Biology of Candidate Species
The White Seabass (*Atractoscion nobilis*) as a Candidate Species for Open Ocean Culture: A Review Based on Four Years of Culture in Nearshore Cages

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and

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Introduction

The feasibility of culturing and releasing juvenile marine fish, with the goal of enhancing depleted wild stocks in southern California, has been investigated since 1984. The research is directed by the California Department of Fish & Game (CDF&G) as part of the Ocean Resources Enhancement and Hatchery Program (OREHP). Revenues to support research are accrued from the sale of sport and commercial marine fishing stamps to fishermen south of Point Arguello, California.

Early OREHP research included developing the culture technology (i.e. spawning induction, larval rearing, nutrition, disease prevention) for the program’s primary target species, white seabass (*Atractoscion nobilis*). Much of this work was conducted at an experimental hatchery on Mission Bay, in San Diego, California. In 1991, OREHP researchers and volunteers from the Ventura Chapter of United Anglers began a pilot program to investigate the feasibility of using cage systems to cost-effectively extend the growout phase of hatchery-reared white seabass. Based on the success of those initial efforts, the United Anglers began to recruit other individuals to develop additional growout facilities that are now being constructed in different locations in southern California.

The primary goal of the volunteer-based, growout program is to maximize the potential of the OREHP by releasing large, healthy juvenile fish in a cost-effective and environmentally protective manner. Additional goals of the
growout program include increasing the geographic range of fish releases and increasing public awareness toward conservation issues.

This paper summarizes the experiences of the OREHP volunteer program in designing, siting and permitting cage systems, and the process of culturing white seabass in these cages.

**Historical Perspective**

Currently, volunteers from ten growout facilities are culturing white seabass for stock enhancement (Figure 1) in southern California. A total of nearly 80,000 white seabass have been successfully cultured, tagged and released from these facilities. The annual contribution of fish released from each facility is illustrated in Figure 2.

*Figure 1. Site map showing locations of satellite growout facilities and the main hatchery.*
Siting and Permitting

Nine of the 10 growout facilities are situated along the southern California mainland and one is located on an inhabited offshore island (Figure 1). The growout program and its associated release area encompasses over 200 miles of coastline from San Diego to Santa Barbara, California. Catalina Island is approximately 22 nautical miles from the mainland at its closest point. White seabass occur naturally throughout this range.

All of the cages are located in fully protected embayments with the exception of the Santa Barbara facility. Although fully exposed, the operation of this cage is regulated by mooring restrictions for the area and must be removed from the water between October and May each year. The depth of water at each site varies (1-10 m), as do the tidal characteristics associated with each.

Site selection for volunteer-based white seabass growout facilities is based on a number of factors. On a broad level, these factors include the range of the OREHP funding base, proximity to volunteer support groups, and areas where white seabass are known to occur. On a local level, sites are targeted that are already permitted for mooring or docking of vessels. This is done to minimize time delays and costs associated with obtaining additional permits and approvals. Among these preferred areas, specific sites are selected in areas believed to
have good water quality and exchange. Accessibility is also a factor in the site selection process.

The permitting requirements for development in the coastal zone of California is a very involved process. The complexity of this process can be attributed largely to the overlap of authority that exists among local, regional and federal regulatory agencies. In addition, mariculture is so new to southern California that many hours are spent educating agency officials at each level. Because of these factors, permitting requirements experienced by OREHP participants are often site and project specific. A list of permits, approvals and supporting documents that are required by growout facility operators is presented in Table 1.

<table>
<thead>
<tr>
<th>AGENCY</th>
<th>Form of Approval</th>
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<tr>
<td>California Coastal Commission</td>
<td>a</td>
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<tr>
<td>California Department of Fish and Game</td>
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<tr>
<td>Regional Water Quality Control Board</td>
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<tr>
<td>State Lands Commission</td>
<td>b</td>
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<tr>
<td>County Parks Department</td>
<td>b</td>
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<tr>
<td>Army Corps of Engineers</td>
<td>a</td>
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<tr>
<td>City Planning Department</td>
<td>b</td>
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<tr>
<td>Harbor Master/Water Director</td>
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<td>Marina Lessor</td>
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**OTHER SUPPORTING DOCUMENTS**

- Building plans
- Site photographs
- Site maps
- OREHP fact sheet
- Club organization description and documents
- Proof of Insurance

<table>
<thead>
<tr>
<th>Key</th>
<th>Description</th>
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<tr>
<td>a</td>
<td>required by all sites</td>
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<tr>
<td>b</td>
<td>required by some sites</td>
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Design and Construction

Currently, there are two cage designs being used to culture white seabass. The first is a traditional design where the cage is moored in open water or alongside a dock and a net bag is used to contain the fish. The bag is supported by a rigid frame, protected by thick netting or rigid mesh, and buoyed by pontoons. The second design consists of a semi-submerged, fiberglass raceway that is affixed to a pier or floating dock (Figure 3). In this design, the raceway serves not only to contain the fish, but also as a predator barrier. General design specifications for existing cage facilities are listed in Table 2.

