Kona Blue Water Farms case study: permiting, operations, marketing, environmental impacts, and impediments to expansion of global open ocean mariculture

Neil Anthony Sims
Kampachi Farms, LLC
Kailua-Kona, HI, United States of America
E-mail: neil@kampachifarm.com

Sims, N.A. 2013. Kona Blue Water Farms case study: permiting, operations, marketing, environmental impacts, and impediments to expansion of global open ocean mariculture. *In* A. Lovatelli, J. Aguilar-Manjarrez & D. Soto, eds. *Expanding mariculture farther offshore: Technical, environmental, spatial and governance challenges. FAO Technical Workshop, 22–25 March 2010, Orbetello, Italy*. FAO Fisheries and Aquaculture Proceedings No. 24. Rome, FAO. pp. 263–296.

ABSTRACT

Kona Blue Water Farms, Inc. offers an example of the integrated development of marine fish hatchery technology and open ocean mariculture. This paper presents an overview of the permitting requirements, operations and marketing, and the presumed and actual impacts on a local and global scale, and highlights some of the constraints to fulfilment of the industry potential.

Kona Blue undertook an extensive consultative process with traditional leaders, community, and conservation interests over a three-year period in acquiring the requisite Federal and State permits for the 90 acre (approx. 36 hectares) open ocean mariculture site. The company produces up to 500 tonnes of sashimi-grade highfin amberjack or Kona Kampachi® (*Seriola rivoliana*) annually, using up to eight innovative, submersible Sea Station® net pens. Operations are heavily reliant on divers, and increased automation is needed to reduce operating costs. The product is marketed as a branded open ocean raised fish, and attains high prices in both sushi and white-tablecloth restaurants across the United States of America. The species is globally distributed, and offers potential for expansion in warm waters worldwide.

The Kona Blue farm is located a half-mile offshore (approx. 0.8 km), in waters over 200 ft deep (approx. 61 m), over a sandy bottom. There are no conflicting recreational or commercial uses for this site. Ongoing monitoring of water quality, substrate beneath the pens, an adjacent coral reef and marine mammals in the area demonstrate that there is no significant environmental impact from the operation. There is no measureable impact on water quality and only minor accumulation of displaced algal biofouling immediately beneath the net pens. The adjacent coral reef retains its pristine condition, and healthy coral colonizes the moorings and rigging around the farm site. Humpback whales and

other marine mammals are neither attracted nor repelled by the operation, with the exception of some bottlenose dolphins that occasionally frequent the farm site.

Development of alternative sources of proteins and oils for feedstuffs is key to the sustainability, scalability and quality control for products in this industry. Of the many potential sources being explored, the most immediately promising are soy proteins and oils, and fishmeal and oil derived from the processing by-products of edible seafoods, such as salmon and pollock. Use of fishmeal and fish oil from the majority of targeted reduction fisheries, such as Peruvian anchovies, is justified by the less efficient alternatives for use of these products, and the increasing feed efficiencies of marine fish. The long-term goal is to ensure effective management regimes around these fisheries. Sustainably maricultured fish, with Fish-In:Fish-Out (FIFO) ratios approaching 1:1, are up to 60 times more efficient in use of limited marine resources such as Peruvian anchovies than commercial fisheries targeting the top of the wild food chain. Expansion of open ocean mariculture should be viewed in a global context for integrated marine resource management, where governments should increasingly expand marine protected areas and apply individual fishing quotas and other regimes to restrict commercial overfishing.

Fulfilment of the promise of open ocean mariculture requires overcoming the existing anti-aquaculture activism. Governments must improve the legislative and regulatory frameworks for growth. There is a need to increase the scale and efficiency of offshore operations, by developing larger net pens with more robust netting materials, reducing reliance on divers and increasing automation for routine tasks. Industry is the best vehicle for driving these innovations, but governments can actively encourage investment through enabling legislation.

THE IMPERATIVES

There are numerous sound arguments for fostering the responsible, rational expansion of open ocean mariculture, such as: reducing user group conflicts in nearshore waters; stimulation of economic development; maintaining the viability of coastal communities; and finding alternative employment opportunities for displaced fishers. However, there are, first and foremost, two powerful drivers that unequivocally compel the expedient development of open ocean mariculture: (1) there is an urgent need to reduce commercial fishing pressure on the oceans, while at the same time there is a (2) pressing need to increase the availability of seafood for better human health and nutrition. Expanding open ocean mariculture is the only means of accomplishing both of these goals simultaneously. There is no practical alternative. Any argument against the expansion of mariculture into the open oceans therefore must be seen as arguing for either: (a) continued, unrelenting commercial fishing pressure; or (b) reduced seafood consumption, with consequent impacts on human health and survivorship. The precautionary principle is often touted as reason for inaction in development of new technologies. Clearly in this case, however, the costs of inaction are significant.

The environmental imperative: reducing the pressure on ocean resources

The demand for seafood continues to increase, with growing affluence in developing countries, and with broader recognition of the health benefits of increased seafood consumption. Yet almost all capture fisheries around the world are either fully fished or overfished. In the United States of America, closures or buyback schemes to reduce effort have effectively shut down once-productive fisheries for Atlantic tunas and swordfish, the groundfish of Georges Bank and other Northeast fisheries, Pacific Coast anchovies, albacore, and more recently, rockfish. Other environmental concerns for endangered species or marine mammals have seen closures or limitations placed on fisheries for shrimp in the Gulf of Mexico, purse seining for tuna in the Pacific, and longlining for tuna and swordfish in Hawaii and the US Pacific. Domestic fisheries production in the United States of America is currently sustained, in the main, by massive harvests of pollock in the Bering Sea – a former trash fish that is now used as a surimi component. In 1999, for the first time ever, the US imported more seafood than was caught by US fishers domestically. The seafood component of the US trade deficit currently runs around US$9 billion, and is increasing annually at around 12 percent.

The global fisheries crisis can be underscored by three examples: the increasing threat of extinction from overfishing and the failed Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listing of Mediterranean and Eastern Atlantic stocks of bluefin tuna (*Thunnus thynnus*); the failure to recover – or the exceedingly slow recovery – of stocks of Western Atlantic cod (*Gaddus morrhua*) from overfishing despite almost complete cessation of trawling since around 1990; and the increasing acts of piracy off East Africa by former local Somali fishers who complain that they have no alternative employment since the decimation of their fisheries by foreign trawlers. These examples starkly reflect the biological and economic consequences of overfishing.

The public health imperative: Increasing protein and reducing heart disease

At the same time, there is increasing awareness of the importance that seafood consumption plays in a healthy diet. The definitive meta-study by Mozaffarian and Rimm (2006) found that a modest increase in seafood consumption in the United States of America, to two meals of oily fish per week, would result in a 35 percent reduction in deaths from heart disease and stroke, and a 17 percent reduction in overall mortality. A study by the US Food and Drug Administration (2009) supports these conclusions, noting that a 50 percent increase in seafood consumption nationally would save somewhere between 13 000 and 19 000 lives per year.

THE KONA BLUE OPERATIONS

The origins of offshore aquaculture in Hawaii

Prior to European contact, Hawaiians practiced extensive aquaculture in "loko" or fish ponds. These were inlets, bays, or shallow areas of reefs that the Hawaiians walled off from the ocean, and where ingress and egress of water was controlled by gates. Larvae recruited to the ponds were retained by the gates, and allowed to grow to harvest size on the pond's natural productivity, or were fed with additional vegetable matter. Many of these ponds fell into disuse after Western contact and with increased sedimentation from agricultural run-off. However, the cultural tradition provided ready receptiveness to development of other forms of aquaculture in the islands.

Up until 1998, Hawaii's ocean leasing legislation restricted any potential project to a maximum of 4 acres (approx. 1.6 hectares), and required that the project be limited to either educational or research purposes, but not commercial gain. Through several years of work by industry aspirants, and strong leadership by the State Aquaculture Development Program, legislation was passed into law in 1998 that allowed commercial aquaculture or energy projects in State offshore waters.

Permitting for the Kona Blue Farm site

Kona Blue Water Farms principals had been involved through the legislative review, and with passage of the bill, began research into developing hatchery culture techniques for high-value marine fish, and simultaneously surveying the Kona coastline (on the western, lee of the Big Island of Hawaii (Figures 1 and 2) for prospective offshore farm sites. After an extensive 3-year process of consultation and consensus-building with the community, Kona Blue was granted the requisite State and Federal permits for the original offshore farm site in March 2004.

FIGURE 1
Location of the Kona Coast on the western side of the Big Island of Hawaii affords moderate protection from trade winds and winter swells

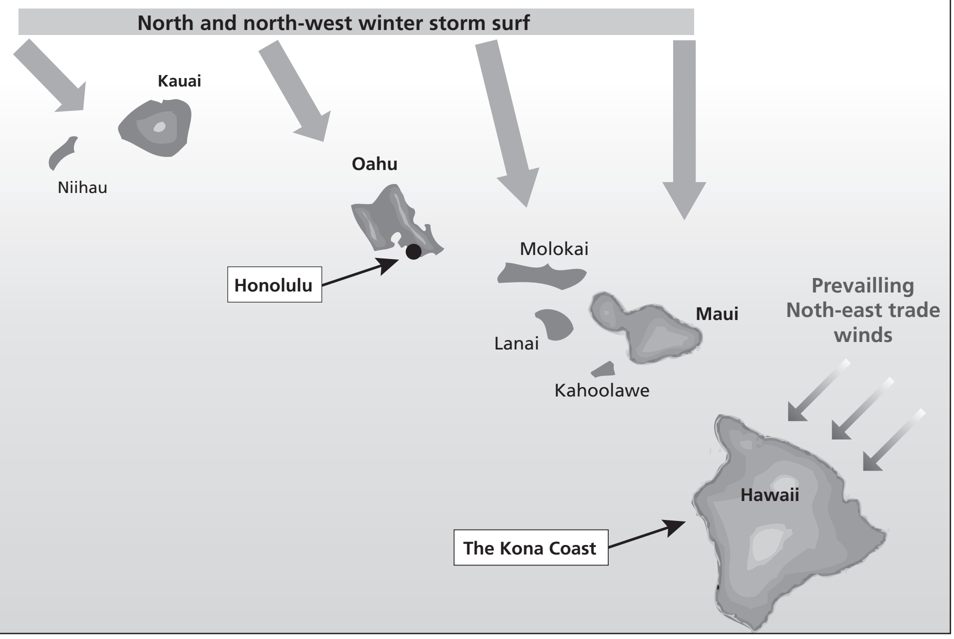
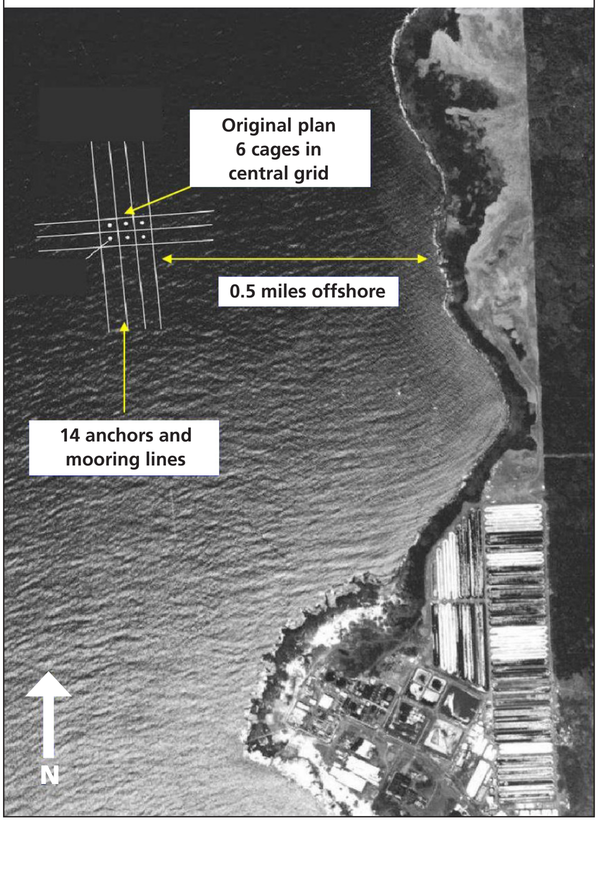


FIGURE 2
Kona Blue Water Farms' site located in waters over 200 ft (approx. 61 m) deep over a sand bottom, a half-mile (approx. 0.8 km) offshore from a pristine coral fringing reef abutting lava cliffs. The site is a mile north (approx. 1.6 km) of Keahole Point, and west of the Kona International Airport



The permitting procedures followed Hawaii's modified laws (Chapter 190 D, HRS, as amended), and other relevant laws. Regulatory requirements include permits and concurrence with a number of Federal, State and County regulations.

Federal

U.S. Department of the Army Permit

The Rivers and Harbors Act, Section 10, requires that a Department of the Army (DA) permit be issued for any activity that obstructs or alters navigable waters of the US Approval was therefore required for deployment of net pens, a feed barge and moorings. The U.S. Army Corps of Engineers (ACOE) is responsible for administering and granting DA permits. The criteria for issuance of a modified DA permit are similar to those for issuance of an environmental assesment (EA), but the DA permit also reviews compliance with all other Federal regulations. At the discretion of the ACOE, the modified DA permit can be processed and issued concurrently with other permits.

State

Conservation District Use Application

The Conservation District Use Application (CDUA) process is managed by the Land Division of the Department of Land and

Natural Resources (DLNR), who issue permits for any use of lands in the State Conservation District (under Chapter 183C HRS and HAR 13-5). This involves an environmental assessment (EA) or an environmental impact assessment (EIA) if there is a finding of significant impact (FOSI) or if there is "significant public controversy". The EA process is relatively simple and Kona Blue has conducted their own EAs for this project. There is no mandated requirement for an environmental impact study (EIS).

The decision to accept or reject the EA is made by the Land Board, who may then proceed to issue the lease and the permit. The decision is based on departmental review and public comment on the EA, and the recommendations of staff (usually the Office of Conservation and Coastal Lands – OCCL). A public hearing is required, and the Land Board hearing where a decision is made also allows for public testimony. Under the laws of the State of Hawaii, the Land Board must make a determination on a CDUA within 180 days of the application being accepted as complete, or else the permit is automatically granted. This avoids bureaucratic stonewalling, and assures an applicant of an expedient process.

A conservation district use permit (CDUP) is in perpetuity, but the lease has a maximum duration of 20 years. The chairman of the Land Board retains the right to modify, amend or withdraw the permit for breach of any of the conditions. The conditions specified by the State are usually extensive, and include monitoring and reporting provisions for a range of parameters.

