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Open Ocean Aquaculture

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Open Ocean Aquaculture

Summary

Open ocean aquaculture is broadly defined as the rearing of marine organisms in exposed areas beyond significant coastal influence. Open ocean aquaculture employs less control over organisms and the surrounding environment than do inshore and land-based aquaculture, which are often undertaken in enclosures, such as ponds. When aquaculture operations are located beyond coastal state jurisdiction, within the U.S. Exclusive Economic Zone (EEZ; generally 3 to 200 miles from shore), they are regulated primarily by federal agencies. Thus far, only a few aquaculture research facilities have operated in the U.S. EEZ; to date, all commercial aquaculture facilities have been sited in nearshore waters under state or territorial jurisdiction.

Development of commercial aquaculture facilities in federal waters is hampered by an unclear regulatory process for the EEZ, and technical uncertainties related to working in offshore areas. Regulatory uncertainty has been identified by the Administration as the major barrier to developing open ocean aquaculture. Uncertainties often translate into barriers to commercial investment. Potential environmental and economic impacts and associated controversy have also likely contributed to slowing potential expansion.

Proponents of open ocean aquaculture believe it is the beginning of the "blue revolution" — a period of broad advances in culture methods and subsequent increases in production. Critics point to concerns related to environmental protection and potential impacts on existing commercial fisheries. Potential outcomes are difficult to characterize because of the diverse nature of potential operations and the lack of aquaculture experience in open ocean areas.

The National Offshore Aquaculture Act was introduced as S. 1195 in the 109th Congress at the Administration's request, but was not enacted. The legislation focused on the need to develop a framework for issuing permits to operate in the EEZ. The bill has been re-drafted by the National Oceanic and Atmospheric Administration (NOAA) and may be introduced in the 110th Congress. Issues raised in connection with the previous bill included potential environmental impacts, the role of states, and permit security and duration.

This report discusses four general areas: (1) operational and business-related challenges; (2) potential environmental impacts; (3) potential economic impacts; and (4) the legal and regulatory environment. It then summarizes recent executive and legislative actions. Significant questions remain about whether an appropriate mechanism exists for any federal agency to provide an open ocean aquaculture lease with the necessary property rights to begin construction and operation. Policy makers and regulators will be challenged to weigh the needs of a developing industry against potential environmental and social impacts.

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Introduction

Open ocean aquaculture is broadly defined as the rearing of marine organisms in exposed areas beyond significant coastal influence. Open ocean aquaculture operations would be located at a considerable distance from shore and subject to relatively harsh environmental conditions resulting from wind and wave action. Open ocean aquaculture employs less control over organisms and the surrounding environment than do inshore and land-based aquaculture, which are often undertaken in enclosures such as ponds.

The National Offshore Aquaculture Act was introduced as S. 1195 at the Administration's request in the 109th Congress, but was not enacted. This legislation focused on the need for a framework for issuing permits to operate in federal waters of the U.S. Exclusive Economic Zone (EEZ), generally 3 to 200 miles from the coastline.[1] The bill has been re-drafted by the National Oceanic and Atmospheric Administration (NOAA) and may be introduced in the 110th Congress.[2] The drafted bill was modified to strengthen environmental provisions, clarify the role of states and fishery management councils, and extend the duration of permits to 20 years, as these were issues raised in connection with the previous proposal.

Background

Several terms for open ocean aquaculture are used interchangeably, including *offshore aquaculture* and *offshore fish farming*.[3] Open ocean aquaculture facilities generally consist of systems (e.g., cages, net-pens, longline arrays) that can be free-floating, secured to a structure, moored to the ocean bottom, or towed by a vessel. Currently operating commercial aquaculture farms in nearshore waters and estuaries use a variety of methods including ponds with earthen dikes, cages and net-pens

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[1] S. 1195 and the current NOAA draft National Offshore Aquaculture Act of 2007 define "offshore aquaculture" as all activities, including operation of offshore aquaculture facilities, involved in the propagation and rearing, or attempted propagation and rearing, of marine species in the United State Exclusive Economic Zone. Open ocean aquaculture is a more general term for operations in exposed ocean areas beyond significant coastal influence and may include areas in state waters within 3 miles of the shoreline.

[2] The NOAA draft National Offshore Aquaculture Act of 2007 and related information are available at [http://www.nmfs.noaa.gov/mediacenter/aquaculture/offshore.htm].

[3] *Marine aquaculture* and *mariculture* are broader terms, also referring to the land-based culture of marine organisms as well as their culture in nearshore, coastal, and exposed environments.

moored to the ocean bottom, enhancement and seeding of the bottom, and suspended lines. There has been some experimentation in offshore shellfish culture on the seabed and from suspended ropes and longlines. Offshore seaweed culture may also be considered.

Internationally, research and commercial open ocean aquaculture facilities are in operation or under development in Australia, Chile, China, France, Ireland, Italy, Japan, Mexico, and Norway.[4] Currently, three commercial open ocean facilities are operating in U.S. state/territorial waters. Cates International, Inc., cultivates moi (Pacific threadfin) near Hawaii, and Snapperfarms, Inc., cultivates cobia (ling) near Puerto Rico. In September 2005, Kona Blue Water Farms of Hawaii celebrated its first harvest of kahala reared in deepwater pens in state waters. Although these are open ocean operations, all three are currently sited in waters under state or territorial jurisdiction. Thus far, only a few aquaculture research facilities have operated in the EEZ. When such operations are located beyond coastal state jurisdiction within the U.S. EEZ, they are regulated primarily by federal agencies.[5]

Development of commercial aquaculture facilities in federal waters is hampered by an unclear regulatory process in the EEZ and technical uncertainties related to working in offshore areas. Regulatory uncertainty has been identified by the Administration as the major barrier to developing open ocean aquaculture in the United States.[6] Uncertainty is also one of the main barriers to commercial investment in new industries. Potential environmental and economic impacts and associated controversy have also likely contributed to slowing potential expansion.

Proponents of open ocean aquaculture position it as the beginning of the "blue revolution" — broad advances in culture methods and application with resulting increases in marine aquaculture production. They tout open ocean aquaculture as an option for meeting consumer demand for marine products, providing new employment opportunities, decreasing the U.S. trade deficit in seafood products, and developing a new economically viable industry. It is also asserted by proponents that development of open ocean sites would have the advantages of avoiding inshore user conflicts and reducing environmental impacts.

Opponents raise a number of concerns related to environmental protection and potential impacts on existing commercial fisheries. They point to inshore aquaculture where mangrove forests have been replaced by shrimp ponds, and waste

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[4] For more information on international efforts, see Biliana Cicin-Sain, et al., "Chapter 6: Lessons from the International Arena," *Development of a Policy Framework for Offshore Marine Aquaculture in the 3-200 Mile U.S. Ocean Zone* (Newark, DE: Univ. of Delaware, Center for the Study of Marine Policy, 2001), available at [http://darc.cms.udel.edu/SGEEZ/SGEEZ1final.pdf].

