A Review of Nursery and Growout Culture Techniques for Marine Finfish in China

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Abstract

Mariculture in China has had a long history. In south China, for example, net cage culture of 20 high-value finfish species began in the late 1970s. They include seabream (Pagrus major), grouper (Epinephelus sp.), yellowtail (Seriola quinqueradiata) snapper (Lutjanus sp.) and pompano (Trachinotus blochii). With improved living standards for the Chinese people and rapid mariculture development of the finfish net cage culture, sale prices for live high-value marine fish have increased and advanced the industry’s standing in the aquatic products market. In 1985, there were about 3,000 net cages with an output of 200 tons. By 1993, the number of net cages in coastal areas of southern China surpassed 57,000. About 6,700 tons of seafood were produced at major culture sites located in Huiyang, Shenzhen, Zhuhai, Nanao and Yangjiang. This paper will present a brief review of the growout and nursery culture techniques for marine finfish, with emphasis on the net cage culture system.

Introduction

In China, marine fish are cultured in two types of culture systems: floating net cages and earthen ponds. Net cages are the primary culture method of high-value marine fishes, such as grouper (Epinephelus sp.), seabass (Lates calcarifer), seabream (Pagrus major), pompano (Trachinotus blochii), yellowtail (Seriola quinqueradiata) and snapper (Lutjanus sp.). Earthen ponds are used to culture seabream, grouper, mullet (Mugil sp.) and seabass.

Floating Net Cage System

Net cages are hung on wooden rafts and kept afloat with cylindrical plastic containers or styrofoam. The average net cage is 3 x 3 x 3 m, and depending on the size of the raft, 6-16 cages are secured together per raft. The cage unit is stabilized with a zinc-plated pipe and anchored to the bottom.

Criteria for selecting suitable marine species culture sites are as follows:

- Area should be protected from waves, currents and typhoons;
- Water depth should range from 5-10 m with a minimal depth of 4 m at low tide;
- Water circulation at the site should improve water quality;
- Water salinity should be stable at 27-33 ppt;
- Water temperatures should range from 15-30°C, with an optimal value of 20-28°C;
- Bottom composition should consist of silt and sand.

Stocking density of fish in net cages usually depends on the rate of water exchange and feed and management levels at any given site (Table 31).

Trash fish is the main food source for fish cultured in net cages. During the nursery stage,
Table 31. Fish stocking density in net cages.

<table>
<thead>
<tr>
<th>Species</th>
<th>Juvenile stage</th>
<th>Growout stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Size</td>
<td>Density (ind/m²)</td>
</tr>
<tr>
<td>Grouper</td>
<td>7-8 cm</td>
<td>600-800</td>
</tr>
<tr>
<td>Seabream</td>
<td>3-5 cm</td>
<td>200-300</td>
</tr>
<tr>
<td>Yellowtail</td>
<td>3-5 cm</td>
<td>800-1,000</td>
</tr>
<tr>
<td>Pompano</td>
<td>3-5 cm</td>
<td>1,000-1,200</td>
</tr>
<tr>
<td>Seabass</td>
<td>4-6 cm</td>
<td>1,000-1,200</td>
</tr>
</tbody>
</table>

Note: Net cage size is 3 x 3 x 3 m.

Table 32. Growth in body length for marine fishes in the coastal waters of Guangdong Province, China. (Unit: cm)

<table>
<thead>
<tr>
<th>Species</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red seabream</td>
<td>21</td>
<td>31</td>
<td>39</td>
</tr>
<tr>
<td>Black Porgy</td>
<td>16</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Flat bream</td>
<td>16</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Yellowfin seabream</td>
<td>17</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>Red grouper</td>
<td>16</td>
<td>24</td>
<td>30</td>
</tr>
</tbody>
</table>

fishermen feed the juveniles at least four times per day. Daily food intake gradually decreases as the fish gain weight. (Fig. 21)(You 1990).

During the adult stage, fish are fed twice a day, 0800-0900 and 1700-1800. During the April to November growing season, fish are fed 5-7% of their total body weight. In the winter and early spring the fish are fed once a day. The trash fish should be fresh, clean and chopped according to the fish's mouth size. Formulated feeds have been increasing in popularity.

During the nursery period, size grading should be conducted every 15 days to avoid cannibalism. At the same time, the net cages should be changed to prevent fouling organisms from clogging the mesh. The cages also should be checked for damage to insure that fish do not escape.

In southern China, it generally takes two years for seabream and one and one-half years for grouper to grow from the juvenile stage to marketable sizes. This coincides with their growth.

Figure 21. Daily feeding rate of red seabream in net cages.
pattern in the wild (Table 32) (Dong and Zhang 1992; Li et al. 1985, 1988, 1990; Li et al. in press). The food conversion ratio (FCR) is 7-8, and the survival rate is 50-60% under normal culture conditions (Table 33) (Yuan and Wong 1988).

**Earthen-Pond Culture System**

In addition to net cages, some farmers monoculture seahream and grouper in earthen ponds. Culture results are listed in Table 34 (Xu et al. 1987; Zhang 1988; Zhao et al. 1992).

Other commercial species, such as mullet and seabass, are polycultured with seahream in earthen ponds. Shrimp crops are also rotated with a second crop of seabass and yellowfin seahream (Zhang 1988). After acclimation, mullet and yellowfin seahream are suitable for rearing in hyposaline water. Stocking begins in February and March each year. Stocking density for mullet (TL 60-70 mm) is 4,500 individuals/ha. For yellowfin seahream (TL 50-70 mm) stocking density is 9,000 individuals/ha. Black porgy and flat bream also can be cultured with mullet in higher salinity conditions. Mullet is harvested in the winter with an output of 1,500-2,250 kg/ha. Seabream are cultured through the end of the following year.

The stocking density for seabass (TL 10 cm) is 6,000-12,000 individuals/ha; for seahream (TL

<table>
<thead>
<tr>
<th>Species</th>
<th>Stocking Density (ind/ha)</th>
<th>Initiative Weight (g)</th>
<th>Culture Period (months)</th>
<th>Harvest Weight (g)</th>
<th>Food Conversion Ratio</th>
<th>Output (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black porgy</td>
<td>19,200</td>
<td>47.2</td>
<td>(April-Oct.) 6</td>
<td>314</td>
<td>3.34</td>
<td>5,533</td>
</tr>
<tr>
<td>Red grouper</td>
<td>26,266</td>
<td>150.0</td>
<td>(June-Jan.) 7</td>
<td>276</td>
<td>--</td>
<td>5,800</td>
</tr>
<tr>
<td>Yellowfin seahream</td>
<td>10,500-12,000</td>
<td>6.9</td>
<td>18</td>
<td>250</td>
<td>12.5</td>
<td>2,250</td>
</tr>
</tbody>
</table>
10-12 cm) is 4,500-6,000 individuals/ha. Seabass are harvested just before winter.

Shrimp crops are rotated with seabass and seabream in coastal ponds where water salinity approaches 0 ppt during the rainy season. Chinese shrimp (Penaeus chinensis), which are tolerant of coldwater temperatures, are stocked as the first crop and harvested in the end of June. The second crop comprises of seabass and yellowfin seabream fingerlings, which are cultured from June through October.

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**Improvements In Culture Techniques**

**Nursery**

In the early stages of net cage culture, fishermen collect 1- to 2.5-cm fry from the wild and stock them for one to two months at a density of 2,000 individuals/net cage. Beyond the nursery period, juveniles are size graded and stocked into separate growout net cages. It has been recorded that in terms of growth, survival and economic results, hatchery-raised juveniles perform better than those stocked directly into cages.

**Culture Site Rotation**

In 1986, culture site rotation was implemented to increase fish survival rates and combat site pollution, which are the consequences of stationary culture sites. Floating rafts that support net cages are secured during typhoon season, after which they are transferred to areas of frequent water exchange.

**Changes from Monoculture to Polyculture**

Monoculture of marine fish shifted to polyculture in 1984. Today, except for L. calcarifer and E. tawina, most aquaculture species are polycultured in net cages. Rearing seabream in net cages with other species, for example, can improve culture results because seabream stimulate other fishes' feeding activity through active swimming, high food intake and omnivorous feeding behavior. Food costs are thereby reduced.

Other advantages of polyculture are described by Zhan and Su (1989). Under the same rearing conditions, individual grouper percent weight gain in net cage monoculture is 57.5% and total weight gain is 1.42 kg/m³. In net cage polyculture with black porgy the percent weight gain is 60.1% and total gain is 1.62 kg/m³. Net cage polyculture of grouper and red seabream is also conducted where the latter is the dominant species. Without increasing fresh or pellet feed amounts, grouper prey on the small fish that enter the net cage. As a result, net cage outputs increase from 4.65-4.96 kg/m³.

**Diet**

Since 1986, fishermen have used artificial and trash fish feed combinations because of trash fish shortages. Artificial feeds consist of peanut cakes, bean cakes, rice bran and corn grain. Protein levels in artificial feed are > 40%.

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**Net Cage Culture Diseases**

**Disease**

Prevention and control of fish disease and the procurement of high and stable fish yields are the primary areas of focus for fisheries development. According to 1985 statistical data, about 7,500 kg of fish died from disease in Guangdong Province, which accounted for 6% of the total net cage output in that year. In 1988, 50,000 kg of fish died, which accounted for 25% of the total output (Li and Ye 1989).

**Gill Rot**

The gill filament tips become dark red or black in the early stage of this disease. This is followed by hemorrhages, body rot and finally death. Control and treatment include immersion in 2 ppm of furazolidone for 15 minutes (Chen personal communication).
Table 35. Economic results of net cage culture.

<table>
<thead>
<tr>
<th>Species</th>
<th>Output  (Yuan/m³)</th>
<th>Cost  (Yuan/m³)</th>
<th>Net income (Yuan/m³)</th>
<th>Net income over output (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epinephelus achoara</td>
<td>489</td>
<td>186</td>
<td>312</td>
<td>62.7</td>
</tr>
<tr>
<td>E. tauvina</td>
<td>476</td>
<td>229</td>
<td>247</td>
<td>51.9</td>
</tr>
<tr>
<td>E. taro</td>
<td>349</td>
<td>274</td>
<td>187</td>
<td>53.6</td>
</tr>
<tr>
<td>E. awoara</td>
<td>181</td>
<td>103</td>
<td>79</td>
<td>43.6</td>
</tr>
<tr>
<td>Chrysophrys major</td>
<td>180</td>
<td>135</td>
<td>45</td>
<td>25.0</td>
</tr>
<tr>
<td>Rhabdosargus scaber</td>
<td>157</td>
<td>105</td>
<td>52</td>
<td>33.1</td>
</tr>
<tr>
<td>Sparus latus</td>
<td>140</td>
<td>83</td>
<td>58</td>
<td>41.1</td>
</tr>
<tr>
<td>S. macrocephalus</td>
<td>145</td>
<td>88</td>
<td>57</td>
<td>39.3</td>
</tr>
<tr>
<td>Seriola sp.</td>
<td>268</td>
<td>223</td>
<td>44</td>
<td>16.4</td>
</tr>
<tr>
<td>Trachinotus spp.</td>
<td>369</td>
<td>229</td>
<td>140</td>
<td>37.9</td>
</tr>
<tr>
<td>Latex calcarifer</td>
<td>316</td>
<td>174</td>
<td>142</td>
<td>44.9</td>
</tr>
</tbody>
</table>

(1 US$ = 8.43 Chinese Yuan - March 1995)

**White Spot**

This disease is caused by a ciliate. White spots are visible on the skin and fins of infected fish. Control and treatment include immersion in 5 to 8 ppm of potassium permanganate (K₂MnO₄) or bleaching powder for 2-3 minutes (Yao et al. 1989).

**Enteritis**

The intestine and stomach of infected fish become red and occasionally hemorrhaging and inflammation occur. Control and treatment include application of medicated feed for five to seven consecutive days. The dose is 20-25 mg antibiotic, or 100-200 mg sulfadiazine/kg body weight/day (Yao et al. 1989).

**Exophthalmus**

Caused by fungi, the infected fish suffer from an enlarged pupil in the early stage of disease, followed by eye protrusion, hemorrhaging and in severe cases, even separation of the eyes from the body. Control and treatment include application of medicated feed for five to seven consecutive days. The dose is 100-200 mg sulfadiazine/kg of feed, or 20-50 mg antibiotic/kg body weight (Yuan and Wong 1988).

**Parasites**

Certain species of copepods often parasitize the gills or skin, causing gill rot or gill filament blockage. Finally, the infected fish die of asphyxiation. Control and treatment include immersion in 20 ppm copper sulfate (CuSO₄5H₂O) solution for 10 minutes (Chen et al. in press).

**Net Cage Culture Economics**

Although production costs, which include operating and fixed costs, are fairly high, net cage culture of high-value marine finfish in China has proven to be an economically profitable industry. According to the data from Huiyang County, 137 tons of seafood were harvested from 828 net cages in 1987, earning 6.85 million yuan (US$2.13 million [1986]) with a net income of 3.77 million yuan. The ratio of income over total output is 55%. Table 35 compares the economical results of net cage culture (Yuan and Wong 1988).
Industry Constraints

Fry

Fry for culture are usually obtained from the wild; however, their availability from natural collecting grounds is inconsistent and unpredictable.

Feed

Marine finfish culture primarily depends on trash fish availability for feed stuffs. An insufficient feed supply is one problem that hampers industry development.

Culture Techniques

To increase industry success and profits, more information is needed about efficient culture techniques, hatchery seedstock, artificial feed production and disease control.

Conclusion

High-value finfish culture is a newly established industry in China that has the advantage over traditional mariculture because it can be done in shallow coastal waters, requires little capital investment, is easily managed, and has high output and shortened production cycles. Recently, a number of government projects have been conducted by universities, institutes and fishery stations, which aim to resolve culture problems, tap potential production yields and minimize production costs. Culture technique improvements and domestic market developments will further promote finfish mariculture.

Acknowledgments

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Literature Cited


A Review of the Nursery and Growout Techniques of High-Value Marine Finishes in Taiwan

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Abstract

Currently, there are more than 30 marine finfish species under cultivation in Taiwan. Most species are cultured in ponds, but a few are cultured in cages. In most species, grading for size uniformity is necessary after the hatchery and nursery stages. In some carnivorous species, such as grouper and Asian seabass (Lates calcarifer), grading during the nursery stage is necessary because of serious (Epinephelus sp.) cannibalistic behavior. Marine finfish feeds include formulated moist pellets, dry floating and sinking pellets, and raw trash fish. Maintaining a suitable green water transparency (Chlorella spp.) is an important pond management strategy. Total pond production per hectare per crop typically ranges from 10-30 tons depending on species, pond size and facilities, water sources and farmers' production techniques. High mortality rates observed in marine finfish culture have been attributed to protozoan infections such as Amyloodinium ocellatum, Cryptocaryon irritans and Trichodina sp. General nursery and growout techniques used in Taiwan are reviewed, as well as the culture and related problems of high-value marine finishes, such as grouper, Asian seabass, red snapper (Lutjanus argentimaculatus) and pompano (Trachinotus blochii).

Introduction

Despite a long history in Taiwan, marine finfish culture activities were limited during the early years to traditional polyculture species, such as milkfish (Chanos chanos), grey mullet (Mugil cephalus), Asian seabass (Lates calcarifer) and Japanese seabass (Lateolabrax japonicus) (Cheng and Huang 1976; Liao 1993). However, following the 1988 prawn industry mortality crisis, this situation began to change. Additionally, coastal marine fisheries resources and wild fry were being seriously depleted by estuarine pollution and overfishing. Hundreds of prawn hatcheries and growout ponds were either abandoned or converted for other types of culture. Consequently, marine finfish fetched high prices on the market, which stimulated the development of marine finfish culture in Taiwan.

