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Occasional Publication No. 39

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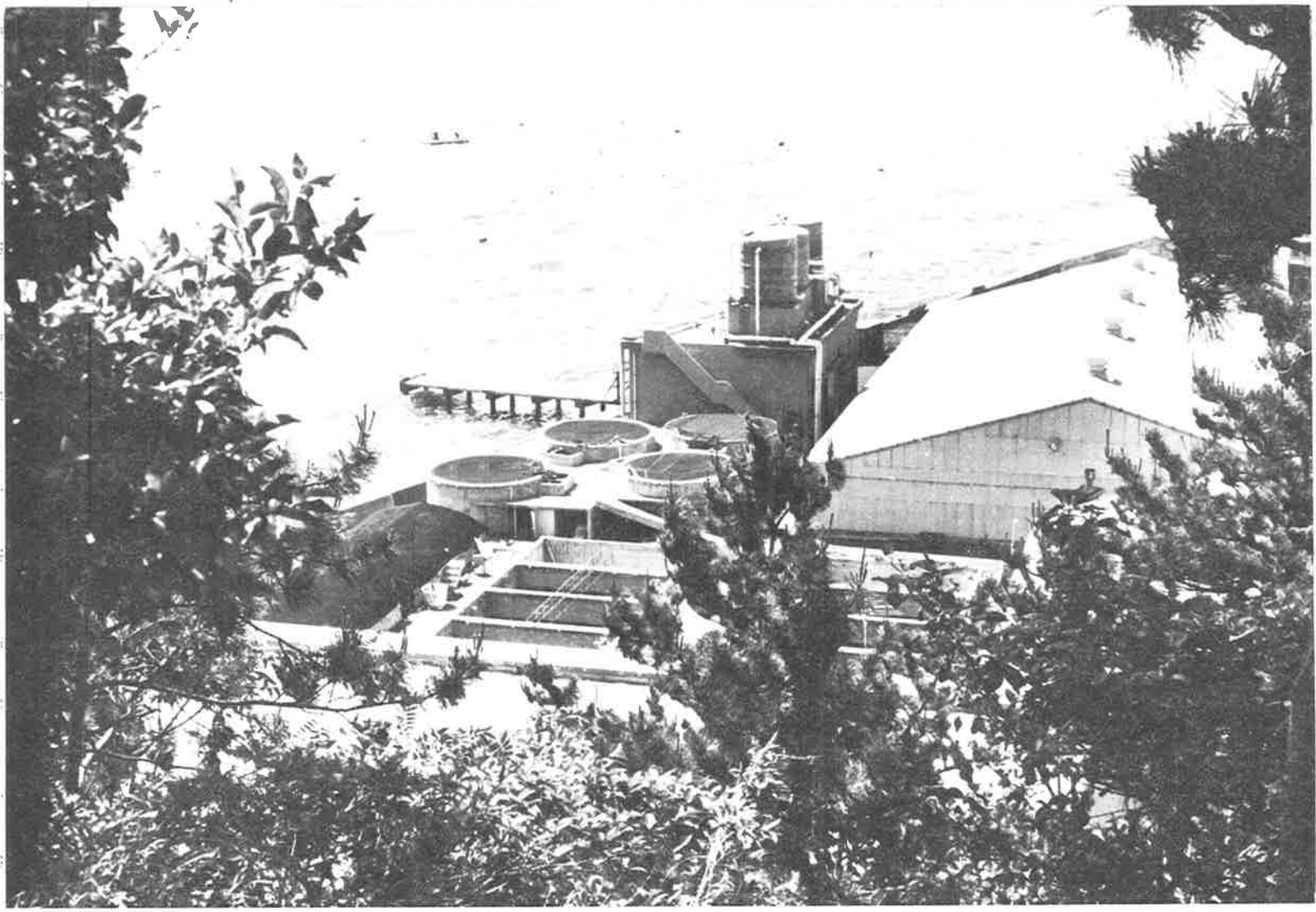


The Shizuoka Prefectural Saibai Gyogyo Centre. The circular ponds are where the red sea bream spawn and the oblong ponds are for algal culture. The 2 towers are filtration plants for incoming sea water. The small boat in the background is being used to feed yellowtail held in submerged cages.

Introduction

In Japan the red sea bream or madai (*Chrysophrys major**) is king of the marine fish. The species is prized for its firm white flesh and delicate flavour, and it is served at religious ceremonies and on festive occasions. It also features in Japanese tradition and legend.

The annual catch of red sea bream is now about 15 000 t and is well below market demand. The drop in catch rates during the 1960s stimulated research into the large scale hatchery production of seed for both farming and reseeding. At present red sea bream is the most important hatchery reared marine teleost. In 1979 farming produced a harvest of about 12 000 t. In addition, 10 million seedlings were released into coastal waters to enhance the natural fishery.

The red sea bream is a member of the family Sparidae and is closely related to the snappers of Australia and New Zealand. The phenotypic similarity between red sea bream and New Zealand snapper (*Chrysophrys auratus*), and the high demand for sea bream in Japan, suggest that snapper farming and reseeding may be appropriate aquaculture ventures in New Zealand. The development of any such industry would depend on a hatchery supply of seed.

This publication describes the hatchery rearing of red sea bream larvae, and the reseeding operations, with specific examples from Shizuoka Prefecture. Methods used at the Shizuoka Prefectural Saibai Gyogyo Centre for the culture of food for larvae of red sea bream are discussed in the Appendix.

Biology of red sea bream

Red sea bream are found off both coasts of Japan, in the East China Sea, and off the coast of South-east Asia. They are most abundant in the East China Sea (40% of total red sea bream landings), the northern and western parts of the Sea of Japan, and the Seto Inland Sea. They are usually found over areas of rough sea bottom, between 50 and 150 m, where they feed on various invertebrates and small teleosts. There is a spawning migration in the Yellow Sea, but the movements and migrations of red sea bream are generally not known. There are 2 hypotheses about the population in the Seto Inland Sea: one that it is a separate population; the other that it is augmented by spawning migration from outside the area. This situation is analogous to that of snapper in the Hauraki Gulf, New Zealand.

*The generic name *Chrysophrys* is used in this publication because it is in common use in New Zealand, whereas the name *Pagrus* is commonly used by Japanese scientists.

Red sea bream can live for more than 20 years and reach a length of 1 m. Sexual maturity occurs at 3–4 years of age, at a length of about 35 cm, and a weight of 1.0–1.5 kg. In the south of their range spawning starts at the end of February and continues until April. Further north spawning starts in April and lasts until June. A 3-year-old female may produce 250 000 eggs over the spawning season, whereas a 10-year-old may produce as many as 5 million.

The Shizuoka Prefectural Saibai Gyogyo Centre

The Japanese Government, in response to declining fish catches, has an ambitious plan to enhance the coastal fisheries by the artificial rearing and reseeding (known as saibai gyogyo) of selected high value species, such as abalone, crabs, prawns, and red sea bream. Research on aquaculture species is carried out in the National Fisheries Research Laboratories and Prefectural Fisheries Experimental Stations, and the technology, or large scale production, is applied in 9 National and 27 Prefectural Fish Farming Centres.

The Shizuoka Prefectural Saibai Gyogyo Centre was completed in 1978 at a cost of 330 million yen (about NZ$1.65 million). Two-thirds of the building costs were met by central government and one-third by the prefectural government. It is near Numazu on the north-western edge of the Izu Peninsula, some 100 km south-west of Tokyo. The site of about 5000 m^2 is on a small peninsula with open sea to the south and a small fishing harbour to the north.

The centre consists of a 2-storey office and laboratory block, 2 large, barn-like buildings for abalone and rotifer culture, and many outdoor concrete ponds. Filtered sea water is supplied at the rate of 90 m^3 per hour through an activated anthracite charcoal filter, which removes all particles greater than 30 μ. Unfiltered sea water is supplied at the rate of 240 m^3 per hour. There is a full time staff of 18 and the centre is run on a team approach to accommodate the shifting seasonal workload imposed by the spawning biology of the species being reared. Additional part time staff are employed at specific periods, such as during abalone and red sea bream reseeding. The main species being reared are red sea bream (spring spawner), prawn *Penaeus japonicus* (summer spawner), and abalone *Haliotis discus* (winter spawner). In addition, some yellowtail (*Seriola quinqueradiata*) are on-grown from wild-caught seed and pufferfish *Fugu rubripes* are cultured on an experimental scale (Smith 1981).

