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Species Profile
Grouper Aquaculture

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Groupers are classified in 14 genera of the subfamily *Epinephelinae*, which comprises at least half the approximately 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 4.7 inches (12 cm) for the Pacific creole-fish (*Paranthias colonus*) to more than 13 feet (4 m) and ≥970 pounds (≥440 kg) for the groper, king grouper or brindlebass (*Epinephelus lanceolatus*). Several grouper species have been raised on a commercial scale (mainly in Japan, Taiwan, Hong Kong, Southeast Asia and the Middle East), but mostly by growing out captured wild juveniles. Hatchery production has increased in recent years (for example, in Japan, Taiwan and Kuwait). Major farmed Asian species are redspotted grouper (*E. akaara*), orange-spotted grouper (*E. coioides*), brownmarbled grouper (*E. fuscoguttatus*), Malabar grouper (*E. malabaricus*), camouflage grouper (*E. polyphekadion*), and greasy grouper (*E. tauvina*). King grouper, polka dot grouper (*Cromileptes altivelis*), and coraltrouts (*Plectropomus* spp.) are raised in some areas. The Chinese perch (*Siniperca chuatsi*) is raised in China, mostly in brackishwater ponds. For farming in the southeastern U.S. and Caribbean, Nassau groupers (*E. striatus*), gag groupers (*Mycteroperca microlepis*), black groupers (*M. bonaci*), and jewfish (*E. itajara*) seem to have good potential.

Natural history

Juveniles and adults of some grouper species live in coastal waters and estuaries, but others prefer the cleaner waters of offshore reefs. Eggs are single, nonadhesive, 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 in shallow water where they can find hiding places. Until a few inches long, they hide almost constantly. As they increase in size they become bolder and 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 such as amphipods and mysid shrimp. Wild juveniles and adults eat mainly fish, crabs, shrimp, mantis shrimp, lobsters and molluscs.

Most groupers that have been studied will mature within 2 to 6 years. Many serranids are protogynous 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; others might change only if there is a shortage of males. In nature, Nassau groupers spawn in large aggregations (hundreds to thousands of fish) with a sex ratio near 1:1. Gags spawn in harems, with a sex ratio often near 1 male:10 females. For both species, individual spawning events usually involve small numbers of fish (for example, two to five). Small serranids often spawn in pairs without aggregating. A few of the small species are simultaneous hermaphrodites (male and female at the same time), but self-fertilization seems to be rare.

Culture techniques

Broodfish procurement

Broodstock can be captured or reared. Most groupers studied have adapted quickly to captivity. Adults usually are captured by traps or hook and line. Depending on species and capture depth, the gas bladder might expand too much for the fish to recover on its own, so that it might float help-

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lessly upside down. When deflation is necessary, I use a hypodermic syringe with a 20-gauge needle attached and the plunger removed. While the fish is gently held upside down below the water surface, the needle is gently pushed through the skin into the body cavity, avoiding internal organs. The fish is deflated only enough for it to stay on the bottom of the tank without struggling to stay down. If the gas bladder is expanded so much that the fish's insides (esophagus and maybe stomach) protrude into the mouth, some fishermen puncture the insides and push them back in; those fish are less likely to survive, but a surprising number do.

Juvenile and adult Nassau groupers (and many other groupers) are among the hardiest of fish. Their skin is so thick it has been made into leather clothing. In one case, a ripe female that sat dry on a boat deck in the sun for 2 hours recovered and was induced to ovulate 2 days later. Despite their toughness, broodfish always should be handled as gently (with soft nets, plastic bags or hands, not towels) and infrequently as possible, kept in well-oxygenated water, and fed well if kept for more than a few days.

Spawning

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. Day length seems to be a less important stimulus for spawning than temperature. At least 27 serranid species have spawned voluntarily in captivity, with groupers spawning in 264- to 5,550,000-gallon (1- to 21,200-m^3) tanks or ponds and 6,869- to 19,815-gallon (26- to 75-m^3) cages. Eggs are collected in automatic strainers or with soft, fine dip nets. 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 so that voluntary or accidental fertilization can occur if the males are running ripe.

