Nursery and Growout Species Review

A Review of the Nursery and Growout Culture Techniques for Yellowtail (*Seriola quinqueradiata*) in Japan

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Abstract

Wild yellowtail seedstock (*Seriola quinqueradiata*) are collected for culture during May and June in the offshore waters of southern Japan. Most fish farmers intensively rear yellowtail in floating net cages for about two years until the fish grow to a marketable size of at least 800 g. Fresh fish, such as sardines are landed in large quantities and commonly used as fish feed. However, to reduce pollution of culture grounds resulting from the use of raw fish feed, formulated dry pellet diets are recommended. Feeds are distributed to fish in the net cages using a shovel, or by pumping it from the farmers boat through a pipe with seawater. Yellowtail grow faster than other species. If culture conditions are good (i.e., water temperature of 18-27°C, specific gravity > 1.015, and dissolved oxygen > 5 ml/L in the net cage), seedstock weighing 10-50 g in May and June grow out to 1 kg by December of the same year. After an additional year they grow to 4-6 kg. Stocking densities in net cages vary with fish size and environmental conditions, however, standard density is based on 7-10 kg/m^3. Daily feed consumption depends on fish size and water temperature, and decreases as the fish grow. In 1-year-old fish, the daily feed consumption (fed in a fresh fish form) is more than 30% of body weight for fish weighing less than 100 g in summer, but in 2-year-old fish it is about 5% in the same season. Yellowtail are intensively cultured to maintain a high production level in net cages, but often, this leads to adverse effects on fish health, such as disease and mortality. The survival rate throughout the rearing period is about 60-70%. Losses are mainly caused by pseudotuberculosis and streptococcal bacterial diseases.

Introduction

Annual production of cultured marine fish in Japan has steadily increased since the end of World War II. In 1992, mariculture accounted for 20% of Japan's fish production. Thus, marine fish culture is very important in mariculture. Yellowtail (*Seriola quinqueradiata*) is one of the most important species in Japan's marine fish culture industry with a total production of 150,000 tons or ¥130 billion (US$1.3 billion)(1992 data).

Yellowtail accounts for 60% of the country's total cultured fish production. This species is distributed from the South Pacific region to the East China Sea. The primary production regions in Japan are Ehime Prefecture in Shikoku (36,000 tons), which has been the largest producer for several years, and Kagoshima (33,000 tons) and Nagasaki (18,000 tons) Prefectures in Kyushu. These three prefectures account for 60% of the total cultured yellowtail production in Japan.

Commercial yellowtail culture began in the late 1920s in Kagawa Prefecture on the island of Shikoku, and is one of the oldest cultured marine fish species produced in Japan. Yellowtail culture expanded in the 1970s and increased rapidly from 43,000 tons in 1970 to 149,000 tons in 1980. Since 1980, the annual production of cultured yellowtail has remained around 150,000 tons. Rapid growth in the 1970s was due to the fish's high-market value and establishment of the floating net cage culture systems. However, total production of cultured marine fish has increased since 1980 (Figure 4) because many producers switched to other fish species, such as red seabream (*Pagrus major*) and striped jack (*Caranx delicatissimus)* when the yellowtail market became saturated. Currently, the price of whole cultured yellowtail fluctuates between ¥1,000-1,400/kg (US$10-14).

Yellowtail Culture Techniques

• Collection of Natural Seedstock

With regard to the supply of fry, yellowtail culture is still entirely dependent upon May and June wild seedstock collections from the Pacific coast of Kyushu and the East China Sea. To maintain the natural population of yellowtail, the Fisheries Agency of Japan regulates the number of seedstock for cultivation each year. The total number of seedlings permitted for collection in 1988 was less than 40 million and in 1992 was about 30 million.

Yellowtail fry live under drifting algae on the ocean surface and are transported by the Kurushu and its tributary to the north. They are caught by fishermen using hand nets or round haul nets. Captured seedstock are transferred to floating net cages in protected inlets, where they are size graded to prevent cannibalism. After they are reared in these facilities for several weeks, they are sold to fish farmers for the growout period.

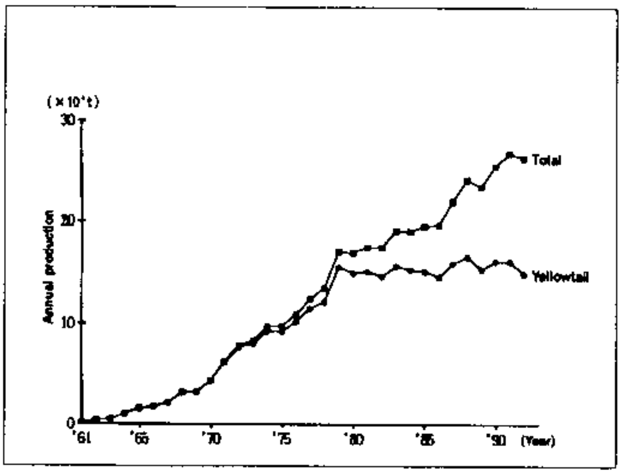

Figure 4. Recent trends in the production of cultured marine fish in Japan.

Research on yellowtail seedstock hatchery production has been continuously conducted in Japan for 30 years. Most recently, it has been successful in the national government hatcheries of the Japan Sea Farming Association (JASFA). In 1992, 941,000 fry (21-58 mm total length) were produced at three JASFA stations. However, hatchery seedstock were not used for commercial mariculture, instead they were released into the coastal regions of southern Japan to enhance the natural stocks.

• Culture System

Three types of culture systems are used for yellowtail production: embankment pond culture; net enclosed culture; and floating net cages. The embankment pond culture system is the oldest type, initiated by Mr. Sakichi Noami in 1927 as the original commercial yellowtail culture in Kagawa Prefecture. In the embankment pond and enclosed net culture systems, yellowtail are cultured in natural seawater areas surrounded by embankments or nets. These systems were utilized until the 1960s, after which time the yellowtail floating net cage system was developed by researchers at Kinki University (Harada 1966). The net cage system increased production because of improvements in environmental conditions, such as increased water circulation. Today, the embankment and net enclosed systems have been virtually replaced by the net cage culture system (Table 5). The total number of floating net cages in 1992 was more than 20,000 (Table 6). The production per m^2 of culture area tends to rise year by year.

In general, the floating net cage system is composed of a net cage and plastic or polystyrene tube float, which are suspended underneath steel frames (Figure 5). The netting is made of

Table 5. The type of culture system and area associated with yellowtail culture in 1992.

Culture System	Number	Area (1000 m^2)
Embankment pond culture	3	74
Net enclosed culture	33	477
Floating net cage	20,549	2,283

Table 6. Changes in yellowtail net cage culture from 1982-1992.

Years	Number of cages	Area (1000 m^2)	Production (x 1000 tons)	Production/area (tons/1000 m^2)
1982	32,313	2,985	146.5	49.1
1984	27,395	2,716	152.9	56.3
1986	24,442	2,432	146.1	60.1
1988	24,703	2,613	166.0	63.5
1990	23,124	2,517	161.3	64.1
1992	20,549	2,283	149.0	65.3

synthetic fiber or metal; the material is selected according to fish size and sea conditions. The fiber net is primarily used for 1-year-old fish and the metal net for fish 2 years or older. The size of the square net cage usually ranges from 5 x 5 x 5 m - 20 x 20 x 10 m. A row of net cages in an inlet is shown in Figure 6. The cages are connected with wire to concrete blocks, which are used as weights (Figure 7).

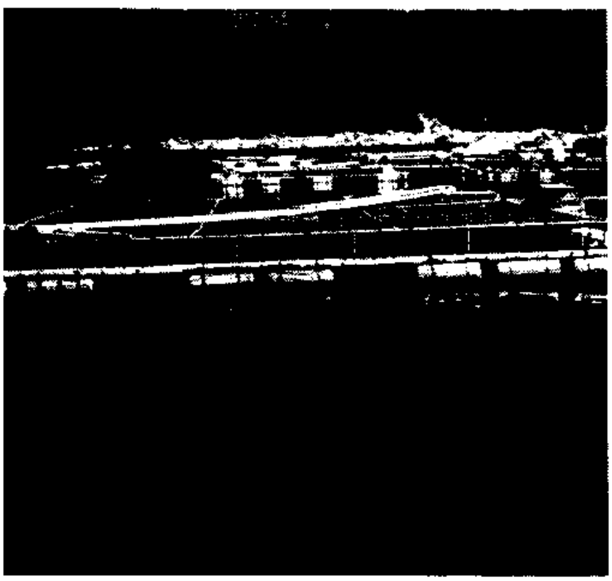

Figure 5. Floating net cage (8 m x 8 m).

• Water Quality and Growth

Yellowtail can survive in water temperatures ranging from 7-28°C, however, the optimum temperature for good feeding activity and growth is between 18-27°C. Fish grow slowly between 14-17°C and do not feed or grow below 11°C (Table 7). Therefore, most yellowtail are cultured in the warm water regions of Japan's Kuroshio current. With regard to the dissolved oxygen (DO) content in seawater, more than 5 ml/L of oxygen is necessary for

Figure 6. Typical view of net cages in an inlet.

Table 7. Feeding responses of cultured yellowtail in relation to water temperature.

Temperature (°C)	Feeding Response
< 11	Fish does not feed at all
11-13	Fish feed a little but do not grow
14-17	Fish feed and grow slowly
18-27	Fish feed actively and grow quickly
> 28	Fish do not feed actively and prolonged exposure to high temperatures may cause exhaustion

normal yellowtail growth. If DO drops below 4 ml/L, fish show poor appetite or abnormal swimming (Table 8). DO often falls during the summer, especially in inlet areas where water circulation frequently decreases. Therefore, fish farmers must carefully monitor the fish and culture conditions during that season.

Table 8. Yellowtail responses to variations in dissolved oxygen levels.

DO (ml/L)	Response
0-1	Death by suffocation
1-2	Breath with difficulty
2-3	Abnormal swimming
3-4	Poor appetite
4-5	Normal
> 5	Swimming actively

Feeding

• Feed Types

Growout diets for yellowtail are divided into three categories: fresh raw fish; moist pellets prepared by mixing 50% minced raw fish with formulated mash; and dry pellets.

