Grouper culture

John W. Tucker, Jr.[1,2]

Groupers are classified in 14 genera of the subfamily Epinephelinae, which comprises at least half of the 449 species in the family Serranidae. Throughout most warm and temperate marine regions, serranids are highly valued for food, and both small and large species are kept in aquariums. Maximum size ranges from about 12 cm total length (TL) for western Atlantic *Serranus* species and the Pacific creole-fish (*Paranthias colonus*) to more than 4 m TL (≥440 kg) for the king grouper, giant grouper, groper, or brindlebass (*Epinephelus lanceolatus*).

Ages (months) at which some western Atlantic serranids reach 454 g in nature are: Goliath grouper (*E. itajara*) about 12, black grouper (*Mycteroperca bonaci*) 17, gag grouper (*M. microlepis*) 18, red grouper (*E. morio*) 27, and black sea bass (*Centropristis striata*, subfamily Serraninae) 51. Nassau groupers (*E. striatus*) reach 500 mm (about 2.5 kg) in 4-5 yr and Goliath groupers reach 500 mm (about 2.7 kg) in about 2 yr. Maximum reported sizes are: 1,220 mm TL and about 27 kg for Nassau groupers, 1,518 mm for black groupers, 1,290 mm for gags and about 2,500 mm and 320 kg for Goliath groupers. Nassau groupers live for at least 29 yr, black groupers 33 yr, gags 21-22 yr, red groupers 25 yr and Goliath groupers 37 yr.

Juveniles and adults of some grouper species live in coastal waters and estuaries, but others prefer the cleaner waters of offshore reefs. Eggs are planktonic — single, non-adhesive and buoyant at normal salinities. Larvae of most species spend at least their first few weeks drifting with the oceanic plankton. As they become juveniles, groupers settle to the bottom, usually in shallow water, where they can find hiding places. Then, until several centimeters long, they hide almost constantly. Their boldness increases with size and they move to deeper water, but most species continue to stay near small caves for security. Wild grouper larvae at first eat copepods and other small zooplankton, then larger crustaceans like amphipods and mysid shrimp. Wild juveniles and adults eat mainly fish, crabs, shrimp, mantis shrimp, lobsters, and molluscs.

More than 20 grouper species have been raised commercially, mostly by growing out captured wild juveniles in the Southeast Asian region. FAO (2002) reported that 9,488 tons of groupers and sea basses worth US$65,339,000 were grown out in Taiwan (5,053), Thailand (2,150), Malaysia (1,217), Indonesia (1,159), Hong Kong (523), Philippines (167), Singapore (111), Kuwait (6) and Brazil (2) during 2000. Sadovy (2001) estimated that for the late 1990s about 60 million juveniles grown out per year resulted in 23,000 tons of live table-size groupers sold in Southeast Asia; however, at least hundreds of millions of wild grouper juveniles were caught and sold each year, so mortality from capture and transportation had to be very high and wasteful. Despite improvements in recent years, only 20,000-80,000 juveniles are produced annually by hatcheries throughout the region, not counting those in Taiwan (Sadovy 2001). About two-thirds of the groupers grown out in Taiwan were from hatcheries. In 1998, about half of the groupers farmed there had been raised from wild juveniles (Cesar *et al.* 2000). In 2000, Taiwanese hatcheries produced 300,000 brownmarbled groupers and 2 million king groupers (Chan 2001). King grouper culture has just been developed in the last few years and is continuing at a strong rate.

The primary farmed Asian species (Sadovy 2001) have been: orangespotted or estuary grouper (*E. coioides*, Figure 1) and Malabar grouper (*E. malabaricus*, Figure 2). Other major species are: duskytail grouper (*E. bleekeri*), redspotted grouper (*E. akaara*), yellow grouper (*E. awoara*), squaretail grouper (*E. areolatus*), and king grouper. Minor species are: blackspotted grouper (*E. amblycephalus*), brownmarbled grouper (*E. fuscoguttatus*, Figures 1 and 3), sixbar grouper (*E. sexfasciatus*), bluespotted grouper (*E. trimaculatus*), longfin grouper (*E. quoyanus*), kelp grouper (*E. bruneus*), polka-dot grouper (*Cromileptes altivelis*), leopard coraltrout (*Plectropomus leopardus*, Figure 4), barred-cheek coraltrout (*P. maculatus*), squaretail coraltrout (*P. areolatus*), honeycomb grouper (*E. merra*), camouflage grouper (*E. polyphekadion*), and greasy grouper (*E. tauvina*). For farming in the southeastern U.S. and Caribbean region, Nassau groupers (Figure 5), gags (Figures 6 and 24), black groupers (Figure 7), and Goliath groupers (Figure 8) seem to have good potential. Dusky (*Epinephelus marginatus*) and white groupers (*Epinephelus aeneus*) have been investigated in the Mediterranean.