Red sea bream brood-stock and egg production

Cultured fish, including hatchery reared fish, are used as adult brood-stock, and these fish are held in outdoor concrete ponds all year. There are 4 circular ponds, each of 60-t capacity, with a diameter of 5.8 m and a depth of 2.5 m (Fig. 1). Sea water is dropped from a height of about 0.5 m into the ponds (to increase aeration) at a rate of about 2 exchanges per day. Air stones are also used to circulate water in each pond. The outflow is normally at the bottom to assist in removing waste food, but this exit can be closed off to force water out through a surface overflow pipe and a plankton trap. This system is used to collect eggs each evening in spring. The ponds, and plankton traps, are covered with a double layer of black fibreglass shade netting to reduce the light intensity, but maintain a normal day length.

Each pond contains a different year class. The recommended stocking density is 0.5–1.0 kg of females per cubic metre, at a female to male ratio of 1.5 : 1. There are no external sex characteristics; so the fish are sexed by gentle hand stripping before they spawn in spring. Males are identified by milt emitted from the vent. Stocking rates and spawning conditions for the 3 ponds are shown in Table 1.

The fish are fed once a day in summer and every second day in winter. The food is either formula food (red sea bream pellets) or a mixture of formula food and minced fish produced as a moist pellet. The formula food contains multivitamins and minerals. Low value species (such as Japanese mackerel and sardine) are used either fresh or frozen, but they must be in good condition. Poor quality fish food can be a source of disease, particularly in summer when temperatures are high.

Between late March and early June, once the water temperature is above 15 °C, spawning occurs naturally in the ponds, without the need for hormone treatment or hand stripping. Spawning usually takes place between sunset and midnight. Several males will chase and nudge a female, forcing her up to the surface and often on to her side. The female releases a stream of eggs which is covered by spermatozoa from several males. Egg production ranges from about 270 000 in small females of 3–4 years of age to 4.8 million in large females of 6–12 years. Eggs are released daily in batches of 50 000–100 000, though not all the eggs produced over a spawning season are released. Egg production figures for the 3 spawning ponds are shown in Fig. 2.

TABLE 1: Stocking rates and spawning conditions in the 3 red sea bream spawning ponds in the Shizuoka Prefectural Saibai Gyogyo Centre in 1981

Pond	Age of fish	Date stocked	No. of fish	No. of males	Mean weight (kg)	Spawning period	No. of spawning days	Water temp. (°C)	No. of eggs collected (× 10^6)
1	3	3/4/81	50	19	1.31	6 Apr–25 May	50	15.9–19.6	9.378
2	5	12/1/79	32	14	2.46	28 Mar–18 May	52	15.4–19.6	18.495
3	6 + 7	14/2/78	44	15	3.37	23 Mar–3 Jun	73	15.4–20.1	100.989

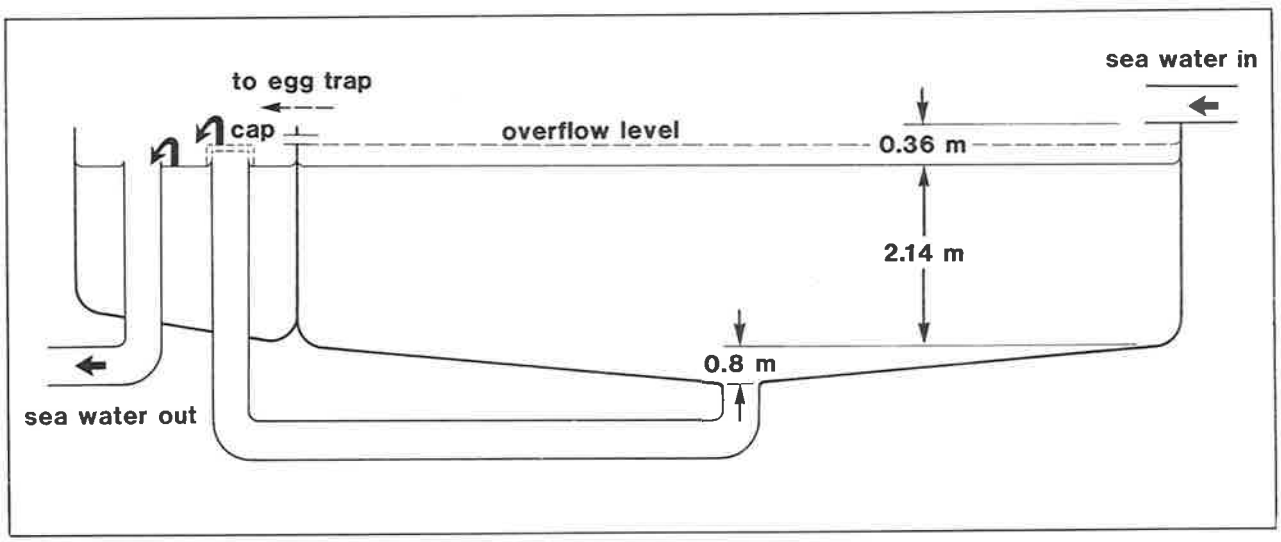


Fig. 1: A red sea bream spawning pond.

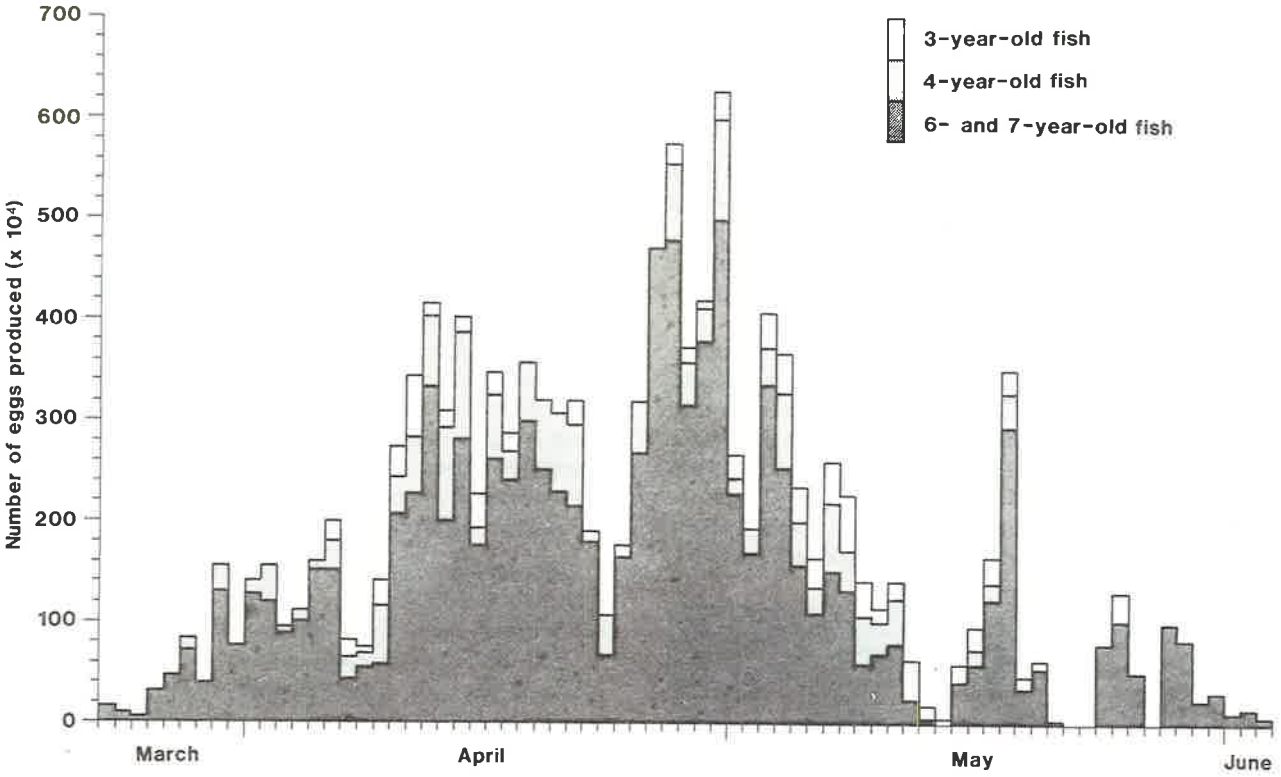


Fig. 2: Egg production and age of red sea bream for the 1981 spawning season.

