August 3, 2009

Secretary Gary Locke
U. S. Department of Commerce
14th Street and Constitution Ave. N. W.
Washington, DC 20230

Delivered via e-mail to Jess Beck, Southeast Regional Office, NMFS at Jess.Beck@noaa.gov; and posted electronically to the Federal eRulemaking Portal at http://www.regulations.gov

Re: Proposed Rule 0648-AS65: Fishery Management Plan for Regulating Offshore Marine Aquaculture in the Gulf of Mexico

Dear Secretary Locke:

Thank you for the opportunity to provide a scientific perspective on the environmental risks of open ocean aquaculture to help inform the Department of Commerce's pending decision to approve or reject the Gulf of Mexico Aquaculture Fisheries Management Plan (FMP). We are a diverse group of academic scientists with experience in marine ecology, aquaculture, and fisheries who have published extensively in the peer-reviewed scientific literature. We identify a range of environmental risks of marine aquaculture, many of which should be addressed at an ecosystem scale to ensure that aquaculture ameliorates, rather than exacerbates, pressure on the oceans. We conclude that a coordinated, ecosystem-based regulatory approach, operating at the national level, is necessary to achieve a sustainable future for open ocean aquaculture in the United States. Without this approach, the piecemeal development of a marine aquaculture industry could result in significant and potentially irreversible environmental consequences. For this reason, we recommend that the Gulf of Mexico Aquaculture FMP should be disapproved.

There are six environmental risks of open ocean aquaculture that are most relevant to decisions about how the United States might proceed with this relatively new method of farming seafood. They are:

1. Use of marine resources,
2. Risks of escaped fish to wild fish and associated ecosystems,
3. Nutrient, chemical, and habitat impacts,
4. Risk of disease and parasite amplification and retransmission,
5. Impacts of drug and chemical use, and
6. Impacts on predators and other wildlife.

Use of Marine Resources

Aquafeed for many of the "carnivorous" species likely to be farmed in open ocean environments (e.g. cod, halibut, seabass, striped bass, yellowtail, and yellowfin tuna) contains very high percentages of fishmeal and fish oil (Tacon and Metian 2008). Average estimates of the ratio of wild fish required to produce farmed fish are 2.2 for "marine fish" and ~5.0 for salmon (Tacon and Metian 2008, Naylor et al. 2009). The wild forage fishes caught for aquafeeds play important ecosystem roles as food sources for higher trophic-level marine predators (Cury et al. 2000, Worm et al. 2006, Alder et al. 2008). As aquaculture has grown dramatically over the past two decades, the total demand for fishmeal and fish oil for use in aquaculture feeds has similarly expanded while the supply has remained relatively constant, thus increasing aquaculture's share of global fishmeal and fish oil use (Tacon et al. 2006, Tacon and Metian 2008, FAO 2009, Naylor et al. 2009). Additional global growth in industrial fish production has the potential to undermine marine food webs by redirecting food sources away from those wild species most dependent on them (Pauly et al. 2002, Pauly et al. 2005, Karpouzi et al. 2007).

These facts all point to the use of marine resources as a key constraint in a sustainable future for aquaculture. Severing the reliance of fish farming on wild fish requires efficiency improvements at the farm level as well as a regulatory structure that sets overarching sustainability requirements for the industry as a whole, as most of the forage fish used for aquaculture are caught outside of U.S. waters (FAO 2009). Minimizing the use of forage fish in feeds and creating incentives for substitutes for wild-caught fishmeal and fish oil (including seafood processing byproducts, terrestrial plants, animal byproducts, single cell proteins and oils, and marine and terrestrial invertebrates) are needed if these feed sources are to be widely adopted by the aquaculture industry (Naylor et al. 2009).