A 13-pound (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. Spawning by this species is among the most synchronized.

At Grand Cayman, one male and four female wild Nassau groupers spawned after 8 months in a 6,869-gallon (26-m^3) cage. In Florida, two males and three or four females spawned near the full moon in March and April after 15, 27 and 28 months in a 10,000-gallon (37-m^3) concrete raceway; each female spawned as many as nine times a day for 1 to 4 days. In both cases, spawning occurred as soon as normal spawning temperatures were reached. For the raceway fish this was 3 to 4 months later than in their home range. Those fish were caught during the spawning season and had adapted very quickly to captivity. If the interval between capture and the onset of spawning conditions had been shorter, the fish probably would have spawned sooner than 15 months. Nassau groupers reared from eggs were mature at 5 to 6 years, but because temperature in their raceway could not be controlled and fluctuated widely, they did not spawn immediately. In April 1998, temperature was more stable and the 8-year-old groupers spawned. Nassau groupers can be conditioned to spawn during any month, mainly by temperature cycling (i.e., raising or lowering temperature to the spawning range of 24 to 27 degrees C). Males begin approaching females several days before spawning begins. On a spawning day, males turn bicolored (black above, white below) early in the afternoon, and the females become bicolored late in the day at the time of ovulation, just before spawning occurs.

Hormone-induced ovulation of ripe wild or captive groupers and sea basses generally is reliable. At least 31 serranid species have been induced to ovulate. Typically, a female with fully-yolked oocytes (developing eggs) is given one to three injections of 227 to 454 IU human chorionic gonadotropin per pound of body weight (500 to 1,000 IU / kg). Ovulation (the release of mature eggs into the center of the ovaries) occurs within 24 to 72 hours (usually 36 to 50 hours) after the first injection. Similar results have been obtained for several species given one to three

Figure 1. Giving an intramuscular injection to a female Nassau grouper to induce ovulation (from Tucker, 1998, with permission from Kluwer Academic Publishers).

Figure 2. A female Nassau grouper that has been induced to ovulate and is about to be stripped (from Tucker, 1998, with permission from Kluwer Academic Publishers).

injections of 4.5 to 22.7 µg gonadotropin-releasing hormone analog (GnRHa) per pound of body weight (10 to 50 µg/kg). GnRHa implants also have worked. If newly caught broodfish are used, the hormone should be administered as soon after capture as possible to limit the effects of stress on oocyte development. For six grouper species with egg diameters of 800 to 1,000 µm, the minimum effective oocyte diameter (seen in biopsy samples) before injection was in the range 41 to 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 (e.g., once an hour) just before the predicted time of ovulation. For Nassau groupers, the time from ovulation to overripeness (deterioration of eggs) is only 1 to 2 hours at 79 degrees F (26 degrees C).

When ovulation has occurred, milt is stripped from one or more males and collected in 3-cc hypodermic syringes (without needle). Then, eggs are stripped from the female into a beaker, milt is added, filtered water is added, and the mixture is stirred. After 3 to 5 minutes, the eggs are transferred to a larger container and washed several times by water exchange or repeated transfer. 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 fertilization rate, normal cell division, high hatching rate, and successful first feeding are subsequent signs. The eggs are incubated under very clean, constant, optimal conditions. Often they are put in conical tanks, which facilitate the removal of any sunken dead eggs. Usually eggs are transferred to rearing tanks just before hatching, or larvae are transferred just before first feeding. However, it is best not to handle grouper larvae.

We first induced ovulation in Nassau groupers in January 1987. With fresh milt and good water, the fertilization rate was 85 to 86 percent. Survival from fertilization to first feeding for six spawns was 73 to 94 percent. In later work, close to 100 percent fertilization and survival to first feeding were routinely obtained. Hormone injection of wild fish was not always necessary because newly captured wild female groupers that were about to ovulate could be identified during the early afternoon and held in 264-gallon (1-m^3) tanks until eggs were ready for release, usually at or just after sunset. If females were held with running-ripe males, the eggs usually were 100 percent fertilized in the holding tanks.

