Commercial Opportunities for Kingfish Aquaculture in Northland

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Executive Summary

The main focus of NIWAs' aquaculture research over the last few years has been to assess the aquaculture potential of New Zealand species and develop that potential for key target species which were deemed to have particularly strong aquaculture and economic potential. Through this research we identified kingfish (*Seriola lalandi lalalndi*) as being biologically suitable to aquaculture conditions and having exciting economic and marketing prospects.

Market research indicates significant export opportunities to Europe, U.S. Asia and Australia. In terms of competitors, Japan are the leading producers of cultured kingfish (139,000mt/pa), although this does not satisfy their own domestic demands, hence the Japanese industry poses little threat to the development of a kingfish aquaculture industry in New Zealand. Conversely, market opportunities exist for our product there, as our local sub-species is particularly well regarded in Japan. There is also a considerable kingfish nutrition technology base from Japan, which New Zealand can draw upon for the development of our own kingfish industry. New Zealands' most likely competitors are in South Australia. In this respect New Zealands' competitive advantage is our substantial information base on the culture biology of *Seriola lalandi lalalndi*, particularly in relation to technology bottlenecks in hatchery production.

Northland is well placed to be the focus of kingfish aquaculture development in New Zealand due to it's: warm annual sea surface temperatures (14-21°C) which will promote faster growth and hence greater economic return; existing kingfish hatchery at Bream Bay Aquaculture Park and a good range of potential sites suitable for seacage culture. Preliminary investigations indicate that there are at least ten areas around Northland that may be suited to kingfish cultivation, and a full evaluation of the Northland region would most likely reveal additional sites. NIWA has produced a conceptual business plan for a kingfish farm that could be located at these sites. The business plan builds on market research, our preliminary research including growth data and information from closely related species. The conceptualised kingfish farm would utilise a 4 ha site, a full production cycle would take 12-18 months and over a 5 year development phase, the farm would sell 2815 mt of the total 3373 mt production from 1.4M fingerlings. The business plan indicates a net profit within 4 years, with an accumulated total net profit of $2.5M over the 5 year period with a 37% return on investment (ROI). However, there is potential for a 68% ROI depending on the structure of loan repayments. At a discount factor of 10% the farm will deliver a positive net present value of $867k over the 5 year period. The establishment of a kingfish industry in Northland, would employ and train workers at many levels in the production chain from culture, harvesting and processing through to transport, marketing and retailing. It would also provide an excellent platform for further aquaculture development on other species.

Introduction

NIWA recently provided Enterprise Northland with an overview of potential aquaculture opportunities in Northland (NIWA Client report: AKL2003-012), and highlighted opportunities for development of particular species with strong aquaculture and economic potential. This report presents a more detailed assessment of opportunities and advantages for kingfish aquaculture development in Northland.

Classification and distribution of *Seriola* species

Kingfish belong to the Genus *Seriola* and Family Carangidae (Laroche et al., 1984). One of the most valuable species, *S. lalandi*, has a non-equatorial distribution and is divided into three physically similar sub-species that are geographically separated (Gillanders et al., 1997); *S. lalandi dorsalis* (California yellowtail), *S. lalandi aureovittata* (asian yellowtail) and *S. lalandi lalandi* (southern yellowtail, locally known as yellowtail kingfish) (Smith, 1987). In New Zealand, *S. lalandi lalandi* is common in the northern half of the North Island but also occur from 29° to 46° S (Kermadec Islands to Foveaux Strait). It is also found around Australia, India, South Africa, and the west coast of America from British Columbia to Chile (McGregor, 1995; Gillanders et al., 1997). A closely related species, *S. quinqueradiata* is endemic to Japan and north Hawaii (Lin and Shao, 1999). The largest member of the genus is the greater amberjack (*S. dumerili*), which occurs in the Mediterranean Sea and the Atlantic, Pacific and Indian Oceans (Manooch and Potts, 1997; Thompson et al., 1999). Other species of the genus include the Samson fish (*S. hippos*) found throughout southern and eastern Australia and occasionally in northern New Zealand (Ayling and Cox, 1982), the almaco jack (*S. rivoliana*) a circumtropical oceanic species that is also occasionally found in northern New Zealand (Lin and Shao, 1999; Paul, 2000), and the Pacific yellowtail (*S. mazatlana*) and *S. peruana* which are both found in East Pacific waters (Laroche et al., 1984; Benetti et al., in press). Less well known are the lesser amberjack (*S. fasciata*) found throughout the Atlantic Ocean, the banded rudderfish (*S. zonata*) found in the West Atlantic, and *S. carpenteri* found in the East Atlantic (Laroche et al., 1984; Manooch and Potts, 1997).

World fisheries for *Seriola* species

Seriola are an important commercial and recreational fish and the worldwide fishing harvest of *Seriola* species in 1996 was 58 000 metric tons, with the vast majority (50 333mt) harvested by Japan (FAO, 1998). However, to put the commercial *Seriola* fishery into perspective, Japan's production of cultured *Seriola species* is around three times this amount (approximately 150 000mt/year since 1996) (Nakada, 2000). The remainder of the world's commercial *Seriola* fisheries is primarily harvested in Korea (4093mt in 1996), USA (1123mt in 1996) and Mexico (1111mt in 1996) (FAO, 1998).

The total landings of *S. lalandi lalandi* in New Zealand between 1983-2001 have varied between 288-532t per annum, with 304t harvested in 2000/2001 (Annala et al., 2002). *S. lalandi lalandi* is not managed by the quota management system and therefore it is only legal for commercial fishers to catch *S. lalandi lalandi* as a bycatch of other fisheries (McGregor, 1995b). In 1999 New Zealand exported 78t of *S. lalandi lalandi* valued at NZ$531 000, primarily to the USA and Australia (Fishing Industry Board statistic). *S. lalandi lalandi* supports an important recreational fishery, and the recreational harvest over the last few years is estimated to be as least as large as the commercial fishery (Annala et al., 2000). The minimum size limit of *S. lalandi lalandi* is 65cm FL for both commercial and recreational fishers and recreational fishers may take a maximum of 3 fish per day (McGregor, 1995b). *S. lalandi lalandi* is also commercially harvested in Australia and South Africa. Australia's total landings have gradually decreased since 1985 from 600t to a current harvest of around 100t (Gillanders et al., 1997 & 1999b), and South Africa's commercial harvest has fluctuated between 488-858mt between 1987-1996 (FAO, 1998).

The wild fishery of *S. lalandi lalandi* in New Zealand is inconsistent in both quality and quantity limiting its domestic and export markets, especially for sashimi quality meat. Aquaculture of *S. lalandi lalandi* would provide a predictable, regular supply of higher quality meat allowing for the expansion of both domestic and international markets.

Biology of New Zealand yellowtail kingfish *Seriola lalandi lalandi*

NIWA has recently collected a considerable amount of information on the reproductive biology and physiology of New Zealand kingfish *S. lalandi lalandi,* as a basis for aquaculture development (Poortenaar et al., 2001). Data were collected from wild kingfish caught along the east and west coasts of northern New Zealand. Seasonal changes in reproductive condition suggest that kingfish spawn October–January, although reproductively mature fish were occasionally collected during winter months. Interestingly, less than 1% of mature females had free flowing eggs, hence, for aquaculture purposes, collection of ripe eggs from wild fish to stock hatchery facilities is not an option. Overseas studies on *S. lalandi* found no females with free flowing eggs. Possible explanations for the lack of ripe females caught include cessation of feeding during spawning, fish move outside normal fishing grounds to spawn, or females pass through the later stages of egg production quickly as in some other species e.g. snapper. NIWA studies reported that the smallest size at which females sexually matured was 78 cm, 50% reached sexual maturity at 94 cm and 100% reached sexual maturity at 128 cm FL. The smallest size at which males matured was 75 cm, 50% reached sexual maturity at 81 cm and 100% matured at 93 cm. These studies suggest that for aquaculture purposes, broodstock collected from the wild need to be >128cm and 93cm FL for females and males respectively, to guarantee reproductive maturity. An earlier study on New Zealand populations of kingfish, reported maturity between 58 and 67 cm, with all fish mature by 70 cm. Additional studies on the size and age at sexual maturity are underway.

All *Seriola* species show rapid growth rates, especially in the first few years. To date there are no published estimates of *S. lalandi lalandi* growth rates based on the analysis of skeletal structures such as otoliths or vertebrae. However, estimates from length increment data from a gamefish tagging programme suggest that kingfish is a fast growing species (Hartill and Davies, 1999).

Juvenile kingfish are strictly pelagic and travel in schools. Small juveniles are often found near clumps of floating seaweeds while sub adults tend to school with other small pelagic fish species (Ayling and Cox, 1982; Sakakura and Tsukamoto, 1997b). Adult kingfish tend to be solitary or travel in small groups. Some of the *Seriola* species are migratory, with migration patterns being influenced by water temperature and sexual maturity (Tanaka, 1979; Kimura et al, 1994; Abe and Homma, 1997). No consistent migration patterns have been shown for *S. lalandi lalandi*, in fact, tag-recapture studies frequently reported identical positions of releases and recaptures, even after long periods at liberty suggesting New Zealand kingfish may be susceptible to localised depletion by target fishing. However, a small number of kingfish have moved large distances from the site of release (>2000km) (Hartill & Davies 2000).

The natural diet of kingfish larvae is almost exclusively planktonic crustaceans, particularly copepods (Anraku and Azeta, 1965; Sakakura and Tsukamoto, 1996).

Intermediate and adult kingfish primarily feed upon schooling fish (e.g. pilchard, koheru, kahawai), squid, and crustaceans and generally hunt in packs with a high degree of cooperation between the hunters (Ayling & Cox 1982).

International status of *Seriola* aquaculture

Seriola quinqueradiata has been farmed in Japan since the 1920's and the current aquaculture production is around three times greater than the wild fisheries[1] (Nakada, 2000). The majority of Japanese farms are stocked with juveniles caught from the wild, although a small number of fish are now reared in hatcheries (Nakada, 2000). Wild caught juveniles are reared on a diet of baitfish such as sardines and anchovy (Nakada, 2000). Today, three other species (*S. lalandi aureovittata, S. dumerili* and burihira (a hybrid of *S. quinqueradiata* and *S. lalandi aureovittata*)) are also cultured in Japan. *S. quinqueradiata* culture in Japan peaked in 1995 with 170 000t produced, but since 1995 production has decreased due to lower profit margins, and in 1998 only 147 000t was produced, valued at US$1.23 billion (Nakada, 2002; Benetti et al., in press). In recent years many fish farmers have changed from rearing *S. quinqueradiata* to rearing *S. dumerili* or *S. lalandi aureovittata*, which are more valuable due to their better quality flesh [2]. The total number of *S. dumerili* and *S. lalandi aureovittata* produced in 1998 was 16 000 000 and 800 000 respectively (Nakada, 2000).

S. dumerili has been cultured in Europe since 1980, especially in the Mediterranean (Porrello et al. 1993; Garcia and Diaz, 1995). In 1994 30t of *S. dumerili* was produced in Europe, valued at ECU$20-30/kg [3] (Garcia and Diaz, 1995; Garibaldi, 1996). Juveniles are still sourced from the wild as breeding trials in the Mediterranean have been relatively unsuccessful, although the Japanese have successfully breed S. dumerili since 1979 (Garcia and Diaz, 1995).