Juveniles weighing up to 1 kg are fed dry pellets as their main feed. However, raw fish is still fed to market-sized adults weighing 5 kg or more. In 1992, cultured yellowtail consumed 1,051,000 tons of raw fish and 174,000 tons of formulated diets (mash plus pellet). Namely, in yellowtail culture more than 85% of the feeds are low-value raw fresh fish such as sardines (*Sardinops melanostictus*), anchovy (*Engraulis ja-*

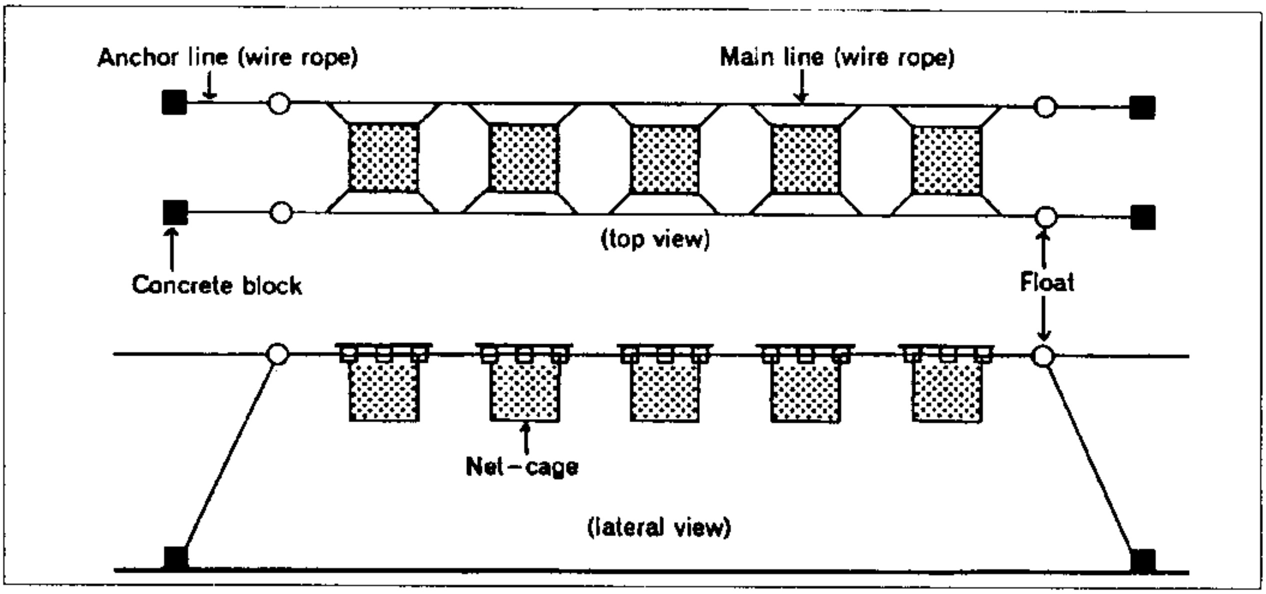

Figure 7. A typical net cage setup for yellowtail culture in a Japanese inlet.

Table 9. Vitamin requirements and recommended levels (mg/kg diet) for yellowtail.

Vitamin	Requirement	Recommended Level
<Water soluble>		
B_1	1.2 - 11.2	22.4
B_2	2.9 - 11.0	22.0
B_6	2.5 - 11.7	23.4
Pantothenic acid	13.5 - 35.9	71.8
Nicotinic acid	12.0	96.0
Biotin	0.22 - 0.67	1.34
Folic acid	0.8 -1.2	2.4
B_{12}	0.053	0.424
Choline	2100-2920	5840
Inositol	190-423	846
C	122	976
<Fat soluble>		
A	5.68	6.88

ponica) and sand lance *(Ammondytes personatus)*, which are landed in large quantities. They are fed whole or minced to the yellowtail, depending on the feed size. Usually, fresh fish feed is frozen (-20°C) and thawed before feeding. When feeding raw fish and/or moist pellets, farmers must add a eutrophic medicine and/or multi-vitamin mixture to meet the yellowtail's dietary requirements. Yellowtail vitamin requirements are shown in Table 9 (Hosokawa et al. 1979, 1982, 1983, 1992a, b).

• Formulated Diets

The development of artificially-formulated diets for yellowtail began in the 1960s, but a suitable diet has not been obtained. In the early 1980s, moist pellets composed of minced raw fish and formulated mash (50:50) were developed to decrease the pollution of culture grounds, which resulted from the use of minced raw fish feeds (Takeda 1985; Nagai 1985). Since then, Watanabe et al. (1991) have succeeded in developing a dry pellet for yellowtail. It is a high-calorie extruded pellet that satisfies the nutritional requirement of the species, and they find it palatable. Fish meal, about 60% of the pellet, is the main protein source and 10-15% wheat flour and potato starch are used as binders. Generally, crude protein is 40-50% and crude lipid is 15-20%. The size of dry pellets and their approximate composition are shown in Table 10. The advantage of a dry pellet is that the diet quality can be manipulated according to culture conditions, such as fish size, season and flesh quality. The pellets also decrease pollution of culture sites and labor requirements. Moreover, the use of dry pellets has opened the possibility of using substitute protein sources (soybean meal or corn gluten meal) for fish meal (Viyakarn et al. 1992). Dry feed will completely replace raw fish and moist pellets in the near future.

• Feeding Frequency and Consumption Rates

The recommended feeding frequency for adult fish is four times per week and once a day on feeding days to prevent overfeeding. However, it is necessary to feed fish weighing less than 100 g two or three times per day. Feeds are added directly to the cage or more commonly,

Table 10. Dry pellet composition for yellowtail feeds.

			Feed Composition			
Stage	Feed size (mm)	Fish size (g)	Crude protein	Crude lipid	Crude ash	Crude fiber
Fry	0.8	0.2-1	50-52	7-10	<15	3-4
	1.2	0.8-4				
	1.6	3-12				
	2.0	10-25				
Fingerling	3.0	20-60	46-51	10-15	15-17	2-3
	4.5	50-150				
	6.5	100-400				
Adult	9.0	300-700	41-45	16-22	12-17	1.2-3
	12.5	600-1500				
	16.0	1200-3000				
	20.0	>2500				

pumped into the cage with seawater through a pipe from the farmers' boat (Figures 8a and 8b). Use of automatic feeders is also increasing.

The relationship between body weight (BW), seawater temperature and daily feed consumption (using a fresh fish diet) for an 18-month culture period is shown in Figures 9a and 9b. The daily feed consumption depends on fish size and water temperature, and it decreases with fish growth. Generally, for 1-year-old fish weighing less than 100 g and cultured at 15-22°C, daily feed consumption is more than 30% of the fish's BW; 15-30% of the BW at 22-26°C for 100-400 g fish; 10-15% of the BW at 26-28°C for 400-800 g fish; and 6-10% of the BW at 26-13°C for 800-1200 g fish. In 2-year-old fish, the daily feed consumption is 5% of body weight during the summer, but decreases to 2% in the winter (Table 11). These feeding rates are based on raw fish diets, and therefore the feeding rate would be decreased by one-third.

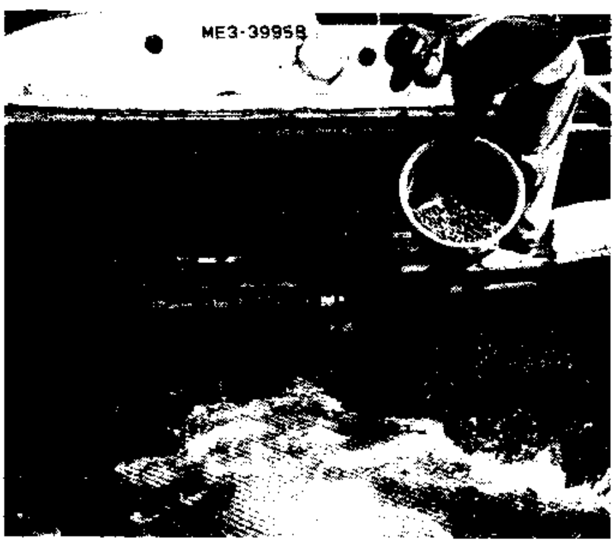

Figure 8a. Hand feeding dry pellets.

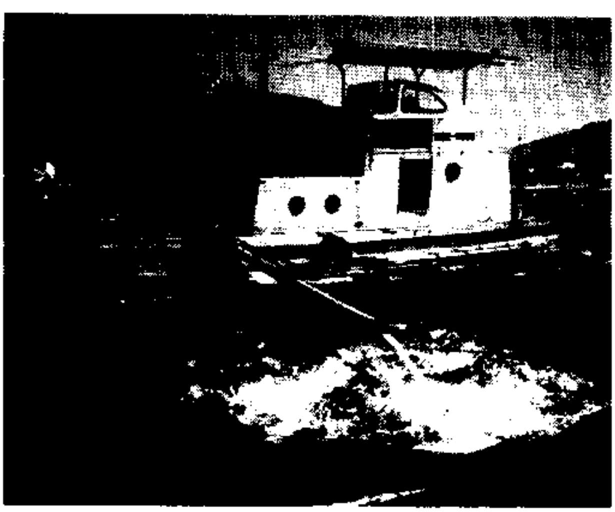

Figure 8b. Pipe feeding moist pellets from the farmers' boat.

Table 11. Daily feed consumption of yellowtail in relation to fish size and water temperature (feeding fresh fish).

Average body weight (g)	Water temperature (°C)	Daily feed consumption in % body weight
10-50	15-22	40-60
50-100	18-24	30-50
100-250	22-26	18-30
250-500	26-28	12-18
500-1000	28-22	12-7
1000-2000	15-21	7-2
2000-4000	20-28	2-4
4000-6000	27-18	5-2

• Feeds and Growth Rates

In general, it requires about two years to grow yellowtail to market size. Wild fry of 10-50 g BW are collected and most commonly used as seedstock. The growth curve for cultured yellowtail is shown in Figure 10. In May and June, fry are stocked into different size net cages and grown to 1 kg BW by December (after five or six months), if culture conditions (i.e., water temperature, specific gravity and dissolved oxygen) are good. By June of the following year (one year later), the fish grow to 1.2-2.5 kg, and to 4-6 kg by December. The daily growth rate (%) rises in the summer and drops in the winter. Growth rates are better when larger seedstock are cultured in larger cages. The survival rate is about 60-80% for 1-year-old fish, and about 80% for fish 2 years or older. Losses are mainly caused by bacterial disease.

The food conversion ratio (FCR) (g feed/g weight gain) for 1-year-old fish ranges from 5-9:1 when a raw fish diet is used. When dry pellets are used, the ratio drops to 1-1.5:1. In 2 years or older fish (cultured for 18 months), the respective FCR is 11-12:1 for a fresh fish diet and 2-2.5:1 on a dry pellet diet.

Culture Density

The fish stocking density depends mainly on fish size and water depth, area and circulation at the culture site. In general, standard density for cultured yellowtail in floating net cages is 120-340 fish/m^3 for fish weighing less than 25 g; 45-60 fish/m^3 for 25-200 g fish; 15-25 fish/m^3 for 200-600 g fish; about 10 fish/m^3 for 600-1000 g fish; and less than 7 fish/m^3 for fish weighing more than 1 kg. Density is based on 7-10 kg/m^3 of total body weight. The Fisheries Agency regulations allows for 10 kg/m^3. Usually, feeding yellowtail at a low stocking density results in increased productivity per net cage.

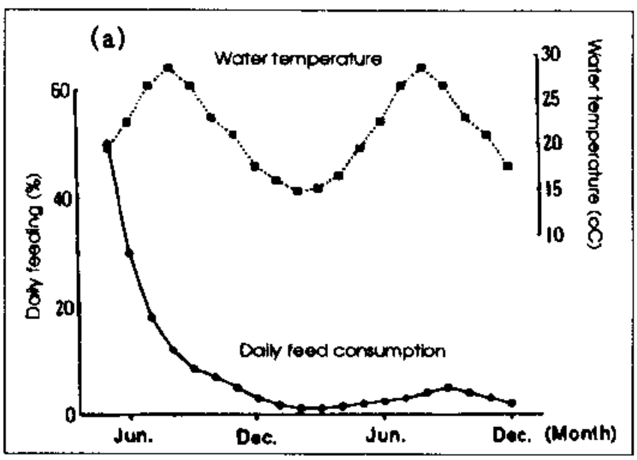

Figure 9a. Relationship between water temperature and daily feed consumption.