Larval rearing

Larvae of most grouper species are small and fragile and have small mouths at first feeding. Known egg diameters range from 0.8 to 1.0 mm, and total length of hatchlings is 1.6 to 2.3 mm. Yolk and oil, which nourish the early larva until after feeding begins, tend to be exhausted quickly (2 to 5 days). Typically, the larval period is long (35 to 70 days), and groupers tend to require live food longer than most marine fish that have been reared.

Commercial-scale Asian hatcheries have raised large batches of juveniles with survival as high as 34 percent from the hatchling stage. The best survival has occurred in larger tanks (15,852 to 132,100 gallons, 60 to 500 m^3) under partial sunlight. Species with small mouths need small rotifers, trochophores (oyster or clam larvae), copepods or other zooplankton at first feeding. Larvae of some species (e.g., Nassau grouper) seem to be especially sensitive to noises (such as bumping of their tanks), which induce 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 because they are attracted to bright areas of the tank. This can result in oxygen depletion, frequent collisions, and feeding difficulty. With too much turbulence, the fish are battered. Larvae stressed by fright, strong current, toxins, pathogens or malnourishment 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* (brine

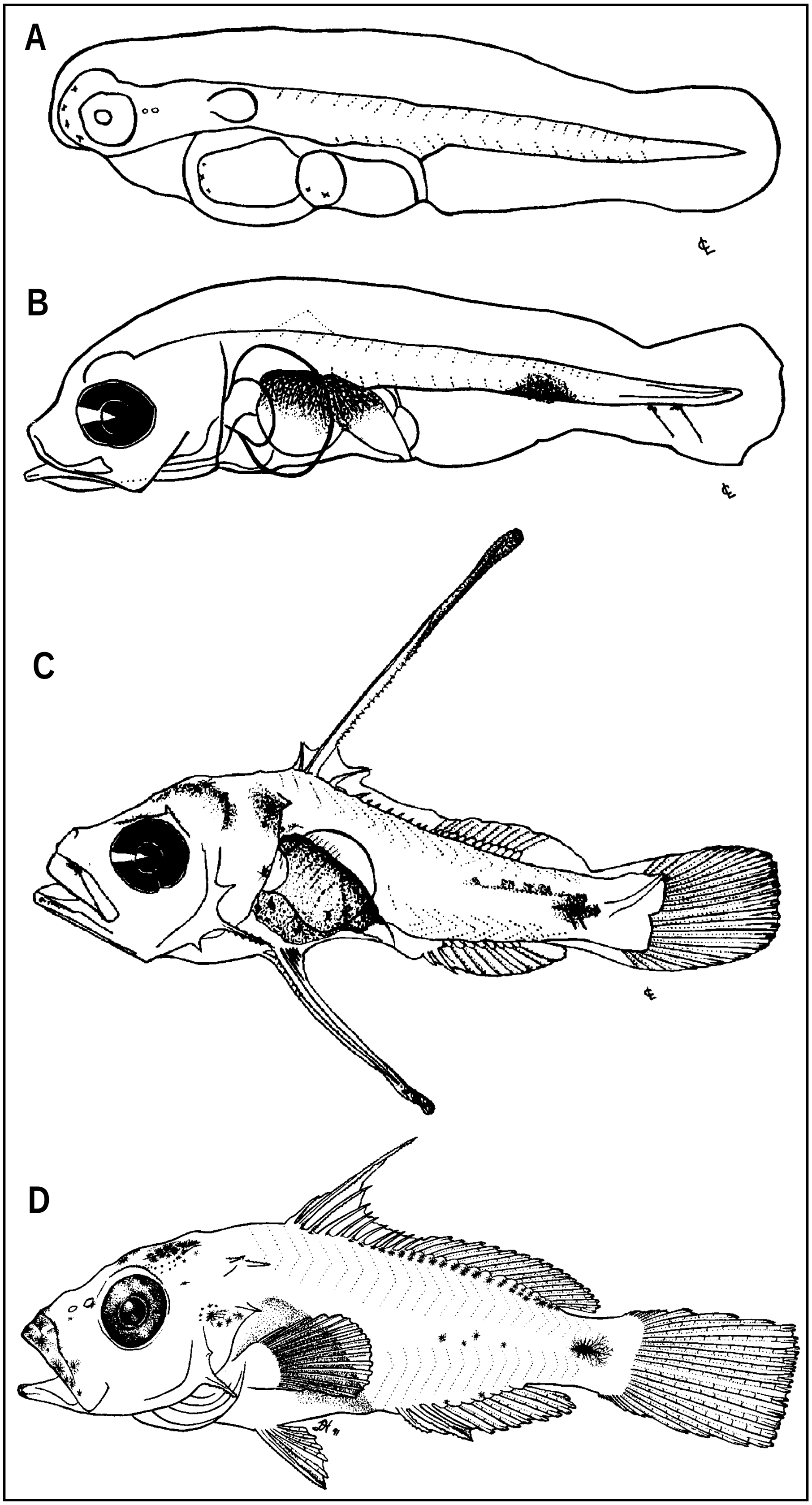

Figure 3. Developmental stages of laboratory-reared Nassau grouper (from Powell and Tucker, 1992, with permission from the Bulletin of Marine Science):

A. 2.5 mm NL (notochord length) early yolk-sac larva, 1 day old;

B. 2.9 mm NL preflexion larva, 5 days old;

C. 6.8 mm SL (standard length) postflexion larva, 25 days old;

D. 13.5 mm SL, 40 days old.

shrimp) 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).

Environmental requirements

Tanks 10 to 16 feet or more in diameter 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 (151/gallon), 5 to 20/L is safer. Providing habitat (e.g., milk crates) near the end of the larval stage can accelerate transformation to the juvenile stage.

Most groupers that have been reared are warmwater fish that spawn and grow best at 75 to 86 degrees F (24 to 30 degrees C); most can tolerate a range of 59 to at least 95 degrees F (15 to 35 degrees C). The best temperature for Nassau grouper larvae is about 75 to 81 degrees F (about 24 to 27 degrees C). Feed intake by juveniles and adults is minimal at <64 degrees F (<18 degrees C), but feeding and growth are good at 72 to 86 degrees F (22 to 30 degrees C); best growth should occur near 86 degrees F. 