Research on the culture of the pacific yellowtail, *S. mazatlana* has been conducted in Ecuador since the 1990's. In a pilot-scale production 670 kg of 1.8-2.7 kg fish were

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[1] In 1998 approximately 45 000t of *S. quinqueradiata* was caught and 147 000t was cultured (Nakada, 2000).

[2] *S. dumerili* maintains its colour and firm texture longer than *S. quinqueradiata* and *S. lalandi aureovittata* has less fat and less dark muscle than *S. quinqueradiata* making it more suitable for sashimi (Nakada, 2000). *S. lalandi aureovittata* is worth around twice the value of *S. quinqueradiata* (Tachihara et al., 1997).

[3] 20-30 ECU is currently the equivalent of 17-25 US dollars.

sold in the US for US$8.80/kg (Benetti et al., 1995). The culture of *S. mazatlana* is currently hampered by disease with cultured larvae having very high mortality rates 98-99.5% (Benetti et al., in press).

S. lalandi lalandi has been commercially cultured in South Australia since 2001. Production originates from two commercial hatcheries, which provide fingerlings for seacage growout in South Australian waters. Production is dominated by the Stehr Group who anticipate 1500 tonnes of fish during 2002 for marketing to Australia, Japan and the U.S. (www.abc.net.au/landline/stories/s782442.htm). To date this industry has evolved with limited R&D effort, however, the on-going commercial viability of the industry is hindered by information and technology deficits in hatchery technology and parasite control. The South Australian Government has recently announced a $2 million research program looking at the future of aquaculture development.

Overview of overseas culture methods for *Seriola* species

Given the reliance of the Japanese kingfish industry on capture and on-growing of wild juveniles, there is comparatively little information on broodstock and hatchery technology. This is where New Zealands' strengths lie, as we have conducted in-depth studies on the culture biology of kingfish during these life stages.

Broodstock management

Viable gametes are obtained from either wild fish, captive broodstock or cultured broodstock. When broodstock are caught from the wild, they are typically quarantined for two weeks (PIRSA, 2002), de-parasitised using chemotherauputants or bathing in formalin followed by a freshwater bath (Benetti et al., in press) then transferred to breeding tanks typically greater than 90 m^3 and 2 metres deep (PIRSA, 2002). Captive broodstock are usually fed fresh or frozen premium quality diets e.g. chopped fish, squid, and often weaned onto a semi-moist or dry pellet. Vitamin and mineral supplements are recommended (Benetti et al., 1998; PIRSA 2002). Recent research on *S. quinqueradiata* has shown that a diet of soft-dry pellets produces better quality eggs and larvae than a diet of fish (Mushiake et al., 1995; Verakunpiriya et al., 1996; Watanabe et al., 1996). Feeds are administered at 1-3% or 10% of total weight daily for pellet and wet diets respectively (PIRSA, 2002).

Most *Seriola sp.* broodstock spawn spontaneously in captivity, although in some instances hormone treatments are required to stimulate maturation and spawning (Fujita and Yogata, 1984; Kagawa, 1989; Tachihara, et al., 1993, 1997; Garcia and Diaz, 1995; Benetti et al., in press) and in these instances, fertilisation and hatch rates are generally low. The timing of hormone treatments needs to co-incide with critical stages of reproductive development (Tachihara, et al., 1993) and various methods have been developed to assess the reproductive condition of broodstock. Ouchi et al., 1985 and Poortenaar et al., 2001 assessed blood plasma steroid hormone levels of *S. quinqueradiata* and *S. lalandi lalandi* respectively at different stages of reproductive development to obtain benchmark indicators of reproductive condition. Mushiake et al. (1998) showed that the oocyte diameter in female *S. quinqueradiata* could be used as an indicator of reproductive success. Females with oocytes less than 650µm in diameter did not spawn, females with oocytes around 700µm did spawn but the subsequent fertilization and hatch rates are poor, whereas females with oocytes greater than 800µm in diameter produced vast quantities of good quality eggs. Samples of oocytes can be collected from anaesthetised broodstock by inserting a biopsy tube into the genital opening. A less invasive method for assessing reproductive condition was developed for female *S. dumerili*, whereby Takemura et al. (1999) found that the level of vitellogenin (VTG) in the skin mucus of female *S. dumerili* directly correlated to VTG levels in the serum, and therefore levels of VTG in skin mucus could be used as an estimate of the reproductive stage of broodstock.

Research on the reproductive condition of sexually mature *Seriola* has shown that they spawn naturally during spring and summer (Grau et al., 1996; Gillanders et al., 1999; Micale et al., 1999; Poortenaar et al., 2001). It is desirable however to extend the natural spawning season or stimulate out-of season spawning to increase production. The former has been achieved in *Seriola* species by controlling the temperature and photoperiod (Mushiake et al. 1994, 1998). Optimum spawning temperatures for *S. quinqueradiata, S. dumerili* and *S. lalandi aureovittata* have been reported to be 19°C, 21± 0.5°C and 21°C, respectively (Mushiake et al., 1994; Andaloro, 1993; Tachihara et al., 1997).

Hatchery Methods

Various aspects of hatchery technology are outlined in: Fujita & Yogata, 1984; Tachihara et al., 1993 & 1997; Garcia and Diaz, 1995; PIRSA, 2002; and Benetti et al., in press. In the case of natural spawning, fertilized eggs are collected from the surface of broodstock tanks with nets or screens and typically treated with a disinfectant such as 100ppm formaldehyde. Fertilised eggs are placed in sloping bottom tanks and maintained under 12:12 photoperiod conditions. The eggs hatch within 2-4 days (depending on water temperature) and larvae are 3-5mm in length. Larvae are stocked at densities ranging from 20-100/l into water conditioned with algae, and aeration is used to maintain the larvae in suspension to reduce the incidence of deformities and mortalities. Surface skimmers are essential to ensure swim bladder inflation. The larvae begin feeding 3-4 days post hatch once the yolk-sac has been absorbed. They are initially fed enriched rotifers (*Brachionus* species) and wild copepods if available and enriched *Artemia salina* are typically added to the diet around 10-14 days post hatch. Metamorphosis occurs approximately 20 days after hatching and weaning to inert foods such as fish eggs, formulated food or minced fish is usually completed 40-50 days after hatching. Water temperatures in the hatcheries is typically maintained at the higher end of the species optimum range (20-28°C). The water exchange rate is gradually increased from 4 L/minute at the time of stocking to 20 L/minute immediately prior to weaning.

Early larval mortality may be expected (PIRSA, 2002). Benetti et al. (in press) reported a survival rate of 0.5-2% for metamorphosed *S. mazatlana* larvae and Tachihara et al. (1997) reported a survival rate of 0.13-1% for *S. lalandi aureovittata* larvae, although the authors note that since then survival rates of up to 14% have been obtained in the commercial-scale production of *S. lalandi aureovittata* larvae. Benetti et al. (in press) conducted semi-intensive and extensive rearing trials of *S. mazatlana* larvae but neither method appears to be commercially feasible as the survival rates were extremely low due to cannibalism and disease. Mortalities in *S. lalandi lalandi* larvae were high during the weaning period (20-50%) (PIRSA, 2002), and it was recommended that due to rapid growth and cannibalism, larval rearing tanks should be stocked at low levels. Fish can be transferred to cages at approximately 5g (PIRSA, 2002).

On-growing

Although a small number of fish are produced in commercial hatcheries in Japan, the vast majority of *Seriola* culture in Japan and the Mediterranean relies on capture and on-growing of wild juveniles (Nakada, 2000; Benetti et al., in press). In Japan, 2-10 g juveniles are typically caught in nets when they begin to move inshore (Watanabe, 1996), while in the Mediterranean fish are caught at a later stage (25-100g) (Gracia and Diaz, 1995). Captured juveniles require immediate feeding to prevent cannibalism, and to ensure adaption to manufactured feeds (Benetti et al., in press). The majority of fish are on-grown in secages allowing little control over environmental conditions. Rearing trials in the Mediterranean have been carried out in outdoor tanks (Garcia and Diaz, 1995), however, most land-based systems are not economic (Benetti et al., in press).

PIRSA, 2002 outlined the following seacage conditions for South Australia. Seacages are ideally located in areas with optimal water quality, low turbidity and adequate clearance beneath cages to ensure suitable flushing and dissolved oxygen concentrations $\leq$4mg/l. Consideration is given to the potential impact on the natural environment, however, well managed farms will produce negligible impacts. The arrangement of seacages should consider accessibility and ease of maintenance. Seacage design is based around the following elements: nets; frames; collars and supports; linkages and groupings and moorings. The mesh size increases as the fish grow and is also replaced when it becomes clogged with fouling organisms, which restrict water flow. Stocking densities can reach 10kg/m^3 in ideal growing areas.

In Japan many seacages have covers and can be lowered 1-2m below the sea surface to protect the fish from birds and to keep the fish in the most suitable water temperature layer (Mitani, 1978). The initial stocking density is around 1600-2000 ind/m^{-3} (Watanabe et al. 1996), with secages being repeatedly size-graded and restocked at lower densities in larger cages as the fish grow. Cage sizes typically vary in dimensions from 5 x 5 x 5m to 15 x 15 x 15 m but more recently there has been a trend towards even larger cages, 50 x 50 x 50 due to greater economic efficiencies (Nakada 2000). Table 1. shows the stocking densities recommended by Nakada (2000) for seacage culture. Stocking densities have increased over the years due to falling profit margins, however, fish consume less food at high densities resulting in less growth and increased susceptibility to disease (Benetti et al., in press).

Table 1. Recommended stocking densities for seacage culture of *Seriola* species (Nakada, 2000).

Size of fish (g)	Stocking density (kg.m^{-3})
<10	4-11
20-50	11-20
100-1400	20-30

Growth

Growth of cultured *Seriola* species is rapid compared to many other cultured fish. Cultured *S. quinqueradiata* can reach 2.5kg in one year and over 6kg two years after capture when reared at 20-24°C (Nakada, 2000). In Japan, *S. dumerili* is reported to grow faster and have a better feed efficiency than *S. quinqueradiata* if the water temperature is greater than 17°C (Nakada, 2000), however rearing trials of *S. dumerili* in the Mediterranean have not been so successful with cultured fish reaching around 1kg after one year (temperature 12.5-25.5°C)[4] (Lazzari and Barbera, 1989; Porrello et al., 1993; Garcia and Diaz, 1995; Marino et al., 1995). Cultured *S. mazatlana* grow very fast reaching 2.5kg in 10-12mths (Benetti et al., in press).

Behaviour

Seriola quinqueradiata displays a range of complex social interactions throughout its lifetime. Initially, no agnostic behaviour is apparent in the larvae, but they become aggressive and cannibalistic just after metamorphosis (10mm TL, 22 days old), with cannibals being able to prey on fish up to half of their own body size (Sakakura and Tsukamoto, 1996). Aggression decreases after 33 days (larvae>12mm TL) as schooling behaviour takes over (Sakakura and Tsukamoto, 1996). Sakakura and Tsukamoto (1998b) showed that a clear dominance hierarchy exists within a school although it is likely that the ranking order changes with time.

