Environmental Observations around Offshore Cages in Hawaii

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Concern for possible environmental damage constrains development of the aquaculture industry in the United States. Potential environmental interactions, including degradation of water quality, introduction of exotic species, pollution of the seafloor, adverse interaction with the seafloor benthic community, adverse interactions with protected species, and genetic interactions of potential escapees are all generally viewed as negative interactions, and thus are of substantial concern to the public and to regulators. Certainly, the culture of finfish in cages can be detrimental to the local water quality and the benthos beneath the cages when the fish are overfed or when too many production units are located in an area of limited carrying capacity or restricted circulation, as has been demonstrated by numerous published reports (see Black 2001 for a summary).

The focus of the Hawaii Open-ocean Aquaculture Research Program (HOARP) (Ostrowski and Helsley 2003) was to establish which, if any, of the above concerns are real in open circulation tropical conditions. Routine observations of water quality, health of the ecosystem outside the cages, interactions with protected species, and changes in the benthic assemblage were made to assess these potential impacts of open ocean aquaculture in tropical oceanic settings.

Observations over the past 6 years demonstrated that there was no measurable change to the water quality at the site. Observations of chlorophyll-a and turbidity suggest there was no important change in phytoplankton abundance near the cages, or that the change was so small that it could not be distinguished from the natural background variability.

The only change in the benthos was an increase in the abundance *Capetella capitata* and *Neanthes arenaceodentata*, known indicator species of organic enrichment. The increase in abundance of these two species, rarely observed in the oligotrophic sediments of the offshore, suppresses the abundance of the more common organisms that characterize the normal assemblage. This change in abundance provides evidence for a local species diversity change under the farm operational site. This change, however, was shown to be entirely reversible in time periods of less than a year of production, and thus it should not be considered to be a long-term detrimental impact.

Observations of environmental variables were made around a research site at the Cates International, Inc. offshore fish farm, about 3.22 km (2 miles) south of Ewa Beach, Oahu for the past 6 years. Initially, these were simply water quality measurements and assessment of changes in the micro-benthos beneath the cages and at control stations some 400 m up and down stream that were made as part of a set of proof-of-feasibility experiments. The research at the experimental site was transferred to the farm site in 2001 when the farm commenced operation.

Technically, these are two separate observational series, but because the water quality and benthos studies have continued at the CII farm site a few hundred meters from the initial research site using the same methodology, for the purposes of this paper, they are treated as one set of observations. Episodic sediment trap studies of the flux of particulate material emanating from the cages were added in an attempt to elucidate more clearly the causes of the changes that were observed in the micro-benthos beneath the cages.

The initial focus on water quality was because this was the item of most concern in the public hearings held during the initial development of the farm. All of the parameters required by the Hawaii Department of Health for discharge into public marine waters were measured. These constituents were measured near the cage and at progressively greater distances from the cage out to distances of 1 km. Table 1 provides a synopsis of the observations made during this work and includes both near cage and far-field measurements. The only parameter that was observed to vary outside the bounds of normal variation of marine offshore waters in Hawaii was the concentration of the ammonium ion (NH_4^+).

Table 1. Water quality observations relative to specific criteria

Parameter	Water quality requirement		Observations[a]
	Geometric mean not to exceed the value below	Maximum not to be exceeded more than 10% of the time	Maximum value observed and Number of occurrences ( )
Total Nitrogen (µg N/L)	150	250	>150 to 250 (2)
Ammonia Nitrogen (µg NH_4/L)	3.5	8.5	>8.5 to 69 (9) >3.5 <8.5 (32)
Nitrate + nitrite N µg (NO_3 +NO_2)/L	5	14	Always <5
Total Phosphorus (µg P/L)	20	40	>20 <31 (1) >40 (0)
pH: 8.2 ± 0.05; Temperature: ± 0.5 C from ambient; Salinity: 35 ± 0.5; DO:[b] >80%			

Note: Based on Hawaii Administrative Rules, Title 11, Department of Health, Chapter 24, Water Quality Standards.
[a]Total number of observations: 373.
[b]DO, Dissolved oxygen.

