Discussion Summary: Open Ocean Aquaculture—Moving Forward

15

Compiled by Cheng-Sheng Lee and Patricia J. O'Bryen

Oceanic Institute, 41-202 Kalanianaole Hwy., Waimanalo, HI 96795, USA
Email: cslee@oceanicinstitute.org

Introduction

In addition to the presentations given by the invited experts at the "Open Ocean Aquaculture—Moving Forward" workshop, valuable information was exchanged during the four discussion sessions held during the workshop. Discussion topics included current definitions of open ocean aquaculture, the non-environmental challenges to its further development, the business aspects, environmental monitoring, and the potential further expansion of open ocean aquaculture. At the end of the workshop, participants listed the main research gaps and strategies for moving open ocean aquaculture forward. We would like to express our thanks to John Corbin, John Forster, John Volkman, and Richard Langan for serving as recorders during the discussions and for their contribution to the content of this summary, which represents a compilation of their notes, a summary of the discussion transcripts, and written comments of the participants. We would also like to extend our appreciation for funding support from the Office of Oceanic and Atmospheric Research of the National Oceanic and Atmospheric Administration (NOAA, Grant #NA05OAR4171169) to Oceanic Institute. The views and opinions expressed in this article do not necessarily reflect those of the National Oceanic and Atmospheric Administration, Oceanic Institute, or of all of the participants at the workshop.

Definitions

Several substantially different definitions of open ocean aquaculture from various sources were discussed. At the "Farming the Deep Blue" conference in Limerick, Ireland (October 6-7, 2004), open ocean aquaculture was divided into four classes based on conditions in the Northeast Atlantic,[1] but which do not necessarily apply in other parts of the world. Some participants at this workshop considered it important to point out that open ocean aquaculture takes place in the pelagic realm, which has moderate or greater rates of circulation that is not entirely tidally-driven and is likely to be exposed to high-energy wave conditions. The pelagic environment in some areas of the U.S. Exclusive Economic Zone (EEZ) may also be nutrient poor and with low wild fisheries production. One participant emphasized site exposure to high-energy wave regimes as a necessary characteristic. Others focused on geographic boundaries or distance from the coast (3 to 200 miles), or an absence of coastal influences at the site, i.e., "….the rearing of marine organisms under controlled conditions in exposed, high-energy ocean environments beyond significant coastal influences."

[1]See Ryan, J. 2004. Farming the deep blue. Accompanying report, Farming the Deep Blue, Limerick, Ireland, 6-7 October 2004. Marine Institute, Dublin, Ireland. 67 pp.

After discussion of the applicability of the various definitions to various situations, it was suggested that defining open ocean aquaculture for all situations would be very difficult. Although some sort of place-based or location definition was required for regulatory purposes, as well as for legislators and politicians, it was questioned whether a precise definition was absolutely necessary at this workshop. Several participants suggested it would be more practical to focus on the goal of "farming the sea."

For the National Oceanic and Atmospheric Administration (NOAA) to have governance at the U.S. federal level, offshore or open ocean aquaculture must be strictly defined as that which takes place within the EEZ, i.e., 3-200 miles offshore from U.S. coastlines. On the other hand, NOAA recognizes that there are aquaculture operations in state waters that would also generally be thought of as open ocean aquaculture. Participants from Asia and Europe pointed out that defining open ocean aquaculture in terms of EEZs has already led to several conflicts between neighboring countries, so the use of the term "EEZ" should be avoided for countries in their regions.

The issues of the distance from shore, the exposure, current velocity, depth, and the relative importance of those factors is going to vary, depending on the type of aquaculture. Because of the complexity of interactions, a matrix might be used as part of the legal definition used by regulatory or permitting authorities to decide whether or not an aquaculture activity would be allowed. Having a series of parameters for open ocean aquaculture would also allow people involved in the industry to better understand each other and to distinguish open ocean aquaculture from that which takes place near shore.

Non-environmental Challenges

A list of challenges, based on reports in the literature and suggestions from various experts, was presented for discussion:

- Fingerling supply
- Government support
- Public perception
- User conflicts
- Status of technology
- Permit and regulatory environment
- Start-up capital
- Market competition
- Species selection

Many of the items on the list were found to be interconnected. For example, fingerling supply is impacted by the status of hatchery technology. Government support and market competition influence the permit and regulatory environment and start-up capital. Public perception is connected with user conflicts, and these aspects directly impact government support and, perhaps, market competition, to a certain extent.