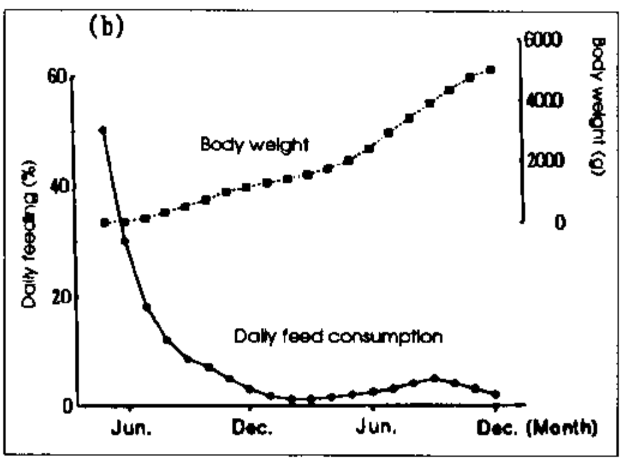

Figure 9b. Relationship between body weight and daily feed consumption.

Diseases and Treatments

With the rapid increase of fish production in the mid-1960s, cultured yellowtail diseases became a serious problem (Kubota et al. 1970; Kusuda et al. 1976). In 1991, yellowtail losses were estimated to be 8,200 tons or ¥10 billion. In general, fish diseases are classified according to the causal agent—bacteria, parasite, virus, nutrition and others. For cultured yellowtail, 90% of the total losses (both volume and value) are caused by bacterial diseases. Recently, pseudotuberculosis, streptococcus disease and vibriosis have become the main summer season diseases of young fish weighing 50-250 g. *Streptococcus* has become the main disease of adult fish. Bacterial diseases often occur when water temperatures are higher than 20°C.

Treatment and preventive measures of primary yellowtail diseases:

- Vibriosis
  - Cause: *Vibrio anguillarum*
  - Dosage of sulfa and antibiotic drugs
- Pseudotuberculosis
  - Cause: *Pasteurella piscicida*
  - Dosage of antibiotic drugs
  - Remove infected fish from the net cage as soon as possible

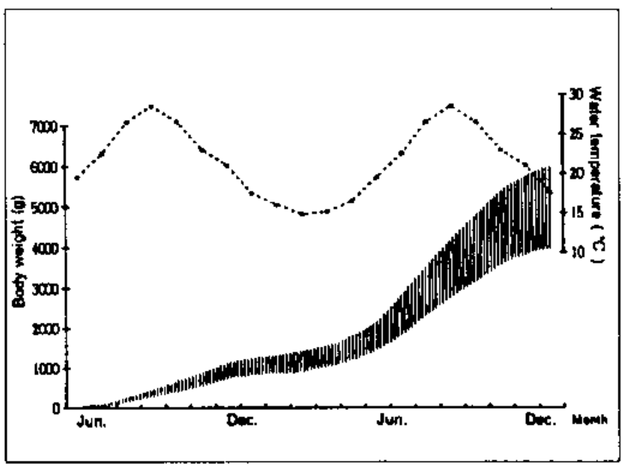

Figure 10. Growth curve for cultured yellowtail.

- Streptococcus disease
  - Cause: *Enterococcus seriolicida, Streptococcus* sp.
  - Dosage of antibiotic drugs
  - Remove infected fish from the net cage as soon as possible
  - Stop feeding the infected fish
  - Avoid overfeeding and over stocking
- Viral diseases
  - Cause: Yellowtail Ascites Virus and Iridovirus
  - Remove infected fish from the net cage as soon as possible
- Parasitic diseases
  - Cause: *Benedenia seriolae* and *Heteraxine heterocerca*
  - Dip in treated fresh or seawater for several minutes

Conclusion

It has been about 30 years since the beginning of floating net cage fish culture in Japan. The current industry, particularly yellowtail culture, has developed and produced large quantities of products, which have become important to the food production industry in Japan. On the other hand, the development of marine fish culture has caused problems, such as the environmental degradation at fish farming sites and increased disease among cultured stocks. Feed losses due to excess raw feeds and feces are main sources of pollution. This is indicated by the wide FCR ranges from 5-12.

The occurrence of drug resistant disease strains, especially *Enterococcus seriolicida,* which cause streptococcal bacterial disease and *Pasteurella piscicida,* which causes pseudotuberculosis, have become serious problems in recent years. Fish are apt to become infected in high density and overfeeding conditions. To solve these problems, it is necessary to do two things: focus on fish nutrition and feeds research, which will improve fish growth; and reduce environmental pollution. Moreover, it is important to control fish density in net cages and administer good quality feed. These approaches can sustain the development of the fish culture industry in Japan.

Literature Cited

Harada, T. 1966. Studies on propagation of yellowtail (*Seriola quinqueradiata* T. & S.) - with special reference to relationships between feeding and growth of fish reared in floating net cage. *Bull. Fish. Lab. Kinki University*. 1: 1-275.

Hosokawa, H., R. Teraoka, Y. Saito, M. Kishimoto, S. Shaman and M. Takeda. 1992a. Dietary pyridoxine requirement of fingerling yellowtail. *Suisanzoshoku*. 40: 215-220.

Hosokawa, H., R. Teraoka, Y. Saito, M. Kishimoto, S. Shaman and M. Takeda. 1992b. Dietary pantothenic acid requirement of fingerling yellowtail. *Suisanzoshoku*. 40: 221-225.

Hosokawa, H., R. Teraoka, Y. Saito and M. Takeda. 1979. Qualitative requirements of water-soluble vitamins in yellowtail. *In*: Abstracts of Oral Presentation at the Spring Meeting of Nippon Suisan Gakkai at Tokyo. p. 127.

Hosokawa, H., S. Ueno, S. Hirata and M. Takeda. 1982. Quantitative requirements of water-soluble vitamins in yellowtail-III and IV. Thiamin, biotin, folic acid, cyanocobalamin, inositol and ascorbid acid. *In*: Abstracts of Oral Presentation at the Spring Meeting of Nippon Suisan Gakkai at Tokyo. p. 102.

Hosokawa, H., S. Ueno, Y. Toyoda and M. Takeda. 1983. Quantitative requirements of water-soluble vitamins in yellowtail-V. Effect of the vitamin mixture based on all the quantitative vitamin requirements. *In*: Abstracts of Oral Presentation at the Spring Meeting of Nippon Suisan Gakkai at Tokyo. p. 44.

Kubota, S., M. Kimura and S. Egusa. 1970. Studies of a bacterial tuberculoidosis of the yellowtail-I symptomatology and histopathology. *Fish Pathol.* 4: 111-118.

Kusuda, R., K. Kawai, T. Toyoshima and I. Komatsu. 1976. A new pathogenic bacterium belonging to the genus *Streptococcus* isolation from an epizootic of cultured yellowtail. *Bull. Japan. Soc. Sci. Fish.* 42: 1345-1352.

Nagai, Y. 1985. Development of Oregon-type of moist pellet for yellowtail. *Yoshoku*. 22: 50-53.

Takeda, M. 1985. Diets for marine fishes. *In*: Fish Nutrition and Diets, Koseisha Koseikaku, Tokyo, Japan. pp. 111-122.

Viyakarn, V., T. Watanabe, H. Aoki, H. Tsuda, H. Sakamoto, N. Okamoto, N. Iso, S. Satoh and T. Takeuchi. 1992. Use of soybean meal as a substitute for fish meal in a newly developed soft-dry pellet for yellowtail. *Nippon Suisan Gakkaiski*. 58:1991-2000.

Watanabe, T., H. Sakamoto, M. Abiru and J. Yamashita. 1991. Development of a new type of dry pellet for yellowtail. *Nippon Suisan Gakkaishi*. 57: 891-897.

Fish Farming in Singapore: A Review of Seabass (*Lates calcarifer*), Mangrove Snapper (*Lutjanus argentimaculatus*) and Snub-nose Pompano (*Trachinotus blochii*)

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Abstract

Coastal seafarming accounts for the bulk of aquaculture production in Singapore. However, the annual production of approximately 2,500 metric tons (MT) is only about 2% of the total fish consumed in the country. About one-quarter of this amount is marine finfish, which represents about 60% of a total annual value of US$25,373,134 (S$17 million* [1993]). The remaining 98% comes from capture fisheries.

The tropical seabass (*Lates calcarifer* Bloch) and snapper (*Lutjanus* spp.) are commonly cultured species in Singapore. The snub-nose pompano or permit (*Trachinotus blochii* Lacepede) and mangrove snapper (*Lutjanus argentimaculatus* Forskal) were introduced from Taiwan in the early 1990s.

Seabass is the only finfish species produced by local hatcheries in Singapore. Its nursery culture (18-60 days after hatching or < 1-10 g) is conducted in ponds, whereas growout (10 g - market weight of 600 g) is in floating net cages. Pompano and mangrove snapper juveniles of 1-10 g are air freighted from other parts of Asia to Singapore in plastic bags. On the farm, they are acclimated directly to floating net cages and grown out in stages to market weight. The polyethylene net cages on commercial floating fish farms are of relatively low volume (6-80 m^3). They are suspended from floating wooden frame structures and cleaned monthly. Fish such as the seabass, pompano and mangrove snapper take about 10 months to grow from 10 g to a market weight of 600 g. They are fed trash fish, which in Singapore is good quality fish not consumed by people; the feed conversion ratio (FCR) is about 4-5:1 (as fed). Pompano are sometimes fed dry commercial pellets, with a FCR of 2.5:1 (as fed). Fish survival ranges from 70-80%. Common farming practices and problems for each species are reviewed and evaluated in this paper.

Introduction

Coastal seafarming accounts for the bulk of aquaculture production in Singapore (Chou 1994a). This activity began in the early 1970s and is now supported by 80 licensed floating fish farms, which produced about 2,600 MT in 1993. This is only about 2% of the annual total fish consumption of Singapore. The rest of the country's fish supply comes from capture fisheries.

Around 25% of the total aquaculture production in Singapore is finfish. The popular farmed species are the Asian seabass (*Lates calcarifer*), grouper (*Epinephelus tauvina, Plectro-*

S$1.00 = US$0.67

pomus maculatus and *Cromileptis altivelis*), snapper (*Lutjanus johni*) and more recently, the mangrove snapper (*L. argentimaculatus*). Other species such as yellowfin jack (*Caranx ignobilis*), golden trevally (*Gnathodon speciosus*), rabbit fish (*Siganus canaliculatus* and *S. guttatus*) (Chou 1989, 1994b) and the snub-nose pompano or permit (*Trachinotus blochii*) are also being farmed. These high-value fish accounted for about 60% of the total 1993 aquaculture production value of US$25,373,134. Shellfish such as green mussels (*Perna viridis*), mangrove crab (*Scylla serrata*) and spiny lobster (*Panilurus polyphagus*) account for the other 75%.