[5] Federal agencies also have regulatory authority over certain aspects of aquaculture development in nearshore waters under state/territorial jurisdiction.

[6] Written statement of Dr. William T. Hogarth, Assistant Administrator for Fisheries National Marine Fisheries Service, National Oceanic Atmospheric Administration, U.S. Dept. of Commerce, *Hearing on Offshore Aquaculture*, before the U.S. Senate, Committee on Commerce, Science, and Transportation, National Ocean Policy Study (Apr. 6, 2006).

from salmon culture has harmed the seabed environment. Their environmental concerns include pollution from unused feed, fish wastes, and treatments (e.g., antibiotics); entanglement of marine wildlife in gear; introduction of nonnative species; and escape of organisms that might affect the genetic makeup of wild species. They say that open ocean aquaculture could also have direct and indirect effects on commercial fisheries, such as degradation of wild fish habitat; preemption of commercial fishing grounds; and market competition between wild and cultured fish products.

The future of open ocean aquaculture in the EEZ is still an open question. A complex and unpredictable mix of technological, biological, and economic elements will likely determine the profitability of open ocean aquaculture. However, the future will also likely depend on the tradeoffs between benefits associated with aquaculture production and costs of potential environmental and social impacts.

Challenges of Open Ocean Aquaculture

A broad array of questions is associated with the viability and impacts of open ocean aquaculture initiation and expansion. These concerns are further complicated by factors such as evolving production technology, uncertain economic costs and benefits, and environmental and social impacts. Generalizations are also difficult to make because of the variety of candidate species, associated technologies, and potential scales of operation.

Major categories of concerns related to open ocean aquaculture development include (1) biological, operational, and business concerns related to development of a new industry; (2) potential social and economic impacts; (3) potential environmental impacts; (4) and the legal and regulatory environment.[7]

Biological, Operational, and Business Concerns

Species and Technology. Current species and culture techniques — including species selection, egg/larval production, and nutritional/dietary requirements — are somewhat limited. Development of open ocean aquaculture probably will need further research, and new culture techniques may be required for rearing species not presently grown.

Many economically important species are currently being studied at various universities and research institutes for possible culture, including amberjack, black sea bass, blue mussels, cobia, cod, corvina, flounder, haddock, halibut, mahimahi,

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[7] Detailed discussions of many of the issues discussed in this section are available in *Development of a Policy Framework for Offshore Marine Aquaculture in the 3-200 Mile U.S. Ocean Zone* (2001) by the University of Delaware's Center for the Study of Marine Policy, at [http://darc.cms.udel.edu/sgeez/sgeez1final.pdf]; and *Recommendations for an Operational Framework for Offshore Aquaculture in U.S. Federal Waters* (October 2005) by the University of Delaware's Gerard J. Mangone Center for Marine Policy, at [http://darc.cms.udel.edu/sgeez/sgeez2final.pdf].

mutton snapper, red drum, striped bass, tuna, and yellowtail snapper. Other research topics being investigated include hatchery culture technologies; automated feeder design; culture of new species; disease identification and control; cages and husbandry technology for rough water environments; identification of alternative food sources; nutrition requirements; definition of carrying capacity of offshore waters; appropriate mooring systems; drifting and self-powered cages; federal regulatory structure; and environmental monitoring technology.

Since open water aquaculture is a relatively new industry, many potential operators are inexperienced with the technical requirements for open ocean facilities. Historically, development has been limited by technology that requires water depths of 100-150 feet; this narrow band of acceptable depth exists from ¼ mile to about 50 miles offshore, depending on location. Open ocean aquaculture facilities, moored or floating miles off the coast in a high-energy environment, experience numerous environmental conditions that differ from nearshore aquaculture operations, including exposure to wind and wave action from all directions, short and steep wave patterns, strong currents, seasonal anoxic (oxygen-lacking) conditions, and unpredictable ocean conditions that can prevent operators from being able to access their cages for days to weeks.[8]

Systems have been developed to overcome these obstacles, including cage designs that do not deform under current and wave loads, submersible cages, and single-point moorings. Cage-mounted autonomous feeding systems have been developed that can operate both at the surface and submerged. Others have developed closed containment systems for open ocean use to address environmental concerns. Universities and private-sector research interests are developing automated buoys that can monitor the condition of stock and feed fish on a regular basis for weeks at a time. Other research groups are working on automated, floating cages that would travel with the currents and be tracked by satellite.[9] These ship-like structures could float on favorable oceanic currents or be held geostationary with low-energy thrusters.

Financing. Estimating profitability and securing financing is difficult for new open ocean aquaculture companies because of an uncertain regulatory environment, the risk associated with operating in exposed open ocean locations, the risk of catastrophic events (e.g., severe storms), limited operational experience, and high capital start-up costs. Proponents of open ocean aquaculture development assert that, without some form of long-term (at least 25 years) permitting or leasing of the water surface, water column, and seabed, open ocean aquaculture will have significant problems in securing capital from traditional funding sources, obtaining suitable insurance on the capital investment and stock, and protecting investments from

[8] A pilot study cage in the Gulf of Mexico was torn from its mooring in December 2000 and was found off the coast of Louisiana after a long search.

[9] Critics question whether floating unmanned remote-control cages could ever be permitted, due to the major navigational hazard they could present.

vandalism and other property threats.[10] Such leasing may be problematic unless property rights beyond the territorial sea are clarified.

The availability of insurance on stock and equipment is relevant to, and can facilitate obtaining, front-end capital for open ocean aquaculture. The insurance sector has more than 30 years of experience in managing and insuring risks to conventional aquaculture stock and equipment in a variety of situations and conditions. Although the insurance industry is unlikely to view pilot projects favorably, the earlier the insurance industry is brought into developing open ocean aquaculture, the earlier insurers are likely to be comfortable with the risks that must be insured.

Proponents of open ocean aquaculture suggest that, if profits are to be made, sufficient investment capital must be available as soon as property rights, permitting, and environmental concerns are resolved. More pessimistic critics suggest that open ocean aquaculture is unlikely ever to have an adequate economic return on investment, and that investment should rather be focused on improving nearshore or shore-based aquaculture.