Fertilisation rates are typically about 80% in young females (3–4 years old), but as low as 35% in older (over 6 years) fish. They are higher in the middle of the spawning season than at the beginning or end. The fertilised eggs, 0.9–1.0 mm in diameter, float close to the surface and are caught in the surface overflow plankton trap. This is a net 0.55 by 0.55 by 0.5 m, with an open top and a mesh size of 400 μ . It is suspended in a tank of sea water and the overflow water from the adult ponds flows through it (Fig. 3). This collects the eggs with a minimum of physical damage.

Fig. 3: Collecting red sea bream eggs. The viable eggs are skimmed off from the top 10 cm of water in the egg trap.

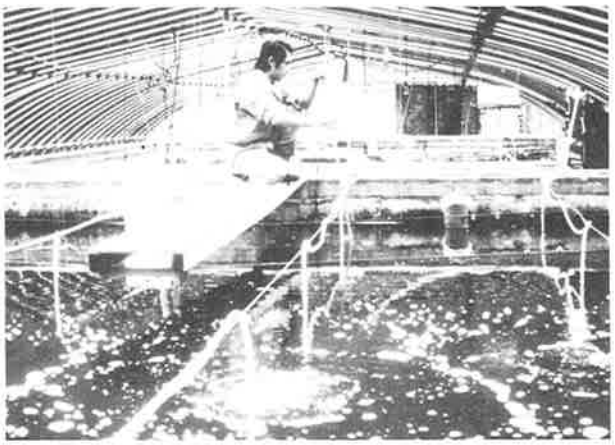
The eggs are removed from the traps each morning, poured through a strainer (which floats in a bucket of filtered sea water) to remove large particles, and weighed to estimate their numbers (1 g = 1800 eggs). The viable eggs tend to float and the non-viable eggs sink. Experiments have shown a hatching rate of 85%–90% for eggs floating in the top 10 cm or so, 38%–70% for suspended eggs, and less than 5% for eggs that sink to the bottom of the trap. After settling has occurred eggs that are to be used for larval rearing are gently skimmed from the top of the water column and weighed. The dead eggs are siphoned off from the bottom of the bucket, filtered, and weighed to estimate the total daily egg production.

At this stage the floating eggs can be placed directly into the larval rearing tanks or, as is more usual, held in an incubating cradle. This is typically a net 0.75 by 0.7 by 0.7 m, with a mesh size of 400 μ, which is suspended in a l-t capacity seawater tank with aerators. Incoming filtered sea water is directed into the net to force water out through the mesh and provide adequate flow and oxygenation. The cradles and tanks are in the laboratory, where they are shaded from direct sunlight and where temperature fluctuations are kept to a minimum. Floating eggs from the cradle are stocked into the larval rearing ponds in the late afternoon or following morning. Eggs that sink to the bottom of the cradle are discarded.

Larval rearing

Larvae are reared in outdoor concrete ponds 6 by 9 by 2 m with a seawater capacity of about 90 t. The ponds are covered with a double layer of shade netting (Fig. 4). Typical midday summer light intensities reach about 100 000 lux, but the netting reduces the intensity to about 30 000 lux at the water surface.

Water aeration is maintained by 16 air stones equally distributed close to the bottom of the pond. Food and chemicals are added through a sprinkler hose-pipe that runs the length of the pond about 0.5 m above the water surface. The water in the pond is not exchanged during the first week after hatching. After this period water is added daily and exchanges are slowly increased to about 3 per day towards the end of larval rearing (Table 2).



Water falls into the pond at one end through a microfilter and is siphoned out at the opposite end through a lantern net. This net (30 by 30 cm by 2 m deep) is changed every 4–5 days initially, but daily towards the end of the larval rearing period. As the larvae grow, the mesh size is increased to allow greater water exchange. A 0.3-mm mesh is used for the first 10 days after hatching, a 0.5-mm mesh for the next 7 days, and a 1.0-mm mesh thereafter. The bottom of the pond is siphon cleaned daily from the twentieth day after hatching. When the larvae are less than 10 mm long the aeration is stopped during cleaning so that the larvae rise to the surface and losses are minimised.

Chlorella spp. are added to the ponds to a density of 300 000–500 000 cells per millilitre 1 day before the red sea bream eggs. Eggs are stocked at a density of 20 000–30 000 per cubic metre to give a larval density of 20–30 per litre. A small sample of eggs is kept aside to test the hatching rate, which is usually above 80%. The eggs hatch about 2 days after fertilisation, though hatching time varies with water temperature: at 14.0 °C hatching takes 95 hours, but at 20.0 °C it takes only 39 hours.

Hatching time (HT) can be estimated from the formula:

HT (hours) $= 427/t - 9$, where t is temperature (°C).

Fig. 4: Cleaning a red sea bream larval rearing pond.

TABLE 2: Rearing details for 1 red sea bream larval pond at the Shizuoka Prefectural Saibai Gyogyo Centre in 1981

Date	Days after hatching	Water temp. (°C)	pH	Salinity (°/oo)	Volume of water added (m^3)	Rate of water exchange per day	Density of *Chlorella* ($\times 10^4$/ml)	Volume of *Chlorella* (m^3)	No. of rotifers ($\times 10^8$)	Wt. of frozen rotifers (g)
28 Apr*										
30 Apr	0	17.5	8.34	33.6	0	0	36	0.5	0	0
6 May	6	17.6	8.38	32.2	3.6	0.04	41	2	6.4	0
11 May	11	18.7	7.98	31.8	8.9	0.10	48	3	3.0	0
14 May	14	18.4	7.88	31.0	12.6	0.14	27	5	7.6	0
18 May†	18	17.7	7.84	33.3	24.5	0.27	49	4	9.4	0
22 May	22	17.8	7.90	34.7	40.8	0.45	25	5	14.8	0
25 May	25	18.7	7.98	33.6	57.6	0.64	35	5	17.6	0
27 May	27	19.4	8.15	23.8	51.0	0.57	33	4	17.9	0
28 May	28	19.6	8.02	33.2	25.2	0.28	52	3	17.5	0
1 Jun	32	18.8	8.05	34.4	86.4	0.96	4	0	13.0	0
5 Jun	36	19.7	8.00	34.1	100.8	1.12	0	0	3.2	3.6
8 Jun	39	21.1	8.10	33.3	220.8	2.45	0	0	0	4.1
9 Jun§	40				0	0	0	0	0	0
		18.55	8.06	33.3	1 867	20.76		106	380	31.1

* 2.55 $\times 10^6$ eggs stocked (hatching rate 91.7%).
† Start of chemical treatment (sodium nifurstyrenate at 1.5 ppm) to clean tank.
‡ Not measured.
§ Transfer to sea cage.

Development ceases below 10 °C and mortality levels are very high above 25 °C; optimum temperatures are between 15 and 18 °C.

The newly hatched larvae are 2.0–2.3 mm long and feed off their yolk sacs for 3–4 days. They float around the pond in the circulation produced by the air stones. Survival over this stage is almost 100%.

Rotifers are added to the ponds 2 days after hatching to ensure an adequate food supply at the onset of larval feeding. *Chlorella* are added daily throughout the rotifer feeding period to maintain their density at about 500 000 cells per millilitre. They are pumped directly into the ponds from the outdoor *Chlorella* tanks. They have a beneficial effect on larval culture by acting as a food source for rotifers and probably stabilising pH in the ponds. They also increase larval survival rates (Kittaka 1977).