The aggressive behaviour of larvae is affected by temperature, light intensity, density, starvation, and the size-difference between fish. Aggression is positively correlated with temperature (15-30°C), starvation (>12 hrs) and the size-difference between fish, and is highest at medium light intensity (10^3 lx) (Sakakura and Tsukamoto, 1997, 1998 & 1998b). Sakakura and Tsukamoto, (1998) found that the number of aggressive encounters per fish decreased with increasing density, however, the level of aggression in dominant fish increased at higher densities (Sakakura and Tsukamoto, 1998b), and based on the results of other fish it is likely that the overall level of cannibalism will increase with increasing density (Hecht and Pienaar, 1993). Although the above factors exaggerate the level of aggression in larvae, aggression still occurs in low density, well-fed conditions amongst individuals of the same size (Sakakura and Tsukamoto, 1998). In order to reduce the level of cannibalism in cultured conditions, Sakakura and Tsukamoto (1998b) recommend an optimum density of 3 fish/l^{-1}. Fish should also be size-graded regularly beginning at 12-15mm TL, as Shiozawa (1996 in Sakakura and Tsukamoto, 1998) found that size-grading at 15mm TL increased the productivity by 1.5 to 3 times. Grading is best done at night when fish are less active to avoid excess stress (Sakakura and Tsukamoto, 1998).

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[4] The growth of cultured *S. dumerili* in the Mediterranean was slower than the growth of wild fish.

Nutrition

Manufactured dry diets are currently the best type of feed available for cultured *Seriola* species as they can be tailored to meet the different nutritional requirements of the various life cycle stages, they have a consistent nutritional value, and they are easy to store, transport and handle. Feeding stimulants are frequently added to manufactured feeds to increase the palatability of feeds encouraging fish to consume more food, more quickly, resulting in enhanced growth and reduced food wastage.

Broodstock nutrition

Broodstock are typically reared on a diet of fish, however recent research on *S. quinqueradiata* has shown that broodstock fed soft-dry pellets (50.5% protein, 24% lipid) produced 25 times more eggs/fish than fish-fed broodstock. Furthermore, the eggs from broodstock fed soft-dry pellets had a much higher fertilization rate (57%) than the eggs from fish-fed broodstock (3%) (Watanabe et al., 1996).

While the majority of research on broodstock nutrition in marine fish concerns the levels of essential fatty acids (EFA) required to support normal larval development, the optimal amount of various EFA for *Seriola* broodstock is not known, although it appears that the ratio of EFA is likely to be more important that the absolute quantities of the individual EFA (Bell, 1998).

Several studies on the broodstock nutrition of *S. quinqueradiata* have shown that certain carotenoids, in particular astaxanthin, improves egg and larval quality (Verakunpiriya et al. (1996, 1997, 1997b). In one study on *S. quinqueradiata* astaxanthin improved egg: buoyancy; fertilization; and hatching rate and prolonged the period of egg production (Verakunpiriya et al., 1997). Not all carotenoids appear to be beneficial to broodstock. For example, Verakunpiriya et al. (1996) showed that β-carotene is very poorly absorbed by *S. quinqueradiata* and high levels of β-carotene in the broodstock diet had little effect on the subsequent egg and larval quality.

Larval nutrition

The first feeding stage of larvae is a major hurdle in fish aquaculture and adequate nutrition is critical to the success of this phase. EFA, in particular docosahexaenoic acid (DHA), are critical for normal larval development, however, rotifers and *Artemia* nauplii, the two most common larval feeds lack sufficient quantities of EFA and need to be enriched with them (Bruce, 1998). An inadequate supply of EFA is the primary cause of failure of cultured fish larvae (Rainuzzo et al., 1997), and therefore it is essential that the appropriate amounts of EFA are added to broodstock and larval diets.

Studies on the effect of the different EFA on the growth and survival of *S. quinqueradiata* larvae have shown that DHA is likely to be the most important EFA (Watanabe, 1993; Furuita et al., 1996; Ishizaki et al., 1998). Ishizaki et al. (1998) found that the growth and survival rate of *S. quinqueradiata* larvae fed DHA-enriched *Artemia* (2.1-2.5% dry wt) was up to ten times better (88%) than larvae fed *Artemia* nauplii enriched with eicosapentaenoic acid (EPA), arachidonic acid (AA) or oleic acid (OA).

On-growing diet

Early in the life history of *S. quinqueradiata* culture, fish are fed various species of fresh or frozen bait fish. However, some bait-fish, anchovy (*Engraulis japonica*), sardine (*Sardinops melanosticta*) and saury (*Cololabis saira*) cause feed-induced diseases when fed exclusively to cultured *S. quinqueradiata,* demonstrating that the nutritional composition of these bait-fish does not meet the nutritional requirements of *S. quinqueradiata* (Ishihara et al., 1978; Nakagawa et al., 1984). There are also problems with the quality, supply and cost of fresh feed, and therefore the majority of farmers are now feeding manufactured pellets to cultured *Seriola* (Nakada, 2002).

In general, carnivorous fish such as *Seriola* species derive most of their energy from protein and high quality lipids. The optimal protein requirements for *S. quinqueradiata* is around 50% dry weight and the optimal calorie:protein ratio is 70 (53% protein, 15% lipid) (Shimeno et al., 1980 & 1985; Takeuchi et al., 1992; Masumoto et al., 1998). Typically both protein and lipids in feeds are of fish origin, however, fishmeal is expensive and the supply and quality is often unreliable. There is on-going research on the substitution of fish protein with plant protein in *Seriola* species. (Masumoto et al., 1998; Ruchimat et al. 1997, 1997b & 1998).

Vitamins and minerals are essential to normal bodily function in fish and most commercial diets contain a general vitamin and mineral mixture, however little is know about the specific requirements of *Seriola* species. Signs of vitamin C deficiency in *S. quinqueradiata* can be eliminated with a supplement of 30-60mg L-ascorbyl-2-phosphate mg/kg diet (Kanazawa, et al., 1992), and vitamin B_1 deficiency in *S. quinqueradiata* can be eliminated by the daily addition of 1mg or more of thiamine nitrate/kg body weight (Nakada, 2000). Vitamin C and vitamin E are also important for gonadal development in fish (Watanabe, 1990 in Verakunpiriya et al., 1996; Jobling, 1998) and Verakunpiriya et al. (1996) found that the levels of vitamin E in the eggs, milt and larvae of *S. quinqueradiata* corresponded to the level of vitamin E in the diet, however no information is available on the optimum levels of vitamin E required by *S. quinqueradiata*.

Feeding rates

Several experiments have been conducted on the optimum feed quantity required to produce maximum growth or maintain body weight in *S. quinqueradiata* (Watanabe et al., 1999; 2000; 2000b & 2000c). Watanabe et al. (1999) found that during winter (12.8-18.6°C) fish only need to be fed to satiation between 3 and 5 times per week to support maximum growth. In a study by Watanabe et al., (2000b) fish were fed soft-dry pellets to various satiation levels (0-100%). Fish fed to satiation showed maximum growth, with growth rate and condition factor decreasing with decreasing satiation level. Fish fed less than 10% satiation showed negative growth. The digestible energy (DE) and protein (DP) requirements of *S. quinqueradiata* for maximum growth are between 30-225kcal and 2.5-27.3g/kg/BW respectively. In general, DE and DP decreases with increasing fish size and decreasing temperature.

Environmental conditions

Little research has been conducted on the optimal rearing conditions for *Seriola* due to the vast majority of fish being reared in seacages where there is little control over the environment. *Seriola* species are very sensitive to temperature changes with small fluctuations affecting their reproduction and food intake. Growth and food intake generally increases with increasing temperature within an optimum range. The optimal temperature range for maximum growth of *S. quinqueradiata* and *S. dumerili* is 22-28°C (Nakada, 2000), while *S. lalandi lalandi* is typically found in temperatures between 15-24°C (Penney, 2000). Growth of *S. quinqueradiata* and *S. dumerili* ceases if the temperature drops below 14°C and 15°C respectively (Murayama, 1992; Garcia and Diaz, 1995), and *S. quinqueradiata* will not survive if the temperature drops below 12°C or rises above 34°C (Nakada, 2000).

Dissolved oxygen levels should be greater than 5.7mg/l with fish displaying abnormal swimming behaviour if the level falls below 4.3mg/l (Nakada, 2000). Oxygen consumption is also affect by feeding and the swimming speed of fish, which should be taken into account if fish are reared in tanks. Oxygen consumption increases from a relatively high resting rate of 200mg/kg/hr to a maximum uptake of 680mg/kg/hr at a swimming speed of 53cm/s (Tsukamoto and Chiba, 1981). Directly after feeding consumption is three times higher than the resting rate (Sakaguchi and Yanagi, 1990). The optimal salinity for yellowtail ranges from 29.8-36.3 ppt (Nakada, 2002).

Diseases and Parasites

Streptococcosis, caused by the bacteria *Latococcus garvieae* (formerly *Streptococcus seriolicida* or *Enterococcus seriolicida*) is the most common disease in cultured *S. quinqueradiata* and has caused mass mortalities in cultured *S. quinqueradiata* in Japan (Alcaide et al., 2000; Nakada, 2000). Two other common bacterial diseases that affect cultured *Seriola* are pseudotuberculosis and vibrosis. In the past these two diseases have caused major economic losses in *Seriola* farms, but vaccines have now been developed for both diseases, which significantly increases the resistance of fish to the diseases (Muraoka et al., 1991; Sano, 1998).

The major disease in *Seriola* culture in the Mediterranean and Ecuador appears to be epitheliocystis, a skin and gill disease that has been reported to occur in several species of marine and freshwater fish including *S. dumerili* and *S. mazatlana* (Crespo et al, 1990; Grau and Crespo, 1991; Benetti, 1997). Currently there is no known cure for epitheliocystis.

Monogenean parasites are often a problem in intensive *Seriola* cultures. The gill parasites *Zeuxapta seriolae* and *Heteraxine heterocerca,* and the skin parasites *Paramicrocotyloides reticularis* and *Benedenia seriolae* have been reported to cause serious damage to farmed *Seriola* (Kearn et al., 1992; Whittington et al., 2002; Benetti et al., in press). Bathing fish in praziquantel, sodium peroxocarbonate, hydrogen peroxide or formalin, usually in combination with fresh water is effective at removing the parasites (Sim, 1985; Diggles, 1999; Whittington et al., 2002; Benetti et al., in press). Bath treatments are expensive in terms of labour and equipment, and cause stress to the fish interrupting feeding and growth (Whittington et al., 2002). The kingfish industry in South Australia currently relies on bath treatments, but this is complimented with seacage husbandry that interrupts the parasite lifecycle (Whittington et al., 2002).

Harvesting and processing of the product

There is little documented information available on harvesting and processing of cultured *Seriola,* however harvesting methods are basically similar to other fish species. Fish should be starved before harvesting to allow any ingested food to be digested and evacuated, otherwise the fish will deteriorate rapidly once killed. Stabbing the fish through the spinal bulb is the best method of killing them and the slaughtered fish should be either bled immediately or placed in ice water. If the fish are moribund for a long period of time or are not sufficiently chilled, rigor mortis of the flesh will occur (Oka et al., 1990; Nakada, 2000).

Murata and Sakaguchi (1986) found that when *S. quinqueradiata* was stored on ice the K value[5] (a measure of freshness) of the white muscle increased from 2% to 20% in 6 days, with 20% being the maximum K value for sashimi quality flesh. The dark muscle lost its freshness much more quickly, with the K value increasing from 14% to up to 77% in the first day of storage, making the dark muscle unsuitable for sashimi.