National Pollutant Discharge Elimination System Permit

The State Department of Health Clean Water Branch (DOH-CWB), under the oversight of the Federal Environmental Protection Agency (EPA), requires a National Pollutant Discharge Elimination System (NPDES) Permit and Zone of Mixing Permit (ZOM) under the Federal Clean Water Act, Section 402, HAR 11–55. This applies specifically to discharges of point sources of pollutants into surface waters of the US from any fish farm operation that contains more than 100 000 lbs (approx. 45 mt) of biomass at any point. All aquaculture projects – including offshore net pen culture – are considered point-sources. The NPDES is valid for five years, and specifies allowable limits of 'pollutants', and monitoring requirements. The permit is issued or rejected after publication of a notice and a public comment period.

Coastal Zone Management Permit

Federal and State laws require that any project within the "coastal zone" requires a Coastal Zone Management Permit, issued by the Coastal Zone Management (CZM) Division of the Office of State Planning, to ensure compliance with all Federal, State and County laws and regulations. The issuance of this permit generally flows from the CDUP, but still offers a public comment period.

Aquaculture License

An Aquaculture Licence is required for commercial culture of a State regulated species under Chapter 187A-3.5 HRS and Sections 13–74–43 and 13–74–44 HAR. The DLNR Division of Aquatic Resources and the Department of Agriculture/Aquaculture Development Program (DOA/ADP) are the coordinating agencies.

Meetings and community consultations

For a finding of no significant impact (FONSI), an EA requires that project proponents have consulted with the community and other stakeholders. Kona Blue's principals spent extended periods of time discussing the company's aspirations for the offshore operation in a series of informational, briefing and consultative meetings with the community and Federal and State bureaucrats for the initial permit application, and then for subsequent permit modifications. Consultations with the community included "kupuna" (traditional Hawaiian leaders) and other native Hawaiian organizations (Office of Hawaiian Affairs, and Royal Order of Kamehameha), conservation interests (Sierra Club, Surfrider Foundation, and the West Hawaii Fisheries Management Council), and community groups (service clubs such as Rotary and Lions).

Subsequent requests for permit expansion and modification

The permits, regulatory issues and consultations required for Kona Blue's original permit application needed to be repeated to varying extents for each subsequent modification to the farm structures or operations. These permits were almost invariably granted, but the extensive time required for community consultation and permit application and approval for modifications – such as changes to the size and form of the net pens with no actual change in the production capacity – was a significant impediment to adaptive farm management, and a discouragement for investment. An application for doubling the size of the net pen capacity and the production volumes from the farm had included extensive, iterative scoping meetings with a range of state and federal agencies, and the public. There were few concerns raised against the requested expansion, but two "contested cases" were filed contesting the issuance of the EA: one complaint asserted that there was inadequate environmental information to justify approval, and one claimed that the permit contravened Hawaiian cultural prerogatives and rights. Although Kona Blue considered these complaints frivolous, a decision was made by the Kona Blue Board to withdraw the application 'without prejudice', and to seek farm expansion opportunities elsewhere (e.g. Latin America), where governments and the public were more receptive to industry development.

The offshore farm site and farm operations

Kona Blue began deployment of the moorings and net pens in February 2005, and first fish were harvested from the offshore site in September, 2005. Since then, production has grown to where the company has been harvesting up to 25 000 lbs (approx. 11 340 kg) per week of the company's sashimi-grade, trademarked Kona Kampachi®, peaking at around 500 tonnes per year in 2008. Kona Kampachi® (*Seriola rivoliana*) is also known as "kahala", longfin or highfin amberjack or Almaco jack. The species is related to the Japanese hamachi (*S. quinqueradiata*), but is native to Hawaii (USA) and is distributed throughout the warm waters of the world.

The lease area

Site selection is a critical component for any mariculture operation, but is particularly so for an innovative offshore farm that is pioneering both a new permitting process, and a new net pen system. The original farm lease site was selected using the following criteria:

- The selected site was in a deep water area, over 200 feet (approx. 61 m) deep, with brisk currents.
- There was little or no public use of this area. The farm site lies between the limits of normal recreational SCUBA diving (around 120 feet; approx. 36 m) and the normal depths for offshore trolling for "ono" (wahoo, *Acanthocybium solandri*).
- The site afforded some protection from both Kona storms and the strong trade winds. The proximity to shore also allows for future telemetry links to shore for farm control and security.
- There was ready access from Honokohau Harbor, five miles (approx. 8 km) to the south, which provides support facilities such as slips, fueling, and land for staging of equipment and feed.

- The site was directly offshore from the Kona International Airport and the Natural Energy Laboratory of Hawaii Authority (NELHA), and as such its use was consistent with the adjacent land uses and it represented no significant impact on the viewplane.

The farm site's bathymetry and oceanography are distinguished by the depth of water; the bare sand substrate; the strong currents through the area; the exposure to high winter surf and strong trade winds; and the adjacent shoreline of a narrow coral bench reef with a steep basalt (lava) cliff. A few black sand beaches also lie along the coastline, to the north of the site, but these are little used, except by recreational fishers. The pre-existing uses of the proposed farm lease area itself were negligible, because of its depth, the paucity of fish, and the barren benthos.

The 90 acre (approx. 36 hectares) lease area initially accommodated eight submersible Sea Station net pens, each of around 3 000 m^3 capacity. The outermost area of the lease is used almost solely for mooring lines, which require a 5:1 scope. The net pens were originally tied into submerged grids that are anchored into the soft substrate using steel embedment anchors and chains. A series of buoys and weights ensure that the anchor lines are perpetually taut, to eliminate any risk of entanglement by marine mammals. Bridles from the mooring grid corners attach to the net pen rims, to hold the net pens in place in each grid square.

The net pens are all concentrated towards the center of the lease area (see Figures 2 and 3), within two mooring arrays: one containing six net pens, and the other containing two net pens and the feed barge. The closest distance from the edge of the central grid array to shore is approximately 2 600 ft (approx. 792 m) or almost half a mile (approx. 0.8 km) to the northeast, to Unualoha Point.

The farm site lease provides "negotiated exclusivity": Transit, trolling, hoop-net fishing and hook-and-line fishing are permitted throughout the lease area, but for liability, insurance and safety reasons there is no authorized anchoring, SCUBA diving or swimming permitted.

Farm operations

The daily activities on the farm primarily consist of feeding the fish in the pens. Underwater video cameras inside the net pens are used to relay visual images to the operators on the feed barge. This enables the feed operators to regulate feed to ensure that no feed is wasted, and that excess feed does not fall below the net pen.

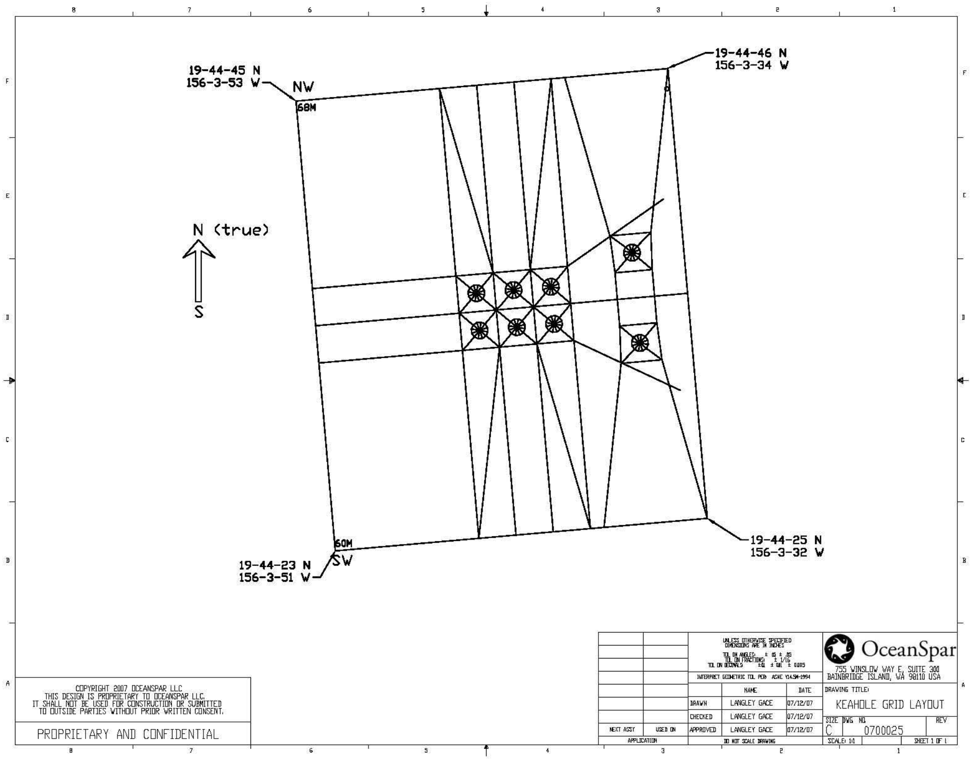
Any fish carcasses are regularly removed by divers. With the submersible net pens, divers must first raise the net pen to the surface (for safety reasons, to provide an air-space inside the pen), then enter and leave through a zipper. Carcasses are disposed of as solid wastes in the county land-fill.

Harvests usually occur twice each week. Fish are harvested into an ice-brine slurry, to quickly and humanely kill the animals with a minimum of damage. Fish are all transported whole, in ice-brine, to a single land-based processing facility, for packing and shipping. No fish processing occurs at sea during the harvests. Disposal of processing wastes is the responsibility of the wholesalers or other purchasers of the fish, but at present most trimmings from fillets go into the land-fill.

Support activities for the existing operation are based out of Honokohau Harbor, where a half acre (approx. 0.2 hectares) of land rented from the State accommodates containers for feed storage, gear storage areas, a closed workshop area, restroom and office.

The farm is also serviced by a semi-permanent feed barge/security platform vessel, which has been deployed on-site since October 2007. A separate harvest boat – the 74 ft (approx. 22 m) F.V. Kona Kampachi - transports harvested product back from the farm site to the harbor. Several other smaller work boats are also used to support net pen and grid maintenance and cleaning, and other tasks.

FIGURE 3
Original mooring array and grid dimensions – Plan view
The number of net pens is presently being reduced from current eight smaller pens to five larger pens, with the same overall culture capacity (24 000 m³). The submerged central grid remains at around 30 ft (approx. 9 m) beneath the surface



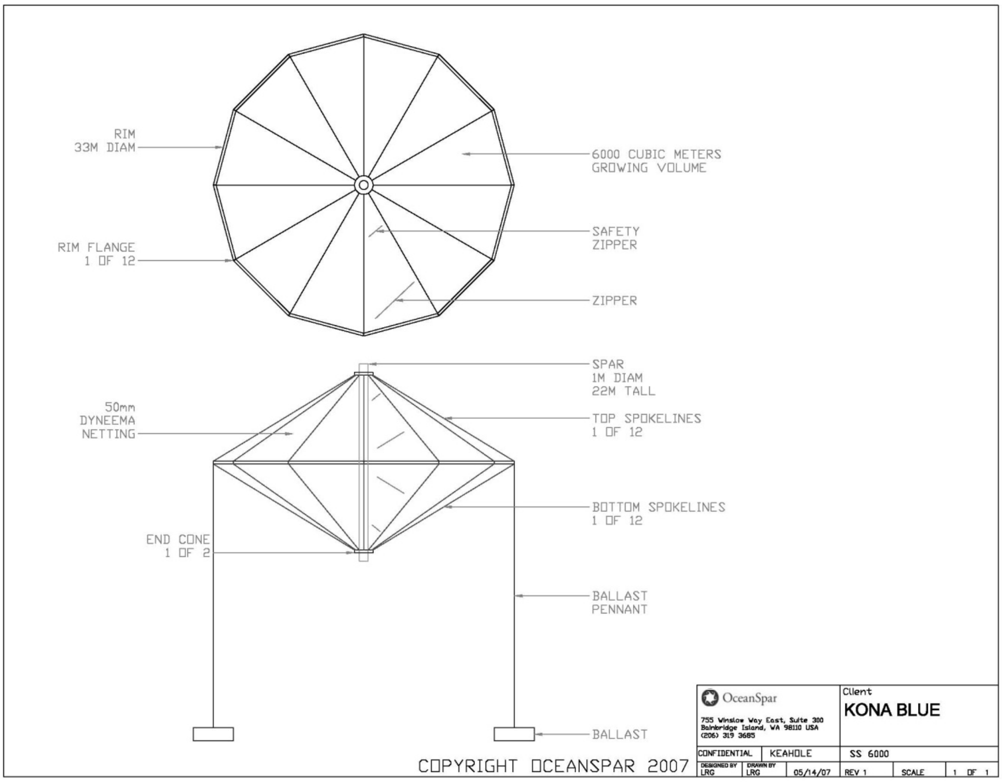
Marketing and Sales

The target market for Kona Kampachi® was the United States of America. Japan had considerable domestic production of hamachi (the traditional yellowtail, *Seriola quinqueradiata*) and local kampachi (primarily *S. dumerili,* but also some wild-caught *S. rivoliana*), and was already exporting the former to the United States of America. Japan also has a complex and costly seafood distribution system, a preference for Japanese-grown products, little interest in carrying a branded fresh seafood, and a tariff on imported seafood that competes with the domestic market. The European Union (EU) was not considered as a market because of the distance to airfreight the fish, and the prohibition against use of genetically modified organisms (GMO) feedstuffs and terrestrial animal by-products in fish feeds.

As this was a new product to the American market, Kona Blue undertook an extensive marketing campaign to introduce Kona Kampachi® to chefs, seafood distributors and the press to publicize both the fish itself, and the open ocean mariculture origins. The response suggested that there is indeed receptiveness among consumers to the Kona Kampachi® brand messages of sustainability, purity and healthfulness. Chefs also particularly liked the consistent availability and freshness of the fish: the company harvested product twice a week, and only enough to fill orders. Food writers and other journalists visited the farm site frequently. The company also sent product samples to chefs and distributors on request, and undertook a menu rebate programme of cash payments to encourage chefs to carry the fish by the brand-name on their menus.

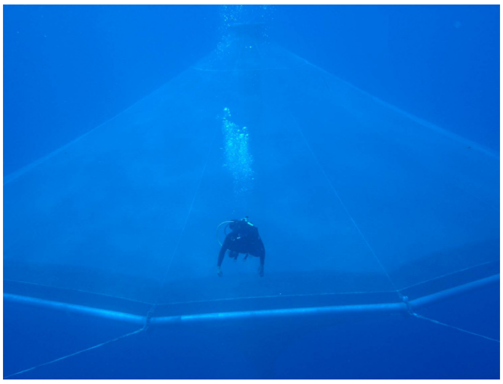
Kona Blue also engaged in active outreach to environmental non-governmental organizations (NGOs) with particular interest in seafood sustainability, and became actively involved in legal issues – such as the ongoing attempts to pass legislation to

FIGURE 4
Submersible Sea Station® Net Pens deployed on Kona Blue farm site



a) Design of submersible SS6200 Sea Station net pens with central steel spar and steel rim.

b) Sea Station SS3000 raised to rim-level on the Kona Blue farm site.



c) A submerged Sea Station SS3000 and diver on Kona Blue site.