Wild groupers tend to be very easy to catch, especially species that form large aggregations for spawning like the Nassau grouper. This grouper historically was the most important through most of the Caribbean islands and coastal reefs, but has been overfished to commercial extinction in many areas. Both commercial and recreational harvests are now prohibited in the U.S. The gag and red grouper, because of their abundance and availability to the fishery, are economically the most important species in the U.S. They and many other grouper species throughout the world have been overfished, leading to reduced numbers and reduced average size. Once grouper production reaches a high enough level, aquaculture will help protect wild stocks by reducing fishing pressure.

In some areas where wild juveniles are caught for growout, supplies (catch-per-unit-of-effort) have decreased in recent

*Fig. 1. Asian red snapper (*Lutjanus argentimaculatus*), orangespotted grouper (*Epinephelus coioides*) and brownmarbled grouper (*Epinephelus fuscoguttatus*) being grown out in Singapore. (Photo by*

*Fig. 2. Malabar grouper (*Epinephelus malabaricus*) broodstock in Thailand. (Photo by John Tucker)*

*Fig. 3. Female brownmarbled grouper (*Epinephelus fuscoguttatus*) two days before spawning at Palau. (Photo by John Tucker)*

*Fig. 4. Leopard coraltrout (*Plectropomus leopardus*) at Palau. (Photo by John Tucker)*

*Fig. 6. Gag (*Mycteroperca microlepis*) in Florida. (Photo by John Tucker)*

*Fig. 5. Nassau grouper (*Epinephelus striatus*) at Grand Cayman. (Photo by John Tucker)*

*Fig. 7. Black grouper (*Mycteroperca bonaci*) at Grand Cayman. (Photo by John Tucker)*

*Fig. 8. Goliath grouper (*Epinephelus itajara*) in Florida. (Photo by Lewis Bullock, Florida Fish and Wildlife Conservation Commission)*

*Fig. 9. Concrete raceways (3.0 x 12.2 x 1.0 m deep) in which wild and reared Nassau groupers (*Epinephelus striatus*) spawned in Florida. (Photo by John Tucker)*

*Fig. 10. Spawning cage (5 x 5 x 3 m deep) in which polka-dot groupers (*Cromileptes altivelis*) spawned, between Singapore and Malaysia. (Photo by John Tucker)*

Fig. 11. A 26-m^2 concrete larval rearing tank at the National Institute of Coastal Aquaculture, Thailand. (Photo by John Tucker)

Fig. 12. Concrete larval rearing tanks, each 50 m^2, in Japan. (Photo by John Tucker)

Fig. 13. A 50-m^3 concrete larval rearing tank in Japan (from the group in Fig. 12). (Photo by John Tucker)

Fig. 14. Concrete larval rearing tanks in Taiwan, usually shaded when larvae are stocked. (Photo by John Tucker)

Fig. 15. The main bay of Lamma Island (southwest of Hong Kong, in background), which contains houseboats and a fairly large number of fish cages. (Photo by John Tucker)

years (Johannes *et al.* 1998), especially near Hong Kong, Taiwan, and China (Sadovy 2001). Possible factors include not only overfishing of juveniles but also overfishing of adults, habitat loss, toxic pollutants, and population cycle variations. In other areas, supplies of juveniles have been relatively constant, despite 20 or more years of collecting. As groupers grow in nature, their numbers naturally decrease. Harvesting small juveniles has less impact than harvesting a similar number of larger fish, and is less likely to be a determining factor of population size. The more that a given grouper population is limited by predation or lack of habitat for fish larger than those caught for growout, the less the impact of such catches will be. If heavy losses naturally occur after the collected stage, then protecting a number of the fish on farms actually could increase the total numbers available for harvest. At least, if collection of moderate numbers is small compared to those lost to natural mortality, significant losses of wild stocks would not result. Therefore, traditional grouper farming in Asia (i.e. wild groupers grown in ponds or cages) has been encouraged by some environmental organizations. But at the same time, grouper hatchery technology needs to be perfected, because the wild supply does fluctuate and there is no guarantee that it will continue indefinitely. Survival of collected juveniles also must be improved.

Shipping of infected wild or reared juveniles to distant growout areas has transferred diseases, especially viral and parasitic ones. There are strong movements to have national and international regulations and agreements enacted to reduce and eventually prevent such problems.

In 1998, there were about 600 grouper hatcheries and farms in Taiwan, producing

5,000-7,000 tons/yr, 90 percent of which was orangespotted and Malabar groupers (Cesar *et al*. 2000). The large number of participants, strong government support, intense research and specialization, availability of large areas of coastal land and mass production of eggs are factors contributing to the Taiwanese success.

Culture Methods

Facilities

Saltwater is needed for broodfish, eggs and larvae. Juveniles and adults of many species can live in brackish but not freshwater. Groupers have spawned voluntarily in fiberglass, concrete (Figure 9), or plastic tanks with volumes of 1-21,200 m^3, concrete ponds of 1.8-860 m^3 and cages (Figure 10) of 26-75 m^3 (Tucker 1994, 1998). Larvae have been reared mainly in fiberglass or concrete tanks (Figures 11-14) holding 1-60 m^3 and sometimes in concrete ponds of up to 500 m^3; while a minimum of 3.5 m^3 is good, 7 m^3 or larger is better. Tanks (Figure 9) and cages (Figure 15) up to at least 75 m^3 and larger ponds (Figure 16) have been used for growout. Good environmental control is especially important for both broodstock and larvae, but not as critical for the other stages.