Because the demand for marine finfish seedstock was high, prawn fry producers and farmers used their experience to become involved in marine finfish fry production. Successful mass fry production of marine finishes gave the Taiwanese aquaculture industry a much needed boost, especially after the downturn brought about by the depressed prawn industry. However, after five years of rapid industry development, the price of most cultured marine species declined because of overproduction. Because of strong competition among hatchery operators, marine finfish with high culture potential were being exploited to meet the consumers' demands and preferences. Currently, there are
Table 36. Principal cultured marine finfish species in Taiwan.

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Culture Status</th>
<th>Culture System</th>
<th>Culture Type</th>
<th>Water Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthopagrus latus</td>
<td>Yellow-fin seabream</td>
<td>WE</td>
<td>I</td>
<td>P</td>
<td>B or F</td>
</tr>
<tr>
<td>A. schlegel</td>
<td>Black porgy</td>
<td>WE</td>
<td>I</td>
<td>P</td>
<td>B</td>
</tr>
<tr>
<td>A. sivicolus</td>
<td>Southern black seabream</td>
<td>WE</td>
<td>I</td>
<td>P</td>
<td>B</td>
</tr>
<tr>
<td>Boleophthalmus pectinirostris</td>
<td>Mudskipper</td>
<td>WE</td>
<td>E</td>
<td>P</td>
<td>B</td>
</tr>
<tr>
<td>Chanos chanos</td>
<td>Milkfish</td>
<td>WE</td>
<td>I or E</td>
<td>P</td>
<td>B or F</td>
</tr>
<tr>
<td>Epinephelus malabaricus</td>
<td>Malabar rockcod</td>
<td>WE</td>
<td>I</td>
<td>P or C</td>
<td>FS or B</td>
</tr>
<tr>
<td>E. coloides</td>
<td>Red spotted grouper</td>
<td>WE</td>
<td>I</td>
<td>P or C</td>
<td>FS or B</td>
</tr>
<tr>
<td>E. tauvina</td>
<td>Estuary grouper</td>
<td>WE</td>
<td>I</td>
<td>P or C</td>
<td>FS or B</td>
</tr>
<tr>
<td>Glossogobius glutis</td>
<td>Flathead goby</td>
<td>D</td>
<td>I or Pl</td>
<td>P</td>
<td>F or B</td>
</tr>
<tr>
<td>Lateolabrax japonicus</td>
<td>Japanese seabass</td>
<td>WE</td>
<td>I or Pl</td>
<td>P</td>
<td>F or B</td>
</tr>
<tr>
<td>Lates calcarifer</td>
<td>Asian seabass</td>
<td>WE</td>
<td>I or Pl</td>
<td>P</td>
<td>F or B</td>
</tr>
<tr>
<td>Lethrinus nebulosus</td>
<td>Blue emperor</td>
<td>D</td>
<td>I</td>
<td>C or P</td>
<td>FS or B</td>
</tr>
<tr>
<td>Liza macrolepis</td>
<td>Large scale liza</td>
<td>WE</td>
<td>Pl or I</td>
<td>P</td>
<td>F or B</td>
</tr>
<tr>
<td>Lutjanus argentimaculatus</td>
<td>Red snapper</td>
<td>WE</td>
<td>I</td>
<td>P or C</td>
<td>B or FS</td>
</tr>
</tbody>
</table>

Culture status: D: Developing; WE: Well established; Culture system: E: Extensive culture; I: Intensive culture; Pl: Polyculture; Culture type: P: Pond culture; C: Cage culture; Water source: FS: Full seawater; B: Brackish water; F: Freshwater

more than 30 marine finfish species under cultivation in Taiwan (Table 36).

Due to distinct environmental conditions, some regions in Taiwan are being developed for specialty species. For instance, Yeong-An Village in southwestern Taiwan is known for its full seawater culture of grouper (Epinephelus spp.) because the village lacks underground brackish water. In addition, the culture system and market for Asian and Japanese seabass are unique in southern and northern Taiwan, respectively, due to water temperature requirements of the species.
Table 36. (continued). Principal cultured marine finfish species in Taiwan.

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Culture Status</th>
<th>Culture System</th>
<th>Culture Type</th>
<th>Water Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mugil cephalus</td>
<td>Grey mullet</td>
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<td>I or PI</td>
<td>P</td>
<td>B or FS</td>
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<tr>
<td>Nibea japonica</td>
<td>Grey croaker</td>
<td>WE</td>
<td>I</td>
<td>P</td>
<td>B or FS</td>
</tr>
<tr>
<td>Pagrus major</td>
<td>Red seabream</td>
<td>WE</td>
<td>I</td>
<td>C</td>
<td>FS</td>
</tr>
<tr>
<td>Platx arcticaris</td>
<td>Round batfish</td>
<td>D</td>
<td>I</td>
<td>C or P</td>
<td>FS or B</td>
</tr>
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<td>Plectomychnus cinctus</td>
<td>Yellow-spotted grunt</td>
<td>D</td>
<td>I</td>
<td>P or C</td>
<td>B or FS</td>
</tr>
<tr>
<td>Plectropomus leopardus</td>
<td>Blue-spotted grouper</td>
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<td>I</td>
<td>C</td>
<td>FS</td>
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<tr>
<td>Polydactylus plebeus</td>
<td>Striped threadfin</td>
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<td>I</td>
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<td>B or FS</td>
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<tr>
<td>Pomadasys hastas</td>
<td>Silver grunt</td>
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<td>I</td>
<td>P</td>
<td>B or FS</td>
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<td>Rachycentron canadum</td>
<td>Cobia</td>
<td>D</td>
<td>I</td>
<td>C</td>
<td>FS</td>
</tr>
<tr>
<td>Scatophagus argus</td>
<td>Spotted butterfish</td>
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<td>I or PI</td>
<td>P</td>
<td>B</td>
</tr>
<tr>
<td>Sciaenops ocellatus</td>
<td>Red drum</td>
<td>D</td>
<td>I</td>
<td>P</td>
<td>B or FS</td>
</tr>
<tr>
<td>Seriola dumeri</td>
<td>Greater yellowtail</td>
<td>D</td>
<td>I</td>
<td>C</td>
<td>FS</td>
</tr>
<tr>
<td>Siganus guttatus</td>
<td>Golden spinefoot</td>
<td>D</td>
<td>PI</td>
<td>P or C</td>
<td>FS</td>
</tr>
<tr>
<td>Siganus fuscescens</td>
<td>Doctor fish</td>
<td>WE</td>
<td>I</td>
<td>P</td>
<td>FS or B</td>
</tr>
<tr>
<td>Sparus sarba</td>
<td>Gold-lined seabream</td>
<td>WE</td>
<td>I</td>
<td>P</td>
<td>FS or B</td>
</tr>
<tr>
<td>Takifugu rubripes</td>
<td>Tiger puffer</td>
<td>D</td>
<td>I</td>
<td>P</td>
<td>FS or B</td>
</tr>
<tr>
<td>Terapon jarbua</td>
<td>Three-striped tigerfish</td>
<td>D</td>
<td>I</td>
<td>P</td>
<td>B or FS</td>
</tr>
<tr>
<td>Trachinotus blochii</td>
<td>Pompano</td>
<td>WE</td>
<td>I</td>
<td>P</td>
<td>B or FS</td>
</tr>
</tbody>
</table>

**Culture status:** D: Developing; WE: Well established; **Culture system:** E: Extensive culture; I: Intensive culture; Pl: Polyculture; **Culture type:** P: Pond culture; C: Cage culture; **Water source:** FS: Full seawater; B: Brackish water; F: Freshwater
Cage culture is not well developed in Taiwan because of seasonal typhoons and lack of protected coastal bays. Only a few cage farms are located in the inland sea bays of Dapong, Sheau-Ryukyu island and the Penghu archipelago and near the coastlines of Zhukeng, which surrounds southwestern Taiwan. Thus, pond culture is the main type of marine finfish culture in Taiwan. The management of pond culture for marine finfish is quite different from cage culture. In this paper, the pond culture of high-value marine finfish species in Taiwan is discussed.

Nursery

- Advantages

Controlling cannibalistic behavior

Cannibalistic fishes, such as grouper and Asian seabass, are primarily size graded during the nursery stages because their behavior would otherwise result in high mortality.

Shortening of the culture period during growout stage

In Taiwan, intensively cultured ponds are utilized for no more than a year without being cleaned and dried. Harvesting is usually done before April because the occasional warm southerly winds between April and July tend to release toxic pond sediments and decrease dissolved oxygen levels. High mortality usually occurs during this period. To appropriately time the nursery stage during the winter, juveniles are stocked in the spring and harvested before the next spring.

Seasonal regulations concerning the price of fry and overwintering

The breeding season for most local marine finfish starts either in March or April, thus mass fry production can only be conducted in May or June. If local fry are stocked, most will not be harvested before winter. Overwintering of cultured fishes will increase production costs because low water temperatures will result in retarded growth and greater disease risks. Although growth performance is poor during overwintering, fingerlings can be sold at higher prices during the spring of the following year. Fry, such as grouper and Asian seabass, therefore, are imported from southeast Asian countries during the autumn and winter seasons because of higher spring prices. Some locally-produced fry, such as pompano (Trachinotus blochii) and red snapper (Lutjanus argentimaculatus) are also cultured throughout the winter because of better spring prices.

Convenience during harvesting

Grading can be undertaken during the nursery stage to ensure uniform-sized fingerlings at harvest. This provides for an easier and more convenient harvest. Uniform body weight of cultured fish also insures better production during growout. Otherwise, additional culture time should be undertaken for fish with retarded growth.

- Ponds

Nursery ponds range in size from several square meters to several thousand square meters, depending on the species. Smaller ponds, usually used for carnivorous species, provide convenience during grading. If grading is necessary during the nursery stage, fry can be held in cages that are suspended in larger ponds.

- Grading

Growth rate disparity is usually found among individuals of a species. Within the same batch of offspring a small percentage of the population may grow very fast and eventually develop into giant fry. These individuals usually show vicious cannibalistic behavior and prey on smaller individuals. Cannibalism occasionally leads to mortalities in both prey and predators because the cannibals can choke to death on their prey. Growth disparity can be attributed to genetic differences and different feeding rates. Thus, grading after the hatchery and nursery stages is essential for higher survival rates, consistent growth rates, facilitation of convenient harvesting and increased production during growout.
Grading apparatus is primarily constructed of stainless wire of different mesh sizes to accommodate different fry sizes. Fry are placed on the grading apparatus, and with a slight upward and downward motion, smaller fry escape through the holes while the larger fry are retained. Fry are then assigned to different ponds according to size.

Fish can be injured from catching and handling stress during grading, which often leads to decreased disease resistance and increased mortality. Drug treatment before or after grading is needed, and methylene blue, furazolidone or formalin are commonly used as prophylactic treatments.

During the winter, grading is harmful to warm-water fish species. To avoid abrupt changes in water quality that can result in the loss of body mucus, which protects the fish from diseases, the fish should not be placed in newly pumped underground water after handling and grading. Using well-aerated water or adding some green water to the fish pond is beneficial to fish health.

Growout

- **Ponds and Growout Facilities**

  For intensive culture of marine finfish, suitable pond sizes range from 1,000 to 5,000 m²—2,000 m² is the recommended size. There are several disadvantages to a big fish pond, such as poor water exchange, and harvest and drug treatment difficulties. At least one water paddle-wheel is established every 1,000-2,000 m². Both sand and earthen substrates are suitable for marine finfish culture. However, earthen pond bottoms tend to stabilize the green algae (*Chlorella* spp.) population.

- **Stocking Density and Production**

  Stocking densities vary depending on the species, culture period, pond size, water source and farmers' experience. For example, pompano are stocked at 20,000 fish/ha and doctor fish (*Siganus fuscescens*) at 150,000 fish/ha. If the pond is larger than 5,000 m², the stocking density should be reduced to compensate for poor water exchange. Fish are easily infected by parasites or other diseases at high stocking densities; infections may reoccur even after the fish have recovered from disease. Total production per hectare per crop of cultured marine finfish is often higher than prawn culture. This is because fish are distributed throughout the water column and shrimps are confined to the bottom. If diseases are controlled in marine finfish culture, production per hectare per crop ranges from 10-30 tons.

- **Pond Management**

  For sanitation purposes fish ponds should be dried, tiled, poisoned and limed before stocking. Some farmers even replace the deteriorated earthen bottom after long periods of culture. To assure greater survival rates during stocking, some farmers stock hatchery fry samples in cages for two to three days. If the test fry survive and continue to feed, stock fry are brought in for production.

  Sedentary fish, such as grouper, initially scatter and then remain at a particular place after stocking, which can become a problem during feeding. To prevent this, the seedstock can be restricted to a section of the pond with a net enclosure or shelter. After the fishes have acclimated to feeding in a designated location, the net enclosure or shelter can be removed. Grouping during feeding leads to uniform growth, which is beneficial at harvest.

  Maintaining suitable green water (*Chlorella* spp.) transparency is an important pond management strategy for marine finfish culture. Dense diatom blooms during the summer are harmful to the fish and tend to depress the fish's appetite. Bubble diseases are occasionally diagnosed in diatom bloom environments, which are caused by high water temperatures and strong sunlight. Small fish tend to be more susceptible to bubble disease infection than larger fish because diatoms with long cell chains and spines clog gills and impede respi-
Table 37. Common feeds for grouper (Epinephelus spp.), Asian seabass (Lates calcarifer), red snapper (Lutjanus argentimaculatus) and pompano (Trachinotus blochii) during growout.

<table>
<thead>
<tr>
<th>Species</th>
<th>Moist Pellet Feed</th>
<th>Dry Floating Pellet</th>
<th>Dry Sinking Pellet</th>
<th>Raw Trash Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grouper</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Asian seabass</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Red snapper</td>
<td>-</td>
<td>+</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>Pompano</td>
<td>-</td>
<td>+</td>
<td>++</td>
<td>-</td>
</tr>
</tbody>
</table>

++: widely used; +: Used; -: Not used

Table 38. Ingredients, percentages and chemical composition of typical formulated feeds for marine fish (Yuan-Yih Feed Manufacturing, Inc.).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Quantity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish meal</td>
<td>70</td>
</tr>
<tr>
<td>Bio-flour</td>
<td>2</td>
</tr>
<tr>
<td>Toploca starch</td>
<td>23</td>
</tr>
<tr>
<td>Vitamin pre-mix</td>
<td>1</td>
</tr>
<tr>
<td>Mineral pre-mix</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>3</td>
</tr>
<tr>
<td>Chemical Analysis</td>
<td></td>
</tr>
<tr>
<td>Crude protein</td>
<td>40-47</td>
</tr>
<tr>
<td>Crude fat</td>
<td>7</td>
</tr>
<tr>
<td>Ash</td>
<td>15</td>
</tr>
<tr>
<td>Moisture</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

Feeds

Marine finfish nutrition studies in Taiwan have been reviewed by Chen and Liao (1991). The feeds commonly used for marine finfish culture are summarized in Table 37. Percentage of ingredients and chemical composition of a typical formulated feed for marine finfish are listed in Table 38.

- Formulated Moist Pellet Feeds

Moist pellet feed use has increased in marine finfish culture because of improved sanitation and convenient mixing with vitamin pre-mixes and fish oils. Moist pellet feeds are prepared by mixing 20 kg of dry powder feeds with 9 liters of water, 0.8-1 liter of fish oil, some digester, and vitamin pre-mix. The mixed feeds are processed in a pelletizer, which produces different sized pellets by changing the sieve size.

Some fish farmers prepare the formulated feed meal into dough (similar to eel culture), and throw it into the pond. Trays are then checked to determine if the dough was fed upon. A disadvantage of this feeding method is that the dough tends to dissolve in water. Some marine fishes, such as southern black seabream (Acanthopagrus sivicolus) and gold-lined seabream (Sparus sarba) are still fed using this method because of their bottom dwelling and some-
what suspicious feeding behavior. Besides specialized feeds for marine finfishes, eel feeds are successfully used for marine finfish cultured in freshwater or low saline (3-5 ppt) water.