In early work on the hatchery rearing of red sea bream larvae, mussel and oyster larvae, and in some hatcheries barnacle larvae, were used as a preliminary food supply for 2–4 days before the rotifers were added (Kittaka 1977). This additional food supply is unnecessary because rotifers breed in the ponds and so provide a smaller food particle which is suitable for the red sea bream larvae. Rotifers are used as the principal food source for as long as possible because they give good growth and survival rates in red sea bream larvae and can be produced easily on a large scale. Each larva may eat 20 rotifers per day at the onset of feeding, but more than 200 per day 2 weeks after hatching. The high consumption and the loss through water exchange mean that millions of rotifers are required each day. The rotifer density in the larval ponds has to be maintained at a minimum of 5 per millilitre to avoid larval starvation; in practice, it is kept at more than 10 rotifers per millilitre. Rotifer counts are made 3 times a day for each larval pond and the required number (in a volume of known rotifer density) is pumped into the pond from the rotifer production unit. The required number of rotifers in each larval rearing pond is estimated from the formula:

$$N_r = R_d N_l (R_w + 1),$$

where N_r is the total number of rotifers required per day, R_d is the number of rotifers eaten per larva per day, N_l is the number of red sea bream larvae in the pond, and R_w is the water exchange rate. The value of R_d is calculated from the formula:

$$R_d = 0.3927 L^{3.676},$$

where L is the mean length of larvae in the pond.

Rotifers are used as a food source for up to 35 days after hatching. Some 20 days after hatching, when the larvae have reached a length of about 6 mm, the rotifer diet is supplemented with *Tigriopus japonicus*, a marine copepod. If *Tigriopus* is used as the sole food source the number eaten per larva per day is estimated from the formula:

$$T_d = 0.6728 L^{3.4658},$$

where L is the mean total length of larvae. In practice, when *Tigriopus* is used to supplement the rotifers, the quantity required is decided from the total weight of rotifers required minus the actual weight of rotifers used (1 rotifer = 0.003 mg, 1 *Tigriopus* = 0.034 mg).

Nauplii of the brine shrimp *Artemia salina* can be used as a food source between 20 and 35 days after hatching, but cannot be used exclusively for more than 4 or 5 days (Fukusho, Hara, and Yoshio 1976). They give good growth rates, but can cause high larval mortalities. A comparison of 2 groups of larvae, 1 fed on *Artemia* and the other on copepods, from 20 to 34 days after hatching, showed a 15% survival rate in the former and a 50% rate in the latter (Kittaka 1977).

Artificial food (g)	No. of *Artemia* ($\times 10^6$)	Wt. of *Tigriopus* (g)	Wt. of frozen *Tigriopus* (g)	Wt. of frozen red sea bream eggs (g)	Wt. of clam (g)	Wt. of opossum shrimp (g)	Wt. of sand lance (g)	Larval length (mm)	No. of larvae ($\times 10^6$)	% survival
0	0	0	0	0	0	0	0	2.87	2.34	100
0	0	0	0	0	0	0	0	3.68	2.04	87.3
0	0	0	0	0	0	0	0	4.14	1.54	65.8
0	0	0	0	0	0	0	0	4.83	1.14	48.8
0	0	0	0	0	0	0	0	5.03	0.90	38.4
0	0	0	0	0	0	0	0	6.56	0.70	29.9
0	0	0	0	0	0	0	0	8.84	—‡	—
0	0	0	0	0	0	0	0	9.11	0.41	17.7
0	0	0	0	0	0	0	0	—	—	—
200	91	1 600	0	0	0	0	0	11.62	0.40	17.0
300	78	140	600	900	900	900	0	13.78	0.23	10.0
300	99	0	400	1 250	0	1 300	900	—	—	—
0	0	0	0	0	0	0	0	15.23	0.21	8.99
2 600	**936**	4 580	1 900	7 410	2 100	6 000	2 700			

Some 30–35 days after hatching, at a length of 10–12 mm, the larvae (or fry at this stage) are weaned on to the juvenile diet. The rotifer, *Tigriopus,* and *Artemia* diet is slowly phased out over 2 weeks as the juvenile diet is introduced. Red sea bream fry crumbs, frozen fish eggs (usually excess production from the spawning ponds), and finely minced opossum shrimp *Neomysis japonicus*, clam *Tapes philippinarum*, and sand lance *Ammodytes personatus* are used over the weaning period. This is a critical stage of larval rearing: too much food can rapidly cause pollution in the ponds; too little food can lead to cannibalism and starvation. The total amount of moist food added per day is 70%–80% of the total weight of fry in the pond.

Forty days after hatching, at a length of about 15 mm, the fry are ready for transfer to sea cages. In some other saibai gyogyo centres larvae are transferred to larger ponds at about 8 mm and then to sea cages at about 20 mm. The larval rearing phase for 1 pond at the Shizuoka Prefectural Saibai Gyogyo Centre is summarised in Fig. 5 and Table 2.

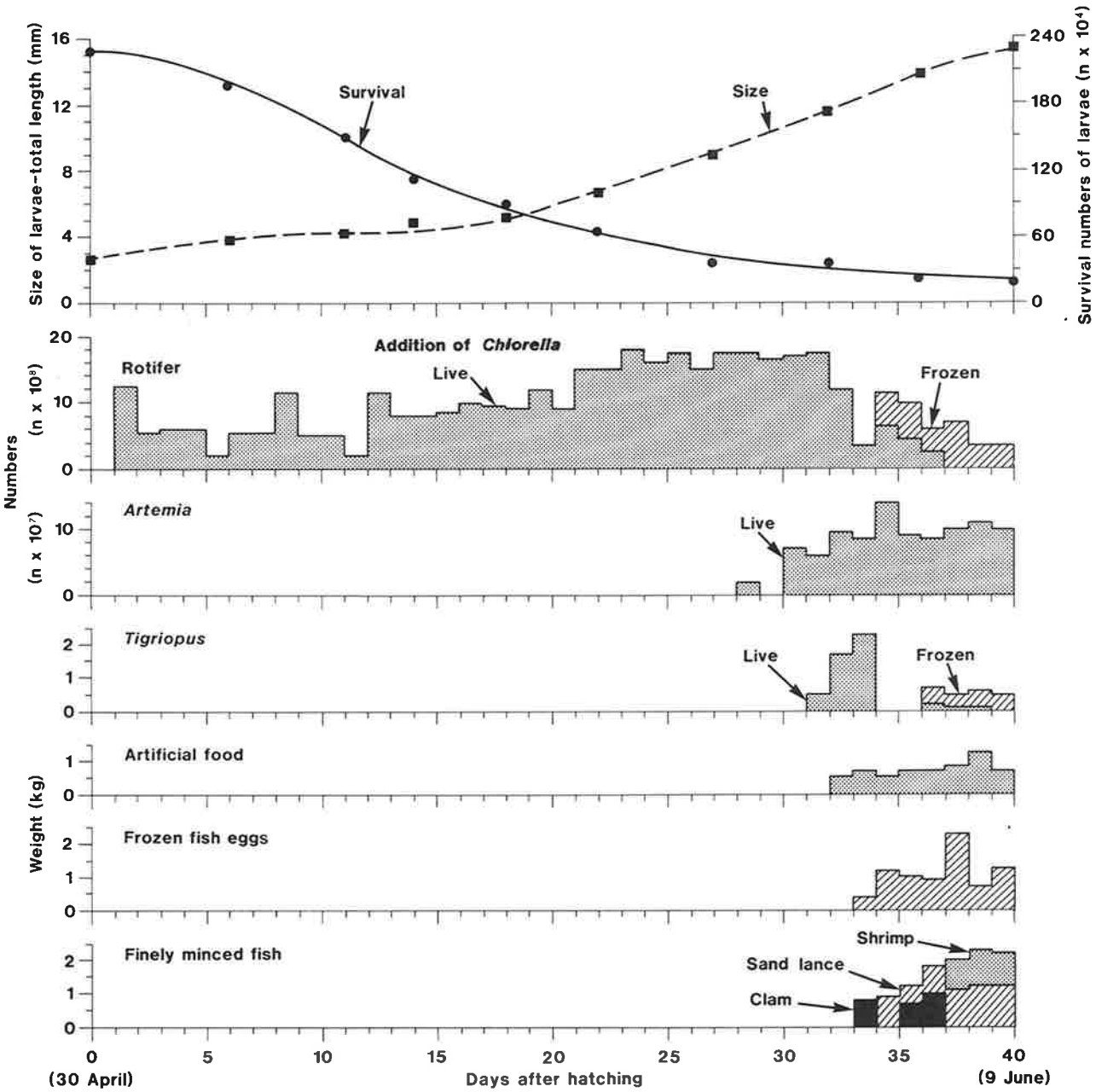


Fig. 5: Summary of red sea bream larval rearing for 1 pond over the 1981 season.