Economic Potential. The economic potential of U.S. aquaculture will likely depend on both operational costs and product prices. Costs will largely depend on several factors, including U.S. regulation, the technology adopted, and national and international economic conditions. Economic conditions will determine labor, energy, capital, and other input costs. Prices of U.S. aquaculture products will likely depend on world demand and the prices of competing products. Competing products include similar imported cultured products, similar wild species, and other agricultural product substitutes such as chicken, pork, and beef. One of the primary challenges for potential U.S. producers is to minimize capital, labor, energy, permitting, and other costs compared to those for aquaculture in other countries and to wild stock harvesting.

The level of government support in other countries is often greater than that provided in the United States. Government assistance could promote the initial development of a U.S. open ocean aquaculture industry, but global market forces would likely determine whether it matures or withers.

The United States has been, for the most part, a technological innovator, and the use of marine resources to farm new species with high market value could give the United States a competitive edge. On the other hand, operating costs and environmental standards in other countries are often lower. In addition to capital costs, the location of aquaculture facilities further from shore will necessitate high variable costs such as fuel, security, and/or surveillance. Dependable air freight has allowed aquaculture operations to market globally. Partially as a result, the U.S. commercial fishing industry has been harmed by lower prices that are directly related

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[10] Some nations (e.g., Canada) lease nearshore areas with implied automatic renewal of tenure as long as the lessee meets current licensing requirements. Alternatives on leasing for short time periods include issuing research permits or vesting tenure in a federal or state agency initially to streamline the process and allow greater control over eventual ownership.

to foreign aquaculture production. For example, many persons believe that the worldwide salmon farming industry depresses wild salmon prices and harms the economy of Alaskan coastal communities.

Shoreside Infrastructure. Supportive shoreside infrastructure, including hatcheries and nurseries, does not exist and would need to be developed. Support industries have the potential to provide employment and other economic benefits to coastal communities. If open ocean aquaculture becomes viable, these business should also grow. However, the relatively high value of shoreline property could be an impediment to finding appropriate sites, especially waterfront sites, in coastal areas with needed transportation infrastructure.

Development and Partnerships. Fostering industry/academic partnerships may benefit open ocean aquaculture development.[11] Some suggest that, for development to occur, open ocean aquaculture should be considered "big science" along the lines of atomic/nuclear physics research and the Human Genome Project. In this light, the developing open ocean aquaculture industry may benefit by seeking and promoting partnerships with multinational industrial, agricultural, and pharmaceutical corporations.[12] Proponents argue that this is the most likely way for open ocean aquaculture to obtain the ocean engineering, marine technology, and floating platform infrastructure at the necessary scale of production. The developing industry will also need to refine biological methods related to commercial-scale hatchery and grow-out facilities. They also state that, without domestic financial support, aquaculture innovation will likely come from other countries already providing greater investment in technology development.

Social and Economic Impacts

Some Members of Congress, especially those from coastal areas with strong fishing communities, are interested in better understanding the social and economic effects of open ocean aquaculture development. If open ocean aquaculture supplied a significant level of production at lower cost, it could supplement commercial fishery production, resulting in greater quantities of products and lower prices. Lower prices would benefit U.S. consumers, who would likely increase consumption.

However, greater aquaculture production also could supplant commercial fishery production. Production from open ocean aquaculture could lower prices and decrease profits of commercial fishing-related businesses. The consequences could include lower landings by commercial fishermen (assuming that the fish stock had

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[11] Critics caution that funding open ocean aquaculture development through universities has the potential to slow commercial development if academic solutions are insufficiently pragmatic for commercial industry.

[12] Potential partners include oil and gas companies with related support industries, defense contractors developing large floating structure technology and platforms, and ocean engineering companies laying submarine cable and developing affiliated technology for telecommunications corporations. Others may include corporations exploring wind and/or wave-energy generation, ocean thermal energy conversion and related deep ocean water upwelling systems, carbon sequestration and mitigation, and ocean fertilization.

not been overfished), lower prices (and revenues) for commercial fishermen, the failure of the least efficient businesses, loss of commercial fishery-related employment, and disruption of fishing communities. However, the degree of displacement would depend on the similarity of products, the scale of aquaculture production, and the characteristics of associated markets for seafood products.

Although the Gulf of Mexico shrimp and Alaska salmon fisheries have been harmed by lower prices, these commercial fisheries were not replaced by aquaculture. The precise levels of impacts are difficult to quantify because of differences in product form, relationships among products, and the general complexity of these seafood markets. In some cases, competition could provide incentives to improve the quality of the wild product, management institutions, and marketing. When the entire economy is considered, greater efficiency in the wild fishery and consumer benefits related to higher product quality and lower prices resulting from aquaculture seem likely to result in net national benefits. To improve understanding of gains and losses to specific sectors and local and national economies, concerned parties suggest that social and economic impact assessments should be part of any aquaculture development plan from the onset.

In 2005, the United States imported approximately 10.16 billion pounds of edible seafood worth $12.1 billion.[13] After accounting for exports of $4.1 billion, there was a trade deficit of approximately $8.0 billion in edible seafood products. Shrimp accounted for $3.6 billion and salmon accounted for $1.1 billion of total U.S. imports.[14] In 2005, annual U.S. aquaculture production was valued at nearly $1.1 billion[15] (more than half of which is from freshwater production), representing less than 1% of global aquaculture production.

Proponents assert that development of open ocean aquaculture would narrow the U.S. deficit in seafood trade. However, many economists would assert that the seafood trade deficit is insufficient reason to advocate for development of a new industry. They say countries gain from free trade when they specialize in products that they are best at producing.[16] If other countries have an absolute or comparative advantage in aquaculture, the United States would likely benefit from specializing in other industries. In reality, say others, it is often difficult to determine whether a comparative advantage will exist because of uncertainties related to technological development and future economic conditions.

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[13] U.S. Dept. of Commerce, National Marine Fisheries Service, *Fisheries of the United States, 2005*, Current Fishery Statistics No. 2005 (Washington, DC: Feb. 2007), p. 48 and p. 64.

[14] Ibid., p. 48.

[15] U.S. Dept. of Agriculture, National Agricultural Statistics Service, "Census of Aquaculture (2005)," *2002 Census of Agriculture*, Volume 3, Special Studies Part 2, (Washington, DC: October 2006), p. 1.

[16] A basic discussion of absolute and comparative advantage can be found at [http://internationalecon.com/v1.0/ch40/40c000.html].

Although shrimp and salmon account for a large portion of the seafood trade deficit, they appear to be poor candidates for open ocean aquaculture. Most shrimp aquaculture is carried out in ponds in tropical coastal areas. Salmon aquaculture generally uses net-pens in protected areas such as fjords or bays. It is questionable whether open ocean aquaculture can be competitive with established inshore aquaculture of these species. For example, one of the current offshore aquaculture operators foresees future investment focusing on new species and warmer climates.[17]

If many of the proposed species for open ocean aquaculture are carnivores, it is possible that increased imports of fishmeal from small wild fish will be required to feed the farmed fish. If so, these imports could increase the U.S. trade deficit. However, these imports may be beneficial to the overall national economy, if the domestic aquaculture industry is economically viable.