- **Dry Pellet Feeds**

Dry pellet feeds include floating and sinking pellets. All cultured marine finfish, except the grouper, can now be successfully acclimated to pellets. Both types can be supplied by an auto-feeder, but for actively feeding species, floating feeds can also be fed directly into the fish pond. Providing dry pellets for marine finfish is the most convenient way of feeding. However, when dry pellet use first began in Taiwan, some nutrient deficiency diseases were found in Asian and Japanese seawasses. The diseases had been attributed to malnutrition or acidization of fish meals. Nutrient deficiencies can lead to lockjaw, especially after handling. Surviving fish with lockjaw will be retarded and stunted and will lose their market value. High mortality may also occur.

- **Raw Trash Fish**

Raw trash fish is primarily used for marine finfish culture; however, there are several disadvantages to this diet. Farmers have experienced supply storages, high labor and preparation costs, and problems with freshness and supplies. Trash fish may also introduce diseases to the fish pond. Thus, some farmers have gradually shifted from trash fish feeds to moist pellets. Based on farmers’ experience, however, cultured fishes are more tolerant to handling when fed trash fish.

**Disease Control**

High marine finfish mortality in ponds is usually caused by protozoans, such as *Amyloodinium ocellatum*, *Cryptocaryon irritans* and *Trichodina* spp. In autumn, when the water temperature drops to 20-25°C and abrupt water temperature fluctuations occur, protozoan parasites seriously infest cultured marine fish. Mortality caused by *A. ocellatum* is very serious because almost all the fish die within a few days. Other parasites, such as *Caligus* sp., *Piscicola* sp. and some diseases caused by unknown factors, have also been found.

Cultured marine finfish diseases occasionally occur a few days after a rainfall. Such occurrences can be attributed to acidic rainwater, which can lead to a change in water quality and the collapse of algal communities. Microorganisms can also propagate rapidly after rainfall. Thus, disinfection is needed.

- **Grouper**

Grouper diseases in the nursery include swim bladder inflation, white spot disease and whirling disease. Swim bladder inflation syndrome, which occurs during metamorphosis, is the primary limiting factor of fry production. Deficiency of highly unsaturated fatty acids (HUFA) may be the reason for swim bladder inflation disease. Unknown factors cause high mortality of fish between total length of 3-4 cm. Pre-mortality syndromes include darkened body color, activity and appetite loss and behaviors, such as facing the pond wall and settling at the bottom with temporary swimming activity.

The predominant growout disease of grouper is white spot disease (*C. irritans*), which causes high mortalities every autumn (Chang 1994; Chao and Chung 1994). The dermis tissue is destroyed by the white spot protozoa. The appetite of infected fish is depressed, and sick fish float to the water surface with an opened gill operculum. The fish also swim slowly against the paddlewheel-produced water current. In the early stages of infection, the fish can be treated with 30-ppm formalin and 0.35-ppm copper sulfate. One method of curing white spot disease is to transfer infected fish to another pond during the warm season.

The fish leech parasite (*Piscicola* sp.) also commonly infects grouper. Although the parasite does not cause mortality, infected fish lose their appetite and marketable appearance. According to farmers’ experience, fish leech infection
can be reduced or avoided by stocking shrimp and grouper together in the pond.

- **Asian Seabass**

  The *Trichodina* sp. parasite commonly appears during the nursery and growout stages of Asian seabass. Formalin (30 ppm) and copper sulfate (0.35 ppm) are used to treat *Trichodina* sp. infections. Serious outbreaks often occur in areas where many Asian seabass nursery farms are situated in close proximity.

- **Red Snapper**

  In red snapper culture, nursery and growout mortality may be caused by *A. ocellatum* and *Trichodina* sp. Dense diatom or dinoflagellate blooms can cause bubble disease, impede gill function and even lead to high mortality.

- **Pompano**

  *A. ocellatum* causes high mortality in most cultured marine finfish, especially pompano. Infected fish gradually cease feeding and die within a few days. Pompano mortality occasionally occurs concurrently with diatom blooms. The long-chain spined diatom species suffocates the fish with long, dense gill filaments.

**Harvesting, Transportation and Marketing**

Market-sized cultured marine finfish range from 400 to 600 g for panfish and from 600 to 1,000 g for recreational fishing ponds. The fish should be starved one to two days before harvesting and then caught by two or three persons with a seine net. Fish are drawn to the edge of the pond with the seine and held in one or more cages. Fresh water is then pumped into the pond. A water paddlewheel, which faces the cage, may also be used.

After grading and weighing, the fish are transferred to a 2 x 1 x 1 m live fish holding tank in a truck. Maximum loading weight per tank is 300 kg and 1.2 tons per truck (9 tons). The water temperature must be decreased to 20-22°C before transportation, and oxygen is gradually supplied to the holding tank. Fish destined for recreational fishing ponds are usually harvested in the daytime. Fish destined for the common market are harvested at midnight and held for the wholesale live fish markets that open at 0300 each morning.

### High-Value Marine Finfishes in Taiwan

#### Grouper

- **Overview**

  In Taiwan, grouper cage culture is normally practiced in the Penghu Archipelago, where wild fry have been caught since 1975 (Yen 1988; Yen and Lin 1988). It can be said that grouper culture first prospered in 1988 when pond culture techniques were developed in Yeong-An Village. In this village, underground brackish water quality is poor. Thus, the only recourse is to pump seawater directly from the seashores. Grouper is the best choice for pond culture because, so far, no other marine finfish have been satisfactorily grown in full seawater. As the profitability of grouper culture became evident, more and more farmers began cultivating them and now Yeong-Ann Village is well known for its grouper culture.

The main grouper species cultured in Taiwan are *E. coioides*, *E. malabaricus* and *E. taupina* (Chang 1991; Chi 1993; Huang et al. 1994; Mo 1994). Fry sources are both reared in local hatcheries and imported from Southeast Asian countries, such as Thailand, the Philippines and Sri Lanka. Hatchery-reared fry are preferred by farmers and command a much higher price. Survival rates of imported wild fry are often poor due to mixing with several unidentified species, undomesticated behavior leading to uneven growth, and poor disease resistance. *E. malabaricus* is the best species for pond culture, but egg production of *E. malabaricus* is more difficult than *E. coioides*. Despite a similar growth rate before 600 g, *E. coioides* is more active and sensitive to harvest stress. The spe-
cies easily loses its bright appearance after harvest due to individual fish bashing each other, which leads to mucus and scale loss. Additionally, red lesions form, which consumers find unappealing. During the winter, there is little difference in harvests between the two species. Such disadvantages can be avoided because lower water temperatures decrease the activity of E. coioides.

Depending on the water temperature (27-30°C) and culture system, it takes 30-45 days from hatching for grouper to reach metamorphosis. The mean body weight of hatchery-harvested E. coioides fry is about 0.38 g (42 days old, 28-29°C). Most of them are semi-transparent with a light reddish color. At an approximate size of 3.2-3.3 cm total length, the body color turns from semi-transparent to a dark brown protective coloration.

**Culture Systems**

There are two types of pond systems for the grouper nursery period: small pond (or small captivity) and big pond systems.

The small pond system has ponds within 100 m² in size. To maintain regular grading, small cages (1.2 x 0.8 x 0.8 m) or various sized hapas can be suspended in the bigger ponds. Uniform small cages are made of plastic net and are the more popular selection for the grouper nursery. Maximum stocking density per cage is 2,000 fingerlings at a total length of 6 cm. The advantage of a small cage is its convenience in grading and handling.

The big pond system is usually used during the winter since handling in low water temperatures is harmful to the juveniles. The price of imported wild fry is cheaper (US$0.2-0.4/fish, 2-2.5 cm TL) during autumn and winter than during the early spring. In spring, juvenile (6-9 cm) prices are higher (US$2-3/fish). Thus, due to lower year-end fry costs, some farmers use the big pond system where these kinds of imported grouper fry are stocked for growout. Before stocking the fry, small shrimp (*Palaemon* spp.) are stocked as prey for grouper fry. Chopped, small trash shrimps and fishes are also supplied as supplementary feed. Results are quite inconsistent. Pond management strategies in this kind of grouper nursery include keeping pond bottoms smooth to prevent fry from grouping in caverns, which leads to cannibalism.

**Feeds**

- **Nursery**

Grouper fry feeds include adult *Artemia*, small shrimp (*Aequipecten chinensis*), small goby (*Gobiidae*) and *Gambusia* spp. The feed conversion ratios of various *E. malabaricus* fingerlings prey or feeds are listed in Table 39. Despite the feed conversion rate of small shrimp being high (high water content in the body), there are sufficient year-round supplies, so it is a popular feed for grouper fry. Grouper are fed to satiation to prevent cannibalism. Fry are fed four to six times a day at the beginning of stocking, and when they reach about 6 cm, feeding is gradually reduced to twice a day. It takes about one and one-half months during the summer at 26°C and three months during the winter at 20-24°C for 80% of the fingerlings to reach 6 cm. Continuous grading at five- to seven-day intervals is necessary during the nursery stage.

<table>
<thead>
<tr>
<th>Kinds of Feeds</th>
<th>Feed Conversion Ratio (FCR)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aequipecten chinensis</em> (Wet)</td>
<td>3.6:1</td>
</tr>
<tr>
<td><em>O. mossambicus</em> fry (Wet)</td>
<td>2.9:1</td>
</tr>
<tr>
<td><em>Palaemon</em> spp. (Wet)</td>
<td>2.7:1</td>
</tr>
<tr>
<td><em>Aplocheilus jatipes</em> (Wet)</td>
<td>2.2:1</td>
</tr>
<tr>
<td>Eel feeds (Dry)</td>
<td>0.8:1</td>
</tr>
</tbody>
</table>

Table 39. The conversion ratio of various feeds for grouper (*Epinephelus malabaricus*) fingerling (body weight: 3.4-14 g) [S. L. Chang 1990 unpublished data].
Table 40. Feed conversion ratio of grouper (Epinephelus spp.), Asian seabass (Lates calcarifer), red snapper (Lutjanus argentimaculatus) and pompano (Trachinotus blochii) (Hanaqua International Corp. and aquafarmers).

<table>
<thead>
<tr>
<th>Species</th>
<th>Feeds</th>
<th>Feed Conversion Ratio (FCR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grouper</td>
<td>Trash fish</td>
<td>4:5:1</td>
</tr>
<tr>
<td></td>
<td>Moist pellet</td>
<td>1.2-1.4:1</td>
</tr>
<tr>
<td>Asian seabass</td>
<td>Trash fish</td>
<td>4:5:1</td>
</tr>
<tr>
<td></td>
<td>Moist pellet</td>
<td>1.2-1.4:1</td>
</tr>
<tr>
<td>Red snapper</td>
<td>Trash fish</td>
<td>7:9:1</td>
</tr>
<tr>
<td></td>
<td>Moist pellet</td>
<td>2.2-2.5:1</td>
</tr>
<tr>
<td>Pompano</td>
<td>Dry pellet</td>
<td>1.6-2.0:1</td>
</tr>
</tbody>
</table>

Grouper culture procedures in Taiwan are shown in Figure 22.

- Growout
  Trash fish are primarily fed to grouper during growout stages. But recently, moist pellet feed has become more popular. Fish are fed twice a day at the beginning of stocking, but once their body weight reaches 200 g or more, feeding is dropped to once a day. In the winter, feed is supplied every other day before sunset; in other seasons, feed is supplied every morning. The feed conversion rates for grouper are listed in Table 40. The feed conversion efficiency of grouper is good because it is a less active fish.

The stocking density and production per hectare for one crop of grouper are listed in Table 41. Grouper with a total length of 6 cm are suitable for stocking in growout ponds. Culture periods in ponds (10-14 months) are longer than in cage culture (8-10 months) due to low water temperatures in winter. In addition, there are unstable environmental conditions in ponds such as algal blooms, rain and drug treatment for diseases, which sometimes decrease the fish’s appetite. Concomitant to growth, numerous caverns will be formed by the grouper. The catch rate during harvest is low due to the caverns on the pond bottom.

![Figure 22. Grouper (Epinephelus spp.) culture procedure in Taiwan.](image)
Table 41. Stocking density and production rates for grouper (Epinephelus spp.), Asian seabass (Lates calcarifer), red snapper (Lutjanus argentimaculatus) and pompano (Trachinotus blochii) in Taiwan (pond culture with intensive system).

<table>
<thead>
<tr>
<th>Species</th>
<th>Stocking Density (fish/m²)</th>
<th>Culture Period (months)</th>
<th>Best Market Size (g)</th>
<th>Production (tons/crop/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grouper</td>
<td>2-7</td>
<td>10-14</td>
<td>400-800</td>
<td>10-30</td>
</tr>
<tr>
<td>Asian seabass</td>
<td>3-5</td>
<td>5-7</td>
<td>400-600</td>
<td>15-20</td>
</tr>
<tr>
<td>Red snapper</td>
<td>3-5</td>
<td>12-18</td>
<td>400-1,000*</td>
<td>15-20</td>
</tr>
<tr>
<td>Pompano</td>
<td>2-3</td>
<td>7-12</td>
<td>400-600</td>
<td>10-15</td>
</tr>
</tbody>
</table>

* The larger sizes are sold for recreational fishing ponds.

Asian Seabass

- **Overview**

Taiwan imports from 16- to 18-day-old larvae from Thailand, where the larvae have been successfully produced. High mortality, however, due to grading stress, disease infection, malnutrition and cannibalism, usually occurs during the nursery stage. The Asian seabass nursery stage is, therefore, a critical culture period.

The Asian seabass breeding season in Taiwan is from May to July. Because local fry production cannot meet growout demands, fingerling prices are higher in the early spring. Thus, many larvae (16-18 days old and 8-10 mm in TL; US$0.012-0.023/fish) are imported from Thailand. Imported larvae are gradually acclimated to low salinity (3-10 ppt) or freshwater within one day. Depending on size, *Artemia* nauplii, *Moina* sp. or *Daphnia* sp. are fed to the fry. Some farmers specialize in freshwater zooplankton production. The price of the zooplankton is US$1.2-1.4/kg wet weight.

Stocking densities for Asian seabass production are shown in Table 41. During the summer, fish attain a market size of 400-600 g in five to seven months. The production per hectare per crop is about 15-20 tons. Asian seabass cultured in saline water is preferred by consumers and fish brokers because the fish are dark and retain their color even after death. When cultured in freshwater, the body color is pale and the meat is soft.

- **Nutrition and Feeds**

From a total length of 3 cm or greater, Asian seabass fry can be fed minced small shrimps (*Acetes chinensis*) and can be acclimated at 4-6 cm to moist pellet feed. Six-centimeter fry can be sold to growout farmers. High mortality of fingerlings occurs occasionally due to an unsaturated fatty acid deficiency and the non-enrichment of *Artemia* nauplii during metamorphosis (Dhert et al. 1990). Such syndromes are controlled by feeding *Moina* sp.

Commonly used feeds during Asian seabass growout are shown in Table 37. The moist pellet feeds are popular because minced trash fish can be mixed with supplements to enhance fish growth. Asian seabass can also be acclimated to floating pellets. However, fish fed floating pellets grow slower than those fed moist pellets and trash fish. Growth disparity will increase as dry pellets are supplied. The feed conversion rate is about 1.2-1.4 for moist pellet feed (Table 40). Feeding rates decrease during the winter when water temperatures drop below 24°C.
- Grading
In the Asian seabass nursery, grading is conducted 14 days after the 16- to 18-day-old larvae are stocked. Nursery ponds range from 100 to 300 m². The fish are collected with seines and temporarily stocked in hapas. Grading methods and apparatus are similar to those used for grouper. To prevent lesions and disease occurrence, drugs are administered after grading.

The Asian seabass culture procedure is shown in Figure 23. During growout, additional grading is needed when the fingerlings reach a total length of 9-12 cm, approximately one month after stocking. Two grading methods can be used. One is to stock fingerlings in small ponds, grade them after one month and then transfer them to two larger ponds. The other method is to enclose the fish with a net enclosure into a section of the big pond. When the fish become acclimated to group feeding, they are seined, graded and then released into the pond.

