Barramundi culture: A success story for aquaculture in Asia and Australia

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Errata

Although this article appeared in the September 2002 issue, final revisions from the authors were not included and computer incompatibility resulted in inaccurate figures. Rather than pointing out each inconsistency the article is reprinted here without the accompanying photographs.

—Editor

The family Centropomidae contains 22 identified species in three genera. Those fishes are found in tropical to warm temperate regions. In addition to barramundi (*Lates calcarifer*), there are seven other *Lates* species that live in African freshwater lakes and rivers, including the Nile perch (*Lates niloticus*) and the Japanese seabass (*Lates japonicus*), which occurs from salt to fresh water in Japan. Twelve snook species (*Centropomus* spp.) live in the Western Hemisphere. The waigeu perch (*Psammoperca waigiensis*) is found from southern Asia to Australia. Most of them are food and game fish.

Barramundi range through the northern Indian and tropical western Pacific Oceans from Iran to the northern third of Australia (to 22°30'S in Western Australia and 26°30'S in Queensland), including China, Taiwan and Papua New Guinea. Barramundi are catadromous. They must spawn and go through egg and early larval stages in salt water, but juveniles prefer to live in fresh or nearly fresh water. Other names include Asian seabass, seabass, giant seabass, white seabass, twofin seabass, blind seabass, twofinned seabass, giant perch, silver sea perch, palmer, giant palmer, nairfish, kakap putih, bekti, apahap, plakapong, nokogirihata, and silver barramundi.

Barramundi are farmed commercially in Southeast Asia and Australia (Tucker *et al.* in press). Much research has been done on this important species. For many years, wild barramundi juveniles have been grown out in ponds and cages in Southeast Asia. The first artificial spawning was accomplished in Thailand in 1973, and now most farmed barramundi are from hatcheries. The Australian barramundi industry began during 1983-1985 with research projects in Cairns, followed in 1986 by the establishment of the first commercial Australian hatchery in north Queensland. After a slow initial period, rapid expansion has occurred since 1992, particularly because of refinement of more extensive larval rearing techniques and more cost efficient feed formulations. During 1998-1999 there were 38 producing farms (18 pond, 20 recirculating) in Queensland (Lobegeiger 2000). In 2000-2001, 25 pond farms, 9 recirculating farms and one sea cage farm were producing in Queensland (Lobegeiger 2002). During 1998-1999, Queensland produced 515.3 tons, South Australia 249 tons, Western Australia 15 tons, the Northern Territory 12 tons, and New South Wales 11.2 tons (O'Sullivan and Dobson 2000).

In 1999, world aquaculture production of barramundi was 3,693 tons in freshwater, 15,962 tons in brackish water, and 242 tons in salt water, with a total value of $65,552,000. Thailand produced 6,437 tons, Malaysia 5,210 tons, Taiwan 4,979 tons, Indonesia 2,060 tons, Australia 895 tons, Singapore 241 tons, Brunei Darussalam 41 tons and Hong Kong 34 tons (FAO 2001).

Culture Methods

Facilities

Salt water is needed for broodfish, eggs and about two-thirds of the larval stage, up to 11-15 dah (days after hatching). Late larvae and juveniles can be raised in freshwater. Therefore, hatcheries require a saltwater source, but nursery and growout facilities do not, which allows more flexibility in siting. Broodfish spawn in tanks or cages. Larvae have been raised in 2 l to 40 m^3 (commonly 1-5 m^3) tanks and 0.05-1.0 ha ponds. Hatchery tanks are cylindrical or rectangular, and usually concrete or fiberglass. Juveniles have been grown to market size in ponds, cages, cages in ponds, tanks, and coastal or inland impoundments. Growout cages are rectangular or cylindrical.