Risks of Escaped Fish to Wild Fish and Associated Ecosystems

Aquaculture is known to be a major vector for exotic species introduction (Carlton 1992, Carlton 2001), causing concern over the ecological impacts that escaped farmed species can have on wild fish and the environment, whether the farmed species are native or exotic to the area in which they are farmed (Volpe et al. 2000, Naylor et al. 2001, Youngson et al. 2001, Myrick 2002, Weber 2003). Farmed salmon are known to regularly escape from net pen systems, negatively impacting wild salmon stocks by increasing competition for food and breeding sites, as well as reducing the fitness of wild fish through interbreeding (Einum and Fleming 1997, Youngson and Verspoor 1998, Volpe and Anholt 1999, Fleming et al. 2000, Volpe et al. 2000, Jacobsen and Hansen 2001, Volpe et al. 2001, McGinnity et al. 2003, Naylor et al. 2005, Hindar et al. 2006). As compared to salmon aquaculture facilities, which are generally sited in sheltered bays, net-pen systems in open ocean environments face increased risk of failure due to increased exposure to storms and stronger currents.

Developing separate broodstock to allow for selection of desirable growth characteristics is a hallmark of traditional agriculture and livestock production. To date, this has been common practice in aquaculture as well. However, allowing these practices to continue for aquaculture in open ocean environments, where fish will inevitably escape, greatly increases the risk to natural ecosystems of genetically-distinct farmed fish, even if these fish are native to the farming area. If the U.S. is to prevent environmental damage related to fish escapes, explicit regulations for broodstock maintenance and fish escape standards are needed that account for both individual farm-level effects and the cumulative impact of escapes occurring across a large number of farms. In the absence of these regulatory safeguards, permitting open ocean aquaculture in the Gulf of Mexico at this time risks significant harm to the environment and should not be allowed.

Nutrient and Habitat Impacts

Wastes, both dissolved and particulate, from open net pen systems are released untreated directly into nearby bodies of water and can have large impacts on the surrounding environment (Gowen et al. 1990, Beveridge 1996, Costa-Pierce 1996). More than half of the total nitrogen and phosphorus fed to fish in commercial farms is released into the surrounding environment (Beveridge 1996, Fernandez-Jover et al. 2007). In Japan, intensive culturing of finfish and its consequent generation of organic wastes has adversely affected the surrounding environment via deoxygenation (Hirata et al. 1994), outgassing of hydrogen sulfide (Tsutsumi 1991), and blooms of harmful plankton (Yokoyama 2003, Nakamura et al. 1998).

While proponents of offshore aquaculture frequently cite deep water and high flushing rates as reasons for low concern over nutrient pollution in these habitats, emerging science suggests this may be unjustified. A detailed study of a commercial-scale open ocean aquaculture facility in Hawaii found striking changes in benthic species diversity and community structure under and nearby submerged sea cages despite relatively deep water and high current velocity (Lee et al. 2006). High-resolution models of waste transport from aquaculture pens indicate that dissolved nutrients (from excess feed as well as fish excretion) do not disperse as rapidly and as uniformly as was previously assumed (Venayagamoorthy et al. 2009). This evidence suggests that the adage of "dilution is the solution" is not the appropriate framework under which to expand open ocean aquaculture in the U.S., especially in areas such as the Gulf of Mexico which are already under severe nutrient stress. To adequately address the cumulative impacts of nutrient input from multiple aquaculture facilities, aquaculture must be regulated and managed at the ecosystem level, not by relying solely on local-scale, individual permitting decisions such as those allowed by the Gulf of Mexico aquaculture FMP.

