A Review of the Nursery and Growout Culture Techniques for Korean Rockfish (Sebastes schlegeli) in Korea

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Abstract

Following the successful production of hatchery-reared seedstock in 1993, rockfish (Sebastes schlegeli) became the most important cultured marine net cage species in Korea. A viviparous species, the Korean rockfish bears well-developed offspring and its newborn larvae should be fed 10 rotifers/ml. Commercial crumbled feed is slowly introduced to establish a strong survival foundation, and rockfish can be acclimated to the crumbled feed around Day 20 following reproduction. Rockfish feed well between 12 and 20°C, but the optimum temperature range is assumed to be 15-18°C. Market size is at least 500 g and can be attained in 18 months. Stocking density is between 15-20 kg/m³, but fish farmers generally yield 8-10 kg/m³. The primary feed type is a moist feed, and the protein requirements for juvenile and growout fish are around 40%. Dietary lipid content ranges from 7-10%. The optimum digestive energy/protein ratio is estimated to be about 8 kcal/g protein. The upper limits of carbohydrate and fiber content are 25% and 10%, respectively. With the development of rockfish aquaculture, disease occurrence is also on the rise.

Introduction

The rockfish (Sebastes schlegeli) had been cultured in Korea for many years before it reached commercial production levels. Wild-caught fry were easily captured with a double-stick net and a hand seine in the shallow west coast waters of the country, but the quantity was insufficient for net cage culture. In 1988, an intensive hatchery seedstock production trial was initiated, and in 1993 successful production levels promoted the rockfish to one of the most important net cage culture species in Korea. Today, the species is known for its commercially-profitable characteristics: It is well adapted to low water temperatures (5°C) and tolerant of crowded culture conditions; it grows quickly and has a high-market value. Therefore, it is anticipated that rockfish aquaculture will increase, despite Korea's harsh oceanographic conditions.

Seedstock Production

Collecting and Holding Broodstock

The age of first maturity is two years for males and three years for females. If female broodstock are too young, they produce very few larvae and if they are too old, they produce a large number of unhealthy larvae. Therefore, 4- or 5-year-old female broodstock are most suitable for reproduction.

Wild-caught broodstock can be held in the delivery tank for two or three days before reproduction without weaning, or they can be held from the previous winter until they are large enough for production. If the broodstock are transported to the indoor tank immediately prior to reproduction, the number of abnormal larvae increases and the survival rate decreases due to capture and transportation stress.
Hatchery-reared broodstock should be carefully selected and reared (Myeong 1994).

**Maturation and Reproduction**

Mature rockfish include 3-year-old females (35.2 cm) and 2-year-old males (28 cm), but the maturation period differs between them. Males mature from September to November, when copulation occurs (Figure 11). The production of newborn larvae is from the end of March to the beginning of June, when water temperatures range from 13-17°C (Hong et al. 1990).

With the approach of reproduction, gravid fish with enlarged abdomens stay primarily in the corner of the reproduction tank without moving. One to three days before reproduction, excretion decreases and broodstock hang around the tank after sunset. Just before reproduction, wild-caught broodstock generally regurgitate their stomach contents. Hatchery-reared broodstock do not regurgitate because they are well adapted to the rearing tank. When active opercular movements begin, larvae are delivered.

During reproduction, the broodstock whirl, stop and release embryos, which are deposited as a mass on the tank bottom. The females disperse the mass to the surface by fanning it with their pectoral fins. If the fanning is not done, the newborn embryos will die because they cannot rise to the surface on their own (Kusakari 1991; Myeong 1994). Reproduction mainly occurs at night, especially from 2100 to 0100 hours (Lee and Ko 1992). The newborn larvae are 5.3-6.2 mm in total length, and they can reach 29.3-33.7 mm by Day 60 (Hong et al. 1990). Generally, the number of larvae a female produces per kg body weight is around 100,000.

**Collection of Newborn Larvae**

Because reproduction occurs mainly at night, rearing water is not supplied until morning, which prevents the outflow of newborn larvae. Since larvae are positively phototropic, they can be concentrated within 20 or 30 minutes by shining a light on the tank side and siphoning the water. The other way to rear newborn larvae is to stock the broodstock in larval rearing tanks just before reproduction, and then remove them following reproduction.

**Larval Rearing Tanks**

Rearing tanks vary in size, but for management purposes, tank depths generally range from 1-1.5 m. To receive direct sunlight and control fouling organisms, a shade cloth is installed above the tank to limit light intensity to 100-500 lux. The larger the tank, the more stable the water quality and the earlier the fry can be weaned onto crumbled feed. Therefore, larger tanks are better for larval rearing (Lee and Ko 1993; Park et al. 1993; Myeong 1994).

**Stocking Density**

Rockfish larvae are generally stocked at 10,000-15,000/m³ (Ko and Lee 1991). Larvae mortality increases when they are about 15 mm, transferred to another tank and weaned onto a crumbled diet. Therefore, the stocking density may be reduced to 5,000-7,000/m³ to prevent transferring the growing larvae to another tank. At 2-3 cm total length (40-50 days old), the suitable stocking level will be 2,300 and 2,000/m³, respectively (Myeong 1994). Because there are usually size variations among individuals, grading is necessary to prevent cannibalism.
However, if grading is too frequent, retarded growth and high mortality may result.

Food

During the first week following reproduction, larvae are fed rotifers. Because rockfish are ovo-viviparous and the larvae are relatively large as compared with other species, the daily rotifer consumption is greater than in other species. Rotifer density should be at least 10/ml. From Day 8 through Day 20, larvae are fed a mixture of rotifers and Artemia nauplii and then weaned onto crumbled feed.

Weaning from live prey onto crumbled feed is difficult. For early weaning and good growth and survival rates, commercial crumbled feed and live feeds can be provided at the beginning of larval rearing. If weaning is not initiated during early larval rearing, massive mortality may occur sometime between Days 20 and 25. During the initial larval rearing stage, crumbled feed for 0.3-mm rockfish is provided several times a day as the prey density is decreased. The fish adapt to crumbled feed around Day 20 and 0.4-mm rockfish are fed at 20-30 minute intervals for early weaning onto a dry diet. From this time on, the size and quantity of feed should be increased gradually (Lee and Ko 1993; Myeong 1994).

Survival Rate

The survival rate of hatchery-reared seedstock varies among hatcheries, but is generally around 20% (Figure 12). As noted earlier, overall seedstock survival rates can be increased with early weaning onto crumbled feed. For example, when larvae are simultaneously fed the crumbled feed between Days 5 and 15, the survival rate increases to 47.8% (Kim and Park 1992).

Water Quality

During the first 10 days following reproduction, 5-10 x 10^5 cells/ml chlorella are added to the larval rearing tanks for shade, water stability and live food supply (Cheon and Lee 1990).

The rearing water is supplied after passing through a 3-μm sand filter.

Rearing water is exchanged at 20-50% until Day 8 or 10. After that, water exchange should be increased gradually. It seems that before weaning onto dry diets, rockfish are more sensitive to the stresses of frequent water exchange and bottom cleaning than other fishes. Therefore, it is important to limit the number of water exchanges by decreasing stocking densities during the initial stages of larval rearing.

Growout

Seedstock Sources

Wild-caught and hatchery-reared seedstock can be distinguished on the basis of survival rates. Between June and August, 3-5 cm wild seedstock are captured using the double stick-net and hand seine method where algae is abundant in Korea's west coast shallow waters. In September and November, when captured seedstock reach 10-15 cm, the fish are stocked into net cages for growout. About 15% of them will die because they cannot adapt to the new farm environment.

The 5-7 cm hatchery-reared seedstock are purchased by farmers between late June and early
July. Seedstock survival ranges from 30-50% when they have been acclimated to the culture environment. Farmers prefer this early-season production, which is controlled by temperature and photoperiod manipulation, because it accelerates the growout period. Rockfish that are 10 cm in May or June can reach marketable sizes of 400 g before winter.

Stocking Density

On fish farms, 25,000 5- to 7-cm fry are generally stocked in 5 x 5 x 5 m$^3$ wooden frame net cages, which are located along the coastlines of selected bays. In autumn, 100-g juveniles are stocked at 15,000 individuals/m$^3$ in the 5 x 5 x 5 m$^3$ cages. Fish weighing 300 g or more, are stocked at 20,000-25,000 individuals/10 x 10 x 10 m$^3$ net cage. Farmers aim for production goals of 8-10 kg/m$^3$.