Physical conditions and food supply are monitored daily in each pond. The larvae are sampled every 3–5 days to measure growth rate and development, and their numbers are estimated every 4–5 days after dark, when the larvae are equally distributed throughout the pond. Substantial resources have to be allocated to larval food production; 2 staff are employed on larval rearing and between 5 and 7 on the production of larval food (*Chlorella*, rotifers, and *Artemia*). Artificial pelletised food is available for even the small larval stages, but it does not give good growth or survival rates and needs to be supplemented with live rotifers. In addition, it causes pollution problems, because uneaten food settles out and encourages the growth of bacteria.

On-growing in sea cages

Fry are removed from the ponds by lowering the water level and herding the fish by seine net so that they can be either scooped up by bucket or siphoned out into transport tanks. An estimate is made of the number of fry harvested. Some are transported by boat to sea cages in neighbouring bays; others are taken to more distant sites by road and then boat. The centre has a 10-m vessel with holding tanks to transport live fish. Fry are carried in fine nets held on a wooden frame in the tanks. Those to be transported by boat are carried at a density of 25 000–30 000 per tonne of sea water for journeys of 1–2 hours and at densities of up to 50 000–100 000 per tonne for journeys of 30 minutes or less. For road transport fry are carried at a density of 25 000–30 000 per tonne. Oxygen is bubbled into the water and if necessary a small amount of freshwater ice may be added to minimise temperature increase.

The criteria used to select cage sites are that they are sheltered from wave action; have good tidal circulation; are away from freshwater, chemical, and sewage run-off; and are out of shipping channels. Cage sizes vary from small experimental cages 3 by 3 by 3 m to large commercial cages 5 by 5 by 5 m with nets suspended from a floating framework of galvanised iron supported on polystyrene floats. Five to 10 cages are joined and anchored fore and aft to lie into the prevailing wind. Mesh size is increased as the fry grow, to facilitate water exchange and reduce fouling (Fig. 6).

Fifteen-millimetre fry are stocked at a density of 2000–4000 per cubic metre in 2-mm-mesh cages. As the fry grow their density is reduced by transfer to other cages. They are fed at least 4 times a day on finely minced fish at an initial rate of 100% of total body weight per day. The rate is reduced to about 20% of total body weight per day. On this diet growth is rapid, from 15 mm in June to 5–10 cm by August, at which size and time the juvenile red sea bream are ready for release. In a typical example from Shizuoka Prefecture, 96 000 seed fish were raised from an average fork length of 2 cm on 1 July to 8 cm on 19 August with a survival rate of 78.5%.

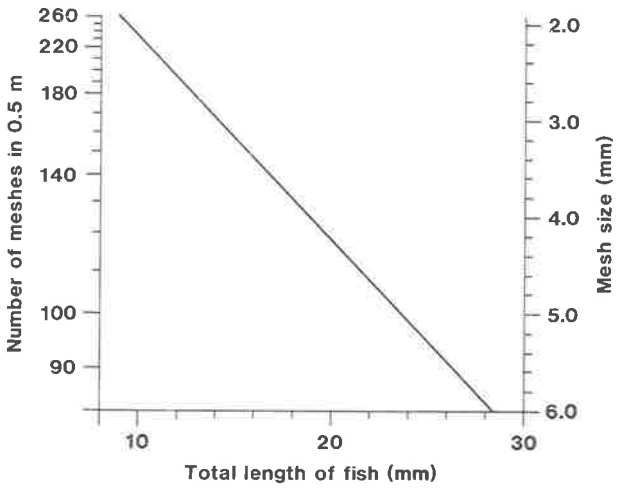


Fig. 6: Mesh sizes for juvenile red sea bream cages.

Disease

The Shizuoka Prefectural Saibai Gyogyo Centre has disease specialists who monitor and treat diseases in all species being reared. There are fewer major disease problems with red sea bream than with other cultured finfish. In adults most problems that arise can be attributed to handling stress or poor diet. In the larval stages *Vibrio* sp. can cause high mortalities. The critical symptom of a swollen abdomen appears in larvae 5–10 mm long. The disease can be treated by the addition of 1.5 ppm nifurpirinol to the larval food (rotifers, *Tigriopus,* and *Artemia*). Daily siphon cleaning of the tanks can help reduce the disease, but ultraviolet irradiation of incoming sea water has little or no effect. Sodium nifurstyrenate is being tested as a treatment for *Vibrio* sp. in the larval rearing tanks. It is dissolved in fresh water and sprayed on to the larval rearing tanks through the sprinkler feeding system to give a final concentration of 1.5 ppm. Water flow in the tanks is stopped for 24 hours during treatment.

Red sea bream juveniles on-grown in sea cages can suffer from bacterial diseases (caused by *Vibrio* sp. and *Flexibacter* sp.) during their first year. Typical symptoms are ulcerations of the skin for infections of *Vibrio* sp. and eroded mouth, frayed fins, and tail rot for those of *Flexibacter* sp. These can be treated by the addition of oxytetracycline hydrochloride to the food at a rate of 30–50 mg per kilogram of juveniles per day for 5–7 days.

The red sea bream fishery and reseeding

The annual red sea bream fishery in the Tokai region on the Pacific coast of central Japan has declined from a peak of 3270 t in 1965 to about 500 t. Landings from the Izu Peninsula coastal fishery of Shizuoka Prefecture, which makes up a small part of the Tokai fishery, have declined from a maximum of 240 t to about 30 t per year. The Izu Peninsula fishery is centred on eastern Suruga Bay and east coast, Izu Peninsula. Most fish are caught by set net and angling in less than 100 m and are 1–3 years old.

The aim of the reseeding programme in Shizuoka Prefecture is to restore the coastal fishery to earlier levels. The programme is monitored by the Shizuoka Prefectural Fisheries Experimental Station, Izu Branch which has a staff of 13 and carries out research on the commercially important resources of finfish and shellfish. Surveys of the red sea bream fishery have been made to estimate numbers, growth rates, movements, and mortalities. The reseeding programme in Shizuoka Prefecture is integrated with that of neighbouring Kanagawa Prefecture, where there are similar declining fisheries in Tokyo Bay and off the west coast of Miura Peninsula. Releases began in 1977 in Kanagawa Prefecture and in 1978 in Shizuoka Prefecture (Fig. 7).

Release sites

Many of the released fish are tagged to estimate growth and mortality rates and the effect on the fishery. The minimum recommended release size is 4 cm,

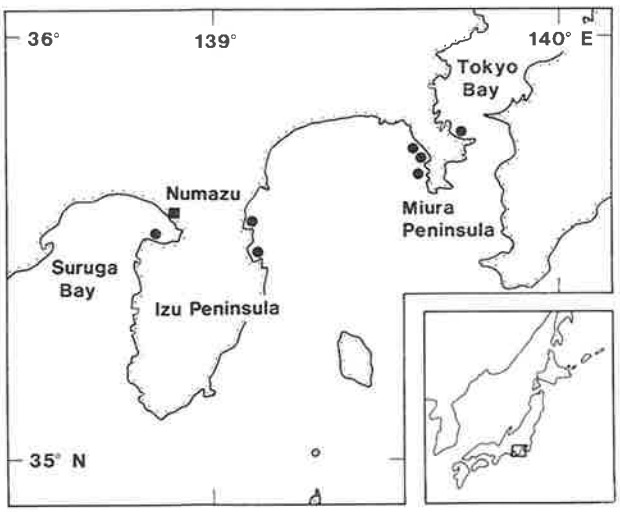


Fig. 7: Red sea bream release sites around the Izu and Miura Peninsulas.

though 8–10 cm is preferred for tagging (Fig. 8). Fish are tagged with small (1.5-cm long) plastic anchor tags, which are injected into the dorsal muscle with a Banok Q3 103-S tagging gun. Code numbers can be written directly on the tag, and different coloured tags indicate release batches or sites. Up to 10 staff work on the tagging programme. Tagging operators wear cotton gloves to reduce scale damage to the fish and to protect their hands from spines. One person can tag 1000–2000 fish per day.

Where fish are to be released close to the on-growing sites, the cages are towed to the release area. The nets are raised and the fish are scooped out in buckets to reduce scale damage. They are tagged and carefully placed over the side. Fish that are not to be tagged are released by lowering the net from the frame. For more distant release sites, fish are scooped up in the same way and transported in the hold of the vessel. Sea water is pumped continuously through the hold. The fish are tagged on board and placed over the side at the release site.