Many of the challenges listed would require another 10 years to arrive at solutions. To make progress in moving aquaculture into the open ocean, it was suggested that specialists in each of the areas work on all of the challenges in parallel, rather than sequentially.

Fingerling supply

Fingerling supply is a key issue for U.S. open ocean aquaculture. The government can develop and build hatcheries to provide fingerlings for the industry at the beginning to expedite expansion, but there should be an agreed upon and reasonable transition period where government phases out of hatchery production for a species as private hatcheries scale up production to support expansion. This is a very difficult issue of what comes first and how to do it so that unfair and constraining competition from government sources is avoided. In other words, the federal government should develop and support the transfer of certain key components of the technology to the private sector to assist them in building hatcheries and growing the fingerlings that they need. Hatchery sites and skilled labor to operate a large-scale hatchery were identified as the constraints in Hawaii.

The United States has much to learn about commercial hatchery operations from other countries. Fish farmers in Asia and Europe can order fingerlings from one of several private hatcheries. Fish producers select fingerlings from whatever hatchery has the best fingerlings for the best price, an integral part of market competition among the hatcheries.

Government support

Participants understood why a private business would want to have a ready supply of its own fingerlings to control stocking and production, but a question was raised about who would be charged with establishing the hatchery technology itself. A lot of the work for the U.S. salmon industry was done with government funding, through government facilities given to the developing industry, both domestically and foreign. For example, government researchers working with public funds established the nutritional requirements of fish and the technology used to make the feeds, which are now used worldwide. Many of the advances that would be considered a requirement for industry development would require a public resource as a basis, because the private open ocean aquaculture industry lacks the financial and technical capability for doing everything that needs to be done to move the industry forward. Government funding agencies may question the economic sense of producing a fish product domestically as opposed to overseas because of higher labor costs and environmental regulations.

It was pointed out that a lot of opportunities have been missed to engender government support to further develop aquaculture. When the coastal fishing communities in the State of Washington went out of business, hundreds of millions of dollars were spent to retrain people to do other things, but they were not retrained to be fish farmers. Retraining unemployed fishermen to produce fingerlings in hatcheries and grow fish out in cages could have provided them with appealing alternative employment opportunities and generated income for the state.

Public perception and user conflicts

Some participants thought that public perception would be the most important factor in generating momentum to move open ocean aquaculture forward. When Maine salmon farming started in East Port in the early 1970s, everyone was happy, because the industry came to an area where there were no jobs. Since that time, however, land in East Port has become high-priced waterfront real estate. Open ocean aquaculture faces opposition because of a viewscape issue among the local community.

Public perception and user conflicts were probably the same challenges that many countries faced when they first started aquaculture. A futuristic vision of open ocean aquaculture that captures people's imaginations is needed to get the momentum going. Once the industry has that type of unified vision, government support is likely to follow. Moving further offshore to get out of view and beyond the area of greatest concern of the permitting authorities and the community at large, however, is not sufficient for addressing user conflict issues. A planned scenario, with appropriate monitoring and safeguards, is needed, because what is not measured cannot be managed.

Status of technology

Because most of the species being cultured in open ocean aquaculture are new to aquaculture, a whole range of technologies, from feeds to vaccines, will need to be developed in addition to technologies unique to the open ocean. Containment technology has advanced substantially in the past decade, but the technology needs to be extended to allow farms to exist farther away from shore and in more challenging marine conditions. Feeding, harvesting, and cleaning technologies also need to be advanced so that more automation can be deployed, thus enabling higher labor cost areas to compete more effectively with low labor cost areas.

There was some disagreement over whether overseas experts should be brought in to improve the status of U.S. hatchery technology. It was pointed out that the United States has not developed a large labor pool with the necessary expertise. On the other hand, because open ocean aquaculture uses a public resource, employing local people was seen as a way to build a more positive public perception. Participants agreed that long-term investment in education is needed in the United States to develop skilled workers who are trained in hatchery technology and fish diseases.

