). Antifoulants are toxic to a wide array of marine organisms, and therefore further compound the toxic effects of pesticides at aquaculture sites.

Genetic Pollution:

Escapes of farmed fish further exasperates the spread of parasites and disease to wild fish stocks, however the most damaging ecological impact is genetic dilution. Farmed varieties of Atlantic salmon have been produced in captivity over several generations to select for marketable characteristics such as fast growth rates, or premium flesh quality and taste. These domesticated versions of salmon are easy to visually identify when found in the wild due to physical differences in appearance. The attributes selected for and bred by the salmon industry make the domesticated fish less fit for survival in the wild. Due to low survivorship, large escapes are publicized as not being a concern to natural populations (Nash, 2001). Unfortunately, the fast growth rates allow escaped fish to be more aggressive than wild counterparts, creating competitive juveniles. Depending on the escape age of the Atlantic salmon, the fish will either join in the wild migration pattern of other salmon as a smolt (fingerling), or congregate in coastal areas as an adult lacking the homing instinct to spawn at the correct time. Large scale escapes of millions of fish during storms in 1994 and 1995 in Chile demonstrated that many of the escaped Atlantic salmon continued to school around the pens and eat feed off the bottom, while a greater percentage of Coho salmon and Rainbow trout tended to feed on crustaceans (Soto et al., 2001).

A combination of genes that select for late maturity to increase farmed fish size, and the loss of olfactory cues for spawning, lead to late spawning of escaped fish (Lura & Saegrov, 1991). Late spawning displaces previously fertilized eggs from wild salmon with the smaller and less fit escapee eggs. Over several generations the impacts to wild varieties could be quite detrimental depending on the percentage of invasive domesticated fish spawning in a particular area. A reduction in genetic diversity of wild species leaves populations more vulnerable to disease or environmental stress in the future.

The UN Convention on the Law of the Seas (UNCLOS) states that "States shall take all measures necessary to prevent, reduce and control pollution of the marine environment resulting from the use of technologies under their jurisdiction or control, or the intentional or accidental introduction of species, alien or new, to a particular part or the marine environment, which may cause significant and harmful changes thereto." (Chuchill & Lowe, 1999).

Unfortunately, there are many cases of intentional introduction that are not related to fish farms. The State of Washington, for example, performed 27 releases of Atlantic salmon smolts (76,000 total), into Puget Sound rivers from 1951-1991 in an attempt to boost local fisheries and sport fishing. Enforcement of the UNCLOS on non-native species for aquaculture offshore and in stock enhancement programs will be vital to preserving wild genetic sources.

Status of Genetically Modified Organisms (GMO's)

Currently there are no genetically modified (GM) fish produced for food in the US, although the approval for transgenic Atlantic salmon that contain a growth hormone from an eel, as well as several other transgenic varieties of salmon and tilapia will continue to be submitted for approval to the FDA for human consumption. GM fish are designed to better handle the environment or grow rapidly with less food. Some transgenic fish are also being designed to be sterile (reversible) in the event of an escape, yet this does not prevent foraging damage for the remaining life cycle of the GM fish. Unfortunately, in the manipulation of genes, there is never a 100% guarantee of sterility or other comparable genetic safeguards. GMO's may be able to hybridize with wild varieties or invade protected habitat. Altered genomes also present the issue of unpredictable disease outbreaks that could also have a negative effect on wild stocks.

Marine mammal interactions:

Salmon pens near shore are often sited much too close to seal or sea lion haul-outs and are constantly harassed by these mammals. Some inlets in British Columbia, Canada have seen reductions in whale and porpoise populations near salmon pen sites that seem to correspond with sea lion deterrent devises that emit loud noises underwater (Morton, 1995). The interactions can also be detrimental to the sea lions, by changing their regular foraging habits, as in the case of sea lions that forage on extra feed fish near tuna ranches in Mexico.

Catching fish to feed fish:

Feed fish make up one-third of global fish catch for use as fishmeal and fish oil in animal feeds, including aquaculture and fertilizer. Small pelagic species used in aquaculture and agriculture feeds include menhaden, capelin, sardines, anchoveta, and herring. These capture fisheries are considered to be well managed and stable, with the exception of El Niño seasons that result in a dramatic decline in world catch of Peruvian anchoveta. Great advances in feed mixes and automation in aquaculture have kept the relative demand on wild stocks constant. Some concessions have been made though, such as the amount of fish meal used in bovine feeds has nearly been eliminated, and is projected to be so by 2010, including reductions of fishmeal in poultry and pork feeds

(Barlow, 2002). Vegetable protein substitutes for ruminants result in better digestibility than substitutes in fish feeds, although feed companies have been able to replace some of the fishmeal (up to 50%) with soy bean meal as well as rape seed oil to reduce the content of expensive fish oil. Efficiency in feed has therefore been spurred by basic economic reasons in both aquaculture and agriculture, with aquaculture purchasing a greater percentage of the capture feed fish as the industry grows. Fish oil however, is expected to be a limiting factor by the year 2010 (Figure 5), when 80-100% of the use could be going to aquaculture feed (Barlow, 2002; Tuominen & Esmark, 2003).

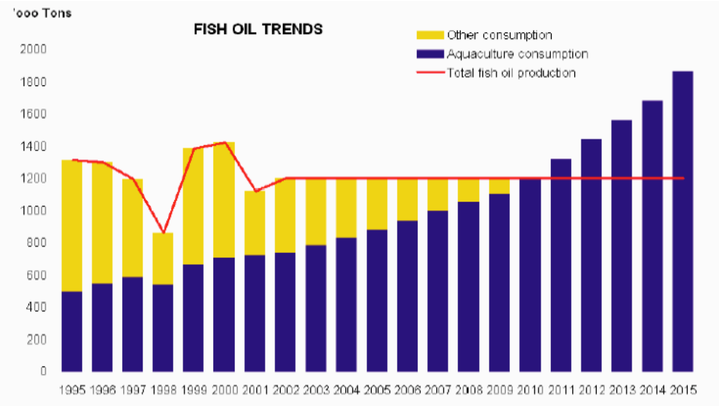


Figure 5. Fish oil use; a limiting factor for carnivorous aquaculture
Source: Tuominen & Esmark, 2003.