COURTESY OF NEIL ANTHONY SIMS

open up the US Exclusive Economic Zone (EEZ) to mariculture, and for development of organic standards for seafood in the US – and in the process of developing sustainability standards for certifying individual farms, through the World Wildlife Fund (WWF) dialog process for *Seriola* and cobia (the *Seriola* and Cobia Aquaculture Dialogue – SCAD).

By mid-2008, Kona Blue was selling approximately 25 000 lbs (approx. 11 340 kg) per week of whole fish into the US market. The vast majority of this was being airfreighted to the mainland (the fish is always sold fresh), with about 50 percent sold on the West Coast, 35 percent sold on the East Coast, and 15 percent sold in Hawaii. The product was carried in both high-end sushi establishments and white table-cloth restaurants, but was still usually served in the latter as a raw appetizer – a sashimi, crudo (i.e. raw), poke ("ceviche") or carpaccio. The high fat content of the fish also makes it highly amenable to cooking. Retail sales volume has not been significant, but with growing brand awareness, this sector of the market is expected to grow.

Production decreased through 2009 and 2010 as the company prepared to reconfigure the offshore net pen array, and to change to fewer, larger Sea Station® cages. This work is presently under way, and sales are again expected to reach 25 000 lbs (approx. 11 300 kg) per week by the end of 2010.

THE IMPACTS

The presumed problems

Aquaculture – or indeed, development of any food production system – brings with it attendant environmental concerns. Fish farms are widely accused of environmental degradation. The concerns that are often voiced include:

- potential for detrimental impacts on water quality;
- potential for nutrient enrichment of the substrate beneath the farm;
- potential for antifoulant paints from net pens to contaminate the substrate;
- potential for therapeutant or antibiotic misuse to harm the surrounding biota;
- potential for escapes to outcompete wild fish for spawning grounds or feed;
- potential for escapes to dilute the wild fish gene pool or establish themselves as alien species;
- potential for proliferation of pests, parasites and diseases inside the net pens, which can then be transferred to wild fish;
- potential for entanglement of whales, dolphins and other marine mammals;
- potential for disruption of marine mammal or other species' migratory paths;
- potential for harmful deterrents or fatal control measures against predators;
- potential for excessive use of fishmeal and fish oil, leading to overharvesting of the smaller pelagic species targeted by industrial reduction fisheries;
- potential for exclusion of other user groups from traditional, cultural or recreational uses of the farm area; and
- potential for visual impact on the viewplane from the net pens.

The potential for any or all of these environmental impacts was used by a small minority to oppose the original Kona Blue farm permit and lease, and subsequent requests for expansion or modifications to the farm site. Opponents against open ocean mariculture also frequently raise some or all of these issues as cautions against any imprudent expansion of the industry, or as reason to oppose any Federal legislation that would allow open ocean fish farming in the US EEZ (i.e. from the State waters boundary at three miles or 12 miles offshore [approx. 4.8 and 19 km, respectively] out to 200 miles [approx. 322 km] offshore).

With almost five years' experience at the Kona Blue farm site, then, it is appropriate to evaluate the actual data and observations recorded at the Kona operation, and to compare this experience with the concerns that are so frequently voiced. Each of these issues is therefore examined in detail, below, beginning with an evaluation of the *de novo* environmental status of the Kona Blue farm site, and then detailing the impacts that have occurred, their context, and their significance.

The actual observed impacts: locally

Water quality and effluent impacts

The water quality at the farm site is close to oceanic, with strong currents and low turbidity. Underwater visibility usually exceeds 100 feet (approx. 30 m) or more.

General water movement patterns at the farm site are governed by the longshore currents past Keahole Point (the western-most point of the Big Island of Hawaii), one mile (approx. 0.8 km) to the south. An S4 current meter deployed at the farm site over several periods since 2004 showed regular peak current speeds of over 50 cm/sec (about 1 knot at a depth of around 40 ft or 12 m). Current headings were either generally to the north (predominantly) or to the south. The two points of first impact downstream from the farm site are therefore either Keahole Point, around one mile (approx. 0.8 km) to the south of the site, or the Mahai'ula-Makalawena shelf area, around three miles (approx. 4.8 km) to the north.

Because of the community concerns about potential impacts from the farm operation on water quality, the company had made commitments during the permit process to ongoing transparency and objectivity in monitoring. These commitments included:

- use of objective, third party experts to collect the water quality samples;
- use of local water quality laboratories – such as NELHA Water Quality Lab, or local private laboratories – for conducting the sample analysis;
- place copies of all monthly water quality monitoring at local repositories, such as the State Aquatic Resources office at Honokohau, or the NELHA library, so that local residents can review this data; and
- provide reasonable access to Federal, State and County officials for monitoring and oversight purposes.

Monthly measures are taken of ammonia and turbidity (the two most relevant water quality parameters for fish farming) at three depths (surface, mid-water – 50 ft. [approx. 15 m] deep, level with the submerged net pens, and at the bottom) and at a total of seven stations (two control stations up-current, one effluent station immediately down-current of the net pen with the greatest biomass, and four ZOM stations 4 000 ft. [approx. 1220 m] down-current; Figure 5). Quarterly measurements are also taken for a range of other parameters.

FIGURE 5
Water quality sampling station map

Aerial photograph of the Kona Blue site showing water quality monitoring sampling station locations. Sampling stations under a prevailing N-setting current are shown. Under a S-setting current, control and compliance stations will be reversed. ZOM = Zone of Mixing

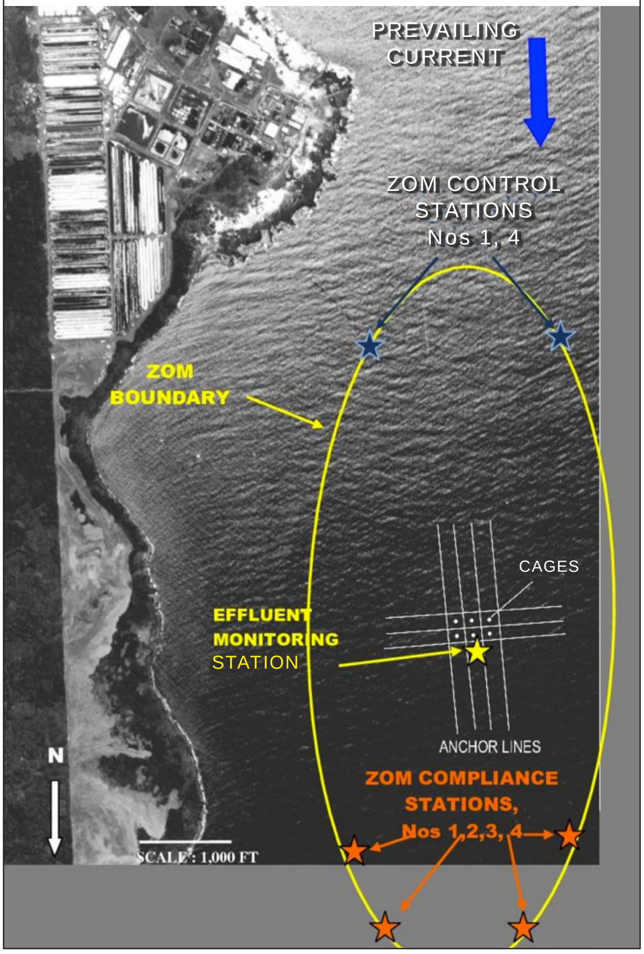


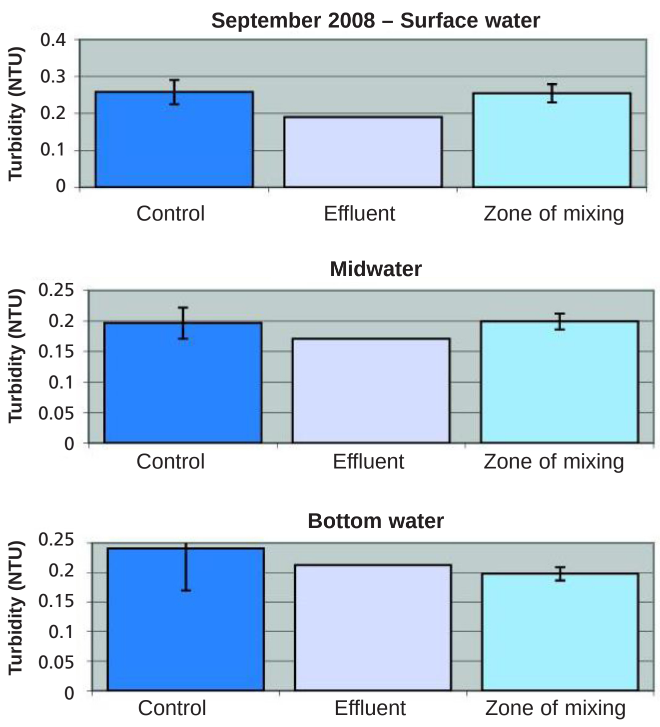
Figure 6 shows means for each sample site for turbidity for September 2008, when the farm was at peak production of around 500 tonnes annually. Turbidity is probably the best metric for fish faeces and other particulates in the water, and so is most likely to reflect any impact from the farm's presence. These data are definitively clear – there is no discernible difference between water quality parameters at the up-current control sites, and the effluent site (1 m down-current of the netpen with the highest biomass) or the "zone of mixing" (ZOM) sites down-current. These results confirm that *there is no measureable impact* on water quality from the existing farm operations.

Benthic impacts

The substrate beneath the farm is over 200 ft (approx. 60 m) deep, and is almost exclusively comprised of bare, coarse sand. Located along the shoreline, some 2 000 ft (approx. 609 m) to the east (directly across the longshore currents) is a diverse coral reef community.

FIGURE 6

Typical turbidity data from monthly sampling around the Kona Blue farm site. There is no discernible difference in water quality between the two control sites (up-current), one effluent site (immediately down-current) and four zone of mixing sites (4 000 ft or 1 220 m down-current) of the farm site



Impacts on substrate beneath and around the farm site

Prior to farm installation, a preliminary survey of the site was undertaken by repeated bounce dives, using SCUBA, to depths of 220 ft (approx. 67 m). Because the depth of the farm site is beyond the limits of normal safe diving, and the strength and unpredictability of the currents precluded ready use of grab samples or drop video-cameras, the original permit provided that no benthic monitoring would be required. Over time, however, permit requirements were tightened to include grab sample monitoring of substrate chemistry and infaunal micro-mollusc community structure, and video monitoring using drop cameras.

These results generally indicate that there has been no measureable impact on the benthic community around the farm site. There have been episodic perturbances of substrate chemistry immediately underneath the cage footprint, with a few instances of anoxic conditions during 2007, during periods when a new feed distribution system was being tested. This resulted in some pulverization of pellets and reduction of feed to a "slurry" rather than discrete pellets. Once the feed system was refined, the substrate returned to its more normal condition, there was no further significant nutrient enrichment of the substrate.

Filamentous algae have also been visible in the drop-camera videos from around the farm site. These appear to have been detached from the cage mesh or the mooring lines, as the algae are not attached to the coarse sand substrate. Presumably these algae are dispersed during periods of high current.

Monitoring of infaunal micro-mollusc assemblages in the substrate samples has also demonstrated that there has been no significant change in the community structure resulting from the farm presence.

Impacts on the adjacent coral reef community

A comprehensive survey of marine biota was conducted on the reef directly adjacent to the existing farm lease area, just south of Unualoha Point. The survey of the benthic biota of the fringing reef crest used protocols identical to those employed by the Hawaii Division of Aquatic Resources (DAR) West Hawaii Reef Management Task Force Survey. This provided an extensive set of "control" sites: the other benthic and fish data from the sites along the 90 miles (approx. 145 km) of coastline on West Hawaii. A series of four transects of 25 × 2 m extended parallel to the reef crest, immediately shoreward of the seaward edge of the reef. Video footage was made of these transects, and digitized for selection of random points on the video frames.

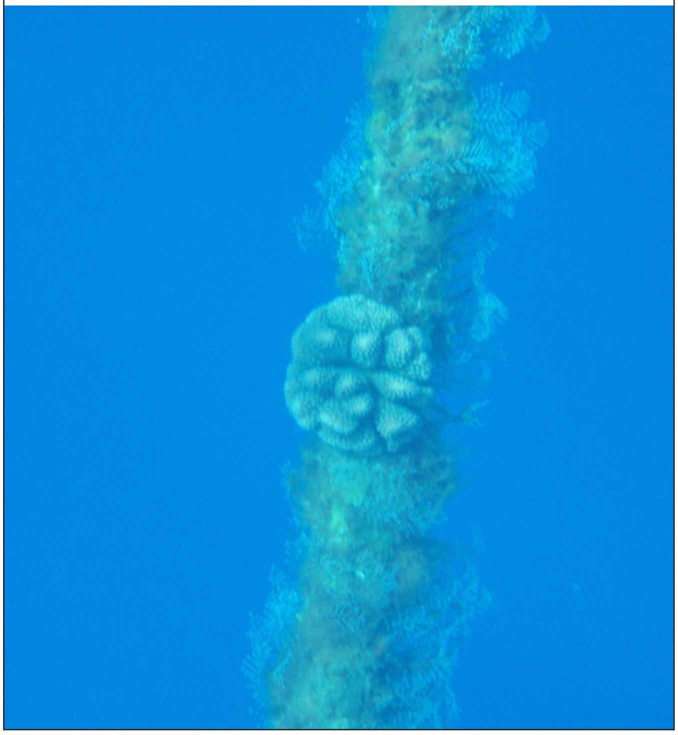
The Makako Bay – Unualoha site has been repeatedly resurveyed since the original 2003 survey. Although no formal reports have been compiled, there have been no significant changes in benthic community composition or fish populations, according to Dr William Walsh, of the State's Division of Aquatic Resources (personal communication, 2010).

Biofouling on the farm structures

There is also profuse growth of macro-invertebrate biofouling on the grid-lines and buoys of the mooring array, as well as on the bridle lines that attach the cages to the grid, and the rims of the cages themselves (Figure 7). This fouling includes diverse macroalgae, bivalves (several species of mussels and oysters: *Pteria* sp. and *Pinctada* spp.), corals (primarily *Pocillopora* and *Porites*), sea urchins (primarily *Echinothrix calamaris*) nudibranchs (*Stylocheilus longicauda*) and sponges. These all settle out of the plankton onto the farm structures, and their presence does not represent any significant or even measureable reduction in the available recruits to the nearby coral reef area. The growth of the corals, particularly, is compelling evidence that the presence of the fish farm operation is not deleterious to benthic organisms.