Permits, Start-up capital, and Market competition

For one participant, the crucial challenge was the permit and regulatory environment that allows open ocean aquaculture to take place outside of State waters. The concern was that much of the open ocean aquaculture industry is already taking place outside the United States, a situation that will be exacerbated if the U.S. permit and regulatory environment is not established soon.

It was suggested that open ocean aquaculture start with high-end niche market products so that producers would get their capital back in a reasonable amount of time. In Hawaii, start up capital was not a big constraint because of the research tax credits given by the state for every dollar that a venture capitalist invested in new technology such as open ocean aquaculture.

Advertising fish as locally grown can be a big selling point, but producers should be careful not to imply that if a product is not grown locally, then there is a problem with it. Most of the U.S. seafood industry imports most of its seafood, and they would not want people saying that imported seafood is bad. Growing seafood locally has a huge long-term benefit due to the distribution advantages and lower freight costs. Farming fish also offers the opportunity to address certain animal welfare concerns by being able to actively manage stock growout conditions and product harvesting, handling, and processing.

Species selection

Species selection can be thought of as overlapping circles of different factors. One circle is the biology or cultivability of an organism. Cultivability a given species can change with advances in technology. Overlapping that circle is an economic circle, i.e., the species has a certain value. If the goal of open ocean aquaculture is to produce affordable seafood, the focus should be on large-scale production of low cost seafood. In that case, the species would be the marine counterpart of tilapia and carps. If the goal is high-value products for niche markets, the focus would probably be on development of multiple species and multiple markets to diversify the products available while maintaining profitable pricing. Overlapped with the economic and cultivability circles is a politically correct or socially acceptable circle that may make a species appropriate or not appropriate (e.g., it is a favorite game fish, or other fishers are dependent on that species). Some participants suggested that candidate species for open ocean aquaculture should perhaps be limited to those that are not currently being cultured in land-based operations or near shore cages.

It was suggested that species selected for open ocean aquaculture should all be high value species. Operators of commercial open ocean farms in Hawaii stated that the main reason for targeting and producing high-value, tasty, carnivorous fish was due to the high cost to produce them in that way. It is not cost effective to produce a low-value species in a 2600 m^3 flipper cage that currently costs $150,000, plus the cost of mooring.

An agricultural industry that is dependent upon a single species is extremely vulnerable to a number of factors, including disease or a change in market conditions. Sustainability is a function of the ability of that industry to change and the diversity of cultivars on a farm. On the other hand, culturing exotic species adds a complexity to open ocean aquaculture development from environmental and other standpoints, because it opens up a plethora of issues such as complications associated with escapes that make the offshore industry objectionable to far more people than would otherwise be the case.

As the open ocean aquaculture industry evolves in the next 10 or 20 years, it will become more efficient. Perhaps one or two species will be identified to become "the salmon of the open ocean," but there is going to be a lot of trial and error to get to that point. At this stage, research should focus on developing more candidate species for open ocean farming.

Additional challenges

Land-based infrastructure, a key component of siting and supporting an offshore fish farm, is required at the right location. The economic imperative to develop open ocean aquaculture was also seen as an important challenge in the United States, where a very different set of circumstances exist to what existed in Chile, Scotland, and Norway during the 1970s and 1980s, when their aquaculture industries experienced rapid growth.

Challenges that have not yet come up because the open ocean aquaculture industry is still in its infancy include the problems of scale and scaling up, and medium-term issues, such as breeding and diseases, which will not hit until the industry reaches a certain scale. Managing 40 open ocean aquaculture cages at one site will be considerably more difficult than managing 10 sites with four cages each. Maintaining different strains of the same species, bred for different characteristics (e.g., growth, disease resistance), is going to be a major issue in each of the species after 10-20 generations. Also, as the industry grows, the issues of disease management and feeds (including alternate protein and lipid sources) are going to increase with it.

Business Aspects

Whether aquaculture operations take place offshore or inshore, many major costs are the same (e.g., the cost of feed and fingerlings, marketing, and shipping). The added costs are the containment systems, transportation, and perhaps, skilled labor. These are balanced by lower building costs and for energy and land. In broad and general terms, most of the costs of an open ocean aquaculture facility are fairly fixed. At a certain point, the fish farmer can control only some of these costs. For example, the manufacturing costs of feeds continue to go up, even though the amount of fishmeal used in the feeds has been greatly reduced. A fish farmer can invest in an expensive advanced technology and justify it in terms of a 15-20 year life, but within 5 years, that technology might be out of date, and the farmer would have to adopt another type of technology. As a result, the business cost calculation becomes quite complex.

