Yellowtail kingfish, from larvae to mature fish – problems and opportunities

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Introduction

Yellowtail kingfish (*Seriola lalandi*) are found in temperate waters of the Pacific and Indian oceans, off South Africa, Japan, and the US. There are a number of species of yellowtail in the genus *Seriola* (Carangidae) (Heine and Kolkovski, 2004). The species cultured in Australian and New Zealand is known as *Seriola lalandi lalandi*. In the Japanese waters, 4 species of *Seriola* are recognized (Nakabo, 1993) and three species are cultured. (Nakada, 2000). Japanese species includes *S. lalandi* (called *HIRAMASA* in Japanese), *S. quinqueradiata* (called *HAMACHI* and *BURI* for the young and adult stages, respectively) and *S. dumerili* (*KANPACHI*) (Poortenaar et al., 2001, Nakada, 2000, Nakabo, 1993). Another notable species that gain interest as aquaculture candidate is the pacific yellowtail *S. mazatlana* (Benetti, 1997).
From 1979 through 1998, about 150,000 tonnes of *S. quinqueradiata* were produced annually in Japan (Nakada, 2000). The culture industries for yellowtail kingfish in Australia and New Zealand are relatively small compared to Japan and commenced in the early 2000.

In 1990, total landed quantity of yellowtail in Japan amounted 213,204 tonnes, of which 75.6% (161,106 tonnes) was from aquaculture production (Honma, 1993). Furthermore, the amount and value of yellowtail aquaculture production reaches about 70% of those of total finfish aquaculture in Japan (Honma, 1993, Japanese Market News, 2000), which represents the importance of yellowtail aquaculture in this country. Most of the

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Japanese yellowtails aquaculture production is *S. quinqueradiata* followed by *S. dumerili*. However, market value is higher for *S. dumerili* and *S. lalandi* than *S. quinqueradiata* due to the stock size in the Japanese waters and preferences of the Japanese people.

Aquaculture of Japanese yellowtails is based on juveniles caught in the wild. Juveniles of *S. quinqueradiata* range from about 10 to 70 mm in total length and are associate with a drifting seaweeds (Anraku and Azeta, 1965, Fukuhara et al., 1986, Sakakura and Tsukamoto, 1996). *S. dumerili* juveniles are also known to associate with drifting seaweeds, however, *S. lalandi* juveniles do not (Ochiai and Tanaka, 1986).

Figure 1a.

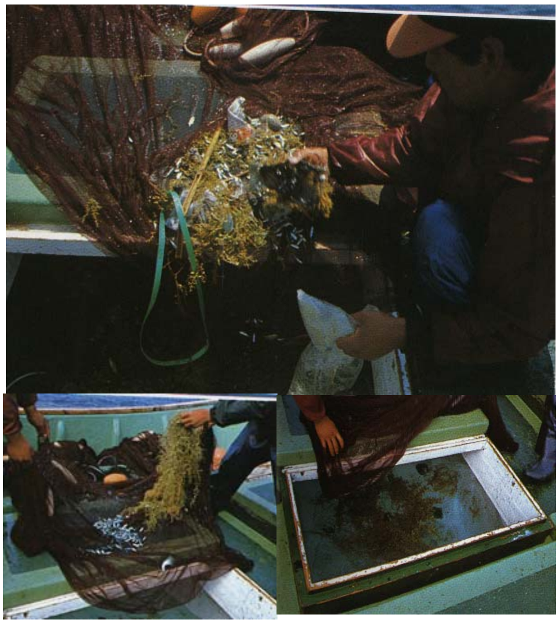


Figure 1 a & b. Yellowtail kingfish (*Seriola quinqueradiata*) juveniles collected from seaweed patches in Japan (Photo from Takashi and Tesao, 1979).

Those juveniles associated with drifting seaweeds (called *MOJYAKO* in Japanese, which means small fish attached to seaweeds) are caught by round haul net (Figure 1a,b). The Japanese Fisheries Agency determines the number of juveniles that can be caught in order to preserve natural yellowtail populations (Honma, 1993). On the contrary, the Australian and New Zealand production of yellowtail kingfish is based solely on hatchery-reared fish.