Brood stock

Barramundi are tank and strip spawned with and without hormones. Males can mature at 2 yr, 42 cm total length (TL), 1.1 kg and females at 3 yr, 60-65 cm, 2.0 kg. Most individuals are protandrous hermaphrodites (first male, then female); by 5 yr, most will be females. Barramundi naturally spawn during the warmer months and have been caught near the time of ovulation and strip spawned during April through September in Thailand and November through March in Australia. Strip spawning was the primary method of obtaining eggs before the development of environmental manipulation techniques, sometimes combined with hormone treatment, which resulted in reliable, routine tank spawning. Eggs and larvae are planktonic; eggs float at 30-35 ppt salinity and because early larvae cannot swim very fast or far, both mostly drift with the current. A 9 kg female can produce 7 million eggs per spawn. A 2 kg female can naturally ovulate 9 million eggs in a season. Induced ovulation can generate at least a quarter million eggs/kg body weight, for example 6.8 million/16.5 kg.

In Asia, under ambient conditions, voluntary spawning occurs from new or full moon to near quarter moon phases and can continue for at least four to five months. At 27-34°C, barramundi spawned voluntarily all year in 100 m^3 (10 m diameter x 1.3 m deep) concrete tanks (Figure 2) in Malaysia and Thailand. With tanks (ranging to 100 m^3), eggs can be collected in 300 µm mesh bags, either inside the tank with airlift tubes pumping them into the bag or outside the tank with water overflowing through the bag. With cages (9-75 m^3), a bag of ~500 µm mesh can be inserted between the cage and broodfish to contain the eggs, which are skimmed out.

Reared adult barramundi have been conditioned to spawn in three phases by the following steps (Kungvankij 1987):

a. Broodfish tanks hold 100-200 m^3 of water, 2 m deep, with 1 fish/2 m^3: 1) feed broodfish well, five percent of body weight daily and 2) transfer equal numbers of males and females to a pre-spawning tank.
b. Pre-spawning tank: 1) reduce daily ration to one percent. 2) simulate the spawning migration by increasing salinity to 30-32 ppt and 3) transfer females and males exhibiting pre-spawning behavior to the spawning tank.
c. Spawning tank: 1) near the full or new moon, decrease water depth and warm the water to 31-32°C in 2-3 h, to simulate a falling tide, 2) quickly refill the tank, dropping the temperature to 27-28°C, to simulate a rising tide, 3) check for eggs the following night and 4) if there are no eggs, repeat steps 6-8.

Spawning should last for three to five days and can be repeated for each of the next four to five months. The same procedure can be used for wild barramundi if they first are allowed to adapt to captivity for at least six months.

Although barramundi have been conditioned to spawn voluntarily in any month, hormone treatment seems more necessary as distance from the equator increases. Human chorionic gonadotropin (HCG), carp pituitary, barramundi pituitary and gonadotropin releasing hormone analog (GnRHa) have been used to induce ovulation in barramundi, usually at 28-30°C (range 26-32°C). The treated broodfish usually are injected in the morning and allowed to tank spawn that night or the following night. Females with oocyte diameters of 400-450 µm have spawned 34-38 h after one injection of GnRHa, while those with oocytes of 500-550 µm spawned 8-10 h after one injection. A dosage of 3-5 µg/kg body weight usually resulted in one spawn, and 10-25 µg/kg resulted in 2-4 spawns, but with egg number, fertilization rate and hatching rate decreasing to near zero by the fourth night. Ovulation occurred within six days after one injection of 20-100 µg GnRHa/kg or after one to four daily injections of 60-100 µg/fish. Ovulation occurred within six days after intraperitoneal implantation of pellets containing 10-200 µg GnRHa/kg, or within one to seven days during daily dosing with 9 µg GnRHa delivered by osmotic pumps.

Hormone-induced tank spawning is the preferred method in Australia. Garrett and O'Brien (1994) stocked four females and four males in a 20 m^3 fiberglass tank in April 1992. During the next four months, conditions were gradually adjusted to simulate those in December, the peak natural spawning month, with salinity of 30-36 ppt, temperature of 28-29°C, and day length of 13 hours, then held constant. By October, oocyte development was sufficient for inducing ovulation and tank spawning for two to three nights starting 34-38 hours after one injection of 19-27 µg GnRHa/kg given to only females. In this manner, tank spawning was induced every month for 15 months (40 nights total); 200 million eggs and 132 million hatchlings were produced.

A similar procedure is currently used by Rimmer (1999). Broodfish are held in 20 to 100 m^3 fiberglass or concrete tanks, usually cylindrical. The fish are fed a daily ration of fresh or frozen food (often pilchards, sometimes squid or shrimp, usually with vitamins added) of one to two percent of body weight or three times a week at three percent of body weight.