Overview of kingfish (*Seriola lalandi lalandi*) aquaculture research and development in New Zealand

During 1998, NIWA and Moana Pacific Fisheries Ltd embarked on a research programme to investigate the potential for kingfish aquaculture in New Zealand. Early research focused on establishing the natural and culture biology of kingfish, developing basic rearing techniques, and identifying culture bottlenecks limiting commercial development of the potential industry. Initially this research funded by the Foundation for Research Science and Technology was based at Moana Pacific Fisheries Pah Farm Aquaculture facility on Kawau Island, with laboratory and experimental work conducted at NIWAs' Auckland and Wellington aquaculture research facilities. More recently the research has moved to Bream Bay Aquaculture Park recently built by NIWA. Access to this new research facility has speed-up the commercialisation process allowing progress up the commercialisation chain (Table 2). As a result, semi-commercial grow-out trials with a number of commercial partners (Moana Pacific Fisheries Ltd, Island Aquafarms Ltd, Ngati Wai Trust Board, Parengarenga Inc, and Federation of Māori Authorities are proposed or underway. Most of these commercial partners are already involved in the aquaculture and/or seafood marketing sectors, and are consequently well aware of the potential opportunities for marketing and exporting cultured kingfish products from New Zealand.

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[5] The K value is the proportion of hypoxanthine and inosine in the total amount of ATP and its degraded products (Murata and Sakaguchi, 1986).

Moana Pacific Fisheries Ltd have successfully reared small numbers of hatchery-reared kingfish in secages located in the entrance to Bon Accord Harbour, Kawau Island since 2000. Growth rates of 2.5 kg were achieved within 12 months. Moana Pacific recently obtained a 5 year resource consent through their subsidiary Haku Tamure Sea Farms Ltd., for access to 4500m^2 of coastal marine area in Peach Cove, Whangarei Heads. However, this resource consent was appealed and delayed until a hearing in the Environment Court. Meanwhile, Haku Tamure Sea Farms have withdrawn from the proceedings.

Table 2. Current status of New Zealand kingfish aquaculture on the aquaculture commercialisation chain

Score	Process in the commercialization chain	
1	Interested industry partner but limited knowledge base and experience	
2	Preliminary marketing research and economic assessment	
3	Basic biological information-collate existing information or collect baseline data.	
4	Preliminary hatchery and nursery research underway	
5	Hatchery and nursery bottlenecks identified and under investigation	X
6	Semi commercial hatchery and nursery trials to refine culture technology	X
7	Preliminary growout research underway	X
8	Growout bottlenecks identified and under investigation	X
9	Semi commercial growout trials to refine culture technology	X
10	Fully commercial	

Overview of NIWA's kingfish aquaculture research program, past, present and future

Much of NIWAs' research has focused on identifying and solving culture bottlenecks, the most significant being: parasite control during sea-cage growout; and jaw abnormalities arising during larval rearing. We have recently made breakthroughs with these issues. Research areas are listed in Table 3, and have been categorised as: complete; in progress (sample collection/analysis in progress); ongoing (some results to date, work-on-going); or proposed. Some of this research is outlined in publicly available publications (Appendix 1).

Table 3. Overview of NIWAs' kingfish aquaculture research programme

Research areas	Purpose	*Status*
Assessment of seasonal changes in reproductive condition and hormone profiles of wild kingfish	Baseline data on reproductive health for reproductive management	Complete
Assessment of seasonal changes in reproductive condition in experimental broodstock	Basis for improving nutrition, broodstock husbandry, reproductive management and photoperiod/temperature control	In progress
Use of portable ultrasound	Non-invasive techniques to assess sex and reproductive condition in broodstock	In progress
Assessment of stress physiology to common husbandry practices	Improved husbandry practices and identification of problem areas. Refinement of harvest methods.	On-going
Virus testing in wild-caught broodstock	Broodstock screening	On-going
Assessment of lipid profiles during ovarian development in wild fish	Useful for broodstock diet formulation to optimise egg quality	On-going.
Examination of spawning behaviour using video analysis including timing, frequency and periodicity of spawning by individuals; number of fish that typically contribute to each egg batch etc	*When to collect eggs? Improvements in egg collection technology. Broodstock screening*	On-going
Assessment of DNA markers in eggs and broodstock	Broodstock screening programme based on egg and sperm quality	In progress
Photoperiod control	Shifted spawning season	In progress
Egg incubation experiments	Identification of optimal egg incubation temperature based on egg and larval survival, respiratory function and utilisation of metabolic substrates. Development of optimal egg disinfection techniques	On-going
Assessment of egg blastomere morphology	Predictive measure of egg and larval quality	On-going
Assessment of digestive development, visual acuity and sensitivity; olfactory sensitivity; lateral line morphology; and identification of preferred light spectrum and intensity in larvae and juveniles.	Identification of optimal feeding conditions e.g. when? how much?, how often?, under what conditions?	On-going
Effect of light, temperature, density and grading on aggressive behaviour during nursery stages.	Identification of optimal feeding and rearing conditions e.g. when? how much?, how often?, under what conditions? feed delivery technology?	In progress
Larval histopathology, bacteriology and probiotics	Improved health and nutrition	On-going
Semi-commercial scale hatchery and nursery experiments	Improvements in system design and rearing protocols including early weaning.	On-going
Assessment of jaw deformities	Identified onset of deformities. Described deformities.	Complete.
Causes of deformities e.g. nutrition (collaborative research with Dr Sagiv Kolkovski)	Reduction in incidence of jaw deformities.	On-going
Assessment of energetic and exercise physiology at all life stages. Involves measurement of metabolic fuels (proteins, lipids, glucose, nitrogenous substrates) and respiratory physiology (using closed chamber respirometer).	Identification of nutritional and environmental requirements e.g. temperature, oxygen, flow. Optimisation of feed strategies, growth and survival.	On-going
Digestive enzymology	Improved nutrition	In progress
Digestive microbiology	Improved nutrition	Proposed
Description of prevalence, intensity and site preference of parasites on wild kingfish	Implications for parasite management in sea-cages	Complete
Bath treatments for parasites	Quarantine protocol for wild-caught broodstock.	Complete
Assessment of parasite lifecycles including effect of temperature.	Basis for parasite management in sea-cages	Complete
Oral administration of praziquantel-feed trials	Parasite control	Complete
Oral administration of natural remedies/feed stimulants	Improved health and condition	In progress
Pharmacology of praziquantel	Licensing requirements. Optimisation of administration techniques. Identification of metabolic inhibitors	In progress
Pharmacology of natural remedies/feed-stimulants	Optimisation of administration techniques. Identification of new natural remedies	In progress
On-growing nutrition	Optimisation of growth and survival	Proposed
Economics	Economic modelling and market research	On-going
Live transport and harvest methods	Optimisation of technology and product	Proposed

Expertise and resources

The wealth of knowledge and experience feeding into NIWAs' kingfish aquaculture programme via NIWA and University scientists, industry participants and international collaborators is clear evidence of NIWA's ability to work and communicate with a wide and highly relevant spectrum of research providers and recipients. The NIWA science leaders involved in this research have proven track records in leading large and successful aquaculture research projects or in managing commercial/research aquaculture facilities, thus providing a healthy mix of scientific excellence and relevant commercial experience. The NIWA team comprises scientists with specific expertise in reproductive physiology, hatchery and grow-out technology, nutrition, fish health and business development. More recently, NIWA has taken on management staff with commercial experience to aid the development of commercially viable rearing technologies.

A feature of NIWAs' kingfish research programme is the active involvement of Auckland University staff and post-graduate student researchers through the Institute of Aquatic and Atmospheric Sciences and the sharing of research facilities between NIWA and Auckland Universities School of Biological Sciences and Leigh Marine Laboratory. NIWA has also actively sought to collaborate with international experts in kingfish aquaculture research and has worked with scientists from Australia, Japan and the U.S.

Marketing opportunities for kingfish (*Seriola lalandi lalandi*) aquaculture

On an international scale, wild harvests of fish are characterised by declining catches of high-value species and increased landings of low value species, consequently, there is an international shortage of high-quality pelagic fish species. While the value of New Zealand's quota management system (QMS) is recognised, harvest levels post QMS have effectively been halved and commercial fishing companies cannot satisfy demands from overseas markets for premium quality pelagic fish (currently 2M mt). Kingfish aquaculture provides an ideal opportunity to ameliorate these international requests, especially given the value-added benefits of a cultured product over wild products i.e. guaranteed quality, supply and specifications e.g. cultural preferences, and presentation. Specific aquaculture attributes of kingfish include:

- High quality-high value. Sashimi grade fish in Japan

- Diverse range of end-products: whole, fillets, steaks, sushi, sashimi
- Significant and diverse market opportunities internationally
- International shortage of high quality pelagic finfish species
- Limited supply of *Seriola* species internationally
- Amenable to culture conditions
- Fast growth rate
- Existing aquaculture technology and expertise for related species.
- Traditional food source for Maori.
- Opportunity for coastal iwi to get involved in commercial kingfish aquaculture and enhance economic wealth and employment opportunities for Maori and rural areas.
- No commercial quota for kingfish, hence, commercial catches are small, seasonal and unpredictable (302mt annum). Aquaculture is the only way to guarantee supply of this premium quality product.
- Preliminary economic models indicate that kingfish aquaculture can be a lucrative industry; with even brighter prospects as culture technology improves

Global kingfish aquaculture production is 139,000 mt, US$1.1 billion p.a., although 99% is produced and consumed in Japan. NIWAs' principal industry partner has conducted market research that suggests 45% of their cultured product could be exported to Europe, 15% U.S., 10% Asia, 10% Australia and 20% domestic.

Competitor analysis

While the development of New Zealand's kingfish industry is based around on-growing of hatchery reared fingerlings, the Japanese industry is largely reliant on wild seed-stock for on-growing. This practise is becoming increasing unsustainable due to over-fishing, but surprisingly, they have invested very little effort into developing hatchery technology. Although Japans kingfish aquaculture production is substantial 139,000 mt p.a., it does not satisfy Japans domestic demand for kingfish. As a consequence, the Japanese industry poses no threat to the New Zealand industry. Conversely, significant opportunities exist for our product, as our local sub-species is particularly well regarded in Japan. New Zealand's principal competitors are in South Australia where commercially farmed kingfish have recently been released onto the international market. This is an example of an industry that has been commercialised with very limited R&D effort, however, the commercial viability of their industry is hindered by culture bottlenecks. In contrast, we are scientific and technical leaders in kingfish aquaculture research (Table 3) and this is our distinctive competitive advantage. Despite scoring lower on the commercialisation chain (Table 2), we have already identified the culture bottlenecks and gone some way to addressing them. We have also developed a substantial information and database on the culture biology of kingfish (Table 4), which we will continue to capitalise on to ensure New Zealand obtains a technology edge over international competitors.

The opportunity for kingfish *Seriola lalandi lalandi* aquaculture in Northland

Wealth creation

As the world demand for seafood grows, the wild fishery cannot increase catch to equal this demand, but aquaculture can, providing access to fishmeal and fish oil is maintained. Aquaculture is the fastest growing sector of the international food industry, averaging 15% growth per annum, but can be as promising as 27% as in the Mediterranean seabass and seabream industries. Given that kingfish are a high quality species with excellent marketing opportunities for a cultured product, we anticipate an aggregated 21% growth p.a. in the markets for this species. The NZ Aquaculture Council predicts NZ aquaculture exports will exceed $1 billion by 2020, and kingfish aquaculture is likely to make a significant contribution to this growth.