Broodstock

It is thought that there are different populations of *S. lalandi* from Japan and Australia-New Zealand (Nugroho et al., 2001, Smith, 1987), however, no significant divergence was found among the Australian, New Zealand and California population samples (Smith, 1987). Poortenaar et al. (2001) reported that 50% to 100% of wild females in northern New Zealand reach sexual maturity between 944 mm to 1275 mm total length. However, in captivity under natural light and constant temperature (20°C ± 1°C), F1 yellowtail kingfish reach sexual maturity at 13 months of age with average weight of 3.2 kg and total length of 500 mm (Kolkovski, pers. comm.). Other reports from Australia (Gillanders et al., 1999 a,b, Marino et al., 1995) also confirm that wild *Seriola* sp. mature slower than cultured fish at around 3-4 years old and 800-1000 mm.

In captivity, the broodstock diet comprises of fresh or frozen fish, squid and mussels as is the case with many other marine finfish species.

In Australia, fresh feeds were supplemented with 'tailor-made' additives containing highly unsaturated fatty acids (HUFAs mainly eicosapentaenoic acid (EPA), decosahexaenoic acid (DHA) and arachidonic acid (AA), vitamins (with high levels of α tocopherol and vitamin C) and immune stimulants. (Kolkovski, 2004).

Verakunpiriya et al. (1996) reported high egg quality using soft-dry pellets containing 10% krill meal as a source of astaxanthin. Watanabe et al. (1996), in a comparison between soft-dry pellets, moist pellets and frozen raw fish, found that the best egg quality achieved with soft-dry pellets. However, brood fish fed moist pellets produced double the number of eggs. Supplying frozen fish (no additional of supplements) to brood fish resulted in the poor egg fecundity. Addition of astaxanthin into the moist (Mushiake et al., 1993) and soft-dry pellets (Verakunpiriya et al., 1997b) improved egg quality.

Seriola quinqueradiata spawns naturally in tanks after conditioning under controlled photoperiod and/or temperature (Mushiake et al., 1998). Spawning may be triggered or inhibited by temperature change. Chuda et al. (2001) investigated artificial induction of oocyte maturation and ovulation by three different hormonal treatments (single injection of HCG at 500 IU/kg, priming injections of HCG one day after the single HCG injection and single implantation of LHRHa at 220-400 μg/kg in a cholesterol pellet) in *S. quinqueradiata*. They concluded that implantation of LHRHa was effective in terms of egg quality and that a priming injection of HCG increased the amount of ovulated eggs, however, when cost-effectiveness was considered, a single injection of HCG was deemed to be appropriate.

In Western Australia, using marine bore water with a relatively small change between summer and winter (20°C±1°C) *S. lalandi* developed gonads and spawn naturally at the natural spawning season (spring-summer) (Kolkovski, pers. comm.).

Larvae rearing

Seriola spp. larvae exhibit fast growth compared to other species such as sparids (red seabream, gilthead seabream). The eggs and first feeding larvae are relatively large at 1.1 mm diameter and 4.5 mm for eggs and larvae respectively (Kolkovski, pers. comm.). Therefore, standard rearing protocols can be used (PIRSA, 2002, Kolkovski, pers. comm.). The protocol includes enriched rotifers *Brachionus plicatilis* (large strain) from first feeding (10-30 rotifers ml^{-1}) and enriched *Artemia* from 12 days after hatching (DAH). Weaning on to a microdiet can commence at 20 DAH (PIRSA, 2002) and can even be administered as early as 15 DAH (Kolkovski, pers. comm.). In *S.*

dumerili, a simplified feeding regime, which shifts directly from rotifers to microdiet, was successful for seedling production (Shiozawa et al., 2003).

It has also been demonstrated that yellowtail (*S. quinqueradiata*) larvae require the addition of fatty acids such as n-3 highly unsaturated fatty acids (n-3 HUFA) including DHA and EPA to the diet. Remarkable findings for incorporation of DHA on the development of *S. quinqueradiata* were reported by Masuda et al. (1998, 1999). DHA is positively accumulated into the central nervous system of the yellowtail, and it is essential not only for the activity and quality of the fish but also for the development of schooling behaviour in the juvenile stage. These fatty acids are added to live feeds such as rotifers and *Artemia* (Furuita, et al., 1996, Kolkovski, 2004). Arakawa et al. (2002) compared fatty acid composition between reared and wild juveniles. They revealed that n-3 HUFA content of reared juveniles (especially 22:6n-3) is lower than that of wild fish whereas triglycerides are higher in reared fish. This finding suggests poorer quality of reared fish even though they were cultured with enriched rotifers and *Artemia*.