The efficiency of farming seafood compared to catching wild fish is debated on the calculations of feed conversion ratios (FCR) of the farmed fish, energy expenditures to catch wild fish, and natural trophic level energy loss of the food chain in the wild. Feed conversion ratios, or the amount of feed required to produce a measure of meat is argued to conversely reduce the total available fish protein for human consumption, by fishing down (Pauly, 1998) and farming up the food chain. Feed conversion ratios have gotten better for some fish, such as salmon and tuna, but for some carnivorous finfish, it may take five kg of wild caught feed fish to produce one kg of farmed fish (Naylor et al., 2000). On average, salmon require 1.2 kg of feed pellets to produce 1 kg of farmed fish flesh. The feed pellets consist of concentrated fishmeal and fish oil of varying levels depending on the season, age of the fish, or the amount of replacement products. Therefore, the amount of capture fish required to produce the pellets for a FCR of 1.1-1.3 is approximately 2.5 to 4 kg of fish per kg of farmed fish produced.

In the wild, the feed efficiency between trophic levels is approximately 10%, therefore, according to Forster & Hardy (2001) aquaculture appears to be a more efficient use of pelagic feed fish with a feed efficiency in pen captivity of 20-30% (Tidwell & Allan, 2001). However, when total non-biological energy requirements for farming and fishing are considered, aquaculture turns out to be a more energy intensive process of producing fish (Tyedmers, 2000).

Fishing pressure on wild stocks:

Fish farming is often used as a rationale for reducing fishing pressure on wild stocks. World fish stocks are estimated to be 28% overexploited or severely depleted, with 47% harvested at maximum sustainable yield (FAO, 2002). Aquaculture production has grown steadily, while fishing pressure on wild stocks have been shown to stay the same over this time. In fact, the opposite has been the case in some areas, where increased disease or habitat loss due to escapees has stressed or caused mortalities in wild stocks. A quarter of all salmon in Norwegian seas are of farmed origin, and these escapees have impacted more than half of the wild salmon stocks in some manner (Esmark et al., 2005).

Aquaculture will only be able to relieve pressures on wild fish stocks when it is able to substitute, not supplement, current capture fisheries as reviewed by Goldburg & Naylor (2005). Currently, aquaculture is only supplementing wild fish stocks through stock enhancement programs. If aquaculture is managed in conjunction with capture fisheries, then coastal resource managers could possibly trade destructive fishing practices or high by-catch fisheries for farming to improve habitat or conservation efforts (J McVey, 2005, personal communication).

Human Health Issues:

Dioxins, PCB's, and other carcinogenic chemicals have been found in farmed and wild salmon. In most cases, the concentrations found in farmed salmon are several times higher than wild salmon (Figure 6; Hites et al., 2004). Whereas these contamination levels appear to coincide with decades of industrial pollution, particularly in the North Atlantic, the question begs to be asked: is aquaculture a healthy choice? Farmed fish accumulate much greater fat stores due to reduced movement in confined pen space as well as being fed on high oil content feeds. Fat molecules accumulate toxic compounds such as PCB's and dioxins, which are then amplified in concentrated feeds, and further stored in greater quantities in the abundance of fat in the fish. Negative press on human health effects can be devastating to farmed fish sales, and it is therefore a priority in the industry to minimize these chemicals through testing of the feed ingredients and substitutions for other contaminant-free feed sources (Tacon, 2002).

Salmon is recommended as a healthy food choice due to the benefits of Omega-3 polyunsaturated fatty acids compared to other animal protein sources. Omega-3 levels have been found to be slightly lower in farmed fish, but the high fat content level of farmed fish appears to even out the deficit per serving (Figure 7). Regardless of the farmed salmon health warnings, many doctors have upheld the health benefits of the Omega-3 over the discovery of carcinogens, as most people do not eat enough fish for these concentrations to be as harmful as other sources they may be consuming such as beef or butter (Figure 6). However, other harmful chemicals used as fungicides or pesticides, such as malachite green have been found in imported salmon from Chile and recently from a farm in BC, Canada. In addition, moderately high levels of mercury in high trophic level fish in the wild may become an increased health issue with the expansion and promotion of tuna farming.

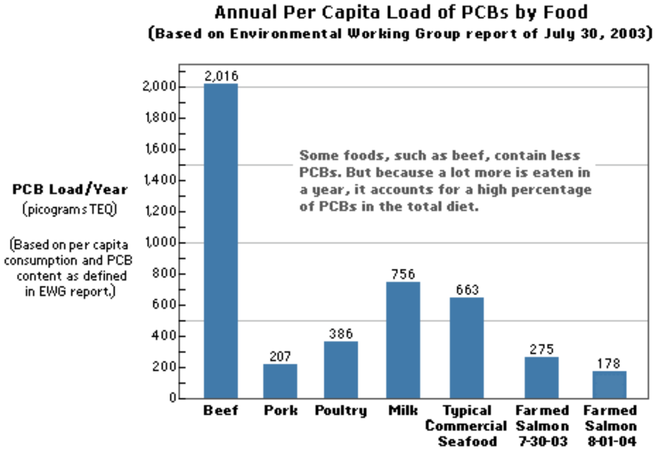
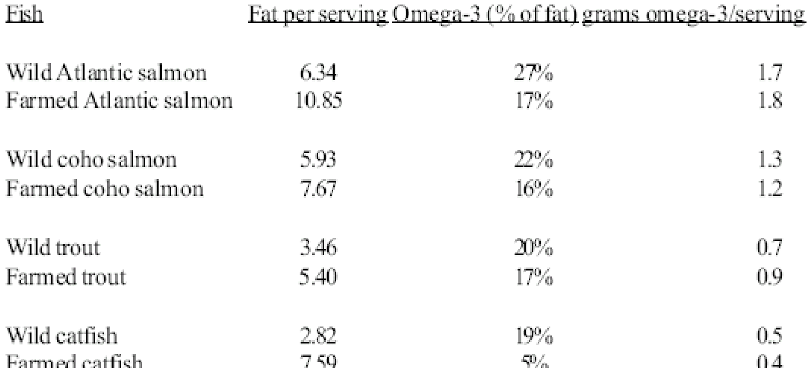