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. Once they are fully developed juveniles, even Nassau groupers can tolerate 15 ppt for at least a few days. Some natural light is good for all stages. Continuous natural and artificial light at 1,000 to 3,000 lux should be suitable for larval rearing.

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 feeding, behavior, or digestion. However, algae decomposition products can contribute to the formation of a sticky surface film.

Good management of the microbial environment can protect larvae from pathogens and eliminate the need for antibiotics and other drugs. 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.

Safe limits for ammonia, nitrite and nitrate are only approximately known; more definitive data will require testing. 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 probably is best to keep nitrate nitrogen lower than 20 mg/L for young stages and 50 mg/L for older fish. For most warmwater marine fish to be healthy, dissolved oxygen should be at least 5 mg/L; near saturation is best.

One of the greatest problems for grouper larvae is a surface film that is sticky, suffocating and/or toxic. Films so thin that they have no effect on other species can kill grouper larvae on contact. The film-producing substances (e.g., 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.

Foods for larvae

Grouper larvae usually are raised in green water (mostly with the phytoplankton *Nannochloropsis, Tetraselmis,* and/or *Chlorella* spp.). 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 not to introduce pathogens or predators. Cladocerans (water fleas) sometimes are used for early to mid-stage larvae. *Artemia* enriched with essential fatty acids can be a staple food beginning at 10 to 30 dah (days after hatching), but the quantity 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 dah 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 to 20 rotifers per 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 one to two per milliliter when first given to larvae, but as many as six per milliliter 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 to 4 weeks. Weaning from live food to dry crumbles or small pellets can be completed just before or during transformation, which occurs at 35 to 70 dah, depending on species. Minced seafood (e.g., muscle of fish, shrimp, scallop) often is used as an appetizer or transitional food.