Hatchery

Barramundi eggs usually are 750-850 µm in diameter (with one oil globule 230-260 µm in diameter) and hatch in about 17 hours at 28°C; hatchlings are 1.4-1.7 mm TL; larvae first feed at about 2.5 dah (2.6 mm) and exhaust their yolk and oil by 4-5 dah (yolk is small by 3 dah; oil could last until 5.8 dah); transformation to juveniles occurs at about 25 dah, about 17 mm TL. At 27°C, larvae hatched at 1.4 mm TL, first fed 54 hah (2.6 mm) with a mouth width of 224 µm; all survivors were feeding by 71 hah and had exhausted their yolk about 74 hours later. Although larvae have small mouths and bodies at first feeding, their high feeding efficiency and the long period from first feeding until yolk and oil are exhausted give them a relatively high survival ability. Gas bladder inflation begins at 1.5-2^+ dah when larvae are 2 mm long. Therefore, during the first 10 dah, oily and sticky surface films in larval tanks should be avoided and light intensity, aeration, circulation and nutrition should be carefully controlled. For about the first two weeks, salinity should be at least 20 ppt. At 11-15 dah, larvae can be transferred to fresh water.

Either eggs or hatchlings can be stocked in rearing units, but handling mortality of larvae can be avoided by stocking eggs. Larvae have been raised in tanks holding 2-40,000 l of water with 5-275 larvae/l stocked (usually 10-30/l) and are provided with laboratory-cultured, pond-cultured or wild zooplankton for food. Fifty percent survival from hatchling to juvenile is typical for intensive tank rearing.

Pond (0.05-1.0 ha, <2 m deep) larviculture has been further developed in recent years, greatly increasing the supply of juveniles in Australia, where currently that is the main production method. Early larvae feed on zooplankton and late larvae feed mainly on benthic animals, such as midges. The method sounds simple, but experience and good timing are essential to ensure that appropriate foods are abundant when the larvae need them and predators, including arrow worms and certain aquatic insects, are not abundant. Monitoring of larvae with plankton nets and juveniles with lift nets is recommended. Twenty percent survival (range 0-90 percent) from 1 dah to juvenile is typical, but the cost per juvenile can be 40-64 percent of that for intensive rearing.

Very good results (90 percent survival, uniform size) have resulted from 2 weeks of intensive greenwater tank rearing followed by a larval/nursery pond stage.

Nursery

In the nursery phase, barramundi are weaned, usually in tanks or cages in tanks, then grown in tanks, ponds or cages from 20-25 mm to 75-100 mm, the minimum size for beginning growout to market size.

During weaning, density typically is 0.5-1/l. In Australia, 1 m^3 nursery cages in tanks holding 10-30 m^3 of water are used to facilitate grading. Grading at least every 7-10 days, possibly at intervals of 2-3 days, is necessary to minimize cannibalism, which diminishes after weaning is complete and the fish reach 15 cm TL. Until then, full and frequent meals also help to control this problem. Farms without their own hatcheries usually buy barramundi at the beginning or end of this phase.

Growout

Growth rates are highly variable and depend on factors such as stocking density, temperature, food quality and feeding rate. Neither genetic stock nor salinity seem to significantly affect the growth rate.