Two other costs to consider are location and the cost associated with monitoring the environment. Where to site a farm is directly related to cost. If open ocean aquaculture is to grow into a bigger industry at depths where cages are currently located, there is an associated cost for environmental monitoring that is likely to increase. On the other hand, moving the cage to a deeper site would require more money initially, but the costs of environmental monitoring may decrease because of fewer monitoring requirements. It would be an important factor in deciding whether or not to select a site at a greater depth. As open ocean cages get larger, a realistic notion about the requisite associated costs is necessary.

Producing affordable fish does not necessarily have to be one of the initial goals of open ocean aquaculture. Many successful farmed species started at much higher prices ($4 to $5 per pound, i.e., $9-$11 per kg) and then dropped down to $2 or $1 per pound ($4.50 to $2.25 per kg). Salmon was an expensive fish in Europe before salmon farming started. Now it is the most common and affordable species. The cost of cultured red sea bream in Japan was $15/kg in the 1970s, but it currently sells for about $5/kg. A similar consequence is expected with other species. It was predicted that if open ocean aquaculture of high-value species became highly successful, supply and demand would take care of its affordability for more consumers.

A basic problem for moving aquaculture further offshore in Japan is the cost of transportation. If open ocean culture technology would not allow producers to ship their product for less than $5/kg, it would be seen as an impractical move. Diversification has helped to create jobs and buffer the aquaculture industry against fluctuating product costs in the northeastern United States. In specific markets, live cod sells for $11-12/kg, while mussels sell for about $3/kg. Mussels are relatively cheap to grow in this area, and this type of product diversity addresses the conflict with other users and people who lost their jobs in the U.S. commercial fishing industry because of declining wild fisheries.

A common way to look at product prices is to think of demand as a stable "pie" that is always the same size, and that once that demand is satisfied, then prices fall to zero. In reality, however, marketing has repeatedly been shown to create a larger pie and to make demand increase. Thus, the survival of a business is not really a matter of managing supply, but of keeping supply slightly behind the demand curve. Low mortality rates and better growth efficiency would allow the fish farmer to survive in the highly competitive market.

The open ocean aquaculture market is going to go worldwide, and the United States will be competing for markets at a global level. As the industry develops, it is important, from a marketing standpoint, to think about what makes one product unique and distinguishable from similar products being produced everywhere else. A native species fits that criterion much better than is often the case with introduced or exotic species. At this point in the development of the industry, the focus should probably be on a few endemic species that have good economic potential to allow the industry to move forward. Introduced species and selective breeding are scientifically complex and controversial issues and may be politically difficult to resolve, given current information.

Several participants thought that branding of fresh fish would help keep open ocean aquaculture producers out of the "commodity" pit for perhaps a 5-15 year period, but not forever. An example was given of the very successfully branded and marketed Copper River salmon. An individual corporate brand, however, is difficult and expensive to maintain. The producers received considerable funds from the federal government to support the marketing campaign for Copper River salmon, and there is a finite supply of the product. A much better approach was thought to be working within a larger framework when branding a product. A country-of-origin or a state-of-origin brand, such as "Hawaii Seafood," would be a powerful brand, and it would bring aquaculture producers and wild-caught producers together. In addition, it is likely that some state funds would be available to support it. Branding might also help to create new markets. The Korean government recommended that aquaculture producers unify the offshore premium brand, to create a new market that would not compete with that of the inshore farmers.

A very positive way of making people feel that the industry belongs at a particular site is to bring them out to the operations site to see for themselves. In Europe, an entire bay is taken up by massive rafts with mussel ropes attached to them. A tourist industry has been built up around bringing tourists out to visit those rafts and giving them some mussels to eat.