Risk of Disease and Parasite Amplification and Retransmission from Farmed Fish to Wild Fish

It is well known that intensive fish culture, particularly of non-native species, has been involved in the introduction and/or amplification of pathogens and disease in wild fish populations (Hastein and Linstad 1991, Nese and Enger 1993, Kent 1994, Nylund et al. 1994, Bakke and Harris 1998, Blazer and LaPatra 2002). In recent years, the issue of amplification and retransmission has received much attention because of the dramatic consequences of the spread of parasitic sea lice from salmon farms to wild salmon (Tully and Whelan 1993; Costelloe et al. 1996; Grimnes and Jakobsen 1996; Gargan 2000; Bjorn et al. 2001; Heuch and Mo 2001; Bjorn and Finstad 2002; Butler 2002; Morton et al. 2004; McKibben and Hay 2004; Penston et al. 2004; Krkosek et al. 2005, 2006, 2007; Morton et al. 2005). Disease outbreaks in other fish grown in open net pens appear to be common as well. For example, yellowtail farmed in the Mediterranean, Japan, and New Zealand have suffered substantial mortalities from monogenean parasites (Whittington et al. 2001; Hutson et al. 2007).

Of the six major environmental risks of open ocean aquaculture, disease is the one for which ecosystem-level management is most critical. Disease at the farm level is a husbandry issue, but it is the transfer of diseases from farm to farm and back to the wild that poses the largest environmental risks. Chile's experience with Infectious Salmon Anemia in farmed salmon (Mardones et al. 2009, Vike et al. 2009) is a cautionary tale. Farm-level management led to numerous salmon farms being sited too closely together. Only after the salmon industry was decimated by the spread of this disease did Chilean authorities take the first steps toward breaking the disease cycle by developing "neighborhoods" to limit both farm-level and regional fish production (Intrafish 2009). If the U.S. is to prevent these types of disease dynamics, it must develop an ecosystem-based approach to aquaculture management that plans for expansion within an explicitly spatial context. As such an approach does not currently exist, approving the Gulf of Mexico aquaculture FMP risks significant harm not only to the environment, but to the aquaculture industry itself.

Impacts of Drug and Chemical Use
Most aquaculture operations use a variety of chemicals, including antifoulants, pesticides, and antibiotics (Tacon and Forster 2000), which can have negative effects on marine ecosystems or human health. Copper-containing paints, commonly-used antifoulants in the aquaculture industry, are toxic to many marine organisms, including seaweeds, mollusks, and Atlantic cod embryos (Andersson and Kautsky 1996, Granmo et al. 2002, Braithwaite and McEvoy 2004). Use of antibiotics has been shown to result in bacterial resistance in some aquaculture environments and to influence antibiotic resistance in humans (Kerry et al. 1996, Sapkota et al. 2008). Pesticides whose residues are known to be harmful to other marine life (Abgrall et al. 2000, Grant 2002) are sometimes used to control sea lice levels on farmed salmon (Roth 2000). In order to minimize the deleterious effects these chemicals have on the marine environment, their responsible use in aquaculture must be regulated by national agencies under a coordinated plan.

Impacts on Predator Populations
Expansion of open ocean aquaculture in the U.S. may also pose environmental risks to predators and other wildlife. In coastal salmon farming, a range of techniques, including the use of predator nets and underwater acoustic deterrent devices, are commonly used to reduce the impact of predators on stocks of farmed fish. These techniques, while generally successful at reducing losses of farmed fish, can have dramatic unintended consequences for the predators themselves, including alteration of natural behavior and the entanglement and subsequent drowning of large numbers of these air-breathing mammals (Morton and Symonds 2002, Wursig and Gailey 2002, CBC News 2007).

In open ocean environments, little is known about the potential impacts of fish farms on predators and other wildlife, but experience with farmed salmon suggests this will be an important concern. Limited evidence suggests that sharks and other large pelagic predators are attracted to submerged net pens (Galaz and de Maddalena 2004, NOAA

2005) and that predators that have become habituated to the presence of net pens, and hence a threat to human safety, have been killed (Lucas 2006). Should this practice become commonplace as the U.S. industry expands, this could put already vulnerable shark populations (Stevens et al. 2000, Baum et al. 2003, Myers and Worm 2005, Camhi et al. 2009) at further risk. Finally, submerged net pens and their associated mooring lines could pose entanglement risks to whales and other cetaceans, whose migration routes or foraging behavior bring them in close proximity to fish farms (Upton et al. 2007). Mitigating the effects of a young and growing aquaculture industry on predators and wildlife will require additional research on the interaction of farms and marine wildlife as well as the population consequences of the cumulative impact of those interactions.