Broodstock

Most groupers that have been studied will mature within 2-6 yr (Tucker 1998). Many serranids are proto-gynous hermaphrodites (i.e. most individuals mature first as females and some of them become males later). Some of those species, as a rule, change from female to male as they grow older, while others might change only if there is a shortage of males. In nature, Nassau groupers typically spawn in large distinct aggregations (hundreds to thousands of fish) with a sex ratio near 1:1. Gags spawn in harems, frequently within aggregations, with a sex ratio often near 1 male:10 females. For both species, individual spawning events usually involve small numbers of fish (e.g. 2-5). Small serranids often spawn in pairs without aggregating. A few of the small serranids are simultaneous hermaphrodites (male and female at the same time) but self-fertilization seems to be rare.

Broodstock can be captured or reared. Most groupers studied have quickly adapted to captivity. Adults usually are captured by traps or hook and line. With protogynous hermaphrodites, sex control sometimes is considered necessary to ensure an optimal male:female ratio for maximizing egg production. If males are

Fig. 16. A pond used for growing out groupers in Taiwan. (Photo by John Tucker)

*Fig. 17. Nassau groupers (*Epinephelus striatus*) spawning in a concrete raceway (3.0 x 12.2 x 1.0 m deep) in Florida. In the center are a female flanked by two males; at the lower right are two females that have ovulated but are not yet spawning. (Photo by John Tucker)*

*Fig. 18. Giving an intramuscular injection to a female squaretail coraltrout (*Plectropomus areolatus*) in Palau to induce ovulation. (Photo by John Tucker)*

*Fig. 19. Stripping eggs from a squaretail coraltrout (*Plectropomus areolatus*) in Palau. (Photo by John Tucker)*

difficult to collect or do not occur in reared broodstock when the females have become mature, sex-reversal of females with dietary or injected methyltestosterone could provide the needed males. When too many females could become males, suppression of sex-reversal has been accomplished by administering female hormones like estradiol or by maintaining enough large males in the tank. With simultaneous hermaphrodites, mature fish of similar size usually can be paired.

Voluntary spawning of captive groupers has occurred mostly with well-fed uncrowded fish during the natural spawning season under conditions of ambient temperature and partial or total natural light (Tucker 1994, 1998). Day length seems to be a less important stimulus for spawning than temperature. More than 30 serranid species have spawned voluntarily in captivity, with groupers spawning in 1- to 21,200-m^3 tanks or ponds and 26- to 75-m^3 cages. Eggs are collected in automatic strainers or with soft, fine dipnets. It should be kept in mind that some species spawn near certain moon phases and others spawn any day of the lunar month. With good timing and luck, groupers can be caught just before spawning and held in tanks or cages for up to a few days until they ovulate naturally. The eggs are stripped, or rarely, the fish are left in the tank for voluntary or accidental fertilization to occur, if the males are running ripe.

A 6 kg female Nassau grouper can produce about 900,000 eggs per day by natural or hormone-induced ovulation and 3.3 million eggs in a 4 day period when spawning voluntarily (Figures 9 and 17).

Hormone-induced ovulation of ripe wild or captive groupers and sea basses generally is reliable (Tucker 1994, 1998). More than 31 serranid species have been induced to ovulate (Figure 18). Typically, a female with fully yolked oocytes (immature eggs) will ovulate (release mature eggs into the centers of the ovaries) within 24-72 hours (usually 36-50 hours) after the first of 1-3 injections of 500-1,000 IU human chorionic gonadotropin/kg body weight. Similar results have been obtained for several species given 1-3 injections of 10-50 μg gonadotropin releasing hormone analog (GnRHa)/kg body weight, and GnRHa implants also have worked. If newly caught broodfish are used, the hormone should be administered as soon after capture as possible to limit stress effects on oocyte development. For six grouper species with egg diameters of 800-1,000 μm, the minimum effective oocyte diameter, as seen in biopsy samples, before injection was in the range 41-61 percent of the fertilized egg diameter. Ovarian biopsies are not necessary if external characteristics can be relied upon as indicators of oocyte development. Females are handled as little as possible, but are monitored closely for swollen abdomen, protruding genital papilla, stretching of the membrane holding eggs in and spawning coloration. They are checked more often, such as once an hour, just before the predicted time of ovulation (Figure 19). For Nassau groupers, the time from ovulation to over-ripeness (deterioration of eggs) is only 1-2 hours at 26°C.