The rockfish is a nonmigratory, demersal fish that inhabits shallow waters on rocky shores. It is more tolerant of crowded conditions than other cultured species. Min et al. (1992) cultured up to 13.8 kg in a small 80-L tank. These performance results were possible because high water exchange rates were maintained in the small tanks. But in practical aquaculture, the higher the stocking density, the higher the negative risk factors. Therefore, it is suggested that stocking densities between 15-20 kg/m$^3$ are the most practical.

Food

Rockfish are fed moist pellets and raw fish, such as sardine and mackerel. The moist pellets are made by adding a 30-50% artificial binder to chopped raw fish. If the binder is less than 30%, more food is lost due to increased floating time. When the fish reach more than 200 g, they are fed a combination of moist pellets and chopped raw fish.

Food production and feeding are labor intensive tasks. Rockfish fry are fed five times a day during the initial stages of net cage culture, but when they reach 100 g, it is sufficient to feed them twice a day. In December, the beginning of the wintering period, food is supplied once a day. However, during the new spring, this amount may be insufficient for fish weighing more than 300 g. When summer water temperatures increase, food intake decreases. Easily digestible food should be provided once every four or five days because rockfish are weak in water temperatures greater than 25°C. Moist pellets are fed at 5% (dry weight) of the fish's body weight per day. As the fish's weight increases, the food supply should be decreased to 2% of their body weight.

Growth

Rockfish stocked in net cages during the early summer can grow to 100-200 g by December of the same year. Between the following spring and summer, fish reach about 300 g. By December, the fish are marketable at 350-600 g and at 2 years of age, the fish weigh at least 1 kg. Figures 13 and 14 represent experimental rockfish growth and feeding results in indoor tanks. Optimum water temperatures for rockfish survival range from 12-20°C, and the optimum water temperature for growth is between 15-18°C. Even though rockfish is tolerant of low temperatures, its survival rate drops to 73.2% after 130 days of wintering because in January, water temperatures can drop to 4.5°C (Kim et al. in press). Water temperatures below 5°C are inhospitable to rockfish. Additionally, rockfish growth decreases in temperatures greater than 20°C, and they die easily.

Nutritional Requirements

Proteins

In a study to determine the protein requirements of Korean rockfish, Lee et al. (1993a) fed six isocaloric diets to juvenile- and growout-stage rockfish initially weighing 8 g and 200 g. To adjust the protein level from 20-60% with 8% intervals, white fish meal (the sole protein source) was gradually increased at the expense of dextrin and fish oil. Results of the experiment are shown in Figures 15 and 16. The growth parameters (daily weight gain, daily
protein gain and daily energy gain) of both groups increased to the 44% protein level with no additional responses beyond this point. With daily weight gain as a criterion, protein requirements were determined using two mathematical models. Maximum daily weight gain, determined by second-order polynomial regression analysis, occurred at 56.7% and 50.6% protein levels for the juvenile and the subadult groups, respectively. However, the minimum protein levels required for optimum growth, determined by broken line analysis, were about 40% for both groups. Nutrient utilization suggested that the protein requirements of both groups were close to 40%. Based on these results, 8- to 300-g Korean rockfish should be fed a 40% dietary protein level for optimum growth and nutrient utilization.

Besides biological protein requirements, economic and culture strategies should be considered when formulating practical feeds. This is a primary concern for Korean rockfish farmers who want to produce marketable size fish (500 g) before a second winter. The fish cannot grow in most inshore areas of Korea because of cold winter temperatures. Despite higher feed costs, increases in dietary protein will improve growth rates and decrease production time. To obtain good growth, it may be necessary to include more than 45% high-quality protein in formulated rockfish feeds. Furthermore, when high-quality fish meal is replaced with animal by-products or plant protein sources, the dietary protein level should be increased to compensate for amino acid imbalance and poor substitute digestibility.

**Energy to Protein Ratio**

Lee et al. (1993b) determined the optimum digestible energy/protein (DE/P) ratio for Korean rockfish (36 g in initial body weight) by feeding them 45% protein diets with graded levels of DE/P from 7.4-10 kcal/g protein. There were no significant differences between diets in daily weight or protein gain, feed efficiency or protein retention efficiency. Daily lipid and energy gain, and body and visceral lipid contents increased with an increasing DE/P, while protein gain per DE fed decreased gradually. These results indicate that increasing the DE/P to ≥ 7.4 kcal/g protein does not derive any performance advantages for Korean rockfish. Increased energy content led only to larger body fat deposits, especially in viscera. However, fish fed a 7.4 kcal/g protein diet showed lower body lipid content compared to initial body measurements. In addition, the energy retention efficiency of a 7.4 kcal/g protein

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![Figure 13](image13.png)

**Figure 13.** Results of indoor tank growth pattern experiments conducted on Korean rockfish from 8/8/92-6/7/94.

![Figure 14](image14.png)

**Figure 14.** Results of indoor tank weight gain experiments conducted on Korean rockfish from 8/8/92-6/7/94.
diet was significantly lower than the others. These results might suggest a slight energy deficiency in the diet. From these findings, the optimum DE/P ratio for the juvenile Korean rockfish diets was concluded to be about 8 kcal/g protein.

**Lipids and Essential Fatty Acids**

Korean rockfish essential fatty acids (EFA) nutrition has been intensively studied by Lee et al. (1993c, d, e, f; 1994a, b). Lee et al. (1993e) fed 5.9-g fish 10 diets containing different n-3-HUFA levels. Levels ranged from 0-4% at 8% dietary lipid levels. Weight gain and feed efficiency increased with increasing dietary n-3-HUFA levels up to 0.9% (Figure 17).

![Figure 15](image1.png)

*Figure 15. Second-order polynomial fitting of daily weight gain to dietary protein level in (A) juvenile and (B) sub-adult Korean rockfish initially weighing 8 g and 220 g, respectively (Lee et al. 1993a).*

![Figure 16](image2.png)

*Figure 16. Broken-line model of daily weight gain to dietary protein level in (A) juvenile and (B) sub-adult Korean rockfish initially weighing 8 g and 220 g, respectively (Lee et al. 1993a).*
Lee et al. (1994b) fed 2-g juvenile Korean rockfish 12 experimental diets containing various levels of EPA, DHA and combinations of both. In this experiment, growth, feed efficiency and nutrient retention efficiency were effectively improved by increasing dietary EPA or DHA up to 1%. There were no additional improvements above this level (Figure 18). Furthermore, growth and nutrient retention efficiency in the DHA feeding group were higher than those in the EPA feeding group. EPA and DHA in polar lipids of the liver were increased as dietary EPA and DHA increased. Whereas, those in nonpolar lipids were not affected by dietary EPA or DHA levels. The data obtained from these two experiments indicate that the n-3-HUFA dietary requirement for juvenile Korean rockfish is 0.9%. EPA and DHA requirements are both 1%, but DHA is more effective than EPA as an essential fatty acid.

The optimal total dietary lipid content for Korean rockfish was not separately quantified. However, referring to studies on DE/P ratios (Lee et al. 1993b) and protein requirements (Lee et al. 1993a), 7-10% of the total lipid content meets rockfish energy needs. However, the exact lipid amount in a diet should be adjusted to include dietary energy contribution from protein and carbohydrates. In Korean rockfish, soybean oil and beef tallow were used successfully as lipid sources for energy supplementation (Lee et al. 1994a; Lee in press).

**Carbohydrates**

Fish meal diets that include up to 10% alpha cellulose do not produce any significant adverse effects on growth, feed efficiency or protein retention efficiency (Lee and Lee 1994). The appropriate carbohydrate intake for 20- to 130-g rockfish has not been determined. However, in the study by Jeong et al. (1994), growth and feed efficiency were the same with 30% wheat flour (about 24% digestible carbohydrate in dry matter) as with 20% wheat flour, dextrin or raw starch. In other studies, Lee and Lee (in
press) and Lee et al. (1993a, b) noted that adding as much as 25% dextrin did not diminish fish performance or nutrient digestibility to any significant extent. Therefore, a 25% digestible carbohydrate level in dry matter could be tentatively recommended as the upper limit for Korean rockfish.

### Disease

Though there are only a few known Korean rockfish diseases, the variety and frequency are increasing with development of net cage aquaculture (Choi 1994).