A Final Note on Cumulative Impacts of Multiple Aquaculture Facilities

When the impacts of a single aquaculture operation are considered in isolation, they may be considered to be relatively mild. However, as the aquaculture industry grows, and should facilities be sited in close proximity to one another for economies of scale, the effects of their combined impacts may be greater than the sum of their individual impacts. This can be the case with nutrients, as well as with disease transfer, impacts of escapes, use of marine resources, and impacts on predators. To avoid these cumulative impacts and help avoid or ameliorate many of the risks discussed above, the precautionary approach should be a central tenet of the planning, management and permitting of aquaculture facilities.

Due to the scientifically documented, serious risks of offshore marine aquaculture outlined in this letter, we conclude it is critical for the U.S. to develop a consistent, precautionary set of environmental standards and implement regulations designed to protect the nation's federal marine waters. In their absence, the development of a marine aquaculture industry in a piecemeal fashion, such as through approval of the Gulf of Mexico aquaculture FMP, could result in significant and potentially irreversible environmental consequences, including water pollution from waste products and chemicals, threats of disease transmission to wild fish populations, harmful effects on native marine species from escaped farmed fish, and ecosystem impacts of the increasing use of wild forage fish for aquaculture feeds.

Thank you for the opportunity to provide this scientific analysis on the ecological risks of marine finfish farming to help inform your decisions on how the U.S. should address this important issue. We conclude that an ecosystem approach to aquaculture management is critical to the long-term future of a sustainable domestic offshore aquaculture industry and incompatible with approval of the Gulf of Mexico aquaculture FMP at this time.

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References

Abgrall, P., Rangeley, R. W., Burridge, L. E., & Lawton, P. (2000). Sublethal effects of azamethiphos on shelter use by juvenile lobsters. *Aquaculture* , 181:1-10.

Alder, J., Campbell, B., Karpouzi, V., Kaschner, K., & Pauly, D. (2008). Forage fish: From ecosystems to markets. *Annual Review of Environment and Resources* , 153-166.

Andersson, S., & Kautsky, L. (1996). Copper effects on reproductive stages of Baltic Sea Fucus vesiculosus. *Marine Biology* , 125:171-176.

Bakke, T. A., & Harris, P. D. (1998). Diseases and parasites in wild Atlantic salmon populations. *Canadian Journal of Fisheries and Aquatic Sciences* , 55:247-266.

Baum, J. K., Myers, R. A., Kehler, D. G., Worm, B., Harley, S. J., & Doherty, P. A. (2003). Collapse and conservation of shark populations in the Northwest Atlantic. *Science* , 299:389-392.

Beveridge, M. C. (1996). *Cage Aquaculture (2nd Edition).* Edinburgh, Scotland: Fishing News Books.

Bjorn, P. A., & Finstad, B. (2002). Salmon lice infestation in sympatric populations of Artic char and sea trout in areas near and distant from salmon farms. *ICES Journal of Marine Science* , 59:131-139.

Bjorn, P. A., Finstad, B., & Kristofferson, R. (2001). Salmon lice infection of wild sea trout and Arctic char in marine and freshwaters: the effects of salmon farms. *Aquaculture Research* , 32:947-962.

Blazer, V. S., & LaPatra, S. E. (2002). Pathogends of cultured fishes: potential risks to wild fish populations. In J. Tomasso, *Aquaculture and the Environment in the United States* (pp. 197-224). Baton Rouge, LA: U.S. Aquaculture Society, A Chapter of the World Aquaculture Society.

Braithwaite, R. A., & McEvoy, L. A. (2004). Marine biofouling on fish farms and its remediation. *Advances in Marine Biology* , 47:215-252.