In southeast Asia, barramundi are grown out mainly in ponds (0.08-2 ha), coastal impoundments and small to medium cages (1-300 m^3). Because expansion of cage culture in many parts of Southeast Asia is limited by saturation of coastal sites, many countries are developing offshore cage culture using larger European-style cages. In Australia, cages, ponds and tanks are used commercially (Lobegeiger *et al.* 1998, Lobegeiger 2002). Size range of cages is 8-150 m^3 and ponds 0.1-1.0 ha (average 0.6 ha). During 2000-2001, on 34 Queensland barramundi farms, about 41 percent of the fish were grown out in cages (usually aerated) in ponds, 56 percent free in ponds and 3.2 percent in recirculating tank systems. Average cage harvest density by area changed from 47 kg/m^2 during 1997-1998 to 65 kg/m^2 in 1998-1999, 43 kg/m^2 in 1999-2000 and 14 kg/m^2 in 2000-2001; from 1999 to 2001, total cage area increased from 3,757 m^2 to 16,161 m^2 (Lobeigeiger 2000, 2001, 2002). Minimum cage density by volume is 15 kg/m^3, maximum 40-60 kg/m^3 and optimal 25 kg/m^3. There also is one sea-cage farm in Queensland. Water exchange in ponds usually is 5-10 percent per day, but with high fish density, 25 percent exchange might be needed. Pond production can be up to 20 tons/ha. Mostly indoor tanks are used in southern Queensland, South Australia and New South Wales. In New South Wales, the climate is too cold for outdoor barramundi farming. A growout facility using flow-through, geothermally heated freshwater has been reported to reach densities as high as 100 kg/m^3 (Makaira Pty Ltd. 1999), but 15 kg/m^3 is more typical (Rimmer and Russell 1998a). A new sea-cage farm in the Northern Territory has plans to grow out 1,000 mt/yr initially, with full production of at least 3,000 mt/yr expected within the next few years.

Barramundi easily reach more than 500 g in 12 months, but some studies have indicated a potential for growing 800 g barramundi in a year at high temperatures, and 3 kg is possible in 18-24 months. Juveniles stocked in a large freshwater reservoir previously stocked with forage fish grew from about 5 to 5,200 g during 2-20 months after hatching. Other stocked barramundi grew to 10 kg in 3 years.

Stock Enhancement

There is some evidence that the Australian recreational and commercial fisheries, particularly in Queensland, are in decline, and stock enhancement is perceived as one management tool for alleviating this problem. Reasons for the decline are debatable, but habitat degradation and over-exploitation seem to be major factors. Both marine and freshwater stocking programs have received widespread support, especially from the recreational sector.

The first major stocking of reared barramundi in Australia was in a Queensland freshwater reservoir during December 1985. The purpose was to increase the value of an underutilized environment through put-and-take fishing (MacKinnon and Cooper 1987). Since then, much more rearing and stocking in reservoirs and coastal waters have been done in that state (Rutledge and Rimmer 1991, Rimmer and Russell 1998b). Most juveniles for both farming and stocking in Australia are produced in ponds. Stocking strategies to improve survival after release are being refined.

Today, stocking of impoundments is widespread in Queensland, and at least one impoundment in the Northern Territory has been stocked. Rutledge *et al.* (1990) estimated that the overall economic benefit from stocking barramundi in an Australian freshwater reservoir could be 31 times the cost of raising and stocking the fish. Coastal rivers in Queensland have been stocked since the early 1990s. In their study river, Rimmer and Russell (1998b) found that 15 percent of the barramundi caught had been stocked, thus demonstrating cost-efficiency. Currently, about 1 million barramundi are stocked per year in Australia, mostly in Queensland.

Nutrition

Foods for larvae

A wide variety of foods and feeding schedules have been used for barramundi larvae. Usually, microalgae, rotifers and *Artemia* nauplii and metanauplii are used for tank culture, but copepods and/or cladocerans can be added and are likely to improve growth and survival. At about 2.5 dah, larvae can begin feeding on protozoans, small rotifers, copepod nauplii or other small zooplankters, especially those 20-100 µm wide. At about 8-10 dah, larvae can begin eating *Artemia*.

When the greenwater technique is used, mostly *Nannochloropsis*, *Tetraselmis* and/or *Chlorella* sp. (= *Nannochloropsis* sp. in some cases) are stocked at 8-300 cells/µL during 0-1 dah to 15-21 dah, and water exchange is <50 percent until transformation (25 dah). Rotifers are fed during at least 2-15 dah and *Artemia* are started by 10-12 dah. The zooplankton is added at rates depending on fish age, fish density and rearing unit size so that the larvae can feed efficiently. Density ranges used have been 2-20 rotifers/ml, 0.1-10 *Artemia*/ml and 0.1-2 cladocerans/ml. Rotifers raised on high-EFA (essential fatty acid) algae do not need to be enriched. Although barramundi can be reared with unenriched *Artemia*, whenever *Artemia* are the main food, they should be enriched. Cladocerans such as *Moina macrocopa* and *Daphnia* spp. can be substituted for or fed with *Artemia* beginning at 15-16 dah. For cladocerans to survive, salinity should be 0-10 ppt. Weaning to conventional dry crumbles is relatively easy and can be accomplished by or before 25-26 dah. Frozen *Artemia* were used as an appetizer by Tucker *et al.* (1988) to wean barramundi during 20-25 dah.