Figure 3. Two typical designs used by volunteers to culture white seabass. Net pen design (top) and floating raceway design (bottom).
Table 2. Design summary for growout facilities operated by volunteers and participating in white seabass stocking program. Active systems are those currently in use. Subunits refer to individual containment areas.

<table>
<thead>
<tr>
<th>Site</th>
<th>System Type</th>
<th>Access</th>
<th>Active (y/n)</th>
<th>Subunit Numbers (n)</th>
<th>Subunit Volume (cubic m)</th>
<th>Total Culture Vol (cubic m)</th>
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<td>San Diego Bay</td>
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<td>Boat</td>
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Because neither the net cage or submerged raceway designs has been standardized and differences in water quality exist among sites, it is difficult to identify the more efficient system of the two. From a fish production standpoint, there is no evidence suggesting improved growth or survival of the white seabass in one system or the other. Net systems offer greater freedom for water exchange because water can move through the cage mesh from any direction. Because of their solid walls, submerged raceways may require mechanical devices such as pumps or aerators to exchange water. These devices require electrical power which increases operating costs. In addition to cost concerns, the operator must consider the catastrophic losses that could result from a power failure. Feeding levels are generally easier to monitor in submerged raceway systems because uneaten food remains visible on the bottom of the raceway and does not fall through to the sea floor as readily as in a net cage design. However, if raceways are not cleaned daily, excess food will have the negative impact of
decreasing water quality in the system. If a vacuum system is available, excess food and detritus can readily be removed from the raceway. Different opinions currently exist on the maintenance requirements of each system with regard to the amount of cleaning required to maintain high water quality standards and sufficient water exchange. The most popular feature of raceways is the smooth texture of the fiberglass walls that can easily be scrubbed to remove algae and encrusting organisms. Because submerged raceways are so rigid, they are better suited for protected waterways, including embayments. This siting restriction may impose an additional limitation on the overall size of a given system. Similarly, since most of the raceways are currently produced from a common mold, there are a limited number of configurations and later modifications (i.e. to increase depth) are difficult. Itemized cost data are not yet available for comparisons between the two system designs.

Culture Operations

Juvenile white seabass are tagged internally in the cheek muscle with a coded wire tag\(^1\) prior to delivery. Fish are typically stocked into growout facilities at a size of 75 mm (5.0 g). Stocking densities vary and are still being evaluated in order to maximize production levels. However, a density of 210 fish/m\(^3\) appears to be safe for most systems regardless of the time of year they are stocked. Fish are fed a high protein (approx. 55%) diet in the form of a sinking pellet\(^2\). A variety of feeding techniques and schedules are employed, but generally, automatic feeders are set to feed during 2-3 periods from dawn to dusk. Maintenance schedules also vary considerably among growout facilities. Some volunteer groups schedule site visits every other day or as frequently as three times per day to clean and inspect feeders, nets, and circulators. Dive inspections are scheduled periodically to check and clean nets and mooring systems.

\(^1\) Manufactured and distributed by Northwest Marine Technologies, Inc. Shaw Island, Washington.

\(^2\) Marine Grower Diet - manufactured and distributed by Moore-Clark, Vancouver, BC.
Growth rates of juvenile white seabass range from approximately 0.4 mm per day during the winter (12-15°C) to as high as 1.8 mm per day during the summer (22-26°C). Harvesting (for release) is done when the fish reach approximately 200 mm (80 g). To date, the maximum harvest density is 26 kg/m³. Prior to release, all fish are counted and inspected by a certified Fish Pathologist from the California Department of Fish and Game. Survival rates vary among facilities and among groups cultured at the same facility during different times of year. However, survival typically exceeds 80% during the 3-6 month growout phase.