Butler, J. (2002). Wild salmonids and sea louse infestations on the west coast of Scotland: sources of infection and implications for the management of marine salmon farms. *Pest Managment Science* , 58:595-608.

Camhi, M. D., Valenti, S. V., Fordham, S. V., Fowler, S. L., & Gibson, C. (2009). *The conservation status of pelagic sharks and rays.* Newbury, UK: IUCN Species Survival Commission Shark Specialist Group.

Carlton, J. T. (2001). *Introduced Species in U.S. Coastal Waters.* Arlington, VA: Pew Oceans Commission.

Carlton, J. T. (1992). The dispersal of living organisms into aquatic ecosystems as mediated by aquaculture and fisheries activities. In A. Rosenfield, & R. Mann, *Dispersal of Living Organisms into Aquatic Ecosystems* (pp. 13-45). College Park, MD: Maryland Sea Grant Publication, The University of Maryland.

Carvajal, P. (2009, July 1). *Neighborhoods take shape in Chile.* Retrieved July 13, 2009, from Intrafish: http://www.intrafish.no/global/news/article250251.ece

CBC News. (2007, April 20). *Dozens of sea lions drown at B.C. fish farm.* Retrieved July 13, 2009, from CBC News: http://www.cbc.ca/canada/british-columbia/story/2007/04/20/bc-sea-lions.html

Costa-Pierce, B. A. (1996). Environmental impacts of nutrients from aquaculture. In D. J. Baird, *Aquaculture and Water Resource Management* (pp. 81-113). Oxford: Blackwell Science.

Costelloe, M., Costelloe, J., & Roche, N. (1996). Planktonic dispersion of larval salmon lice, *L. salmonis*, associated with cultured salmon, *S. salar*, in western Ireland. *Journal of the Marine Biological Association of the United Kingdom* , 76:141-149.

Cury, P., Bakun, A., Crawford, R. J., Jarre, A., Quinones, R. A., Shannon, L. J., et al. (2000). Small pelagics in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. *ICES Journal of Marine Science* , 57:603-618.

Einum, S., & Fleming, I. A. (1997). Genetic divergence and interactions in the wild among native, farmed, and hybrid Atlantic salmon. *Journal of Fisheries Biology* , 50:634-651.

Fernandez-Jover, D., Sanchez-Jerez, P., Bayle-Sempere, J., Carratala, A., & Leon, V. M. (2007). Addition of dissolved nitrogen and dissolved organic carbon from wild fish faeces and food around Mediterranean fish farms: implications for waste-dispersal models. *Journal of Experimental Marine Biology and Ecology* , 340:160-168.

Fleming, I. A., Hindar, K., Mjolnerod, I. B., Jonsson, B., Balstad, T., & Lamberg, A. (2000). Lifetime success and interactions of farm salmonids invading a native population. *Proceedings of the Royal Society of London B* , 267:1517-1523.

Food and Agriculture Organization. (2009). *The State of World Fisheries and Aquaculture 2008.* Rome: FAO.

Galaz, T., & de Maddalena, A. (2004). On a great white shark trapped in a tuna cage off Libya, Mediterranean Sea. *Annales Series Historia Naturalis* , 14:159-163.

Gargan, P. (2000). The impact of the salmon louse on wild salmonid stocks in Europe and recommendations for effective management of sea lice on salmon farms. *Aquaculture and the Protection of Wild Salmon, Speaking for the Salmon Workshop Proceedings* (pp. 37-46). Simon Fraser University.

Gowen, R. J., Rosenthal, H., Makinen, T., & Ezzi, I. (1990). The environmental impact of aquaculture activities. In N. De Pauw, & R. Billard, *Aquaculture Europe '89 - Business Joins Science* (pp. 257-283). Bredene, Belgium: European Aquaculture Society.

Granmo, A., Ekelund, R., Sneli, J. A., Berggren, M., & Svavarsson, J. (2002). Effects of antifouling paint components (TBTO, copper and triazine) on the early development of embyros in cod. *Marine Pollution Bulletin* , 44:1142-1148.