However, Benetti (1997) reported high mortalities during and after metamorphosis with Pacific yellowtail (*S. mazatlana*). Some bacterial infections occurred during the larvae stage. The infections were transferred by live enriched *Artemia*. A large experiment addressing this problem and looking at the bacteria levels at all the *Artemia* stages (hatching, enriching, etc.) was carried out. Comparison between several commercial and experimental enrichment products resulted in significant differences in survival of yellowtail kingfish (*S. lalandi*) post-larvae at 30 days after hatching (Kolkovski, 2004).

Generally, there are 2 peaks of mortality in the process of seedling production in *Seriola*. One is the so-called ‘critical period’ with high mortality occurring from hatching to the first feeding period (Sakakura and Tsukamoto, 1999, Yamazaki et al., 2002). The other is caused by cannibalism in the juvenile stages (Sakakura and Tsukamoto, 1999, Yamazaki et al., 2002). During the mouth-opening phase, larvae of *S. quinqueradiata* and *S. dumerili* tend to sink at the bottom of the rearing tank, and this causes high mortality. This mortality was reduced by the strong aeration (Shiozawa et al., 2003, Yamazaki et al., 2002). To prevent such occurrences, a special system was developed. The larvae rearing system is based on up-welling current, preventing the larvae from sinking to the bottom of the tank. The system was also proved to be very efficient when dry microdiet was used, by retaining the inert particle longer in the water column (Kolkovski et al., 2004).

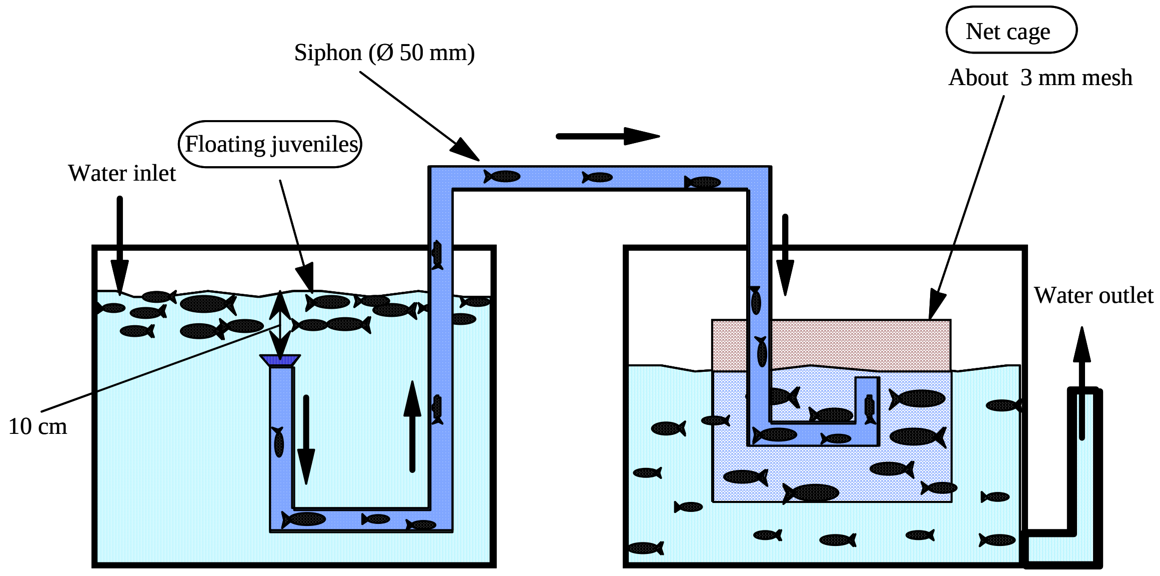


Figure 2. Diagram of size grading for yellowtail (redrawn from Shiozawa et al., 2003).