This paper reviews the farming of seabass, mangrove snapper and pompano. Seabass is one of the more popular finfish species in Singapore and the surrounding region, and is produced both locally and imported. The fry of the other two species are presently imported for farming.

Farming Practices

Of the three species reviewed in this paper, only the seabass is produced in local Singapore hatcheries. The fry are reared in earthen ponds and growout is conducted in floating net cages. Pompano and mangrove snapper fry are imported from Taiwan and stocked directly into floating net cages where they are reared to sizes suitable for growout culture.

Seabass Nursery Stage

Culture System - Ponds

Just after metamorphosis (Days 18-20), seabass are reared in 2,400-m^2 and 1-ha earthen ponds, which are located in Singapore or Johor, West Malaysia. Pond dimensions are 60-120 x 40-83 x 1.5 m with water depths of 1 m (2,400 m^3 and 10,000 m^3 water volume). Smaller ponds have concrete sides and earthen bottoms; larger ponds are completely earthen. Seawater is pumped directly into them and changed daily at a 20% exchange rate. Every three months the ponds are limed and left fallow.

Stocking Density, Growth and Survival

Metamorphosed seabass of mean total length (TL) 12 mm (mean weight 0.05 g) are stocked into ponds at about 80 fish/m^2 and reared for one week. Then they are harvested, culled, sold or grown for another four weeks. At this time 25-30 day-old fry (mean TL 30 mm; 0.5 g) are stocked in ponds at 40 fish/m^2. Around Days 55-60, the fingerlings (TL 63-115 mm; 3-20 g) are harvested and culled and the larger fish (10 g and more) are sold. If there is no demand for the smaller fish (2-5 g) they are grown for another 10 days (Days 65-75) to 10 g. Survival is about 60% during the nursery period. Losses are mainly due to cannibalism and predation by birds. Fish ≥10 g can be grown in floating net cages.

Feeding and Performance

Newly metamorphosed seabass are stocked in nursery ponds and weaned off their natural food, namely zooplankton and minced trash fish. Trash fish species such as gerrids, threadfin and goatfish are freshly caught in coastal palisade traps, but not demanded for human consumption. Instead, the trash fish are minced and fed twice daily to the cultured fish at 10-15% of their body weight. Feed is hand-fed where fry congregate.

Disease and Control

Because the fish are raised in ponds, disease control and drug administration are only possible through the feed. However, most farmers do not practice this method. Instead they give the fry prophylactic baths of 15 ppm oxytetracycline during culling and just before transfer to other locations.

Harvest and Transfer

Pond fry are harvested with a fine-mesh soft seine net (mesh sizes: 6 mm for Day 25-30 fish; 10 mm for Day 60 fish). Following harvest, fry are transferred to a large container and culled

Table 12. Transport packing conditions for seabass fry.

Age of fish (days after hatching)	Mean total length (mm)	Mean weight (g)	Percentage in size class
25-30	13	0.6	30
	25	0.4	50
	38	1.5	20
60	50-80	2-5	55
	90	10	37
	110	18	8

in trays with an appropriately-sized stainless steel mesh. The size composition of fry at Days 25-30 and Day 60, the most common period for harvesting and culling periods, are shown in Table 12.

Day 25-30 fish (0.5 g) are packed for air freighting at 700/box (70 fish/L or about 35 g/L), while larger fish of 5-10 g are packed at 80-100/box (8-10 fish/L or 40-100 g/L). Fish being shipped to local fish farms can be packed more densely because of shorter travel distances.

General Growout System

The following description of the floating net cage culture system is applicable to seabass, pompano and mangrove red snapper. A 2-4.5 x 2-4.5 x 1-4.5 m deep polyethylene net cage is tied to a 2.5-5 m square wooden frame at the corners and weighted at the bottom. Culture-effective water volumes range from 6-80 m^3. Thirty-two to 55 of these frames are joined to form a raft about 1,500 m^2, which is kept afloat by 400 plastic or molded fiberglass drums, each with a 200-250 liter capacity. The floating structure, which occupies about 20% of the 5,000 m^2 sea space designated for each farm, is anchored to the sea bottom (8-10 m from the surface at low water). Fish farms are located in sheltered coastal waters where water exchange is dependent on the diurnal tidal flow (Anon. 1986).

• Feeds

Trash fish, which is wild-caught and landed by trawlers throughout the year, is comprised mainly of gerrids, threadfins and goatfishes. However, during the monsoon months of December and January, supplies may be limited. Trash fish is boxed, iced and stored for no more than four or five days on board fishing vessel. Agents distribute trash fish daily to various designated drop-off and collection points close to farm areas. The use of trash fish as feed is traditional among farmers who operate small-sized farms with relatively low-volume net cages. Seabass farmers feed their stocks by hand at least twice daily; usually in the morning and evening at slack tide to minimize feed losses in tidal currents.

Trash fish is usually bought in ice-chilled or frozen form. The frozen fish is thawed by putting it in a net bag and immersing it in the sea, or by spraying it with seawater. It is finely chopped by hand when being fed to fingerlings, and fed by machine when larger pieces are required. Seabass, pompano and mangrove red snapper are all fed trash fish. Pompano may also be fed dry or semi-moist pellets, which are made from a dry commercial mash (Chou 1991).

• Harvest and Transfer

Net cages are manually lifted by farm workers who then gather, scoop and transfer the fish into boats fitted with small aerated seawater tanks, drums and bins. The low-volume cages allow small batches of fish to be sold without stressing other stocks. Live fish take one to 20 minutes to reach collecting points and from

Table 13. Transfer conditions for live market size (600 g) marine food fish from farm to landing point.

Type of container	Water volume (L)	Fish/L	Fish biomass (g/L)	Number fish/ container
Small plastic tank	36	0.25-0.6	150-300	8-19
Plastic drums	96	1.5	900	216
Shallow fiberglass or plastic tanks	40	1.8	1,080	45

Table 14. Seabass growout in regular volume (20-65 m^3) floating net cages.

Description	Early Growout	Growout to market size
Net cage size (m)	3 x 3 x 3	4 x 4 x 4
	4 x 4 x 4	4.2 x 4.2 x 4.2
	4.2 x 4.2 x 4.2	4.6 x 4.6 x 3
	4.6 x 4.6 x 3	4.6 x 4.6 x 4.6
mesh size (mm)	10-20	25
Fish at Stocking		
number/m^3	19-36	10-18
number/net cage	500-2,000	--
size at stocking (g)	10-20	200-300
Fish at transfer/harvest		
survival (%)	80	90
yield of 600 g fish (kg/net cage)	--	300-600

there, the fish are trucked in large aerated seawater tanks to restaurants. Table 13 summarizes how live fish are transported from fish farms to shore-based collecting points.

Seabass - Growout Stage

Culture System

Seabass yields are 300-600 kg/net cage from regular and low-volume cages. Table 14 is a record of typical seabass farming conditions in regular (20-65 m^3) net cages. Young seabass (10-15 g mean weight) are stocked in 10-20 mm mesh net cages at 19-36 fish/m^3. They are grown to 200-300 g and then transferred into larger mesh (25 mm) net cages. The fish are grown out to a market weight of 600 g in about 10 months.

Table 15 is a record of seabass culture in low-volume net cages (>20 m^3). In the survey, 10-20 g mean weight seabass are stocked at 125-174 fish/m^3 in 9-16 m^3 volume net cages with 10-mm mesh. The fish are grown to 50-100 g and then transferred to net cages with larger mesh sizes (25 mm). Here the fish are grown to a market weight of around 600 g in about 10 months.

Table 15. Seabass growout in low-volume (< 20 m^3) floating net cages.

Description	Early Growout	Growout to market size
Net cage size (m)	2.4 x 2.4 x 2.4 2.7 x 2.7 x 2.7	2.4 x 2.4 x 2.4 2.7 x 2.7 x 2.7
mesh size (mm)	10	25
Fish at Stocking		
number/m^3	125-174	43-62
number/net cage	2,000	--
size at stocking (g)	10-20	50-100
Fish at transfer/harvest		
survival (%)	80	90
yield of 600 g fish (kg/net cage)	--	300-600

Feeds

Seabass are fed 10% of their body weight decreasing to 5%, 5 % to 3%, and 3% from 10-50 g for one month; 50-200 or 300 g for another two to three months; and from 200-300 g to a market weight of 600 g for another six to seven months, respectively. The average and optimal feed conversion ratio (FCR) is 4-5:1 and survival is 60-70%. However, FCRs as high as 7-10:1 and survival as low as 20% have been recorded. Higher FCRs may have been reported because fish were fed even when feeding responses were poor, resulting in feed waste. Lower survival was usually due to diseased or poor quality fish stocks.

Disease

Fish farm surveys conducted in 1992 show that high incidence of *Vibrio* sp. and *Trichodina* sp. ciliate parasite infections occur in seabass (Chua et al. 1993). *Trichodina* infestations were found in 76-205 mm (about 5-15 g) fish from November 1992 to January 1993. This appeared to be stress related and not a seasonal occurrence. The condition is recognized by progressive erosion of the tail and fins, and death within three to seven days. Morbidity rates were 10-30%.

The survey also recorded high incidences of "body rot" or extensive focal body ulcers, which may or may not be covered by hanging whitish material and affect seabass of all sizes. Again, this did not follow any seasonal pattern and was generally regarded as precipitated by stress. Body rot is due to generalized ectoparasitic infections with bacterial and fungal components. Morbidity rates were estimated at 10-30%.

Other recorded diseases were lymphocystis and sporadic cases of unknown disease aetiologies with viral implications.

Common disease control practices used by farmers for all finfish species include treatments in the course of a disease outbreak, regular removal of floating fish carcasses and sanitation of introduced stock. Some farmers stock carrion feeders (e.g., lobsters) in the cages, isolate sick fish, treat fish when feeding response is reduced or aerate the water in times of fish stress. Therapeutic bath chemicals include formalin, malachite green and copper sulphate as antiparasitics and, acriflavine as an antiseptic. The common antibiotics and antibacterials (bath and oral treatments) are the tetracyclines, trimethoprim-sulphonamide, nitrofurans, chloramphenicol and erythromycin.

Table 16. Snub-nose pompano growout in regular volume (20-65 m^3) floating net cages.

Description	Early Growout	Growout to market size
Net cage size (m)	4 x 4 x 4	4 x 4 x 4
mesh size (mm)	10	25
Fish at Stocking		
number/m^3	10	6
number/net cage	1,200-13,000	--
size at stocking (g)	10-50	50-100
Fish at transfer/harvest		
survival (%)	80	90
yield of 600 g fish (kg/net cage)	--	250-600

Table 17. Snub-nose pompano growout in low-volume (< 20 m^3) floating net cages.

Description	Early Growout	Growout to market size
Net cage size (m)	2.7 x 2.7 x 2.7	2.7 x 2.7 x 2.7
mesh size (mm)	10	25
Fish at Stocking		
number/m^3	75	62
number/net cage	1,200	--
size at stocking (g)	1-5	50-100
Fish at transfer/harvest		
survival (%)	80	90
yield of 600 g fish (kg/net cage)	--	250-600

Snub-nose Pompano (Permit) - 1-10 g to 250-600 g

Culture System

Tables 16 and 17 are records of typical pompano farming conditions in regular and low-volume net cages. When stocked in regular net cages at a density of 10/m^3, 10- to 15-g imported pompano take 10 months to reach marketable weights of 250-600g. In low-volume net cages, farmers report a higher productivity. Imported fry of 1-5 g are stocked at 75/m^3 and still take 10 months to reach the same market weight range. The yield is 15.5-37.2 kg/m^3 compared with lower yields reported for growth in regular net cages (1.5-3.6 kg/m^3).