A schedule used for barramundi in 5- to 25 m^3 tanks in Thailand included microalgae (0-15 dah), rotifers (2-15 dah), *Artemia* nauplii (8-30 dah), *Daphnia* sp. (20-30 dah, optional) and ground trash fish beginning 25 dah (11 mm TL).

Barramundi were raised in 1000 l tanks with rotifers (fed *N. oculata*) during 3-15 dah and *Artemia* nauplii 10-25 dah (Tucker *et al.* 1988). Salmon starter was first offered 20 dah. Transformation occurred during 21-25 dah (17 mm TL). The fish began to eat commercial salmon starter 23 dah and were weaned by 26 dah. A cannibalistic tendency in juveniles was mostly controlled by grading and feeding well.

Rutledge and Rimmer (1991) raised barramundi extensively in a fertilized pond with mixed zooplankton - mainly copepods, rotifers and cladocerans - and obtained about 43 percent survival during 2-22 dah. Some cannibalism was witnessed as early as 18 dah.

Feeds

Barramundi generally are fed trash fish in Asia and pellets in Australia. Published dietary requirements include: 43 percent protein for juveniles, 10 percent fat, 0.5 percent ω6 PUFA (polyunsaturated fatty acids), 0.5 percent ω3 PUFA and 20-25 percent carbohydrate (Feed Development Section 1994). Boonyaratpalin (1991) reported that, for growout, barramundi need at least 40-45 percent protein (with 12 percent fat) and juveniles need 1.0-1.7 percent ω3 HUFA (highly unsaturated fatty acids). Fat contents of 9-24 percent have been used in experimental feeds. In Asia, the use of sinking soft-moist or dry pellets is increasing, but trash fish is still widely used. In Australia, floating extruded pellets are preferred by commercial farmers, but when water is very clear, barramundi do not always feed well at the surface and sinking pellets are sometimes used.

Barramundi (9-566 g) were raised in Australia at suboptimal temperatures (22-27°C) in tank trials with commercial salmon starter and experimental barramundi feeds containing 48-52 percent protein and 8-14 percent carbohydrate (Tucker *et al.* 1988, MacKinnon 1990). Growth rate ranged from 2.68 to 0.67 percent/day and feed conversion ratio (FCR) from 0.89 to 1.13. A mean weight of 566 g was reached 12 months after hatching. The experimental feed containing the most fish meal (60 percent) and fat (16.9 percent fat, 9.4 percent total fish oil) produced the best growth (0.97 g/day, 2.68 percent/day), FCR (0.89) and protein conversion ratio [PCR (0.46)] with fish of 16-72 g; however, a feed containing only 20 percent fish meal and 13.4 percent fat (5.3 percent total fish oil) gave similar results (1.01 g/day, 2.64 percent/day, FCR 1.04, PCR 0.50). Thus, for early juveniles, total fat in the range 13-17 percent with at least half from fish oil (or equivalent) seems appropriate. Feeds containing as much as 65 percent poultry and meat meal or 28 percent poultry and meat meal with 30 percent soybean protein gave excellent results (PCR 0.50).

In Tahiti, Fuchs (1987) raised barramundi in tanks and cages on a starter feed (56 percent protein, 16 percent fat) and a grower feed (55 percent protein, 12 percent fat) containing normal fish meal (35, 33 percent), fish protein concentrate (21, 18.9 percent), meat and bone meal (5, 4.7 percent), dried whey (0, 3.7 percent), soybean meal (8, 10.3 percent), lactic yeast (9, 9.4 percent), leaf protein concentrate (1.5, 2.8 percent); wheat (4.5, 8 percent); corn (6, 0 percent); guaranate (2, 2 percent), red capelin oil (2, 3.7 percent) and corn oil (2.6, 0 percent). With the starter feed, fish were raised from 1.1 g to 25.6 g in 95 days (growth 3.28 percent/day, FCR 0.9). With the grower feed, fish grew from 32 g to 677 g in 187 days (growth 1.62 percent/day, FCR 1.4). A mean weight of 500 g was reached about 12 months after hatching.