Grant, A. N. (2002). Medicines for sea lice. *Pest Management Science* , 58:521-527.

Grimnes, A., & Jakobsen, P. J. (1996). The physiological effects of salmon lice infection on post smolt of Atlantic salmon. *Journal of Fish Biology* , 48:1179-1194.

Hastein, T., & Lindstad, T. (1991). Diseases in wild and cultured salmon: possible interaction. *Aquaculture* , 98:277-288.

Heuch, P. A., & Mo, T. A. (2001). A model of salmon louse production in Norway: effects of increasing salmon production and public management measures. *Diseases of Aquatic Organisms* , 45:145-152.

Hindar, K., Fleming, I. A., McGinnity, P., & Diserud, A. (2006). Genetic and ecological effects of salmon farming on wild salmon: modelling from experimental results. *ICES Journal of Marine Science* , 63:1234-1247.

Hirata, H., Kadowaki, S., & Ishida, S. (1994). Evaluation of water quality by observation of dissolved oxygen content in mariculture farms. (In Japanese). *Bulletin of National Resarch Institute of Aquaculture* , 61-65.

Hutson, K., Ernst, I., Mooney, A. J., & Whittington, I. D. (2007). Risk assessment for metazoan parasites of yellow tail kingfish *Seriola lalandi* in South Australian sea-cage aquaculture. *Aquaculture* , 271:85-99.

Jacobsen, J. A., & Hansen, L. P. (2001). Feeding habits of wild and escaped farmed Atlantic salmon in the Northeast Atlantic. *ICES Journal of Marine Science* , 58:916-933.

Karpouzi, V. S., Watson, R., & Pauly, D. (2007). Mdelling and mapping resource overlap between seabirds and fisheries on a global scale. *Marine Ecology Progress Series* , 343:87-99.

Kent, M. L. (1994). The impact of diseases of pen-reared salmonids on coastal environments. *Proceedings of the Canada-Norway Workshop on Environmental Impacts of Aquaculture*, (pp. 85-95). Havforskningsinstututtet, Norway.

Kerry, J., Coyne, R., Gilroy, D., Hiney, M., & Smith, P. (1996). Spatial distribution of oxytetracycline and elevated frequencies of oxytetracycline resistance in sediments beneath a marine salmon farm following oxytetracycline therapy. *Aquaculture* , 145:31-39.

Krkosek, M., Ford, J. S., Morton, A., Lele, S., Myers, R. A., & Lewis, M. A. (2007). Declining wild salmon populations in relation to parasites from farm salmon. *Science* , 318:1772-1775.

Krkosek, M., Lewis, M. A., & Volpe, J. P. (2005). Transmission dynamics of parasitic sea lice from farm to wild salmon. *Proceedings of the Royal Society B* , 272:689-696.

Krkosek, M., Morton, A., Lewis, M. A., Frazer, N., & Volpe, J. P. (2006). Epizootics of wild fish induced by farm fish. *Procedings of the National Academy of Sciences* , 103:15506-15510.

Lee, H. W., Bailey-Brock, J. H., & McGurr, M. M. (2006). Temporal changes in the polychaete infaunal community surrounding a Hawaiian mariculture operation. *Marine Ecology Progress Series* , 307:175-185.

Lucas, C. (2006, May 6). *Fish farm seeks second location.* Retrieved July 13, 2006, from West Hawaii Today: http://www.westhawaiitoday.com/articles/2006/05/06/local/local02.txt

Mardones, F. O., Perez, A. M., & Carpenter, T. E. (2009). Epidemiologic investigation of the re-emergence of infectious salmon anemia virus in Chile. *Diseases of Aquatic Organisms* , 84:105-114.