Red Snapper
Successful red snapper (Lutjanus argentimaculatus) breeding was first accomplished in 1984 by private hatchery operators. Mass production of fertilized eggs began in 1990 (Chang 1993b). Uncovered outdoor large pond systems were converted for fry production, where fertilized eggs were stocked directly into the pond.

In an indoor system, it takes 30-40 days for red snapper to attain 2.45 cm in total length. The advantages of fry production in a big pond system include fast fingerling growth, easy water quality control and feed administration. Acetes chinensis and chopped trash fish are the main diet in red snapper nurseries, but the fry can be also acclimated to floating or moist pellets. Feeds commonly used for red snapper culture are shown in Table 37. The best feed efficiency for freshwater-cultured red snapper is about 31.15% in a 40% crude protein feed (Wu and Tang 1989). The feed conversion rate of red snapper in growout is shown in Table 40.

The red snapper culture procedure is shown in Figure 24. Fry produced during the warm season are usually sold to growout farmers, but fry produced in autumn are usually stocked in nursery ponds for overwintering. They can be sold the following spring for higher prices. Due to the low red snapper fry prices (US$0.04-0.08/fish, 2.5-3 cm TL) and limited markets in Taiwan, most fry are exported.

- Growout
As with Asian seabass, grading is carried out one month after stocking, when the fingerlings reach a total length of 9-12 cm. The red snapper growth rate is poor in intensive pond culture as it takes 12-18 months to attain market sizes of 400-1,000 g. In addition, harvests last for six
months due to growth disparity and limited market demands. Stunted red snapper are transferred to other ponds where additional culture is conducted. Stunted growth can be attributed to competition among fish of different sizes.

Red snapper is less resistant to diatom blooms than grouper. As a result of summertime blooms in the pond, fingerlings are easily infected with bubble disease. The lethal oxygen concentration for red snapper fingerlings (4.7-5.2 g) is 1.2 mg/L at a water temperature of 30°C and a salinity of 25 ppt (Chen et al. 1990).

Red snapper body color darkens when the fish are given artificial feeds and cultured in low salinity (3-10 ppt). Dark-bodied fish bring lower market prices, which is also the case with tilapia. Body color can be improved by supplementing the feed with shrimp heads two to three weeks before harvesting. Commercial products such as xanthophyll and astaxanthin can also be used to enhance body color.

**Pompano**

Pompano (*Trachinotus blochii*) fry production was first carried out in 1989 by private hatchery operators (Cheng 1990; Lin 1991; Chang 1993a). The industry developed quickly because of the fish's tasty meat, fast growth rate and appealing appearance. The pompano culture procedure is shown in Figure 25.

In 20-30 days, pompano fry attain a body weight of 0.27 g, and in the 7- to 12-month growout stage, they attain a market size of 400-600 g. Growth disparity and cannibalistic behavior are not significant, thus, grading is usually undertaken only at the end of the hatchery stage. Fry produced during spring and summer are stocked directly into growout ponds. Fry produced in autumn are stocked in the nursery for overwintering. Pompano are fed on custom-sized pellets throughout production. Pellets are better than chopped trash fish because the latter can lead to disproportionate feeding and increase the growth differences among individual fish, which is disadvantageous during harvesting. Feed conversion efficiency is lower than grouper or Asian seabass due to pompano’s active swimming behavior (Table 40).

The stocking density and production of pompano per hectare per crop are shown in Table 41. Suitable stocking densities range from 20,000 to 30,000 fish/ha depending on the size of the pond and water sources. Pompano is a euryhaline marine fish. It can be cultured at salinities of 3-33 ppt. The fish grow quickly in salinities less than 20 ppt (seven to eight months to harvest), and poorly when cultured in full seawater (about 1 year to harvest). Pompano are intolerant of coldwater temperatures. Minimum water temperature for survival is 14°C.

---

![Figure 24](image.png)

**Figure 24.** Red snapper (*Lutjanus argentimaculatus*) culture procedure in Taiwan.
and when the water temperature drops that low for two days, mortality occurs.

Sinking pelleted feed is commonly used during pompano growout (Table 37); however, pellets should be custom sized because the fish's pharynx is small and its feeding behavior is voracious. The fish also spit out old food to feed on the new pellets. Pelleted feeds can be gradually supplied by an automatic feeder for about one hour in the morning and before sunset.

Pompano culture ponds can be stocked with 60,000 grass prawns (Penaeus monodon), which serve as an additional aquaculture product. This method stabilizes water quality because leftover feeds can be efficiently consumed by grass prawn, which are harvested with a trap net three to four months after stocking.

Others

Besides high-value finfish, such as Asian seabass, red snapper and pompano, the Japanese seabass (Lateolabrax japonicus), cobia (Rachycentron canadum) and doctor fish (Siganus fuscescens) are good candidates for aquaculture. The Japanese seabass has already been successfully cultured in Taiwan, and cobia growth is best among the cultured marine finishes. White cobia meat is also suitable for sashimi (raw fish). An advantage of S. fuscescens culture is its short duration (six to eight months) and high production (27 tons per hectare per crop).

**Marine Finfish Culture Problems in Taiwan**

Much has been said about the prospects and problems of aquaculture development in Taiwan (Liao 1988; Liao 1990; Liao 1991). Developmental problems for marine finfish culture include a number of biological and nonbiological factors.

**Biological Factors**

- **Enhancement of Finfish Nutrition Studies**
  Nutrition research is important to the development of intensive marine fish culture. Poor survival rates and abnormal syndromes such as lockjaw and easily shed scales during handling of Asian seabass are thought to be related to nutrition. In addition, consumers prefer the taste of wild-caught fish to artificially-fed fish. Thus, further nutrition studies are needed.

- **Selective Breeding**
  Genetic gain in selectively-bred fishes is even better than in other farm animals. A genetic gain of 10-20% per generation is obtainable through selection (Gjedrem 1993) and can be

![Larval Stage to Growout Stage Diagram]

Figure 25. Pompano (Trachinotus blochii) culture procedure in Taiwan.
used to promote fry quality among competing fry producers.

**Disease Control**

Disease research should focus on *A. ocellatum* biology because high mortality in cultured marine finfishes is caused by this disease.

- **Hatchery-Reared Fry Quality**
  Several poor characteristics, such as swim bladder, gill, operculum and fin abnormalities were found in hatchery-reared fry. Poor growth performance was sometimes found in growout, especially in fish bought from low-growth groups. Fry quality can be improved by genetic manipulation and improved nutrition and fry production systems.

**Non-Biological Factors**

- **Quarantine System in International Finnish Seedstock Trade**
  There are complementary advantages to international finfish seedstock trade; however, the spread of disease must first be considered. Strict international quarantine systems should be imposed to control the spread of diseases.

- **Proper Use of Underground Water**
  Most cultured marine finfish have better growth performance in brackish water than in full seawater. Thus, just like prawn culture, the problem of overutilizing underground brackish water in Taiwan remains unresolved. Overuse will lead to land depression.

- **Licensing for Aquafarmers Should be Required**
  Due to the lucrative benefits, inappropriate land exploitation for aquaculture, which includes converting rice farms into aquafarms, have been experienced in Taiwan. Furthermore, discharging seawater pollutes neighboring rice fields, which then become saline. Thus, agricultural fields that were rapidly converted into aquafarms are a menace. Poorly integrated fish ponds and confusing drainage locations impede the further development of aquaculture. The production, price of fish and problem of underground water overutilization can be controlled by imposing a licensing policy for aquafarmers.

- **Inadequate Information**
  A communication gap exists between researchers and aquafarmers. New findings from the scientific community are not easily transferred to farmers, and production figures are not relayed by farmers to the appropriate government agencies. Thus, library facilities and computerized databases should be established and extension services strengthened where needed. An information center for collecting and analyzing fish production information is also needed.

**Conclusion**

Nursery and growout technology and production of high-value marine finfishes in Taiwan compare well with other countries that have highly developed industries. Taiwanese producers, for example, have succeeded in developing culture techniques for a wide variety of commercial species and continue to search for more economically important species that better meet the needs and demands of its consumers and aquafarmers.

Despite its progress, Taiwan still needs to further develop its aquaculture industry. Development of cage culture, exploitation of domestic and international finfish markets, improvement of fish processing techniques to increase the value of fishes, and publication of educational materials explaining the advantages of eating fish and other aquatic products are needed to expand the industry. Development of marine fish culture techniques would also benefit the entire Southeast Asian region.

Although production problems do exist, Taiwan industry representatives are confident that the marine finfish industry will eventually overcome industry shortfalls.
Literature Cited


Lin, L.T. 1991. A general introduction to the completion of a generation cycle of permit fish (Trachinotus falcatus). In: Finfish Hatchery in Asia'91: Conference Program and Abstracts. Tungkang Marine Laboratory, Taiwan Fisheries Research Institute, Tungkang, Taiwan. p. 44.


A Review of the Nursery and Growout Culture Techniques for Flounder (Paralichthys olivaceus) in Japan

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Abstract

Japanese flounder (Paralichthys olivaceus) culture has progressed in Japan over the past 10 years owing to technical developments such as stable seedstock supplies and artificial feeds improvements. Aquaculture production of flounder was about 7,100 tons in 1992, which was more than 11 times as much as nine years ago. Flounder culture is conducted either in land-based tanks or ocean-based net cages. Rapid growth of the flounder culture industry has been accompanied by an increase in disease. This paper describes the current status of flounder culture and disease-related problems in Japan.

Introduction

The Japanese flounder (Paralichthys olivaceus) (Japanese name: hirame), is one of the most important species for coastal fishing and aquaculture in Japan. This species, which in the wild grows to 80 cm in length, is found around Sakhalin, Kurile Island, Japan, the Korean Peninsula and from the Yellow Sea to the East China Sea. Juvenile flounder are mass produced in governmental fish farming centers for release into coastal waters to augment wild populations; private hatcheries produce seedstock for aquaculture. In Japan, more than 18 million cultured juvenile flounder were released in 1992, and the recapture fisheries has increased in recent years. Flounder has been extensively cultured in land-based tanks and ocean-based net cages since the late 1970s. Flounder aquaculture production is shown in Figure 26 (Matsuoka 1993).

Flounder was produced in large quantities in Ehime (1,661 tons), Kagoshima (999 tons), Nagasaki (841 tons), Oita (671 tons) and Mie (566 tons) prefectures in 1991 (Figure 26). These prefectures, except for Mie, are located in western Japan where water temperatures range roughly from 12-27°C throughout the year. This range is almost suitable for flounder growth; however, large quantities of flounder are produced in tanks because surface water temperatures in the summer are too high for net cage culture. It is believed that flounder cannot survive for one month in water temperatures higher than 26°C.

The annual production of cultured flounder was first reported in 1983 as 648 metric tons; however, this accounted only for 0.1% of the total cultured marine finfish production in Japan. According to 1992 statistics, annual production increased to 7,128 metric tons (MT), which represents 2.7% of the total cultured marine finfish. On the other hand, wild flounder catches in 1992 were 6,817 MT. The ratio of cultured to wild flounder has increased rapidly in the last decade, and since 1990, the production of cultured flounder has exceeded wild catches (Figure 27). Today, cultured flounder are primarily shipped live to big cities, though the number of facilities have been increasing in cooler regions such as Hokkaido (northern island in Japan). Most fish produced in these areas are consumed locally.
Background Overview

Four factors have been involved in the rapid growth of flounder culture. First, in 1965, a technique for flounder seedstock production was successfully developed at the Kinki University Fisheries Laboratory (Harada et al. 1966). With additional improvements in techniques, public and private hatcheries can now produce enough juvenile flounder for culture and release. Fertilized eggs are obtained from natural spawning or by temperature (mainly cooling) or light manipulations to induce spawning (Ijima et al. 1986; Saitoh et al. 1991). Hormone treatments are not usually applied to broodstock. The flounder larval rearing technique is one of the most advanced for marine fish species in Japan.

Second, the price for commonly cultured marine finfish, such as yellowtail (Seriola quinquergiata) and red seabream (Pagrus major), has decreased because of overproduction. Thus, culturists have been searching for a new marine culture species. In general, based on taste and appearance, cultured fishes are ranked lower than wild fish. But, in truth, the cultured flounder taste is not inferior to wild-caught, and in the wave of current prosperity, many Japanese people are demanding better tasting fish. About five years ago the market price for live cultured flounder was ¥4,000-6,000/kg; however, the present price has dropped to ¥2,000-3,000/kg. Production costs for tank-raised flounder are ¥1,400-1,700/kg.

Third, the growth and survival rates for flounder are higher than those for other cultured marine fishes.

And fourth, flounder can be farmed by anyone because it can be reared in land-based tanks. Other marine fishes are generally reared in net cages by fishermen who have the authorized right to use the coastal waters. Thus, land-based facilities have played a major role in the expansion of flounder culture.

Culture Systems

Flounder tank culture techniques have been known since 1977. On a typical farm anywhere from 5-100 tanks are placed in several small buildings built of slate. To reduce light intensity, houses have very few windows. The tanks

Figure 26. Aquaculture production (1991) of flounder in different Japanese prefectures.

Figure 27. Annual catch of wild flounder and annual production of cultured flounder in Japan.
Table 42. Average tank stocking densities for flounder in Ehime Prefecture.

<table>
<thead>
<tr>
<th>Fish Size (g)</th>
<th>Stocking Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fish/m²</td>
</tr>
<tr>
<td>5-10</td>
<td>100-200</td>
</tr>
<tr>
<td>10-50</td>
<td>70-100</td>
</tr>
<tr>
<td>50-100</td>
<td>50-70</td>
</tr>
<tr>
<td>100-300</td>
<td>40-50</td>
</tr>
<tr>
<td>600-800</td>
<td>27-38</td>
</tr>
</tbody>
</table>

are constructed from concrete, fiberglass reinforced plastic (FRP) or vinyl sheeting and framed with steel or concrete panels. Tanks are round, or square with rounded corners and range from 25-100 m² and 1 m deep. Water depth is 0.5-0.8 m. If the height of the tank is less than 50 cm above the water surface, the tank must be netted to prevent the fish from jumping out. In southern areas such as Kagoshima Prefecture, farmers use 1,000-ton outdoor circular tanks (36 m in diameter x 1 m in depth), originally built for shrimp culture.

Seawater is generally pumped from 10-20 m below the ocean surface and 50-100 m away from the shore. Pumped seawater is either passed through a sand filter and supplied to individual tanks or supplied without filtration. The tanks gently slope down to a central drain, the water current is circular and seawater is exchanged every 1.6-3.4 hours.

Since about 1985, floating net cage culture has been conducted mainly in the Inland Sea of Japan and its neighboring regions. Before that time, flounder was not thought to be appropriate for net cage culture because the species is very sensitive to waves. At present, most net cages are constructed from polyethylene or zinc-galvanized iron, and are located in small bays or inlets. Generally, chemical fiber net cages are 5 x 5 x 2 m and have vinyl sheeting sewn on the bottom of the cage. The structure of the iron net cage, 10 x 10 x 7 m without vinyl sheeting on the bottom, is similar to those used for culturing yellowtail. To reduce light intensity in the culture area, many farmers cover the net cage surface with black-colored cloth net.

The advantages and disadvantages of flounder culture in land-based tanks and ocean-based net cages are as follows: Tank construction costs are much more expensive than net cages and fish can be reared at higher densities in net cages. In contrast, culturists can manage fish easier in tanks. Additionally, net cage fish bring lower prices because of skin abrasions caused by rubbing against the net.

**Culture Techniques and Growth Rate**

Almost all cultured seedstock is produced by hatcheries. After two to three months of rearing, 3- to 15-cm juvenile flounder are purchased for ¥50-200 each, depending on the fish size and hatchery reputation. The juveniles are transferred directly to growout tanks. The stocks for net cage culture are usually reared in land-based nursery tanks because fish less than 10 cm cannot withstand wave action.