Environmental Monitoring

There was general agreement that a range of potential environmental interactions, which have been documented or implied for near shore finfish cage culture, must be addressed for offshore culture. These include:

- Benthic impacts: sediments and benthic communities
- Water quality: increased nutrients, phytoplankton
- Disease and parasite transmission
- Escapees: genetic pollution, competition with native stocks, predation on protected species
- Exploitation of lower trophic levels: fishmeal and fish oil
- Increased biomass of wild fish external to the cages
- Seaweeds and biofouling organisms

Some of these interactions have positive aspects, such as biomass and diversity enhancement from spreading wastes in nutrient poor pelagic and benthic ecosystems. Whether positive or negative, the degree of impact may be different for aquaculture in the open ocean from that in near shore areas, as will society's perceptions. Scientific knowledge of possible offshore effects is not, as yet, well known. Existing knowledge and standards, however, that have been developed for ecosystem protection in countries including Australia, Ireland, and the United Kingdom (particularly, Scotland) as well as for U.S. state waters in Maine and Washington, have many common features and provide a good starting point for addressing environmental concerns.

The workshop participants agreed that an expectation of "no effects" was unrealistic and not achievable. Some environmental effect within the lease area due to aquaculture is to be expected. With upscaling, the additive effects need to be considered and the scale of the ecological footprint must be assessed relative to the size of the ecosystem in which farming takes place.

Models play a major role in synthesizing knowledge and understanding processes. They enable scenarios to be simulated for predicting possible effects due to different management strategies. A variety of models are available, ranging from those that address aspects of fish physiology, nutrient fluxes, hydrodynamics and sediment processes, to full ecosystem models. Farm-focused models such as AquaModel and DEPOMOD that simulate water column and benthic effects can be used to evaluate the effects of changing parameters using a Windows™ PC operating system. A different modeling approach is to put aquaculture in the context of the whole ecosystem, which requires much higher computing power, depending on the number of trophic levels and degree of complexity involved. A 3-dimensional hydrodynamic model can be used to examine dispersion of wastes from the farm and how the physical environment varies on seasonal to inter-annual timescales. This type of modeling is especially useful for offshore aquaculture. In Australia, CSIRO researchers within the Aquafin CRC have coupled a full 3-dimensional hydrodynamic model to a sediment model to examine the role of sediment resuspension in dispersing the organic matter and to a biogeochemical model for defining the relationship between nutrients released into the water column and effects on phytoplankton abundance.

All participants agreed that efforts must be made to minimize negative effects of aquaculture, both spatially and temporally. The degree of environmental impact is greatly influenced by a number of factors, including the following:

- Site selection
- Assimilative capacity
- Appropriate engineering
- Management practices (feeds, feed management, containment management, cage maintenance)
- Effective monitoring and assessment
- Strategies for corrective action

Aspects of the ecosystem that are of high value and potentially vulnerable (sometimes called protected ecosystem values) need to be identified so that monitoring strategies can be developed to ensure positive environmental outcomes. This process needs to be transparent and involve a wide range of stakeholders. It must also recognize that the list of concerns may vary from place to place. Science plays a vital role in informing this process, but ultimately, the decisions will be made by the designated regulatory authority.

Monitoring at offshore locations has its own set of restrictions. Detailed enumeration of benthic species obtained from sediment grab samples may be required during the initial site assessment and during the first few stocking cycles, because these types of analyses provide detailed information about sediment conditions and perturbations. Video or photographic systems that have been calibrated against this information may be adequate for on-going monitoring.

The importance of establishing baseline conditions for water column and benthos (sediments, fauna) and the use of circulation (dispersion and dilution) models and model verification to locate monitoring stations were discussed. The effects of annual variability also need to be understood to ensure that the site is suitable for aquaculture and to provide a framework for understanding any measurable changes in the ecosystem.

There was a strong view that an assessment of environmental interaction and some on-going monitoring would be required, to ensure that environmental standards can be appropriately established and then are being met. In this manner, any cumulative changes over the longer term can be discerned. This is important information for the fish farmer, because fish health is strongly influenced by environmental conditions. It is also vital to make this information available to the general public to allay any concerns that some might have about the aquaculture operation. With time, the frequency of monitoring can usually be reduced as more information is obtained, regional-specific standards are set, monitoring methods are refined and simplified, and uncertainty about possible effects is reduced.

For water quality assessment, automated sensing systems that relay information from sensors back to land in real-time are particularly important. These can be sited at the farm, but they require on-going maintenance and periodic calibration to be effective. There was consensus that, while possible in some ocean environments, water column pollution, such as eutrophication of coastal areas by dissolved nutrient discharge, was unlikely in the open ocean. Also, while the risk of benthic pollution from deposition of uneaten feed and feces may be reduced in the open ocean, the risk is site specific and must be managed as such. It is also necessary to consider positive impacts, such as increased habitat for local fish and lessening of fishing pressure on stressed local fisheries.