#### Larval Rearing Diseases

- **Vibriosis**
  > Pathogen: *Vibrio ordali* (gram-negative rod)
  > Cause: high density, transportation, frequent grading stresses and low water exchange rates
  > Symptoms: head deformity, hemorrhaging and hypertrophy of opercula, exophthalmia, whitish muscle, furuncle and caudal hemorrhaging
  > Affected size: 3-5 cm total length
  > Treatment and countermeasure: increase water exchange rate and decrease stocking density
  > Drugs: Josamycin, Oxolinic acid

- **Gliding Bacterial Disease**
  > Pathogen: *Flexibacter maritimus* (gram-negative long rod)
  > Cause: high stocking density
  > Symptoms: pale skin color, tail rot and jaw erosion
  > Affected size: 4-5 cm in total length
  > Treatment: Oxytetracycline dip at 50-100 ppm, decrease stocking density

- **Whirling Disease**
  > Pathogen: *Staphylococcus epidermidis* (gram-positive rod) (Sim 1994)
  > Symptoms: blackish skin color, twirling, spiral and erratic movement
  > Treatment: Florphenicol, Erythromycin, Josamycin, Oxolinic acid

#### Growout Diseases

- **Streptococcus Disease**
  > Pathogen: *Streptococcus* sp. (gram-positive coccus)
  > Cause: diseased trash fish (food fish)
  > Symptoms: external - exophthalmia, hemorrhage, distended abdomen, protruded anus and fin base hemorrhaging; internal - abdominal ascites, intestinal and brain hemorrhaging and spleen enlargement
  > Treatment: decrease the cause of stress and suspend feeding
  > Drugs: Josamycin, Erythromycin, Florphenicol

- **Microcotyle Disease**
  > Pathogen: *Microcotyle* sp.
  > Treatment: 5-6%-sodium chloride dip for 2-3 minutes

- **Trichodina Disease**
  > Pathogen: *Trichodina* sp.
  > Treatment: 200-ppm formalin bath for 30-60 minutes

- **Lymphocystis Disease**
  > Pathogen: *Lymphocystis virus*
  > Symptom: pearl-like tumors on the head and fins
  > Occurrence: low temperature periods
Conclusion

Korean aquaculture species are separated into three groups based on culture seasons: warm-water species, such as yellowtail, seabream and bastard halibut; cold water species such as silver salmon and trout; and nonmigratory species such as rockfish, seabass and mullet. Warmwater species are cultured between the summer and autumn season in most Korean waters. Coldwater species are cultured between the winter and spring seasons under natural conditions. Nonmigratory species can be cultured throughout the year. In general, the nonmigratory species growth rate is low, but rockfish reach a marketable size of 500 g within one and one-half to two years. Furthermore, it is possible to obtain seedstock earlier in the year by controlling the temperature and photoperiod during broodstock production. When rockfish culture is initiated in the spring at water temperatures above 12°C, the fish can be grown to a marketable size before the water temperature drops below 12°C. Therefore, rockfish may become the most important net-cage cultured species in Korea. The limiting factor of rockfish aquaculture in Korea is securing a stable food supply.

Literature Cited


Lee, S.M. In Press. Effects of different dietary lipids on growth and body composition of the Korean rockfish (Sebastes schlegeli) and biochemical changes with starvation. Aquaculture. 7(2). (In Korean with English abstract).


Yellowtail (*Seriola quinqueradiata*), Red Seabream (*Pagrus major*) and Salmon (*Oncorhynchus sp.*) Culture in Korea

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Abstract

Mass culture of marine finfish was initiated in Korea around 1987 when fish farmers began culturing hatchery-reared fingerlings. In 1989, farmers began harvesting marketable sized fish and the production of yellowtail (*Seriola quinqueradiata*) peaked at 1,569 metric tons in 1989. However, because of poor wild fingerling harvests, yellowtail production decreased to 287 metric tons in 1992. Initially, juvenile yellowtail were exported to Japan for growout because winter water temperatures drop below 10°C in Korea. However, in the past two years, new aquaculture techniques have permitted the overwintering of fish. Juvenile red seabream (*Pagrus major*) grow to 40 g, 1-year-old fish to 350 g, 2-year-olds to 800 g and 3-year-olds to 1,280 g in weight. Mariculture of coldwater species, such as salmon (*Oncorhynchus sp.*) and trout, also has been introduced into Korean waters. Between November and December, coho salmon and trout smolts weighing about 100 g are transported from inland hatcheries to ocean net pens. By the following June, the average coho salmon weighs more than 2 kg.

Introduction

Marine culture was first introduced to Korea in the 1960s and since then has become a major component of the aquaculture industry. Production reached 787,000 metric tons (MT) in 1985, which accounted for 24% of the total fisheries production in the same year. However, most of those products were invertebrates and seaweeds. In 1985, marine finfish production remained at 1,413 metric tons, of which 93% was yellowtail (*Seriola quinqueradiata*) (Table 22).

The growout and marketing of high-value marine finfish was initiated around 1987 in Korea when fish farmers began culturing hatchery-reared flounder (*Paralichthys olivaceus*), rockfish (*Sebastes schlegeli*), seabass (*Lates calcarifer*) and red seabream (*Pagrus major*) fingerlings. The industry has been limited mainly by low winter temperatures, which occasionally drop below 10°C. For example, yellowtail cannot survive winter temperatures in Korea, so its farming is limited to summer seasons. Therefore, before water temperatures drop too much, the fingerlings are exported to Japan. Coldwater fishes, such as trout (*Salmo sp.*) and salmon (*Oncorhynchus sp.*), also have been introduced into Korean waters.

Coho salmon has been cultured successfully in seawater using net pens (cages). Coho salmon and trout smolt raised in southern coast mariculture facilities have proven to be fast-growing fish that reach market sizes within six or seven months, generally in the late spring.

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Regional Environmental Characteristics

Samchonpo

June through October water temperatures in the Samchonpo area remain above 20°C because of warm effluent from the local power plant. Thus, in terms of water temperature and dissolved oxygen, Samchonpo is an ideal place to culture yellowtail and red seabream. But, since the water is shallow, transparency is easily disturbed by small waves or rain. Another problem is that the culture area is completely dependent upon the power plant for warm water.

Chungmu

In terms of water circulation and depth (15 m), the Chungmu area is ideal for culturing various fish species. Furthermore, since water temperatures remain above 20°C from July through September, the area provides natural growout conditions for warmwater species, such as yellowtail and seabream. However, during the winter, water temperatures drop below 10°C and inhibit overwintering of fish.

Yellowtail (Seriola quinqueraudata)

Yellowtail grow 30-40 cm a year, reaching 1 m or more by adulthood. The spawning period is from March to April, and juvenile fish are found from May to June in the coastal waters of southern Korea (Chyung 1977). Yellowtail move south when the temperature drops below 10°C, and seedstock can be collected in the seas around Hongdo and Kukdo Island of Kyungsangnam-do Province (KORDI 1987). The optimal growout temperature for yellowtail is around 28°C, and the upper limit is 30-32°C. From July 9 to November 5 (Figure 19) in the Chungmu region, 4.6-g fingerlings (7.3 cm) grow to 371.2 g (28.3 cm). In the Samchonpo region, fish weighing 17.6 g on July 19 grow to 690.0 g by December 16 of the same year. When water temperatures remain above 20°C, a combination of frozen fresh fish and commercial feed (1:1 moist pellet) is as efficient a feed as frozen fish alone. As the winter seawater temperature falls below 10°C, special methods for wintering yellowtail stocks are necessary.

Experiments were conducted using heated effluent from the Samchonpo Electric Power Plant to maintain at least 10°C temperatures at the discharge area. It was determined that successful wintering is possible if a generator is
operated during the entire winter season. The overwintered 654-g yellowtail, however, grew slowly from March to June. But from that time on, the 1-year-old yellowtail that were 810 g (initial) in body weight showed remarkable growth up to 3.17 kg (final) by December (Figure 20).

During the experimental culture period, several diseases or parasites affected yellowtail. Skin suckers, gill suckers, _Vibrio_ sp., pseudotuberculosis, feed toxicosis, abdominal dropsy and streptococcus disease occurred in some of the fish. Pseudotuberculosis and feed toxicosis are known to cause death.