Northland is the ideal location for the establishment of a kingfish aquaculture industry due to its range of potential sites suitable for seacage culture, existing kingfish hatchery at Bream Bay Aquaculture Park and warm annual sea surface temperatures (14-21°C) which would promote faster growth and hence, greater economic return.

Below we have indicated that there are at least ten areas around Northland that may be suited to kingfish cultivation, and a full evaluation of the Northland region would most likely reveal additional sites. We have produced a conceptual business plan for a kingfish farm that could be located at these sites. The business plan builds on market research, our preliminary research including growth data and information from closely related species. The conceptualised kingfish farm would utilise a 4 ha site, a full production cycle would take 12-18 months and over a 5 year development phase, the farm would sell 2815 mt of the total 3373 mt production from 1.4M fingerlings. The business plan indicates a net profit within 4 years, with an accumulated total net profit of $2.5M over the 5 year period with a 37% return on investment (ROI). However, there is potential for a 68% ROI depending on the structure of loan repayments. At a discount factor of 10% the farm will deliver a positive net present value of $867k over the 5 year period. We will continue to update this model as new information becomes available. During year one, the farm would employ two staff growing to 15 staff by year 5.

Employment and training

Bream Bay Aquaculture Park is the largest and most advanced aquaculture development centre in New Zealand where scientists work on site with industry to provide the support, expertise and training required to commercialise new aquaculture species. This ensures that the research maintains commercial focus and momentum and delivers innovation that is directly relevant to the commercial goals. The results are immediately captured and commercialised by industry and the science capacity of the industry partners is greatly increased. NIWA also offers training courses in specific areas of aquaculture.

Aquaculture is a labour intensive industry as evidenced by the 2,000 people already directly employed in the New Zealand industry. The development of kingfish farms in Northern New Zealand will employ and train workers at many levels in the production chain from culture, harvesting and processing through to transport, marketing and retailing. This will bring new aquaculture employment opportunities into rural and urban areas in Northern New Zealand. Given the compilation of Maori commercial partners involved in kingfish aquaculture R&D, Maori will be directly involved in capturing the employment, training and commercial benefits.

Opportunities for Maori

There are significant opportunities to enhance wealth, employment and human capital capabilities of Maori from the corporate level through to iwi and young Maori researchers. Industry NZ and Te Puni Kokiri are providing funding to: develop economic opportunities in aquaculture throughout Northland and increase wealth, employment and human capital capabilities of Maori. Kingfish is a priority species in this regard. Further to this, NIWA has attracted an impressive array of Maori industry partners, principally Moana Pacific Fisheries Ltd, with whom we have a long-standing research relationship. More recently NIWA has formed relationships with Ngati Wai Trust Board, Parengarenga Inc and the Federation of Maori Authorities, to assist them with their interests in kingfish sea-cage and land-based on-growing. The majority shareholdings of these companies are held on behalf of New Zealand's Maori, and they are key players in the current growth of Maori participation in the fishing and aquaculture industries.

NIWA has further complimented these opportunities by recruiting high achieving Maori researchers (Cea Kapiri-Smith and Deborah McLauclan) into the kingfish aquaculture research programme. Cea is a young Northland Maori researcher supported by Te Ohu Kai Moana and Auckland University Maori scholarships. Deborah is funded by a University of Auckland Maori and Polynesian Summer Studentship.

Selection of suitable kingfish farming sites in Northland

The selection of a suitable site for fish farming is critical to the commercial viability of an aquaculture operation. Fish farms should be located, designed and operated to provide optimum water quality and to avoid conditions that may induce stress, reduce growth or predispose the fish to disease. This requires shelter, high water quality, suitable current regimes, accessibility and adequate depth. Access to near shore sites with these characteristics may be limited. Technology does exist for offshore cage farming systems, however, offshore developments are more suited to cage farming operations where husbandry protocols are well established and all available inshore sites have been exploited. Consequently, this report will concentrate on site criteria and attributes for sheltered inshore sites.

Water Quality

It is highly advisable to undertake water quality assessment prior to, and during development of any aquaculture enterprise. This is especially true for harbour sites where salinity fluctuations and high suspended solids loads may be detrimental to cultivation of kingfish. Water quality assessment should include consultation with individuals who have local knowledge, to ensure that best and worst case scenarios are covered. Sites that are deemed to be “low risk” may then be used for pilot studies, with higher risk sites being developed as knowledge of the species and cultivation requirements grows.

S. lalandi lalandi are typically found in temperatures between 15-24°C (Penney, 2000). NIWA has successfully cultured kingfish in temperatures between 12-22°C, albeit with reduced appetite and growth below 14°C. During farming operations, dissolved oxygen levels should be greater than 5.7mg/l (Nakada, 2000). The optimal salinity for yellowtail ranges from 29.8-36.3 ppt (Nakada, 2002). Water pH should range from 6-9, unionised ammonia <0.01 mg/l, carbon dioxide <10 mg/l, chlorine <0.04mg/l, nitrate <100 mg/l, nitrite <0.2 mg/l and toxins undetectable (PIRSA, 2002)

Water depth

General practice with finfish cultivation is to use cages of between 10m and 15m depth and to allow a similar depth of water below the cage to allow any uneaten food and faeces to disperse. Kingfish seacages in Japan are generally 15 m deep, but even larger cages up to 50 m deep are in use (Nakada, 2000). Established growout sites in South Australia use cages as little as 4 m deep (PIRSA, 2002), but these may be too shallow for meaningful commercial development.

Current speed

Optimum current speed is a balance between bringing sufficient fresh water to the cages to meet the fish's oxygen requirements (and remove waste) and the requirements to anchor the cages. Current speeds between 0.5m/sec and 1m/sec (1 - 2 knots) are generally considered to be acceptable.

Wind and waves

Modern sea cages can be designed to withstand severe weather and seas in excess of 8m swell height, but for practical purposes cultivation sites should be as sheltered as possible, to allow maximum access for feeding and harvesting and to avoid technological difficulties associated with mooring and servicing marine farms located in exposed or offshore areas. The prevailing winds in northern New Zealand are south-westerly, although strong winds can occur from the north East. Ideally sites should be sheltered from winds in the eastern quarter.

Access

A shore station with road access for storing food, nets and accessing the cultivation site is essential. The closer this is to the cultivation site, the greater the degree of monitoring and stock control that can be achieved. Potential access sites have been identified as part of this preliminary survey. Cages would need to be monitored on a daily basis.

Area available

South Australian aquaculture license conditions recommend a maximum stocking density of 10 kg/m^3 (PIRSA 2002). Compared to stocking densities in Japan, this is conservative, but more environmentally acceptable. For kingfish aquaculture in Northland, large cages (50-150 m diameter) could be used once the farms technology and expertise are developed, but during the development phase, cage dimensions of 15 x 15 x 15 m are recommended. If stocked at 10kg/m^3, such a cage could produce 34 tons of kingfish. When tidal movement, mooring areas, access and walkways are taken into consideration a 1ha area could hold 10-12 cages, giving a production of 340-408 tons. A site of 4 ha is probably the minimum area that should be considered for commercial scale development to allow for expansion, movement of cages and fallow areas under the cages.

Other users

Fish farm sites may not be suitable or allowable in areas where there is heavy yachting, commercial or shipping activity or in sites with high recreational use or marine conservation status. Consideration should also be given to Tangata Whenua with their ancestral taonga.

Summary of fish farm areas with potential for development.

It is not possible to recommend any particular site or area for kingfish farming in Northland without a more thorough investigation into shelter, water quality and accessibility issues. However, we have provided a brief description of some Northland areas with kingfish farming potential. These sites are listed in geographic order and images are supplied to aid with identification and with estimating total available area (shaded pink). Many areas indicated offer more space than is required for a single commercial cultivation unit and there is therefore potential to develop several cultivation sites in some areas or to site individual farms to optimise cultivation conditions within the area. This is not an exhaustive list of potential kingfish farming sites, there are likely to be other areas with similar potential.

Bream Head (35° 52’ S 174° 34’ E)

This area is sheltered from the North East by Bream Head. It is exposed to seas from the East and South East. Water depth varies from 15m to 25m. Access to the site can be gained from Home Point. The site has a total area of around 15ha, but expansion to find deep water may increase exposure to wind and waves from the North East.

Figure 1. Bream Head (red square = 1 hectare)

Whangaruru Harbour (34^o 23' S 174^o 22' E)

The site, at the mouth of the harbour, is sheltered from all directions. Water depth at the site is 15m, restricting the depth of seacages used at this site. Access to the site could be established at Oakura approximately 2km from the site. The site does not appear to obstruct the navigation channel into the harbour and there are approximately 6 ha available for expansion. Further work would be required to assess the water quality, in particular salinity fluctuations and turbidity coming from the harbour.

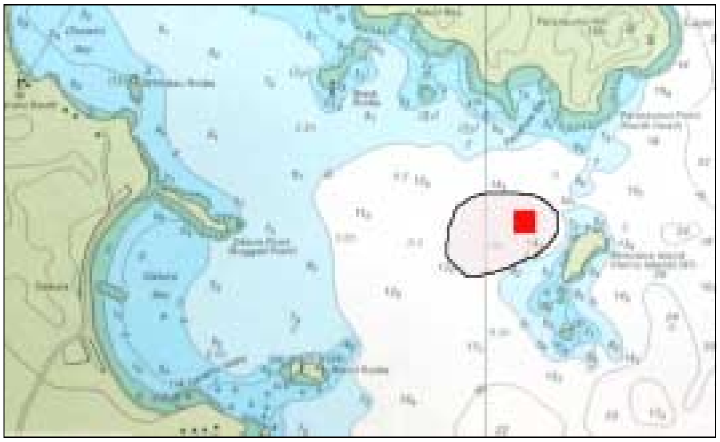

Figure 2. Whangaruru Harbour (red square = 1 hectare)

Howe Point (35^o 10' S 173^o 07' E)

This area is, at the North West tip of the bay of Islands is sheltered from most directions, but is exposed to south easterly winds coming across the bay. Water depth at the site is 15m restricting the depth of seacages used at this site. There is an area of around 20 ha which may offer potential for development. There is no direct access to the area, but a road to Howe Point may offer some access from Whale Bay. As the area is on the open coast, water quality is likely to be high. The proximity to the Bay of Islands may make obtaining a licence difficult.

Figure 3. Howe Point (red square = 1 hectare)

West Cavalli Islands (34^{o} 59’ S 173^{o} 51’ E)

The west side of the Cavalli Islands provides shelter from the prevailing south westerly winds and from wind from the east. The area around Cavalli Passage has in excess of 50 ha with water depths over 20m, providing sufficient room for expansion to a full commercial scale unit. This area is also shown to have current velocities around 0.5 ms^{-1}. Access to the area is by boat, from Waiheke Bay, a trip of around 2km. As the area is on the open coast, water quality is likely to be high

Figure 4. Cavalli Islands (red square = 1 hectare)

Flat Island (35^{o} 00’ S 173^{o} 55’ E)

The west side of Flat Island provides shelter from the prevailing south westerly winds and wind from the east. The area around Flat Island and East Bay has in excess of 25 ha with water depths over 20m, providing potential for expansion to commercial scale. Shore Access is shown on shore close to the area. As the area is on the open coast, water quality is likely to be high.