In the Seto Inland Sea, experiments have been carried out on the audio-signal training of red sea bream. Juveniles held in enclosed bays or sea cages have been subjected to sound pulses from an underwater speaker just before feeding. Results have shown that over a 2-week period most of the fish become conditioned to respond to the sound. It is intended to lure juveniles away from the hatchery rearing site to more suitable nursery areas by slowly moving the underwater speakers.

Release sites are selected from experimental fishing and diving surveys. Ecological studies and tagging experiments have been made on natural populations of red sea bream. These have found fry, 2–4 cm long, in water depths of 1–5 m between May and June, fish of 4–7 cm in 5–10 m between June and August, and fish of 6–13 cm in 8–20 m between July and October. Larger fish (over 12 cm) move into deeper water, down to 60 m, over the first winter. Several release sites, ranging in depth from 5 to 30 m, have been tested from August to October.

Four release areas have been tested by the Shizuoka and Kanagawa Prefectural Fisheries Experimental Stations and Saibai Gyogyo Centres, 1 in each of the 4 red sea bream fishing areas. Release sites varied from eelgrass beds at a depth of less than 5 m to natural reef and mud-sand areas between 10 and 20 m (Table 3). All were areas inhabited by wild juveniles (Kawajiri 1981). The best returns (2.99% of released fish) were recorded from natural reef and mud-sand areas. Growth rates varied between release sites; 2-year-old fish in eastern Suruga Bay were about twice the weight of 2-year-old fish in other areas. The 0-group fish remained in the release area; most recaptures were within 2 km of the release site and there was a maximum movement of 10–15 km. There is a general movement into deeper water in autumn, when some tagged fish are caught under culture rafts. Few fish are recaptured over winter. Most 1-year-old fish were taken within 5 km of the release site, with a maximum movement of 25–30 km; and most 2-year-olds were taken within 8 km of the release site, with a maximum movement of 30–35 km (Kawajiri 1981).

From these results it has been recommended that commercial and sports fishing be banned within 3 km of the release site for 11 months from the release date. To help enforce this recommendation, the work of the

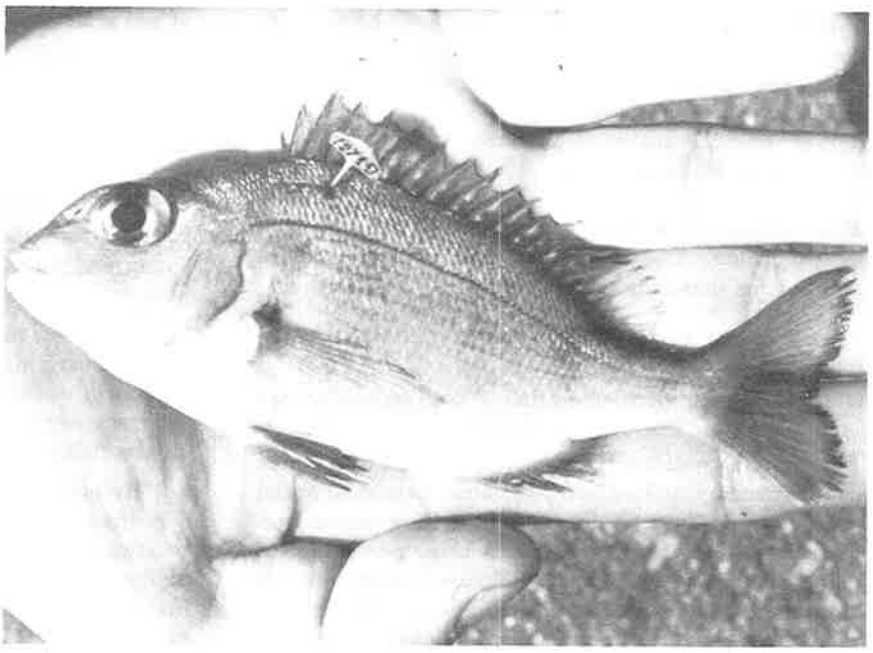


Fig. 8: A tagged juvenile red sea bream ready for release.

TABLE 3: Release site details, recapture rates, and size at 4 reseeding areas in Shizuoka and Kanagawa Prefectures

Reseeding area	Release site	% recapture	Size (cm, g) after 1 year	Size (cm, g) after 2 years
Eastern Suruga Bay	Nursery area, *Eckloniopsis* colonies, sand-mud, and loose stone; 15 m	1.28	20.8, 223	32.4, 821
East coast, Izu Peninsula	*Ecklonia* colonies and sand; 10–15 m	0.73	18.9, 155	27.1, 458
West coast, Miura Peninsula	1. Eelgrass; less than 5 m 2. Sand, rock, and weed; less than 10 m 3. Nursery area; less than 10 m	1.19	18.1, 130	24.5, 347
Tokyo Bay	Natural reef and sand-mud; 10–20 m	2.99	18.7, 158	24.8, 397

saibai gyogyo centres is made known to local fisheries co-operatives and anglers' associations. In addition, private fishing companies are encouraged to participate in, and in some areas undertake, the sea-cage rearing and releasing part of the programme.

Effect on the fishery

The Kanagawa Prefectural Saibai Gyogyo Centre released 209 000 red sea bream in 1977, 372 000 in 1978, 1 029 000 in 1979, and 1 079 700 in 1980 into the Tokyo Bay and west coast, Miura Peninsula nursery areas. Of these released fish, 141 373 were tagged.

At 1 site in the Tokyo Bay fishery the proportion of 1-year-old (less than 200 g) red sea bream increased from less than 5% to between 40% and 60% of the total 1979–80 catch. In previous years this fishery was dominated by 3- and 4-year-old fish (50%–80% of the catch).

An estimate of the effect of 3 years of releases (1977, 1978, and 1979) on the 1980 fishery can be made from tag returns (Kawajiri 1981). However, there has been a high tag loss. Estimates of this loss have been made from experiments with tagged fish held in sea cages and from observations in fish processing sheds, where fish which have lost a tag can be identified by a scar on the dorsal surface. A survey in Shizuoka Prefecture showed that tag loss can be as high as 64% after 1 year and 78% after 2 years. In addition, it has been estimated that about half of the recaptured tagged fish are not reported by fishermen. The tag return data are adjusted to account for these underestimates.

The return to the fishery is estimated from the following formula:

effective number of released fish × true recapture rate × average weight.

The effective number released is the actual number of fish released multiplied by 0.7 because there is an initial mortality of about 30% from handling stress and predation. The true recapture rate is the percentage of returned tags multiplied by 2 to allow for recaptures that are not reported by fishermen. In addition, after the first year, the recapture rate is adjusted to allow for tag loss (the rate is multiplied by 3.3 for 2-year-olds and by 10 for 3-year-olds).

The expected return to the 1980 Tokyo Bay fishery after 3 years of releases is as follows:

1-year-old fish released in 1979 (656 900 × 0.7) × (0.23% × 2) × 104 g	= 220.0 kg
2-year-old fish released in 1978 (272 200 × 0.7) × (0.29% × 2 × 3.3) × 387 g	= 1425.6 kg
3-year-old fish released in 1977 (202 400 × 0.7) × (0.1% × 2 × 10) × 800 g	= 2266.9 kg
	3912.5 kg

From these recapture figures it is estimated that a release of 1 million seed fish each year would eventually produce a net return to the fishery of about 35 t per year (Takama 1981).

Future rearing and reseeding

Future research on the larval rearing and reseeding of red sea bream will centre on 3 key areas:

1. Substantial resources in terms of staff and hatchery facilities are devoted to larval food production. Artificial foods could greatly reduce the work load and necessary facilities. The artificial foods available now do not give good growth or survival rates when used as the sole food supply, and they rapidly break down and pollute the ponds. An improved, encapsulated larval food, and/or changes in pond design, could eliminate these problems with artificial foods.

2. There is a high tag loss in the fast-growing juvenile stages during the 2 years after release. An improved tagging or marking technique would greatly increase the accuracy of estimates of the effectiveness of reseeding on the fishery.

3. Returns of tagged fish are greater from some release sites than others. There is a need for more data on the behaviour of juvenile red sea bream and on the ecology of the nursery areas. Such information may lead to improvements in reseeding operations and provide greater returns in the fishery.