FIGURE 7

A *Pocillopora damicornis* coral colony on a mooring grid line around the Kona Blue net pens (within about 15 m of net pen stocked with fish). The presence of coral colonies that are highly sensitive to nutrient enrichment on moorings and buoys confirms that the operation has no significant impact on marine biota in the area.



Apart from the one brief instance of anoxic conditions beneath the net pens, then, there have been no other adverse impacts on benthic communities in, underneath or around the net pen area.

Pests, parasites and pathogens

Kona Blue employs an integrated pest management strategy to optimize fish health, reduce interactions or minimize impacts on wild fish stocks, and reduce any potential environmental impacts from therapeutant use. Any therapeutant use is conducted under the oversight of US Fish and Wildlife Service (USFWS), and Food and Drug Administration (FDA), with State oversight through Office of Conservation and Coastal Lands (within Department of Land and Natural Resources) and Clean Water Branch (CWB – within the Department of Health). Federal Environmental Protection Agency (EPA) has oversight through the NPDES (National Pollutant Discharge Elimination System), which is administered by CWB.

As with most farmed animals, *Seriola rivoliana* is subjected to small external pests – in this case, the skin fluke, *Neobenedenia* sp. – that attach themselves to the skin of the fish. These flukes do not pose any risk to human health, and do not themselves detract from the quality of the harvested product, but may cause irritation to the fish. If left unchecked, the flukes can become a health problem for the animal, as the fish rub themselves on the netting to ease the irritation. Kona Blue uses occasional treatments of dilute hydrogen peroxide solution (at effective dosage rates of 200–300 ppm) to control levels of skin flukes among the fish in the net pens. Hydrogen peroxide (H_2O_2) breaks down very rapidly in sunlight to form oxygen and water. Hydrogen peroxide is also considered an acceptable organic aquaculture treatment under the draft USDA organic aquaculture guidelines, and USDA organic agriculture standards.

Under the permits in place at the existing site, such therapeutant use must demonstrate that there is no risk to the fish under treatment, or to the environment or human health. Monitoring of the effluent from any bath treatment at 100 percent concentration is mandated under the "Whole Effluent Toxicity" (WET test) section of the NPDES permit. Results to date from the existing farm operation suggest that there are no significant environmental impacts from the use of the hydrogen peroxide. Ongoing effluent monitoring for WET test bioassays using larval fish (Pacific topsmelt, *Atherinops affinis*; conducted by Nautilus Laboratories in San Diego, California, United States of America) confirm that there is no significant difference in the rates of larval fish survival between control samples taken 4 000 ft. (approx. 1 219 m) up-current of the net pen, and samples taken of the whole effluent (100 percent concentration of the bath treatment water) at the conclusion of the bath treatments. There is therefore no mechanism for any measureable impact on the pelagic or benthic communities, or the surrounding water quality from the use of this therapeutant.

In addition, monitoring of wild kahala (*Seriola rivoliana*) stocks indicates that there is no significant proliferation of *Neobenedenia* sp. in the population around the farm area. Broodstock are regularly collected by commercial fishers from around the farm area, to replenish the wild stocks in Kona Blue's hatchery. These fish are usually taken along the "drop off" of the marlin fishing grounds, about one mile (approx. 0.8 km) to the South of the farm, and are sampled for ectoparasites upon capture by immersion in a freshwater dip. Although these fish are usually infested with a number of other ectoparasites, the prevalence of *Neobenedenia* sp. has never averaged much more than one individual per fish. By contrast, a parasitic copepod (sea lice, similar to *Caligus*) infests wild fish at average rates of around ten individuals per fish, and yet is not found at all on the farmed fish, and does not proliferate within the net pens.

A number of innovations, either in progress or planned, should also further reduce the proliferation of *Neobenedenia* sp. on fish inside the net pens. The farm is being re-configured to fewer, larger Sea Station net pens. With a planned reduction in the number of net pens, a reduction in the surface area-to-volume ratio of the remaining net pens (from double-cone net pens to a more cylindrical shape), the improved surface material characteristics and rigidity of the Kikkonet™ plastic monofilament net mesh (which make it easier to clean), and the improved access for offshore crew to regularly clean the nets from the surface (thereby breaking the skin fluke life-cycle by dislodging the adhesive eggs on the mesh), the proliferative tendencies of the skin fluke should be further reduced.

Kona Blue does not use prophylactic antibiotics, but has, under the same regulatory oversights described above, used Florfenicol® to treat *Streptococcus iniae* infections that sometimes afflict juvenile fish after the stresses of transfer offshore. These treatments last for only ten days, and are also accompanied by WET test water quality monitoring. These WET tests have repeatedly demonstrated no impact on marine biota from the therapeutant. A vaccine is available for other strains of *S. iniae*, and one specific for use in Hawaii is under development for future fingerling transfers, to thereby circumvent the need for Florfenicol. *S. iniae* infections are also not an issue with larger fish, once they have overcome the initial stress of transfer from the nursery to offshore.

Much of the concern over proliferative capacities for fish farm pests, parasites or pathogens is derived from conflicts between salmon farming and wild salmon runs. Some research – though disputed – suggests that sea lice from salmon farms is detrimental to survival rates of juvenile salmon as they migrate through fjords or river mouths to the sea. Most marine fish, however, are broadcast spawners. Juvenile marine fish are therefore dispersed over vast areas of ocean and reef, and do not usually have vulnerable migratory patterns. Given such a distinct difference in life-histories between salmonids and marine fish, there would seem to be limited applicability of the salmon and sea lice research, or the concerns with impacts on vulnerable life stages, to open ocean mariculture.

Interactions with wild fish

Kona Blue cultures only Kona Kampachi® (*Seriola rivoliana*), but the pertinent State permit also allows the company to possibly culture other amberjack (the other "kahala" species, *S. dumerili*), mahimahi (*Coryphaena hippurus*) and Pacific threadfin (*Polydactylus sexifilis*).

Aggregative effects on wild fish stocks

The existing operation does have an aggregative impact on some species of fish in the area, but this is considered neither deleterious nor significant. Fish are attracted to the site for a number of possible reasons: the fouling on the net pen, the occasional release of small quantities of uneaten food from the net pen during periods of strong currents, and the aggregative nature of objects in open water (as for fish aggregation devices). The make-up of the resident and transient fish communities around the net pens may vary over time.

Pelagic or larger demersal fish frequently occurring around the Kona farm site include mackerel scad ("'opelu", *Decapterus macarellus*), "ulua" (giant trevally, *Caranx ignobilis*), wild kahala (*Seriola rivoliana* and *S. dumerili*) and barracuda (*Sphyraena barracuda*). Occasionally, schools of rainbow runners ("kamanu", *Elegatis bipinnulatus*) and false albacore tuna ("kawakawa", *Euthynnus alletteratus*) move through the net pen area. Larger pelagic fish, such as yellowfin tuna ("ahi", *Thunnus alabacares*) and occasionally ono (wahoo, *Acanthocybium solandri*) are also attracted to the area by the baitfish, or by the net pens themselves.

A number of other, smaller fishes that are more normally associated with coral reefs settle out of the plankton and assume residence either around the subsurface buoys or around the cages themselves. Such residents include schools of Sargeant-majors (*Abudefduf abdominalis*), dascyllus (*Dascyllus albisella*), chromids (primarily *Chromis hanui* and *C. ovalis*) wrasses (primarily *Coris* spp. and *Thalassoma* spp.) and kyphosids (*Kyphosus* spp.). As these fish are settled from the plankton, their presence is not considered a significant detraction from the biomass or diversity of the fish fauna on the adjacent reef.

Escaped fish interaction with wild stocks

Concerns about potential negative impacts of escaped fish are often cited as one of the reasons for objections to fish farming. However, this issue is most pressing only where non-native fish are cultured in areas where escapes might become established or compete with local species, such as Atlantic salmon in the Pacific coast of Canada. Kona Kampachi®, by contrast, is native to the waters of Kona. In addition, Kona Blue recognizes that the innovative net pen engineering means that there is some possibility of escape incidents over the initial proving period, and development of refinements. In consideration of this, Kona Blue has deliberately not applied any selective breeding in the hatchery, and has not used any broodstock beyond F2 (i.e. all broodstock are either wild-caught, first or second generation captive-reared). There is therefore no mechanism for development of any significant difference in the genetic make-up of the fish inside the net pen from the fish in the wild. This reduces any potential impact from escapes to merely direct ecological impacts.

Furthermore, the concerns with the effects of fish farm escapees on wild fish genetics are again largely a consequence of the conflicts between salmon farming interests and wild salmon conservationists. Yet wild salmon stocks are unique, in that each river system or stream may have a genetically discrete stock from the adjacent watershed. Any blurring of this finer-scale differentiation, by inter-breeding between escaped salmon and wild stocks, could represent a loss of genetic diversity. Again, however, these concerns are not germane to farming of marine fish in the open ocean. As marine fish are broadcast spawners, there is only a coarse zoogeographic genetic granularity.

Tagging research demonstrates that *Seriola* and other carangids migrate frequently between islands in the Main Hawaiian Archipelago. One *Seriola* migrated from French Frigate Shoals, in the Northwestern Hawaiian Islands, to the Big Island – a distance of 678 miles (over 1 000 kilometres) over 3.6 years at liberty (Tagawa and Tam, 2006). The potential genetic impacts of Kona Kampachi® escapees on the wild stocks of *S. rivoliana* are therefore, minimal.

Those Kona Kampachi® that have escaped from the Kona Blue net pens – either through "leakage" as divers enter or leave the pen through a submerged zipper, or from breaches in the netting – are invariably subjected to very heavy predation pressure. Individual escapees survive outside of the zipper for usually less than a minute before being eaten by either the resident ulua, or by the bottlenose dolphins that are frequently in the area. The long-term prospects for survival and reproductive success of any escapees are therefore highly dubious. In addition, any escapes that do survive in the wild are presumably entering a wide-open ecological niche, due to the severe depletion of other deep water species – such as the deep water snappers – from commercial fishing. There is little likelihood of escapees competing in any significant manner with the few remaining wild snapper stocks.

Other wildlife interactions

Sharks

The single overarching feature of shark interaction with the offshore fish farm site has been – contrary to conventional wisdom and activist concerns prior to the farm deployment – the general absence of sharks around the net pens. For the first eight months of operation, only one fleeting shark sighting occurred: a small tiger shark ("mano", *Galeocerdo cuvier)*. There are generally brief influxes of tiger sharks to the area in the months of September and October of each year. Most of the animals appear individually, or in pairs, with a range of sizes from 8 to 15 ft. (approx. 2.4 to 4.6 m) in length, and generally seem to not take up residence on the farm site. Most tiger sharks only show interest in dead fish inside the net pens, and generally exhibit no interest in or aggression towards the farm workers.

In the first year of operation, however, before workable dive plans and efficient farm operations had evolved, the company divers were not able to keep the pens sufficiently clear of dead fish. Over about a six week period, in September and October of 2005, tiger shark sightings had become increasingly regular. One animal began to appear repeatedly, over consecutive days. This shark seemed to take up residence at the farm site, and began to exhibit more aggressive behaviour – on one occasion attacking an inert plastic float moored as a surface marker. The following day the shark chased a diver out of the water and onto a raised Sea Station™ net pen. At this point, farm managers decided that preventative action needed to be taken to assure the divers' safety, and the animal was humanely dispatched by a "bang-stick" (powerhead charge detonation) to the skull.

Recognizing the long-term unacceptability of such predator control measures, from a sustainability perspective, a cultural context, and a moral position, Kona Blue sought alternative means of addressing this issue. A shark management plan was developed in consultation with State Aquatic Resources personnel in Kona, which included a range of measured responses. Observations from research tagging trials had also shown that sharks which were caught, subdued, and implanted with a radio-marker tag usually vacated the area for an extended period. This, then, provides an acceptable, sustainable, non-terminal solution, if tiger sharks ever again become problematic at the site.

In subsequent years, tiger shark sightings usually increased in frequency at the farm site in the late-September early-October period. However, sharks were neither persistent, nor consistent. Farm operations had become more adept at removing dead fish, and the shark management plan allowed divers to continue to work safely. One animal or rarely two contemporaneously, may appear at the site, and remain for an hour or so, before moving away, presenting little inconvenience to farm operations, and no real risk to diver safety.

Kona Blue has also, in collaboration with the researchers of DAR and the Hawaii Institute of Marine Biology (HIMB), established a receiver station on the farm site, as part of the larger research program for tracking tiger shark movements along the West Hawaii coastline. The first data series obtained suggested that the observations by the farm work crews was correct - that tiger sharks only very infrequently pass by the site, and rarely do they show any interest in the operation. From July 2006 to May 2007, there were a total of eight records of tagged tiger sharks in the Kona Blue farm area. None of these sharks took up residence. One animal passed by the farm site three times in two months, another animal was recorded twice in two months, and three other animals had single records (Figure 8).

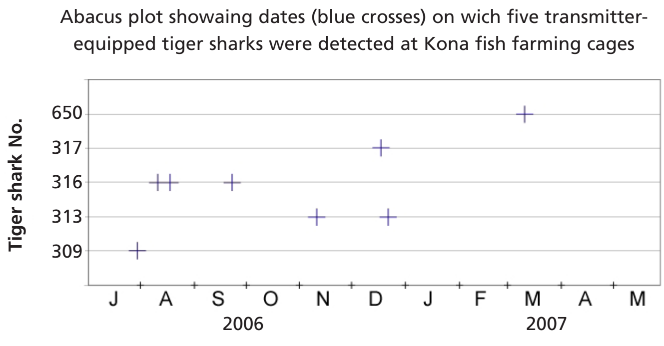
Over 2008 and 2009, however, further tiger shark tagging trials showed that two animals appeared to regularly return to the farm site over periods of up to five months. Two other sharks ranged over the entire Kona coast area, but for several weeks at a time were recorded exclusively from the farm site. All animals eventually moved on; one was later detected off Maui. While these results suggested that the farm site became a "waypoint" for the animals over a few months, the "long-term entrainment (e.g. years) of tiger sharks is unlikely" (C. Meyer, personal communication, 2010).

There have also been sightings of sandbar sharks ("mano", *Carcharhinus plumbeus*) around the net pens. Initially, these were rare (none in the first year of operation), but since October 2006, the frequency of sightings and number of sandbars has increased. These animals are usually seen in small groups (one to four sharks), below the net pens at depths of over 100 ft. (approx. 30 m). They rarely rise up to the level of the net pens. Sandbar sharks are more secretive, and cannot readily be distinguished by any markings. No sandbar sharks were caught during the tagging trials in 2008–2009 (ibid). It is therefore, unclear if these are always the same individuals, or if they represent a larger population of animals that periodically move through the area.