Cannibalism are found in the process of seedling production of *S. quinqueradiata* (Mizuta, 1981, Sakakura and Tsukamoto, 1996), *S. dumerili* (Shiozawa et al., 2003) and *S. lalandi* (Ebisu and Tachihara, 1993). *S. quinqueradiata* and *S. dumerili* are considered to be more aggressive than *S. lalandi*. In *S. quinqueradiata*, cannibalism is observed among the schools associated with drifting seaweeds in the field (Sakakura and Tsukamoto, 1996), and it was estimated by age determination that school members were formed from the same age batch (Sakakura and Tsukamoto 1997a). Cannibalistic behaviour is observed even in a low density, under a well fed condition, and among individuals of the same size (Sakakura and Tsukamoto, 1996, 1997b, 1998). It is considered that the aggressive behaviour of this species may not be an abnormal behaviour under extraordinary environmental conditions but a normal behaviour of healthy seedlings (Sakakura and Tsukamoto 1998). Therefore, size grading can be most effective to reduce cannibalism in *Seriola*.

At nighttime, juvenile yellowtails cease swimming and drift at surface to make dense patchiness in the rearing pond and are easy to handle (Sakakura and Tsukamoto 1997b). Shiozawa et al. (2003) reported that size grading at night (Figure 2) improved total production of juvenile *S. dumerili* by 150-300%. This size-grading method is also effective in *S. quinqueradiata* (Yamazaki et al., 2002).

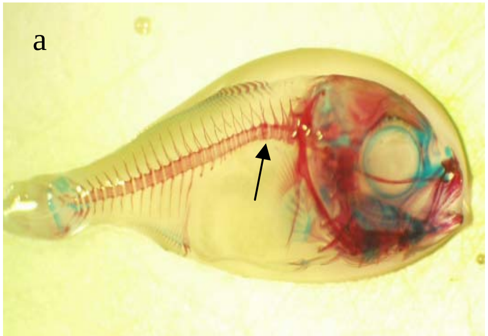
In wild conditions, juvenile yellowtail schools are formed by the same batch as estimated from age composition (Sakakura and Tsukamoto, 1997a). They aggregate to drifting seaweed in current rips, and forage on pelagic copepods and fish larvae, which are not associated with the seaweed (Anraku and Azeta, 1965, Sakakura and Tsukamoto, 1996). Field observations also revealed that the body sizes of school members are uniform (CV = 15 %), and that cannibalism occurs among school members (Sakakura and Tsukamoto, 1996). Therefore, aggressive behaviour and social rank in schools of yellowtail are assumed to make the body size of school members uniform both in wild and artificially rearing groups conditions (Sakakura and Tsukamoto, 1999). The fact that *S. lalandi* is less aggressive than other 2 species may reflect the difference in the ecology of early life stage, as *S. lalandi* do not utilize the drifting seaweeds.

Deformities

One of the biggest problems with yellowtail kingfish is the level of deformities that occur in hatchery-reared fish. This problem is common to fish cultured in different places including Japan, Australia and New Zealand. The deformity prevents the utilization of artificial seedlings for aquaculture by fish farmers in Japan and presents the biggest problem in the culture of *Seriola sp*.

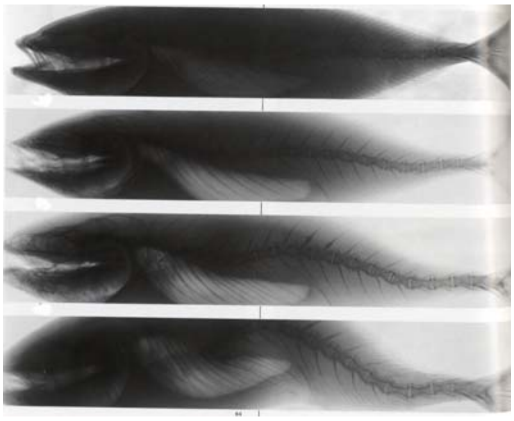
The deformities range from skeleton deformities (fused vertebrates, scoliosis), jaw deformities (bended lower jaw, shorter jaw), operculum (shorter or missing) and compacted body and tail (Figure 3a-d). Although some work were carried out looking at deformities with several fish species the cause to the deformities in hatchery-reared fish is still not clear (Poortenaar et al. 1999).

Figure 3a.