Figure 6. PCB loading based on annual consumption.
Source: Salmon of the Americas Environmental Working Group



Fish	Fat per serving	Omega-3 (% of fat)	grams omega-3/serving
Wild Atlantic salmon	6.34	27%	1.7
Farmed Atlantic salmon	10.85	17%	1.8
Wild coho salmon	5.93	22%	1.3
Farmed coho salmon	7.67	16%	1.2
Wild trout	3.46	20%	0.7
Farmed trout	5.40	17%	0.9
Wild catfish	2.82	19%	0.5
Farmed catfish	7.59	5%	0.4

Figure 7: Grams of omega-3 fatty acids per 100 g serving of selected wild and farmed fish. Source: Hardy, 2003. Data from USDA Nutrient database.

Public concern regarding color additives in farmed salmon, used to produce a more natural appearance, has for the most part been dismissed. The two chemicals, canthaxanthin and astaxanthin, appear to be innocuous, however strict labeling of these additives in farmed fish sold on supermarket shelves is required by the FDA. The additives are made either synthetically by drug companies, extracted from yeast, microgalgae, or grown in bacterial cultures.

The FDA will have to continue to step up the level of seafood testing, imported and domestic, similar to the scrupulous tests for agriculture that assay an array of antibiotics, pesticides, and toxins. The small percentage of imported seafood tested, approximately 1.2% as of 2002, does not hold farmers responsible for possible contaminants, nor does it protect the consumer (GAO, 2004).

CHILE: A CASE STUDY

I traveled throughout the Xth region of Southern Chile to get a better understanding of the current aquaculture industry, how it operates, and to investigate the previously discussed environmental issues that are driving aquaculture farther offshore (Figure 8). Chile is an interesting case study for intensive aquaculture as the Chilean situation has parallels to the US, such as similar coastal resources. Just as the US intends to rapidly develop its aquaculture production, Chile managed to develop the second largest farmed salmon industry in a relatively short amount of time. Some species farmed in Chile are still wild caught as well, an issue that the US may face, which will require balanced management of all ocean resources.

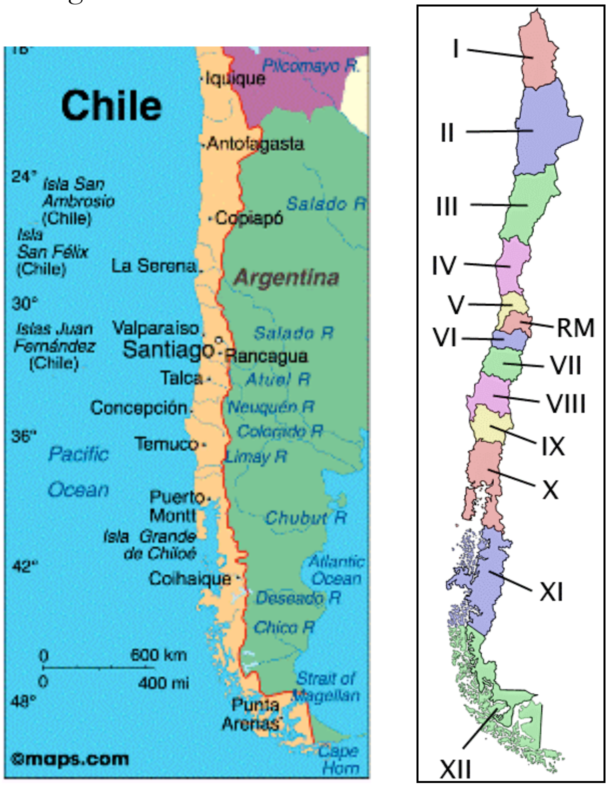


Figure 8. Puerto Montt, X Region, Chile.
Source: maps.com; nationmaster.com

Invasive species:

Chile has focused on the lucrative demand for Atlantic salmon (*Salmo salar*), a carnivorous fish that has been pushed to the brink of extinction in many native North American areas of the Atlantic through habitat loss and degradation and fishing. An absence of native salmon in Chile has allowed for invasive explosions of naturalized populations of Atlantic salmon, Coho (*Oncorhynchus kisutch*), and sea trout: brown (*Salmo trutta*) and rainbow (*Oncorhynchus mykiss*) seeded in rivers and streams in the southern regions, and escaped from fish farms. These non-native fish have voraciously taken over new habitat, competing with other planktivorous and piscivorous native species, such as percas (*Percichthys trucha),* while providing a government supported sport fishing industry to the Xth and XIth regions. Natural resource scientists at the Universidad del Mar, Valparaiso are racing to document the native fish species and abundance in freshwater lakes, streams, and coastal habitats before this baseline data is possibly lost with the invasion of non-endemics. In addition, several universities in the southern region are studying the feasibility of farming new species, or improving on current hatchery and husbandry techniques, similar to the goals of the US Aquaculture Sea Grant College Program.

Aquaculture for socioeconomic development:

Mariculture in Chile has been one of the most important socioeconomic drivers developing the country by increasing global exports, attracting foreign investment, and creating thousands of jobs for Chileans. Chile produces 32% of the global salmon market with expectations of being the leader in the near future, second to Norway which has 39% of the salmon market (Gajardo & Laikre, 2003). The majority of salmon production in Chile is exported to the US and Japan. Since 1998, automation has decreased jobs in the industry by 40%, as well as decreased average worker wages in Chile, while profits for mariculture companies have continued to rise substantially (Barret et al., 2002). This is a trend seen in many other aquaculture producing countries; therefore the US rationale to create jobs by promoting aquaculture in the EEZ should be weighed against possible jobs that will be lost in localized commercial fisheries due to price competition of farmed species. Ideally, total seafood demand will continue to rise creating a net increase in seafood production and harvest jobs overall. Regardless of total jobs created or the country, socioeconomic profit, above all other stated secondary benefits, is the primary incentive for governments to support aquatic farming.