In the period from June to August 2008 there were a series of breaches of varying sizes in the Dyneema® webbing of one net pen that corresponded to shark bites. The same net pen was also breached in August 2009 by a small Galapagos shark that entered the net pen. The Galapagos was captured and released alive by company divers, unharmed except for a small dorsal fin notch for later identification. In each instance, breaches were sealed immediately on discovery. These incidents underscore the vulnerability of even sturdy Dyneema® nylon mesh, and have led to a plan for wholesale installation of Kikkonet® rigid plastic webbing across the farm. This material has been used in *Seriola* culture in Japan for over 25 years, and has been successfully used in crocodile and shark-infested waters by a sea-cage barramundi farmer in North Queensland, Australia. Kona Blue therefore anticipates that the use of Kikkonet webbing will reduce mesh breaches to negligible levels, and significantly reduce escapes and the attractant nature of the escapes to the bottlenose dolphins and sharks.

FIGURE 8

Frequency of tagged tiger shark occurrence at Kona Blue farm site: 2006–2007. Five tagged sharks were recorded over an 11–month period, with the most frequently occurring shark being present three times over a two month period. No animals took up residence, or showed any strong site affinity.



Overall, the evidence from the Kona Blue site confirms that there are no significant negative impacts from any aggregating effects of the net pens on sharks. The evolution of a non-terminal, humane plan for managing sharks on the farm site underscores the importance of commercial experience to improve open ocean farming practices.

Turtles

The threatened green sea turtle (*Chelonia mydas*) is common in the nearshore waters of the main Hawaiian Islands. The endangered hawksbill turtle (*Eretmochelys imbricata*) is infrequently found in Hawaiian waters. The principal nesting site for the green turtle is in the Northwest Hawaiian Islands, on French Frigate Shoals (Balazs, 1980). No turtles have been observed in the area of the farm site, but it is possible that they occasionally transit through the site. If they were to do so, the taut-line mooring system and stiff-mesh net pens will prevent animals from becoming entangled.

Seabirds

The submerged net pens used by Kona Blue do not significantly impact seabird populations. The farm area itself is infrequently used as a foraging area by seabirds. Most seabird activity in the area is confined to the fishing "grounds" which extend to the northwest of Keahole Point.

Monk seals

There are four conceivable ways for open ocean fish farming to have a significant negative impact on rare, threatened or endangered wildlife, such as monk seals, dolphins or whales. The project may: (a) present a significant obstruction to natural migratory patterns; either (b) attract; or (c) repel the animals and thereby disrupt their normal behaviour; or (d) the animals may become entangled in the ropes of mesh of the net pens or moorings.

Monk seals have been observed at the existing farm operation on two occasions, both in association with escape incidents from the nylon mesh nets on the surface nursery pens that were previously in use at that site. (These nylon mesh surface net pens were removed in 2006, as Kikkonet was, at that time, not yet available outside of Japan). On each of these occasions, the monk seal was preying on the small, escaped Kona Kampachi™, but once the school was effectively eradicated by predators, the monk seals moved away. A radio tag allowed movement of one monk seal to be tracked from the Unualoha site one day, to a beach on Maui the following day, clearly affirming that the animal did not take up residence or become conditioned to the availability of escapees.

Dolphins

Makako Bay, almost a half mile (approx. 0.8 km) to the south of the farm site, is frequented by large schools of spinner dolphins (*Stenella longisrostris*), on nearly a daily basis. These animals usually follow a diurnal pattern of movement from the Makalawena shelf area to the north, along the reef edge to the shallow areas of Makako Bay, where they rest for some time during the middle of the day. Some concerns were expressed during preliminary hearings about the potential for the farm operation to interfere with the spinner dolphin patterns of movement or resting habits. There is no evidence to suggest that this has been the case. There have only been a few occasions over the five years of operation offshore when divers or workers on the farm site have witnessed spinner dolphins coming anywhere near the net pens. The net pens clearly do not impede the usual pattern of spinner dolphin movement towards Makako Bay, and nor do they affect the resting pattern of the dolphins.

Over the last three years, the existing farm operation has demonstrated a propensity to attract bottle-nose dolphins (*Tursiops truncatus*). No bottle-nose dolphins were previously present on the farm site, but the animals have begun to appear regularly at the site since about October 2006. Patterns of dolphin movement are best characterized as one or two animals, every day or so, with occasional instances of groups of up to seven or eight animals. There is no regularity to the animals' appearance on the farm site: they may be present all day or only in the morning or only in the afternoon.

Kona Blue staff monitor and report on dolphin activity to the Hawaiian Islands Humpback Whale National Marine Sanctuary (HIHWNMS) and NOAA's Pacific Islands Regional Office (PIRO) Public Relations Department (PRD). The bottlenose dolphins are probably attracted to the farm site by a combination of: (i) the presence of the midwater structures acting as a fish aggregating device (FAD) and the associated fish community that is present around the net pens; (ii) the occasional provisioning from "leakage" escapes when divers enter or exit a net pen, and from the rare larger escape incidents when predators have breached the Dyneema nylon webbing; and (iii) interaction with divers outside of the net pen, as the divers move about the farm from boat to net pen and back.

One individual dolphin has taken up residence over 2009 and 2010. This animal was suffering from a large fishing hook and leader line that had become lodged in its jaw, and it was present on the farm site almost continuously during this period. For many months, the dolphin was lethargic and lost weight, but more recently (as of late 2009) has appeared to be more active and in better condition (J. Viezbieke, personal communication, 2009). The aggregative effective of the net pens for this one animal might therefore be interpreted as beneficial.

No other individual bottlenose dolphin has taken up permanent residence at the farm site. There are no other animals present on the farm site on around one-quarter to one-third of days. Even when other animals are present, they are often only there for part of the day, rather than the entire day. In October-November 2008, for example, dolphins were present for some period of time on 22 days out of 34 days (2009 Draft EA Appendix 2: Marine Mammal Report from Kona Blue to NOAA, dated 11/26/08). There were dolphins present at the farm site for some or all of the day on 65 percent of the days. On 35 percent of days there were no dolphins reported as observed on the site. On only one day were six dolphins present. Most other days there were one or two animals present for some portion of the day.

Other dolphin species may be found in and around the proposed farm lease area, but are usually most commonly seen on the "grounds" to the south of the site. Spotted dolphins (*Stenella attenuata*), rough-toothed dolphins (*Steno bredanensis*), and false killer whales (*Pseudorca crassidens*) have all been observed on the "grounds" or in other offshore waters of the Kona Coast, but have not been reported from the farm site.

In summation, although there has been behaviour modification in one compromised individual, the presence of the farm operation has not had a significant negative impact on dolphin behaviour.

The overall long-term impact on dolphins from the farm operation is difficult to discern at this stage, but will probably be further reduced. Modifications to net pens currently under way should help to alleviate the attractive nature of the farm to the dolphins, by reducing the potential for escapes through mesh breaches, and for leakage escapes, and by reducing the amount of time that divers need to operate outside of the net pens. Kona Blue will continue with the ongoing monitoring and reporting of marine mammal activity around the farm site, and continues to collaborate in this with HIHWNMS and PIRO PRD staff.

Humpback whales

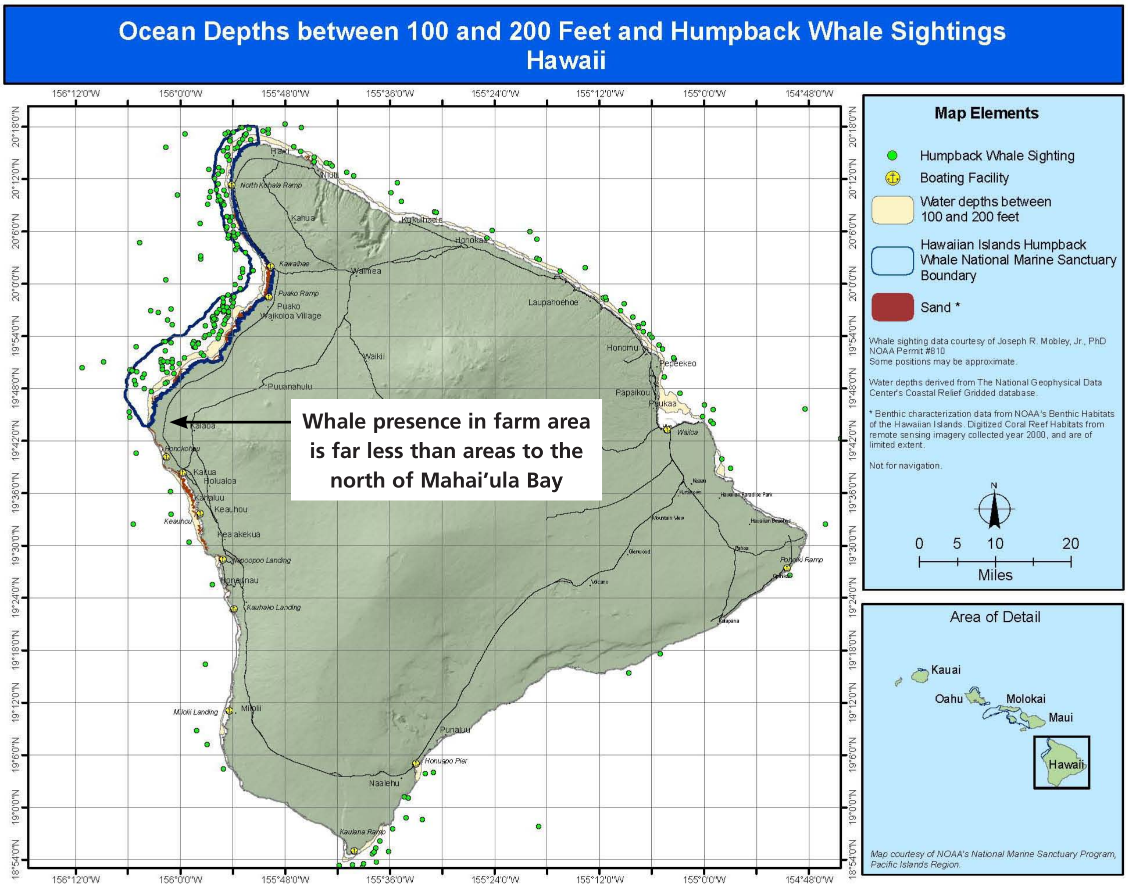
Populations of the endangered humpback whale (*Megaptera novaeangliae*) winter in the Hawaiian Islands, and the project site lies around one mile (approx. 0.8 km) inside the southernmost boundary of the Hawaiian Islands Humpback Whale National Marine Sanctuary (HIHWNMS). Humpbacks are known to frequent the entire Kona coast area in winter. The whales move throughout the general area, usually following a longshore track (north to south, or vice-versa).

Concerns about the reduction in whale habitat by the existing project were previously expressed by HIHWNMS and DLNR/DAR officials. Some concerns were also earlier expressed with the potential for entanglement of whales in the mooring lines of the net pens. A comprehensive analysis of available records on entanglement by whales (NMFS Stock Assessments), a review of interactions between marine mammals and Hawaii's fisheries (Nitta and Henderson, 1993), and details of marine mammal strandings compiled by NMFS Pacific Area Office (NMFS-PAO) shows that most whale entanglement events occur in slack net mesh (such as drift nets or fish weirs), slack vertical lines (such as crab pot or lobster pot floats), or surface lines (such as long-lining gear). Amongst all these observations, there is no record from any U.S. aquaculture operation of entanglement of humpback whales, or other marine mammals, in the taut moorings or net panels of fish net pens. With heavy mooring gear, and taut lines and mesh, the potential for entanglement is considered negligible (Celikkol, 1999; Wursig and Gailey, 2002).

It further appears that the waters in the vicinity of Keahole Point are not as heavily frequented by the whales as other waters of the sanctuary, further to the north (Figure 9). Observations from workers at the farm site suggest that the farm does not interfere with the movement of the humpback whales, beyond the immediate and obvious exclusion from the waters inside the net pens. The distance of around half-mile (approx. 0.8 km) from the inshore side of the net pens to the shoreline offers ample room for the whales to move around the eastern end of the farm structures, without any chance for any funneling or bottleneck effects.

FIGURE 9

Typical humpback whale sighting patterns around the Big Island of Hawaii



COURTESY OF

There is no definitive pattern of whales avoiding, or being attracted to the cages. Whales are occasionally seen within the lease area. On one instance, the farm workers witnessed a humpback on the surface inside the mooring grid array; the animal appeared to negotiate its path between the net pens and mooring lines with ease.

As part of the company's Marine Mammal Monitoring Plan (MMMP), farm workers provide data for assessing whale abundance and patterns of movement around the farm site. The MMMP describes Federal recommendations or instructions in the unlikely event of any entanglement, and also details ongoing reporting requirements for any close interaction with humpback whales, or any physical interaction between the farm array and other marine mammals.

Recreational use impacts

The farm site lies offshore from the Natural Energy Laboratory of Hawaii Authority, and the Kona International Airport, and as such, has little effect on shore-based recreation. The heavily used public recreation area of Kekaha Kai State Park (Mahai'ula) lies more than three miles (approx. 4.8 km) further to the north.

A survey of recreational activity in the general area, north of Keahole Point was conducted prior to the farm installation, from August to September 2001, in conjunction with the original farm site environmental assessment. The survey covered two months of summer conditions, which was considered the best means of ensuring that the data represented the heaviest use of the area. The overarching finding of the survey was that the area is only used for transit: of the 150 observations made over the 61 consecutive days of the survey, only one boat was seen within the farm site – a boat transiting through the area. Most activity in the general Keahole-to-Unualoha area was recreational dive boats and commercial dive tour operations along the reef and shoreline south of Unualoha Point (directly inshore from the farm site), and in Makako Bay itself.

Observations by the Kona Blue staff on the farm site suggest that this trend continues – the only use of the farm lease area is merely transit. Fishing boats now occasionally troll lines close to the central area, to try to take advantage of the aggregative effects of the net pens. There are no records of catch rates around the farm, but anecdotal evidence indicates that catches are primarily "ono" (wahoo, *Acanthocybium solandri*), with infrequent catches of "ahi" (yellowfin tuna, *Thunnus alalunga*).