Transparency, buoyancy, roundness, normal egg size, size uniformity, lack of stickiness, possession of a single oil globule and normal oil globule size are initial signs of quality. High

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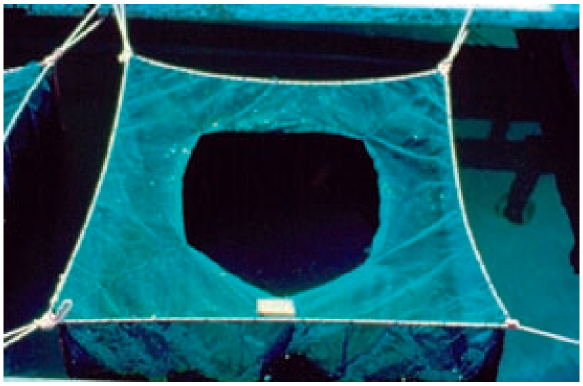

Fig. 20. A nursery cage (1 x 1 x 1m) used for groupers in Singapore. (Photo by John Tucker)

fertilization rate, normal cell division, high hatching rate and successful first feeding are subsequent signs. Usually, eggs are transferred to rearing tanks just before hatching, or larvae are transferred just before first feeding, but it is best to avoid handling of grouper larvae.

Hatchery

Known egg diameters are in the 0.8 to 1.0 mm range and total length of hatchlings in the 1.4-2.3 mm range. Larvae of most grouper species are small and fragile and have small mouths at first feeding. Yolk and oil, which nourish early larvae until after feeding begins, tend to be exhausted quickly, generally within 2-5 days (Kohno *et al*. 1994, Tucker 1998). Typically, the larval period is long (often about 50 days, range 35-70 days), and groupers tend to require live food longer than most marine fish that have been reared. They have been stocked at 0.3-60 eggs or larvae/l, usually 5-20. Careful administration of thyroid hormones could be used to increase health and survival of grouper larvae and to accelerate transformation.

Commercial-scale Asian hatcheries have raised large batches of juveniles, with survival as high as 34 percent from hatchlings. The best survival has occurred in larger tanks (60-500 m^3) under partial sunlight. Species with small mouths need small rotifers, trochophores (oyster or clam larvae), copepods, or other zooplankters at first feeding. Larvae of some species, like Nassau grouper, seem to be especially sensitive to noises, such as bumping of their tanks, which induces rapid, frantic swimming. Providing the correct amount of turbulence in larval tanks is critical. With too little turbulence, the water stratifies (maybe thermally), and zooplankton and fish can aggregate dangerously, possibly with oxygen depletion, frequent collisions or feeding difficulty, because they are attracted to bright areas of the tank. With too much turbulence, the fish are battered. Stressed (e.g., by fright, strong current, toxins, pathogens or malnourishment) larvae might appear exhausted or stunned, swim erratically, drift with the current and/or not feed well. Early grouper larvae, especially when stressed, sometimes exude a large amount of mucus, which can cause them to stick to each other, to the surface film, or to solid objects.

Gorging on *Artemia* is another source of mortality for mid-stage larvae, and cannibalism among early juveniles is a potential problem. Gorging can be minimized by adding the *Artemia* in small amounts and by feeding rotifers and copepods for at least several days after *Artemia* are started. Cannibalism can be minimized by feeding the fish well, weaning them as soon as possible and removing extra large fish regularly (grading).

Nursery

In the Philippines and other areas, when fish are too small to stock directly in growout ponds, the early juveniles are raised in cages (Figure 20) in the ponds, usually from 20-30 mm to 50-100 mm (Figures 21-23) in about 30-45 days (Baliao *et al*. 1998). About 60 fish/m^3 are stocked in the cages (size range 4 x 2 x 1.5 m to 8 x 4 x 1.5 m, with 0.5-cm mesh).

In Taiwan, up to 2,000 juveniles are raised per cage (1.2 x 0.8 x 0.8 m) in small ponds (about 100 m^2) for 1-3 months until they reach about 6 cm TL (Rimmer 1998). Larger ponds are used mainly for over-wintering. Pond temperatures are about 26˚C in summer and about 20-24˚C in winter. To limit cannibalism, grading is performed at 5-7 d intervals.

Grow-out

In the Indo-Pacific and Middle Eastern regions, several species of grouper are farmed in cages, ponds and tanks, but mostly they are raised from wild juveniles and are fed trash fish. They

Fig. 21 (below). Minimum stocking-sized Goliath grouper in Florida (55 mm, 2 g). (Photo by Lewis Bullock, Florida Fish and Wildlife Conservation Commission)

Fig. 22 (above). Stocking-sized Malabar grouper (3 g) in Taiwan. (Photo by John Tucker)

Fig. 23 (left). Stocking-sized Nassau grouper (3 g) in Florida. (Photo by John Tucker) sometimes are fed small tilapia and sometimes are polycultured with them. Typical market size is 500-1,000 g, which can be reached in 6-8 months of growout. The usual minimum size to begin growout, 75-100 mm, about 10 g (age 3-4 months), can be obtained in nursery tanks, cages, or ponds. Initially, they are stocked up to 60 fish/m^3 (<1kg/m^3) in cages. Density usually is reduced somewhat as they grow.