Figures 3 c

Figure 3b



Figures 3 d

Figure 3 a-d. Deformities in yellowtail kingfish, a & b - skeleton, c – lower jaw, d – operculum.

Previous works suggested that ‘mega’ doses of vitamins E (α tocopherol) and C (ascorbic acid) might increase stress resistance in fish (Merchie et al., 1995, Kolkovski et al., 1998). Therefore, an experiment looking at the effect of inclusion of ‘mega’ doses of vitamins E and C in ‘tailor-made’ enrichment to rotifers and/or *Artemia* on stress resistance and deformity occurrence in *S. lalandi* larvae were carried out (in collaboration with the New Zealand Institute for Water and Atmospheric, Bream bay, NZ).

The experiment comprises four treatments involving different combination of basic enrichment and ‘mega’ dose vitamins for rotifers and/or *Artemia*. Initial results suggested that ‘mega’ dose of vitamin E and C have significant effect on yellowtail kingfish growth when added to *Artemia* enrichment. However, no significant difference was found when added to the rotifer enrichment. Larvae fed *Artemia* enriched with ‘mega’ dose vitamins resulted in a significantly lower incidence of deformities compared to larvae fed the base enrichment (Kolkovski pers. comm.).

Initial results also shown that ‘mega’ doses of vitamins E and C are also effective with other species such as mahi-mahi *Coryphaena hippurus* (Nell and Kolkovski, pers. comm.)

Grow out

In Japan, yellowtail are grown out in traditional square sea cages ranging from 4 x 4 x 4 m up to 50 x 50 x 50 m, with metal and reinforced plastic frameworks (Honma 1993, Figure 4). In recent years, ‘polar circle’ type cages were also introduced. The advantages to this system are good water exchange, low maintenance costs, and ease in harvesting (Nakada, 2000). Biofouling of the nets can be a problem, and frequent net exchanges may be required, especially as the fish grow.

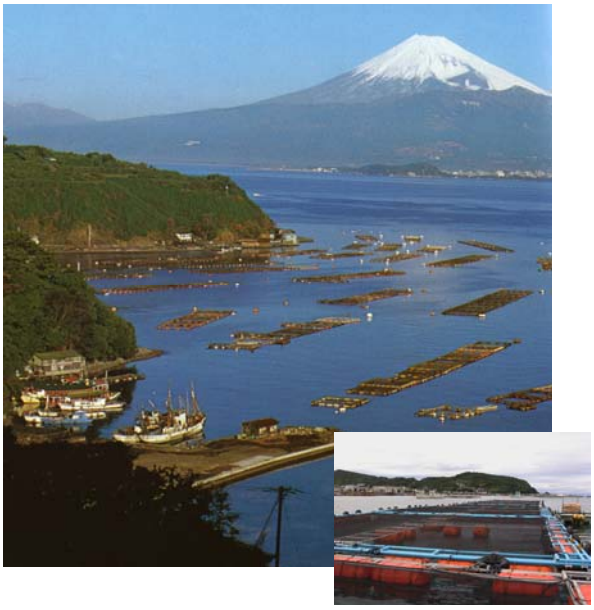


Figure 4. Cage culture in Japan, traditional square cages.

In South Australia, there are established grow out sites in sea cages off the Eyre Peninsula, Fitzgerald Bay, Arno Bay, and Port Lincoln. The cages (‘polar circle’ type) are 25 m in diameter and 4-8 m deep (Figure 5). Fingerlings of approximately 5 g size can be transferred to sea cages for grow out (PIRSA, 2002). The stocking density is determined by factors such as depth, area, and water current. A maximum standing crop of 10 kg fish m $^{-3}$ of seawater is allowable under South Australian aquaculture licence conditions (PIRSA, 2002). Between 100-200 juveniles m $^{-3}$ are stocked.

Figure 5. Cage culture in Australia, ‘polar circle’ type cage and feeding pellets using blower.

Site location is extremely imported since combination of shallow water depth and muddy bottom increase the probability of skin and gill flukes epidemics. Due to this problem, cages must be rotated to different locations periodically.