McGinnity, P., Prodohl, P., Ferguson, K., Hynes, R., O'Maoileidigh, N., Baker, N., et al. (2003). Fitness reduction and potential extinction of wild populations of Atlantic salmon, *Salmo salar*, as a result of interactions with escaped farm salmon. *Proceedings of the Royal Society of London B* , 270:2443-2450.

McKibben, M. A., & Hay, D. W. (2004). Distributions of planktonic sea lice larvae in the intertidal zone in Loch Torridon, Western Scotland in relation to salmon farm production cycles. *Aquaculture Research* , 35:742-750.

Morton, A. B., & Symonds, H. K. (2002). Displacement of *Orcinus orca* by high amplitude sound in British Columbia. *ICES Journal of Marine Science* , 59:71-80.

Morton, A., Routledge, R., Peet, C., & Ladwig, A. (2004). Sea lice infection rates on juvenile pink and chum salmon in the nearshore marine environment of British Columbia. *Canadian Journal of Fisheries and Aquatic Science* , 61:147-157.

Morton, M., Routledge, R. D., & Williams, R. (2005). Temporal patterns of sea louse infestation on wild Pacific salmon in relation to the fallowing of Atlantic salmon farms. *North American Journal of Fisheries Management* , 25:811-821.

Myers, R. A., & Worm, B. (2005). Extinction, survival or recovery of large predatory fishes. *Philosophical Transactions of the Royal Society B* , 360:13-20.

Myrick, C. A. (2002). Ecological impacts of escaped organisms. In J. R. Tomasso, *Aquaculture and the Environment in the United States* (pp. 225-245). Baton Rouge, LA: U.S. Aquaculture Society, A Chapter of the World Aquaculture Society.

Nakamura, A., Okamoto, T., Komatsu, N., Ooka, S., Oda, T., Ishimatsu, A., et al. (1998). Fish mucus stimulates the generation of superoxide anion by *Chattonella marina* and *Heterosigma akashiwo*. *Fisheries Science* , 64:866-869.

Naylor, R., Hardy, R., Bureau, D., Chiu, A., Elliott, M., Farrell, T., et al. (2009). Feeding aquaculture in an era of finite resources. *Proceedings of the National Academy of Science* , (Under final review).

Naylor, R., Hindar, K., Fleming, I., Goldburg, R., Williams, S., Volpe, J., et al. (2005). Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture. *BioScience* , 55:427-437.

Naylor, R., Williams, S., & Strong, D. R. (2001). Aquaculture - a gateway for exotic species. *Science* , 294:1655-1656.

Nese, L., & Enger, O. (1993). Isolation of *Aeromonas salmonicida* from salmon lice and marine plankton. *Diseases of Aquatic Organisms* , 16:79-81.

NOAA Small Business Innovation Research Program. (2005). *Development of effective and low cost predator exclusion devices for offshore aquaculture facilities in the United States EEZ.* Contract No. DG133R05-CN-1200: Snapperfarm, Inc.

Nylund, A., Hovland, T., Hodneland, K., Nilsen, F., & Lovik, P. (1994). Mechanisms for transmission of infectious salmon anaemia (ISA). *Diseases of Aquatic Organisms* , 19:95-100.

Pauly, D., Christensen, V., Guenette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., et al. (2002). Towards sustainability in world fisheries. *Nature* , 418:689-695.

Pauly, D., Watson, R., & Alder, J. (2005). Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Transactions of the Royal Society B* , 360:5-12.

Penston, M. J., McKibben, M. A., Hay, D. W., & Gillibrand, P. A. (2004). Observations on open-water densities of sea lice larvae in Loch Sheildaig, Western Scotland. *Aquaculture Research* , 35:793-805.

Roth, M. (2000). The availability and use of chemotherapeutic sea lice control products. *Contributions to Zoology* , 69:109-118.

Sapkota, A., Sapkota, A. R., Kucharski, M., Burke, J., McKenzie, S., Walker, P., et al. (2008). Aquaculture practices and potential human health risks: current knowledge and future priorities. *Environment International* , 34:1215-1226.