Open ocean aquaculture development also has the potential to interfere with maritime transportation and commercial fisheries, with potential conflicts over access and transit rights.[18] Because of this potential for conflict, a process would need to be developed to identify the more suitable areas in federal waters for open ocean aquaculture development and/or to mediate disputes. Also, safety issues with offshore facilities may need to be addressed.

Proponents of open ocean aquaculture assert that economic benefits will result from the development of this industry. Individuals familiar with the experiences of coastal aquaculture have raised questions about the sustainability of offshore fish farming and its impact on local communities. They assert that, in many cases, shrimp and salmon have been produced at the expense of local communities and environmental concerns.[19] From another perspective and with appropriate research support, open ocean aquaculture might provide opportunities for commercial fishermen who no longer pursue harvests in managed capture fisheries. Based on the history of salmon farming, some have questioned the claims of aquaculture as a jobs creator, especially since it seems likely to become a highly automated industry. Additionally, little evidence has been provided for the economic benefits of open ocean aquaculture beyond the general acknowledgment that marine aquaculture has proven profitable elsewhere, especially in inshore areas with little or no environmental regulation and/or enforcement (e.g., Chile).

Advocates of open ocean aquaculture operations view it as additional means to support the domestic seafood industry, which has some of the highest unemployment

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[17] Written statement of John R. Cates, President of Cates International, *Hearing On Offshore Aquaculture*, before the U.S. Senate, Committee on Commerce, Science, and Transportation, National Ocean Policy Study (Apr. 6, 2006).

[18] Submerged technologies for open ocean aquaculture may reduce or eliminate some of these concerns.

[19] Norwegian Directorate of Fisheries, Dept. of Aquaculture, *Key Figures from Norwegian Aquaculture Industry, 2000*, (Bergen, Norway: 2001), 15 p.; Neal Gilbertson, "The Global Salmon Industry," *Alaska Economic Trends*, v. 23, no. 10 (Oct. 2003): 3-11; Rosamond L. Naylor, et al., "Salmon Aquaculture in the Pacific Northwest: A Global Industry with Local Impacts," *Environment*, v. 45, no. 8 (Oct. 2003): 18-39.

rates in the country. However, others counter, unemployment in the seafood industry/wild fisheries is also partly the result of the development of aquaculture, especially salmon farming. Critics also argue that the potentially higher cost of tending fish far from shore means these facilities are likely to be automated, and local employment benefits may be minimal.[20] However, employment is required for much more than tending to offshore farms — support roles are required in land-based hatcheries to provide sufficient numbers of fingerlings; feed mills are necessary to provide feed for the fish; manufacturing is essential to fabricate the cages and other culture materials; maintenance, logistics, and transportation are critical; and finally, all the fish raised in offshore farms would need to be harvested, processed, and sold, thereby potentially increasing the use of presently underutilized fish processing plants along much of the coast.[21] Others question whether it is realistic to assume that these jobs can be filled by unemployed domestic seafood workers.

Due to international markets and foreign production, some of the socioeconomic impacts of open ocean aquaculture production (e.g., changes in prices and markets) will likely occur, whether the United States permits or denies open ocean aquaculture development. For example, the State of Alaska prohibited salmon aquaculture, but its development elsewhere resulted in significant socioeconomic losses for Alaska fishermen. Lower prices would benefit U.S. consumers, who would likely increase consumption regardless of whether open ocean aquaculture is developed inside or outside the United States.

Environmental Impacts

Proponents of open ocean aquaculture and many environmental groups suggest that open ocean finfish aquaculture systems may produce fewer and less severe environmental impacts than those imposed by nearshore aquaculture systems. This may be in part because dissolved and particulate waste products and excess feed may be assimilated and recycled more efficiently in the open ocean environment. However, the scope of any effects may vary greatly, depending on the culture

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[20] Many are researching ways to increase automation, especially with feeding and harvesting, such that few workers may be needed. At the extreme, all the work may be able to be done from a computer in a shoreside office with a satellite-controlled robotic system attached to the offshore cages. Also, the history of salmon farming indicates that, as the industry becomes more efficient, production per unit labor increases and employment decreases, especially compared to commercial fishing.

[21] The Gulf of Mexico Offshore Aquaculture Consortium estimated that, for a 12-cage offshore production system, eight individuals would be required to tend a sophisticated, automated offshore facility. However, they forecast that such an operation would produce an additional annual regional economic output reaching more than $9 million and provide additional employment for at least 262 persons, when all shoreside support was included. Although some suggest that, for every dollar of fish landed from fishing, there is a multiplier of as much as 5-7 in the shoreside economy (with the implication that this relationship would be roughly equivalent for aquaculture), others argue that these extreme multipliers may be suspect since the multiplier for the entire U.S. economy is around 2 — meaning that a new dollar entering the economy manages to generate an additional dollar's worth of goods and services before the demand "leaks out" (i.e., gets spent on imports). See [http://www.choicesmagazine.org/2003-2/2003-2-06.htm].

technique, location, size/scale, and species raised.[22] Open ocean aquaculture pens would be open to the surrounding environment. Some critics of open ocean aquaculture cite concerns with the escape of fish, water pollution from uneaten feed and waste products (including drugs, chemicals, and other inputs), use of antibiotics and other animal drugs, alteration of benthic habitat by settling wastes, and the spread of waterborne disease from cultured to wild fish.[23] The present lack of knowledge — owing to limited experience, lack of research funding, and few studies focusing specifically on open ocean aquaculture — limits understanding of potential environmental concerns. Critics of open ocean aquaculture hope that regulation of this emerging industry will be stringent.

An opposing view holds that open ocean waters are normally nutrient-deficient, and nutrients released from open ocean aquaculture operations may increase wild production in adjacent areas, much like coastal areas benefit from natural upwelling. A related concern is whether large operations will result in significant waste settling that could alter benthic habitat. However, research indicates that, in some areas, currents keep water around fish cages well circulated, dissipating waste products quickly, resulting in minimal impact of open ocean aquaculture facilities on water quality. Critics, however, question whether the experience with experimental facilities is relevant to future commercial operations, which will likely need to be much larger to be profitable.[24] A possible solution might be to combine finfish operations with the culture of seaweeds or bivalves to consume the excess nutrients; this approach is being tested by the University of New Hampshire at their open ocean aquaculture research project, but may be more appropriate for nearshore operations where waste diffusion is slower and nutrient concentrations are higher.[25]

Another environmental concern is the use of pharmaceuticals, antibiotics, growth-enhancing chemicals, other animal drugs, and antifouling agents used on gear and enclosures in open water environments. Chemicals used on foods have to be approved for use by the Food and Drug Administration, and veterinarian oversight can ensure proper application and minimal environmental impact. Drugs, some of

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[22] An extended discussion of most of the issues summarized in this section can be found in *Guidelines for Ecological Risk Assessment of Marine Fish Aquaculture* (Dec. 2005) by NMFS, available at [http://www.nwfsc.noaa.gov/assets/25/6450_01302006_155445_NashFAOFinalTM71.pdf].