Environmental regulations:

In Valparaiso, Chile I interviewed the *Subsecretaria de Pesca* (Environmental Affairs, Secretary of Fisheries) to review the laws and regulations the cabinet had developed based on those of other countries, such as Norway, as well as their own learning process with siting pens too close together or in low-flow areas. Originally, Chile had an "open-access" policy to salmon farming, but the dramatic environmental impacts in bays and inlets crowded with fish pens led to the development of aquaculture regulations (collectively referred to as "RAMA") in 1997 that were enforced starting 2001 and baseline monitoring and sampling in 2003 (DDP No. 1186, 2001;Res. No. 404, 2003). The numerous pens already in production when these regulations went into effect have been grandfathered into the monitoring program under certain provisions. If the site fails the basic qualifications, recommendations are made to the site for changes, such as dredging the accumulated waste below the pens, and then repeat tests are performed the following year. Another failing grade requires the farm to reduce the pen stock by 30% or face closures.

The number of agencies involved in the Chilean aquaculture permitting process parallels the current permitting structure of the US, and not surprisingly, it still takes one and a half to two years to receive a permit (F Paredes, 2005, interview). However, transportation costs in Chile are five times lower than the US, not to mention other factors such as low labor costs that make this time frame fiscally feasible, especially if companies continually apply for more sites in advance of needing them for future expansion. Geographic Information System (GIS) analysis of the area for pen siting, including calculating distance from other farms, water depth, current, and bottom structure usually takes at least one year to complete. This is in addition to baseline studies of sediment granulometry, organic matter in the sediment, benthic macrofauna, pH and Redox potential in sediment, and dissolved oxygen profiles in the water column (Resolution N. 404/2003).

Many of the near shore environmental problems in Chile have been greatly reduced from pressure exerted by companies purchasing farmed salmon in large volume from Chile, such as Costco and WalMart. Good management practices (GMP's), hazard analysis and critical control point (HACCP), and environmental certificates up to ISO 14001 are important for production giants such as Nutreco Holding N.V., that produces agriculture, aquaculture and feed products internationally (Nutreco, 2003). Strict production guidelines from hatchery management and fish harvesting methods, to waste reclamation and recycling capabilities are important to many consumers and insure a better product.

Some issues that continue to be a concern for Chilean aquaculture are the use and type of antibiotics or fungicides administered in hatcheries and grow-out facilities, the rapidly expanding production heading farther south into pristine ecosystems, and water pollution from pen wastes (Staniford, 2002). The increased environmental regulations have caused salmon farms to spread out and move into deeper water, while the majority of near shore sites have already been leased or are being held by companies for future use when fallowing rotations are necessary, which in effect is the reason the farms are quickly moving into new territory in the south of Chile. In the temperate waters of coastal southern Chile, nitrogen is a limiting factor in primary production; however the vast increase in farming activity in the region has corresponded with frequent, year-round red tides that used to only occur seasonally (Buschmann, 2002). The increase in red tides has become a concern for locals that commercially farm or harvest shellfish.

Several aquaculture industry professionals I spoke with were worried about sharing information about their farming or feed production processes, as they have had their share of damaging press. Chile may have been quick to turn profit in the start-up of salmon farming, but this country has also been quite versatile at trying to reduce or eliminate many of the negative impacts to the environment in an effort to address consumer concerns and maintain the large market share they have built. Some companies, such as Marine Harvest Chile, and AquaChile were proud to demonstrate new technologies in hatcheries and processing plants that make their product superior to those in capture fisheries in regards to meat quality, transport, and processing efficiency. Employees of mariculture feed technology companies and environmental consultant groups were also helpful in explaining the most pressing sustainability issues of the aquaculture industry. These conversations helped to inform the following discussion that analyzes the US transition from near shore to offshore farming.

US POLICY TO DEVELOP OFFSHORE AQUACULTURE IN FEDERAL WATERS

Some, although not all, of the problems associated with aquaculture as currently practiced might be reduced in an offshore setting. For this reason, the US Department of Commerce is currently drafting legislation for the purpose of creating a streamlined permitting process for offshore aquaculture facilities in the US EEZ. The waters of the EEZ extend from three to 200 nautical miles from the coastline of the US and associated territories. The US EEZ is larger than the combined total US land areas, and is estimated to be approximately 4-4.5 million square miles, therefore, this legislation may have far reaching implications for many diverse and valuable marine ecosystems (Figure 9). The aquaculture legislation will be a revision of the current National Aquaculture Act of 1980, which calls for the promotion, legal framework, and development of aquaculture production. These tasks have been headed up by the Joint Sub-committee on Aquaculture for the purpose of promoting development and research for a globally competitive US aquaculture industry (JSA, 1998). The objective of the new legislation, referred to as the National Offshore Aquaculture Act of 2005, is to increase current aquaculture production from a $1 billion per year industry to $5 billion annually by the year 2025.

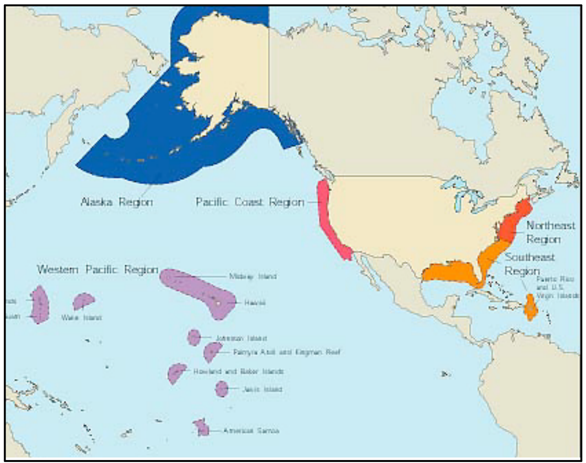


Figure 9. Area of US EEZ
Source: National Marine Fisheries Service

The rationale for promoting offshore aquaculture is economic as well as environmental, "to create jobs, increase related goods and services, and reduce the seafood trade deficit", which exceeds $7 billion annually, as well as to "preserve and possibly improve coastal and marine habitats and ecosystems" (DOC, 2002). However, opening the US EEZ to aquaculture investment may have negative impacts on marine biodiversity in regards to increased disease transmission to wild stocks, pollution, escaped exotic or genetically modified species, as well as interference with natural marine mammal behavior and protected species.