*Fig. 24. Gag (*Mycteroperca microlepis*) in Florida (32 mm, 1 g). (Photo by Lewis Bullock, Florida Fish and Wildlife Conservation Commission)*

In the Philippines, 500- to 10,000-m^2 rectangular earthen or concrete ponds with depths of 1-2 m and level bottoms are the preferred types for growout. Double water gates, aeration devices, and emergency water pumps should be present. Typically, juveniles are stocked at 5,000/ha and grown from 50-100 mm to 400-1000 g. Foods include trash fish and sometimes tilapia living in the ponds.

In Taiwan, undersized (25-mm) juveniles are raised in 100-m^2 nursery ponds or tanks to about 60 mm before being stocked in 2,000 m^2 growout ponds. Sometimes cages (1.2 ´ 0.8 ´ 0.8 m), with a maximum of 2,000 fish each, are used in the nursery ponds. Intensive pond farms have stocked juveniles at 60,000-80,000/ha and harvested 80 percent of them, for a production density as high as 30,000-40,000 kg/ha (usually 10,000-30,000 tons) with aeration and 20 percent water exchange/day. Those groupers are fed mostly trash fish and can grow from 46 mm (2-3 months old) to 600 g in 12 months and can reach 2 kg in 19 months. Orangespotted groupers can grow from 60 mm TL to 400-800 g after 8-10 months in cages or 10-14 months in ponds (Rimmer 1998). King groupers can grow from 75 mm to 2.4 kg in 1 yr and 15 kg in 2 yr.

Improvement of early growth rates (e.g., with better temperature control and earlier weaning) will allow production of 600 g Nassau groupers within 12 months, 1 kg groupers within 18 months and 2 kg groupers within 24 months.

Stock Enhancement

In isolated locations where groupers have been severely depleted, it might be possible to replenish spawning stocks with reared fish. In an experimental study, 27 Nassau grouper raised in tanks in Florida (309-367 mm TL, 579-1,098 g, mean 909 g) were released and monitored by a diving team on an open ocean reef with depths of 1-15 m at St. Thomas, U.S. Virgin Islands (Roberts *et al*. 1995). For three months before release, live and frozen foods were added to their diet. Although they had been raised on pellets, the groupers ate live goldfish and crabs within seconds after they were placed on the bottom of their raceway. After release, they exhibited behavior until then expected only from wild groupers. Within 1 hour after release from a holding cage, all the groupers had gobies and shrimp remove ectoparasites obtained while they were in the cage. Within 2 days, some were seen hunting alongside a moray eel or octopus. It was surprising that these behaviors known for wild groupers were innate and did not have to be learned by the hatchery fish. Although their tags had been lost, two groupers seen at 297 days and one at 16 months probably were released fish.

Nutrition

Foods for Larvae

Grouper larvae usually are raised in green water, mostly with the phytoplankton *Nannochloropsis*, *Tetraselmis* and/or *Chlorella* spp. stocked at 10-500 cells/µl during 0-3 days after hatchinging to 12-40 days after hatchinging. At first feeding, most species can easily eat small rotifers, but oyster, clam, or mussel eggs and larvae sometimes are used as a supplement. Growth and survival tend to be better if copepods or mixed zooplankton are included in the diet, but care must be taken to avoid introduction of pathogens or predators. Certain ciliates (with widths of about 20-80 µm) could be added to improve survival during the first few days of feeding, but some types are not nutritious. Cladocerans (water fleas) are sometimes used for early to mid-stage larvae. *Artemia* enriched with essential fatty acids can be a staple food beginning at 10-30 days after hatchinging, but their abundance should be controlled to minimize gorging and incomplete digestion by the larvae. It is best to delay feeding of *Artemia* as long as other foods are sufficient (until 20 days after hatchinging or later). Mysid shrimp sometimes are used for late larvae and early juveniles. Unless the water is very well mixed, the live foods are not distributed evenly in the tank and average prey density is only of theoretical value. What matters is that the fish can find and catch nutritious prey with a minimum of effort, maximize their intake of nutrients and grow fast. Depending on age and number of larvae, an average density of 5-20 rotifers/ml seems appropriate if larvae are feeding well enough to prevent the rotifers from becoming more numerous and crowding the fish. *Artemia* usually are stocked at about 1-2/ml when first given to the larvae, but as many as 6/ml can be used if the fish eat them within 12 hours, before their nutritional quality deteriorates.

Microfeeds have been tried as a supplement during the first week but probably are not digested much until at least 2-4 weeks. Weaning from live food to dry crumbles or small pellets can be completed just before or during transformation, which occurs at 35-70 days after hatchinging, depending on species. Minced seafood, such as muscle of fish, shrimp or scallop often is used as an appetizer or transitional food.