**Red Seabream (Pagrus major)**

Red seabream are widely distributed in Korea’s coastal waters. The optimal temperature range for the species is 10-28°C. When they reach 27 cm in body length, seabream mature and begin to spawn. The spawning season is April through June, and major spawning grounds are distributed along the coast of southern Korea and around Kyushu, Japan. Juvenile red seabream spend their early lives in the coastal waters of Korea, and when the water temperature drops below 10°C, they move southward for wintering. During natural larval and juvenile stages, the major food organisms are protozoans and copepods. When the fish reach 3 cm in total length, they feed on isopods, shrimp, crabs and polychaetes. Red seabream grow about 130 mm a year and mature at 3 years of age. The minimum broodstock size for red seabream females is 33 cm (880 g) and 22 cm (840 g) for males.

At the Chungmu hatchery, red seabream fingerlings are reared as follows: newly-hatched 2-mm larvae grow to 3.8 mm in 10 days (KORDI 1990a). The survival rate during this period is 98%, and those that survive are 7.7 mm in total length. However, from Days 10-22, the mortality rate increases to about 60%. When larvae

---

*Figure 19. Body weight changes in 1-year-old fish at Chungmu and the Samchonpo experimental fish culture stations.*

*Figure 20. Body weight changes of 1-year-old yellowtail.*
Table 23. Results of a rearing experiment on 1-year-old red seabream.

<table>
<thead>
<tr>
<th>Period: July 7 - November 15 (122 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Group: 1-year-olds</td>
</tr>
<tr>
<td>Cage Size: 5 x 5 x 5 m</td>
</tr>
<tr>
<td>Initial</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Final</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Mortality</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Survival rate (%)</td>
</tr>
<tr>
<td>Increment (kg)</td>
</tr>
<tr>
<td>Dry weight of feed (kg)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Daily feeding rate (%)</td>
</tr>
<tr>
<td>Daily growth rate (%)</td>
</tr>
<tr>
<td>FCR</td>
</tr>
<tr>
<td>Food conversion rate (%)</td>
</tr>
</tbody>
</table>

display size disparity, cannibalism is also observed. It is therefore necessary to size grade and adjust culture densities. After 40 days, seabream grow to 13.5 mm and another massive mortality takes place. By this time the survival rate is about 25%. The surviving fish are moved to net pens in an enclosed coastal sea. At 130 days of age, the survival rate is 7.5% and fingerlings grow to 9.5 cm.

Growth experiments on 1- and 2-year-old red seabream were conducted at the warmwater Chungmu station. During an 122-day experiment (Table 23), 1-year-old fish grew from 132.6-335 g in average weight. The food conversion ratio (FCR) and daily growth rate (DGR) were 3.1:1 and 0.7%, respectively. During a 213-day experiment (Table 24), 2-year-old fish grew from 441.8-769.9 g and FCR and DGR were 3.5:1 and 0.2%, respectively. During an 181-day experiment, 2-year-old fish grew very little (769-861 g) because of low water temperatures during the winter season.

**Coho Salmon**

Coho salmon remain in freshwater until they reach the smolt stage, after which time they are grown in seawater.

Coho salmon eggs imported from the United States are hatched and cultured for two to three years in freshwater (KORDI 1989). Eggs collected in November and December are viable for 20 days in 12.4°C water. Eggs are 0.6-0.8 mm in diameter and weigh 0.16-0.30 g. Females weighing about 1 kg carry 700-1,500 eggs. The eye development rate is 37-78% and the hatching rate is 35-75%. Feeding experiments demonstrate better growth rates when fingerlings are fed cow liver, tubifex worms (thread worms) and formulated trout diets. Two-year-old fish (290-530 g) reared in marine waters are acclimated in freshwater for four days with 100% survival. This makes it possible to culture large marine broodstock in freshwater.

The average hatching rate of 50,000 imported eyed-eggs is 89.9%. Fry average 2.02 cm in
length and 0.21 g in weight. The eggs hatch in January and by September grow to an average 17.8 cm in length and 64.4 g in weight. Domestic coho salmon average 17.4 cm in length (KORDI 1991) and 55.6 g in weight, showing a lower growth rate than their imported counterpart. Freshwater coho salmon (11-132 g) show 100% survival during one to three days of marine water acclimation.

To relieve transportation stress, three to four days of acclimation is required. After a six-day acclimation period, fish were transported from Yangyang Inland Fisheries Institute to the Chungmu region. During this experiment, 96% of the 288 dead were 40- to 85-g parr-stage fish. Therefore, it is recommended that only smolts weighing more than 100 g be used as marine culture seedstock.

Experiments on two size classes were conducted to determine the appropriate seedstock size for culture (KORDI 1990b). In December, the average weight of the smaller size class was 63.3 g and the larger class was 127 g. Until April, the growth rate for both classes was similar with a food coefficient of 1.4 and 1.6, respectively. However, by June 30, the larger fish accelerated to an average weight of 2.24 kg. The average weight of the smaller size class was 546.7 g—too small for commercial use. Because coho salmon cage culture is limited to six or eight months, fish larger than 100-200 g are recommended as seedstock.

A comparative study of domestic and imported fish growth was conducted from February 20 through April 7, 1989. The daily growth rates did not differ significantly. They reached a rate of 1.3 and 1.4, and the food coefficient ratios were 1.3 and 1.4, respectively. Two cage sizes were tested for coho salmon growth rates. The daily growth rate in a 10 m x 10 m x 5 m cage was 1.3 and in a 5 m x 5 m x 5 m cage growth was 1.1.

Three kinds of diets were fed: frozen, formulated and mixed (half frozen and half formu-
Table 25. Growth comparisons between net cage cultured juvenile and 1-year-old coho salmon.

<table>
<thead>
<tr>
<th>Period: December 17 - February 21 (66 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cage Size: 5 x 5 x 5 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experimental Group</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>juveniles</td>
<td>1-year-olds</td>
</tr>
<tr>
<td><strong>Initial</strong></td>
<td>800</td>
<td>400</td>
</tr>
<tr>
<td>Number of fish</td>
<td>133.6</td>
<td>158.4</td>
</tr>
<tr>
<td>Total weight (kg)</td>
<td>167.0</td>
<td>396.0</td>
</tr>
<tr>
<td>Mean body weight (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Final</strong></td>
<td>796</td>
<td>397</td>
</tr>
<tr>
<td>Number of fish</td>
<td>503.9</td>
<td>339.3</td>
</tr>
<tr>
<td>Total weight (kg)</td>
<td>633.1</td>
<td>854.6</td>
</tr>
<tr>
<td>Mean body weight (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mortality</strong></td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Number of fish</td>
<td>1.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Survival rate (%)</td>
<td>99.5</td>
<td>99.3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Increment (kg)</strong></td>
<td>371.9</td>
<td>182.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry weight of feed (kg)</td>
<td>Raw feed</td>
<td>272.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>144.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Formulated feed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>68.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td>213.1</td>
</tr>
<tr>
<td><strong>Daily feeding rate (%)</strong></td>
<td>2.2</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Daily growth rate (%)</strong></td>
<td>2.0</td>
<td>1.2</td>
</tr>
<tr>
<td>FCR</td>
<td>1.1:1</td>
<td>1.2:1</td>
</tr>
<tr>
<td><strong>Food conversion rate (%)</strong></td>
<td>93.4</td>
<td>85.8</td>
</tr>
</tbody>
</table>

The food coefficient for the mixed diet was 1.4, which was lower than the 1.6 and 1.5 of the frozen and formulated diets, respectively. The daily growth rate was 1.4 (mixed diet), 1.2 (frozen diet) and 1.1 (formulated diet).

Growth comparisons of juvenile and 1-year-old coho salmon (Kim et al. 1990) were conducted at Chungmu Experimental Fish Culture Station from December 17, 1989 to April 26, 1990. During the first 66 days of the experiment (Table 25), the juvenile group grew on average from 167-633.1 g and the FCR and DGR were 1.1:1 and 1.2%, respectively. In the same period, the 1-year-old fish grew on average from 396-854.6 g and the FCR and DGR were 1.2 and 1.2%, respectively. During the second 63 days (Table 26), the groups grew to 1,171.9 g and 1,239.7 g, respectively. FCRs of these two groups were 1.5 and 2.6, respectively and DGRs were 1.0% and 0.7%, respectively. Juvenile fish consumed more feed and demonstrated better FCR and DGR than the 1-year-old fish. FCR and DGR sharply decreased as fish weight increased. Therefore, juveniles appear to be the more appropriate seedstock size for seawater cage culture. Increasing juvenile smolting rates within a single season may be necessary.