Presently, it is cost and time prohibitive to obtain a permit to lease federal waters, held in public trust as a common resource for commercial marine aquaculture due to restrictive marine laws and the number of agencies involved in the application process (McCoy, 2000; Cicin-Sain et al., 2001). The new permitting process would reduce lease approval complexity by reducing the minimum of five agencies currently involved to just the Secretary of Commerce, thereby streamlining the permitting process to a matter of months instead of years (NOA Act, 2004).

"The Secretary [of Commerce] shall confer with the Environmental Protection Agency, the Minerals Management Service, the Army Corps of Engineers, and other Federal agencies with permitting authority in the Exclusive Economic Zone to develop a coordinated and streamlined permitting process for offshore aquaculture. This process shall take into account the needs, requirements, and authorities of each Agency, including the need to consult with State agencies and the requirement for public review and involvement" (NOA Act, 2004).

The Department of Commerce had planned to present the permit guidelines of the National Offshore Aquaculture Act in March or April of 2005, but according to the Director for Aquaculture of the National Sea Grant College

Program, Dr. James McVey, legal advisors have delayed the release for interagency review due to issues yet to be resolved or disclosed. However, foreseeable conflicts may have arisen with several marine laws or the agencies that currently have jurisdiction and management responsibilities. It will be necessary, for example, to make aquaculture exempt from the Magnuson-Stevens Fishery Conservation and Management Act, as aquaculture is currently defined as a fishery (Churchill & Lowe, 1999).

"Fisheries management councils have developed species management plans that set size and quotas for the allowable catch that makes it illegal to possess undersized fish, or to have more than the daily catch, in some cases as few as two fish, in possession at one time. This makes aquaculture impossible for those managed fisheries and [currently] requires an exempted fisheries permit for usually one year at a time. Aquaculture companies need a time frame of at least 10 years to make the investment pay-off [and to qualify for bank loans]" (J McVey, 2005, personal communication). While it is stated that "nothing in this Act shall be construed to displace, supersede, limit, or modify the jurisdiction, responsibilities or rights of any Federal or State agency…" (NOA Act, 2004), there will be resistance by affected stakeholders, such as commercial fisherman, on fisheries management councils.

CURRENT US DEMONSTRATION SITES FOR OFFSHORE LEGISLATION

US Test Sites:

Three US test sites have been used as the scientific basis for the offshore aquaculture legislation. The primary site is managed by the University of New Hampshire, followed by the participation of two other sites, Cates International in Hawaii, and Snapperfarm in Puerto Rico. These experimental sites have been used to develop what will become the environmental monitoring protocol and possible US industry codes of conduct, while also expanding and investigating the feasibility of new species development. In 1999, the University of New Hampshire started to receive the majority of the funding for aquaculture research from Congress amounting to $2.4 million annually (J McVey, 2005, personal communication). NOAA and UNH created a cooperative called CINEMAR (Cooperative Institute for New England Mariculture and Fisheries) in 2000. Annual reports are published on the success of various species and techniques such as Atlantic cod and halibut. According to the published annual report for 2004 and reported in NOAA Magazine Online, benthic ecologist Ray Grizzle states "There has been no measurable environmental impact" of the tested farming practices.

Cates, Int. and Snapperfarm were chosen through a competitive process in 1999 and again in 2001, during which several other small projects were funded through National Sea Grant (J McVey, 2005, personal communication). According to Dr. Leonard Young of the Hawaii Aquaculture Development

Program, the demonstration project for Cates, Int. was performed as a proof of concept for Hawaii law changes and was never declared an official test site at the time by the DOC, and in addition "there has been no official correspondence between Hawaii and the DOC/NOAA regarding future siting of structures in federal waters" (L Young, 2005, personal communication). Cates, Int. has gone on to successful large scale production of 6,000 lbs. per week for pacific threadfin (*Polydactulus sexfilis*).

Snapperfarm in Culebra, Puerto Rico is a private venture that collaborates with the University of Miami, and NOAA. Their two Sea Station™ submerged pens are several miles from shore in a remote area. Snapperfarm only produces one species of fish at this time Culebra Cobia™ (*Rachycentron canadum*), although the company is able to boast good feed conversion, and antibiotic/pesticide free growing conditions.

ADDITIONAL INTENSIVE AQUACULTURE OPERATIONS

Unfortunately, other offshore commercial sites have not been included in the exchange of information for future environmental regulations. Essentially the DOC is using information primarily from one commercial capacity experimental test site, out of three chosen, all of which have started small, while in addition, information could be made available from other commercial capacity farms that will be more predictive of future sites in the EEZ.

Hubbs-SeaWorld Research Institute:

Currently, there are no commercial farms operating in the EEZ surrounding US States, although Hubbs-SeaWorld Research Institute (HSWRI) has been engaged in the permitting process for the past year and a half to farm a variety of fishes on oil platform Grace (B Chesney, 2005, personal communication). The oil platform is owned by Venoco, Inc. and is used as an oil transfer station located 10.5 miles offshore Ventura, California. The farming demonstration has proposed a three year lease to culture commercially profitable and native species such as California halibut (*Paralichthys californicus*), California yellowtail (*Seriola lalandi*), white seabass (*Astractoscion nobilis*), striped bass (*Morone saxatilis*), and bluefin tuna (*Thunnus thynnus orientalis*). For the sake of the demonstration, the tuna will be wild caught, but the hope is that viable "domesticated" stocks of tuna will be available for farming in the future. The goal of the Grace Mariculture Project is to "help governmental and environmental organizations develop national guidelines through extensive, proactive monitoring and reporting programs. The results will be directly applicable to, and serve as a model for the responsible development of sustainable offshore aquaculture" (HSWRI, 2005). However, HSWRI is not a federal test site for offshore aquaculture at this time, although it is a classic example of the current lengthy permitting process.