In tank culture, flounder seedstock are sometimes placed in small (2 x 2 x 0.5 m) net cages, which are installed in the tank. This inner net cage is helpful for grading, although it may damage fish less than 5 cm. Until fish reach 10 cm, grading must be done frequently, otherwise smaller fish are cannibalized by larger ones. The stocking density of flounder in tanks varies with fish size; however, average densities are shown in Table 42. The walls and tank bottoms are cleaned once a week.

In net cage culture, 15-cm flounder are transferred into net cages between April and June. The number of fish stocked in one cage is 2,000-3,000 in small (5 x 5 x 2 m) cages and 6,000-10,000 in large (10 x 10 x 7 m) cages. No further grading is necessary in large cages until flounder are harvested.

Flounder growth rates in land-based tanks and net cages are affected by a number of factors, including environmental parameters (i.e., water temperature, dissolved oxygen), seed-
Table 43. Flounder feeding rates for various sized fish on different feeds.

<table>
<thead>
<tr>
<th>Fish Size</th>
<th>Daily Feeding Rate (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>raw fish</td>
</tr>
<tr>
<td>length (cm)</td>
<td>weight (g)</td>
</tr>
<tr>
<td>4-5</td>
<td>1-2</td>
</tr>
<tr>
<td>10-15</td>
<td>8-32</td>
</tr>
<tr>
<td>20-25</td>
<td>90-180</td>
</tr>
<tr>
<td>&gt;25</td>
<td>&gt;150</td>
</tr>
</tbody>
</table>

* weight of feed/weight of fish.

stock source, fish density, feed type and feeding rate. Generally, on most flounder tank farms, it takes 8-12 months to grow the fish to a market size of 500 g or more. Although the growth rates are a little better in net cages, survival rates are generally higher in tanks than in net cages. The survival rate during tank growth generally ranges from 60-80%, and sometimes as high as 90%. The survival rate in net cages ranges from 50-70%; in larger (10 x 10 x 7 m) iron net cages, the rate is usually lower.

**Feeds**

Cultured flounder are fed frozen fish, such as sand lance (*Ammodites personatus*), and moist and dry pellets. Moist pellets are prepared by mixing crushed frozen fish with a formulated powder diet at a ratio of 1:1 or 3:2. Moist pellets are made on each farm or supplied by a dealer. Dry pellets are always prepared by commercial companies. Because of user demand, about 20 companies are currently selling specially formulated and blended flounder feeds. Generally, juveniles smaller than 10 cm are given dry pellets as an initial diet. After that, they are fed frozen fish or moist pellets. Moist and dry pellets are superior to frozen fish in many respects, including labor reduction, less food waste, decreased water pollution and easy oral drug supplementation.

Recently, water pollution resulting from marine fish net cage culture has become a problem in Japan. Thus, the use of dry pellets has been strongly recommended. However, many culturists switch from moist pellets to frozen fish about one month before harvest because it is thought that the growth rate and quality of market-sized flounder are better if they are fed raw fish. Flounder fed moist pellets can easily switch to raw fish diets; however, fish fed raw fish cannot easily switch to a formulated diet.

The daily feeding rate, which varies with fish size, density, water temperature and type of feed, is shown in Table 43. Generally, feeding frequency is four to six times per day for fish weighing less than 100 g, three to four times per day for 100- to 300-g fish and one to two times per day for fish larger than 300 g. The food conversion ratio (g feed/g weight gain, FCR) in cultured flounder is 3.5 when fed raw fish. This FCR is much better than yellowtail and red seabream culture ratios.

The flounder growth rate is high at water temperatures of 13-25°C, but is highest at 20-23°C. The lowest growth rates occur at temperatures below 10°C or above 26°C (Morizane 1984). Low concentrations of dissolved oxygen affect the feeding activity of fish; lower salinity is less influential. Flounder can survive in freshwater for eight hours without any apparent adverse effects.

**Disease**

Diseases identified in cultured flounder are listed in Table 44. Although the most common flounder diseases are bacterial infections (Matsuoka and Muroga 1993), problems due to viruses and parasites have recently increased. Figure 28 shows the change in frequency and cases diagnosed.

Thirty to 70% of the flounder diseases diagnosed at Ehime Prefectural Fish Disease Control Center (EPFDC) are caused by bacterial diseases and pathogens that include gliding bacterial disease (*Flexibacter maritimus*) (Baxa et al. 1986), Edwardsielliosis (*Edwardsiella tarda*) (Nakatsugawa 1983a), streptococciosis (*Strep-
Table 44. Diseases of cultured flounder and their epidemiology.

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Disease</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virus</td>
<td>Viral epidermal hyperplasia (VEH)</td>
<td>only in 10- to 25-day-old larvae</td>
</tr>
<tr>
<td></td>
<td>Rhabdovirus infection by HRV</td>
<td>only at 2.18°C</td>
</tr>
<tr>
<td></td>
<td>Lymphocystis disease</td>
<td>in any season and size</td>
</tr>
<tr>
<td></td>
<td>Bimavirus infection</td>
<td>in juveniles</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Gliding bacterial disease</td>
<td>in juveniles (&lt;10 cm)</td>
</tr>
<tr>
<td></td>
<td>Edwardsielliosis</td>
<td>at higher water temperatures (&gt;20°C)</td>
</tr>
<tr>
<td></td>
<td>Vibriosis</td>
<td>in juveniles (&lt;10 cm)</td>
</tr>
<tr>
<td></td>
<td>Streptococcus</td>
<td>at higher water temperatures (&gt;20°C)</td>
</tr>
<tr>
<td>Parasite</td>
<td>White spot disease</td>
<td>at higher water temperatures (&gt;20°C)</td>
</tr>
<tr>
<td></td>
<td>Scuticociliate infection</td>
<td>in juveniles (&lt;10 cm)</td>
</tr>
</tbody>
</table>

Gloss: *E. tarda* is rarely isolated from the intestine of apparently healthy flounder cultured in net cages (Yamano et al. 1988), the pathogen is commonly found in apparently healthy tank-cultured flounder (Rashid et al. 1994). At present, only oxytetracycline or alkyl trimethyl ammonium calcium oxytetracycline are orally administered. Sodium nifurtyrenate drug baths are also permitted in Japan. But the effectiveness of drug treatments have gradually decreased because of the appearance of drug-resistant bacterial strains. Vaccination trials have been conducted to prevent edwardsielliosis in flounder (Iida and Wakabayashi 1992); however, no satisfactory results have been reported (Mekuchi et al. unpublished).

Viral epidermal hyperplasia (VEH), caused by a herpes virus, occurs in Japanese flounder larvae and usually causes high mortality (Iida et al. 1989; Masumura et al. 1989). Lymphocystis disease occurrences have rapidly increased in recent years. This famous disease is characterized by conspicuous small nodule formations on the body surface and fins of juvenile to adult fish. The debilitating effect of lymphocys-
tis disease on its host is generally minimal, but commercial value is completely lost.

Major flounder parasites include Cryptocaryon irritans (white spot disease), Ichthyobodo sp. (Urawa et al. 1991), an unidentified scuticociliatid ciliate (Otake and Matsusato 1986) and Neobenedenia girellae (Ogawa et al. 1995). Except for the scuticociliatid ciliate, these parasites attach to the gills or body surface. Parasite damage is generally less serious than bacterial or viral diseases. However, if treatment is not administered against white spot disease in a timely fashion, mortality can reach 100%.

Some of the previously mentioned pathogens and parasites may have been transported and introduced to Japan in uninspected and non-quarantined live seedstock shipments from other Asian countries. In order not to introduce new pathogens, establishment of a quarantine system should be considered.

Occurrence of albinism (abnormal coloration) in hatchery-reared juvenile flounder is often observed. The mechanisms of abnormal pigmentation have been recently reported. Kanazawa (1993) suggests that nutritional factors may be the culprit.

**Industry Constraints**

Due to the yen’s rising exchange rate and increasing fishery imports, the price of fishery products in Japan has stagnated. Additionally, the price of flounder has dropped as a result of increased production in Japan and product imports from the Republic of Korea.

High-density fish culture in coastal waters gives rise to water pollution. The problem is addressed in the same manner as with other cultured marine finfish, but the food conversion ratio for flounder is better than other species.

Flounder diseases are increasing with expansion of the culture industry, and incurable juvenile viral diseases are reported more frequently. Also, public concerns about drug use in finfish culture has become a primary industry issue.

**Conclusion**

Flounder culture in Japan has expanded and progressed over the past 10 years, but several problems remain unresolved. To maintain a sound and stable flounder industry, for example, further study and improvement of culture techniques are necessary. Inexpensive improvements are important to compete with foreign product imports. Additionally, incorporation of formulated diets is essential for sustainable culture and healthy environmental conditions. Also, improved selective breeding techniques for production traits such as high growth rate and disease resistance are expected for the future.

**Acknowledgments**

The author wishes to thank Drs. Kiyokuni Muroga and Toshihiro Nakai of Hiroshima University and Mr. Tsuneo Morizane of Ehime Prefectural Fish Farming Center for their valuable advice and critical reading of the manuscript.

**Literature Cited**


A Review of the Nursery and Growout Culture Techniques for Flounder (Paralichthys olivaceus) in Korea

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Abstract

In the last decade, flounder (Paralichthys olivaceus) has become the most commonly cultured marine fish in Korea. The techniques and facilities for its culture are diverse, but juvenile growout in net cages has been established as effective and practical. The stocking density for 70-mm juveniles in net cages ranges from 1,500-2,000/m². Land-based tanks and enclosures are also used for flounder growout, but their shapes and dimensions vary from farm to farm. Water exchange rates range from 7-20 times a day, and stocking densities range from 20-40 kg/m².

Introduction

Flounder (Paralichthys olivaceus) is one of the most favored species for raw fish dishes on the Korean market. During the last decade, flounder culture in Korea has rapidly developed and become a large part of the aquaculture industry.

In 1985, the first commercially produced flounder seedstock were supplied to growout facilities. In 1994, production was estimated to be more than 20 million seedlings. Additionally, land-based culture facilities have expanded to 800,000 m² of culture tank surface area, where more than 16,000 tons of live flounder are produced each year.

Along the peninsular Korean coastline and Cheju Island, 500 land-based tanks, 300 net cage farms and about 40 enclosure fish farmers are growing flounder. On the east coast, there are mainly land-based tank farms with a dozen or so enclosure farms; only land-based tank farms are found on Cheju Island. Along the southern coast, there are mainly net cage farms and about 50 land-based tank farms. On the west coast, there are mainly enclosure farms (Figure 29).

Until 1990, net cage farmers on the southern coast also cultured pelagic fish species. In 1991, flounder culture in net cages was attempted with little success. Red tides, caused by eutrophication and typhoons, were the major constraints to net cage farming in this area.

Enclosure farms on the west coast of Korea were originally constructed for shrimp farming and salt ponds. Recently, farmers attempted flounder culture in the area, but tidal ranges were too large for continuous water exchange, and extreme water temperatures prevented successful production. The future of enclosure fish farming in this area does not appear prosperous.

Land-based marine fish culture is still in its infancy (less than 10 years old), and culture techniques have been developed by trial and error. Therefore, flounder culture has few easily generalized principles. Each farmer has his own culture and feeding regime, water and tank management and stocking procedures. A few examples of flounder growout techniques are reviewed in this paper.

Mean water temperatures on coastal flounder farms range from 10-25°C. Depending on locality and microclimatic effects, extremes of 6°C in winter and 30°C in summer are recorded a few days each year. To mitigate extreme water tem-
peratures, some flounder farmers use heated effluent from thermal power stations in the winter and cooled underground seawater from Cheju Island in the summer.

Optimal water temperatures for flounder culture range from 16-23°C. However, from January through April, when water temperatures drop below 12°C in most culture areas, flounder decrease their food intake. Cheju Island is the exception because winter water temperatures remain slightly above 12°C, which is the lowest tolerable temperature.

In this paper, land-based tank and enclosure growout procedures for flounder on the east coast of Korea are discussed.

**Nursery Stage**

Generally, net cages are used during the nursery stage to stock metamorphosed juveniles from larval rearing tanks. In some hatcheries, farmers stock the juveniles directly into the tanks without the net cages. This reduces handling and labor requirements, but frequently this method achieves poor harvests because of the difficulties in managing water quality and sorting fish.

Juveniles from larval rearing tanks range from 10-13 mm in body length, are very fragile and difficult to handle. Though various net cages are used in the hatcheries, it was determined that 1 m² x 45 cm deep net cages are the most practical to handle. It takes about one minute for two men to change the cage mesh. Close observation of the fish is also possible.

Net cages are installed in concrete tanks for easier handling of the fish. For example, 12 net cages can be placed in a 6 x 6-m² and 1-m deep tank. The bottom of the cage hangs about 50 cm above the tank bottom, which is easily cleaned by siphoning (Figure 30).

Water turnover rates are adjusted from once a day in the beginning of growout to three times a day when juveniles reach 50 mm in body length. Water temperatures during nursery range from 17-23°C, but if they drop below 17°C, a heating system is operated to maintain the temperature range.

Culture tanks are artificially illuminated. Two 40W fluorescent lamps are located 2 m above
Flounder Nursery and Growout in Korea

the water surface to illuminate each tank. Natural light coming through the windows is reduced by dark screens or shade nets.

Tanks are aerated throughout the juvenile culture period. An air stone is installed at each cross point of the four net cages, just beneath the net cage bottom and about 40 cm above the tank bottom. Aeration facilitates convection and creates water currents in the center of the net cages. These currents force feces and uneaten feed underneath the net cage, where the waste is siphoned out twice a day.

Juveniles are hand-fed crumble (less than 2-mm pellet) and pellet diets. Larger fish (215 mm) are fed six times a day between 7 a.m. and 10 p.m. The feeding frequency for smaller fish is not fixed; however, it is more often than for larger fish. In some hatcheries automatic feeders were installed, but were found to be impractical because of the flounder’s benthic dwelling behavior—its range of movement is more restricted than other pelagic species.

One net cage is stocked with 15,000-20,000 juveniles from larval rearing tanks. Deformed and albino individuals are hand-culled, while the dead and dying fish are siphoned from the cage. Stocking densities are adjusted according to fish growth. A net cage holds about 2,000 70-mm seedlings, which are later sold to farmers for growout.

During the 80-to 100-day nursery period to 70-mm seedlings, sorting procedures are indispensable. Because growth is not uniform and fish are continuously size differentiated, juveniles less than 20 mm are sorted through a stainless wire mesh net. Two nets with successive mesh sizes can grade three size groups of juveniles. After sorting, the juveniles are treated with antibiotics to prevent disease introduction resulting from mechanical damages. Flounder seedlings are thoroughly sorted in small hatchery net cages before being sold to fish farmers with large growout tank farms. Well-sorted seedlings do not need to be graded for another two months, even during the summer.

Juveniles larger than 20 mm in body length are sorted by hand. This sorting procedure may enlist at least one-fourth of the hatchery laborers.

Disease

Disease data is currently unavailable.

Transportation

Live seedlings are transported from the hatchery to growout farms via trucks equipped with oxygen supply and water temperature control systems. Truck transportation reduces labor and time constraints, but during loading and unloading, mechanical damage to the fish is unavoidable. As a precaution, seedlings transported by trucks are treated with antibiotics after transport. Fish transported from fishing boats to markets may also experience mechanical damage. In contrast, the oxygenated-vinyl bag transportation method employs a lot of labor, but fish experience very little mechanical damage or infection. A vinyl bag in a styrofoam box is filled with 3 L of 16°C seawater and 10 L of oxygen. It carries 100 70-mm seedlings for four hours. The number of seedlings per bag is adjusted depending on transportation time.

Growout

Culture Water Intake

The first step to fish culture in land-based tanks is pumping seawater. Where sand dunes are well developed, seawater is collected in a bottomless concrete cylinder. The cylinder, which measures 6-8 m in diameter and is 10-15 m long, has hundreds of screened holes on its lower half and is buried 8-12 m below sea level. Incoming seawater is filtered through the sand and pumped into the culture tanks.