Kona Blue's permit allows restricted public activities in the lease area, precluding anchoring, SCUBA diving, spear-fishing or swimming within the 90 acres (approx. 36 hectares). These limits are considered the minimum needed to protect the company's investment, to limit their liability (and retain insurance coverage), and to assure public safety. Fishing by the public from unanchored boats (trolling, or line-fishing from drifting boats) is still permitted, but with the caveat that any fishing lines that become entangled in the net pen mooring lines must be left in place, and cannot be retrieved by divers. The company also requests that fishers not troll through the centre of the farm site, because of the potential for fishing lines to entangle divers, or for lures to hook into mooring lines or nets. Boats transiting the net pen area are also requested to observe a slow "no-wake" boat-speed, to maximize safety for divers. Unguided recreational SCUBA diving or unauthorized commercial SCUBA dive tours are not permitted within the lease area, because of liability, safety and security concerns.

The loss of access to recreational activities within this relatively small area of ocean space is not considered significant. Kona Blue's ongoing observations affirm that there is virtually no fishing or other recreational use of the lease area, or the areas adjacent to the lease area, beyond trolling, which is probably enhanced by the farm's presence.

Viewplane aesthetics

Community value judgments and perceptions of how the oceans should be used largely govern the impact of the project on the community's aesthetic enjoyment of the area.

In community meetings, Kona Blue generally enjoys strong support for the broad goals of the company. There is wide recognition of the severely depleted status of bottomfish species in Hawaii. The awareness of the global fisheries crisis has recently been amplified by several scientific studies, such as that of Worm *et al.* (2006), which projected a collapse of world fish stocks by 2048, unless significant remedial changes are made to fisheries and marine ecosystem management.

The visual impact of the project is minor, compared with the adjoining properties of Kona International Airport and the aquaculture operations at NELHA. The major visual impact from the farm operation is from the experimental surface pens and the feed barge. There is also the additional presence of work and dive boats, and harvest boats, on some days. However, the impacts of these structures and activities are not significant, given the distance from the nearest residences, more than 3 miles (approx. 4.8 km) away.

There is general community acceptance that the project fits in well with the overall ambience of innovative aquaculture at NELHA, and the need for Kona to develop alternative industries beyond tourism. Fisherfolk and other mariners recognize the validity of the criteria that Kona Blue has used to select this site (c.f. deeper or shallower sites), and have not expressed a strong preference for the project to be located elsewhere. Applicants for farm permits in other areas of the Kona Coast (around Kawaihae) have, on occasion, been told that their project would more appropriately be located "down near NELHA and Kona Blue".

Cultural resources, practices, and mechanisms for impact

The farm lease area is too deep for free-diving or SCUBA diving activity, except for "blue-water" spear fishing. Usually, however, blue-water spear fishing is practiced close to a point or drop-off, rather than over bare sand substrate around 200 ft. (approx. 61 m) deep. There are no significant benthic plants or animal populations in the farm lease area, and there are virtually no benthic or pelagic fishing activities in this depth range. Kona crabs and "nabeta" (*Xyrichtys pavo*) are the only benthic resources that occur on sand bottom at this depth, but informants suggest that the currents are too strong for any significant fishing effort this close to Keahole Point (R. Punihaole, personal communication, 2003).

The only potentially-impacted cultural resource that was cited during extensive discussions with community and kupuna (elder) groups for the original farm site was the several 'opelu ko'a ("holes" or schooling places for mackerel scad – *Decapterus macarellus*) that occur in the general region. The locations of these ko'a are considered to be part of traditional marine lore, and are considered inappropriate for publication, or for sharing outside of the families or community groups who have traditionally fished these ko'a. However, in private meetings with the most knowledgeable kupuna, the locations of the traditional 'opelu ko'a were determined to be outside of the proposed project location. 'Opelu aggregations usually occur in water around 120 ft. (36.5 m) deep, close to reef drop-offs, and well shoreward of the farm area.

Prior to the 1801 lava flow that inundated the area, Keahole was the site of the largest fish pond in the Hawaiian islands. The Pai'ea pond (reputedly King Kamehameha's favorite pond) was approximately three miles long and one-half mile wide; canoes were used to traverse from one side to the other. The farm site is directly offshore from where Pai'ea once stood. Fish farming could therefore be considered historically and traditionally appropriate to the area.

The farm site constitutes part of the Hawaiian ceded lands trust, since all submerged lands are ceded lands. The 1999 amendments to the Ocean and Submerged Lands Leasing law (Chapter 190D HRS) directly addressed the issue of Office of Hawaiian Affairs' share of the lease revenues, by stipulating that the designated 20 percent of lease payments should be due to OHA.

The public perceptions of ocean access and ownership in Hawaii are an amalgam of two conflicting cultural traditions. The legal regime has, up to now, been largely based on the ancient western concept of *Mares Librum* – Freedom of the Seas, or the ocean as a common property resource. The traditional Hawaiian concepts of land-use and ocean-ownership practices were related to the principles of the ahu-pua'a, fish ponds and the konohiki fisheries. This provided for ownership of ocean resources and was recognized as a sustainable, efficient means of managing the ocean and reducing conflicts.

The 1999 amendments to the Ocean and Submerged Lands Leasing law (Chapter 190D HRS) were the first major step to view the oceans as a resource that could be occupied and sustainably utilized, rather than simply exploited. This represents a change in the legislative and community thinking. It could be interpreted to represent a shift in current policies away from the Western *Mares Librum* ideas towards the more traditional Hawaiian concept. It might also reflect increasing recognition – evident in increased regulation and licensing of fishing activities in the state – that open-access fisheries and unrestricted access to the ocean does not appear to provide sufficiently for effective management of ocean resources.

Access to or practice of any other customary activities has not been significantly constrained by the farm array or operations. The exclusive control over the waters (and the fish) inside the net pens is consistent with traditional and cultural practices that identified fish traps or lobster traps – and the animals therein – as the private property of the trap owner. The same principles apply here.

The actual observed impacts: globally

Fishmeal and fish oil usage

Fish such as *Seriola rivoliana* usually feed towards the top of the trophic chain in the wild. They therefore possess digestive systems and nutritional requirements that are adapted for feeds with high protein and lipid levels, and low levels of carbohydrates.

Fishmeal and fish oil usage in fish feeds is considered a valid use of a natural, sustainable, renewable resource, so long as the fishery from where the fishmeal and fish is sourced is responsibly managed. Although stocks such as the Peruvian anchoveta fishery are sustainable in the sense that they are very well managed, they are not scalable. If mariculture is going to fulfil its potential for increasing seafood consumption to meet growing demands, then some alternative sources of proteins and oils will be required.

Kona Blue has therefore, been focused on reducing the inclusion rate of fishmeal and fish oil from targeted reduction fisheries, such as Peruvian anchovies, and increasing the use of agricultural oils and proteins, such as soy, canola, wheat, corn and poultry meal and oil.

Improving feed conversion efficiencies: an evolutionary approach

Though efficient use of fishmeal and fish oil from targeted reduction fisheries is both rational and justifiable, this by no means suggests that these resources are unlimited, or we should not search for alternatives. If open ocean mariculture is to develop into a food production system that can provide a significant proportion of the nutritional needs for a growing planet, then we must find additional sources of sustainable proteins and oils for feedstuffs for this industry. The arc of Kona Blue's feed development strategies is perhaps instructive of directions that open ocean mariculture, as a global industry, might follow to achieve such scalable sustainability.

Initially, Kona Blue Water Farms fed the Kona Kampachi® with a diet that was considered "organic" by European standards. At the time, USDA did not have (and still does not have) organic standards for aquaculture feeds. In the EU, however, organic fish food was considered to be that which is most similar to the animal's diet in the wild. This feed, therefore, was comprised largely of fishmeal and fish oil derived from Peruvian anchovies.

With recognition of the need for more scalable feedstuff alternatives, however, Kona Blue worked with the feed vendor to develop a new diet that lowered the inclusion rate of fishmeal and fish oil from Peruvian anchovies to 50 percent. This diet included soybean meal, wheat gluten, canola, and other grain proteins and oils. The biological efficiency for this diet, however, was still suboptimal, with a Fish-In:Fish-Out ratio (FIFO) of around 3:1. (i.e. an input of 3 lbs [approx. 1.35 kg] of anchovies for each pound of Kona Kampachi® produced).

The inclusion rate of agricultural proteins in diets for marine piscivorous fishes is limited by the presence of a range of "anti-nutritional factors" in the grains and less-purified meals. (Note: although often described as carnivorous, most marine fish such as groupers, snappers, jacks, and bream, are perhaps more accurately described as "carbohydrate intolerant". They require diets that are high in protein and lipid, and low in carbohydrate. There is no specific nutritional requirement that these fish eat meat). For this reason, soybean meal is restricted to about 20 percent of the diet for most marine fishes. To reduce the fishmeal and fish oil inclusion rate further, and to further lower the FIFO, would therefore require proteins and oils from other sources. By-products from both edible fishery processing and poultry processing were therefore included in the revised Kona Blue diet, allowing the Peruvian anchovy inclusion rate to be further reduced to 30 percent of the ration, or 20 percent fishmeal and 10 percent fish oil.

Inclusion of poultry processing by-products, however, meant that some customers, such as Whole Foods Markets (WFM), a high-end organic and natural foods retailer, would no longer carry Kona Kampachi®, even if the poultry used for the by-products was of organic origin. This position by WFM was out of consideration for those of their customers that were vegetarians, but still wanted to eat fish. WFM asserted that these customers would not want to eat fish if that fish had eaten a pellet that contained proteins or oils that were derived from mammals or birds. Kona Blue appealed to WFM to review their position, given the importance of reducing our global footprint on the oceans – i.e. our reliance on natural marine resources, but as of 2010, there has been no change in this policy.

Kona Blue has recently tested two diets that completely eliminate from the Kona Kampachi® diet any fishmeal and fish oil sourced from targeted reduction fisheries, and any land animal processing by-products. These innovative diets use processing by-products from sustainably-managed fisheries intended for human consumption. As the trimmings from these sources would otherwise have been discarded, used as fertilizer, or burnt as fuel, the use of these fishmeal and fish oil products in the Kona Kampachi® diet represents an ideal re-use of natural resources. These diets therefore would result in a zero FIFO ratio – i.e. no targeted reduction fishery by-products included in the diet of the end product.

Alternative feedstuffs for open ocean mariculture

Kona Blue is involved in testing a range of alternative feedstuffs for Kona Kampachi® diets, which also offer potential for other species of marine fish. Alternative soy products, other agricultural grain concentrates, yeast and other single cell proteins, edible fishery by-products and – more recently, with the boom in microalgae culture for biodiesel production – defatted microalgae by-products have all either been tested, or are under development for Kona Kampachi® feed trials.

Kona Blue has tested a range of soy-based diets, with soy protein concentrates and omega-3 oil rich strains of soybeans. These trials suggest that the inclusion rate of soy protein concentrates cannot, by itself, exceed the same 20 percent threshold that limits soybean meal. Above this level, growth rates and feed conversion ratios are depressed. With the inclusion of taurine in the formula, however, soy protein concentrates could replace fishmeal as the source of protein up to 40 percent of the diet with no detriment to fish growth rates or feeding efficiencies.

There is a diverse array of edible fishery processing by-products that are available for use in aquaculture diets, and this direction offers tremendous potential for further development. The processing by-products from most wild salmon runs, for example, are woefully underutilized, and are often disposed of directly back into the rivers from which the fish are taken. Logistical and economic constraints limit the use of these trimmings, however, as the processing plants are usually small and isolated, the salmon runs are of only short duration, and storage and transport of fishmeal or fish oil by-products from these villages to fishmeal or fish oil reduction facilities, or feed mills, is challenging. Development of fish silage systems offers one potential, partial solution. However, even the less-seasonal, larger-scale processing of farmed salmon in more centralized plants presents difficulties for utilization of by-products. For biosecurity reasons, most fish feed plants will not run salmon-derived feed stuffs through their machinery, because of the potential for contamination of feeds from viruses, bacteria or other pathogenic vectors that may be found in the by-products. Screening for known pathogens is not an adequate solution: even though the chance could be considered very slim that some unknown pathogen may be unwittingly dispersed via extruded feed, the potential catastrophic consequences of such widespread and rapid disease dissemination are sufficient to ensure that no such chance be offered. This therefore excludes almost all large feed mills in salmon-farming regions from using salmon by-products.

Similar inefficiencies are found in re-use of trimmings from the pollock fishery (*Theragra chalcogramma*) in the northern Pacific. This fishery primarily processes most of the catch at sea, into surimi. Trimmings from these fish constitute around 65 percent of the wet weight of the catch. For a fishery that has averaged around 1.3 million tonnes, this then represents around 850 000 tonnes of wet weight by-product annually that could be converted into fishmeal and fish oil. For many years, much of this by-product was discarded back into the ocean, or the rendered fish oil was burnt in the diesel generators of the processing vessels. Some 8 million gallons (approx. 30 million litres) of fish oil in Alaska (United States of America) is largely disposed of as bio-diesel (Alaska Energy Authority, undated). More recently, some proportion of these trimmings have been used to make a high-quality white fish meal that is largely exported to Asia, where it is valued in feeds for farmed eels. However, the proportion of by-product that is re-used or recycled is not reported. Again, economics and logistics conspire against development of a rational supplement to targeted reduction fisheries. With increasing prices for fishmeal and fish oil, however, driven by growing demand for animal feeds from developing economies (notably China and India) there may be greater incentive to resolve these constraints. Edible fishery by-products may yet play a significant role in aquaculture feedstuff sourcing.

There is ample evidence that some or all of these innovative feedstuffs could help to reduce the demand for fishmeal and fish oil from clupeids in the medium- to long-term. Removal of this last constraint to growth should then see a true "blue horizon" of opportunity dawn for open ocean mariculture: a future food production system that can feed the world, without any significant negative impacts on the ocean environment. The Kona Blue example suggests that this is indeed achievable. The challenge, going forward, is for us to grow this industry in a manner that provides the best chance for what is achievable to become a reality.

Aquaculture in the food chain

Much interest has been recently focused on the problem of "fishing down the food chain" (Pauly *et al*., 1998; Taylor *et al*., 2000). This is the trend over time for commercial fisheries – driven by serial stock depletion – to shift their target species to those lower on the trophic pyramid. Fishers first start out exploiting the high-value, top-end predators, then move on to mid-level predators, and then on down towards herbivores and detritivores – what was previously considered bycatch. Fisheries generally start out targeting the larger, sweeter-tasting species – tunas, snappers, groupers, and such. As these become increasingly scarce, fishers apply greater fishing power, and fish longer and deeper, retaining or targeting what was previously considered "trash". The argument portends that at some stage, the food web is reduced to an ocean full of jellyfish. "Fishing down the food chain" is a condemnation of the inherent unsustainability of most commercial fisheries management – or rather, mismanagement.