Factors that negatively impact white seabass health are often attributed to either the siting, design or operation of the growout facility. Siting problems include proximity to bait receivers, the contents of which may serve as a source for pathogens; proximity to thermal effluent from power plants, which may result in supersaturated water conditions; and siting in water that is too shallow, which may lead to high turbidity or supersaturated water. Problems attributed to system design include electrolysis of window panels, which may lead to escapement of fish or entry by predators; restricted water exchange caused by solid wall panels, which may lead to poor water quality; and depth limitations imposed by rigid systems, which may limit hydrostatic compensation by the fish. Other problems related to system design include malfunctioning feeders or water circulation systems. Operational procedures connected to health problems include stress caused by delivery, inadequate feeding ration, and extremes in water quality—especially temperature.

Discussion

The OREHP has demonstrated that white seabass, a highly prized food fish, can be cultured successfully in land-based systems. Hundreds of volunteers from the recreational fishing community, across a 200 mile range, have been involved in an effort to cost-effectively culture and release white seabass to a larger release size. These groups have
successfully constructed and supported small-scale cage systems in protected coastal areas. Since 1991, nearly 80,000 juvenile white seabass have been released by these volunteers. The infrastructure established to support this program includes technical staff from private and state organizations, and a Procedures Manual written to assist volunteers in designing, permitting, constructing and operating a growout facility. This same infrastructure could readily be adapted to commercial interests, including redirecting the efforts of commercial fishermen toward mariculture, once the marketability of smaller, cultured white seabass has been determined. A commercial demonstration project is currently planned to accomplish this.

Experimental work conducted in land-based raceways, combined with data collected at volunteer-based growout facilities, suggests that biologically, white seabass is a viable species for commercial culture. Sufficient water exchange and good water quality consistently result in high survival, fast growth and healthy fish. White seabass held in land-based raceways have grown to 1.0 kg in 17 months.

In order to meet OREHP’s stocking goals (>350,000 fish per year), and to support future commercial needs, larger cages are now required. Nearshore areas, especially embayments, are unsuited for this expansion due to user conflicts and view issues, space limitations and poor water quality. Unless a more pro-active, user-friendly regulatory process is established supporting open-ocean aquaculture, expansion of OREHP will be limited.

Acknowledgements

This work was conducted as part of the Ocean Resources Enhancement and Hatchery Program, under the guidance of the Advisory Panel and the California Department of Fish and Game. Much of the data reported in this paper was collected by members of the growout facilities and represents thousands of hours of volunteer work. Our sincere thanks to these dedicated individuals.
Candidate Species of the Pacific: The Hawaiian Fisheries Development Project

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One of the major constraints to mariculture in the United States is limited access to high-quality water resources. Coastal zone development is limited by competing interests, such as urban development and recreation. High land costs and regulatory constraints limit the economic feasibility of certain pond or nearshore systems, and water quality is often affected. It has been and will continue to be increasingly difficult to justify locating growout systems nearshore.

Use of offshore cage systems circumvents many of the environmental and regulatory problems associated with growout of marine finfish species. Engineering aspects have rapidly advanced to the point that demonstration trials can proceed, and several cage designs either currently exist in the marketplace or are being refined. However, bottlenecks exist in the lack of reliable hatchery techniques for mass production of fingerlings for targeted species and the absence of established marine finfish hatcheries for seedstock production. In fact, the majority of seed for marine finfish growout operations worldwide is captured from the wild. Techniques for maintaining and spawning broodstock and raising larvae are not well established for the most marketable of U.S. marine finfish species.

There has yet to be a concerted effort to develop a multi-species concept for hatchery and growout development of marine finfish in the United States. Federal support has been granted largely to pursue solutions or alternatives in response to regional problems that have affected the commercial fishing industry. For instance, recent closures or severe restrictions on traditional fishing areas have provided incentive and interest in farming such marine species as cod, halibut, and other bottom fish. Maine has established a Groundfish Hatchery Study
Commission to examine the feasibility of developing a hatchery to produce cod larvae for stock replacement (USDA, 1994). This has mostly concentrated on development of techniques to raise fingerlings from eggs stripped from wild broodstock. In July of 1995, the federal government approved funding for 13 aquaculture projects, mostly in Massachusetts, as part of a $4.5 million aid package to the ailing fishing industry in New England. At least three operations are in the permitting and construction stages for both offshore and land-based production of summer flounder *(Paralichthys dentatus)* in Massachusetts, New York, and Rhode Island (Spatz et al., 1996). In addition, haddock, halibut, cod and eel are being considered.