The oil platform will serve as feed storage, as well as a hatchery laboratory until the juveniles are large enough for the four offshore net pens that will be anchored near the platform in sandy bottom sediments (P Sylvia, 2005, personal communication). In addition to these market species, HSWRI has 20 years experience in fishery enhancement programs for heavily degraded stocks, and continues rearing programs for species such as the red abalone (*Haliotis rufescens*), yelloweye rockfish (*Sebastes ruberrimus*), bocaccio (*Sebastes paucispinis*), and lingcod (*Ophiodon elongates*). Additional financial support to commercial operations in the future could make use of their existing hatchery facilities for rearing endangered or threatened species for state or federal replenishment programs, as performed by HSWRI. It should be noted, however, that it is impractical to completely regenerate endangered or over-fished species globally through hatchery programs due to the sheer scale and funding that would be required to attain even a semblance of historical biomass. Aquaculture technology is advantageous for learning more about the lifecycles and threats to endangered species through the process of optimizing hatchery success, and this information can be transferred to better habitat protection and assist in reducing dramatic declines in localized populations if instituted in time, such as the hatchery programs for salmon in several Alaskan rivers.

Kona Blue Water Farms, LLC:

Another aquaculture facility neglected by the offshore legislation participants is Kona Blue Water Farms of Hawaii. This commercial farm grows Kona Kampachi™ (*Seriola rivoliana*), in six submersible net cages half a mile from shore. The 3,000 M^3 Sea Station™ cages are anchored to the soft sediment bottom at a depth of 200 feet. The deep water and high flow location of the cages provide an excellent test site for comparable parameters to offshore conditions. An extensive permitting process and substantial private investment were needed to get the project started. Wherein the investors avoided the problems associated with federal farming approval, there were still hurdles for Hawaii State waters including permitting in a whale sanctuary (D Sarver, 2005, personal communication).

TRANSITION FROM NEAR SHORE TO OFFSHORE AQUACULTURE

The prominent environmental issues that will persist, be reduced, or possibly become worse due to expanding offshore aquaculture efforts in the US include impacts to biodiversity, pollution, and feed sources, respectively. An environmental goal, as stated by the DOC (2002), is to improve coastal and marine habitats & ecosystems. Up to this point large scale aquaculture has proved to be a greater stress on coastal ecosystems, rather than an improvement, due to disease, pollution, and escapes of non-native fish, and while moving the pens offshore will reduce coastal pollution, it will take dedicated ecosystem based management with aquaculture being inclusive of these catch values, for it to be possible to trade some forms of destructive fishing, such as bottom trawling, for aquaculture. However, the environmental tradeoffs that will be based on farm location, the amount of feed required, and the production rates, may need to be adjusted to reduce further environmental impacts from offshore farming to accomplish a true reduction in unsustainable marine resource extraction.

Issues that will persist offshore

Impacts to biodiversity:

Naturalization of non-endemic species or genetically modified species approved in the future, as well as changes in the microbial diversity will have the greatest impacts to marine biodiversity. Escapees will continue to spread viruses, bacteria, and parasites to wild stocks, and compete for habitat with native fish (Staniford, 2002).

The open ocean environment poses new challenges in preventing fish escapes, and this risk must be a calculated with contingency plans, just as oil tankers must be prepared for inevitable future spills. Commercial-capacity, submersible pens, such as the Sea Station™, produced by Ocean Spar Technologies, LLC, have withstood storms and even hurricanes, which provides some reassurance for preventing fish escapes into the environment. However, the greatest numbers of escapes in near shore farms are a result of construction failure or collisions (WWF, 2005). As a safety precaution, equipment should be regularly inspected by a third party to ensure integrity. As for navigational hazards, offshore pens should be relatively clear of boating traffic, and common fishing zones. Without surface markers it may be inevitable that fishing gear or anchors will eventually come into contact with a submerged pen.

The best contingency plan is to only farm species that will not be invasive or harmful to wild stocks upon escape. Unfortunately, breeding fish for certain characteristics to enhance and maximize farming production also creates genetic divergence from the wild native variety (Weber, 2003). Further studies should be conducted on the genetic divergence of native domesticated fish to determine the number of generations of brood stocks that can be captive raised before posing a risk of genetic dilution to wild species in the event of an escape. This is particularly true of anadromous fish that have greater genetic divergence than most marine finfish as they have been cultured in captivity much longer than most finfish (Nash, 2001). It is possible to implant tracking devices in fish for easier recovery, however large scale escapes in the open ocean have yet to be experienced to assume that it will be just as easy to recover lost fish offshore as in the shallow near shore sites for which the tracking devices have been designed, not to mention the cost of the implantations may be prohibitive without legislation in place to enforce this safety precaution across the industry.

Antibiotics, pesticides, and antifoulants are responsible for various levels of disturbance to marine biodiversity, whether it is the development of antibiotic resistance, or pesticide resistance over time, or the accumulation of antifoulant metals that are harmful to local macrofauna. Open ocean net pens will not completely eliminate the need for antibiotics or pesticides as they are currently administered to prevent fish infections or parasites, such as sea lice, however new vaccines can greatly reduce the amount of antibiotics required. Offshore sites are intended to provide more circulation, and removal of wastes, but the high density pen-farming environment will likely continue to foster disease in the penned stock and to passing wild stocks at large commercial capacities. Norwegian veterinarians have noted that all aquaculture facilities go through a disease bottle neck, which is essentially the fish density saturation point that leads to disease (Molyneaux, 2004). Thus, the lack of disease in small scale offshore experimental cages says little about whether diseases will pose problems at higher densities in larger cages. Many valuable lessons have been learned from near shore pens about the toxic consequences of overdosing pesticides in fish pens. These lessons will have to be transferred to open ocean sites as higher flushing rates may require higher dosages of chemicals to eliminate pests such as sea lice. Traditional use of antifoulants may also need to be modified in the open ocean system. Faster currents will transport metal compounds, copper and zinc, farther than protected coastal sites. It is unlikely that toxic metals such as copper or zinc will be used on the net pens to prevent biofouling, although it may be a consideration for existing oil platforms that are painted with copper, antifoulant paint that will require maintenance and are planned for future commercial sites.

The damages or changes to marine biodiversity are difficult to quantify and measure, and therefore will probably persist as a hazard of aquaculture, whether the facilities are located near shore or offshore.