Nassau groupers at 79 degrees F (26 degrees C) hatch in about 26 hours at 1.9 mm long, first feed at about 2.5 dah, and finish their yolk and oil about 5 dah. The larval period is long, with a wide time range for transformation to the juvenile stage at 1.4 to 2.0 inches (35 to 50 mm) (Tucker and Woodward, 1996). In 1990, larvae reared in green water in 925-gallon (3,500-L) tanks received rotifers enriched with Frippak Booster® microcapsules, *Artemia* nauplii, and 2- to 5-day-old *Artemia* enriched with Frippak Booster®. Larvae were planktonic until 42 dah, when they began orienting to the tank walls and bottoms. Then, white plastic milk crates were added to provide cover. Transformation of all fish occurred during the period from 46 to 70 dah, with individuals making the change in less than a week. Weaning to 1/16-inch (1.6-mm) dry pellets was accomplished by feeding minced penaeid shrimp and crumbled pellets during the period from 56 to 61 dah (when the fish were 1.6 to 2.4 inches or 40 to 60 mm long), but a small amount of shrimp was given to the fish 63, 66 and 69 dah to enhance growth of smaller individuals. Mortality peaks were at 5 dah (yolk and oil exhausted) and at about 20 dah, when consumption of *Artemia* nauplii was highest. In 1990, survival from fertilization to 98 dah was 5.0 percent and would have been higher if fewer *Artemia* nauplii had been used (gorging, partial digestion, and death were observed). Transformation might have been accelerated by providing cover or feeding shrimp earlier. In 1994, trochophores, rotifers, *Artemia* and copepods were used. In one trial, survival from eggs to 15 dah in a 32-gallon (120-L) aquarium was 25 percent. In another trial, survival from 10 to 75 dah in a fiberglass tank was 59 percent.

Watanabe *et al.* (1996) raised Nassau grouper larvae in 8,930-gallon (33.8-m^3) rectangular tanks on wild zooplankton (protozoans, copepods), rotifers and *Artemia* in green water, with highest survival from hatching to 62 dah of 1.4 percent. Preliminary research showed that survival was better (8.0 versus 2.1 percent) when rotifers sieved to ≤200 µm were fed during the period from 2 to 10 dah than when rotifers were not sieved (lorica length range of 50 to 264 µm in the culture population). Survival from 1 to 10 dah was better with a mixed diet of oyster trochophores and rotifers (T+R, 15.6 percent) than with rotifers alone (R, 9.7 percent) or a sequential diet of trochophores and rotifers (T→R, mixed during the period from 5 to 7 dah, 2.6 percent). Growth was better with the rotifer and the trochophore + rotifer diets (R 4.1, T+R 3.7, T→R 3.1 mm final notochord length). Therefore, it is likely that rotifers should be included from first feeding even when trochophores are used.

Feeds

In Thailand and other areas, groupers have been fed mainly trash fish supplemented with vitamins and minerals, secondarily moist or semimoist pellets, and rarely high protein dry pellets. A suitable starter feed for groupers would contain 50 to 60 percent high quality protein, 12 to 16 percent fat, ≤15 percent carbohydrate, <3 percent fiber, and <16 percent ash. By the time they reach 1.1 pound (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 higher feed conversion ratios (FCR, weight of dry feed necessary to produce a unit weight of wet fish) and possibly slower growth.