In most cases on-shore grow-out is not considered cost effective, especially compared to sea cages, mainly, due to the high capital costs and other costs associated with maintenance. A unique opportunity is presented in Western Australia (WA) where holding facilities for western rock lobster (*Panulirus Cygnus*) exist along the west coast. These facilities were built to hold live cray fish during the fishing season. These facilities, in many cases, can hold tens of metric tonnes of live lobsters. Therefore, they have a very high pumping capacity and the tanks and raceways are ideal as fish rearing facilities (Figure 6). A pilot scale trial was carried out to test whether it is possible and commercially feasible to rear yellowtail kingfish in the out-of-fishing season period. 1200 and 600 juvenile yellowtail (130 days old, ~250 g) where transferred to Batavia Coast Fisheries, Geraldton (North West coast of WA, ~20°C) and Great Southern Marine Hatcheries, Albany (South West coast of WA, ~17°C), respectively, for the grow-out trials. The fish were split to ten rock lobster holding raceways (Batavia) and three abalone raceways (Albany). Initial biomass ranged from 14 to 28 kg/m^3 and final biomass reached 60 to 80 kg/m^3. The fish were grown in these facilities for 100 days and during this period more than double their weight. The temperature ranged between

17°C and 21°C (winter season, July – November), below the optimal temperature for this species (Kolkovski, 2004).

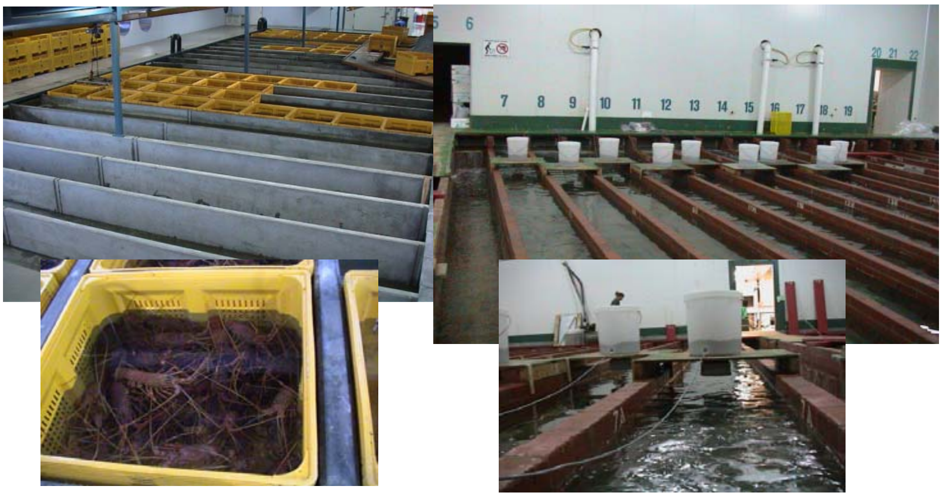


Figure 6. Rock lobster holding facility in Western Australia used for yellowtail kingfish grow out.

In South Australia under sea cage culture conditions, yellowtail kingfish grow rapidly. Juveniles weighing 8-50 g can reach 1.5 kg by the end of a 6-8 month growing season (PIRSA, 2002). However, due to low water temperatures, the fish stop growing in winter and they are held in a steady state condition.