Feeds

Young pompano of 1-10 g are fed minced trash fish at 3-5% of their body weight. They are then fed a dry commercial pellet feed several times a day at 1-3% per day until they are ready for the market. Trash fish may also be fed at 3-5% of total body weight.

Harvest and transfer follows the general procedure described for seabass. In addition, pompano (375-600 g) are exported mainly to Hong Kong in large boats that have tanks or holds

Table 18. Mangrove snapper growout in low-volume (< 20 m^3) floating net cages.

Description	Early Growout	Growout to market size
Net cage size (m)	2.4 x 2.4 x 2.4 2.7 x 2.7 x 2.7	2.4 x 2.4 x 2.4 2.7 x 2.7 x 2.7
mesh size (mm)	10	25
Fish at Stocking		
number/m^3	125-174	43-62
number/net cage	500-1,000	--
size at stocking (g)	1	30-100
Fish at transfer/harvest		
survival (%)	90	90
yield of 600 g fish (kg/net cage)	--	300-600

with flow-through seawater to keep the fish alive during the journey.

Disease

Pompano may be affected by light to moderately heavy *Trichodina* infestations. However, little is known about pompano diseases in Singapore waters because the fish is a relatively new introduction.

Mangrove Snapper - 1 g to 600 g

Culture System

Table 18 is a record of typical mangrove snapper farming conditions. The fish are cultured in low-volume net cages because of limited fry supplies from Taiwan. Fry of about 1 g are imported and yield 300-600 kg/net cage. Harvest and transfer follow the procedure described for seabass and pompano. Like the pompano, the mangrove snapper is also exported mainly to Hong Kong in large boats.

Feed

Snapper are voracious feeders and the farmer must take care not to overfeed the fish. From 30-60 or 100 g, in the early three-month growout period, they are fed 5% decreasing to 3% of their body weight. From 60-100 g, the fish are fed 3% of their body weight until they a reach market weight of 600 g, which takes another seven months. The average optimal FCR is 4-5:1 and survival is 70-90%. The mangrove snapper will readily accept dry pellets, but farmers still hand feed trash fish twice a day. This practice also extends to pelleted feeds, which promotes either underfeeding or overfeeding of the fish. This has resulted in high FCRs and underfed fish that take longer than the average 10 months to reach a market weight. Farmers still prefer to use trash fish, which for them is cheaper than pelleted feeds and more familiar.

Disease

Mangrove snapper survival is better than seabass and pompano, and disease is mainly confined to sporadic cases of ciliate infestation. Farmers have not reported any serious snapper mortalities to date, and do not seem to have any major disease problems. This is probably due to limited fry farming.

Discussion

Problems facing seabass farmers include declining profitability and heavy fry mortalities shortly after transfer. Local seabass hatchery managers prefer to export eggs, larvae or newly metamorphosed fry to outside nursery systems and later re-import the fish as fingerlings, which are grown out in floating net cages. Exportation is preferred because of limited pond space and the ability to circumvent disease problems during the nursery period. Fish farmers face high seedstock, feed and labor costs.

Costs and competition from cultured fish imports have compelled farmers to look to high-value species such as the pompano and mangrove snapper for production. While pompano seedstock is still readily available, zealous production of this fish in the region has dampened consumer, and therefore producer, demand and lowered market prices. Mangrove snapper is still a good option because of its high demand and market price, but this is largely because supply is limited to local small-scale farm production. Use of relatively low-volume cages also limits the live fish supply.

To overcome some of these production limitations, it is necessary to establish appropriate breeding technology for a variety of high-value species; to better understand the nature of fish diseases; and to better educate farmers in farm management. To establish viable alternatives to increasing labor costs, the industry also must be technologically driven and mechanized. More importantly, industry advancement is necessary to demonstrate the feasibility of industrial fish production in the tropics.

Conclusion

The regional culture of seabass, pompano and mangrove snapper is conducted on small-scale farms in relatively small culture units. As a result of overzealous production and strong competition, yields are limited by seedstock supplies, disease susceptibility and flagging demands. Other high-value species must be considered and the difficulties of fish farming addressed. Some solutions may be realized through appropriate farm technology development and application. However, research and development into breeding, disease control and adequate feed designs for high-value fish species are also necessary.

Literature Cited

Anon. 1986. Manual on Floating Net cage Fish Farming in Singapore's Coastal Waters. Fisheries Handbook No. 1. Primary Production Department, Republic of Singapore. 17 pp.

Chou, R. 1989. Singapore Country Paper on the Progress of Seafarming Activities, Research and Development. *In*: Report of the Third National Coordinators' Meeting on Regional Seafarming Development and Demonstration Project. 24-27 Aug. 89, Qingdao, China. Regional Seafarming and Demonstration Project, Network of Aquaculture Centres in Asia, Bangkok, Thailand. pp. 80-92.

Chou, R. 1991. Singapore Country Paper on Fish Nutrition and Feed Development, ASEAN-EEC Aquaculture Development and Coordination Programme (AADCP) Component 4 (Singapore) Fish Nutrition Workshop. 28-29 June 91, St. Pee-sur-Nivelle, France. AADCP/PROC/1, pp. 176.

Chou, R. 1994a. Aquaculture Development in Singapore. *In*: Lacanilao, F., R. M. Coloso and G. F. Quinito (eds.). Proceedings of the Seminar-Workshop on Aquaculture Development in Southeast Asia and Japan and Prospects for Sea Farming and Sea Ranching. Aquaculture Department, Southeast Asian Fisheries Development Center, Tigbauan, Iloilo, Philippines. pp. 79-83.

Chou, R. 1994b. Seafarming and Sea Ranching in Singapore. *In*: Lacanilao, F., R. M. Coloso and G. F. Quinito (eds.). Proceedings of the Seminar-Workshop on Aquaculture Development in Southeast Asia and Japan and Prospects for Sea Farming and Sea Ranching. Aquaculture Department, Southeast Asian Fisheries Development Center, Tigbauan, Iloilo, Philippines. pp. 115-121.

Chua, F., J. J. Loo, J. Y. Wee and M. Ng. 1993. Findings from a fish disease survey: An overview of the marine fish disease situation in Singapore. *Singapore J. Pri. Ind.* 21(1):26-37.

Review of Nursery and Growout Culture Techniques for Red Drum (*Sciaenops ocellatus*)

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Abstract

Commercial red drum (*Sciaenops ocellatus*) aquaculture is developing, and its future is promising. Red drum broodfish can be maintained in captivity and spawned as needed to produce a continuous supply of larvae. Nursery production involves the culture of live food organisms until the fish reach 25 mm total length. Growout production systems include pond culture, cage culture and intensive closed tank systems. Recent information on dietary requirements has allowed better formulation of specific red drum diets. Under controlled conditions, the fish can reach market size in 10 months. Cold winter temperatures and irregular market demands are still the main obstacles to commercial red drum production in the United States.

Introduction

Red drum (*Sciaenops ocellatus*) are a commercially valuable member of the sciaenid or drum family. Also called redfish, channel bass or spottail bass, it is closely related to other commercially important species such as black drum (*Pogonias cromis*), spotted seatrout (*Cynoscion nebulosis*) and croaker (*Micropogonias undulatus*). Red drum are endemic to the southeastern coastal United States, with spawning occurring from North Carolina southward to northern Mexico. Wild populations once supported large commercial and recreational fisheries. However, commercial aquaculture of red drum is still in its infancy.

Aquaculture of red drum began with state-supported population supplementation programs. Early research on spawning and pond culture began during the 1970s, with Texas releasing millions of fingerlings into coastal waters and inland freshwater impoundments (Rutledge and Matlock 1986). As commercial and recreational harvests of red drum increased, restrictive catch quotas were instituted to protect wild populations (Swingle 1990). Limited catches, coupled with a surge of interest in "Cajun" style cooking, increased the market demand for red drum. Increased demands have sparked interest in commercial red drum aquaculture.

Aquaculture production of red drum can be divided into four phases: spawning, incubation, nursery and growout.

Spawning

Wild red drum spawn in autumn (late August to early November) offshore. In general, wild fish mature between 3 and 4 years of age at 700-800 mm total length (TL), although Arnold (1991) spawned F_1 cultured red fish that were 19.5 months old. Red drum are serial spawners and normally release several large spawns during a season (Simmons and Breuer 1962). Males develop a red-bronze coloration and make drumming sounds during courtship or when handled.

Two spawning methods are used: induced ovulation and spawning by chorionic gonadotropin (CG) or luteinizing hormone-releasing hormone analog (LHRHa) injection followed by either strip-spawning or tank spawning; and controlled environmental conditioning to induce maturation and spawning in captive broodstock.

Hormone-Induced Spawning

Red drum can be maintained in outdoor ponds or captured from the wild during late summer or autumn. Male spermiation is determined by the flow of milt when abdominal pressure is applied. Milt production can be enhanced with an intramuscular injection of 250 IU/kg body weight of CG. Females are catheterized with a 2-mm flexible tube, and a small amount of ovarian tissue is withdrawn, examined and the degree of oocyte maturation determined. Stages of oocyte maturation were described by Colura et al. (1992). When vitellogenesis is complete and oocytes are at least 0.5 mm in diameter, an intramuscular injection of 500-600 IU/kg body weight CG will induce ovulation in 24-30 hours at 25°C (Colura 1990a). Alternatively, 0.1 mg/kg body weight injections of LHRHa will also induce spawning in mature fish about 30-35 hours post-injection (Thomas and Boyd 1988). Injected broodfish can be placed in tanks and allowed to spawn naturally, or eggs can be strip-spawned and fertilized manually. Eggs are expelled from the female when gentle abdominal pressure is applied, and milt is similarly expressed from a male. Eggs and milt are mixed gently and 1-2 L of 28-32 ppt seawater is added while stirring. Approximately 1-3 million eggs can be obtained from an 11-14 kg female (Colura 1990a).

Environmental Conditioning

Regulated temperature and photoperiod regimes can induce maturation and repeated spawning in captive broodfish. This is the most commonly used spawning method by research, state and commercial operations.

Broodfish are maintained in large recirculating tank systems and subjected to a controlled regime of temperature and photoperiod changes (Arnold et al. 1977; Roberts et al. 1978). Tank systems may be of any design, as long as adequate water quality is maintained and the fish are able to swim without restriction. Tank systems are usually equipped with external egg collectors (Holt et al. 1990). Annual seasonal changes in temperature and photoperiod are compressed, and fish are induced to spawn in as few as three months. The fish usually spawn during the "autumn" part of the cycle, when temperature and photoperiod are decreasing. Courtship and spawning are stimulated by varying the temperature between 23 and 28°C. The temperature can be quickly raised 2-3°C over a day, then decreased to 21 or 22°C to induce natural spawning (Roberts 1990). Spawning can be repeated at periodic intervals; Arnold (1988) induced repeated spawning for 41 months while maintaining broodfish continuously under spawning conditions. Spawn size varies; one 11.4-kg female averaged 636,000 eggs/release, producing a total of 4.45 million eggs in seven spawns over 26 days (Texas Parks and Wildlife Dept., unpublished data). Arnold (1988) reported 50,000 to 2 million eggs/spawn, with an average of 400,000 eggs/release. Most producers allow spawning to continue until all nursery systems are stocked. Spawning is stopped by decreasing the temperature below 20°C, and the fish are usually subjected to a "winter" resting period.