[23] Institute for Agriculture and Trade Policy, *Open Ocean Aquaculture*, at [http://www.environmentalobservatory.org/library.cfm?RefID=37057].

[24] Critics assert that the experience with research facilities poorly indicates the impacts that could be expected if the open ocean aquaculture industry reaches the size or scale NOAA is promoting. Proponents argue that this research has been conducted with an awareness that impacts will vary in proportion to size of the operation. Cumulative impacts, both in multiple farms combining to cause impacts and in multiple impacts from farms examined as a whole, have not been studied.

[25] Critics of this approach point out that, because of the practical limits of photosynthetic rates of seaweed and filtering rates of bivalves, such a nutrient recycling system might have to be 50 or more times the size of the finfish operation to handle the anticipated nutrient loads. The cost of such a massive nutrient recycling operation might far exceed any potential benefits.

which were developed and approved for use in a contained or controlled environment, are often introduced to cultured fish in their feed. Unconsumed feed and the metabolic waste from the fish feeding on it pass through and out of the containment system, where some of this escaped feed may be consumed by wild organisms. However, the use of some of these products may be declining, as efficacious vaccines eliminate the need for antibiotics and other therapeutants. Proponents of open ocean aquaculture suggest that, because of the more pristine and better oxygenated water conditions offshore, no use of antibiotics has been necessary in any of the offshore areas being tested in the United States.[26]

Most fish currently proposed for open ocean aquaculture are carnivorous and require feeds containing fishmeal and fish oil, which are obtained from wild stocks. As a result, three or more pounds of wild fish are required to produce one pound of farmed fish. Some question whether aquaculture production could exacerbate pressures and cause overfishing of these ocean fish stocks.[27] Others assert that wild fish stocks are well managed and commercial harvest for fishmeal would occur with or without demand from open ocean aquaculture.[28] In addition, a feed conversion rate of three pounds feed to one pound of farmed product is favorable compared to wild production.[29] Use of a less desirable commodity to produce a more highly valued product is the basis of most livestock and aquaculture operations.

The price of fishmeal and fish oil could increase if large quantities are required for open ocean aquaculture. While concerns could be addressed by improving feed formulations or by raising more herbivorous fish, the choice of open ocean aquaculture species will likely depend on profitability.[30] Many high-value candidate fish or shellfish species are carnivorous. Plant protein sources, such as canola, algae, or soybean meal, are being used to partially replace fishmeal, with significantly positive results emerging, especially where soybean meal is supplemented with certain essential amino acids. Another approach might use more waste from fish-processing plants to alleviate pressures to increase wild harvest for fishmeal. In some

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[26] Personal communication from Dr. James P. McVey, Aquaculture Program Director, National Sea Grant College Program, NOAA, September 2005.

[27] Rosamond L. Naylor, et al., "Effect of Aquaculture on World Fish Supplies," *Nature*, v. 405 (June 29, 2000): 1017-1024. Others, however, point out that harvesting of forage fish stocks may be mismanaged, rather than directly harmed by aquaculture.

[28] Clifford A. Goudey, "Letters: Aquaculture in Offshore Zones," *Science*, v. 314 (Dec. 22, 2006): 1875.

[29] Actual feed conversion rates can range widely, with wild production often considered to be around 10 pounds of feed per pound of growth. At one extreme, a feed conversion rate of 20 pounds of feed per pound of farmed tuna is reported (Sergi Tudela, "Tuna Farming: Grab, Cage, Fatten, Sell," *Samudra*, no. 32 (July 2002): 9-17). At the other extreme, feed conversion rates approaching 1.2 pounds of feed per pound of farmed Atlantic salmon have been reported (British Columbia Environmental Assessment Office at [http://www.eao.gov.bc.ca/epic/output/documents/p20/1051572085662_da81e53841c84e47b5ea9ab15075741a.pdf]).

[30] There has been little research on herbivorous species. NOAA has shown minimal interest in these species and has not offered much direction in addressing the "net-loss" of fish protein issue.

operations, the feed may contain as little as 30% fishmeal. An obstacle to increasing the amount of plant material that can be substituted for fishmeal appears to be the presence of anti-nutritional factors in the plant-derived materials.[31]

Another concern involves the spread of fish-borne disease from aquaculture to wild populations. In one instance the opposite occurred, a 2003 outbreak of infectious hematopoietic necrosis virus in British Columbia farmed salmon was confirmed to be a virus that had been circulating in wild fish for many years. Yet, problems with the transfer of sea lice from salmon farms to wild salmon have been noted recently.[32]

Genetic anomalies could occur if wild fish are exposed to or interbreed with hatchery-raised fish. This issue might arise if genetically modified or non-native fish escaped from aquaculture facilities and interbred with wild fish.[33] The potential interbreeding problem can be greatly reduced if only sterile fish are farmed; fairly simple technology exists to accomplish such sterilization. Critics speculate that, since selectively bred and genetically modified fish may grow faster and larger than native fish, they could displace native fish in the short term (both through competitive displacement and interbreeding), but might not be able to survive in the wild for the long term.[34] This is especially a concern in states (e.g., California, Maine, Maryland, and Washington) where genetically modified fish are banned within state waters but could be grown in offshore federal waters.

A related concern is the introduction of exotic species, such as Atlantic salmon in British Columbia. Escaped fish could be a problem in open ocean facilities that may be particularly vulnerable to storms, although recent hurricanes and tropical storms in Hawaii, Puerto Rico, and the Bahamas have caused no damage or loss of fish in submerged cage-culture operations. The experience with salmon farming indicates that escaped fish could easily be a problem, either through interbreeding with closely related native species (genetic interactions) or through competitive displacement of native species. Although management techniques at net pen sites are improving and modified cage designs better prevent escapes, closed containment systems may be the only way to fully address this problem.

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[31] G. Francis, H. P. S. Makkar, and K. Becker, "Antinutritional Factors Present in Plant-Derived Alternate Fish Feed Ingredients and Their Effects in Fish," *Aquaculture*, v. 199, no. 3-4 (2001): 197-227.