Snapper rearing in New Zealand

New Zealand snapper and Japanese red sea bream are closely related and occupy similar ecological niches. There seem to be no biological reasons why the techniques developed for rearing and reseeding red sea bream in Japan could not be applied to snapper in New Zealand. Snapper have spawned in aquaria at Napier and juveniles have been held in tanks for up to 6 months by Fisheries Research Division staff. In addition, technical staff of Fisheries Research Division have acquired the skills necessary for the successful hatchery rearing of shellfish and the associated culture techniques.

Snapper farming

The major constraints on the development of snapper farming in New Zealand are economic. As in most western fish farming enterprises, the aim is to produce a quality product for a high priced luxury market. At present, and for the foreseeable future, the only high priced market for snapper is in Japan. This market is limited and may be close to saturation point because of the increased production of farmed red sea bream, which rose from about 460 t in 1970 to about 12 200 t in 1979.

In addition to the unstable nature of the market, there are other economic factors acting against the development of snapper farming in New Zealand (Cosh 1982). Food costs are typically about 50% of the production costs of farmed red sea bream. In New Zealand improved export prices for traditional low value species (for example, mackerel and kahawai), which could be used as food sources for snapper, suggest that food production costs would be much greater unless alternative species such as sprat, sardine, and anchovy could be used. Farmed snapper would also incur an extra cost over hatchery farmed red sea bream, in the form of air-freight charges to the Japanese market.

Snapper reseeding

Reseeding is likely to be successful only where snapper stocks have been depleted. It is unlikely to increase production to a level above the natural carrying capacity of the environment. In the Hauraki Gulf there is little evidence of recruitment overfishing: catches are close to their historical level (Boyd 1982), and the number of juveniles does not seem to have declined over the past 15 years (Paul 1982). From a preliminary assessment, reseeding would not be warranted in the Hauraki Gulf.

Less is known about the ecology of the west coast, North Island and Tasman Bay snapper fisheries. In Tasman Bay recruitment is irregular and the fishery is dominated by a few successful year classes (Mace 1982). The reasons for this are not clear, but could include factors such as spawning success and larval and juvenile survival. Reseeding in years of poor recruitment may help to stabilise the fishery and reduce its dependence on a few strong year classes. There are several other factors in favour of reseeding in Tasman Bay. Snapper in this area have a faster growth rate than those in the Hauraki Gulf. There are fewer processing companies involved in the fishery, which would make the reseeding programme easier to monitor, and the costs of reseeding could be more readily shared among those exploiting the resource.

With the rapidly expanding aquaculture industry in the Marlborough Sounds-Tasman Bay area, there is a possibility of incorporating a snapper reseeding programme with other hatchery based aquaculture activities. Green-lipped mussels are farmed in the Marlborough Sounds, scallops are being farmed on a trial basis, and there is potential for farming paua and oysters. A multi-species hatchery, similar to those in Japan, could provide experimental and seed-production facilities for all these species. It would be particularly suitable for production of snapper (spring spawner), oyster (summer spawner), and paua (winter spawner).

In the short term the results of forthcoming red sea bream releases, carried out with the experience gained in past programmes, need to be monitored. If there are improvements in larval food formulation and release methods, they could be applicable to snapper. From information to date it seems that Tasman Bay would be the most appropriate area for trials.

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Appendix

Culture of larval foods at the Shizuoka Prefectural Saibai Gyogyo Centre

Algae

Chlorella spp.

Chlorella are cultured in outdoor concrete ponds with a seawater capacity of 50 t. Fourteen ponds are used from February to June and 4 ponds from June to September, the other 10 being used for prawn culture. Most of the *Chlorella* production is used for rearing red sea bream larvae and rotifers, though some is used for rearing pufferfish larvae. The ponds are filled with 70% sea water and 30% fresh water. A little fertiliser is added at the start of the culture. The fertiliser is made to the following recipes:

	Quantity/m^3 of sea water
Recipe 1	
Ammonium sulphate	100 g
Disodium orthophosphate	20 g
Urea	10 g
Chelating agent	20 g
Vitamin B_{12}	0.015 g
Recipe 2	
Ammonium sulphate	100 g
Liquid urea complex	30 ml

Calcium hypochlorite is used to give a level of 1 ppm free chlorine if it is needed to kill protozoa. Circulation and aeration are maintained by a PVC pipe framework (with 1-mm holes every 0.8 m) on the bottom of the ponds.

Chlorella from laboratory stock cultures are multiplied up from 2-t capacity tanks to 50-t capacity ponds. They are stocked at a density of 4–6 million cells per millilitre. In spring water temperatures they increase by about 2 million cells per millilitre per day and can be harvested after 7–10 days, when numbers reach 15–20 million cells per millilitre. Three harvests are taken from each pond before the culture is started again. Ponds are cleaned between cultures with a high pressure water jet (Fig. 9), and culture is restarted with a one-third dilution from another pond. Daily records are made of water temperature, salinity, and *Chlorella* density in each pond.

Rotifers

Brachionus plicatilis

Rotifers are cultured in indoor concrete ponds. There are nine 50-t seawater capacity ponds in 1 building and two 170-t ponds in the abalone building. Each building has light panels in the roof so that artificial lighting is not needed. Rotifers are used for rearing red sea bream and prawn larvae. Production starts in March and runs until September, and a stock tank is sustained from October to February. Stock cultures, from different parts of Japan, are maintained in the laboratory.

The ponds are filled with 3 parts *Chlorella* (15–20 million cells per millilitre) to 5 parts fresh water and 2 parts sea water. Circulation and aeration are provided by PVC framework or large air stones equally spaced on the bottom of the pond. Rotifers are added to give an initial density of 30–40 per millilitre and are fed twice a day on yeast at a rate of 1–2 g per million rotifers per day. Harvesting takes place after about 10 days, when the density is greater than 100 rotifers per millilitre, and can be repeated every 4–6 days. Pond cultures are run for about 30 days. After the final harvest the ponds are drained and cleaned and a new culture is started. Daily records are kept of rotifer density, temperature, dissolved oxygen, pH, salinity, and weight of yeast added. The density is estimated by taking a 1-ml sample, diluting it to 100 ml, and then counting the number of moving rotifers in 1-ml subsamples.

The rotifers are harvested by pumping the pond water through a 50–60 μ filter (35 by 55 by 30 cm) held on a wooden frame and suspended in a plastic rack in the pond. The numbers harvested can be estimated from the pond density after harvest. The harvested rotifers are cultured on *Chlorella* for a minimum of 6 hours and a maximum of 24 hours before they are fed to the red sea bream larvae.

The final stage takes place in 1-t capacity tanks in the main laboratory building. The tanks are filled with 3 parts fresh water to 7 parts sea water. Concentrated *Chlorella* is sometimes used as a substitute for cultured

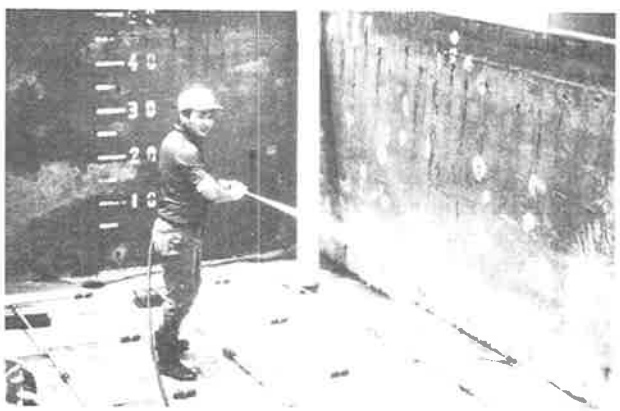

Fig. 9: Cleaning an algal rearing pond. Note the grid of air stones on the bottom of the pond. The figures refer to tonnes of sea water.

Chlorella. The concentrated *Chlorella* is purchased from the Japan Chlorella Manufacturing Company in 1-kg sachets containing 1 billion cells per millilitre. The sachets cost about 1000 yen or NZ$4.50. To add a specific number of rotifers to the larval ponds, a known volume of known rotifer density is pumped through a 50–60 μ filter to concentrate the rotifers. These are then pumped in fresh sea water from the rotifer tank to the larval pond through the sprinkler hose system.