Taiwanese hatcheries use a range of systems to raise grouper larvae, and survival of seven percent to four weeks (25-30 mm) is considered good (Rimmer 1998). Indoor systems include fiberglass or concrete tanks holding up to 100 m^3 where larvae are reared in green (50,000-500,000 cells/ml) or clear water with oyster trochophores (about 4-6 days after hatching), small rotifers (beginning about 4 days after hatching), and *Artemia* and/or adult copepods (beginning 16-22 days after hatching). Outdoor systems include concrete or earthen ponds of 200-5,000 m^2 (sometimes 1

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ha), which are filled through a fine-mesh sock filter 1-2 days before stocking eggs to limit the size of zooplankters. Stocking rate is 600-1,500 eggs/m^2. Larvae are held in floating bags for the first 2 days of feeding (about 4-6 days after hatching) to keep the trochophores concentrated. Rotifers, copepods and other zooplankters raised in separate ponds of 0.05-0.1 ha are pumped directly into the fish ponds or collected in nets and transferred.

Feeds

In Southeast Asia, groupers have been fed mainly trash fish supplemented with vitamins and minerals, secondarily moist or semi-moist pellets, and rarely high protein dry pellets. Nursery foods include larger zooplankton, chopped fish or shrimp and compound feeds. About 70 percent of Taiwanese farmers were using compound (mainly moist) feeds in 1998 (Rimmer 1998).

A suitable starter feed for groupers would contain 50-60 percent high quality protein, 12-16 percent fat (half or more from marine sources), £15 percent carbohydrate, <3 percent fiber and <16 percent ash (Tucker 1998). By the time they reach 500 g, Nassau groupers (and others) can be given a feed with about 45 percent protein, about 9 percent fat, £20 percent carbohydrate, £4 percent fiber and £22 percent ash. Lower quality feeds likely would result in worse feed conversion and possibly slower growth.

Environmental Conditions

Tanks with diameters of 3-5 m or more are better for grouper larvae than smaller ones because surface film removal is safer, temperature and water quality changes are moderated, and the fish contact the tank walls less often. Although eggs or larvae have been stocked up to 40/l, 5-20/l is safer. Providing habitat, such as milk crates, near the end of the larval stage can accelerate transformation to the juvenile stage. Juveniles and adults of estuarine and coastal species tend to be more tolerant of environmental extremes, turbidity and pollutants than those of offshore (especially reef, species).

Most groupers that have been reared are warmwater fish that spawn and grow best in the range 24-30˚C; most can tolerate a range of 15˚C to at least 35˚C. Eggs of groupers that spawn at sea will require a salinity of about 30 ppt or higher for them to float, but slightly lower salinity can be tolerated even though the eggs sink. Salinity tolerance usually increases with age. Oceanic species are healthiest at close to seawater salinity (35 ppt), but some estuarine species can survive at less than 10 ppt. Some natural light is good for all stages. Continuous natural and artificial light at 1,000-3,000 lux should be suitable for larval rearing, but higher intensities have been used. For most warmwater marine fish to be healthy, dissolved oxygen should be at least 5 mg/l and, preferably, near saturation. Safe limits for ammonia, nitrite and nitrate are only approximately known. Ammonia should be kept near zero (£1 µg/l [ppb] unionized ammonia nitrogen for larvae, £5 µg/l for adults); 10 µg/l unionized ammonia can be toxic to larvae, and juveniles and adults are only slightly more tolerant. Likely limits for nitrite nitrogen are 0.1 mg/l (ppm) for larvae and 1 mg/l for older fish, but zero is best. It is probably best to keep nitrate nitrogen lower than 20 mg/l for young stages and 50 mg/l for older fish.

One of the greatest problems for grouper larvae is a surface film that is sticky, suffocating and/or toxic. Films that are so thin that they have no effect on other species can kill grouper larvae on contact. The film-producing substances (polysaccharides, organic oils, proteins, inorganic oils, soaps, plasticizers) have to be excluded from larval tanks as much as possible, so that removal efforts are not necessary while larvae are too vulnerable. For the first several days of feeding, skimming the surface with air jets and standpipes can be dangerous, because early grouper larvae tend to drift with the current rather than swim against it and they cannot tolerate much turbulence, especially when they are near the surface. The larger the tank, the safer the larvae are from such localized disturbances and from going down the drain. Standard skimming devices can be used once larvae can swim well enough to avoid them.

A possible alternative approach to prevent larvae from sticking to the surface is to lubricate the water surface with oil extracted from omega yeast for the first few days after hatching, but the oil has to be removed before larvae begin gas bladder inflation (Yamaoka *et al*. 2000).

Usually, a moderate growth of phytoplankton is maintained in rearing water for grouper larvae (greenwater culture). Besides being food for the zooplanktonic prey of the fish, the algae also can remove ammonia, generate oxygen and keep pH high, release anti-bacterial or growth-promoting substances, promote growth of beneficial bacteria and stimulate behavior, feeding or digestion. However, algae decomposition products can contribute to formation of a sticky surface film.

Health

Good management of the microbial environment can protect larvae from pathogens and eliminate the need for antibiotics and other drugs. As a major management component, we routinely inoculate larval rearing systems with probiotic (beneficial) bacteria isolated from healthy fish raised in our hatchery (Kennedy *et al*. 1998). Without this seeding, the bacteria populations can vary from bad to good.