[32] Alexandra Morton, et al., "Sea Lice (*Lepeophtheirus salmonis*) Infection Rates on Juvenile Pink (*Oncorhynchus gorbuscha*) and Chum (*Oncorhynchus keta*) Salmon in the Nearshore Marine Environment of British Columbia, Canada," *Canadian Journal of Fisheries and Aquatic Sciences*, v. 61 (2004): 147-157.

[33] Rebecca J. Goldburg, Matthew S. Elliott, and Rosamond L. Naylor, *Marine Aquaculture in the United States: Environmental Impacts and Policy Options*, Pew Oceans Commission (Arlington, VA: July 2001), pp. 6-9. See [http://www.pewtrusts.org/pdf/env_pew_oceans_aquaculture.pdf].

[34] The *Trojan gene* hypothesis (William M. Muir and Richard D. Howard, "Possible Ecological Risks of Transgenic Organism Release When Transgenes Affect Mating Success: Sexual Selection and the Trojan Gene Hypothesis," *Proceedings of the National Academy of Sciences of the United States*, v. 96, no. 24 (Nov. 23, 1999): 13853-13856).

Since facilities will be offshore and underwater, some are concerned about possible harm or disturbance to marine mammals and other wildlife. To address these concerns, current cage designs avoid the use of small diameter or loose lines or loosely hung netting to prevent the entanglement of sea turtles and marine mammals in net-pens and associated gear. Since net-pens would be under tension, the possibility that a turtle flipper or whale fluke would get tangled in lines or nets is unlikely. However, experience has shown that dolphins and other marine mammals do get entangled in fish farms.[35] In addition, shellfish farms have many ropes/longlines and could be problematic. Sound devices at farms to keep animals away could harass or harm marine mammals. Open ocean facilities could potentially affect some endangered species, such as North Atlantic right whales as they migrate, or alter essential habitat for feeding, breeding, and nursing. Also, there could be renewed interest in killing "nuisance" animals, as has been the case with salmon farmers killing seals and sea lions. There could be problems with other predatory animals, such as sharks, as well.

Legal and Regulatory Environment

The legal and regulatory framework for open ocean aquaculture will, in large part, determine whether private industry succeeds in establishing commercial operations. Legal and regulatory challenges may be particularly time-consuming and costly, although some suggest that moving aquaculture away from the coast, and out of the view of the majority of coastal residents, could alleviate some public concerns. The complexities of multi-agency permitting are not clearly understood by all interested parties, leading to uncertainty for the open ocean aquaculture industry and making it difficult to plan and finance operations. Current permitting requires approval by at least three federal agencies that have jurisdiction over various aspects of aquaculture — the U.S. Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers, and the National Marine Fisheries Service (NMFS).[36] The review required under each of these agencies' responsibilities can delay a permit or deny it if the expected effects are too great. These agencies will likely be involved in future decisions that might provide legal rights to open ocean aquaculture operators.

For aquaculture projects in offshore federal waters, the lead federal permitting agency must assure consistency with approved programs in adjacent states under the Coastal Zone Management Act (16 U.S.C. §§1451, et seq.). In addition, state waters are traversed both to operate open ocean aquaculture sites and to bring harvested fish ashore for processing. States with approved Coastal Zone Management plans may veto federal permits for activities that are inconsistent with the state's plan. This

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[35] See C. M. Kemper et al., "Aquaculture and Marine Mammals: Coexistence or Conflict?" *Marine Mammals and Humans: Towards a Sustainable Balance*, N. Gales, M. Hindell, and R. Kirkwood, eds., (CSIRO Publishing: 2003). However, bycatch also occurs in many harvest fisheries, where its extent may be greater and its control may be more difficult than at stationary aquaculture facilities.

[36] NMFS (also popularly called "NOAA Fisheries") is part of the National Oceanic and Atmospheric Administration (NOAA) in the U.S. Dept. of Commerce.

oversight ensures that operations occurring in federal waters adjacent to state waters will neither harm that state's interests nor be inconsistent with state policies.

EPA regulates the discharge of pollutants into waters of the United States from finfish aquaculture facilities under the Clean Water Act (CWA; 33 U.S.C. §§1251, et seq.). Under the CWA's National Pollutant Discharge Elimination System, such facilities are regulated under the category "concentrated aquatic animal production facilities."[37] For aquaculture facilities located in offshore federal waters, Section 403(c) of the CWA requires an additional review to prevent unreasonable degradation of the marine environment. Discharges that cause unreasonable degradation are prohibited, and are evaluated according to ocean discharge criteria established by the EPA.

Because of navigation concerns, the Army Corps of Engineers has jurisdiction over permanent or temporary "devices" used to explore, develop, or produce resources on or around the seabed in federally controlled waters (33 C.F.R. Part 322). The Coast Guard, in the Department of Homeland Security, regulates vessel traffic and dictates safety measures (lights and signals) for aquaculture structures to ensure safe vessel passage under the Rivers and Harbors Act of 1899 (33 U.S.C. §407). In addition, the Department of Defense may become involved, reviewing proposals that might interfere with naval operations.

Through a NOAA General Counsel opinion,[38] NOAA assumed the lead role in promoting open ocean aquaculture development and has supported this developing industry. In some cases, NMFS has authorized open ocean aquaculture operations for scientific purposes through an exempted fishing permit and has defined marine aquaculture as fishing, under the authority of the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. §§1801, et seq.).[39] In addition, the Magnuson-Stevens Act requires the federal permitting agency for any aquaculture facility to consult with NMFS for potential impacts to essential fish habitat (EFH). EFH is designated for all marine species for which there is a federal fishery management plan (FMP). NMFS also has review responsibilities under the Marine Mammal Protection Act (16 U.S.C. §§1361, et seq.) and the Endangered Species Act (16 U.S.C. §§1531, et seq.). These reviews could impede or prevent open ocean aquaculture development in some areas.

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[37] 40 C.F.R. Part 451; see 69 *Fed. Reg.* 51891-51930 (Aug. 23, 2004).

[38] Jay S. Johnson and Margaret F. Hayes, *Regulation of Aquaculture in the EEZ*, Memorandum, Office of the General Counsel, NOAA (Washington, DC: Feb. 7, 1993), 5 p.

[39] Based on a legal opinion by NOAA General Counsel, landings or possession of fish in the EEZ from a commercial marine aquaculture operation producing species managed under FMPs constitutes "fishing" as defined in the Magnuson-Stevens Act. Therefore, to allow such commercial production in the EEZ, FMPs must be amended to allow for such activity for managed species and for the regulation of the activity by NMFS. Scientific activity for marine aquaculture in the EEZ is regulated by federal exempted fishing permits (50 C.F.R. §600.745).