Issues that will be reduced offshore

Pollution:

Aquaculture increases nutrient loads of nitrogen, phosphorus, and organic wastes, which can be a problem in protected bays or low flow areas. By moving fish pens into faster moving water the amount of accumulated wastes can be greatly reduced locally. The question of where those wastes go, and how diluting large pollution sources aids in the overall health of the ocean ecosystem, are not yet quantifiable. However, there is a consensus among the scientific community that the oceans are being nutrified from various forms of non-point source pollution including agricultural run-off (Pew, 2003). A prime example is the Gulf of Mexico dead zone that forms annually from the vast quantities of fertilizers and sediments that originate in the bread basket of the US. The algal blooms quickly consume the dissolved oxygen, creating an anoxic environment that kills fish. The only organisms that can thrive in this eutrophic dead zone are bacteria and jellyfish.

Siting pens offshore allows for higher stocking densities and greater volumes than can be grown near shore due to the risk of disease or microorganismal blooms, which translates into greater pollution discharge. However, future advances in fish feed and automation will reduce nutrient pollution. Vegetable replacement proteins, for example, do not contain the high levels of phosphorus found in fish meal feed that contribute to nutrient loading (Seppala et al., 2001).

To meet the DOC goal of increasing our aquaculture production to $5 billion annually, would result in nitrogen discharges of 108,000 mt to 158,000 mt per year, or the equivalent of disposing of raw sewage from a city of 17 million people (Goldburg & Naylor, 2005). Based on estimates for annual nitrogen flux, the new aquaculture production will be the equivalent to 10% of the nitrogen currently entering the Gulf of Mexico, which is 1,567,900 mt/year (Goolsby et al., 1999). In regards to total nitrogen fixation in the world oceans (121 mmt), this is only one tenth of one percent, however in combination with all other mariculture producing countries it is a contribution to nutrient loading worth regulating and reducing.

Issues that will be limiting

Feed Sustainability:

The future of farming carnivorous fish is dependent on the sustainability of fish feed production and the development of future feed technologies that are not dependent on wild fish stocks.

Feed fish do not have the market value that farmed or wild carnivorous species generate for human consumption, therefore the argument for eating lower on the food chain is contested by popular seafood marketers that consumers avoid these fish due to "unpalatable fishy flavor". Just as cattle are highly inefficient at converting grains into meat, affluent consumer choice tends to be driven more by flavor and less by the environmental impacts of that choice. It is recognized that the demand for small pelagic fish will likely increase in relation to population growth in developing countries. Currently, there has not been any dramatic change in demand for wild feed species, but this is projected to change over the next decade (Naylor et al., 2000). In order to maximize current feed fish for increasing carnivorous fish farming the following must take place: first, a total acquisition of the feed fish market by mariculturists from other agricultural sectors; second, increased use of global by-catch as a fishmeal source (Naylor et al., 2000); and third, greater use of fish offal, currently being dumped at sea by countries such as Norway at on-site processing operations (Tuominen & Esmark, 2003). Utilizing the vast amounts of discarded by-catch would be a more efficient use of ocean resources, although it may also encourage high by-catch fisheries to maintain status quo if there is a new market for by-catch.

Genetically modified organisms could be the silver bullet for the feed sustainability issue. Crops that could be engineered to produce proteins needed to develop omega-3 fatty acids in carnivorous fish, would allow the feed industry to no longer be dependent on wild feed fish stocks. Substitution of wild stocks in the feed products and final consumer products, rather than supplementation to wild stocks will be important in removing pressure from current fish stocks and defining the sustainability of aquaculture as a food source industry.

Unfortunately, there is the possibility that new technologies, such as GM feed ingredients, may never be developed, or at least not in the immediate future without further health or environmental concerns. If technology cannot provide the solution, aquaculture may never be weaned from wild fish feed, and therefore will be dependent on the health and productivity of those wild fish stocks. GMO technology in salmon feed has been strictly avoided by major feed fish producers in countries such as Norway and Scotland, and may not be an acceptable alternative by consumers even if it is brought to fruition (Tuominen & Esmark, 2003).

At this point in time the US can choose to promote more feed-efficient or herbivorous/omnivorous species to farm, although without policy to dictate the environmental management above the economic management of the oceans, this decision could be left up to regional fishery managers to determine the species and allowable quotas that should be farmed offshore. NOAA or marine resource managers may face lawsuits from powerful multinational companies if difficult business decisions regarding species and quantity have to be made at the ecosystem level. A new form of farmed quota may actually arise out of ecosystem management, however ecosystem management may never be perceived in that manner and permits could be distributed based on merit rather than species or wild quotas. At this time the actual management scheme is not clear in the draft offshore aquaculture legislation.

POLICY CHALLENGES & OPPORTUNITIES IN THE US

Offshore aquaculture will not be a competitive or feasible approach for many small scale farmers without the aid of subsidies or existing structures. Therefore, with increased transport and maintenance costs, combined with the production size required to make the operation profitable, it is expected that only large aquaculture companies or certain investors will take the plunge into the EEZ.

A streamlined permitting process for farming in the US EEZ will attract investment, both national and international, yet more obstacles are bound to arise from individual states. Alaska, for example, the state with by far the largest portion of EEZ has already submitted two bills to Congress to prevent fish farming in federal waters. Senator Lisa Murkowski recently submitted the Natural Stock Conservation Act, on April 14, 2005 that would require the permit issuing body to "consult with the Governor of each State located within a 200-mile radius of the aquaculture facility" as well as approval from the regional fishery management council. This legislation requires an analysis of biological interactions as well as "social and economic impacts of such facility on other marine activities, including commercial and recreational fishing" (S.796), in part as a result of the economic impact of the US importation of farmed salmon from Chile and Norway that has devalued the price of wild Alaska salmon. This bill may have also stemmed from the absence of any specific mention of the regional fishery management councils in the draft 2004 aquaculture legislation, which may not have any jurisdictional power over decisions made regarding aquaculture in federal waters (NOA Act, 2004).