Stevens, J. D., Bonfil, R., Dulvy, N. K., & Walker, P. A. (2000). The effects of fishing on sharks, rays, and chimaeras, and the implications of marine ecosystems. *ICES Journal of Marince Science* , 57:476-494.

Tacon, A. G., & Forster, I. P. (2000). Global trends and challenges to aquaculture and aquafeed development in the new millennium. In *International Aquafeed - Directory and Buyers' Guide 2001* (pp. 4-25). Uxbridge, UK: Turret RAI.

Tacon, A. G., & Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture* , 285:146-158.

Tacon, A. G., Hasan, M. R., & Subasinghe, R. P. (2006). *Use of fishery resources as feed inputs to aquaculture development: trends and policy implications.* Rome, Italy: FAO.

Tsutsumi, H., Kikuchi, T., Tanaka, M., Higashi, T., Imasaka, K., & Miyazaki, M. (1991). Benthic faunal succession in a cove organically polluted by fish farming. *Marine Pollution Bulletin* , 23:233-28.

Tully, O., & Whelan, K. F. (1993). Production of nauplii of *L. salmonis* from farmed and wild salmon and its relation to the infestation of wild sea trout off the west coast of Ireland in 1991. *Fisheries Research* , 17:187-200.

Upton, H. F., Buck, E. H., & Borgatti, R. (2007). *Open Ocean Aquaculture CRS Report for Congress.* Congressional Research Service, Order Code RL32694.

Venayagamoorthy, S. K., Fringer, O. B., Koseff, J. R., Chiu, A., & Naylor, R. L. (2008). Numerical modeling of aquaculture dissolved waste transport in a coastal embayment. Submitted.

Vike, S., Nylund, S., & Nylund, A. (2009). ISA virus in Chile: evidence of vertical transmission. *Archives of Virology* , 154:1-8.

Volpe, J. P., & Anholt, B. R. (2001). Atlantic salmon in British Columbia. *Marine Bioinvasions: Proceedings of the First National Conference (January 24-27, 1999)* (pp. 256-259). Cambridge, MA: Massachusetts Institute of Technology.

Volpe, J. P., Anholt, B. R., & Glickman, B. W. (2001). Competition among juvenile Atlantic salmon and steelhead: relevance to invasion potential in British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* , 58:197-207.

Volpe, J. P., Taylor, E. B., Rimmer, D. W., & Glickman, B. W. (2000). Evidence of natural reproduction of aquaculture-escaped Atlantic salmon in a coastal British Columbia river. *Conservation Biology* , 14:899-903.

Weber, M. L. (2003). *What price farmed fish: a review of the environmental and social costs of farming carnivorous fish.* Providence, RI: SeaWeb Aquaculture Clearinghouse.

Whittington, I. D., Corneillie, S., Talbot, C., Morgan, J. A., & Adlard, R. D. (2001). Infections of *Seriola quinqueradiata* and *S. dumerii* in Japan by *Benedenia seriolae* (Monogenea) confirmed by morphology and 28S ribosomal DNA analysis. *Journal of Fish Diseases* , 24:421-425.

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., et al. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science* , 314:787-790.

Wursig, B., & Gailey, G. A. (2002). Marine mammals and aquaculture: conflicts and potential resolutions. In R. R. Stickney, & J. P. McVay, *Responsible Marine Aquaculture* (pp. 45-59). New York: CAP International Press.

Yokoyama, H. (2003). Environmental quality criteria for fish farms in Japan. *Aquaculture* , 226:45-56.

Youngson, A. F., & Verspoor, E. (1998). Interactions between wild and introduced Atlantic salmon. *Canadian Journal of Fisheries Aquatic Science* , 55:153-160.

Youngson, A., Dosdat, A., Saroglia, M., & Jordan, W. C. (2001). Genetic interactions between marine finfish species in European aquaculture and wild conspecifics. *Journal of Applied Ichthyology* , 17:155-162.