Also under the authority of the Magnuson-Stevens Act, several regional fishery management councils have exercised regulatory oversight over open ocean aquaculture. The New England and Gulf of Mexico Councils have been particularly active in this respect.[40] The New England Council has established evaluation criteria for open ocean aquaculture proposals that encourage the use of best management practices aimed at reducing environmental and fishery impacts. The Gulf of Mexico Council has adopted an open ocean aquaculture policy and has prepared a management options paper. Although the key installation, navigation, and water quality permits can be obtained from the agencies mentioned above after a permit development and public review process, commercial aquaculture is less likely to occur in other offshore federal waters, because other regional fishery management councils have not prepared aquaculture FMPs or generic aquaculture amendments to the appropriate FMPs for species that could be cultured. In addition, it is unclear what regulatory authority NMFS and the regional councils might have over species, like mussels, that are not managed under a federal FMP.

Finally, using offshore waters will probably be legally controversial. Traditionally, nearshore waters and their resources under state jurisdiction are considered to be held and managed "in the public trust." Open ocean aquaculture may be perceived by some as the de facto privatization of the ocean, which has historically been considered a common property resource.[41] Precedents in leasing offshore areas for developing oil and gas resources may be relevant to these concerns. However, significant questions remain concerning whether an appropriate mechanism exists for any federal agency to provide an open ocean aquaculture permit or lease applicant with the necessary property rights to begin construction and operation. Siting and site tenure in federal waters are important issues for development and private investment — without assurances and protection of exclusive rights, there is little incentive for financial investment.

Marine Aquaculture Task Force

In 2005, the Pew Charitable Trusts and Lenfest Foundation requested the Woods Hole Oceanographic Institution to convene a task force to examine the potential risks and benefits of open ocean aquaculture. The nine-member panel developed a set of national policy recommendations to guide future development of the industry.[42] The panel concentrated on potential environmental impacts with recommendations related to:

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[40] "Agency Sinks Proposal for Gulf Fish Farm," *St. Petersburg Times* (Dec. 30, 2003), at [http://www.sptimes.com/2003/12/30/Southpinellas/Agency_sinks_proposal.shtml].

[41] The government regularly grants exclusive use of public resources when there are public benefits, establishing a precedent for ocean leasing for commercial aquaculture to increase domestic fish supply. For a more detailed discussion of these issues, see CRS Report RL32658, *Wind Energy: Offshore Permitting*, by Aaron M. Flynn.

[42] A copy of the 128-page Task Force report is available at [http://www.whoi.edu/cms/files/mcarlowicz/2007/1/Sustainable_Marine_Aquaculture_final_1_02_07_17244.pdf].

- escapes resulting in introduction of nonnative species;
- disease and parasite spillover into natural ecosystems;
- aquacultural waste resulting in water pollution; and
- market-based incentives to reward environmental protection.

The panel also provided a general governance framework to address environmental impacts that would provide clear federal leadership and standards to protect the marine environment. The framework would assign NOAA a lead role in planning aquaculture in federal marine waters, with emphasis on related activities such as evaluating environmental risks, consulting with regional and state bodies, and developing environmental standards.

Federal Action

Legislative Efforts

In 2005, NOAA developed a draft "National Offshore Aquaculture Act." Modified legislation was introduced in the 109th Congress as S. 1195. The National Ocean Policy Study of the Senate Committee on Commerce, Science and Transportation held related hearings in April and June of 2006. S. 1195 would have established a regulatory framework for aquaculture in federal waters. It would have provided for the issuing of permits to operate in ocean tracts for 10 years with potential extensions and established a "one-stop" permitting system for open ocean aquaculture operators.[43] S. 1195 would have:

- authorized the Secretary of Commerce to issue open ocean aquaculture permits and to establish environmental requirements where existing requirements under current law are inadequate;
- exempted permitted open ocean aquaculture from legal definitions of fishing that restrict size, season, and harvest methods;
- authorized a research and development program to support open ocean aquaculture;
- required the Secretary of Commerce to work with other federal agencies to develop and implement a streamlined and coordinated permitting process for aquaculture in the EEZ; and
- offered certain exemptions for foreign ownership.

Current aquaculturalists and related industries have been supportive of offshore aquaculture expansion. They have voiced a general belief that offshore aquaculture can be established in a manner that minimizes potential environmental and commercial fishing impacts while providing a valuable source of seafood. Aquaculture industry representatives expressed concern that the 10-year site permit and five-year permit renewals were too short because of the need for a longer

[43] See "Aquaculture for the Future" at [http://www.pnwer.org/meetings/Summer2004/Presentations/Chaves.pdf].

investment time frame. Another common concern involved the need for public investment to support and promote aquaculture development.[44]

Most environmental and commercial fishing interests have been skeptical or opposed to plans for offshore aquaculture development. Both groups of interests generally opposed S. 1195, because they believed it contained weak environmental provisions.[45] Commercial fishing interests also voiced concerns related to potential impacts on markets and coastal communities.[46] In most cases, neither group is opposed to all development, but both show concern regarding how aquaculture expansion will proceed. A precautionary approach has been advocated by most commercial fishing and environmental interests.

NOAA has redrafted legislation for possible re-introduction in the 110th Congress. In response to public comments and hearing testimony, NOAA modified S. 1195 to:

- strengthen the environmental provisions;
- clarify the role for fishery management councils and states;
- substitute a single offshore aquaculture permit for separate site and operating permits; and
- extend the duration of offshore aquaculture permits to 20 years rather than 10 years.

Additional provisions retained from the original draft include requiring a bond or other form of financial guarantee; data monitoring and collection; clarifying that the bill does not supersede other laws and agencies; and providing sufficient authority for NOAA to address more detailed environmental requirements through rulemaking. This legislation would also implement a U.S. Commission on Ocean Policy recommendation to designate NOAA as the lead federal agency for marine aquaculture and create an Office of Sustainable Marine Aquaculture in NOAA.[47] Such an effort within NOAA could result in one agency being responsible for both promoting and regulating the industry.

Agency and Fishery Management Council Actions

NOAA Aquaculture Plan. In November 2006, NOAA released the interim final version of a 10-Year Plan for its aquaculture program. The plan provides a

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[44] Written statements of Sebastian Belle and John R. Cates, *Hearing on Offshore Aquaculture*, before the U.S. Senate, Committee on Commerce, Science, and Transportation, National Ocean Policy Study (Apr. 6, 2006).

[45] P. N. Spotts, "Fish Farms in the Ocean? Group Pushes Congress to Pass Tough Rules," *The Christian Science Monitor*, (Jan. 10, 2007).

[46] Written statement of Mark Vinsel, *Hearing on Offshore Aquaculture*, before the U.S. Senate, Committee on Commerce, Science, and Transportation, National Ocean Policy Study (Apr. 6, 2006).