In Australia, Williams *et al.* (1998) reported that an experimental feed containing 50 percent meat meal (with 9 percent blood meal, 10 percent full-fat soybean meal, 10.4 percent wheat, 10 percent gluten, 6 percent fish oil, 47.8 percent protein, air dry) produced slightly better growth (3.3 versus 3.0 g/day) and similar FCR (1.31 versus 1.22) when compared with a feed containing 35 percent fish meal (with 10 percent meat meal, 16 percent soybean meal, and 30.4 percent wheat, 5 percent gluten, 2.5 percent fish oil, 43.8 percent protein) over the weight range 226-445 g. Fifty gram barramundi gained 2.0 g/day and 300 g ones gained 4.5 g/day on a 46 percent protein feed at 29°C.

Although barramundi are carnivorous, much flexibility is possible in feed formulation. Fish meal is not necessary. A variety of animal and plant protein sources can be used, and up to 20-25 percent carbohydrate can be included for protein sparing. Whenever trash fish are used, they should be of high quality and if used for more than a few days should have vitamins added or be fed alternately with pellets.

Environmental Conditions

Barramundi spawn at 26-34°C with 28-30°C best; 27-28°C is best for larvae (26-30°C is acceptable; range 25-31°C and perhaps as high as 35°C); 27-30°C is best for juveniles (26-32°C is acceptable, with the range being about 21-39°C; 12-16°C and about 43°C can be lethal). Feeding and growth of juveniles are best at 27-30°C and drop sharply at <25°C to near zero at 20°C.

Barramundi spawn at 28-36 ppt salinity with 30-32 ppt best; 25-31 ppt is best for larvae (range 20-35 ppt); 0-35 ppt and higher is suitable for juveniles and adults. Barramundi survive and grow well if transferred from saltwater to freshwater at about 15 dah and can tolerate transfer as early as 11 dah. We have found that juveniles will grow as well in nearly pure water (5 mg/l hardness) as in saline water, if their feed contains enough minerals.

Broodstock held under a 13 hours light:11 hours dark photoperiod and 28-30°C remain reproductively active throughout the year. Growth of barramundi larvae improved as day length increased from 8 to 16 to 24 hours/day, but survival did not change. Growth and survival of juveniles did not differ at 12, 18, and 24 hours/day of light.

A minimum of 4 mg/l dissolved oxygen keeps juveniles healthy; 3 mg/l can be tolerated; the lethal minimum is in the range about 0.5-1.0 mg/l. Larvae probably can tolerate up to about 82 µg/l unionized ammonia nitrogen. A practical limit of 380 µg/l NH_3-N has been suggested for early juveniles in salt water. Unionized ammonia should be less than 20 µg/l NH_3-N (<1.2 mg/l TAN) for growout. Zero is best. Larvae probably can tolerate up to about 61 µg/l nitrite nitrogen. At 0 ppt and 28°C, juveniles were injured by 1.45 mg/l NO_2-N and killed by 14.5 mg/l, but at 15 and 32 ppt, about seven times more nitrite was tolerated. Zero is best. Larvae probably can tolerate up to about 226 µg/l nitrate nitrogen (NO_3-N). Less than 10 mg/l suspended solids is recommended for growout.

Health

Viruses (viral nervous necrosis, *Lymphocystis*), gram-negative bacteria (*Vibrio* spp., *Aeromonas* spp., *Edwardsiella, Flavobacterium columnare*, *Pasteurella* spp., *Pseudomonas* spp., *Yersinia*), gram-positive bacteria (*Streptococcus iniae*), epitheliocystis, ecoparasitic protozoans (*Amyloodinium ocellatum*, *Cryptocaryon irritans*, *Brooklynella* spp., *Trichodina* spp., *Chilodonella* spp.), monogeneans (*Diplectanum* sp. and others) and *Lymphocystis* are significant pathogens in some areas. Abnormal or hyperinflated gas bladders, bladder stones and essential fatty acid deficiency can adversely affect larvae.