In 1995, a multi-year project was funded by the National Oceanic and Atmospheric Administration (NOAA) through the National Marine Fisheries Service (NMFS) to develop a multi-species, marine finfish hatchery concept for commercial-scale production of fingerlings for stock enhancement and farm production purposes. The project, titled “Hawaiian Fisheries Development (HFD)” systematically addresses development of hatchery technologies for species prioritized as having the greatest potential for aquaculture and stock enhancement in the Pacific, as well as for the ease of application of the technology to other, similar species in other regions of the country. The project targets development of standardized approaches to broodstock management, maturation and spawning, and larval and nursery rearing through comparative analysis of species. Development of the multi-species hatchery concept is based on the principle that diverse species exhibit fundamental biological commonalities that allow them to be mass cultured within the constraints of modern aquaculture techniques. The HFD project targets representative species from different ecological and environmental habitats including nearshore, offshore, and deepwater regions in Hawaii. Successive stages build upon commonalities of the previous stages, and incorporate only those aspects unique to the representative species of interest. In this respect, development through each successive stage occurs more rapidly and more efficiently. This also provides the
rationale for rapid development of newly targeted species. Because targeted species represent a wide range of habitats, it is believed that the technology developed would be immediately applicable to a large number of species of economic importance not represented and in different regions of the country. Having determined the common factors to rearing different species, hatchery facilities could readily modify techniques and/or change species to target the most economically desirable product at any given time.

**Does this approach work?**

In 1995, the Oceanic Institute (OI) successfully completed a NMFS-funded project to develop commercial-scale hatchery and growout techniques for the dolphin fish or mahimahi (*Coryphaena hippurus*), a warm-water marine carnivore that inhabits pelagic, open-ocean regions within 20°C isotherms. This species is clearly one of the more difficult to master exhibiting very stringent environmental, physiological, and behavioral requirements.

Lessons learned during the phases of mahimahi research created a theoretical base for marine finfish culture in the western Pacific and set in motion the vision for the HFD project. It was envisioned that culture techniques for new species could be developed more rapidly if each was developed around a common technology. Confirmation was obtained when research was being conducted on the Pacific threadfin (*Polydactylus sexfils*), a surf-zone species indigenous to Hawaiian waters. Research with mahimahi established ways to address aggressive behavior and cannibalism in the nursery (Kim et al., 1993) and the importance of fishmeal quality in diet development (Ostrowski et al., 1996a). The techniques were applied to the Pacific threadfin, rapidly advancing hatchery technology of this species (Ostrowski et al., 1996b).

The most dramatic example that the approach was viable was in transfer of nursery techniques (Figure 1). In mahimahi culture, a shallow water raceway design was used to greatly improve weaning onto pelleted feeds and overall survival
during the nursery stage when juveniles (20-40 days of age) are highly aggressive. The shallow system coupled with high water current speeds and a better understanding of feeding rates provided lengthy contact time between pellets and fish to increase feeding opportunities, animation of pellets to induce strikes, and rapid swimming against the current to occupy and distract more aggressive individuals and provide a quick means of escape from attacks by change in direction. For Pacific threadfin, high cannibalism rates (yielding circa 50% survival) in the nursery was identified as a key technological constraint to mass culture development. The shallow raceway developed for mahimahi was applied as well as satiation feeding rates and high quality diets. In just a few trials, the survival rate increased dramatically to upwards of 95% in experimental testing. It was also found that the animals were more uniform in size.

Currently, nursery survival averages 85% for large scale production of Pacific threadfin at OI. Pacific threadfin is expected to be one of the major aquacultured species in Hawaii in the near future and is one of the best candidates for offshore demonstration tests in the region. It is a popular food fish in Hawaii and has been well received in vertical fish tasting events in Philadelphia and San Francisco (Deese, personal communication) that can be steamed whole or filleted. It is also
of a family of fishes popular in Asia (Wong 1995). Farmers in Hawaii receive approximately $6.00/lb in the round for 3/4 to 1 pound fish, which is achieved at 6-8 months of age. Techniques developed at OI have resulted in year-round egg production, survival rates of 25% from egg to larval, 85% from larval to stockable juvenile, and 95% in growout. Techniques have been developed for year-round spawning. Based on current seedstock production levels, commercial sales of this species in Hawaii will be 50% of the total finfish aquaculture production in the state by 1999.