[47] The U.S. Commission on Ocean Policy, *An Ocean Blueprint for the 21st Century*, is available at [http://oceancommission.gov/documents/full_color_rpt/welcome.html].

blueprint of likely NOAA involvement in marine aquaculture over the next decade, including program goals and strategies, budget and staffing requirements, potential benefits of aquaculture, and associated challenges. The plan was prepared at the request of the agency's Marine Fisheries Advisory Committee (MAFAC), which advises the Secretary of Commerce on living marine resource matters that are the responsibility of the Department of Commerce. According to the plan, the NOAA aquaculture program will:

- establish a comprehensive regulatory program for marine aquaculture;
- develop appropriate technologies to support commercial marine aquaculture and enhance wild stocks;
- improve public understanding of marine aquaculture; and
- influence the development and international adoption of sustainable practices and standards for marine aquaculture.

The plan projects potential increases in annual domestic seafood aquaculture production in the next 20 years of approximately one million metric tons, with nearly 900,000 tons attributable to anadromous or marine aquaculture production. The projection of future production depends on changes in the current institutional framework that governs marine aquaculture. According to NOAA, challenges to achieving these production levels include:

- a complicated, inefficient, and uncertain federal regulatory process to permit marine aquaculture facilities;
- insufficient research on environmental implications and ecosystem carrying capacity of marine aquaculture;
- the lack of an adequate supporting research and development infrastructure and technical infrastructure; and
- the lack of access to coastal sites for marine aquaculture facilities because of competing high-value uses for housing and tourism.

The first three program challenges are directly related to open ocean aquaculture. Since inshore marine aquaculture production has been stagnant over the last decade, a large proportion of future production increases, if they occur, could result from open ocean aquaculture.

Council Actions. At its November 2003 meeting, the Gulf of Mexico Regional Fishery Management Council adopted an open ocean aquaculture policy for the Gulf of Mexico EEZ.[48] The council developed this policy, consisting of a variety of guidelines, to encourage environmentally responsible open ocean aquaculture, opposing the use of non-native species that could harm native species, and recommending that only FDA-approved therapeutic and chemical treatments be used as part of best management practices. This policy also contains guidelines on the location, design, and operation of facilities to prevent damage to the environment and minimize conflicts with other stakeholders. The Gulf of Mexico Regional Council also developed a management options paper for open ocean aquaculture under the

[48] Available at [http://www.gulfcouncil.org/downloads/mariculture_policy_GMFMC.pdf].

Magnuson-Stevens Act, and has discussed developing an FMP amendment on this subject.[49] In 1996, the New England Regional Council adopted Amendment 5 to its sea scallop fishery management plan to facilitate the SeaStead Scallop Aquaculture Project — one of the earliest U.S. open ocean aquaculture ventures. Some worry that regional management of open ocean aquaculture under the Magnuson-Stevens Act may add another layer of bureaucracy, especially if several regional fishery management councils develop their own, possibly contradictory, open ocean aquaculture management policies.

Funding. Sporadic federal funding has been provided for open ocean aquaculture. Under NOAA's Ocean and Atmospheric Research budget, $1.7 million was appropriated in FY1998, followed by $2.4 million annually in FY1999-FY2001 for the open ocean aquaculture demonstration project at the University of New Hampshire. Some critics of federal funding argue that aquaculture development funds should be awarded competitively and that directly allocating funds to specific projects should be avoided.

As part of a National Marine Aquaculture Initiative (NMAI), the National Sea Grant College Program has initiated research throughout the United States on open ocean aquaculture.[50] For several years, NMAI also funded the Gulf of Mexico Offshore Aquaculture Consortium, whose research program was sited in federal waters beyond state jurisdiction. In addition, NMAI, through competitive grants, supported policy and regulatory analysis as well as pilot studies in Puerto Rico and Hawaii, research into fishmeal alternatives, and investigations of potential new species for culture.[51] Specific NMAI funding included $800,000 annually in FY1999 and FY2000; $5.6 million in FY2001; $2.6 million in FY2002; $700,000 in FY2004; and $4.6 million in FY2006. Most of the NMAI-funded research has been conducted to support and help promote the aquaculture industry and often has been done in collaboration with the industry.

Proponents of development also contend that there has been inadequate federal research funding of the amount and duration needed to develop and demonstrate suitable technologies for meeting open ocean aquaculture's technical challenges. Private industry has often been at the forefront in addressing and solving pragmatic technical issues in a new field. Yet there generally has been minimal public or private research, especially on environmental and socioeconomic impacts.

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[49] 69 *Fed. Reg.* 7185-7186 (Feb. 13, 2004).

[50] Charles E. Helsley, "Open Ocean Aquaculture — a Venue for Cooperative Research Between the United States and Japan," *Ecology of Aquaculture Species and Enhancement of Stocks*, Y. Nakamura, et al. (eds.), Proceedings of the Thirtieth U.S. — Japan Meeting on Aquaculture, UJNR Technical Report No. 30 (Sarasota, FL; Mote Marine Laboratory, 2003), pp. 1-6.

[51] For a list of funded projects, see [http://www.lib.noaa.gov/docaqua/docresearch.html].

Discussion

Proponents of aquaculture development wonder what might have happened if Alaska — with its processing plants, distribution system, infrastructure, excellent water quality, and massive coastline — had decided to embrace salmon aquaculture rather than prohibit this industry. These proponents suggest that, if Alaska had decided differently, Alaska might still "own" the world salmon market and enjoy a major source of employment and economic development, rather than having to watch wild Alaskan salmon compete with aggressive salmon aquaculture development by Chile, Norway, and other nations.

However, environmentalists and commercial fishermen might view the absence of salmon aquaculture in Alaska differently. Potential environmental and social problems may have been avoided by concentrating on traditional wild fisheries. Wild salmon populations have been maintained at high levels and much of the Alaska coastline is pristine. Although competition from aquaculture salmon imports may have hurt Alaska salmon fisheries, improvements in marketing and product quality have kept many market segments competitive and provided greater benefits to U.S. consumers.

The future of open ocean aquaculture in the U.S. EEZ is still an open question. A complex and unpredictable mix of technological, biological, and economic factors will likely determine the profitability of open ocean aquaculture. The outcomes associated with these questions will likely involve a mix of innovation and technical advances. Although government may play a role in funding research and pilot projects, large-scale production will likely depend on private initiatives. The aquaculture industry may learn from its successes and failures as firms test different technical, business, and marketing approaches.

In addition to broad policy questions, specific questions revolve around setting a regulatory framework for a developing industry. The main challenge for policy makers is to allow for sufficient flexibility while balancing the needs of the aquaculture industry with public concerns related to environmental and social impacts.