Possible factors contributing to bacterial infection in barramundi include very high or low temperature, low water quality, malnutrition, overstocking, excessive handling such as during grading, bad sanitation and possibly, large salinity changes. Bacterial fin rot usually occurs after fins are injured by handling or from bacterial septicemia with the bacteria settling inside the small capillaries of the fins. Vaccines for pathogenic bacteria are being developed.

Epizootic ulcerative syndrome, which causes deep open necrotic ulcers on fish kept in freshwater, is thought to be caused by a fungus, but viruses and bacteria can be present. Other internal or external fungal infections can occur, especially at low temperatures and if the skin is injured.

The ectoparasitic ciliated protozoan *Cryptocaryon irritans* causes cryptocaryoniasis, or saltwater ich (white-spot) in many species, including barramundi. Other protozoans, monogenean flatworms, myxosporidians and crustaceans are not as serious in Australia as they are in Asian cage farms.

Economics

Sizes of wild barramundi have decreased as the stocks have, but 30 kg and larger fish are caught occasionally. Market size of farmed fish usually has been in the range 250-600 g, but it is economical to raise them to 3 kg or more. A trend to produce larger fish (1-3 kg), by raising them through a second summer, occurred during the 1990s in Queensland (Lobegeiger *et al.* 1998). Marketable product (≈ fillet yield) from plate-size barramundi, 500 g, 8 months old, can be as low as 40 percent but increases to near 50 percent for 3 kg fish, 18-20 months old (Cann 1996).

Total production for Queensland rose from 327,669 kg (whole fish) in 1995-1996 to 569,439 kg in 2000-2001, with total value increasing from A$3,332,000 to A$5,116,269 (Lobegeiger 2000, 2001, 2002). Production changes in four categories were: whole fish 247,506 to 526,676 kg, gilled and gutted 63,441 to 20,604 kg, live 8,673 to 17,819 kg and fillets 100 to 861 kg. In 2000-2001, 551 tons were grown out in ponds and 18,276 kg in recirculating systems. Average prices for juveniles were A$0.22 in 1997-1998, A$0.27 in 1998-1999, A$0.34 in 1999-2000 and A$0.18 in 2000-2001.. Changes in farm gate prices were A$9.94 to 8.89/kg whole, A$12.34 to 11.73/kg gilled and gutted, A$10.11 to 9.83/kg live, and A$20.00 to 18.30/kg filleted.

Future Prospects

World production of barramundi has been relatively constant since 1993. Wide salinity range, tolerance to crowding, excellent feed conversion and high growth rate are some of the qualities making barramundi one of the best coastal species for farming. Improved nutrition, health management and engineering will make it even more reliable and will facilitate expansion of indoor farming in cooler regions. Some hatcheries have started genetic selection programs, which are likely to result in faster growth, at least.

As Australian farm production and potential imports of barramundi increase, the freshness of domestic farmed barramundi will need to be emphasized to maintain a price advantage over frozen or captured fish (Lobegeiger *et al.* 1998). Development and maintenance of markets for diverse products, such as fillets, will be important. Oversupply could be a future problem. Care should be taken so that barramundi farming and/or stock enhancement practices do not endanger the genetic diversity and health of wild populations or regional biodiversity.

Notes

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References

Boonyaratpalin, M. 1991. Asian seabass, *Lates calcarifer*. Pages 5-11 In R.P. Wilson, editor. Handbook of Nutrient Requirements of Finfish. CRC Press, Boca Raton, Florida, USA.

Cann, B. 1996. Barramundi aquaculture in the Northern Territory: An economic evaluation. Northern Territory Department of Primary Industry and Fisheries, Darwin, Australia, Technical Bulletin No. 244.

FAO. 2001. Aquaculture production 1999. Food and Agriculture Organization of the United Nations, Rome, FAO Yearbook of Fishery Statistics, Vol. 88/2.

Feed Development Section. 1994. Feeds and feeding of milkfish, Nile tilapia, Asian sea bass, and tiger shrimp. SEAFDEC Aquaculture Department, Tigbauan, Iloilo, Philippines.