Nassau groupers (1.6 inch or 40 mm long and 1 g in weight) raised in 1990 were weaned from *Artemia* to a starter feed containing 60 percent herring meal, 3.5 percent blood meal, 5 percent feather meal, 8 percent textured vegetable protein, 5 percent corn gluten meal, 5 percent high gluten wheat flour, 1 percent brewers yeast, and 7.5 percent menhaden oil (total of 60 percent protein, 16.2 percent fat, 13.4 percent fish oil; feed JT9010 in Tucker and Woodward, 1996, and Tucker, 1998). After the fish reached 6 to 7 g at about 3 months, grower feeds with similar ingredients but less fish meal (40 to 45 percent) and fish oil (6 to 8 percent total) were used. Under less than optimal conditions (including a 63 to 91 degree F [17 to 33 degree C] temperature range) the groupers reached a mean weight of 3.3 pounds (1.5 kg) at 23 months (FCR rising from 0.90 to 1.32) and 4.4 pounds (2.0 kg) in 28 months (FCR up to 1.80). Growth rates ranged from 4.28 percent per day at 0 to 6.1 g to 0.25 percent per day at 4 pounds (1.8 kg). Protein conversion ratio (PCR, weight of dry dietary protein necessary to produce a unit weight of wet fish) also was good at 0.54 to 1.05. When the pelleted feed was supplemented with live and frozen food, growth was slightly better. Reared Nassau groupers almost always will eat right after being caught and moved, if handled gently. Once they grow larger than the human hand, they become very tame. An hour after capture in a trap, even 10-inch wild juveniles ate pellets from my hand.

Nassau groupers (2.3 to 14.2 g) raised for 56 days in 1993 grew better with an experimental dolphin feed (62 percent protein and 14.2 percent fat; 3.19 percent per day growth) and a commercial Japanese carnivorous-fish feed (56 percent protein and 7.8 percent fat; 3.05 percent per day growth) than with commercial salmon (53 percent protein and 15.2 percent fat; 1.71 percent per day growth) and trout (44 percent protein and 5.9 percent fat; 0.93 percent per day growth) growers (Ellis *et al*., 1996). FCR was 0.94 for the carnivorous-fish feed, 1.32 for the dolphin feed, 1.60 for the salmon grower, and 5.55 for the trout grower.

Nassau groupers (1994) given a commercial starter feed (46 percent protein, 10 percent fat) grew fastest (3.3 to 12.4 g in 63 days; 2.07 percent per day) at 88 degrees F (31 degrees C) and had slightly but not significantly better FCR (1.04) than at 72 degrees F (22 degrees C) and 77 degrees F (25 degrees C) (Ellis et al., 1997).

Growth to market size

In the Indo-Pacific and Middle Eastern regions, several grouper species are farmed in cages, ponds and tanks, but mostly they are raised from wild juveniles and are fed trash fish. They sometimes are fed small tilapia and sometimes are polycultured with them. Typical market size is 1.1 to 2.2 pounds (500 to 1,000 g), which can be reached in 6 to 8 months of grow-out. The usual minimum size to begin grow-out is 3 to 4 inches (75 to 100 mm) and 10 g (age 3 to 4 months); this size can be obtained in nursery tanks, cages or ponds. Initially, they are stocked up to 0.23 fish per gallon (60 fish per m^3), <0.13 ounces per gallon (<1 kg/m^3), in cages. Density usually is reduced somewhat as they grow.

In Taiwan, undersized (1-inch) wild juveniles are raised in 100-m^2 nursery ponds (or tanks) to about 2.4 inches before they are stocked in 2,000-m^2 grow-out ponds. Sometimes cages (3.9 x 2.6 x 2.6 feet, 1.2 x 0.8 x 0.8 m) with a maximum of 2,000 fish each are used in the nursery ponds. In intensive pond culture, juveniles have been stocked at 24,000 to 32,000 per acre (60,000 to 80,000/ha) with an 80 percent harvest efficiency. Production density was as high as 26,700 to 35,600 pounds per acre (30,000 to 40,000 kg/ha, with aeration and 20 percent water exchange per day). The groupers are fed mostly trash fish and can grow from 1.8 inches (46 mm, 2 to 3 months old) to as large as 1.3 pounds (600 g) in 12 months and 4.4 pounds (2 kg) in 19 months.

Improvement of early growth rates (e.g., with better temperature control and earlier weaning) will allow production of 1.3-pound (600-g) Nassau groupers within 12 months, 2.2-pound (1-kg) groupers within 18 months, and 4.4-pound (2-kg) groupers within 24 months.