The final stage of rotifer culture is critical for the survival of the red sea bream larvae. It is not economic to culture the millions of rotifers only on *Chlorella*, yet a diet of yeast alone gives poor growth in red sea bream larvae and can result in high mortalities about 10–20 days after hatching. Chemical analyses of yeast-cultured and *Chlorella*-cultured rotifers have shown differences in fatty acid composition (Kitajima 1978). Yeast-cultured rotifers have very low levels of ω3 highly unsaturated fatty acids (HUFA), whereas *Chlorella*-cultured rotifers have much higher levels. These fatty acids are essential for marine teleost larval growth.

Reculturing the yeast-cultured rotifers on *Chlorella* for 48 hours increases the concentration of HUFA to normal levels seen in *Chlorella*-cultured rotifers. In practice, a period of about 6 hours is sufficient to raise the level of HUFA above the critical minimum. Further experiments have suggested that it may be possible to eliminate the *Chlorella* reculture by feeding the rotifers with fat-enriched yeast for 24 hours. Pollock liver or cuttlefish liver oils at levels between 8% and 15% of the yeast volume give high HUFA levels in the rotifers and good growth and survival rates in red sea bream larvae (Kitajima, Arakawa, Oowa, Fujita, Imada, Watanabe, and Yone 1980). This method is much cheaper than the use of cultured *Chlorella*. Abnormal swim bladder development in the larvae has been associated with a HUFA deficiency. Many hatchery reared red sea bream have a smaller than normal swim bladder which contains jelly-like substances in the lumen instead of gas (Takashima, Arai, and Nomura 1980). The swim bladder opens at the 4-mm stage and an abnormality can usually be detected within 10 days of hatching. This abnormality is far less common in juveniles which have been reared on a larval diet of *Chlorella*-cultured rotifers than in those reared on yeast-cultured rotifers.

There is an association between the abnormal swim bladder development and a skeletal deformity known as lordosis (a type of curvature of the vertebrae). Lordosis is first noticeable in larvae greater than 10 mm total length, but is most common in juveniles about 5–7 cm long, after which length its frequency decreases because of the recovery of slightly deformed individuals (Kitajima 1978). The degree of deformity varies from severely misshapen fish with hunched backs to those in which the spinal curvature is detected only by X-ray examination. Lordosis occurs only in fish with abnormal swim bladders. In earlier hatchery studies the skeletal deformity occurred in as many as 50% of the fish reared; with improved larval diet, the proportion of abnormalities has decreased and now varies from 5% to 30% of the fish reared. The percentage of larvae with normal swim bladders, and the subsequent percentage of juveniles with skeletal deformities, for the 3 larval rearing ponds in the 1981 rearing season in Shizuoka Prefecture is shown in Fig. 10.

Copepods

Tigriopus japonicus

This species can be cultured on a large scale on a diet of yeasts and *Chlorella*, but this is costly and inconvenient for application on a hatchery scale, and alcohol fermentation wastes are used as an alternative. Four 1-t capacity tanks in the laboratory and one 60-t outdoor pond are used for *Tigriopus* culture. The small tanks are heated to about 20 °C, whereas the outdoor pond is run at ambient temperatures. Aerators and an air-lift pump maintain circulation in the tanks and pond.

Tigriopus is cultured from April to June, with an initial stocking density of about 100 per litre. Alcohol fermentation wastes are added daily at a rate of 1–2 ml per 10 l of culture. The adult copepod is used as food for the red sea bream larvae. Harvesting takes place when numbers (including nauplii and copepodites) have reached 2000–3000 per litre and, under optimum conditions, it can be repeated every few days. The adults are harvested by use of an air-lift pump which circulates water through a small net (mesh size 300–500 μ) suspended in the tank or pond. The nauplii and copepodites pass through the net and remain in the culture tank or pond.

Experiments in which *Tigriopus* was cultured on yeasts have shown that the level of HUFA in the food source

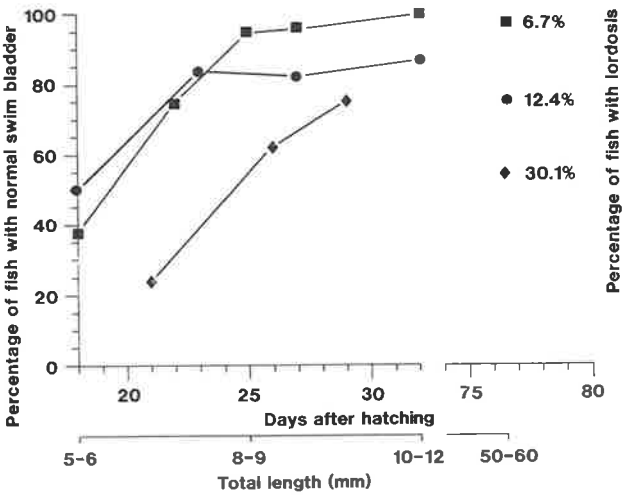

Fig. 10: Percentage of juvenile red sea bream with swim bladder and skeletal deformities.

can be critical for the growth and survival of marine teleost larvae. *Tigriopus* cultured on enriched yeast gave higher growth and survival rates than when cultured on ordinary yeast.

Brine shrimp

Artemia salina

Artemia nauplii, hatched from commercially available eggs, are used as larval food for short periods. The nauplii are not fed and are added to the larval rearing tanks as soon as they have separated from the egg capsules and unhatched eggs. *Artemia* nauplii give good growth rates in larvae, but high mortalities are experienced if they are used as the sole larval food source for more than 4 or 5 days.

Two scales of *Artemia* production are used: 150-l tanks and 1-t tanks, both of which are similar in design and shape (Fig. 11). Between 0.3 and 0.6 g of eggs are added per litre of sea water, which is aerated vigorously and heated to about 28 °C. Hatching occurs after about 2 days, and the nauplii are separated from the egg capsules and unhatched eggs by drainage. There are large (50 %–90 %) variations in hatching rates, both between eggs from different sources (Brazil, The People's Republic of China, and the United States) and between batches.

Two strains of *Artemia* have been identified (a freshwater type and a marine type) and their fatty acids have different compositions. The freshwater type causes high mortalities in red sea bream larvae (Watanabe, Oowa, Kitajima, and Fujita 1980). Unfortunately, both types can be found in 1 area and batches of eggs differ substantially in their proportions of marine and freshwater types. Experiments have shown that by feeding the freshwater type *Artemia* on *Chlorella,* or fat-enriched yeast, for 24 hours it is possible to increase the HUFA levels in the nauplii. These nauplii cause lower mortalities in red sea bream larvae (Watanabe, Oowa, Kitajima, and Fujita 1980).

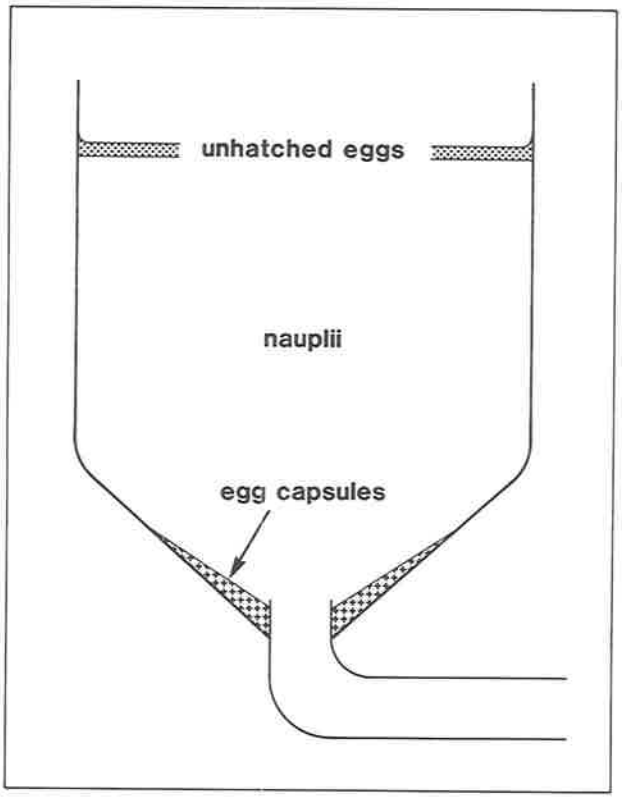

Fig. 11: A tank for production of *Artemia salina* nauplii.

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