Another seawater collection method in dune areas is to use a 200- to 400-m long galvanized steel pipe. It contains hundreds of screen-covered holes on the seaward end and stretches toward the sea. The pipe is naturally buried in the sand by waves. This long-pipe collection
method has proven successful from both a practical and economic perspective.

Where rocky shores are the dominant terrain, a canal, which directs seawater into the land-based pumping station, is constructed below sea level. Though this system maintains the water supply, continuous attention should be given to loose seaweed and garbage, which must continuously be cleared from the canal to prevent choking the pumps.

**Culture Tanks**

Flounder tanks are grouped into three categories: circular, square with rounded corners and rectangular.

Circular tanks are usually constructed of polyethylene or polypropylene sheet walls and waterproof liners. Since the circular concrete tanks are expensive to build, farmers prefer the square concrete tanks with rounded corners.

Circular and square tanks vary greatly from 6-10 m in diameter, and construction of larger 18-m tanks is on the rise.

Circular and square tanks are 1 m deep in the center and 60 cm along the edge because of a 5% slope. Seawater inlet pipes along the edge are directed clockwise and create a spiral water flow, which leads to a center discharge standpipe. The central standpipe has holes to drain water and waste. A drainpipe is at the end of the tank to control the water level. The number, size and position of the holes vary from one farm to another.

Many farmers along the east coast of the Korean peninsula and on Cheju Island have recently attempted fish culture in large rectangular tanks. Tank dimensions range from 12-15 m in width, from 30-40 m in length and from 2.5-3 m in depth. An 18- to 25-m wall in the middle of the tank allows the water to circulate as if it was a circular tank. There are several seawater inlet pipes placed clockwise along the edge of the tank at 5- to 6-m intervals, and several drainage standpipes along both sides of the middle wall. The pressure created by the inlet pipes forces the culture water to circulate in a clockwise direction.

**Aeration**

Every flounder farm has an aeration system. Some farmers aerate their culture tanks 24 hours a day with air stones, and some aerate only during the night for security against an accidental cutoff in the water supply. Others aerate only during chemical or drug treatment baths. Some aeration systems are equipped with ozone generators to improve dissolved oxygen levels in the tanks. However, the positive effects have not yet been confirmed.

**Feed**

Most flounder farmers prepare their own feeds. Trash fish, such as sand lance (*Ammodytes personatus*), young amber fish (*Trachurus japonicus*) and sand eel (*Hypoptychus dybowskii*) are quick frozen and stored. Farmers chop the frozen fish with or without powdered fish meal supplements, feed additives and binders. Commercially prepared powdered diets are rarely used to make moist pellets.

When frozen trash fish are chopped, molded into pellets and quickly extruded without powdered supplements, the meat remains frozen and maintains its shape. In a strict sense, they are “frozen pellets,” not moist. The frozen pellets are fed to and consumed by the flounder without thawing. Excess frozen pellets may foul the tank water, but half an hour later it is drained by lowering the outer standpipe. Farmers include premix feed additives, antibiotics and chemicals in their pellets when necessary.

Feeding regimes differ from one farm to another. However, an example of a feeding regime is when fish under 50 g in body weight are fed five to six times a day from 7 a.m. to 9 p.m. Fish weighing more than 50 g are fed three times a day, and fish weighing more than 1 kg are fed twice a day when the water temperature is above 16°C. The food conversion ratio (FCR) for the frozen pellet diet is 3.7:1.
A flounder farmer once tried feeding his fish expanded pellets from a feed company for eight months. He was able to reduce his labor and cold storage costs by one-third, but found the fish growth rate was not comparable to the fresh fish diet.

**Stocking Growout Tanks**

Flounder farmers stock their tanks with 70-mm juveniles between late December and June. From December to April natural water temperatures range from 10-13°C, so farmers must equip the culture units with heating systems. Water temperatures must be maintained at 15°C to grow the juveniles. Cheju Island has a volcanic origin and supplies 16°C underground seawater, which is naturally warm enough to culture juveniles during the cold season. In this region, farmers who stock their tanks in May and June can support fish without artificial heating systems.

Farmers stock their tanks with early-season juveniles in heated seawater so they will growout to market sizes of 0.6-1 kg before the next winter. The May to June juveniles must be grown out over the four winter months when no growth occurs, and then wait until late summer to reach marketable sizes.

Juvenile stocking densities range from 300-400 fish/m² for 70-mm fish; 10,000 seedlings in a 6-m diameter tank; and 15,000 seedlings in a 7-m tank.

**Sorting**

If body weight differences of up to 200% are exhibited between the largest and the smallest fish, the population should be sorted. Sorting procedures are conducted by hand, and because not all employees use the same size grading criteria, sorting results are frequently inconsistent. Because of the fish’s flattened body form, there is no specific, effective or safe sorting procedure for flounder.

After sorting, the fish are bathed in antibiotics or other drugs. Antibiotics also are administered through the feed.

**Water Supply and Fish Density**

Water turnover rates in the tanks range from 12-20 times a day, depending upon the farm and stocking densities, which range from 20-40 kg/m² of tank bottom area.

Tanks stocked at 40 kg/m² use a water turnover rate of 12 times a day. The seawater is pumped to a reservoir tank and pressurized to 2 kg/cm². The pressurized seawater is supplied to the culture tanks through a water-jet nozzle, which creates a spiral water current. The water-jet also saturates the water with dissolved oxygen.

Even though experience has shown that stocking densities greater than 30 kg/m² darken body color, lower the market value, increase stress and vulnerability to disease and hinder growth, farmers who have cultured fish at 40 kg/m² for the past two years still successfully produce flounder under these conditions.

In general, flounder farmers stock their tanks at 20-25 kg/m². On a farm, there are two 13 x 32 x 2.5-m rectangular tanks. The farmer stocks them with 200-g flounder at a density of 25 kg/m². The water is exchanged seven times a day, and culling is conducted periodically. Farmers expect that at a stocking density of 40 kg/m², the fish will grow to 800 g by harvest time.

**Culture Tank Maintenance**

Culture tanks are hygienically maintained. Whenever emptied (by sorting procedures or for harvest), the tanks are mechanically cleaned with a brush and sterilized with a compound such as calcium hypochlorite. The drainpipes, standpipes and air stones are also cleaned and sterilized. In addition, waterproof tank liners are replaced every two years.

**Enclosure Method**

The enclosure culture method has only a five-year history, including construction and stocking and three years production experience. To create the rectangular enclosure, a 5-m thick concrete dam is constructed in shallow water
along the rocky shore. The enclosure extends 50 m from the shore toward the sea. It is 80 m wide and 3 m deep and has 4,000 m² of surface area. (Figure 31).

Seawater enters the enclosure through five gates along the 80-m wide side and exits through three gates along the 50-m seaward side. The gates, 2 m wide and 2.5 m high, are immersed in water and screened to keep the fish inside, and seaweeds and floating materials outside.

In front of one of the gates a specially manufactured boat-like impeller continuously pushes the culture water from the enclosure. Two smaller impellers inside the enclosure create a circular water current.

In May or June, the enclosure is stocked with juvenile flounder, which are enclosed in the corner by a net. The net compartment is 15 m wide and 30 m long and is stocked with 180,000 70-mm juveniles. Stocking density is 400 fish/m². The net compartment area is adjusted according to juvenile growth rates.

After the flounder stocked from the previous year are sold in January, the net compartment is removed and the fish are released into the entire enclosure. Upon release, the fish weigh 300 g each and will grow to more than 1 kg in body weight by the end of the year.

Periodically, divers equipped with scuba equipment clean the bottom and corners of the enclosure. The bottom is covered with 5 cm of sand to prevent mussel and barnacle growth.

Culture density in the enclosure is 30 kg/m², and annual production is about 120 tons. Mortalities during growout are high because the enclosure depth prevents farmers from observing the fish. The dead fish perish without a trace.

The enclosure construction makes it impossible to completely drain the water; therefore, it is not possible to dry or clean the inside. If a chronic disease is present, it would be very difficult to control.

**Perspective**

The market demand for live fish for use in raw fish dishes, especially in Korea, makes the future of fish culture very prosperous. Contamination, depletion of natural resources and labor are the inevitable constraints on the coastal fishing industry, which is the main supplier of live fish. The constraints of coastal fishing support marine fish culture in land-based tanks and enclosures, promoting the development of the aquaculture industry.

Present flounder culture techniques have been arbitrarily developed by farmers. Scientific information on the biology and ecology of flounder are not sufficiently available to develop more productive techniques. Focus is especially needed in engineering and culture facility development. Efforts to improve culture techniques will provide a basic foundation for higher productivity.

![Figure 31. Schematic diagram of a typical rocky shore enclosure along the east coast of Korea.](image)
Nursery and Growout Production Techniques for the Mahimahi (*Coryphaena hippurus*) and Pacific Threadfin (*Polydactylus sexfilis*)

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Abstract

In Hawaii, the mahimahi (*Coryphaena hippurus*) and Pacific threadfin (*Polydactylus sexfilis*) are high-value, carnivorous sport fish and potential candidates for aquaculture development. For the past five years, The Oceanic Institute (OI) personnel have been examining the commercial potential of mahimahi. Intensive nursery techniques and land-based growout production developed for the mahimahi have been successfully applied to the threadfin. Acceptable nursery survival rates have been achieved in both species by paying attention to sibling aggression, cannibalism, feeding and feed nutritional quality. High density growout of both mahimahi (15 kg/m³) and threadfin (25 kg/m³) has been achieved at loading rates of 1.0 kg/L per minute. Growout to six months of age yields harvestable products of both mahimahi (1.7 kg) and threadfin (0.5 kg). Techniques currently used at The Oceanic Institute for land-based nursery and growout production of both species are reviewed.

Introduction

Due to declining world stocks and increasing fishing costs, global marine capture fisheries are hard pressed to meet increasing demands for fish and fishery products. In the United States, imports of edible seafood products represent a $2.6 billion annual trade deficit, which is rising at an annual rate of 5-8% (USDA 1992). A continuing dependence on fishery products from imported sources and a rising seafood deficit are inevitable unless aquaculture technologies for marine species are developed. Technology development for high-value species is regarded as the best avenue to pursue because the more favorable economic returns realized with these species offset the relatively high cost of aquaculture in the United States (USDA 1992; Chamberlain 1993). Recognizing the importance of establishing a commercially sustainable marine aquaculture industry, The Oceanic Institute (OI) has initiated efforts to research the potential of a number of high-value species.

The mahimahi (*Coryphaena hippurus*) and Pacific threadfin (*Polydactylus sexfilis*) are both high-value, sport fish that have attracted much attention as potential candidates for aquaculture development in Hawaii. The mahimahi is a highly predatory, open-ocean fish, with a worldwide tropical and subtropical ocean range (Falko et al. 1982). Its rapid growth rate, high fecundity and adaptability to culture (Hagood et al. 1981; Szyper et al. 1984; Ostrowski et al. 1989; Kraul 1991) have stimulated global interest in the aquaculture community, although most research has been conducted in Hawaii. The Pacific threadfin, called moi in Hawaii, is a near-shore species (May 1979), whose stocks have become depleted largely due to the accumulated effects of overfishing (Shomura 1987). Threadfin and mahimahi are highly regarded for their flesh quality and in Hawaii they command premium prices in the
wholesale and retail markets (US$ 8/1b). Established markets for threadfin do not exist because of the scarcity of supply. To date, there is no large-scale commercial production of either species.

The Oceanic Institute has been conducting mahimahi research for the past 10 years, but only within the last five years have programmatic level efforts been directed toward establishing intensive rearing techniques for commercial development. Formal research efforts on threadfin were initiated in 1993.

The purpose of this paper is to convey nursery and growout techniques currently used for mahimahi and threadfin at The Oceanic Institute. Information presented on mahimahi is extracted from a culture manual that is based on research conducted at OI over the past five years. Information presented on the threadfin is based on recent research, primarily from two studies whose manuscripts are currently in preparation.

Mahimahi

Larval Rearing

Widely diverse rearing methods have been successfully employed in mahimahi culture, although research efforts at OI have been directed toward streamlining the methodology to promote commercialization of the techniques.

Publications by Kraul (1991), Kraul et al. (1988), and Szyper (1991), for example, describe feeding methods that employ rotifers, copepoda and yolk sac larvae of mahimahi as live foods. Techniques used to raise larval mahimahi at OI have also been reviewed by Kim et al. (1993). The use of the rotifer Brachionus plicatilis, especially for the first two days of feeding, is common, and it is preferred when rearing temperatures are below 26°C (Ostrowski et al. 1990).

Feeding experiments have shown a 14% higher incidence of first-feeding survival when rotifers (B. plicatilis) are offered instead of Artemia (unpublished results). However, experience shows that the additional cost of culturing rotifers and their algae feed is not offset by the potential increase in first-feeding success (Ostrowski et al. 1990). As a result, the technique used to raise mahimahi larvae at OI employs Artemia, without algal inputs, as the sole food source. This is considered a more practical method for commercial development.

Mahimahi larvae grow rapidly and begin to metamorphose around Day 17. They are considered juveniles by Day 20, and the nursery stage of mahimahi development is between Day 20 and Day 45.

Nursery

- Overview

The period between Days 20 and 45 is often marked by unacceptably high juvenile mortalities. During this period, fish are trained to accept dry, pelleted feeds (weaning) and natural agonistic behaviors peak. Mahimahi nursery survival at OI was traditionally less than 15%, even at extremely low stocking densities. More recent research efforts have resulted in 60% nursery survival rates with small populations of fish (≤ 1,000) when careful and continuous size sorting have been conducted. However, in large-scale operations, sorting may not be practical because it is labor intensive for this species. High density rearing with low maintenance yields only 30-40% survival. Essential features of the OI nursery system include the use of oval raceway tanks, high fish density, high water exchange rates, abundant food supplies, continuous feeding and frequent tank cleaning.

No further significant developmental changes are apparent until maturity. Metamorphosed juveniles are active swimmers and very resilient. During the 25-day nursery period, mahimahi grow 85-fold from an average 0.06-5 g wet weight (WW). This corresponds to an average compounded daily weight gain of 20%. Figure 32 represents typical growth of mahimahi during the first 45 days of age; the Gompertz curve was fitted to data in standard length (SL). The Gompertz model assumes that growth (instan-
taneous) declines exponentially with age. The equation for the line shown in Figure 32 is:

\[ SL_t (mm) = SL_0 \times e^{(-11.77) \times (e^{-0.0062 \times t - 1})} \]

Where \( t \) is the age of fish in days post-hatch. The regression relationship between standard length and wet weight is:

\[ \log_e (WW) = 3.08 \times \log_e (SL) - 11.62 \]

Mahimahi grow rapidly during the growout phase and can reach up to 2 kg by Day 180. Sexual maturity begins around Day 150 and sexual dimorphism between males and females begins to appear. It is also the time when size differences between males and females arise; males typically grow 15-40% larger than females. Females will begin to release eggs in growout tanks any time after Day 150, which are often fertilized by mature males. Sexual maturity, aggressive behavior and feed utilization are of primary concern in mahimahi growout.

- **Behavior**

Juvenile mahimahi are highly aggressive, frequently chasing and nipping their siblings during daylight hours. Individuals under attack often develop frayed dorsal and caudal fins, stop eating and die within a day or two. Fish that are small or weak are especially vulnerable, although this aggressive behavior can be exhibited by the smallest to the largest individuals. Cannibalism occurs when there is sufficient size disparity among siblings, although individuals who are attacked and killed are not always eaten. In those fish that do cannibalize, it is not uncommon for them to die from attempting to consume too large a sibling that then becomes lodged in its mouth. The antagonistic phase of juveniles is more size- than age-related. It first appears among fish around 20 mm SL (Day 20) and declines when fish reach about 50 mm SL (Day 30). This phase coincides with weaning onto pelleted feeds, although the behavior is clearly independent of the food availability. The behavior is also somewhat batch specific. For unknown reasons, some batches of fish display very little aggression toward each other, while others are incorrigible. After fish are completely weaned, antagonism persists but to a much more limited extent.