Fish farming has somehow been implicated in this practice, on the basis that farmed fish are fed pellets that are partly comprised of fishmeal and fish oil derived from anchovies, menhaden, sardines or the like. These fish (collectively, the clupeiforms) usually form the first step in the ocean food chain beyond primary production. Some scientists and anti-aquaculture advocates misconstrue or deliberately misinterpret the complexities of ecological and economic cause-and-effect, and represent the use of clupeiforms as feed for farmed fish as wanton. This has been led by respected institutions such as the Monterey Bay Aquarium, but has also spilled into mainstream media, such as the New York Times, Conservation Magazine's article on "10 Solutions to Save the Ocean", The Ecologist and the Economist. The notion that aquaculture is guilty of "fishing down the food chain" is now lodged within the public consciousness.

The bottom of the food chain, however, is where we should preferentially be fishing. It makes far more sense to use herbivores or planktivores from the base of the trophic pyramid as either human food or feed for farmed fish, than to be targeting top-end predators. This makes economic sense, but it also makes sense from other perspectives: it is better for the ocean's ecosystems, it is better from the viewpoint of bioenergetics transfer through the trophic pyramid, it is better for consumer health, and it makes for better fisheries management.

The economics are simple: Peruvian anchovies and menhaden are not highly valued in the market, so they are cheap. Maybe this will change in time, and prices for anchovies and sardines will increase, as more people develop a taste for oily baitfish, but it is more likely that most consumers will still prefer larger piscivorous marine fish as sashimi or fillets.

The ocean's ecosystem offers several reasons why the bottom of the trophic pyramid is a better place for us to extract our nutrition from the sea. It is, most simply, a matter of mass and mathematics. Herbivorous fish are more abundant, with greater biomass. To catch 1 000 tonnes of Peruvian anchovies has little impact on the 6 million ton spawning biomass (around 0.025%). By contrast, 1 000 tonnes of tuna represents around 10 percent of the bluefin tuna spawning stock in the Western Atlantic: the biomass of which is currently estimated at less than 10 000 tonnes.

Moreover, Clupeiforms are classic "R-selected" species: smaller body-size, faster maturing, with shorter life spans. They are highly opportunistic: a decrease in population size in Peruvian anchovies often results in increased recruitment from the next spawning. From an ecological perspective, these species are precisely where fishing effort should be targeted; not on the larger, more vulnerable, slower-growing "K-selected" species at the top of the food chain. In agricultural terms, most of the crops that humans raise are strongly "R-selected" – wheat, corn, barley, rice, while targeting a "K-selected" species in agriculture might be the equivalent of chopping down oak trees to eat the acorns.

Herbivorous clupeiforms also grow and reproduce faster. Menhaden stock resilience to fishing pressure is "high", with a population doubling time of only 15 months. Northern bluefin tuna, by contrast, have "low" stock resilience, and a minimum population doubling time of 4.5–14 years. If half the menhaden were harvested, it would therefore take 15 months for the stock to recover. However, if half the tuna population was taken, it would take – at a minimum – between 4.5 and 14 years to recover. Southern bluefin tuna also do not begin to spawn until they are perhaps

11 years old, and may live to "at least 40 years of age". However, Peruvian anchovies are sexually mature within one year, and only live for around three years. The 3-year old anchovies then die and fall to the ocean floor.

The public health imperative should also provide impetus to source fishmeal and fish oil from lower down the food chain. Menhaden and anchovies filter algae and zooplankton directly from the water. They are therefore, high in heart-healthy omega-3 oils, yet low in the persistent organic pollutants, such as mercury and polychlorinated biphenyls (PCBs). These pollutants, however, are concentrated as they move further up the food chain. It is primarily top-level predators – sharks and tuna – that are on FDA advisories for pregnant and nursing mothers and children. By contrast, an aquaculture species that can achieve a feed conversion efficiency of close to 1:1 (FIFO or Fish-In:Fish-Out) contain essentially the same contaminant loading as the clupeiforms at the base of the food chain.

Clupeiform fisheries are also more readily managed, with relatively simple stock dynamics and ecosystem interactions. The major inputs to clupeiform stocks are the spawning biomass and primary productivity, which is usually driven by the strength of the nutrient-rich upwelling. Most of the fisheries occur within the EEZ of a single nation, where there are direct incentives for sound management and enforcement, and where access can be regulated. Tuna and swordfish, by contrast, are highly migratory species. Donut-holes of high-seas waters, beyond any country's 200-mile zone (approx. 322 km), provide opportunities for distant-water fishing nations to concentrate their boats and effort. Attempts at managing tuna stocks are typified by the International Commission for the Conservation of Atlantic Tunas (ICCAT), which has 46 Members and almost no enforcement capabilities. And while Hawaii's longline fishery targeting big-eye tuna may be very well managed, for example, heavily-subsidized European or Asian purse-seiner fleets target the juveniles of the same stock in the South-Western Pacific.

Moreover, the carbon footprint of clupeiform fisheries is minimal. These fish are usually taken by purse-seiners, working close to the coast, encircling schools containing hundreds of tonnes at a time. The carbon footprint for species higher on the food chain is much higher, with fish caught by diesel-powered trawlers or trollers, or – for blue-fin tuna and swordfish – harpooning the fish, one at a time.

Most importantly, however, it is far better from a bioenergetic perspective to target fish closer to the bottom of the food chain. Applying the 10 percent trophic transfer rule means that the one pound (approx. 0.45 kg) of wild tuna sashimi on a consumer's plate needed to eat ten pounds (approx. 4.5 kg) of anchovies – or the equivalent in fishmeal and fish oil. Or maybe, if there were two steps in the trophic pyramid, each pound of wild tuna required 100 pounds (approx. 45 kg) of anchovies to first be converted into ten pounds (approx. 4.5 kg) of mackerel.

Aquaculture, by contrast, is always a single step – clupeiforms-to-crop. But aquaculture can also use alternative agricultural proteins and oils, such as corn and wheat gluten, soy proteins and oils, canola and other animal processing by-products. These other proteins and oils reduce the fishmeal and fish oil inputs, to where some of the purported "carnivores" can thrive on a diet that is around 20 percent fishmeal and fish oil. On the "sustainability quotient" – the number of pounds of fish-in to produce one pound of fish-out (the FIFO) can then attain the perfectly efficient goal of parity or 1:1 (i.e. every pound of Peruvian anchovies in the farmed fish diet produces one pound of product). The result is efficient conversion of a low-value anchovy into a high value marine fish, without disrupting the fragile top of the trophic pyramid.

Larger, wild fish are more bio-energetically wanton. Wild fish lose energy through inefficient digestion, in hunting prey, trying to avoid predation, spawning, and succumbing to natural mortality. As wild fish grow larger, so too do they become increasingly inefficient – a greater proportion of energy is needed to maintain the animal's metabolism. Any by-catch will compound these inefficiencies further. The global by-catch ratio is around 0.28 lbs of discard for every pound of target species.

Earlier estimates suggested that farmed fish might be more efficient than wild fish, based on a single trophic step, by a factor ranging from two to five. Combining the life-cycle inefficiencies, trophic inefficiencies and by-catch inefficiencies of wild fish, however, means that farmed fish may be more efficient than wild fish by a factor of around 60 (Table 1).

This reasoning does not advocate for greater fishing effort on anchovies. To the contrary – caution is called for. While most of these stocks are sustainably managed at current levels, they could not withstand any greater pressure. These clupeiform stocks should continue to be very closely monitored, and highly regulated. Large marine protected areas should also be established to allow some clupeiform-based ecosystems to flourish in their natural state (rather than attempting ecosystem-based management). But it is imperative that we should better manage the fisheries at the base of the food chain, and endorse environmentally sound aquaculture, so that we can safely take pressure off the top of the food chain.

Fishing at the bottom of the food chain should therefore be encouraged preferentially over any other kind of fishing. This is not a function of recent overfishing: even 100 years ago, this principle would have still held true. We always should have been fishing at the bottom of the food chain. To continue to accuse aquaculture as being part of the

TABLE 1

Relative ecological efficiencies of farmed and wild-caught fish. The table shows the compounded cost in terms of anchovy-equivalents for farmed and wild-caught fish. Low-end estimates and high-end estimates are provided for each type of fish, and compared cross-ways to obtain a lowest-relative rate and highest-relative rate

	Farmed fish		Wild-caught fish		Global mean
	Low-end estimate	High-end estimate	Low-end estimate	High-end estimate	Ratio of wild to farmed
Life-cycle efficiency[(1)]	1	1	3	10	6
Trophic transfer efficiency[(2)]	1	8	10	100	7.3[(3)]
"Bycatch" efficiency	1	1	1[(4)]	11[(5)]	1.3[(4)]
Compounded "cost"	1	8	30	11 000	57

Note: The lowest relative rate extrapolated from this table is that the least-sustainably-farmed fish are around 4× more ecologically efficient than the most sustainably-harvested wild fish (i.e. 30:8). The highest relative rate is that the most sustainably-farmed fish could be 11 000× more ecologically efficient than the least-sustainably-harvested wild fish (i.e. 11 000:1). The Global Mean of wild fish efficiency to farmed fish efficiency is around 57×.

[1] There are no published estimates of the relative life-cycle efficiencies of farmed vs. wild fish. However, fish that reach reproductive age in captivity can see feed conversion ratios increase by factors of 5 or 10 over juvenile and subadult fish. Natural mortality and the nutritional cost of maintenance of basal metabolic processes during periods of food depravation also increase the "economic" feed conversion ratio for wild fish populations.

[2] In 1997, food conversion efficiencies (FCE) for farmed marine fish and farmed salmon were around 5:1 and 3:1, respectively (Naylor *et al*., 2000). By 2010, however, FCEs are projected to reach 1.5:1 for farmed marine fish, and as low as 1.2:1 for farmed salmon (Tacon, 2005). Kona Blue has been able to culture Kona Kampachi® on a diet that equates to a 1:1 ratio of wet-fish-in to wet-fish-out. However, if a less-sustainably-farmed fish is fed a pellet high in fishmeal and fish oil (say, to meet the Scottish Soils Association's Organic standards, with around 80 percent fishmeal and fish oil), this diet could equate to around 4 lbs (approx. 1.8 kg) of wet anchovy-equivalents for every 1 lb (approx. 0.45 kg) of dry pellet (a wet-fish to fish-meal ratio of 5:1 is considered standard). On this diet, most commercially-farmed species might have food conversion ratios of around 2:1 (dry-pellet to wet fish), implying an FCE of 8 lbs (approx. 3.6 kg) of wet-fish-in for every one pound (approx. 0.45 kg) of wet-fish-out.

[3] Tacon's (ibid) estimate of FCEs for farmed salmon and farmed marine fish might be conservatively pooled at, say, 1.5:1 – i.e. 1.5 pounds of anchovy-equivalents for every pound of farmed fish produced worldwide. There is a differential of around 1.1 trophic levels between global fishery landings (with a mean trophic level of around 3.3), and the Peruvian anchovetta fishery (with a trophic level of around 2.2; Pauly *et al*., 1998). At a presumed 10 percent biomass transfer efficiency up each trophic level, implies 11 pounds (approx. 5 kg) of anchovy-equivalents to produce a pound of harvested wild fish. The median ratio of wild to farmed trophic transfer efficiencies can therefore be estimated at 11:1.5 or 7.3:1 overall.

[4] Harrington, Myers and Rosenberg (2005) report a "nationwide discard to landings ratio of 0.28" (i.e. for 3.7 million tons landed, some 1.06 million tonnes were discarded). However, for highly-selective fishing methods, such as harpooning, by-catch is effectively zero as for farmed fish.

[5] "For finfish, the ratio of bycatch to target fish (in the Northern Pacific) can be as high as 11:1 because the bycatch is either too young, out of season, or the vessel has no permit to keep it." (Alverson, 1998).

problem of "fishing down the food chain" is therefore, disingenuous. Aquaculture is an important part of the solution for how we should feed our growing humanity. To assert otherwise is confusing to the consumer, and is discouraging the policy shifts that we need to make towards more sustainable aquaculture and healthier oceans.

THE IMPEDIMENTS

Overcoming the antagonism to aquaculture in major markets

In many parts of the Western world, the major impediment to expansion of open ocean mariculture is a generalized negative association with fish farming, or concerns with privatization of the oceans. This is most robustly manifested in the anti-salmon farming lobby: an extensive group of NGOs throughout the US Pacific Northwest and Canada, and parts of Scotland, Ireland and Norway. This lobbying is supported by private foundations, such as the Pew Environmental Trust, the Moore Foundation and the Packard Foundation.

Although much of the opposition to mariculture stems from salmon, the lobbying is becoming more widely opposed to the farming of other marine fish. The litany of objections listed by these groups includes all of those discussed above, but is perhaps more honestly portrayed as a philosophical opposition to the involvement of multinationals in the aquaculture industry (Pauly, 2009). Even though environmental standards and farm practices were previously far more rustic in the 1980s and 1990s, it was only with growth and consolidation of the industry since around the new millennium that the opposition has reached this new level of intensity.

With growth of a new industry of the scale and rapidity that salmon farming has seen, there are indeed very real risks that subsistence or artisanal fishers will suffer disenfranchisement or face commercial competition for limited resources. However, rather than creating economic inefficiencies by opposing the growth of the new industry, such concerns may perhaps be more effectively met with other initiatives or management measures. For example, if the concern is the consolidation of the industry, then it may be more appropriate for legislation to limit the extent of stakeholder dominance through anti-trust laws, or a "quota" over farm areas. If the concern is the targeting of small pelagic fish stocks for reduction into fishmeal and fish oil, then – instead of actively discriminating against the farming of higher trophic level fish – governments with jurisdiction over these stocks might rather limit access by foreign fleets, or establish catch quotas or preferential area access to artisanal fishers who are selling into local markets for human consumption. Governments might also provide loan or tax incentives for construction of canneries for anchovies or sardines. Governments in countries where marine fish farming shows most growth potential may – instead of restricting such growth and placing their entrepreneurial and investment resources at a disadvantage with other countries – instead choose to support fish nutritional research, or development of alternative protein and oil resources.

On a global level, there should be far more focus on optimum use of fishmeal and fish oil resources. At-sea processing vessels often dump fish trimmings overboard, when these resources might find better use in marine fish diets. In the United States of America, tax incentives are available for pollock processing vessels to burn the fish oil residues in their diesel generators, and thus defray their reliance on imported fossil fuels. Given the human-health value of fish oils, this practice seems to be even more egregious than the more generally recognized competition between energy and nutrition: the much-derided use of corn and other grain crops for ethanol production. There is also a need for development of efficient means of processing and transport of edible fishery by-products from geographically dispersed or seasonal fisheries, such as Alaskan salmon fisheries. Processing plants for salmon runs in remote areas often dispose of trimmings and carcasses directly into rivers, rather than undergo the technological and logistical challenges of stabilization and transport of the by-products, or silage or meal and oil (fish processing vessels in Alaska, United States of America, are permitted under their NPDES permits to dump up to 3 million pounds [approx. 1.36 million kg] of wet fish offal per year into any one square nautical mile area).