Other Salmonid Species

A feeding experiment on salmon (KORDI 1992) (coho salmon, rainbow trout, kamloops trout and steelhead trout) was conducted at Chiac Fisheries Company from January to December 1991 to determine the species' growth rate and feed intake efficiency. After 11 months, the trout reached 154 g, 110 g and 85 g, respectively. Among them, kamloops trout's growth, feed intake and disease resistance were superior. Steelhead and kamloops trout needed three, and seven to 10 days for seawater acclimation, respectively. However, kamloops trout showed greater resistance than native rainbow trout to external wounds and stresses caused by transportation. At the end of the experiment, kamloops trout weighed 3.2 kg, and the native
Table 26. Growth comparisons between net cage cultured juvenile and 1-year-old coho salmon

<table>
<thead>
<tr>
<th>Period: February 22 - April 26 (63 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cage Size: 5 x 5 x 5 m</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>Experimental Group</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Number of fish</td>
</tr>
<tr>
<td>Total weight (kg)</td>
</tr>
<tr>
<td>Mean body weight (g)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Final</td>
</tr>
<tr>
<td>Number of fish</td>
</tr>
<tr>
<td>Total weight (kg)</td>
</tr>
<tr>
<td>Mean body weight (g)</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Mortality</td>
</tr>
<tr>
<td>Number of fish</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Survival rate (%)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Increment (kg)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Dry weight of feed (kg)</td>
</tr>
<tr>
<td>Raw feed</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Formulated feed</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Daily feeding rate (%)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Daily growth rate (%)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>FCR</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Food conversion rate (%)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Rainbow trout and coho salmon weighed 2.0-2.2 kg. Rainbow and kamloops trout (Table 27) showed higher FCRs (1.2:1 and 1.2:1) and daily growth rates (1.7% and 1.6%) than coho salmon (51.5%, 1.3%). Feeding experiments were conducted using various moist pellets (MP), which were mixtures of commercial feed and frozen fish. Mixing rates for commercial and frozen feeds were (A) 7:3, (B) 5:5, (C) 3:7 and (D) 0:10. The FCR for A (1.4) and B (1.7% and 1.6%) were lower than C (2.0) and D (1.9). Daily growth rates were similar, 1.6% and 1.5% for the different initial stocking densities of 1.6 kg/m² and 3.4 kg/m². Feeding experiments on rainbow trout were conducted using (A) 5:5 and (B) 3:7 MP. The food efficiency for group (A) was 1.0, which was lower than group (B) 1.30.

Conclusions and Recommendations

Seedstock production techniques need to be improved for high-value fishes, such as yellow-tail, seabream, puffer (Tetraodontidae), flounder (Paralichthys olivaceus) and grouper (Epinephelus sp.), to encourage fish farming in Korea.

Fish stocks should be cultured during the low winter temperatures in warmwater discharges from local power plants to increase the overall production and profitability of nursery and growout operations.

Alternating culture species based on seasonal differences is recommended for yellowtail and salmonids. Using yellowtail facilities, coho salmon and rainbow trout smolt can be reared to marketable sizes within seven to eight months.

Studies indicate that kamloops trout may be the most suitable species for salmonid culture. The newly imported species is superior in growth and food conversion, and its seedstock are more available than salmon and other trout species.
Table 27. Growth comparisons between net cage cultured coho salmon, rainbow trout and kamloops trout.

<table>
<thead>
<tr>
<th>Experimental Group</th>
<th>Coho salmon</th>
<th>Rainbow trout</th>
<th>Kamloops trout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of fish</td>
<td>603</td>
<td>1,067</td>
<td>491</td>
</tr>
<tr>
<td>Total weight (kg)</td>
<td>161.5</td>
<td>161.7</td>
<td>161.6</td>
</tr>
<tr>
<td>Mean body weight (g)</td>
<td>267.9</td>
<td>151.5</td>
<td>329.4</td>
</tr>
<tr>
<td>Final</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of fish</td>
<td>597</td>
<td>979</td>
<td>462</td>
</tr>
<tr>
<td>Total weight (kg)</td>
<td>652.6</td>
<td>977.3</td>
<td>894.8</td>
</tr>
<tr>
<td>Mean body weight (g)</td>
<td>1,093.1</td>
<td>998.3</td>
<td>1,936.7</td>
</tr>
<tr>
<td>Mortality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of fish</td>
<td>6</td>
<td>88</td>
<td>29</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>3.5</td>
<td>41.5</td>
<td>28.1</td>
</tr>
<tr>
<td>Survival rate (%)</td>
<td>99</td>
<td>91.8</td>
<td>94.1</td>
</tr>
<tr>
<td>Increment (kg)</td>
<td>494.6</td>
<td>857.1</td>
<td>761.3</td>
</tr>
<tr>
<td>Dry weight of feed (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw feed</td>
<td>480.1</td>
<td>499.8</td>
<td>469.4</td>
</tr>
<tr>
<td>Formulated feed</td>
<td>480.1</td>
<td>499.8</td>
<td>469.4</td>
</tr>
<tr>
<td>Total</td>
<td>960.2</td>
<td>999.6</td>
<td>938.8</td>
</tr>
<tr>
<td>Daily feeding rate (%)</td>
<td>2.5</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Daily growth rate (%)</td>
<td>1.3</td>
<td>1.7</td>
<td>1.6</td>
</tr>
<tr>
<td>FCR</td>
<td>1.91</td>
<td>1.21</td>
<td>1.21</td>
</tr>
<tr>
<td>Food conversion rate (%)</td>
<td>51.5</td>
<td>85.7</td>
<td>81.1</td>
</tr>
</tbody>
</table>

To make kamloops trout farming a more competitive industry, the following approaches are recommended:

- develop hatchery seedstock production techniques similar to those for yellowtail (this a major constraint in large-scale fish farming);
- develop wintering techniques similar to those for yellowtail and seabream seedstock;
- develop experimental diets with low fish meal content;
- develop low-cost culture techniques (reduce production costs);
- develop processed food varieties (expand trout consumption and demand).

**Literature Cited**


A Review of the Nursery and Growout Culture Techniques for Red Seabream (*Pagrus major*) and Striped Jack (*Caranx delicatissimus*) in Japan

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Nachikatsuuracho, Wakayama
Japan

Abstract

Red seabream (*Pagrus major*) seedstock are primarily cultured in land-based hatchery tanks until they reach 15-20 mm. These juveniles are transferred to ocean net cages, reared to 70 mm and then distributed to farmers. During growout, fish are accommodated in net cages measuring 7-10 x 7-10 x 4-8 m and fed moist or hard pellets. It is desirable to place the net cage where there is a good supply of open seawater and the water temperature is between 12 and 28°C. The optimum culture density is 7-10 kg/m³. Although red seabream growth varies with water temperature, the fish can reach 80-300 g in one year, 0.5-1.5 kg in two years and 0.8-3.0 kg in three years. The 1.0-1.5 kg brilliantly colored red seabream sell for the highest prices. Cultured red seabream tend to be darker in color and techniques to improve the color are still being developed. Color is primarily improved when the fish are fed a diet that includes astaxanthin. Cultured red seabream develop diseases from viral, bacterial and parasitic infections, and from eating nutritionally inadequate diets. Remedies and preventions are presented for each disease.

Striped jack (*Caranx delicatissimus*) farming began in 1955 and production has increased since then. Recently, seedstock production techniques have been developed and now striped jack seedstock are primarily produced in hatcheries. Juveniles are transferred to ocean net cages from land-based hatcheries when they reach 40 mm. At 70 mm, they are sorted, counted and distributed to farmers. Striped jack farming equipment is the same as that used for red seabream culture. Water temperatures should be kept within 15-29°C because striped jack prefer warm water. Moist and hard pellets are widely used for feeding. The striped jack reaches 150-400 g in one year, 0.7-1.0 kg in two years and 2.0-2.5 kg in three years. Fish weighing 1.0-1.5 kg are the most marketable. The total annual production of striped jack is about 2,000 tons in Japan. The striped jack is said to be resistant to disease, but should be handled carefully because it is easily injured by handling. Also, the species is seriously affected by red tides. Remedies and preventions of bacterial and parasitic infections are given in this paper.