- **Nursery System**

A shallow raceway system is used to enhance weaning success and control agonistic behavior (Figure 33). Both the shallow design and directional water current aid in making pelleted diets more attractive and available to the fish. The raceway increases their ability to wean successfully by encouraging contact between the pelleted feed particles and fish, while the feed particles appear animated. Furthermore, the directional water current forces fish to occupy their time swimming against the current, which makes them less prone to sibling attacks. It also provides a means by which attacked individuals can quickly escape an aggressor. Raceways at OL are made of fiberglass (painted with a black epoxy) with a working volume of 1,200 L. Tanks are operated with a water depth of about 15 cm.

Good nursery runs have been achieved at OL using both inshore and deep well water sources. Ambient temperatures between 26-29°C appear optimal, although recent research indicates that a 2°C increase in temperature (26.5 vs. 28.5°C) results in a near doubling of growth. Water turnover rates are adjusted ac-

![Figure 32. Growout in standard length (SL) of mahimahi in the hatchery (D0-D45).](image)
According to fish size and weaning progress. Water turnover rates are typically 12 tank volumes/day during *Artemia* feeding, and 24 tank volumes/day after weaning. Water current speeds are normally maintained between 3-4 fish lengths/s. Although the effect of water currents on growth (or energy utilization) is unknown, this velocity seems to be near optimum for growth and maintenance. It is certainly required to control aggressive behavior and improve weaning success.

Around Day 20, fish are initially stocked into raceways at a density of 3 fish/L. It was demonstrated that although fish grew and survived best at a density of 0.5 fish/L, overall production was the best at 3 fish/L, the highest density tested (Kim et al. 1993). Higher density promoted fewer mortalities from agonistic behavior than intermediate densities of 1.0, 1.5 and 2.0 fish/L. Crowding appears beneficial as aggressive individuals have difficulty in targeting victims.

- **Feeding**

Fish are fed enriched *Artemia* metanauplii in raceways for three to five days during the weaning process. Appropriately sized pelleted feeds (500 μ to 1 mm) are first introduced when fish obtain a silvery body pigmentation (around Day 22; 20 mm SL and 0.1 g WW). Attractability and nutritional quality are essential considerations for a weaning diet. Less palatable diets delay the weaning process and increase mortality. Nutritional requirements at weaning are still unclear, but clearly fish meal quality plays a key role. High dietary protein levels are also essential.

Good growth and survival rates depend on the nursery stage feeding regimen. Sufficient amounts of food are required to maintain rapid growth and reduce agonistic behavior and cannibalism. Aggressive behaviors are always present in mahimahi but are reduced when food is abundant. Both live *Artemia* and pellets are offered on a semi-continuous basis throughout the light period (0600 to 1800 hours). A 24-hour belt-feeder (Zeigler Bros., USA) is used to dispense the pellets. Weaning is conducted over a four- to seven-day period. Special attention is paid to the timing of feeding pellets and the amount dispensed.

Despite the use of highly acceptable diets, there are always fish that will not wean onto pelleted feed. Throughout the weaning process, fish that do not wean should be removed and isolated for weaning at a later date. These fish are characteristically thin, less mobile and weaker than those fish that have weaned successfully. Feeding requirements for mahimahi during this stage are great; and fish can starve within one day, even if only a few meals are missed. In addition, weakened fish are targets of attack by stronger individuals.

By Day 28, all fish should have been weaned onto pelleted feed. Feed is supplied continuously throughout the light period using a belt feeder. Pellet sizes are increased gradually from 1.2-3 mm as the fish grow. Fish should be fed daily at a rate equivalent to 10-20% of the tank biomass. High feeding rates are required because of the mahimahi’s rapid growth during this period.

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**Figure 33.** Oval raceway systems used in mahimahi and moli nursery culture. The shallow raceway design and directional water current animate pelleted feeds and orient the fish, reducing mortality due to aggressive behavior and cannibalism.
• Mortality
Mortality of nursery-stage fish depends, to a large extent, on management techniques—survival rates can vary from 15-60% during the 28-day nursery period. With continuous intensive care, survival rates of 60% can be achieved consistently. With less care, an average 30-40% survival rate is more likely. Key factors responsible for high survival are specific to the developmental stage of fish: (1) an abundance of food is required for pre-weaning fish in the raceways; (2) at weaning, the main factors are strict adherence to weaning techniques and quick isolation of individuals that do not wean well. The extent of aggressive behavior displayed during weaning contributes significantly to overall survival; and (3) for post-weaning fish, prevention of “red-tail” disease is the most important factor.

Weaning mortality is variable (range 15-40%) depending on management techniques and the aggressive behaviors displayed by certain batches of reared fish. With careful size sorting and attention to fish behavior, mortality during this phase can be reduced to 20%. However, 35% mortality is more realistic under practical farming conditions where attention to size sorting may only occur at stocking.

If a particular batch of fish shows pronounced antagonistic behavior, fish become susceptible to red-tail disease (LeaMaster and Ostrowski 1988). An outbreak results in a slow, but steady daily mortality rate of 2-3%. Red-tail disease can result in 50% mortality of all fish that survive to this stage.

Site specific management of the weaning period and labor costs should be considered as a means of deciding whether size sorting should be employed to increase nursery survival. Delaying the weaning process until Day 30 results in a 25% higher overall weaning mortality. Fish will not accept pellets if given a choice that includes live feed. The higher mortality is due to pronounced aggression from weaned, fast-growing fish or those fish that have been delayed. Once fish are completely weaned onto pellets, mortality decreases to an average 0.1%/day.

• Diseases and Other Problems
Red-tail disease, or caudal fin necrosis, is the primary disease encountered in the mahimahi nursery stage. It is a myxobacterial infection similar to caudal peduncle disease in salmonids. It is diagnosed as a reddening and erosion of the caudal fin, which quickly progresses up the caudal peduncle (LeaMaster and Ostrowski 1988). The etiology of red-tail begins as a primary, opportunistic bacterial infection (Vibrio spp.) caused by tail nipping, followed by a myxobacteria species infection. Fish that have been repeatedly attacked by aggressive siblings develop wounds that become vulnerable to infection. If left untreated, the fish’s appetite becomes depressed and death usually ensues within several days of infection. Prior to the post-weaning period, outbreaks of red-tail infection are rare. The disease can be treated with 75-100 mg oxytetracycline (OTC) and hydrochloride (HCl) in the feed and/or by isolation. Because the disease is contagious, infected individuals should be transferred immediately to another tank for treatment. It is recommended that oral OTC treatment continue for seven to 10 days, even if overt signs of infection have disappeared. If tail-rot threatens to become an epidemic in the raceway itself, feed containing OTC should be administered directly to all fish in the raceway. Treatment by static bath, using either nitrofurazone or OTC is not effective.

• Alternative Rearing Methods
Juveniles grow well on alternative food items such as older Artemia, mahimahi eggs, other marine nauplii and/or younger larvae (Kraul 1991). The use of larger food items is beneficial since less energy is spent on the feeding activity itself. The diversity might also add some nutritional benefit. However, the cost of rearing and obtaining alternative food items is considered too prohibitive compared to the benefits of Artemia metanauplii.
Growout

- Overview

Because more than 90% of production costs are in growout, successful growout is the most critical component of profitability. During this phase the cost and value of an individual mahimahi increases 10- to 20-fold, depending on the size of the fish at harvest. Each fish represents a substantial investment in feed, labor, capital, equipment, and utilities.

At present, mahimahi growout is divided into two phases that address size-specific problems associated with fish growth and development. Phase I is from Day 40 through Day 90, where fish are raised in small, 10-m$^3$ circular (3.65-m diameter) tanks. Phase II is from Day 90 through Day 180, where fish are raised in larger tanks (30-m$^3$ circular [6.1-m diameter]). Fish are fed pelleted diets throughout both phases and harvested at Day 180, weighing an average of 1.7 kg with a feed conversion ratio (FCR) of 1.3.

- Juvenile Biology in Growout

Mahimahi grow at an average rate of 4% /day from Day 40 to Day 180. As with the feeding rate, growth rate is high during the initial stages of growout and declines rapidly thereafter. Fish reach an average harvestable weight of 1.7 kg by Day 180 (Figure 34). On average, males grow faster than females and are typically 15-40% larger than females by Day 180. The slower growth of females may be due to the energy required in gonadal development during the maturation period (Day 120 to Day 180). At Day 150 gonadal somatic indices of females (6.0) are higher than that of males (0.5).

Growout trials to Day 240 at OI have yielded males up to 4 kg. However, weights of females (2.0 kg) and most males (3.0 kg) were less, yielding an average mixed population weight of only 2.4 kg (Figure 34). The FCR from Day 180 to Day 240 also increased to 4.0, increasing the average FCR through growout from Day 60 to Day 240 to 2.1. Extended growout of this species to greater than 2 kg harvest size may not be economically feasible.

- Stocking Densities and Survival

Phase I growout fish are stocked into 10-m$^3$ tanks on Days 40 to 45. Fish at this age typically weigh 4-6 g and are stocked at a density of 0.25 kg/m$^3$, or about 500 fish/tank. By Day 90, the density will have increased to 10 kg/m$^3$ assuming a survival rate of 85% and an average weight of 250 g/fish. At this point, remaining fish (425) need to be transferred to the larger 30-m$^3$ tanks for Phase II growout.

Phase II growout tanks are stocked at an initial density of 3-4 kg/m$^3$, assuming a working volume of 20 m$^3$. By Day 180, a density of 13-15 kg/m$^3$ will be obtained, assuming 40% mortality from Day 90. Fish have been safely raised at densities up to 18 kg/m$^3$ and loading rates to 1.0 kg/L per minute. At 1.0 kg/L per minute, total ammonia (NH$_4$) levels peaked at 1.87 ppm, corresponding to an un-ionized ammonia (NH$_3$) concentration of 0.027 ppm in the OI systems. This level of ammonia is near the maximum recommended level for production of other fishes (Alabaster and Lloyd 1980).

Mahimahi naturally exhibit vast size differences through all stages of development. Survival can be increased and growth rates improved if fish are graded into growout tanks at
stocking times. Larger fish tend to be highly aggressive toward smaller siblings, which may result in an outbreak of red-tail disease. In addition, smaller fish do not feed well because they are stressed and crowded by larger individuals during feeding. Recent research at OI has shown that smaller (Day 45) individuals exhibit compensatory growth if size sorted. Growth compensation usually takes about one to two months and is achieved by an increased feed intake with no change in the feed conversion ratio. Compensatory growth does not appear to occur in fish older than Day 120.

- **Oxygen Regulation**

Normal seawater oxygen levels do not sustain high-density growout of mahimahi. Figure 35 illustrates oxygen consumption patterns of mahimahi in growout trials conducted at OI. Once loading rates reach approximately 0.2 kg/L per minute, it becomes necessary to supplement dissolved oxygen (DO) with pure oxygen. The optimum DO level for mahimahi is about 6.0 ppm, and should never fall below 5.7 ppm. Mass mortalities will occur at levels below 5.2 ppm. Fish tolerate DO levels between 8 and 10 mg/L.

- **Ammonia Production and Excretion**

The concentration of un-ionized ammonia is considered the major limiting factor to high density/loading rate growout of mahimahi because its oxygen needs can be supplemented through oxygen injection methods. At present, the maximum loading rate recommended at OI is 1.0 kg/L per minute because of the observed NH3 concentrations. Higher loading rates may be achieved at different facilities due to the effects of water temperature and pH on the ratio of NH4 to NH3. Lower water temperatures and lower pH will support higher loading rates.

- **Nutritional Requirements**

The nutritional requirements of mahimahi in growout have been the focus of much research at OI. In the past, mahimahi could only be reared on raw fish, but advances made at OI have led to the development of practical pelleted feeds. Feed type is of utmost importance in mahimahi culture and will define the success of the venture. Because of stringent nutritional needs, there are only a few commercial feeds presently available that promote good feeding and growth rates for this species.

Research has shown that juvenile mahimahi grow most rapidly and efficiently on diets high in protein and moderate in lipid and carbohydrate content (Ostrowski et al. 1992). Diets containing between 55-60% protein, 10-14% lipid and ≤12% carbohydrate (dry matter basis), balanced at 32-35 mg protein/M metabolizable energy are recommended for rapidly growing juveniles. It is suspected that dietary protein needs decrease after Day 90, although research has not yet confirmed this.

Probably the most important characteristic of a mahimahi diet is fish meal quality. Only those diets made with high quality, low temperature processed fish meals (herring or whitefish) provide sufficient attractability and quality to promote high feeding rates, good feed utilization and rapid growth (Ostrowski and Duerr 1994).

Figure 35. Oxygen consumption of mahimahi in growout. Solid circles depict oxygen consumption per individual. Open circles depicts mass specific oxygen consumption rates.
Table 45. Feed conversion ratios (FCR) of mahimahi fed practical diets (60% protein) during various stages of growout. Overall FCR from D60-D180 averages 1.3.

<table>
<thead>
<tr>
<th>Age (Day)</th>
<th>FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-90</td>
<td>0.8</td>
</tr>
<tr>
<td>90-120</td>
<td>1.0</td>
</tr>
<tr>
<td>120-150</td>
<td>1.4</td>
</tr>
<tr>
<td>150-180</td>
<td>2.1</td>
</tr>
<tr>
<td>180-210</td>
<td>2.8</td>
</tr>
<tr>
<td>210-240</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Juvenile mahimahi also require essential fatty acids. To promote good growth and feed utilization the lipid content of diets should contain between 10-15% highly unsaturated fatty acids (HUFAs), or 1.0-1.3% of the dry diet. (Kim and Ostrowski unpublished).

The micronutrient (vitamin and mineral) requirements for mahimahi have yet to be studied. Practical diets made with standard vitamin and mineral mixes presently used for salmonids have yielded acceptable results in mahimahi growout.

- **Feeding**

  In Phase I growout, mahimahi are fed four times daily (0800, 1030, 1300 and 1600 hours) to satiation. During Phase II, feeding is reduced to three times daily (0800, 1030 and 1600 hours). It has been observed that fish fed at dawn and dusk are more aggressive and eat more. In addition, gut evacuation time in this species is about six hours (Suzuki 1992). A greater time spread in the feeding schedule may prove beneficial. Demand feeders have been used successfully to feed Day 45 fish at OI and appear to be promising for use in growout as well.

  The feed conversion ratio is the ratio of the amounts of dry matter feed eaten to the wet body weight gain. FCR increases with fish age (Table 45). The overall FCR from Day 40 to Day 180 is 1.3.

Dry (ca. 10% moisture) feeds are preferred because they are relatively easy to store and handle. Pellet size should be increased as the fish grow. In a commercial setting, growout stage mahimahi would be fed on either a fixed rate by automatic feeder or on a demand basis during daylight hours. Figure 36 is an empirically derived curve depicting a declining feeding rate as a percentage of body weight through an entire growout period where fish were fed to satiation. The equation can be used to approximate daily feed needs and to construct fixed feeding regimens. Recent research at OI showed that a fixed feeding regimen produced similar growth, but better FCR of fish than those fed to satiation from Day 40 to Day 150. It should be noted that fish will often vary their food consumption on a particular day. Demand feeders have yet to be tested with mahimahi but appear promising.

- **Mortality**

  Growout survival is a key issue that has yet to be adequately addressed in a commercial setting. Presently, survival rates achieved in growout trials conducted at OI average only 62% from Day 40 through Day 180. Survival declines steadily over time, and each growout period has specific problems that cause mortality. The major causes of mortality identified in

![Figure 36. Decline in feeding rate of mahimahi in growout. Curve empirically based on satiation rates of fish fed 3-4 times daily.](image-url)
mahimahi growout are red-tail disease, bloating and unknown causes.