It is both undesirable and inefficient to encourage use of by-catch for reduction purposes. Management and development agencies should not be providing any incentives for alternative use of fish that are undersize, over quota or otherwise unsaleable. In addition, the taxonomic diversity of by-catch means that there is little consistency in the make-up of the catch, which would result in fishmeal and fish oil of varying qualities. This significantly diminishes the commercial value of these products for use in compound feeds for mariculture.

But the activist-driven negativity towards aquaculture already influences national policies, and may further hinder the rational and responsible development of open ocean mariculture, with consequent detriments for the ocean environment, for human health and for economic activity. Repression of open ocean innovation or entrepreneurial activity in one country or region will simply drive it elsewhere – either into international waters or into countries where monitoring and regulation are inadequate and rents are lowest. This forcing of offshore mariculture would appear to be counter to the best interests of governments, peoples and the environment.

There would therefore appear to be justification for the Food and Agriculture Organization of the United Nations (FAO) to play a leadership role in co-ordinating the accumulation and dissemination of objective, factual information on the impacts of open ocean mariculture, the most appropriate means of monitoring operations, and the best way of regulating the industry's growth.

There may also be some call for cautious optimism: in the face of the continuing commercial pressure on wild fish stocks, the overwhelming evidence in favour of increasing seafood consumption, and the gradual accumulation of evidence that open ocean mariculture – if conducted responsibly – can avoid most of the negative impacts normally associated with nearshore systems, there is some gradual – if begrudging – acknowledgement from some leading academics and NGOs that aquaculture may be an essential and desirable part of seafood and oceans policies. A 2009 life cycle analysis (LCA) of all seafood production and distribution systems concluded that the differences in carbon footprint between farmed and wild-caught seafood was inconsequential, compared with the stark differences between seafood that is delivered to market fresh by airfreight, and that which is delivered through the frozen supply chain, by seafreight or trucking (Pelletier *et al.*, 2009). Naylor *et al.* (2009) recently touted the "impressive gains" in FIFO ratios for aquaculture, and highlighted the mean global FIFO of 0.63:1 for all aquaculture (i.e. net protein production). Ocean Conservancy Magazine (Fox, 2009) carried a cover story about the opportunity for environmentally-responsible open ocean mariculture entitled "Farmed fish: Getting it right from the start".

But many of the anti-aquaculture activists have direct interests to continue perpetuating the myths and misinformation in the media and the public's minds. Without an aquaculture crisis to stimulate public donations or drive foundation-funded research, the support for many activist groups is severely curtailed. There is therefore still a long way to go before these entrenched interests are overcome, or they are reconciled with the reality of what needs to happen in our seas, and where and how this must happen.

Lack of legislation

Legislation in national waters

Many countries do not presently have legislation for open ocean mariculture beyond their coastal waters. These regulatory vacuums both discourage investment and innovation, and also run the risk that commercial projects will become established and grow in an unplanned manner. Many countries are recognizing the need for broadly-based marine spatial planning, and offshore mariculture should be an essential component of such initiatives.

Most activities in nearshore waters are administered by state or local agencies, where the interests of competing user-groups can perhaps be better voiced and adjudicated. The regulation of activities in deeper waters, further offshore, however, more naturally falls under the jurisdiction of national governments. State and local governments have historically extended their rights only into territorial waters, and the expanded EEZs are administered on a national level. However, few national governments possess the legislative or regulatory frameworks for supporting applications for mariculture leases or permits within their EEZs, or for monitoring and regulating the activities.

There would appear to be a role for FAO in supporting regional fisheries management agencies and national governments in developing such policies and frameworks.

Regulation of activities on the high sea

There would also appear to be a need for leadership from FAO in co-ordinating the regulation of open ocean mariculture on the high seas, beyond 200 mile (approx. 322 km) boundaries. Although often dismissed as science fiction, the powerful economic incentives of the tightening seafood supply chain and restricted access to more nearshore waters are combining to drive innovation in this direction. The attraction to international waters is also driven somewhat by biology: in deeper waters, fish health concerns and environmental impacts are reduced to *de minimums*, becoming essentially perpetual fallowing sites, and mobile fish farm platforms may find advantage in positioning in water masses with optimum temperatures for fish growth.

The "trans-ocean drifter cages" that have been depicted in popular media (e.g. Wired Magazine) have caught much public fascination, but are not practical with today's technology. There are also logistical challenges of sustaining operations in mid-ocean by providing feed and staffing for long periods. However, the initiation of discussions on high seas regulatory framework for mariculture by FAO would not be inappropriate, and may abet and hasten the development of these technologies.

Technological and capital requirements

There still remain some significant technological, economic and operational challenges before open ocean mariculture can truly fulfil its potential. Primary amongst these is validation of the commercial viability of submersible net pen technology in exposed ocean locations, where currents are unpredictable and strong, and where sea states may regularly exceed the relatively calm seas of Kona.

There are pressing needs for larger net pens to allow greater operational efficiencies, and increased automation to remove or reduce the reliance on SCUBA diving for servicing the net pens. Routine tasks such as remote feeding, automatic retrieval of mortalities and net cleaning must be able to be accomplished in submerged net pens without divers. The underlying technologies for these tasks appear to be available off the shelf (such as ROVs, and remote video links), but the components have yet to be integrated and tested on working farm sites. Kona Blue is pursuing some of this work in conjunction with Lockheed Martin, as part of a National Science Foundation research project, and other companies and research institutes, such as University of New Hampshire, are also directing increasing attention to these fields.

Submerged cages can be difficult to manage in terms of handling of the cages, cleaning of the net mesh, and management of the fish stock, given the inability to fully apply mechanical advantage (it is difficult to bring boats alongside submersible net pens, and the barrier nets do not readily allow functions such as seining), and the diving requirements. Almost all work around submerged cages requires SCUBA diving. This is both a heavy burden on the practicality of operations, as well as an onerous economic burden on a company's bottom line. In the United States of America commercial diving regulations require four workers to undertake any SCUBA-diving task (two divers, one dive supervisor, and a back-up diver), essentially quadrupling the payroll burden. SCUBA diving insurance rates are also very costly. Additionally, the heavy reliance on SCUBA-diving limits participation by commercial fishers in the offshore fish farming industry.

Ocean currents over one knot (50 cm/sec) occur frequently at the Kona Blue farm site, and other potential offshore aquaculture sites. As these currents are driven by ocean gyres, they do not follow predictable tidal/lunar cycles, and therefore are not predictable in strength or periodicity. This can significantly impact work with the submersible cages and with other tasks such as transferring fish or seining. The Sea Station cages can be sometimes held underwater by strong currents, preventing harvest, collection of mortalities, cleaning or other diver work. US Federal Occupational Safety and Health Administration (OSHA) dive regulations preclude any diving in currents over one knot. OSHA dive rules also require that there be an air-gap at the top of any enclosed space before SCUBA divers may enter; this effectively eliminates any work inside a submerged cage, and dictates that cages must be raised to the surface for even the most routine of tasks, such as removing mortalities.

The nylon netting on submersible cages has also proven difficult to keep clean, requiring diver-operated high-pressure net washing machines to remove biofouling. It takes between 2–4 days for divers to clean a single cage (i.e. 6–12 man-days, with a crew of three). Excessive fouling on the net material, resulting from infrequent pressure-washing, can exacerbate fish health in *Seriola* culture. The biofouling acts as a reservoir for eggs of the highly pernicious skin fluke, *Neobenedenia* spp. This ectoparasite is the major challenge for most yellowtail farming operations around the world. Losses due to skin fluke infestations and related infections – particularly for the more vulnerable juvenile fish – have resulted in significant lost revenues for Kona Blue. The inability to corral the fish in a fixed volume cage also makes it difficult to efficiently seine the fish, which can prevent effective treatment with therapeutants or vaccines.

In addition, the Dyneema netting on the Sea Stations in Kona has proven vulnerable to predators (*Seriola rivoliana* is native to the area and Kona Blue undertakes no selective breeding in the hatchery, so the ecological impacts from such escapes are not significant). Kona Blue has conducted tests with the recently-available Japanese rigid plastic netting material: Kikkonet®. This material offers significantly greater protection from predators, with no risk of entanglement, and – because of the monofilament nature of the material – easier cleaning. The life-span for Kikkonet is also reputed to be far longer than nylon nets: 20–30 years.

Submersible cages may also not be the most efficient cages for feeding the fish stock. The bi-conical shape of the cage and the inability to accurately monitor feed responses on the water surface may lead to feed inefficiencies. This may be particularly so in high-current situations, where the feed may be carried outside of the cage before the fish can ingest the pellets. In land-based tank trials, *S. rivoliana* can attain feed conversion ratios of around 1:1 (dry pellet feed to wet fish produced). In Kona Blue offshore cage array, however, feed conversion ratios are usually around 1.8:1, and can reach 2:1 for some cages. Video cameras are already used to monitor feeding throughout the eight-cage Sea Station grid, but the underwater connections for these cameras are proving problematic. SCUBA diving is needed each time that a connection or cable needs to be replaced, which has become a costly and inefficient task, and leaves feeding in many cages inadequately monitored.

It is therefore, imperative that we identify and validate: (a) an alternative, predator-proof mesh material that represents no entanglement risk to marine mammals; and (b) a more efficient cage design that improves farm operational efficiencies and productivity by affording frequent net cleaning, and reducing the SCUBA diving burden.

Surface accessible cages would also be safer for workers, requiring dramatically less SCUBA diving. (Less dependence on SCUBA also affords the option to hire employees who are not commercially trained divers). Cage cleaning, harvesting, and removal of mortalities could all be accomplished without SCUBA diving. SCUBA diving beyond a maximum depth of 10 metres should be limited, and there should always be direct access to the surface for safety of the diving practices. Ideally, divers will also be able to enter and exit the cage directly from the surface, thereby eliminating the "leakage" of occasional fish through the underwater zippers (as divers enter and exit the cage). This would also remove the presumptive attractant for the bottle-nose dolphins to farm sites.

Kona Blue has already received permit modification approval from the State government to modify the offshore array to deploy larger submersible net pens, each up to 7 000 m^3 volume, which will be able to be largely tended from the surface, similarly to a standard surface pen, and will have Kikkonet walls. These are to be deployed starting in May 2010. These further technological developments should allow open ocean mariculture efficiencies to approach those of surface pens in more protected locations, but with the attendant fish health and environmental benefits from open ocean production. With proof of these efficiencies, then, the capital for industry expansion should become more widely available.

REFERENCES

Alverson, D.L. 1998. *Discarding practices and unobserved fishing mortality in marine fisheries: An update*. From a report prepared for National Marine Fisheries Service, 29 April 1998. Seattle. Sea Grant Washington. Sea Grant Publication WSG 98-06, 76 pp.

Balazs, G.H. 1980. *Synopsis of biological data on the green turtle in the Hawaiian Islands*. U.S. Department of Commerce, NOAA. Technical Memorandum. NOAA-TM-NMFS-SWFC-7, 141 pp.

Celikkol, B. 1999. *Biological assessment of the University of New Hampshire open ocean aquaculture demonstration project finfish component*. Prepared for U.S. Army Corps of Engineers, New England Division, Concord, MA. 60 pp + appendices.

Fox, C.C. 2009. *Farming fish: Getting it right from the start*. Ocean Conservancy Magazine, Spring 2009: 22–26.

Harrington, J.M., Myers, R.A & Rosenberg, A.A. 2005. Wasted fishery resources: discarded by-catch in the USA. *Fish and Fisheries*, 6: 350–361.

Mozaffarian, D. & Rimm, E.B. 2006. Fish intake, contaminants and human health: Evaluating the risks and the benefits. *The Journal of the American Medical Association*, 296(15): 1885–1899.

Naylor, R.L., Hardy, R.W., Bureau, D.P., Chiu, A., Elliott, M. Farrell, A.P. Forster, I. Gatlin, D.M., Goldburg, R.J., Hua, K. & Nichols, P.D. 2009. Feeding aquaculture in an era of finite resources. *Proceedings of the National Academy of Sciences USA*, 106(36): 15103–15110.

Naylor, R., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, I.H. & Troell, M. 2000. Effect of aquaculture on world fish supplies. *Nature*, 405: 1017–1024.

Nitta, E.T. & Henderson, J.R. 1993. A review of interactions between Hawaii's fisheries and protected species. *Marine Fisheries Review*, 55(2): 83–92.

Pauly, D. 2009. *Aquacalypse now: The end of fish*. (available at www.tnr.com/article/environment-energy/aquacalypse-now).

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. & Torres Jr., F. 1998. Fishing down marine food webs. *Science*, 279(5352): 860–863.

Pelletier, N., Tyedmers, P., Sonesson, U., Scholz, A., Ziegler, F., Flysjo, A., Kruse, S., Cancino, B. & Silverman, H. 2009. Not all salmon are created equal: Life cycle assessment (LCA) of global salmon farming systems. *Environmental Science and Technology*, 43(23): 8730–8736.

Tacon, A.G.J. 2005. *State of information on salmon aquaculture feed and the environment*. Report prepared for the WWF US Initiated Salmon Aquaculture Dialogue. World Wildlife Fund, Washington, DC. 80 pp.

Tagawa, A.W. &. Tam, C.K.M. 2006, *Hawaii's ulua and papio tagging project 2000 to 2004*. DLNR, Honolulu. DAR Technical Report 06-01. 75 pp.

Taylor, R., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney H. & Troell, M. 2000. Effect of aquaculture on world fish supplies. *Nature*, 405: 1017–1024.

US Food and Drug Administration. 2009. *Report of quantitative risk and benefit assessment of consumption of commercial fish, focusing on fetal neurodevelopmental effects (measured by verbal development in children) and on coronary heart disease and stroke in the general population.* (available at www.fda.gov/Food/FoodSafety/Product-SpecificInformation/Seafood/FoodbornePathogensContaminants/Methylmercury/ucm088794.htm).

Worm, B., Barbier, E.B., Beaumont, N., Duffy, J.E., Folke, C., Halpern, B.S., Jackson, J.B.C., Lotze, H.K., Micheli, F., Palumbi, S.R., Sala, E., Selkoe, K.A., Stachowicz, J.J. & Watson, R. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science*, 314(5800): 787–790.

Wursig, B. & Gailey, G.A. 2002. Marine mammals and aquaculture: conflicts and potential resolutions. *In* R. Stickney & J.P. McVey, eds. *Responsible Marine Aquaculture*, pp. 45–59. Oxford, UK, CAB International.