Red Seabream Culture

Overview

The Japanese people often purchase red seabream (*Pagrus major*) for celebrations and holidays. Consequently, it is in demand throughout the year. Like turkey in the United States, red seabream has been the king of fish since old times in Japan, not only because of its delicious taste but also for its beautiful red color and shape. In spite of overproduction, red seabream recently sold for prices as high as ¥1,000-1,500/kg, however, the maximum price was ¥3,000-3,500/kg.

In Japan, Kitahara first studied red seabream culture in 1887. In 1902, the first hatchery center was built at Onomichi, Hiroshima Prefecture, and the second national hatchery center was
Built at Oocho, Hiroshima, where Kajiyama, Nishioka and other researchers gained basic knowledge about red seabream culture. After a break of a few decades, research on red seabream culture was restarted by Shikama Yamashita. The first successful rearing of hatchery-fertilized red seabream eggs through the juvenile stage was in 1962. It demonstrated the possibility of culturing hatchery-reared fish (Yamashita 1967). Afterwards the technology for mass seedstock production progressed on the basis of these studies.

Commercial farming of red seabream started around 1965 and spread throughout the eastern part of Japan by 1970. The rapid expansion of red seabream farming was a result of increased scientific knowledge, decreased wild red seabream catches, stable production of hatchery-reared-seedstock, development of formulated feeds, low prices for cultured yellowtail (Seriola quinqueradiata), improvements in Japan’s social conditions and the corresponding drive to meet people’s more expensive tastes in the expanding economy (Akazaki 1991).

Total aquaculture production of red seabream in Japan was 453 tons in 1970, 14,757 tons in 1980, 51,676 tons in 1990 and 65,950 tons in 1992 (Data Book of Fish Culture 1993). Today, production is estimated to be as high as 70,000 tons.

**Seedstock Production**

There are three seedstock sources for culture: open-water capture, foreign country imports and hatchery production. In 1965, wild seedstock were used for the most part; however, the catches were unstable. Supplies were supplemented with imported seedstock from Hong Kong, Korea and other countries. As rearing techniques progressed and mass production became possible, hatchery-reared seedstock replaced wild seedstock. Hatchery-reared seedstock production was 2.78 million in 1977, more than 10 million in 1982, and by 1989 reached 77.56 million (Obata 1991).

Production of rapidly growing seedstock has been possible by repeating the process of select-
Table 28. Commercially available formulated diets for juvenile marine fishes.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrolyzed fish meal 1</td>
<td>50.0</td>
</tr>
<tr>
<td>Krill meal</td>
<td>25.0</td>
</tr>
<tr>
<td>Others 2</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Approximate Composition

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein</td>
<td>&gt; 55.0</td>
</tr>
<tr>
<td>Crude fat</td>
<td>&gt; 11.0</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>Crude ash</td>
<td>&lt; 18.0</td>
</tr>
<tr>
<td>Calcium</td>
<td>&gt; 2.0</td>
</tr>
<tr>
<td>Phosphate</td>
<td>&gt; 1.5</td>
</tr>
</tbody>
</table>

1 Hydrolyzed by microbial protease
2 includes squid meal, skim milk, egg white powder, yolk powder, clam extract, squid powder, shrimp powder, active gluten, lecithin, fish oil, calcium phosphate, betain and inosinic acid.

mm total length. However, growth rates vary with location. Healthy, well shaped juveniles are then hand-selected and counted. During selection and counting, care should be taken not to injure the fish. This will reduce the incidence of vibriosis infections. Selected seedstock are transported to other farms in well boats or carts.

Growout Culture

• Culture Systems

There are two types of red seabream farms: net cages or embankment ponds that are separated from the ocean by a) soil banks or b) partitioning small bays by banks, piles or netting. Currently, net cages are the primary growout culture system. Synthetic, and occasionally wire nets, are used for cages, which are usually square, but may be octagonal or round. The galvanized steel frame, 7-10 x 7-10 x 4-8 m, is kept afloat with 200- to 400-kg anchored styrofoam buoys (Yamaguchi 1978; Fukusho 1986). During the first stage of growout culture, an 18-mm mesh net is used, and as the fish grow, a wider mesh net is installed. Finally, a six or seven meshes/15-cm net is used for 3-year-old fish weighing 0.8-3.0 kg. Changing or flushing nets is necessary every 10 to 20 days, especially in summer because the nets become clogged by fouling organisms. Formerly, Distributylin oxide-based (TBTO) anti-fouling agents were used, but they are now prohibited because they pollute the surrounding water and fish. Harmless anti-fouling agents are now being developed.

Net cages have many advantages. They are cheap and easy to make, anti-corrosive and have a long life. It is possible to use high stocking densities because of good water supply, ease of fish harvest and placement, mobility and compactness. On the other hand, net cages have some disadvantages. They are susceptible to damage or storm loss, feeding is time consuming when many small cages are in use, the nets must be frequently changed or flushed, and there is the possibility that escaped fish will be overlooked (Yamaguchi 1978).

It is important to adjust the fish density with growth because it limits the amount of stress the fish experience. Optimum densities differ between localities and farmers. For example, in Kumamoto Prefecture, 1-year-old fish are reared at 1.3-2.9 kg (2.0 kg average)/m³, 2-year-olds at 4.5-14.0 kg (6.9 kg average) and 3-year-olds at 7.5-15.6 kg (9.4 kg). If 2-year-old fish are cultured at densities greater that 14.0 kg per/m³, they are in danger of suffering abrasions during the winter season. A fish density of 7.0 kg/m³ is recommended by many government agencies as the optimum density (Iseda 1986).

• Farm Environmental Conditions

Red seabream feed and grow well in water temperatures ranging from 20-28°C. They feed poorly in water lower than 20°C and cease feeding at temperatures lower than 10°C. In stationary water where the temperature decreases gradually, the fish can survive in 5°C, but in actively moving water, they will die at 7°C. At temperatures higher than 29°C, red seabream do not feed well and often develop diseases (Yamaguchi 1978; Fukusho 1986).
Generally, the dissolved oxygen (DO) content decreases in July and reaches its lowest point in September and October. For seabream culture, DO should not drop below 4 ppm/L. The fish come to the surface in water of 3.5 ppm/L DO and will die in water less 1.8 ppm/L DO (Hamaguchi 1993). If salinity is decreased gradually, red seabream can tolerate salinities as low as 16 ppt for a limited time. However, in the case of sudden salinity decreases, they are apt to be physically damaged (Ishioka 1984).

Red tide is an unresolved problem for the aquaculture industry. Red tides caused by Cochlodinium ’78-Yatsushiro type cells can be serious. It is reported that red seabream juveniles, most weighing an average of 5 g, died within one hour in water containing 5,000 cells Cochlodinium/ml. The fish may have suffocated because of poor gas exchange through gill filaments that were covered with Cochlodinium cells (Iseda 1986).

- Feeds and Growth

Since 1965, frozen and raw fish, such as sardines, mackerel, sand lance and jack mackerel, have been fed to red seabream and yellowtail. For example, red seabream juveniles weighing 9.7 g were grown out from August to November of the following year at Nagasaki Prefectural Fisheries Experimental Station. The highest feeding rate per day was 24.4% of body weight on August 1 and lowest at 1.15% in the January coldwater season. During the cold season body weight decreased. In the next August warmwater season, the feeding rate increased to a high of 7.76%. Generally, the feeding rate decreased as fish grew. The conversion factor, although it fluctuated monthly, ranged from 4.17% to 24.23%, averaging 11.29%. The feed efficiency ranged from 4.20% to 23.94%, averaging 8.83%. Fish grew to an average 715.5 g at the end of the culture cycle (Yamaguchi 1978).

Red seabream that feed on raw fish have large amounts of fat in the abdominal cavity (Morishita 1988). Using formulated feeds and seaweed additives is reported to be effective in reducing the accumulated fat (Nakagawa and Kasahara 1986; Yone et al. 1986; Nakagawa 1990a, b).

Formulated feed has been used in Japan since around 1970. According to 1992 statistics, red seabream formulated feed use amounted to 132,459 tons and expanded to where farmers now use it for 64% of feed supplies (Nakayama 1994). The advantages of using formulated feeds are as follows; 1) easy to transport, store, prepare and feed, 2) easy nutrient and vitamin supplementation, 3) reduced farm and water pollution, and 4) improved meat quality.