The process for establishing environmental standards for benthic conditions was a topic of lengthy discussion. Monitoring methods to determine the degree of organic enrichment vary in cost, precision, clarity of interpretation, and the ability to standardize methods and establish meaningful performance standards. Monitoring under and around the cages by visual inspection (e.g., divers, remote photography) requires a good database on benthic fauna to act as an indicator of more subtle changes in sediments or benthos. Total organic carbon (TOC) in sediments is generally a good indicator of organic enrichment, but this type of monitoring requires a qualified laboratory facility. Organic content by loss on ignition (LOI) is similar to TOC, and it is generally well correlated with changes in the benthic community, but it is a less accurate measurement of carbon than TOC. Depth of the Redox Potential Discontinuity (RPD) layer (Eh) is good measure of sediment oxygen/sulfide and it is generally well correlated with changes in the benthic community, but it is difficult to gather the data in deep water because of high spatial variability and it requires an undisturbed sediment core. Benthic faunal community monitoring can consist of measures of biomass, species diversity, number of taxa, the presence and ratio of pollution tolerant/intolerant organisms, or a combination of these variables. This type of monitoring is very expensive and time consuming. Interpretation of the results may be somewhat ambiguous, making it difficult to establish performance standards.

There was some discussion about the potential to use tools such as multi-beam sonar for inspection of submerged infrastructure (cages, mooring lines, anchors), broad scale seafloor site assessment, and for monitoring cage inventory (biomass and numbers). The usefulness of such observations, however, has yet to be verified.

How "impact" is actually defined and quantified was briefly discussed. For example, at what level would an increase in the abundance of *Capitella* spp. constitute an impact? This led to a discussion about the need for effective performance based standards. There was broad agreement that some change would take place directly beneath the cages. It was suggested that changes within the zone near the cages be accepted as necessary. Thus, monitoring should be directed to establishing the amounts of change (if any) at the edge and outside the sediment impact zone (the National Pollutant Discharge Elimination System zone of mixing in the United States). The difficulty and cost of benthic monitoring in deep water was also discussed, but the participants did not arrive at a definite conclusion. Integrated aquaculture (co-culture of plants and bivalves) was mentioned as means of mitigating wastes from finfish. For fish farmers, however, it would create a level of complexity that could be difficult to manage.

Expansion of Open Ocean Aquaculture

Technology is one critical factor for the expansion of an open ocean farm. Experience and knowledge gained from the salmon farming and other seafood industries, including the wild-caught sector, have provided open ocean aquaculture with a jump start on technology. Open ocean fish farmers know the minimal number of cages and market value of their target species required to keep their operations economically viable. Their challenge as an industry is to keep up with the technology, whether it is hatchery technology or the technology offshore. Their survival as an industry will depend on making production more cost effective to operate in an offshore environment. For example, with automated technology for cleaning the cages and automated feeders, the number of cages to be handled under one operation can increase considerably.

Basic research that needs to be done on the physiology of cultured fish species can have a huge impact on the ability of fish to express their genetic potential. Funding for feed manufacturing technology development is also needed for reducing feed costs, improving feed conversion ratios, and controlling diseases.

Scale issues become a major consideration unless the product has a very high premium. A general rule for one open ocean salmon aquaculture site would be 10 cages, each producing 1,000 tonnes. The 1,000-tonne production unit is believed to be the viability limit for salmon farming under ordinary conditions. This prediction was based on existing offshore operations. The 10,000-tonne limit, however, does not apply to all types of open ocean aquaculture. If the culture species are scarce, at a production scale for a niche market, the prices should remain stable. On the other hand, the prices would start to drop when producers expanded their products and competed with each other.

It is expected that the deeper the site, the easier the permit would be to acquire, and the more the business would expand and be successful in the long term. Open ocean aquaculture of the future may not be just one huge fish farm, but a complex of 10 large submerged cages, each growing 1,000 tonnes. With a 10,000-tonne business, a producer could afford to have his or her own feed mill and provide the supporting infrastructure for this type of large-scale activity.