Viruses (viral nervous necrosis, golden eye disease, herpes, *Lymphocystis*), gram-negative bacteria (*Vibrio*, *Aeromonas*, *Pseudomonas*, *Flavobacterium*, *Pasteurella* spp.), gram-positive bacteria (*Streptococcus*, *Mycobacterium*), ectoparasitic protozoans (*Amyloodinium ocellatum*, *Cryptocaryon irritans*, *Brooklynella* spp., *Ichthyophthirius* sp., *Trichodina* sp.), monogeneans (*Benedenia* spp., *Neobenedenia* spp., *Diplectanum* spp., *Megalocotyloides epinepheli*, *Pseudorhabdosynochus epinepheli*), copepods and leeches are among the most important pathogens of cultured groupers (Baliao *et al*. 1998). Many internal parasites (microsporans, myxosporans, trematodes, cestodes, nematodes, acanthocephalans) also have been reported. Nervous suffering disease (signs could include gill, blood, gas bladder, liver, heart, brain, nerve damage) probably was caused by rancid dietary fats.

Bacterial diseases usually result from mechanical injury (e.g., excessive handling) combined with low water quality, and signs often include darkening, hemorrhaging, ulceration and erosion of skin (including the fins), cloudy eyes, anorexia, loss of coordination and mortality.

Parasitic ciliates and dinoflagellates (*Trichodina* spp., *Cryptocaryon irritans*, *Amyloodinium* sp.), have caused high mortality of early and older juveniles. The most common problem reported for western North Atlantic species has been infestation of the gills, eyes and skin by monogenean or protozoan parasites, which feed on blood, skin and mucus. They also frequently infest caged Asian groupers, causing small hemorrhages and secondary bacterial infections.

Routine monitoring combined with the latest rapid detection methods will help prevent the spread of disease. The current published treatment methods and government regulations always should be consulted before treating fish. Vaccines for certain grouper diseases might be available in the near future. Many drugs still used in certain regions are dangerous to the environment, the fish and/or the consumer. It is better to prevent disease by practicing good sanitation methods, such as stocking specific-pathogen-free juveniles, not using raw trash fish for food and raising fish in a clean environment. Spread of diseases from shipping of infected stock should be avoided. For maintenance of good health, factors to be avoided are: overstocking, underfeeding, low oxygen, low water quality, handling injuries and lack of sanitation.

Economics

Nearly all species in this family large enough to eat are preferred food fish. Groupers usually are very easy to catch, and in many areas, stocks have been highly depleted by overfishing.

Typical market sizes are 400-700 g in the Philippines, 600-900 g in Singapore and >1kg in Kuwait (Baliao *et al.* 1998). The usual minimum market size for groupers in the U.S. is 2 kg, but smaller fish can be sold in specialized markets, especially in large cities. Recent wholesale prices for dead groupers in the eastern U.S. were in the range $6.15-9.37/kg depending on species and season. Skinless, boneless fillet yield for groupers is about 36-40 percent, at least as good as channel catfish, tilapia and hybrid striped bass. Fillets typically sell for $15 to $20/kg wholesale and $24-33/kg retail. In east central Florida during summer 2002, gag fillets sold for up to $20/kg wholesale and $33/kg retail. In Nassau (Bahamas), live Nassau groupers are sold for $11.00-13.20/kg by dealers who buy directly from fishing boats. In Hong Kong, live groupers (0.5-2 kg) are worth $22-44/kg wholesale, depending on species, but prices can drop to near $13/kg (Chan 2001) when supply is high. Cesar *et al.* (2000) reported that Hong Kong market prices for live groupers were $15-65/kg in May 1999.

Although studies have been conducted on spawning and larval rearing of dozens of serranids, grouper farming fluctuates because of the lack of sustained hatchery production for most species and variability in the (mostly decreasing) supply of wild juveniles. Inconsistent quantity and quality of trash fish and the lack of economical compound feeds have also been handicaps in some areas. The extended larval period and variable survival make the effort and cost of producing grouper juveniles in hatcheries higher than for most other types of fish. Once the juvenile stage is reached, survival should be near 100 percent. Good growth and feed conversion will make growout economical; however, water quality must be maintained at a higher level than for purely estuarine or coastal fish. In many areas, cages have been preferred for growout, but there has to be good water exchange and a minimum of 3-5 m of water below the cages to limit diseases and self-pollution. Ponds are not necessarily better. If the value of the fish is high enough, recirculating tank systems can be justified.