Another nearshore species being investigated by the IFD project and an excellent offshore candidate is the bluefin trevally, Caranx melampygus, a reef inhabiting representative of the large jacks family (Figure 2). OI has cultured an F1 generation of this species and successfully grown them out. Using NMFS data for growth rates of the animals in the wild, it was determined that the cultured growth rate is approximately two times that in the wild. Market size is 500 grams and that can be reached at age 10-12 months. Sexual maturity is achieved earlier, but at a larger size than in the wild. It is a hardy species, adaptable to life in captivity, and amenable to

![Bluefin Trevally Growth Rate](image)

*Figure 2. Bluefin trevally growth rates.*
varied culture conditions. Flesh quality is high, particularly for raw (sashimi) product because of high levels of inter-muscular fat.

Year-round spawning has also been achieved with this species (Figure 3). Egg production is high therefore fewer broodstock are needed for commercial production. Current research shows that they are multiple spawners and release multiple clutches of eggs during a spawning period.

![Bluefin Trevally Maturation and Spawning](image)

*Figure 3. Bluefin trevally year-round spawning.*

The next species identified for development is the greater amberjack, *Seriola dumerili*, another member of the large jack family, but a more transitional zone species that also inhabits deeper waters (Figure 4). The same species exists in the Gulf of Mexico. *Seriola dumerili* is considered a good candidate for intensive aquaculture because of its rapid growth rate (García Gómez, 1993; Greco et al., 1993; Porrelo et al., 1993), high commercial value (Greco et al., 1993; Porrelo et al., 1993), adaptability to close confinesments (Miale et al., 1993), and handling tolerance (Greco et al., 1993). Greater amberjack is intensively cultured in sea cages and/or tanks in the Mediterranean (Greco et al., 1993; García Gómez, 1993; Grau
Greater amberjack growth and sexual maturation rates.

et al., 1993), Japan (Masuma et al., 1990; Tachihara et al., 1993), and Hong Kong (Wong 1995). However, hatchery production in one of the major stumbling blocks. Broodstock and hatchery techniques are currently being aggressively pursued in the Mediterranean (Grau et al., 1996), Japan (Tachihara et al., 1993) and Taiwan (Liao et al., 1995).

Work at OI has just begun on this species, but is showing promise. Greater amberjack grow as rapidly as mahimahi. In fact, mahimahi reach sexual maturity much earlier, so after a few months the growth rate of amberjack is actually better than a mixed population of mahimahi. Young juveniles captured in the wild have been fed on pelleted feeds at feed conversions of approximately 1:2. Vitellogenic eggs have been identified in females (6 kg) captured as young juveniles (circa. 20 gm) after less than two years in captivity. In Hawaii, commercial capture fisheries for both bluefin trevally and amberjack do not exist because of potential problems associated with ciguatera outbreaks in the region, and worms. Mariculture production of such species has clear potential.

Other species targeted, but yet to be investigated, are in the Etelinae subfamily of snappers. Snappers are considered a
high-value food fish in many parts of the world; however, culture has been confined to the subfamily Lutjaninae (i.e., *Lutjanus* sp.) (Pooley 1987; Wong 1995). Snapper (*Lutjanus argentimacula*, *L. malabaricus*, *L. russelli*, and *L. johni*) are cultured in China, Hong Kong, Malaysia, the Philippines, Singapore, and Taiwan (Anonymous 1995). In 1994, cultured snapper production totaled 4,379 metric tons, with an estimated value of $21,832,000 (FAO, 1996). Culture of *Lutjanus campechanus*, popular in the Gulf of Mexico, is currently being addressed in the United States for stock enhancement purposes. The Hawaiian subfamily has been heavily over-fished, leading to introduction of legislation to impose strict regulations and some area closures.

**Conclusion**

It is evident that the commercial fishing industry in the United States will be unable to supply the rising domestic demand for fish and fisheries products in the near future. Stable catches and area closures have placed limits on supply and access to traditional fishing grounds, while lowered catch per unit effort and increased operating costs have placed severe economic pressures on fishermen. Concern for the inevitable domestic supply problem and the potential for development of a robust offshore mariculture industry has created a rising interest in marine finfish hatchery technology. The Oceanic Institute is committed to development of a multi-species approach toward hatchery development for production of fingerlings for stock enhancement and commercial growout. Bluefin trevally, greater amberjack, and the Etelinae subfamily of snappers are targeted. There is also great potential to demonstrate and develop offshore systems in the islands. Hawaii offers optimum conditions for offshore aquaculture with stable water temperatures, nearshore steep ocean drop-offs, and a strategic market location close to Asia and the greater seafood eating communities.
References