Formulated feed is processed into hard and moist pellets. The former is divided into two feeds for larvae and juveniles and for young fish. Several brands are sold at the market. Among these, the formula feed nutrient composition is shown in Table 29. The results of a feeding experiment conducted from May to December 15, 1993 are shown in Table 30. There was no difference between feeding hard and moist pellets. Researches from Kinki University Fisheries Laboratory have successfully bred rapid-growing red seabream that reach more than 1.0 kg in two years.

Red seabream require vitamin B1, B2, B6 and C, choline, pantothenic acid, nicotinic acid and inositol. Biotin and folic acid are not as important. Vitamin deficiencies in red seabream have been studied and shown to decrease growth rates and appetites (Takeda et al. 1989; Yone 1989).

Improving body color is an important area of research in red seabream culture. Generally, the natural red seabream habitat is in deep water where sunlight is limited. Astaxanthin-, lutein- and tararaxanthine-rich crustaceans are the fish's preferred food, hence their brilliant red body color (Katayama et al. 1965). In contrast, cultured red seabream color is darker because of ultraviolet rays at depths shallower than 10 m, which increase the skin melanins. Furthermore, the color is poor due to the scarcity of astaxanthin in the cultured food fish.
Table 29. Red seabream formulated diet composition.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Growout Pellet (%)</th>
<th>Compound (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish meal</td>
<td>62.0</td>
<td>48.0</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>2.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Corn gluten meal</td>
<td>-</td>
<td>5.0</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>23.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Rice bran</td>
<td>2.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Pollack liver oil</td>
<td>8.0</td>
<td>-</td>
</tr>
<tr>
<td>CMC</td>
<td>-</td>
<td>1.5</td>
</tr>
<tr>
<td>Guar gum</td>
<td>-</td>
<td>2.0</td>
</tr>
<tr>
<td>Calcium phosphate</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Vitamin mixture</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Mineral mixture</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Approximate Composition

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein</td>
<td>47.1</td>
</tr>
<tr>
<td>Crude fat</td>
<td>13.6</td>
</tr>
<tr>
<td>Crude fiber</td>
<td>1.0</td>
</tr>
<tr>
<td>Crude ash</td>
<td>12.5</td>
</tr>
<tr>
<td>Calcium</td>
<td>2.8</td>
</tr>
<tr>
<td>Phosphate</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Farmers give high priority to improving seabream body color because it influences the market price. Until recently, krill (*Euphausia* sp.) and mysids (*Neomysis* sp.) have been fed to improve seabream color. However, large quantities are needed, they are perishable and take a long time to feed (Yamaguchi 1978). Synthetic astaxanthin and astaxanthin-producing yeast and oils containing extracted pigments from krill or red swamp crawfish have been effective supplements. Stretching shade cloth across the top of the net cage also helps reduce pigmentation (Fujita et al. 1983; Yamaguchi and Miki 1985; Ito et al. 1986; Shitanda et al. 1987; Yone 1989; Fujii 1992; Mori 1993).


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dry Pellets (g)</th>
<th>Moist Pellets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total body weight (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>initial</td>
<td>22,050</td>
<td>21,100</td>
</tr>
<tr>
<td>final</td>
<td>45,400</td>
<td>44,200</td>
</tr>
<tr>
<td>Number of fish</td>
<td></td>
<td></td>
</tr>
<tr>
<td>initial</td>
<td>46</td>
<td>47</td>
</tr>
<tr>
<td>final</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Mean body weight (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>initial</td>
<td>479</td>
<td>457</td>
</tr>
<tr>
<td>final</td>
<td>1,009</td>
<td>982</td>
</tr>
<tr>
<td>Body weight of dead fish (g)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>998</td>
<td>1,055</td>
</tr>
<tr>
<td>Number of dead</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Feed intake (g)</td>
<td>61.796</td>
<td>107.257 (64,357)¹</td>
</tr>
<tr>
<td>Weight gain (g)</td>
<td>24,348</td>
<td>23,755</td>
</tr>
<tr>
<td>Feed efficiency (%)</td>
<td>39.4</td>
<td>36.9</td>
</tr>
<tr>
<td>Daily growth rate (%)</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>Daily feed rate (%)</td>
<td>1.07</td>
<td>1.14</td>
</tr>
</tbody>
</table>

¹ dry weight basis

Kumai and Nakamura (1977) crossbred red seabream with crimson seabream (*Eupynnis japonica*), whose body color does not become dark in culture conditions, and produced a cross-bred Machidai (tentative name). The cultured Machidai body color was greatly improved over the red seabream; however, its growth was inferior. To improve the growth rate, Kumai and Nakamura (1977) backcrossed Machidai with the red seabream and produced Machimodoshi (tentative name). Machimodoshi grows fast and has little melanin in its skin.
When astaxanthin is then added to Machimodoshi diets, the desired color is produced.

**Disease**

Red sea bream is said to be more resistant than yellowtail to disease; however, many kinds of seabream diseases have been reported. They are classified into four major categories: viral, bacterial, parasitic and nutritional diseases.

**Viral Diseases**

Lymphocystis infection, though rare, occurs during the cold water seasons and is accelerated in stressful conditions, such as transport or handling. Although it is not fatal, the fish cannot be sold at the market because of fin blisters and nicks. Treatment is currently unknown, so the fish are left alone until they recover.

Iridovirus infection first occurred in 1992. The infection starts in summer when water temperatures exceed 20°C, and continues until the end of November when water temperatures drop below 20°C. Young fish weighing 20-100 g are most susceptible to infection and the cumulative mortality has reached 20-30% on certain farms. The dark body color, pop-eyes and abrasions are recognized symptoms of sick fish. There is no known remedy; however, prevention may include separating and burning infected fish (Inoue 1991).

**Bacterial Diseases**

There are two types of Vibriosis infections. One breaks out in the warmwater season (primarily summer) and the other in the coldwater season (primarily winter). Symptoms of this infection are flaring and melting of fins, flaring of skin, scale-to-scale depilation, skin ulcerations and nebulia ramus of the eyes. The oral administration of the antibiotic substance oxytetracycline (OTC) is an effective remedy. To prevent infection, it is important to handle the fish carefully, avoid trauma and promote health care with proper medicine and nutrition (Kimura and Kusuda 1983; Hatai 1989).

Edwardsielliosis infections break out from August to November and are characterized by skin abscesses on the head, caudal peduncle and gills. Sometimes white tumors are formed in the spleen and the kidney. This bacteria is highly sensitive to OTC (Hatai 1989).

During nursery culture, 15-60 mm fish are apt to become infected with gliding bacteria (*Flexibacter maritimus*), which often badly damages the crop. Symptoms include ulceration of the snout skin and melting of the caudal fin. The bacteria is highly sensitive to OTC. To prevent the spread of this infection, remove the sick fish and culture the remaining fish at lower densities (Hatai 1989).

**Parasitic Diseases**

In the winter, *Breviglena* sp. disease is one of the main causes of death among 1-year-old fish. The simultaneous death of many fish is rare, but the disease paralyzes the fish by infecting the gill filaments. A 6-ppt salinity or hydrogen peroxide water bath for about two minutes is effective; however this remedy is apt to injure the fish. For prevention, parasite adhesion can be avoided with frequent net flushing (Ogawa 1988a, b; Hatai 1989).

Longicollum disease is caused by the parasite, *Longicollum pagrosomi*, which attaches to the red seabream rectum. Fish growth declines if the worms are present and the intestine will collapse if the fish are in serious condition. Abdominal inflation and flaring of the anus limbus often occur at the same time. There is no effective method of prevention because the worm's life cycle is unknown (Hatai 1989).

Fish develop nutritional diseases, such as yellow-fat and green-liver disease, after prolonged diets of raw fish. The oxidized oil is said to become harmful to fish because it decreases the protein digestive rate and creates vitamin E shortages. To prevent nutritional diseases, the feeds should be fresh and multiple vitamins should be included in the diet (Hatai 1989; Nakagawa 1990b).
Nursery and Growout of Red Seabream and Striped Jack

- Culture Problems

Red seabream culture has developed as a result of Japan's improved economic situation, established mass seedstock production techniques and improved culture techniques. However, recent overproduction of seedstock and adult fish has caused concern. If the situation continues, it is feared that red seabream aquaculture will collapse as a result of supply and demand imbalances. Since governmental control is not possible in Japan, voluntary control of the seedstock producers is needed to maintain appropriate production levels.