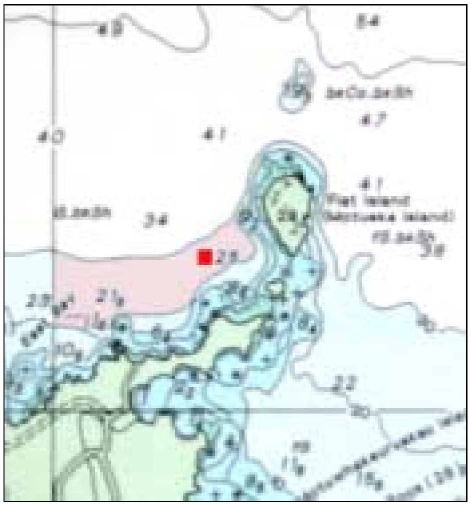

Figure 5. Flat Island (red square = 1 hectare)

Stephenson Island (34° 58’ S 173° 46’ E)

The west side of the island provides shelter from all but Northwesterly winds. There appears to be sufficient deep water (over 20 m) to allow for expansion to around 25 ha. The area could be accessed from Tauranga Bay, a trip of around 5km by boat. As the area is on the open coast, water quality is likely to be high.

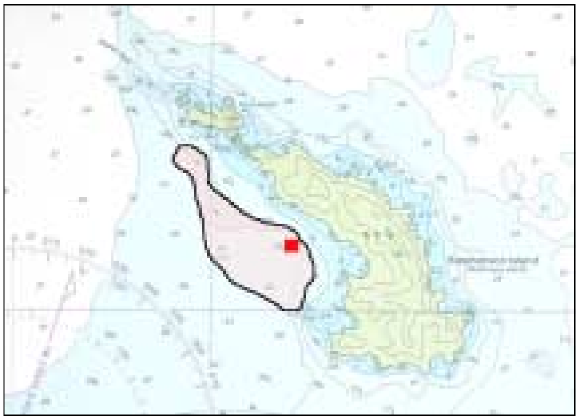

Figure 6. Stephenson Island (red square = 1 hectare)

Whangoroa Harbour (35° 01’ S 173° 45’ E)

The harbour is sheltered and has three deep areas suitable for cage culture. The total available area within the required depth range is around 6 ha. Evidence of extensive oyster farming and yachting in the area suggests that conflicting existing uses may make licensing difficult. In addition water quality, in particular salinity fluctuations and turbidity in the harbour, may be areas of concern.

Figure 7. Whangoroa Harbour (red square = 1 hectare)

Moturoa Islands (34° 47’ S 173° 21’ E)

The islands, at the North East tip of Rangaunu Bay, offer protection from Northerly winds, however the area may be vulnerable to south-westerly winds coming across the Bay. Water quality at this area should be high and the area would offer over 40ha of space for expansion. The average water depth around this area is 17m. The nearest access point (Maraewhiti point) is 5km by boat. Road access to this point is poor and there are no launching facilities shown on the chart.

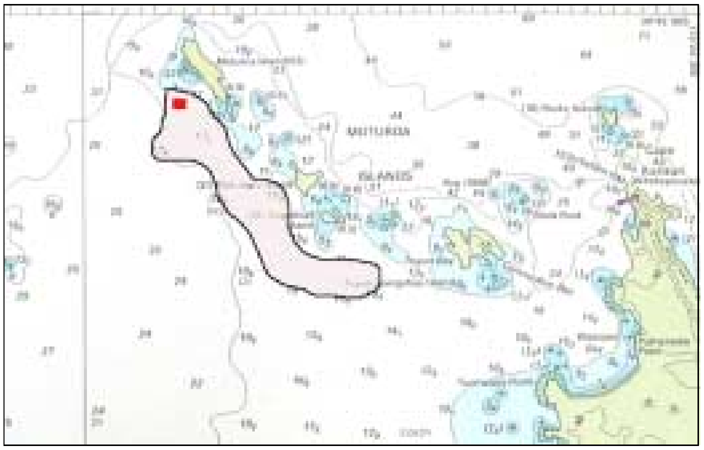

Figure 8. Moturoa Islands (red square = 1 hectare)

Rangaunu Harbour (34° 53' S 173° 17' E)

Although Rangaunu Bay appears to be exposed to the North, the outer parts of the harbour appear to be sheltered and some areas, within the 15m depth range are shown on the chart. However, these areas are small (2 –3ha) and lie in the navigable channel into the harbour. Further work would be required to assess the water quality, in particular salinity fluctuations and turbidity, in the harbour. The area has good access.

Figure 9. Rangaunu Harbour (red square = 1 hectare)

Parengarenga Harbour (34^o 31' S 172^o 58' E)

The harbour offers a sheltered location for all wind directions. Water depth in this area may be limiting, and flow rates shown on the chart are at the upper end of the acceptable level. The area available for farming is likely to be limited to 3-4 ha. This area lies in the navigable channel into the harbour. There is access from a wharf at Akatarere Point, approximately 2km from the site. Further work would be required to assess the water quality, in particular salinity fluctuations and turbidity in the harbour.

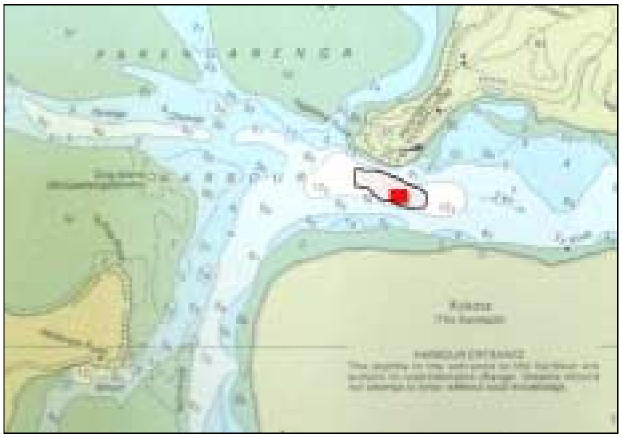

Figure 10. Parengarenga Harbour (red square = 1 hectare)

Hokianga Harbour (35^o 31' S 173^o 23' E)

This harbour provides a sheltered deepwater site. A number of areas offer potential for developing cage based kingfish culture. The highest water quality and deepest water (42m) are found near the mouth of the estuary, but the chart indicates a strong tidal current, and the area may be exposed to westerly winds. Further inside the harbour at Opononi there is an area with acceptable water depth (15-24m) that would appear to be more sheltered and offer around 8 ha of space for expansion. Further information would be required to asses whether a development in this area would interfere with shipping activity. In addition water quality, in particular salinity fluctuations and turbidity in the harbour, may be areas of concern.

Figure 11. Hokianga Harbour (red square = 1 hectare)

This preliminary investigation indicates that there are at least ten areas around the northern New Zealand that may be suited to kingfish cultivation, but a full evaluation of the Northland region could reveal additional sites. These areas described above largely consist of sheltered bays, harbours, and areas sheltered by Islands. However, the requirements for shelter and high water quality often conflict with each other. Estuarine harbour sites offer shelter, but have potentially variable water quality, whilst offshore sites with high water quality, may not offer sufficient shelter. Once more experience in kingfish cultivation has been gained, and acceptable culture conditions for kingfish have been more clearly defined, it may be possible to develop either the estuarine and harbour areas of more exposed sites offshore.

Legislative issues

To occupy space on the seabed within 12 nautical miles of shore for marine farming activities requires consent under the Resource Management Act (RMA) 1991. Resource consents are applied for and administered by the Northland Regional Council through the proposed Regional Coastal Plan[6]. The proposed plan allows

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[6] The proposed Regional Coastal Plan is still under preparation until various legal appeals on it's content are finalised.

aquaculture as a discretionary activity[7] throughout most of the coastal region of Northland, but prohibits aquaculture in any Marine 1 (Protection) Management Areas[8].

During 2001, the government declared a 2-year national moratorium on issuing coastal permits for new marine farms, in order to allow local government to implement aquaculture Management Areas. The risk that the current aquaculture moratorium on new sea-farming licenses will be extended beyond the remaining year is unlikely to influence the early development of kingfish aquaculture. Industry partners currently working with NIWA have opted to pursue landbased kingfish aquaculture or possess existing kingfish farming licenses and/or can legally transfer existing licenses to kingfish. We would anticipate that the moratorium would be lifted by the completion of the R&D phase, allowing new commercial companies to develop their farming interests in this species.

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[7] Discretionary activities require a resource consent prior to the activity proceeding and are required to demonstrate that the activity would not have undue effects on the environment of the proposed area.

[8] Marine 1 Protection Management Areas are deemed to have high conservation significance.

Literature cited

Abe, T and Homma, A. (1997). Modern Fish Dictionary. NTS Inc, Tokyo.

Alcaide, E., Sanjuan, E., de la Gándara F., García-Gómez, A. (2000). Susceptibility of amberjack (Seriola dumerili) to bacterial fish pathogens. Bulletin of the European Association of Fish Pathology. 20(3)::153-156.

Andaloro, F. (1993). Biologia, distribuzione e valutazione dello stock di ricciola, Seriola dumerilii (Risso, 1810) in basso tirreno e mei mari siciliani in relazione alla gestione della risorsa e alle prospettive in acquacoltura. Technical report prepared for the Italian Merch Navy Ministry, Rome. 235pp.

Anraku, M. and Azeta, M. (1965). The feeding habits of larvae and juveniles of the yellowtail, Seriola quinqueradiata Temminck et Schlegel, associated with floating seaweeds. Bulletin of the Seikai Regional Fisheries Research Laboratory, 195:13-45.

Annala, J.H., Sullivan, K.J. and O'Brien, C.J. (2002). Report from the Fishery Assessment Plenary, May 2000: stock assessments and yield estimates. Ministry of Fisheries unpublished report, 640p.

Ayling, T. and Cox, G.J. (1982). Collins guide to the sea fishes of New Zealand. Collins. Auckland. p.217-218.

Bell, J.G. (1998). Current aspects of lipid nutrition in fish farming. In Black, K.D. and Pickering, A.D. (eds). Biology of farmed fish. Sheffield Academic Press, England. pp. 114-145.

Bell. A.S., Yokoyama, H., Aoki, T., Takahashi, M. and Maruyama, K. (1999). Single and nested polmerase chain reaction assays for the detection of Microsporidium seriolae (Microspora), the causative agent of 'Beko' disease in yellowtail Seriola quinqueradiata. Diseases of Aquatic Organisms. 37:127-134.

Benetti, D.D. (1997). Spawning and larval husbandry of flounder (Paralichthys woolmani) and Pacific yellowtail (Seriola mazatlana), new candidate species for aquaculture. Aquaculture. 155:307-318.

Benetti, D.D., Nakada, M., Shotten, S., Poortenaar, C., Tracy, P., Menomoto, Y. and Hutchinson, W. In press. Current status of aquaculture of yellowtail jacks (Carangidae, Seriola spp). In Marine Aquaculture. American Fisheries Society.

Bruce, M.P. (1998). Broodstock management and nutrition and egg and larval quality in the Atlantic halibut (Hippoglossus hippoglossus) and European seabass (Dicentrarchus labrax). PhD thesis, University of Sterling, U.K.

Crespo, S., Grau, A., Padrós, F. (1990). Epitheliocystis disease in the cultured amberjack Seriola dumerili Risso (Carangidae). Aquaculture. 90:197-207.