A ban on finfish farming in Alaska State waters (1990) was followed by a similar ban in California (2003); therefore California may also sign onto similar legislation to slow the permitting process of mariculture in federal waters. California is slated as a prime location for aquaculture activities, especially tuna ranching, which is quickly growing just south of the border near Ensenada, Mexico where 3 ranches exist and another 6 have been approved for tuna harvest. Controversy over the ownership of these highly migratory species has been debated in multinational arenas for decades in the capture fishery, and once the permitting is no longer an obstacle in the US it is probable that tuna ranching will also boom in States, such as California, along with lawsuits over management.

Off the outer continental shelf of the Gulf of Mexico lies the perfect partnership between decommissioned oil platforms and the investment for offshore aquaculture. The costly dismantling of oil rigs could be deferred, which combined with continued profits from lease agreements with mariculturists, is more than a gesture of charity from oil companies (Fletcher & Weston, 2004). Senator David Vitter of Louisiana is expected to introduce a bill this year that would allow for the conversion of thousands of oil platforms to fish farms or artificial reefs. The Gulf of Mexico Fishery Management Council projects that the platform farms will focus on finfish, so as not to compete with Gulf shrimp fishers (McVey et al., 2004). Just as the Grace platform in California appears to be a feasible farming option, the question of sustainability will depend on species selection for the Gulf and commercial farming carrying capacity for the already nutrified Gulf, with ample oil platforms becoming available in the future.

RECOMMENDATIONS

Aquaculture has developed rapidly in some countries, and brought with it numerous environmental problems that have partly contributed to the decline of world fisheries. The challenge for the Department of Commerce, as the permitting process extends to federal waters, will be to learn from the mistakes of other intensive aquaculture projects around the world to minimize the environmental damages and risks that are inherent to aquaculture, as well as to collaborate with other progressive experiments that are ongoing. A balance between using aquaculture technology to enhance hatchery development and survival of endangered species in combination with raising commercial species for human consumption is a positive return of natural resources.

Government financial incentives:

The draft Aquaculture Act of 2004 appropriates an Offshore Aquaculture Fund established in the US Treasury "without appropriation or fiscal year limitation, only to the Secretary [of Commerce] for the necessary expenses for the purpose of carrying out the provisions of this Act…" (NOA Act 2004). A portion of this fund should be devoted to aquaculture activities that promote or rebuild depleted stocks in exchange for reduced fishing pressure of these species, and/or increase farmed production of native species that are herbivorous or omnivorous. Shellfish, such as oysters, mussels, or clams for example, are low impact, low technology species that should be encouraged by the Secretary of Commerce. A financial incentive from the government to produce sustainable aquaculture is important to meet environmental goals set by NOAA (NOAA, 2002), as it is not clear at this time if carnivorous fish farming can be sustainable on a global scale.

Detailed monitoring protocol needed:

In addition to expanding on the small number offshore test sites, the monitoring methods should also include more biological indicators of ecosystem health. Presently, the standard for environmental monitoring in the US is the change in macrofauna in the pen vicinity (McVey & Stickney, 2002). Other indicators such as dissolved oxygen and sulfides are being monitored at some test sites; however microbial changes have not been tested or monitored. Changes in microbial diversity in the sediments or within the pens may be a predictor of disease and an indicator of ecosystem health (Danovaro et al, 2003). The criteria for environmental monitoring of offshore aquaculture production will be determined once the new offshore legislation is established (J McVey, 2005, personal communication). According to the draft EEZ aquaculture legislation, "the Secretary is authorized to establish the monitoring and evaluation protocols" (NOA Act, 2004).

Use of the precautionary principle:

Given the many uncertainties, the Department of Commerce should consider the following limits to offshore aquaculture projects.

1) Non-native species
No aquaculture activities producing non-native species should be permitted in federal waters to protect wild species that may be at risk of hybridizing or losing habitat to non-endemic escapees.

2) Genetically modified organisms
A moratorium on genetically modified species should remain until their safety can be proven in land locked closures over several generations.

3) Escapes in the EEZ
Require farm specific finfish identification tags or transmitters to hold companies financially responsible for escaped fish with significant fines.

3) Therapeutics
Antibiotics and pesticides should only be administered to fish in quarantine by a veterinarian. Therapeutics should not be added to the feed or water. Chemical antifoulants should also be banned, and manual cleaning of the pens should be done on land. Mandatory reporting of therapeutic types and quantities used by offshore aquaculture farms will assist in public awareness and project transparency.

4) Negative marine mammal interactions
Pens should not be sited in areas that overlap with marine mammal activities that will cause disruption, stress, or disease to these animals in compliance with the Marine Mammal Protection Act.

5) Identify areas that will be restricted from offshore aquaculture activities that may pose additional stress to protected species or recovering wild fish stocks. Aquaculture exclusion zones (AEZ's) should be determined in collaboration with fisheries management councils, and abide by the protections afforded by the Endangered Species Act.

CONCLUSIONS

Development of aquaculture in the EEZ will be feasible once the streamlined permitting process is in place. The investment capital already exists in the US, and with the possibility of healthy profit margins from growing demand in the seafood market, it will be a lucrative investment for many mariculturists. International companies already own a large share of the production market and are continuing to improve fish farming technology and efficiency. Presumably, these companies will have the upper hand on new US aquaculture companies in startup production and long term financing in the US EEZ, backed by years of experience in the international aquaculture arena.

Sustainability of aquaculture in the US EEZ will depend on feed sources and related issues, species choice and the degree of farming efficiency, as well as total ecosystem management of aquaculture within the context of harvested wild fisheries. The future still holds some unknowns that are difficult to predict at this time, including the development of new diseases or the spread of known diseases due to mariculture, and the effects climate change will have on all aspects of our oceans. It is dangerous to assume we can fully prevent disease, or have complete control over wild stocks that may still be providing the feed for aquaculture in the future. Aquaculture has become the solution to ever growing demand from an ever growing population, and in many cases it is the only solution. We have the opportunity at this point in time to make decisions that are healthy for our oceans, to rebuild depleted or endangered stocks through adequate fishery management and stock enhancement programs, to eat lower on the food chain and to preserve biodiversity—will we accept the challenge?

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