Fuchs. 1987. Growth of introduced larvae and fingerlings of sea bass (*Lates calcarifer*) in Tahiti. Australian Centre for International Agricultural Research, Proceedings 20: 189-192.

Garrett, R. N., and J. J. O'Brien. 1994. All-year-around spawning of hatchery barramundi in Australia. Austasia Aquaculture 8(2):40-42.

Kungvankij, P. 1987. Induction of spawning of sea bass (*Lates calcarifer*) by hormone injection and environmental manipulation. Australian Centre for International Agricultural Research, Proceedings 20:120-122.

Lobegeiger, R. 2000. Report to farmers: Aquaculture production survey Queensland 1998-99. Queensland Department of Primary Industries, Brisbane, Australia, Information Series QI00042.

Lobegeiger, R. 2001. Report to farmers: Queensland aquaculture production survey 1999-2000. Queensland Department of Primary Industries, Brisbane, Australia. Information Series QI01019.

Lobegeiger, R. 2002. Report to farmers: Queensland aquaculture production survey 2000-2001 Queensland Department of Primary Industries, Brisbane, Australia, Information Series Q101

Lobegeiger, R., J Gillespie, P Duncan and N. Taylor-Moore. 1998. Aquaculture in Queensland. Queensland Department of Primary Industries, Brisbane, Australia. Information Series QI98021

MacKinnon, M. R. 1990. Status and potential of Australian *Lates calcarifer* culture. Advances in Tropical Aquaculture. AQUACOP, Institut Français de Recherche pour l'Exploitation de la Mer. Actes de Colloque 9:713-727.

MacKinnon, M. R. and P. R. Cooper. 1987. Reservoir stocking of barramundi for enhancement of the recreational fishery. Australian Fisheries 46:34-37.

Makaira Pty Ltd. 1999. The translocation of barramundi. Fisheries Western Australia, Perth, Fisheries Management Paper No. 127.

O'Sullivan, D. and J. Dobson. 2000. Status of Australian aquaculture in 1998/1999. Austasia Aquaculture, Trade Directory 2000/2001.

Rimmer, M. 1999. Barramundi farming: recent improvements in hatchery and culture techniques. Pages 8-22 In C. L. Lee and D. C Harvey, editors. Proceedings of the WA Conference on Tropical Aquaculture in the Kimberley, 27th-29th May 1999, Broome, Australia. Fisheries Western Australia.

Rimmer, M. A. and D. J. Russell. 1998a. Aspects of the biology and culture of *Lates calcarifer*. Pages 449-476 In S. S. De Silva, editor. Tropical Mariculture. Academic Press, San Diego, USA.

Rimmer, M. A. and D. J. Russell. 1998b. Survival of stocked barramundi, *Lates calcarifer* (Bloch), in a coastal river system in far northern Queensland, Australia. Bulletin of Marine Science 62:325-335.

Rutledge, W. P. and M. A. Rimmer. 1991. Culture of larval sea bass, *Lates calcarifer* (Bloch), in saltwater rearing ponds in Queensland, Australia. Asian Fisheries Science 4:345-355.

Rutledge, W. P., M. Rimmer, J. Russell, R. Garrett and C. Barlow. 1990. Cost benefit of hatchery-reared barramundi, *Lates calcarifer* (Bloch), in Queensland. Aquaculture and Fisheries Management 21:443-448.

Tucker, J. W., Jr., M. R. MacKinnon, D. J. Russell, J. J. O'Brien and E. Cazzola. 1988. Growth of juvenile barramundi (*Lates calcarifer*) on dry feeds. The Progressive Fish-Culturist 50:81-85.

Tucker, J. W., Jr., D. J. Russell and M. A. Rimmer. Barramundi culture. In Manual of Fish Culture, Volume III. American Fisheries Society, Bethesda, MD. In press.

Williams, K., C. Barlow and F. D'Souza. 1998. Larval penaeid and grow-out finfish nutritional research in Australia. Annex 5-2. Pages 26-35 In M. A. Rimmer, K. C. Williams and M. J. Phillips, editors. Proceedings, Grouper Aquaculture Research Workshop, Bangkok, Thailand, 7-8 April 1998. Australian Centre for International Agricultural Research.