Diggles. B.K. (1999). Disease prevention, treatment and management at Pah Farm. Unpublished NIWA technical report.

FAO, 1998. FAO yearbook fisheries statistics (1996). Vol. 82. Food and Agriculture Organization of the United Nations. Rome.

Fujita, S. and Yogata, T. (1984). Induction of ovarian maturation, embryonic development and larvae and juveniles of the amberjack, Seriola aureovittata. Japanese Journal of Icthyology. 30(4):426-434. (In Japanese with an English abstract).

Furuita, H., Takeuchi, T., Watanabe, T., Fujimoto, H., Sekiya, S. and Imaizumi, K. (1996). Requirements of larval yellowtail for eicosapentanoic acid, docosahaenoic acid, and n-3 highly unsaturated fatty acid. Fisheries Science. 62(3):372-379.

Garcia, A. and Diaz, M.V. (1995). Culture of Seriola dumerilii. In Seminar of the CIHEAM network on technology of aquaculture in the Mediterranean (TECAM) Cypress, 16. Zaragosa, Spain, p.103-114.

Garibaldi, L. (1996). List of animal species used in aquaculture. FAO Fisheries Circular. No. 914. www.fao.org/docrep/w2333e/w2333e00.htm

Gillanders, B.M., Ferrell, D.J. and Andrew, N.L. (1997). Determination of ageing in kingfish (Seriola lalandi) in New South Wales. Unpublished report by NSW Fisheries Research Institute.

Gillanders, B.M., Ferrell, D.J. and Andrew, N.L. (1999). Size at sexual maturity and seasonal changes in gonad activity of yellowtail kingfish (Seriola lalandi;

Carangidae) in New South Wales, Australia. New Zealand Journal of Marine and Freshwater Research. 33:457-468.

Gillanders, B.M., Ferrell, D.J. and Andrew, N.L. 1999b. Aging methods for yellowtail kingfish, Seriola lalandi, and results from age- and size-based growth models. Fishery Bulletin. 97(4):812-827.

Grau, A. and Crespo, S. (1991). Epitheliocystis in wild and cultured amberjack Seriola dumerili Risso: ultrastructural observations. Aquaculture. 95(1-2):1-6.

Grau, A. and Crespo, S., Riera, F., Pou, S. and Sarasquete, M.C. (1996). Oogenesis in the amberjack Seriola dumerili Risso, 1810. An histological, histochemical and ultrastructural study of oocyte development. Scientia Marina. 60(2-3):391-406.

Hartill, B.; Davies, N.M. (1999). New Zealand billfish and gamefish tagging, 1997–98. NIWA Technical Report No. 57. 39 p.

Hartill, B.; Davies, N.M. (2000). New Zealand billfish and gamefish tagging, 1998–99. NIWA Technical Report No. 79. 20 p.

Hecht, T. and Pienaar, A.G. (1993). A review of cannibalism and its implications in fish larviculture. Journal of the World Aquaculture Society. 24:246-261.

Ishihara, T., Hara, K., Nakayama, H. and Yasuda, M. (1978). Studies of thiaminase I in marine fish-VII Effect of thiamine on yellowtail fed with saury. Bulletin of the Japanese Society of Scientific Fisheries. 44(6):653-657. (In Japanese with an English abstract).

Ishizaki, Y., Takeuchi, T., Watanabe, T., Arimoto, M and Shimizu, K. (1998). Preliminary experiment on the effect of Artemia enriched with arachidonid acid on survival and growth of yellowtail. Fisheries Science. 64(2):295-299.

Jobling, M. (1998). Feeding and nutrition in intensive fish farming. In Black, K.D. and Pickering, A.D. (eds). Biology of farmed fish. Sheffield Academic Press, England. pp.67-113.

Kagawa, H. (1989). Reproductive physiology and induced spawning of yellowtail (Seriola quinqueradiata). Marine Ranching. 18:15-18.

Kanazawa, A., Teshima, S.I., Koshio, S., Higashi, M. and Itoh, S. (1992). Effect of L-ascorbyl-2-phosphate-Mg on the yellowtail Seriola quinqueradiata as a vitamin C source. Bulletin of the Japanese Society of Scientific Fisheries. 58(2):337-341.

Kawakami, H., Yamashita, H. and Sakai, M. (2000). Comparative sensitivity of yellowtail Seriola quinqueradiata and goldstriped amberjack S. aureovittata to Photobacterium damsela subsp. piscicida. Journal of the World Aquaculture Society. 31(2):213-217.

Kearn, G.C., Ogawa, K. and Maeno, Y. (1992). Hatching patterns of the monogenean parasites Benedenia seriolae and Heteraxine heterocerca from the skin and gills, respectively of the same host fish, Seriola quinqueradiata. Zoological Science. 9:451-455.

Kimura, S., Kasai, A. and Sugimoto, T. (1994). Migration of yellowtail in relation to intrusions of warm water from the Kuroshio. Fisheries Science. 60(6):635-641.

Laroche, W.A., Smith-Vaniz, W.F. and Richardson, S.L. (1984). Carangidae:development. In Moser, H.G., Richards, W.J., Cohen, D.M., Fahay, M.P., Kendall Jr. A.W. and Richardson, S.L. (eds). Ontogeny and systematics of fishes. American Society of Ichthyology and Herpetology. Special Publication 1:510-522.

Lin, P.L. and Shao, K.T. (1999). A review of the Carangid fishes (Family Carangidae) from Taiwan with descriptions of four new records. Zoological Studies. 38(1):33-68.

Manooch III, C.S. and Potts, J.C. (1997). Age, growth and mortality of greater amberjack, Seriola dumerili, from the U.S. Gulf of Mexico headboat fishery. Bulletin of Marine Science. 61(3):671-683.

Masumoto, T., Itoh, Y., Ruchimat, T., Hosokawa, H. and Shimeno, S. (1998). Dietary amino acid budget for juvenile yellowtail (Seriola quinqueradiata). Bull. Mar. Sci. Fish., Kochi Univ. 18:33-37.

McGregor, G. (1995). Is the northern region the kingfish capital of the Pacific? Part 1: The fish. Seafood NZ. 3(5):28-30.

McGregor, G. 1995b. Stock assessment of the Kingfish (Seriola lalandi lalandi). New Zealand Fisheries Assessment Research Document. Draft. p.1-27.

Micale, V., Maricchiolo, G. and Genovese, L. (1999). The reproductive biology of the amberjack, Seriola dumerilii (Risso 1810). I. Oocyte development in captivity. Aquaculture Research. 30:349-355.

Mitani, F, (1978). The present status and perspectives of the yellowtail fisheries in Japan. Biologie et Aquaculture. Sète 9-12 Mai 1978. Actes de colloques du C.N.E.X.O., 8. pp. 195-200.

Montero. F.E., García, A. and Raga, J.A. (1999). Fisrt record of Paradeontacylix Mcintosh, 1934 species (Digenea: Sanguinicolidae) in Mediterranean amberjack, Seriola dumerili (Risso, 1810), culture. Bulletin of the European Association of Fish Pathology. 19(3):107-109.

Muraoka, A., Ogawa, K., Hashimoto, S. and Kusuda, R. (1991). Protection of yellowtail against pseudotuberculosis by vaccination with a potassium thiocyanate extract of Pasteurella piscicida and co-operating protective effect of acid-treated, naked bacteria. Nippon Suisan Gakkaishi. 57(2):249-253. (In Japanese with an English abstract).

Murata, M. and Sakaguchi, M. (1986). Storage of yellowtail (Seriola quinqueradiata) white and dark muscles in ice: Changes in content of adenine nucleotides and related compounds. Journal of Food Science. 51(2):321-326.

Murayama, T. (1992). Growth of yellowtail Seriola quinqueradiata in the Japan Sea in recent years. Nippon Suisan Gakkaishi. 58(4):601-609.

Mushiake, K., Kawano, K., Kobayashi, T. and Yamasaki, T. (1998). Advanced spawning in yellowtail, Seriola quinqueradiata, by manipulations of the photoperiod and water temperature. Fisheries Science. 64:727-731.

Mushiake, K., Kawano, K., Sakamoto, W. and Hasegawa, I. (1994). Effects of extended daylength on ovarian maturation and HCG-induced spawning in yellowtail fed moist pellets. Fisheries Science. 60(6):647-651.

Mushiake, K., Kawano, K., Verakunpiriya, W., Watanabe, T. and Hasegawa, I. (1995). Egg collection from broodstocks of yellowtail fed commercial soft dry pellets. Nippon Suisan Gakkaishi. 61(4):540-546. (In Japanese with an English abstract).

Nakada, M. (2000). Yellowtail and related species culture. In Stickney, R.R. (ed). Encyclopaedia of Aquaculture. John Wiley and Sons, Inc, New York. pp. 1007-1036.

Nakagawa, H., Kumai, H., Nakamura, M., Naba, K. and Kasahara, S. (1984). Diagnostic studies on disease of sardine-fed yellowtail. Bulletin of the Japanese Society of Scientific Fisheries. 50(5):775-782.

Oka, H., Ohno, K. and Ninomiya, J. (1990). Changes in texture during cold storage of cultured yellowtail meat prepared by different killing methods. Nippon Suisan Gakkaishi, 56(10):1673-1678 (In Japanese with an English abstract).

Ouchi, K., Adachi, S., Nagahama, Y. and Matsumoto, A. (1985). Ovarian maturity and plasma steroid hormone levels in the cultured and wild yellowtail (Seriola quinqueradiata) during spawning season. Bull. Nansei Reg. Fish. Res. Lab. 7:13-20. (In Japanese with an English abstract).

Penney, A.J. (2000). Seriola lalandi. In Mann, B.Q. (ed) Southern African marine linefish status reports. Oceanographic Research Institute, special publication no. 7. South African Association for Marine Biological Research, South Africa. pp. 20-21.

PIRSA. (2002). Yellowtail Kingfish Aquaculture in SA. Fact Sheet. Primary Industries and Resources South Australia.

Porrello, S., Andaloro, F., Vivona, P., Marino, G. (1993). Rearing trial of Seriola dumerili in a floating cage. Production, Environment and Quality. Ghent Belgium Europeaan Aquaculture Society. 18:299-308.

Poortenaar, C.W., Hooker, S.H. and Sharp, N. (2001). Assessment of yellowtail kingfish (Seriola lalandi lalandi) reproductive physiology as a basis for aquaculture development. Aquaculture. 201: 271-286.

Poortenaar, C.W., Sharp, N. and Roberts, K. (2001). Kingfish Aquaculture: Update Report June 2001. NIWA Client Report: AK01090.

Rainuzzo, J.R., Reitan, K.I., Olsen, Y. (1997). The significance of lipids at early stages of marine fish: a review. Aquaculture. 155:103-115.

Ruchimat, T., Masumoto, T., Hosokawa, H., Itoh, Y. and Shimeno, S. (1997). Quantitative lysine requirement of yellowtail (Seriola quinqueradiata). Aquaculture. 158(3-4):331-339.

Ruchimat, T., Masumoto, T., Hosokawa, H. and Shimeno, S. (1997b). Quantitative methionine requirement of yellowtail (Seriola quinqueradiata). Aquaculture. 150(1-2):113-122.

Ruchimat, T., Masumoto, T., Itoh, Y. and Shimeno, S. (1998). Quantitative arginine requirement of juvenile yellowtail Seriola quinqueradiata. Fisheries Science. 64(2):348-349.