Initially, the water quality observation program focused on changes both in the cage and just outside the cage. The NH_4^+ concentration rapidly declined to that of background seawater. It was assumed during these early observations that this was due to the lack of adequate biomass in the cages to provide a signal that was above background. As the farm grew in size and the resident biomass increased to more than 50,000 kg, with feeding rates up to 2000 kg/day, an intensive effort to examine the NH_4^+ discharge plume downstream of the cages was initiated, but the plume was unobservable beyond a few hundred meters. The mixing due to turbulence downstream of the cage (see Helsley and Kim 2005) was deemed sufficiently large to preclude observation of elevated NH_4^+ at distance. Thus, after three years of observation, research water quality measurements were suspended, because no readings higher than the ambient ocean values were observed at distances greater than 200 m from the cage. Measurements just outside the cage did show elevated NH_4^+ concentrations a few hours after feeding that rapidly decreased to ambient levels as distance from the cage increased.

To satisfy the National Pollution Discharge Elimination System (NPDES) monitoring requirements, however, water quality measurements continue to be made regularly by the farm operator at sites near the cages and on a quarterly basis at the boundary of the NPDES zone of mixing. No values exceeding the water quality standards have been observed at the zone of mixing boundary. The seafloor under the cages was photographed, videotaped, or both at approximately monthly intervals throughout the 6-year period. No visible change in appearance of the seafloor was seen in the photographs (Randy Cates, personal communication, August 2006).

A formal program for the health of Mamala Bay, the broad reentrant in the south coast of the island of Oahu lying between Diamond Head (Waikiki) and Barbers Point (the southwest corner of the island) was begun a number of years ago as part of the compliance program for sewage discharge from the City of Honolulu. The protocols for this monitoring program are summarized in Bailey-Brock (1996) and Bailey-Brock et al. (2002), and which formed the basis for the assessment of impact on the benthos beneath the aquaculture farm.

The benthic biota residing in and on the seafloor was examined under the cages, at distances of about 80 m, and at distances of 200 and 400 m, by analysis of the infauna at more or less quarterly intervals for the past 6 years. A progressive change was noted for the stations under and near the cages. Organisms tolerant of a high nutrient environment became abundant at the expense of those adapted to a low nutrient condition typical of tropical open ocean environments (See Bybee and Bailey-Brock 2003 and Lee et al. 2006 for details). This nutrient enriched condition of low species diversity initially only affected the area under the cages. The station 80 m from the cage later showed the same trends as those observed under the cages. The stations at 200 and 400 m from the cages showed no changes in the diversity of the benthic assemblage.

The opportunity to conduct an interesting experiment arose after a hatchery failed to produce fingerlings in 2005 through 2006. The lack of fingerlings resulted in a progressive decrease in farm output over an 8 month period and was followed by a period in which there were no fish in the cages. Because no feeding was taking place on the farm, there was no added discharge during that time, although the cages were still in place awaiting a new batch of fish. Bottom samples continued to be taken for benthos assessment. After a period of approximately 9 months with low or no production, the seafloor essentially re-established its initial species diversity (Julie Brock, personal communication, October 2006). This was the same type of response that occurred during the experiment in which assemblage changes were observed while feeding was taking place and a recovery to pre-existing conditions a few months after the harvest was completed (Bybee and Bailey-Brock 2003). After 3 years of continuous production, the recovery period was about 9 months rather than the 3 to 6 months previously observed.

Sediment traps deployed under and shoreward of the cages were used to examine the flux of debris shed from the cage and the flux of waste material from the fish culture. Initial observations indicated a sharp drop off in the amount of particulate flux as one moves away from the cages. Moreover, the flux beneath the cages appeared to be higher than expected, suggesting that the assimilation of the feed by the fish was less than optimal. Further studies are currently underway to try to identify the reason for this higher than expected flux of waste material.

Many species of fish are now abundant external to the cages, indicating that the cages may be performing as fish aggregating devices. During the initial surveys at the site before the experiment began, no fish were observed. After the experiment, fish were abundant outside the cage. Three protected species are potentially present at the farm site: humpback whales, sea turtles, and monk seals. During 6 years of operation, no monk seals were seen, but whales and turtles were seen frequently. Neither type of animal seemed concerned about the presence of the cages. In fact, the turtles seemed to find the cages a preferred feeding and resting place.

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