Incubation

Fertilized eggs are sampled and the total number estimated volumetrically, or the eggs can be placed in a graduated cylinder and the total egg volume (in ml) can be multiplied by 1,000 to determine eggs/ml. Eggs are placed in 37.8-L glass aquaria and aerated gently in 28-35 ppt seawater for one to two hours, then examined for mitotic division. Percent fertilization is determined, and the dead eggs are carefully removed. Aeration in the aquarium is stopped, and the live eggs float on the surface while dead eggs sink and can be removed with a siphon. Fertilized eggs are transferred to larger, cone-bottomed tanks for incubation and hatching (Colura 1990a; Henderson-Arzapalo 1990).

Eggs and fry can be maintained at densities as high as 500 eggs/L. Eggs are about 1 mm in diameter, clear, with a gold-colored oil droplet.

Temperatures are maintained between 22 and 30°C and salinities between 28 and 35 ppt. The incubator water is static (no water exchange) with gentle aeration until hatching. Eggs are fragile and are always handled in water, never netted. Hatching occurs in about 24 hours at 25°C. A slow water exchange is started at hatching to maintain ammonia nitrogen levels below 0.55 mg/L, nitrite less than 100 mg/L and dissolved oxygen above 5.0 mg/L (Holt 1990). Larvae are maintained in the incubator until the alimentary tract is developed, generally about 48 hours post-hatch at 25°C. At this point, larvae are gently concentrated into a smaller chamber, the number estimated and the fish transferred to nursery systems (Henderson-Arzapalo 1990).

Nursery Culture

Red drum larvae are about 2 mm TL at hatching; they are pelagic and take about two days to develop eyes and an alimentary tract. The optimum larval rearing environment is 25-30°C and 25-35 ppt salinity (Holt 1990); however, larvae survive salinities between 10 and 40 ppt. Larval growth can average 1.0 mm/day under optimum conditions. Scale formation begins when the larvae are about 9.0 mm TL; scales are fully formed at 25 mm TL. Between 22 and 28 days are required for larvae to reach 25 mm, and fingerlings can tolerate transfer to freshwater at this point.

Nursery culture is done in intensive tank systems or fertilized ponds. Tank culture is used where space is limited and usually produces fewer fish. Pond culture is more commonly used, as it can produce millions of fish with less labor.

Tank Culture

Larval rearing tanks may be of any design, but all employ small mesh (0.5 mm) drain screens, slow water exchange and gentle aeration to keep larvae in suspension. Total ammonia should not exceed 1.0 mg/L. Cleaning must be done very carefully to prevent larval removal or damage. Initially, larvae can be stocked at 10-20 larvae/L for the first two weeks of culture, then reduced to one to two fish/L for the last few weeks (Holt et al. 1990). Feeding begins about three days after hatching, and larvae will only feed on live food. The first food offered are rotifers between Days 3 and 10, then brine shrimp nauplii between Days 11 and 15, followed by a blended diet of fresh shrimp or artificial food. The major obstacle to tank culture is the labor required to rear the food organisms (Holt et al. 1990).

Pond Culture

Nursery pond culture uses fertilized culture techniques similar to those described for striped bass (Bonn et al. 1976). Ponds are fertilized with a combination of organic and inorganic materials (cottonseed meal, alfalfa meal, urea, triple phosphate) and filled about two weeks prior to larval stocking to allow zooplankton populations to develop. Fertilization is staggered throughout the production period to maintain high zooplankton densities (Colura 1990b). Incoming water is filtered through a 0.5-mm mesh bag to eliminate competitors and predators. Larvae are stocked two to four days post-hatch, and temperatures should be > 18°C and salinities > 10 ppt. Stocking densities are generally between 156,000 and 1,225,000 larvae/ha; 750,000 larvae/ha is average. Larvae feed on rotifers, copepod nauplii, copepods and polychaetes. If zooplankton populations are exhausted before harvest, a salmon starter or #1 crumble diet can be fed.

Production period and nursery harvest size differs between the Texas restoration program hatchery production and commercial operations. Texas hatchery production period is between 22 and 35 days depending on temperature, and survival averages between 30 and 70%. The fish are generally harvested when they reach about 25 mm TL; they are removed and weighed, survival is estimated and the fish are then restocked at lower densities into growout systems or transported for release. Commercial operations often stock at lower

Table. 19. Summary of commercial U.S. producers of red drum in 1994.

Commercial U.S. Producers			
Farm	**Location**	**Product Type**	**Production Method**
Redfish Unlimited	Texas	Fingerlings	Ponds
Cow Bayou Fish Farm	Texas	Market Fish	Ponds/Tanks
Southland Fisheries	South Carolina	Fingerlings	Ponds
LaFourche Mariculture	Louisiana	Market Fish	Cages
HarvestFresh	Texas	Fingerlings	Ponds/Tanks
Westover Fisheries	Louisiana	Market Fish	Ponds

densities (500,000 larvae/ha), begin feeding at two weeks after larval stocking and do not harvest until the fish are 7-9 cm TL (D. Dunseth, Redfish Unlimited personal communication).

Transport

Minimum size for safe handling and transport is about 25 mm TL or when scale formation is essentially complete. The fish can also tolerate direct transfer to freshwater at this size (Crocker et al. 1981). Transport procedures are similar to those for other fish. Stress responses (increased serum cortisol and glucose levels) are transient, returning to normal in about 24 hours (Robertson et al. 1987). Stress was reduced when the fish were anesthetized prior to handling and transported in anesthetic-free water (Robertson et al. 1988) and when transport water salinity was isosmotic or about 11 ppt (Weirich and Tomasso 1991).

Growout or Market Production

Most red drum culture research has focused on spawning and nursery production. Recent interest in commercial production of red drum has sparked interest in diet formulation, disease research and market production. Information on growout or market production is limited. In 1994, there were six successful commercial U.S. producers of red drum (Table 19), several experimental evaluations, one research evaluation in Martinique and one operation in Ecuador. Data on diets and growth are specific for individual producers. The information presented is based on estimates provided by the producers.

Commercial producers are using three culture methods: intensive recirculating tank culture; pond culture; and cage culture. Two producers (HarvestFresh and Redfish Unlimited) maintain their own broodstock, produce larvae and rear fingerlings for sale to other growers. They also produce fish for market.

Pond Culture

Pond culture is the most commonly used production method despite overwintering problems. Several catfish or hybrid striped bass producers purchase red drum fingerlings and have attempted market production with mixed success. Basically, fingerlings are stocked into ponds at moderate stocking densities and fed a commercial diet until harvest. Production period in the United States is between 14 and 22 months (Table 20).

Redfish Unlimited is one of the oldest and largest red drum producers. The company maintains a spawning facility and nursery pond complex and recently expanded to 48 ha of growout ponds. Larvae are reared to fingerling size following the general nursery pond procedures outlined previously. Fingerlings are transferred to other ponds at lower densities for growout. Initially, they stock about 500,000 larvae/ha (0.4-0.8 ha pond size) for 75-90 days or until the fish are between 7 and 9 cm TL. The fish are then moved into "stocker" production (densities between 20,000 to 30,000 fish/ha for

Table 20. Reported growth rates for growout or market production of red drum.

Reported Growth Rates for Red Drum				
System Type	**Final Fish Size**	**Production Period**	**Location**	**Source**
Extensive Ponds	1.54 kg	22 months	South Carolina	Hopkins et al. (1986)
Floating Brackish Water Cages	400 g	6-7 months	Martinique	Goyard et al. (1991)
Low Density Tank Culture	2.9 kg	19.5 months	Texas	Arnold (1991)
Pond and Tank Culture	1.6 kg	680 days	Texas	Procarione and Bumguardner (1989)
Intensive Closed Tank Systems and Intensive Ponds	1.1 kg	10 months	Texas	M. Schwarz (personal communication)
Extensive Ponds	1.2 kg	14 months	Texas	D. Dunseth (personal communication)
Extensive Ponds	0.9-1.6 kg	14 months	Texas	L. Levingston (personal communication)
Intensive Ponds	1.0-1.3 kg	18 months	South Carolina	Sandifer et al. (1993)

three to four months or until they average 0.5 kg) or directly into growout production. Final growout production densities average about 5,000 kg/ha and the fish are between 1.1 and 1.4 kg at harvest. Although Redfish Unlimited has attempted some overwintering of fish in ponds, 1994-95 will be its first large-scale attempt. The company sold about 73,000 kg in 1994, and is targeting production at 181,818 kg/year, averaging between 4,545 and 6,818 kg/ha. Production is staggered so that market-size fish are available several times during the year. During the last harvest, fish averaged 1.4 kg and were sold for $3.96/kg in the round at the farm (David Dunseth, Redfish Unlimited personal communication).

Redfish Unlimited has supported itself mainly by the sale of fingerlings to other producers, although this market is decreasing. They receive between $0.10-0.50 for fingerlings, however, they project most of their income will be generated by market production. Redfish Unlimited has done some preliminary research on creating "thermal refuges" for overwintering red drum in ponds. Refuges are created by partitioning a small portion of the pond and supplying water that is warmer than the ambient pond water. During cold periods, the fish can move into these refuges of warmer water until the ambient temperature increases.

Redfish Unlimited has been using a "red drum" diet manufactured by Rangen, Inc. (Buhl, ID). A floating diet is fed during spring and summer and a sinking pellet during winter. Food conversion is estimated at 1.8.

Cow Bayou Fish Farm is a small producer. The company purchases 25-mm TL fingerlings in fall, overwinters the fingerlings at high densities in a greenhouse and then restocks the fish at lower densities in spring. They used 0.4-ha ponds and harvested between 3,750 and 4,205 kg/ha in a 14-month production period. Fish were fed a 40% fish protein diet and survival was about 40%. The fish were between 0.9 and 1.6 kg at harvest. The company has maintained fish in ponds during winter and except for bird predation, has experienced no major mortality problems. Red drum production is still in the development phase (L.M. Levingston, Cow Bayou Fish Farm personal communication).

Southland Fisheries in South Carolina runs a fingerling production facility; it could not make a profit doing market production. The company produces fingerlings in pond culture and sells them for about $0.10/2.5-cm fish. Regulatory and permitting problems prevent the development of additional pond space (J. Chapell, Southland Fisheries personal communication).

Several other commercial fish producers are attempting pond culture of red drum as an alternative product to catfish or hybrid striped bass. Problems plaguing these smaller producers include overwintering, inconsistent market supply and erratic survival (W. Landry, Westover Farms personal communication).