Future Prospects

With one larval rearing tank, six nursery tanks, six phase-I growout tanks, and 24 phase-II growout tanks, it would be possible to raise 54,545 kg of Nassau groupers worth US$382,000-$545,000 in 2 yr (Tucker 1999). Hatchery costs would be less than $1.00 per weaned, 70-day-old, 50-mm juvenile. In nursery tanks, those early juveniles would be raised to robust 125-mm juveniles, with pellet size increasing from 1.6 to 2.4 mm. During growout, those juveniles would be raised to 230 mm (pellets up to 4.0 mm) in the first phase and 450 mm (pellets up to 9.5 mm) in the second. The culture period would be about 115 d shorter for 1.36 kg fish, but to take advantage of their fast growth in this size range (≥4.0 g/d), the groupers should be raised to at least 1.8 kg. Overall feed cost would be $0.70-1.40/kg of fish (feed $0.55-1.10/kg, overall feed conversion ratio 1.275, overall protein conversion ratio 0.757). The 1.8 kg groupers would be worth at least $7-10/kg whole and at least $15-20/kg as fillets (wholesale).

A $36.3 million recirculating intensive tank farm (including hatchery and processing plant) in the southern U.S. that can produce 7.8 million kg of live marine warmwater fish per year with gross sales of $50.3 million has been estimated to have $18.7 million annual operating costs and $2.9 million depreciation (Tucker 1999). Itemized operating costs would be: feed 33 percent (assuming $0.55/kg); utilities 12 percent; labor 40 percent; marketing, sales and freight 10 percent; and miscellaneous 5 percent.

For fish farming in the southeastern United States and Caribbean region, Nassau groupers, gags, black groupers and Goliath groupers are good candidates. In the U.S., growout most likely will occur in offshore cages or recirculating tanks.

Traditional Asian style grouper farming is not appropriate for the U.S. Inshore areas suitable for cage culture, such as well-flushed deep bays, are very rare in the southern U.S. Collection of wild juveniles is seasonal, unreliable and in most cases, unethical and illegal. The use of trash fish for food is wasteful and could result in disease transmission. It would be unwise to initiate such non-sustainable methods.

Sophisticated hatcheries with good environmental control and very dedicated staffs are necessary for raising groupers from eggs. Obtaining eggs from most species is relatively easy. However, larvae of most are fragile, and reported survival from eggs to juveniles often has been only 0-1 percent. With a good hatchery and staff, routine survival of at least 10 percent is attainable. Juveniles and adults are among the hardiest of fish and their feed conversion is good.

Year-round egg production in environmentally controlled spawning tanks will permit a continuous supply of market size groupers. Good management of broodfish and the larval rearing environment, including the bacteria, will allow production of specific-pathogen-free juveniles, which greatly reduces the risk for growout operations. Vaccination of groupers for major diseases, such as vibriosis, is likely in the future.

Notes

[1] John Tucker is Head of the Fish Biology Department, Division of Marine Science, Harbor Branch Oceanographic Institution, 5600 North U.S. One, Fort Pierce, Florida 34946 USA.

[2]For a more in-depth review, see John Tucker's chapter on Grouper Culture in A. M. Kelly and J. Silverstein, editors. "Manual of Fish Culture", Volume III, to be released in 2002.

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part of the 41 percent of aquacultured product, in which case it might very well be a CCP. Also, if this is the point where shrimp will be assessed for excessive bisulfite (an additive, and listed here under hazards) then this indeed **is** a critical control point, as sulfites are a potential health hazard and not only must be used correctly so as not to exceed 100 parts per million, but also must be included on the package label. Unfortunately, sulfite use is not considered critical further on in the worksheet under either Additive Treatment or Packing/weighing.

When teaching the seafood HACCP class I never list critical limits, preventive measures, monitoring procedures, corrective actions, records and verification for processing steps that are **not** critical, as was done in table 4.4. Most of the comments describing these "non-CCP" processing steps describe quality, not safety issues and further confuse the reader as to the distinction between the two.

Table 4.6 "Hazard Analysis for Breaded Shrimp," states that battering and breading is **not** a critical control point when in fact it **is** a CCP, and is addressed in detail in Chapter 15 of the US Food and Drug Administration's (FDA) Fish and Fisheries Products Hazards and Controls Guidance, 3rd edition, 2001.

Chapter 6 discusses sampling and monitoring. While providing an excellent reference on designing sample schedules, carrying out organoleptic analyses, physical testing and determination of filth in shrimp this chapter again could confuse the reader as to just what HACCP is all about; that is, food safety, not quality. I would quote from the FDA training manual entitled HACCP: Hazard Analysis and Critical Control Point Training Curriculum, 4th edition, 2001. "In HACCP, 'hazards' refer to conditions or contaminants in foods that can cause illness or injury. It does not refer to undesirable conditions or contaminants such as: Insects, Hair, Filth, Spoilage, Economic fraud and Violations of regulatory food standards not directly related to safety."

Combining monitoring and sampling in the same chapter is confusing in that monitoring is routinely performed (continuously if possible) under the "monitoring" part of a CCP, whereas sampling is more often thought of as a periodic procedure used in the "verification" part of a HACCP Plan.

As I stated in the introductory paragraph, I found several chapters in this book to be excellent references. However, I would recommend that a shrimp processor also consult the FDA HACCP manuals referenced above before undertaking a hazard analysis and subsequent development of a HACCP Plan for their particular shrimp processing operation.

—Russell Miget
Texas Marine Advisory Service
Corpus Christi, Texas USA