Sakaguchi, H. and Yanagi, T. (1990). Temporal variations in the dissolved oxygen content in the fishfarms of yellowtail and red sea bream. Bulletin of the Japanese Society of Fisheries Oceanography. 54(4):352-356 (In Japanese with an English abstract).

Sakakura, Y. and Tsukamoto, K. (1996). Onset and development of cannibalistic behaviour in early life stages of yellowtail. Journal of Fish Biology. 48:16-29.

Sakakura, Y. and Tsukamoto, K. (1997). Effects of water temperature and light intensity on aggressive behaviour in the juvenile yellowtails. Fisheries Science. 63:42-45.

Sakakura, Y. and Tsukamoto, K. (1997b). Age composition in the schools of juvenile yellowtail Seriola quinqueradiata associated with drifting seaweeds in the East China Sea. Fisheries Science. 63(1):37-41.

Sakakura, Y. and Tsukamoto, K. (1998). Effects of density, starvation and size difference on aggressive behaviour in juvenile yellowtails (Seriola quinqueradiata). Journal of Applied Ichthyology. 14:9-13.

Sakakura, Y. and Tsukamoto, K. (1998b). Social rank in schools of juvenile yellowtail, Seriola quinqueradiata. Journal of Applied Ichthyology. 14:69-73.

Sano, T. (1998). Control of fish disease, and the use of drugs and vaccines in Japan. Journal of Applied Ichthology. 14(3-4):131-137.

Shimeno, S., Hosokawa, H., Takeda, M., Kajiyama, H. (1980). Effects of calorie to protein ratios in formulated diet on the growth, feed conversion and body composition of young yellowtail. Bulletin of the Japanese Society of Scientific Fisheries. 46(9):1083-1087. (In Japanese with an English abstract).

Shimeno, S., Hosokawa, H., Takeda, M., Kajiyama, H. and Kaisho. (1985). Effect of dietary lipid and carbohydrate on growth, feed conversion and body composition in young yellowtail. Bulletin of the Japanese Society of Scientific Fisheries. 51(11):1893-1898.

Sim, D-S. (1985). Experiments on the control of Heteraxine heterocerca parasitizing the gill of cultured yellowtail, Seriola quinqueradiata. Bull. Fish. Res. Dev. Agency, Pusan. 36:105-115. (In Korean with an English abstract).

Smith, A.K. (1987). Genetic variation and dispersal of the yellowtail kingfish, Seriola lalandi, from New South Wales waters. Hons. Thesis. University of New South Wales, Australia.

Tachihara, K., Ebisu, R. and Tukashima, Y. (1993). Spawning, eggs, larvae and juveniles of the purplish amberjack (Seriola dumerilii). Nippon Suisan Gakkaishi. 59(9):1479-1488. (In Japanese with an English abstract).

Tachihara, K., El-Zibdeh, M.K., Ishimatsu, A. and Tagawa, M. (1997). Improved seed production of goldstriped amberjack Seriola lalandi under hatchery conditions by injection of Triiodothyronine (T_3) to broodstock fish. Journal of the World Aquaculture Society. 28:34-44.

Takemura, A., Takeuchi, H., Teruya, K., Oka, M. and Kanematsu, M. (1999). Immunochemical estimation of reproductive activity in hatchery-reared female greater amberjack, Seriola dumerili, using skin mucus. Fisheries Science. 65(5):792-793.

Takeuchi, T., Shiina, Y., Watanabe, T., Sekiya, S. and Imaizumi, K. (1992). Suitable protein and lipid levels in diet for fingerlings of yellowtail. Nippon Suisan Gakkaishi. 58(7):1333-1339.

Tanaka, S. (1979). Migration model and population dynamics of large-sized yellowtails in the Pacific Ocean along the Japanese coast inferred from tagging experiments -I. Same year recaptures. Bulletin of the Japanese Society of Scientific Fisheries. 45(3):297-303.

Thompson, B.A., Beasley, M. and Wilson, C.A. (1999). Age distribution and growth of greater amberjack, Seriola dumerili, from the north-central Gulf of Mexico. Fisheries Bulletin. 97:362-371.

Tsukamoto, K. and Chiba, K. (1981). Oxygen consumption of yellowtail Seriola quinqueradiata in relation to swimming speed. Bulletin of the Japanese Society of Scientific Fisheries. 47(5):673.

Verakunpiriya, V., Watanabe, T., Mushiake, K., Kiron, V., Satoh, S. and Takeuchi, T. (1996). Effect of broodstock diets on the chemical components of milt and eggs produced by yellowtail. Fisheries Science. 62(4):610-619.

Verakunpiriya, V., Mushiake, K., Kawano, K. and Watanabe, T. (1997). Supplemental effect of astaxanthin in broodstock diets on the quality of yellowtail eggs. Fisheries Science. 63(5):816-823.

Verakunpiriya, V., Watanabe, K., Mushiake, K., Kawano, K., Kobayashi, T., Hasegawa, I., Kiron, V., Satoh, S., and Watanabe, T. (1997b). Effect of krill meal supplementation in soft-dry pellets on spawning and quality of eggs of yellowtail. Fisheries Science. 63:433-439.

Watanabe, K., Aoki, H., Sanada, Y., Hidaka, E., Kimura, H., Yamagata, Y., Kiron, V., Satoh, S. and Watanabe, T. (1999). A winter-based assessment on energy and protein requirements of yellowtail at the optimum feeding frequency. Fisheries Science. 65(4):537-546.

Watanabe, K., Aoki, H., Yamagata, Y., Kiron, V., Satoh, S. and Watanabe, T. (2000). Energy and protein requirements of yellowtail during winter season. Fisheries Science. 66:521-527.

Watanabe, K., Hara, Y., Ura, K., Yada, T., Kiron, V., Satoh, S. and Watanabe, T. (2000b). Energy and protein requirements for maximum growth and maintenance of bodyweight of yellowtail. Fisheries Science. 66:884-893.

Watatanabe, K., Ura, K., Yada, T., Kiron, V., Satoh, S. and Watanabe, T. (2000c). Energy and protein requirements of yellowtail for maximum growth and maintenance of body weight. Fisheries Science. 66:1053-1061.

Watanabe, T. (1990). Roles of vitamin E in aquaculture. Yukagaku, 39:299-306.

Watanabe, T., (1993). Importance of docosahexaenoic acid in marine larval fish. Journal of the World Aquaculture Society. 24:152-161.

Watanabe, T., Verakunpiriya, V., Mushiake, K., Kawano, K. and Hasegawa, I. (1996). The first spawn-taking from broodstock yellowtail cultured with extruded dry pellets. Fisheries Science. 62:388-393. 1999.

Whittington, E.I., Corneillie, S. and Talbot, C. (2002). Monogenenan parasites in sea-cage aquaculture. Austasia Aquaculture, 16(1): 46-48.

Appendix 1

Publicly available publications

Refereed Publications

Sharp, N.; Poortenaar, C.W.; Diggles, B. (in press). Metazoan parasites of yellowtail kingfish, *Seriola lalandi lalandi*, in New Zealand. Prevalence, intensity and site specificity. *New Zealand Journal of Marine and Freshwater Research.*

Poortenaar, C.W., Hooker, S.H. and Sharp, N. (2001). Assessment of yellowtail kingfish (*Seriola lalandi lalandi*) reproductive physiology, as a basis for aquaculture development. *Aquaculture*, 201: 271-286.

Book chapters

Benetti, D.D., Nakada, M., Shotten, S., Poortenaar, C., Tracy, P., Menomoto, Y. and Hutchinson, W. In press. Current status of aquaculture of yellowtail jacks (Carangidae, *Seriola* spp). In *Marine Aquaculture*. American Fisheries Society.

Popular articles

Poortenaar, C.W. (2002). Good prospects for kingfish aquaculture. Seafood New Zealand, 10:(6), 18-19.

Sharp, N.; Poortenaar, C.; Diggles, B. (2001). Monogenean parasites in kingfish aquaculture. *Fish Farming International:* 28(8) 32.

Poortenaar, C.W. (2000). NZ update on kingfish. Fish Farming International, 27(6): 39.

Tait, M. (2000). Kingfish farming-can it be done in New Zealand. Aquaculture Update, 25: 1-3.

Poortenaar, C.W. and Hooker, S. (1999). Yellowtail kingfish - an exciting new aquaculture species for New Zealand. Austasia Aquaculture, 13(2): 49 – 50.

Poortenaar, C.W., Hooker, S. and Sharp, N. (1999). Update on kingfish aquaculture research. Seafood New Zealand, 7(7): 33 - 34.

Poortenaar, C.W., Hooker, S. and Sharp, N. (1999). Where are we at with kingfish aquaculture. Aquaculture Update, 23: 9 – 10.

Poortenaar, C.W., Hooker, S. and Sharp, N. (1999). Kingfish aquaculture research in New Zealand. Austasia Aquaculture, 13(6): 45 – 46.

Poortenaar, C.W., Hooker, S. and Jeffs, A. (1998). Yellowtail kingfish - New Zealand's next aquaculture species. *Seafood New Zealand*, 6(11): 34.

Poortenaar, C.W. and Hooker, S. (1998). Yellowtail kingfish - an exciting new aquaculture species for New Zealand. *Aquaculture Update*, 22: 1 – 5.

Poortenaar, C.W. (1998). Kingfish farming. *Bay of Islands Swordfish Club Newsletter*, December 1998.

Conference presentations

Poortenaar, C. (2002). Reproductive biology and early life history of yellowtail kingfish *Seriola lalandi lalandi*. Presented at the 5th International Congress on the Biology of Fish, Vancouver, Canada, July, 2002.

Poortenaar, C.W., Sharp, N., Tait, M., and Diggles, B. (2000). “Overview of kingfish Aquaculture Research”. Presented at Aquafest Australia 2000, Hobart, October 2000.

Sharp, N., Poortenaar, C. and Diggles, B. (2000). “Controlling monogenean parasites in kingfish aquaculture”. Presented at Aquafest Australia 2000, Hobart, October 2000.

Poortenaar, C.W. (2000). “Assessment of natural reproductive cycles in potential aquaculture species. Why is this important?”. Presented at New Zealand Marine Sciences Society Conference, University of Waikato, September 2000.

Sharp, N., Poortenaar, C. and Diggles, B. (2000). "Controlling monogenean parasites in kingfish aquaculture". Presented at New Zealand Marine Sciences Society Conference, University of Waikato, September 2000.

Poortenaar, C.W. (2000). "New directions in kingfish aquaculture research: development of kingfish farming". Seafood Week, Nelson, May 2000.

Poortenaar, C.W. and Hooker, S. (2000). "Assessment of the kingfish stress response as a basis for aquaculture development". World Aquaculture Conference, France, 2000.

Poortenaar, C.W., Hooker, S. and Sharp, N. (1999). "Assessment of yellowtail kingfish biology, as a basis for aquaculture development". NZ Marine Sciences Conference, Wellington, 1999.

Poortenaar, C.W. and Kato, K. (1999). "Kingfish farming in Japan: what is the New Zealand potential?". NZ Marine Sciences Conference, Wellington, 1999.

Poortenaar, C.W., Hooker, S. and Sharp, N. (1999). "An assessment of yellowtail kingfish reproductive biology, as a basis for aquaculture development". World Aquaculture Conference, Sydney, 1999.