Cage Culture

LaFourche Mariculture currently conducts cage culture in a brackish water estuary for red drum growout. LaFourche purchases 15-cm fingerlings for about $0.50 each and stocks one fish/28 L into 2.5-cm mesh cages (30.5 m long x 9.1 m wide x 1.8 m deep). The cages are located in the tidal section of an estuary for water exchange. The fish are fed a hybrid striped bass diet containing about 38% fish meal (42% total protein) with a food conversion ratio of about 2.2:1. Survival is estimated at 95%. Cages are stocked with several age groups at one time; fish are harvested periodically by passing a large mesh seine through the cage and removing large fish. Harvest size is targeted at 0.9 kg, and purchase price has varied between $4.40 and $6.05/kg for whole fish. LaFourche Mariculture is not in full production; it projects an annual harvest of 45,455 kg (R. Fernandez, LaFourche Mariculture personal communication).

Intensive Tank Culture

HarvestFresh (formerly known as Prime Reds) uses high density tank culture and outdoor ponds to produce red drum for market. The company schedules two spawning and nursery production cycles per year. The broodfish are subjected to a 120-day conditioning cycle, with nursery production during spring and fall. After fall nursery production, fingerlings are maintained in indoor raceways during winter. The fish are reared to about 115 g, then transferred in the spring either to outdoor growout ponds or indoor raceways. The fish are fed a combination of salmon and trout diets.

HarvestFresh currently has eight 3.2-ha growout ponds. The company stocks at moderate densities and produces about 9,091 kg/ha. Fish are maintained in ponds during the winter and suffer only minor mortality. The inside raceways are 226,800-L recirculating systems with limited water exchange and oxygen injection. Tank biomass is between 0.06 and 0.09 kg/L. Company personnel stock a mixture of different size fish in the systems and use a fish pump with graders to selectively harvest larger fish. The fish grow to an average of 1.1 kg in 10 months and have been sold for between $3.96 to $5.28/kg in the round. HarvestFresh expects to produce 454,545 kg in 1994 and is hoping to expand. The company plans to automate water quality measurements and regulation, feeding and other production activities, to increase the number of raceway systems and to develop recirculating tank systems for 100% water reuse (M. Schwarz, HarvestFresh personal communication).

Growth Rates

Information on growth rates for larger red drum in aquaculture is limited; most data are from wild fish. Beckman et al. (1988) reported 1- and 2-year-old red drum grew an average of 0.58 mm/day and 4.2 g/day in a saltwater impoundment, while Simmons and Breuer (1962) estimated growth at 0.59 mm/day. Simmons and Breuer (1962) also noted seasonal temperature effects on growth, with rapid increases in the summer and slow growth rates during the winter. Pond production in the United States is also affected by seasonal temperatures, with most producers reporting an average production period of 14-22 months to reach 1-kg market size (Table 20). The author raised red drum from March through November 1984, and the fish grew an average of 0.92 mm/day (Henderson-Arzapalo et al. 1994). If red drum are reared under optimum temperatures in closed systems, they can reach 1.1 kg in 10 months (M. Schwarz, HarvestFresh personal communication). Research on brackish water cage culture conducted in Martinique (French West Indies) yielded a 400-g fish in six to seven months, an indication of growth potential in tropical areas (Goyard et al. 1991). Producers that increase rearing temperatures through closed-system production, geothermal water or tropical locations have a distinct economic advantage.

Temperature Tolerance

Overwintering of fish or protection from cold temperatures is still the major obstacle to commercial production in the United States. Large winter kills of wild red drum attributed to rapidly decreasing water temperatures have been documented on the coast of Texas (Gunter 1952; McEachron et al. 1984). Low temperature tolerance is affected by the ionic composition of the water (survival is improved in saline or very hard freshwater), acclimation temperature and the rate of temperature change (Miranda and Sonski 1985; Procarione 1986). Feeding and growth cease between 7-9°C, regardless of salinity (Procarione 1986). Critical thermal maxima and minima for juvenile red drum were 29.51°C and 1.57°C for fish acclimated at 12°C, and 34.84°C and 4.79°C for fish acclimated at 20°C (Ward et al. 1993). Each 1°C decrease in acclimation temperature resulted in about a 0.4°C gain in cold tolerance, and each 1°C increase in acclimation temperature resulted in about a 0.66°C gain in heat tolerance (Ward et al. 1993). Although the temperature in the southern United States does not frequently fall below the red drum thermal limit for extended periods, producers must still protect the fish during cold periods. In addition to direct mortality, growth rate is reduced in ponds during winter and the overall production period is longer (Table 20).

Salinity Tolerance

Juvenile and sub-adult red drum are euryhaline and will survive and grow in hard freshwater or salinities as high as 45 ppt. Salinity tolerance increases with scale development and size; 6-mm standard length (SL) fish survive down to 5 ppt salinity, while 20-mm SL fish can survive direct transfer to freshwater with little mortality (Crocker et al. 1981). Tolerance of freshwater is related to chloride and calcium concentrations; survival and growth were greater when chloride levels were above 400-500 mg/L (Pursley et al. 1989; Thomas and Wolters 1992) and calcium between 19-403 mg/L (Wurts and Stickney 1989). The fish's wide salinity tolerance has increased the aquaculture potential and allowed stocking programs in freshwater power plant impoundments. Cold tolerance is lower in freshwater, and the growth rate in laboratory rearing trials indicated that growth was slightly slower in freshwater (Crocker et al. 1981). In freshwater, fish will grow to adulthood and mature; however, successful spawning will not occur. Red drum require saltwater for activation, and egg and larval survival is very poor at salinities of 10 ppt and less (Crocker et al. 1981).

Diet

During early red drum production, fish were fed commercial catfish, salmon and trout diets because of product availability. The fish readily consume salmon or trout diets, but these diets contain excess lipid, which creates abdominal fat in the fish. Growth is highest in fish that are fed a salmon diet rather than a trout or shrimp diet, and fish fed a catfish diet grew significantly slower (Wisner et al. 1991). Feed conversions ranged from 0.99 for a salmon diet to 4.02 for a catfish feed.

Recent advances in determining the dietary requirements for this species has allowed better formulations of diets specific for red drum. Ro-

Table 21. Summary of recent research on red drum dietary requirements.

Dietary Requirement	Source
16.1 Kj gross energy/g diet, 10% lipid and 24% carbohydrate	Ellis and Reigh (1991)
Total sulfur amino acid requirement is 1.06% of diet (3.03% of dietary protein)	Moon and Gatlin (1991)
Zinc requirement 20-25 mg/kg dry diet	Gatlin et al. (1991)
2% dietary salt improved growth in fresh and brackish water	Gatlin et al. (1992)
35-44% protein; 1.54-1.72 x 10^4 Kj/g dietary energy	Daniels and Robinson (1986)
60-75 mg/kg ascorbic acid	Collins (1990)
Lysine 1.55% dry diet or 4.43% of dietary protein	Craig and Gatlin (1992)
Lysine 5.7% of the dietary protein	Brown et al. (1988)

binson (1990, 1991) estimated that the diet should contain 35-45% high quality protein (12-15% animal protein), 3.5-4.0 kilocalories of energy/g diet and 5-6% fat. Red drum cannot fully utilize plant protein. Reigh and Ellis (1992) found the best (i.e., most cost effective) formulation for growth contained at least a 1:1 ratio of soy protein:fish protein. Growth was higher for juvenile red drum fed diets formulated entirely with fish meal or muscle extracts as a protein source (Moon et al. 1991). Serrano et al. (1992) reported maximum growth and feed conversion from a diet with 40% protein; a 10% lipid level led to lipid deposition in the liver and peritoneal cavity. Williams and Robinson (1988) reported dietary lipid levels (menhaden oil) of 7.4% and 11.2% gave the greatest weight gain, food conversion and survival. Red drum are limited in their ability to utilize carbohydrates. Ellis and Reigh (1991) found weight gain, feed efficiency, protein retention and energy retention of juvenile red drum were inversely related to dietary carbohydrate content. In the same study, dietary lipid was more effectively utilized for energy and spared more protein than dietary carbohydrates. Other dietary requirements are shown in Table 21. Some feed manufacturers have used these recent research results to formulate red drum diets (D. Brock, Rangen, Inc. personal communication).

Diseases

There have been few reported disease problems in red drum; however, this will probably change as aquaculture production expands. Infestations with *Amyloodinium ocellatum*, an external parasite, are problematic in tank systems, but can be controlled with chelated copper treatments. Parasitic infestations of *Lernaenni-cus affixus* (copepod) and *Apicomlexa* and *Eimeriorina* (coccidia) have also been documented (Hein and Shepard 1984; Landsberg 1993). The author has observed problems with parasitic copepods, fish lice (*Argulus* sp.) and general bacterial septicemia following stress, while culturing red drum. Fungal (*Saprolegnia* or *Achlya*) outbreaks after handling or exposure to cold are also common.

Standard fish treatments are generally effective (Johnson 1990). Landsberg et al. (1991) found 20-minute freshwater dip treatments effective for eliminating parasitic copepods. Lewis et al. (1988) reported that 10-70 mg/kg body weight of chloroquine (an anti-malarial drug) incorporated into the feed effectively prevented amyloodinosis. In the United States, there are currently no government-approved drugs for treating diseases in red drum.

Summary

Commercial production of red drum is still developing. From 1986-89, when the market demand peaked, aquaculturists attempted red drum culture with mixed success. The technology needed for successful production is available, but application can be costly. To compete with producers located in the tropics, U.S. producers must use temperature control or high density production to rear red drum profitably. Most U.S. producers are comparing red drum production to hybrid striped bass, another popular mariculture fish. Both species have somewhat similar production requirements, but the current market for hybrid striped bass is larger and more stable. Successful red drum production will require application of temperature control technology and development of a stable market and product supply. With these factors carefully considered, the future of commercial red drum production is promising.

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Names and Addresses of U.S. Commercial Red Drum Producers

HarvestFresh
P.O. Box 412
Bacliff, TX 77518
(713) 339-6000

Cow Bayou Fish Farm
P.O. Box 148
Bridge City, TX 77611
(409) 735-8626

Redfish Unlimited
HC 2, Box 386
Palacios, TX 77465
(512) 972-6108

Southland Fisheries
600 Old Bluff Road
Hopkins, SC 29061
(803) 776-4923

Westover Fisheries
P.O. Box 628
Red Bluff, CA 96080
(916) 527-4601

LaFourche Mariculture
P.O. Box 776
Golden Meadow, LA 70357
(504) 475-6600

Literature Cited

Arnold, C.R. 1988. Controlled year-round spawning of red drum (*Sciaenops ocellatus*), in captivity. *Contrib. Mar. Sci.* 30 (supplement):65-70.

Arnold, C.R. 1991. Precocious spawning of red drum. *Prog. Fish. Cult.* 53: 50-51.

Arnold, C.R., W.H. Bailey, T.D. Williams, A. Johnson and J.L. Lasswell. 1977. Laboratory spawning and larval rearing of red drum and southern flounder. *Proc. Southeast. Assoc. Fish. Wildl. Agencies* 31: 437-440.

Beckman, D.W., G.R. Fitzhugh and C.A. Wilson. 1988. Growth rates and validation of age estimates of red drum (*Sciaenops ocellatus*), in a Louisiana salt marsh impoundment. *Contrib. Mar. Sci.* 30 (supplement): 93-98.