**Red-tail Disease**

Chronologically, the first potential problem encountered in mahimahi growout is red-tail disease (LeaMaster and Ostrowski 1988). Problems with red-tail are most prevalent in fish from Day 40 to Day 90. The disease may carry over from an outbreak in the hatchery or may arise anytime during this stage. It usually occurs when there is a large size difference between stocked individuals, or when environmental conditions of the tank produce a high degree of stress (e.g., low oxygen levels, excessive handling of fish at stocking). Prevention of red-tail outbreaks is critical, and trials can proceed without incidence if special attention is paid to reducing conditions that create stress. The best strategy is to grade fish prior to stocking and not to stock fish that exhibit signs of the disease. Initial stocking densities should not exceed previous recommendations because crowding also appears to cause stress. Since the disease can be spread to others, it is best to either isolate or destroy individuals that exhibit signs of infection. Careful inspection of fish on a daily basis during the first two weeks after stocking is advised to prevent catastrophic outbreaks.

**Bloating**

Bloating is characterized by an accumulation of fluid in the stomach one to two hours after feeding (Ostrowski et al. 1989). It can occur during all stages of growout, but appears most prevalent during the Day 40 to Day 90 period. The exact nature and causes are not known, but in severe cases it can be lethal within several hours. Bloating appears to be related to diet type, amount consumed and overall stress. Diets made from low-quality fish meal (high-temperature process) induce bloating more readily than those made from high-quality fish meal (low-temperature process). Bloating is rare among mahimahi fed raw fish or squid diets. Bloating is more likely to occur if the quantity of a low-quality diet eaten at a single feeding is more than about 2% of the fish's weight (dry weight of feed:wet weight of fish). Bloating is also more likely to occur, even on high-quality feeds, when feeding is associated with certain stresses (e.g., handling, a switch in feed type or a drop in dissolved oxygen less than 5.5 mg/L). Increasing the water content of dry feeds has little or no effect on bloating. The solution to the bloating problem appears to lie in optimizing feed quality and scheduling and minimizing stresses of all kinds. It is recommended that when a new diet or pellet size is introduced, feeding should be carefully monitored for the first several days following the change.

**Unknowns**

During the growout period, the largest number of mortalities fall into the unknown category. Mortality characteristically occurs only after Day 90, and persists throughout the rest of growout. The peaks tend to occur between Day 120 and Day 150, resulting in the loss of 25% of the fish in a tank. Unknown mortalities almost always occur overnight, and fish typically do not exhibit prior signs of disease or histological evidence of abnormal functioning.

The vast majority of unknown mortalities are assumed to result from trauma caused by fish running into tank sidewalls after dark; hemorrhages within the brain cavity have been observed in fish examined soon after death. Mahimahi are an open-ocean species and are not used to solid barriers. Fish often become excited or frightened, and dash across the tank hitting the sidewalls. It is not uncommon to hear loud bangs from collisions along the tank sidewalls during daylight hours. Though not completely eliminated, the problem has been reduced by rearing the fish in padded fiberglass tanks as opposed to concrete tanks. Light is provided above tanks during the overnight period and closed-cell foam padding is installed along tank sidewalls. Foam padding must be sealed water tight; otherwise, accumulation of stagnant food rations and bacterial buildup may lead to increased incidence of red-tail disease, even during the latter stages of growout.
Use of tank designs that limit potential collisions with tank side walls is most important for mahimahi growout. Doughnut-shaped tanks, with a 1.5-m wide swimming space have proved useful in reducing mortality (Kraul personal communication), although stocking densities in these systems are limited.

**Pacific Threadfin (Mol)**

**Larval Rearing**

Larval rearing techniques for threadfin are currently under development at the Oceanic Institute. Unlike mahimahi, threadfin larvae are too small to consume newly hatched Artemia directly. So during the first week of culture, rotifers must be used as the primary food source. Concentrations of rotifers and algae (Nannochloropsis oculata) are maintained until Day 14. Artemia, enriched with an oil emulsion replete in HUFAs (Nutripack, New Zealand), are typically introduced by Day 10 as an additional food item. Artemia densities are increased and rotifer densities decreased from Day 15 until Day 26, when threadfin larvae complete metamorphosis. Fish are harvested on Day 26, graded in a 5/64" or 6/64" grader, and transferred into nursery tanks. Grading helps to reduce cannibalism, which begins to appear at about this age.

**Nursery**

- **Overview**

Recent collaborative efforts between OI and the state of Hawaii’s Anuenue Fisheries Research Center (AFRC) have provided dramatic improvements in nursery production techniques (Ostrowski et al. 1995). In a series of trials conducted at both facilities, the effect of diet and nursery rearing systems on growth and survival, and the incidence of cannibalism were investigated. Previous attempts to produce juvenile threadfin from the OI hatchery had limited success (< 30% survival) because of a high degree of cannibalism during the nursery stage when fish were weaned from live to pelleted feeds (The Oceanic Institute 1990).

Results of the collaborative trials indicate that threadfin mortalities due to cannibalism are most prevalent during the Nursery I (Day 26 to Day 40) stage but can be greatly reduced with the proper diet and rearing system (Table 46). Overall fish survival is inversely related to the rate of cannibalism and was highest when fed an in-house, high quality feed developed for mahimahi (OIM=88±7%). Survival is also best when threadfin are raised in oval raceways (86±8%) rather than in doughnut-shaped (70±4%) or round (65±13%) tanks. Use of oval raceways minimizes the effects of poor diet performance on both growth and survival. Overall growth and apparent feed conversion are best on the OIM feed as well.

In contrast, survival during Nursery II (Day 40 to Day 54) was independent of rearing system and diet. Overall survival averaged 91±5%, and cannibalism was commensurately low (6±5%). Fish grew an average 10.6±0.5% body weight daily, at a FCR of 0.9±0.1.

- **Nursery Rearing Techniques**

At present, threadfin nursery culture is divided into two phases that address size-specific problems related to survival, similar to those encountered with the mahimahi. As indicated, juvenile threadfin are highly cannibalistic during this stage, and are first graded prior to stocking into the nursery. Juveniles are also positively rheotactic and begin to orient and swim near the bottom of holding tanks. These behaviors facilitate the use of oval raceways, as well as improve weaning onto pellets and overall production management. The fish are also able to locate feed more efficiently since they are more frequently in contact with it, and utilization of rearing space is maximized. Fish are weaned onto pelleted feeds within two days with very little weaning mortality. They are fed continuously throughout the daylight hours to satiation using an automatic belt feeder. The amount of dry matter diet, equivalent to about
Table 46. Summary of trials conducted at The Oceanic Institute (OI) and Anuenue Fisheries Research Center (AFRC) during 1993 on juvenile threadfin (Polystictus sexfilis) during Nursery 1 (D26 - D40) in response to diet fed (RNB = Rangen, Nippai, Brine shrimp flake feed; RAN = Rangen Salmon Elite; OIM = Oceanic Institute Mahimahi nursery diet OIMV930; MCM = Moore-Clark, Inc. mahimahi diet) and rearing system tested (R = round tanks; O = oval raceways; D = doughnut-shaped circular tanks).

<table>
<thead>
<tr>
<th>Date</th>
<th>Facility</th>
<th>Tank</th>
<th>Diet</th>
<th>Stocking Density (#/L)</th>
<th>Survival (%)</th>
<th>Cannibalism Rate (%)</th>
<th>Final Wt. (gm)</th>
<th>Fork Length (mm)</th>
<th>Harvest Density (#/L)</th>
<th>Total Harvest (#)</th>
</tr>
</thead>
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<tr>
<td>7/13</td>
<td>AFRC</td>
<td>R</td>
<td>RNB</td>
<td>0.7</td>
<td>53</td>
<td>30</td>
<td>0.29 ± 0.24</td>
<td>26.5 ± 7.2</td>
<td>—</td>
<td>0.4</td>
</tr>
<tr>
<td>7/28</td>
<td>OI</td>
<td>R</td>
<td>RAN</td>
<td>0.5</td>
<td>60</td>
<td>37</td>
<td>—</td>
<td>20.4 ± 5.6</td>
<td>—</td>
<td>0.3</td>
</tr>
<tr>
<td>8/07</td>
<td>OI</td>
<td>O</td>
<td>OIM</td>
<td>2.3</td>
<td>92</td>
<td>7</td>
<td>0.63 ± 0.28</td>
<td>36.6 ± 4.6</td>
<td>1.2</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>OIM</td>
<td>RAN</td>
<td>2.3</td>
<td>82</td>
<td>16</td>
<td>0.25 ± 0.18</td>
<td>27.7 ± 5.3</td>
<td>4.0</td>
<td>1.9</td>
</tr>
<tr>
<td>8/20</td>
<td>OI</td>
<td>O</td>
<td>OIM</td>
<td>4.4</td>
<td>84</td>
<td>13</td>
<td>0.80 ± 0.15</td>
<td>40.2 ± 4.7</td>
<td>0.9</td>
<td>3.7</td>
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<tr>
<td></td>
<td>O</td>
<td>OIM</td>
<td>RAN</td>
<td>4.4</td>
<td>73</td>
<td>24</td>
<td>0.40 ± 0.08</td>
<td>31.1 ± 5.0</td>
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<tr>
<td>9/07</td>
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<td>79</td>
<td>20</td>
<td>—</td>
<td>29.5 ± 4.3</td>
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</tr>
<tr>
<td></td>
<td>R</td>
<td>RAN</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>23.7 ± 3.5</td>
<td>—</td>
<td>0.4</td>
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<tr>
<td></td>
<td>O</td>
<td>OIM</td>
<td>—</td>
<td>—</td>
<td>88</td>
<td>11</td>
<td>0.77 ± 0.15</td>
<td>45.5 ± 14.0</td>
<td>1.2</td>
<td>3.4</td>
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<tr>
<td>9/30</td>
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<td>D</td>
<td>OIM</td>
<td>0.7</td>
<td>81</td>
<td>9</td>
<td>0.42 ± 0.22</td>
<td>30.1 ± 5.4</td>
<td>1.8</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>OIM</td>
<td>96.5</td>
<td>0</td>
<td>1.08 ± 0.48</td>
<td>42.1 ± 6.4</td>
<td>1.1</td>
<td>0.5</td>
<td>0.6</td>
<td>5,147</td>
</tr>
<tr>
<td>10/20</td>
<td>OI</td>
<td>R</td>
<td>RAN</td>
<td>0.6</td>
<td>40</td>
<td>54</td>
<td>—</td>
<td>33.2 ± 5.1</td>
<td>—</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>MCM</td>
<td>—</td>
<td>—</td>
<td>61</td>
<td>37</td>
<td>—</td>
<td>36.8 ± 3.5</td>
<td>—</td>
<td>0.3</td>
</tr>
<tr>
<td>11/05</td>
<td>AFRC</td>
<td>D</td>
<td>MCM</td>
<td>1.0</td>
<td>75</td>
<td>9</td>
<td>0.39 ± 0.15</td>
<td>30.9 ± 4.4</td>
<td>1.1</td>
<td>1.0</td>
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<tr>
<td></td>
<td>OI</td>
<td>MCM</td>
<td>3.2</td>
<td>88.5</td>
<td>12</td>
<td>1.9 ± 0.13</td>
<td>40.0 ± 6.9</td>
<td>1.0</td>
<td>3.1</td>
<td>3.7</td>
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<tr>
<td></td>
<td>O</td>
<td>OIM</td>
<td>3.2</td>
<td>97</td>
<td>2</td>
<td>1.1 ± 0.17</td>
<td>47.2 ± 4.2</td>
<td>0.9</td>
<td>2.8</td>
<td>2.5</td>
</tr>
</tbody>
</table>

1. Cannibalism rate determined by difference from total number stocked minus total harvested and daily counted mortalities.
2. Mean ± standard dev. of n=10 pooled samples containing 5-25 fish.
4. Apparent feed conv. (FCR=A=total as-is fed fed/tot. wt. of fish on D40).
5. Round tank with a sheltering floating algal mat float of Gracilaria sp.
50% of the body weight, is fed daily initially, and is increased daily.

Graded threadfin from the hatchery are stocked into oval raceway systems at densities from 2-4 animals/L. Water current speeds are maintained between 10-13 fish length/s at stocking, and are reduced to about 4-5 fish length/s near Day 40.

During Nursery Phase II, fish are stocked into 10-m$^3$ circular tanks with a working volume of 5 m$^3$, and a density of 0.5 fish/L. Attention to cannibalism is not as important as during Phase I, although fish are size-graded to promote more uniform growth within tanks. Initial loading rates are 0.02 kg/L per minute. Fish are fed four times daily to satiation. Harvest densities of 25 kg/m$^3$ have been achieved.

**Growout**

- **Overview**

The threadfin growout phase extends from Day 54 to Day 240. High density growout of threadfin was recently achieved at OI (unpublished results). Threadfin reach a harvestable size of about 0.5 kg within eight months. Fish are raised in 10-m$^3$ tanks at an initial stocking density of 3.7 kg/m$^3$. Threadfin can tolerate lower DO levels than mahimahi in growout, and DO levels can be maintained between 5.4-5.8 ppm without adverse effects on growth or feeding rates. The preferred DO range for threadfin is 5.8-6.0 ppm, but feeding is unaffected at levels as low as 4.9 ppm. Most animals can survive at levels as low as 3.0 ppm, but feeding does cease at 3.0 ppm. Harvest densities of 24.4 kg/m$^3$ at loading rates of 1.2 kg/L per minute have been achieved with minimal use of supplemental oxygen. Using a high protein (62-64% dry matter basis [dmb]) and moderate lipid (13-14% dmb) commercial diet between Day 40 to Day 255, designed specifically for mahimahi (unpublished results), the threadfin gained 2.9% body weight/day with an average feed conversion of 1.6. Like mahimahi, growth rate declines and feed conversion increases over time.

- **Nutritional Requirements**

Very little is known about the nutritional requirements of threadfin. Like mahimahi, threadfin grow well and feed most efficiently on diets that contain high quality fish meals, although the threadfin requirements are not as stringent as those of the mahimahi (Ostrowski et al. 1991a). Unlike mahimahi, juvenile threadfin will accept feeds made with lower quality meals or high plant protein content, although growth rates and feed conversions are adversely affected.

Protein requirements for juvenile threadfin are not as high as those determined for mahimahi. Day 40 to Day 70 fish require between 41-48% protein (dmb) for rapid growth (Ostrowski et al., 1991b). Like mahimahi, threadfin require between 10-14% (dmb) lipid in their diets and are relatively intolerant to lipid levels of 17% or above. Dietary carbohydrate is better utilized as an energy source than dietary lipid (Ostrowski et al. 1991b).

**Mortality**

Juvenile threadfin appear highly resilient and adaptable to high density culture. Given optimum environmental conditions, proper diet and appropriate rearing systems, 90% survival during Nursery I and Nursery II can consistently be achieved. Survival in growout averages 94% from Day 54 through Day 240. Most growout mortalities in threadfin result from the inability of smaller individuals to transition from smaller to larger feed sizes.

Pathogenic outbreaks have yet to be encountered in the threadfin nursery. Shortened or flared operculae are common (5-25% after Nursery II), and the cause is the subject of much speculation. The presence of shortened operculae does not appear to affect the general health or survival of fish and thus, is not considered a key impediment toward aquaculture production of this species. However, there would be adverse genetic and aesthetic ramifications for stock enhancement produced fish.
Therefore, remedies for the conditions should be examined.

Conclusions

Both mahimahi and threadfin are high-value species in Hawaii that exhibit considerable potential for aquaculture development. Although specific behaviors and adaptability to culture vary between these two species, there appear to be similar attributes that are the keys to their successful nursery and growout culture. Special attention is needed in the areas of aggressive behavior, system design, feeding and feed quality in the nursery to maximize growth and survival of both species. Feed quality and system design are especially important for mahimahi growout; dietary requirements for mahimahi are also more stringent than for threadfin. Threadfin appear more resilient and adaptable to high density, land-based culture than mahimahi.

Literature Cited