Feed

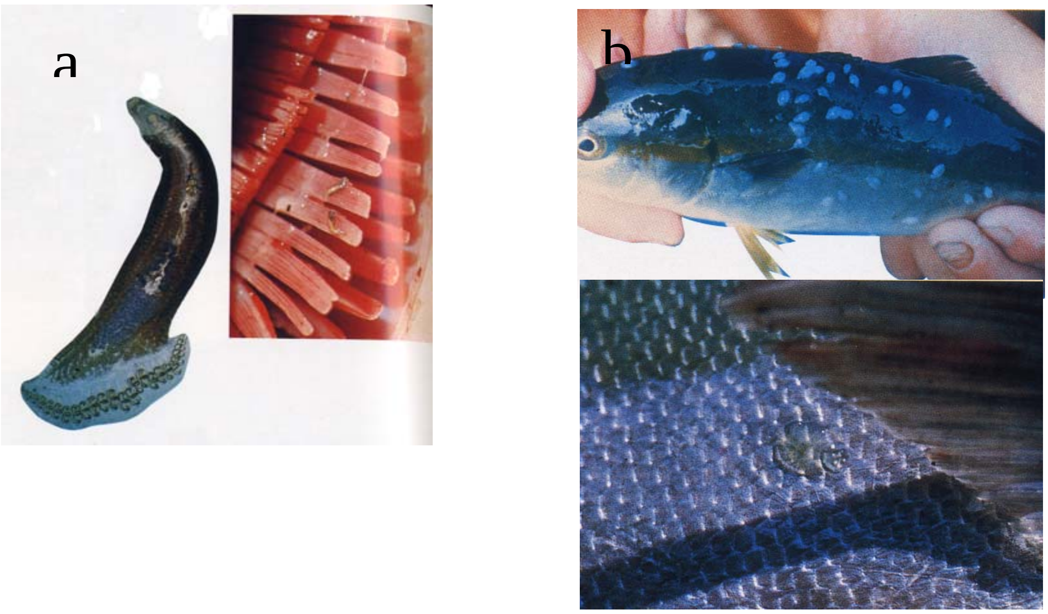
In Australia and New Zealand, yellowtail kingfish are reared exclusively on dry pellet (PIRSA, 2002, Kolkovski pers. comm.). In Japan, “trash fishes”, which are discarded from the catch of other fisheries, were initially used in yellowtail culture (Nakada, 2000). As demand exceeded the supply of trash fishes, sardines became the primary feed, especially minced frozen fish. Sardines as a sole feed led to nutritional disorders due to unsuitable protein and energy levels. Also, the fat content of sardines changes dramatically with season and location (Nakada, 2000). If fed only Japanese anchovy, feeding activity decreases and mortality occurs due to a deficiency in vitamin B1. This can be avoided by adding vitamin B1 to the feed. Other vitamins, such as C and E are also added to prevent oxidation and deterioration of fat.

Yellowtail (*S. quinqueradiata*) fingerlings were fed diets with differing levels of protein (35-55%) and lipid (6-20%). Growth rate and feed efficiency were higher in fish fed on diets containing around 50% protein, 15% lipid and an n-3HUFA level of 2.1% (Takeuchi et al., 1992). Similar results were reported for *S. dumerili*, with best growth at 50% protein, but the effect of lipid level was not significant, nor were nutritive parameters such as feed intake, feed conversion ratio, and PER (Jover et al., 1999).
In a comparison between 3 commercial finfish diets fed to yellowtail kingfish (*S. lalandi*) juveniles (57 ± 5) for 42 days (between 94 and 136 DAH) yielded no significant growth differences. The protein – lipid ratios were as follow, 45%:25%, 54%:18% and 50% (Kolkovski and Glencross, pers. comm.).

Diseases

Seriola species are considered to be robust species with relatively strong stress resistance. However, there are several health issues that present a challenge for culture.
The main health problems in Australia and New Zealand include flatworm (fluke) parasites (*Benedenia seriolae* and *Zeuxapta seriolae*) that inhabit the skin and gills in yellowtail (Sharp et al., 2000, Figure 7a&b). These flatworms can cause reduced appetite, slower growth, and in extreme cases can cause death to the host by loss of osmotic control (skin flukes) or anoxia (gill flukes) (Sharp et al., 2001). In 2003, Farms in South Australia have lost up to 15,000 fish (39 tonnes) with a value of AU$600,000. Mild infections can be treated with hydrogen peroxide in water temperatures below 25^{0}C, and severe infections or during periods of warmer temperatures, can be treated with praziquantel or formalin. These treatments in cage culture systems present major time, manpower and cost burdens.

A breeding project is ongoing in Japan, which uses QTL markers to indicate broodstock resistant to the diseases by (Ohara et al., 2003).



Figures 7 a & b. Gills and skin flukes (Photo from Takashi and Tesao, 1979).

Future needs

Several improvements needed for culture of *Seriola spp* have been outlined (Nakada, 2000, Benetti, 2000, Sakakura and Kolkovski, pers. comm.):

1. Improved production of juveniles year around, which have better growth rates and less vulnerability to diseases.
2. Increased resistance to parasites in cage culture systems (mainly in Australia).
3. Reduced incidence of deformities in hatchery-reared fish.
4. Reduced and managed environmental impacts of fish farms (this can apply to any fish species).
5. Development of more efficient, ‘environment friendly’ feeds.

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