Research Gaps and Strategies for Moving Open Ocean Aquaculture Forward

At the end of the workshop, research gaps and strategies for moving open ocean aquaculture forward were elicited informally from the invited speakers. Although the result was not a comprehensive list of the research gaps, it provides the readers with a collective overview of the ideas expressed by the participants on the research needs and strategies for moving open ocean aquaculture forward to the next level.

Research Gaps

Engineering

- Deep water containment systems
- Design and development of fully integrated farming systems, free floating and other more open water systems, matched to specific environments that maximize production efficiencies and minimize risk to personnel and specific environments.
- Development of large semi-stationary systems as distinguished from drifters
- Increased automation of routine operations such as inspection, cleaning, mort removal, stocking and harvesting to reduce diver time and improve production efficiencies
- Improved structures to reduce escapes through prevention of predator interaction
- Develop new materials to replace netting that will reduce biofouling and minimize escapement
- Synergistic possibilities for aquaculture with other areas, e.g., energy development or other offshore industries

Environment

- Key component characterization of bioenergetics for environmental assessment and optimization of growout to maximize economic gain and minimize environmental impacts
- Assessment of relative magnitude of environmental potential risks to allow prioritization of monitoring efforts
- Development of site recovery strategies and bioremediation methods
- Development of criteria and assessment of cumulative impacts for multiple farm placement in an area
- Potentially beneficial effects of organic enrichment on an environment that is nutrient poor, i.e., pelagic and benthic.
- Better understanding of the interactions of escaped fish with wild stocks
- Cost effective methods for monitoring benthic conditions at deep water sites
- Area specific development strategies that balance fed species with extractive species
- Standardize monitoring methods and interpretation of data
- Develop thresholds for water quality and benthic condition indicators
- Develop Hazard Analysis and Critical Control Point- (risk-) based containment management plans

Management

- Risk assessment protocols to identify specific social values worth protecting
- Development of risk management strategy for open ocean aquaculture
- Identification and system development of protocols for stock management
- Operating procedure development, including staff safety
- Management protocols for treatment of the farm as an ecosystem

Technology

- Seaweed farming technology
- Feeding, cleaning, monitoring, and harvesting technology development for large cage systems
- Predator and protected species monitoring and deterrents
- Establish effective technology transfer infrastructure (including personnel) for all technologies
- Video products to provide imagery of the condition of the environment before and during operations
- Cost effective tools for site selection and site assessment, before, during, and after operations
- More dependable and large scale hatchery production technology

Feeds

- Alternative feed ingredients from diverse sources (e.g., land plants, byproducts, and ocean based alternative feed stuffs)
- Improved feed and feeding efficiency

Health

- Improved disease resistance of stock by nutrition, development of high health seed, or both.
- Basic immunological research on target culture species
- Integrated health management plans for each species

Strategies for Moving Forward

- Consider a workshop to create a vision for this industry (both United States and international).
- Create a critical mass of industry participants to move development forward.
- Look at a variety of scenarios for the future marine protein production that features open ocean aquaculture technology.
- Make risk assessment transparent to allow contrasting the inshore with the offshore and offshore technology versus fishing technology.
- Hire a professional to set the framework for making open ocean aquaculture a sustainable industry.
- Provide comments and language for the U.S. Offshore Aquaculture Bill that makes it more acceptable to all parties.
- Bring in the seafood industry as a partner.
- Bring the nongovernmental organizations and various groups into a cooperative dialogue on the open ocean aquaculture opportunity.
- Meet with the environmental groups that want to have a constructive dialogue on sustainable open ocean aquaculture development.
- Develop consistent, easy to understand messages to educate the government and the public on open ocean aquaculture issues.
- Develop greater international cooperation and exchange of information for research, industry, development, and effective policy formulation for sustainable open ocean aquaculture.
- Develop aquaculture as a community social event (social marketing).
- Form a marine aquaculture association with responsibility to:
    - Advocate for open ocean aquaculture
    - Advocate a legal framework for open ocean aquaculture
    - Increase interaction and cooperation among research programs
    - Coordinate public education strategies
- Coordinate and increase public and private funding for multidisciplinary open ocean aquaculture research.
- Conduct market research for open ocean aquaculture products in general.
- Improve the quality of on-farm research.
- Develop several successful pilot projects to demonstrate the economic and social value to the public.