Bonn, E.W., W.M. Bailey, J.D. Bayless, K.E. Erikson and R.E. Stevens (eds.). 1976. Guidelines for striped bass culture. Striped Bass Committee of the Southern Division, American Fisheries Society, Bethesda, Maryland.

Brock, D. personal communication. Rangen Inc., Buhl, Idaho.

Brown, P.B., D.A. Davis and E.H. Robinson. 1988. An estimate of the dietary lysine requirement of juvenile red drum (*Sciaenops ocellatus*). *J. World Aquacult. Soc.* 19: 109-112.

Chapell, J. personal communication. Southland Fisheries, Hopkins, South Carolina.

Collins, J. 1990. The vitamin C requirement of red drum. M.S. thesis. Mississippi State University, Mississippi State, Mississippi.

Colura, R.L. 1990a. Hormone-induced strip spawning of red drum. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603, Texas A&M University, College Station, Texas. pp. 33-34.

Colura, R.L. 1990b. Saltwater pond fertilization. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603, Texas A&M University, College Station, Texas. pp. 78.

Colura, R.L., A. Henderson-Arzapalo and A. F. Maciorowski. 1992. Culture of red drum. *In*: Handbook of Mariculture: Finfish Aquaculture Vol II. CRC Press, Inc., New York, New York. pp. 149-166.

Craig, S.R. and D.M. Gatlin, III. 1992. Dietary lysine requirement of juvenile red drum (*Sciaenops ocellatus*). *J. World Aquacult. Soc.* 133-137.

Crocker, P.A., C.R. Arnold, J.A. DeBoer and J.D. Holt. 1981. Preliminary evaluation of survival and growth of juvenile red drum (*Sciaenops ocellata*) in fresh and salt water. *J. World Aquacult. Soc.* 12: 122-134.

Daniels, W.H. and E.H. Robinson. 1986. Protein and energy requirements of juvenile red drum (*Sciaenops ocellatus*). *Aquaculture.* 53: 243-252.

Dunseth, D. personal communication. Redfish Unlimited, Palacios, Texas.

Ellis, S.C. and R.C. Reigh. 1991. Effects of dietary lipid and carbohydrate levels on growth and body composition of juvenile red drum (*Sciaenops ocellatus*). *Aquaculture.* 97: 383-394.

Fernandez, R. personal communication. La Fource Mariculture, Golden Meadow, Louisiana.

Gatlin, D.M., III, D.S. MacKenzie, S.R. Craig, and W.H. Neill. 1992. Effects of dietary sodium chloride on red drum juveniles in waters of various salinities. *Prog. Fish. Cult.* 54: 220-227.

Gatlin, D.M., III, J.P. O'Connell, and J. Scarpe. 1991. Dietary zinc requirement of the red drum (*Sciaenops ocellatus*). *Aquaculture.* 92: 259-265.

Goyard, E., P. Soletchnik and E. Thouard. 1991. Main results on intensive aquaculture of red drum (*Sciaenops ocellata*) in Martinique (F.W.I.). *J. World Aquacult. Soc.* 22: 27A. Abstract.

Gunter, G. 1952. The import of catastrophic mortalities for marine fishes along the Texas coast. *J. Wildl. Manage.* 16: 63-69.

Hein, S. and J. Shepard. 1984. *Lernaennicus affixus* found to parasitize red drum. Louisiana Department of Fisheries, Marine Research Laboratory Technical Bulletin No. 38. 21 pp.

Henderson-Arzapalo, A. 1990. Red drum egg and larval incubation. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603, Texas A&M University, College Station, Texas. pp. 51-52.

Henderson-Arzapalo, A., R.L. Colura and A.F. Maciorowski. 1994. A comparison of black drum, red drum and their hybrid in saltwater pond culture. *J. World Aquacult. Soc.* 25: 289-296.

Holt, G.J 1990. Growth and development of red drum eggs and larvae. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603, Texas A&M University, College Station, Texas. pp. 46-50.

Holt, G.J., C.R. Arnold, and C.M. Riley. 1990. Intensive culture of larval and post larval red drum. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603, Texas A&M University, College Station, Texas. pp. 53-56.

Hopkins, J. S., A.D. Stikes, P.A. Sandifer, R.A. Smiley and T.R. McTeer. 1986. Spawning and growout trials with red drum in South Carolina. *Proc. Southeast. Fish Wildl. Agenc.* 40: 178-186.

Johnson, S.K. 1990. Recognition and control of disease common to growout aquaculture of red drum. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603, Texas A&M University, College Station, Texas. pp. 113-130.

Landry, W. personal communication. Westover Fisheries, Red Bluff, California.

Landsberg, J.H. 1993. Two species of coccidian parasites (*Apicomplexa, Eimeriorina*) from red drum (*Sciaenops ocellatus*). *Dis. Aquat. Org.* 16: 83-90.

Landsberg, J.H., G.K. Vermeer, S.A. Richards, and N. Perry. 1991. Control of the parasitic copepod (*Caligus elongatus*) on pond-reared red drum. *J. Aquat. Anim. Health.* 3: 206-209.

Levingston, L.M. personal communication. Cow Bayou Fish Farm, Bridge City, Texas.

Lewis, D.H., W. Wenxing, A. Ayers and C.R. Arnold. 1988. Preliminary studies on the use of chloroquine as a systemic chemotherapeutic agent for amyloodinosis in red drum (*Sciaenops ocellatus*). *Contrib. Mar. Sci.* 30 (supplement): 183-189.

McEachron, L., G. Saul, J. Cox, C.E. Bryan and G. Matlock. 1984. Winter's arctic weather takes a heavy toll on marine life. *Texas Parks Wildl. Mag.* 42: 10.

Miranda, L.E., and A.J. Sonski. 1985. Survival of red drum fingerlings in freshwater: dissolved solids and thermal minima. *Proc. Southeast. Assoc. Fish Wildl. Agen.* 39: 228-237.

Moon, H.Y. and D.M. Gatlin, III. 1991. Total sulfur amino acid requirement of juvenile red drum (*Sciaenops ocellatus*). *Aquaculture.* 95: 97-106.

Moon, H.Y., W.H. Neill and D.M. Gatlin, III. 1991. Evaluation of protein sources for red drum (*Sciaenops ocellatus*) diets. *J. World Aquacult. Soc.* 22: 42A-43A. Abstract.

Procarione, L.S. 1986. Ultimate lower lethal temperature of red drum (*Sciaenops ocellatus*) as a function of water hardness and salinity. M.S. Thesis, Texas A&M University, College Station, Texas.

Procarione, L.S. and B.W. Bumguardner. 1989. Long-term growth of South Carolina and Texas red drum. Texas Parks and Wildlife Dept. Management Data Series No. 5. 10 pp.

Pursley, M.G., W.R. Wolters and R.P. Romaire. 1989. Effect of total water hardness and chlorides on growth, survival and feed conversion of juvenile red drum (*Sciaenops ocellatus*). *J. World Aquacult. Soc.* 29: 63A.

Reigh, R.C. and S.C. Ellis. 1992. Effects of dietary soybean and fish protein ratios on growth and body composition of red drum (*Sciaenops ocellatus*) fed isonitrogenous diets. *Aquaculture.* 95: 97-106.

Roberts, D.E., Jr. 1990. Photoperiod/temperature control in commercial production of red drum (*Sciaenops ocellatus*) eggs. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603, Texas A&M University, College Station, TX, pp. 35-43.

Roberts, D.E.,Jr., B.V. Harpster and G.E. Henderson. 1978. Conditioning and induced spawning of the red drum (*Sciaenops ocellatus*) under varied conditions of photoperiod and temperature. *Proc. World Maricult. Soc.* 9: 311-332.

Robertson, L., P. Thomas and C.R. Arnold. 1988. Plasma cortisol and secondary stress response of cultured red drum (*Sciaenops ocellatus*) to several transportation procedures. *Aquaculture.* 68: 115-130.

Robertson, L., P. Thomas, C.R. Arnold and J.M. Trant. 1987. Plasma cortisol and secondary stress response of red drum to handling, transport, rearing density and a disease outbreak. *Prog. Fish. Cult.* 49: 1-12.

Robinson, E.H. 1990. Nutrition and feeding of red drum. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603. Texas A&M University, College Station, Texas. pp. 109-112.

Robinson, E.H. 1991. Red drum (*Sciaenops ocellatus*). *In*: Handbook of Nutrient Requirements of Finfish. CRC Press, Boca Raton, Florida. pp. 145-152.

Rutledge, W.P. and G.C. Matlock. 1986. Mariculture and fisheries management - a future cooperative approach. *In*: Fish Culture in Fisheries Management. Fish Culture Section, American Fisheries Society, Bethesda, Maryland. pp. 119-127.

Sandifer, P.A., J.S. Hopkins, A.D. Stokes, and R.D. Smiley. 1993. Experimental pond growout of red drum (*Sciaenops ocellatus*), in South Carolina. *Aquaculture.* 118: 217-228.

Schwarz, M. personal communication. HarvestFresh, Bacliff, Texas.

Serrano, J.A., G.R. Nematipour and D.M. Gatlin, III. 1992. Dietary protein requirement of the red drum (*Sciaenops ocellatus*) and relative use of dietary carbohydrate. *Aquaculture.* 101: 283-291.

Simmons, E.G. and J.P. Breuer. 1962. A study of redfish (*Sciaenops ocellata* Linnaeus) and black drum (*Pogonias cromis* Linnaeus). *Inst. Mar. Sci.* 8: 184-211.

Swingle, W.E. 1990. Status of the commercial and recreational fishery. *In*: Red Drum Aquaculture. Texas A&M Sea Grant # 90-603. Texas A&M University, College Station, Texas. pp. 22-24.

Texas Park and Wildlife Dept., Palacios, Texas.

Thomas, P. and N. Boyd. 1988. Induced spawning of spotted seatrout, red drum and orangemouth corvina (Family: Sciaenidae) with luteinizing hormone-releasing hormone analog injection. *Contrib. Mar. Sci.* 30 (supplement): 43-48.

Thomas, R.G. and W.R. Wolters. 1992. Factors affecting the survival of fingerling red drum in freshwater ponds. *Prog. Fish. Cult.* 54: 215-219.

Ward, R., I.R. Blandon, T.L. King and T.L. Beltinger. 1993. Comparisons of critical thermal maxima and minima of juvenile red drum (*Sciaenops ocellatus*) from Texas and North Carolina. *Northeast Gulf Scie.* 13: 23-28.

Weirich, C.R. and J.R. Tomasso. 1991. Confinement and transport-induced stress on red drum juveniles: effect of salinity. *Prog. Fish. Cult.* 53: 146-149.

Williams, C.D. and E.H. Robinson. 1988. Response of red drum to various dietary levels of menhaden oil. *Aquaculture.* 70: 107-120.

Wisner, B.B., T.R. Capo and J. Cramer. 1991. Comparison of four commercial aquaculture diets for red drum. *J. World Aquacult. Soc.* 22:66A. Abstract.

Wurts, W.A. and R.R. Stickney. 1989. Responses of red drum (*Sciaenops ocellatus*) to calcium and magnesium concentrations in fresh and salt water. *Aquaculture.* 76: 21-35.