Striped Jack Culture

Overview

Striped jack farming began in Japan in 1955 (Harada 1986). The jack mackerel species is a high-value fish that sells for prices as high as ¥2500/kg. Before seedstock production techniques were developed, the price used to be as high as ¥4000/kg. In spite of its high price, striped jack production is quite poor. For example, only 1,853 tons of fish were produced in 1993 because of market limitations, wild-caught seedstock shortages and limited year-round warm farming areas. Striped jack hatchery culture was successfully developed in 1973 (Harada et al. 1984). However, by 1983, seedstock production barely attained 50,000 tons. By 1989, production had gradually increased, and reached 2.33 million tons. Over the next two years, production dropped and then increased abruptly after 1992. Current production is more than 6 million tons. Although striped jack culture has a 40-year history, the study of culture techniques, especially nutrition, has only recently begun. This focus resulted from the development of successful hatchery production techniques.

Seedstock Production

From May to August, limited quantities of 10- to 15-cm wild seedstock are captured and sold for as much as ¥1,000-1,500. Wild seedstock should be handled carefully to avoid injury; however, sometimes juvenile striped jack die anyway as a result of abrasions on their delicate skin. Hatchery seedstock production has only recently reached sufficient quantities for aquaculture, although the technology was implemented over 20 years ago.

Nursery Culture (Intervening Culture)

In the land-based hatchery, seedstock are produced and reared until they reach 4 cm in total length and then transferred to ocean net cages. The net cages used for striped jack nursery culture are the same as those used for red seabream nursery. However, since juvenile jack are larger than juvenile seabream, the net is 28 meshes/15 cm at the beginning of the cycle and 18 meshes/15 cm by the end of the culture cycle.

Fish are transferred to net cages in November, when the negative affects of low temperatures become a concern. During the winter, juveniles experience water temperatures ranging from 11.8-20.3°C. From late January to early February, the temperature drops as low as 11.8-12.4°C. Adult striped jacks have a low tolerance for cold temperatures, but the juveniles show a higher tolerance. Generally, before juveniles can be used as seedstock, they must reach 8 cm total length. Afterwards, the size graded and counted seedstock are transported by well boat and cart to the farms.

At Kinki University Fisheries Laboratory, researchers cultured 50,000-60,000 individuals per cage and fed them only a granular formulated feed (Table 28). Feed oils and vitamins were added as needed. At first the granular size was 700-1400 µm in diameter, increasing as the fish grew, and finally reaching 2000-2600 µm. There has not been a specific feed developed for striped jack at this time.

Growout Culture

- Culture Systems

The net cage has replaced the previously used embankment nursery ponds. The cage size,
materials and frequency of net replacement (as a result of fouling) are the same as those for red seabream or yellowtail.

For example, the culture density adopted at Kinki University Fisheries Laboratory was 0.69 kg/m$^3$. That is based on a density of 5,800 juveniles weighing 30 g each in a 256-m$^3$ net cage, which measures 8 x 8 x 4 m. As the fish grew, density increased to 6 kg/m$^3$. At the end of the first year, density was decreased to 4.7 kg/m$^3$ by dividing the stock into two portions. At the end of the second year, the density was 8.7 kg/m$^3$. That summer, density was decreased again by 60% to 7.3 kg/m$^3$. In November, the density increased to 11.9 kg/m$^3$. Following this procedure, it is proposed that the optimum density is about 10 kg/m$^3$ (Kumai 1990).

- **Farm Environmental Conditions**

Striped jack is intolerant of poor environmental conditions, such as inadequate temperatures and red tides. Therefore, the farm location is important. An appropriate location should have a good supply of open seawater and water temperatures should range from 18-28°C. For striped jack, temperatures higher than 24°C are optimum. Feeding is very poor at temperatures lower than 15°C. For example, fish enter a state of suspended animation at around 10°C—especially at 8°C (Kumai 1990). The striped jack is one of the least tolerant fish to red tide conditions and is more seriously damaged by the Gymnodinium 1965-type of red tide than other fish species. To prevent such losses the net cage should be moved to open water, where the red tide does not have an affect. If this cannot be done, or if the tides occur suddenly, it is effective to sink the net to a depth below the red tide organisms. This also keeps the fish from becoming restless. Starving the fish during a red tide outbreak also increases the fish's chances for survival (Torishima 1986a; Kumai 1990).

- **Feeds and Growth**

Until recently, the striped jack diet consisted of raw fish, such as sardines, mackerel and sand lance, or moist pellets. But now, dry or moist pellet feeds have been developed that striped jack will eat. For example, in Oita Prefecture feeding rates were standardized to around 20% of the fish's body weight for fish less than 20 g, 15% for 50- to 150-g fish, 10% for 300- to 500-g fish and 4% for 800- to 1,000-g fish at temperatures higher than 20°C.

The body weight is 400-650 g for 1-year-old fish, 700-1,000 g for 2-year-old fish and 2000-2500 g for 3-year-old fish (Torishima 1986a). This growth rate was achieved in winter conditions when the water temperatures were higher than 15°C. For example, seedstock with an average fork length of 6.4 cm and body weight of 3.2 g grew to 32.6 cm and 782.8 g during the nine months from April to January (Aoki et al. 1986). This research was conducted in the Bonin Islands at Chichi-jima, where water temperatures do not drop below 18°C. At Chichi-jima the striped jack grows well even in winter (Kato et al. 1987). During growout, the striped jack feed is the same as that used for red seabream and yellowtail, but further nutritional research on an exclusive striped jack feed is needed.

Striped jack production yields are higher than for other fish. Barring disaster, a 90% yield is expected for the three-year culture period.

- **Disease**

Currently, fewer diseases have been reported for striped jack than for red seabream or yellowtail. However, one viral disease and a few bacterial and parasitic diseases have been documented.

**Bacterial Diseases**

Striped jack are easily injured and develop Vibrio infection. Grazings and abrasions are the main infection routes (Torishima 1986b; Kumai 1990).
Viral Diseases

VNN (*Nodaviridae*) infections have occurred in cultured striped jack over the past five years. When broodstock are infected, their eggs often become infected and fry mortality increases. Symptoms of infection in adult fish include vacuolation of the brain and eyes. There is no effective remedy except for increasing water temperatures in the tank.

Symptoms of streptococcus infection include eye limbus, pop-eye, congestion and ulceration of the interior gill cover and caudal peduncle. The impact of streptococcus infection is not serious for the yellowtail, and antibiotic substances are an effective treatment. However, starving the fish is the most effective cure for this infection (Kumai 1990).

Parasitic Diseases

Striped jack infected with *Caliques* sp. become nervous and feed poorly. Also, the fish injure themselves and often die from rubbing against the net. *Caliques* sp. cannot tolerate freshwater baths, so when the fish is dipped, the parasite falls off. However, it does not die (Kumai 1990).

Culture Problems

More than 6 million striped jack seedstock are currently produced, which exceeds the market demand. However, production is unstable because seedstock often die from broodstock-derived viruses. Stable production will not develop until this virus problem is solved. It has been shown that striped jack feed well on formulated feed and grow as fast as when they are fed raw fish. An exclusive striped jack feed has not been developed and further nutritional studies are required.

Conclusions

Traditionally in Japan, red seabream has been in high demand for celebrations and holidays. Consequently, seabream culture has been practiced for the past 100 years. Since the first successful seedstock production in 1962, the technology for mass seedstock production progressed and spread rapidly throughout the country. Today, almost all red seabream seedstock are hatchery-reared and production of the species has become the most advanced in Japan's marine finfish culture industry. Wild red seabream catches amount to about 15,000 tons per year, but over 80% (65,000-70,000 tons) of all production in Japan is from aquaculture production. This is second only to yellowtail production. Successful commercial farming has familiarized the Japanese people with the product, but it also decreased the price, which used to be very high.

Commercial demand for striped jack, considered the most delicious among the *Carangidae* fishes, promoted aquaculture production of the species. Wild striped jack catches are limited, so the price of cultured fish is very high on the Tokyo market. Striped jack aquaculture started at the Fisheries Laboratory of Kinki University in 1955. At first, very little wild seedstock was caught and its unstable yields arrested the development of striped jack farming. Striped jack production first succeeded in 1973 and more than 6 million seedstock were produced in 1992. As a result, the striped jack industry was prosperous for a short time. Eventually, the price dropped ¥2,000 due to overproduction. The balance between supply and demand will assure the prosperity of striped jack aquaculture in the future.

Acknowledgments

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