Transporting groupers

Grouper eggs and larvae should be shipped in 4-mil or thicker, food-grade, polyethylene bags about half full of oxygen and half full of water. Bags should be kept at the spawning temperature or a few degrees lower in an insulated, rigid container. We have shipped Nassau grouper eggs at 16,000 per 2 L for 10 hours at 23 degrees C. Larvae of other species have been shipped at 16,000 per L (60,560 per gallon) for at least 2 hours at 27 degrees C. Juvenile groupers have been shipped in bags at 120 g per L for 12 hours, at normal or slightly lower than normal temperatures. One 2-pound Nassau grouper can be shipped in a box in 10 L of water at 23 degrees C with oxygen for 12 hours. One 20-pound Nassau grouper can be held in 100 L of water at 26 degrees C with aeration for at least 8 hours.

Health concerns

For groupers, snappers and similar warmwater fish, gram-negative bacteria (*Vibrio, Aeromonas, Pseudomonas, Pasteurella* spp.), *Streptococcus, Mycobacterium*, ectoparasitic protozoans (*Amyloodinium ocellatus*, sporozoans, *Cryptocaryon irritans, Brooklynella* spp., *Ichthyophthirius* sp.), and monogeneans (*Neobenedenia melleni, Diplectanum* spp.) are among the most important pathogens. The lethal sleepy grouper disease in Singapore probably was caused by a virus introduced with wild juvenile groupers imported for cage farming. Other viral pathogens and diseases include golden eye disease, red grouper reovirus, spinning grouper disease, and viral nervous necrosis. Nervous suffering disease of groupers (signs could include gill, blood, gas bladder, liver, heart, brain and nerve damage) probably was caused by rancid dietary fats. In Japan, pasteurellosis was a major disease of young redspotted groupers. 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. Monogeneans have been controlled by baths of fresh water, hydrogen peroxide, praziquantel, mebendazole, formalin or trichlorfon. Protozoans have been controlled by baths of fresh water, chloroquine diphosphate, formalin, or copper salts (dangerous in salt water). The latest published treatment methods and government regulations always should be consulted before treating fish. It is better to prevent disease by practicing good sanitation methods such as stocking juveniles free of serious pathogens, not using trash fish for food, and raising fish in a clean environment.

Results with western North Atlantic species

Induced spawning and larviculture methods for Nassau grouper were developed during the period from 1987 to 1990 in the Cayman Islands and Florida (Tucker *et al.*, 1991; Powell and Tucker, 1992; Tucker and Woodward, 1996). In the first complete rearing study, 129 juveniles were produced from one spawn in 1990. From fertilization to 98 dah, the best survival was 5.0 percent; during the period from 98 to 243 dah, overall survival was 97 percent. Some of those fish were tagged and released (Roberts *et al.*, 1995), and ten were raised for more than 9 years. The minimum market size of 4 pounds (1.8 kg) can be reached in less than 24 months, with FCR rising from 0.9 to 1.8. Maximum size of wild fish is more than 55 pounds (25 kg).

Watanabe *et al.* (1996) raised 5,651 Nassau groupers to 62 dah in two 8,930-gallon tanks in a greenhouse with 70 percent shade at 75 to 79 degrees F (24 to 26 degrees C). The best survival from hatching to 62 dah was 1.4 percent.

Jewfish produce many eggs and grow quickly, but the broodfish are large and would be difficult to handle and expensive to maintain. Wild juvenile jewfish fed fresh fish in floating cages grew from 1.73 pounds (787 g) to 3.94 pounds (1,788 g) in 90 days (Cervigon, 1983). In circular tanks, 6.6- to 13.2-pound (3- to 6-kg) jewfish reached 26.4 to 28.6 pounds (12 to 13 kg) in 480 days. Similar studies have been done with black groupers (Alfonso *et al.*, 1983).

Black sea bass (*Centropristis striata*), a very high quality serranine that reaches about 7.7 pounds (3.5 kg), has been spawned and raised experimentally (Hoff, 1970; Roberts *et al.*, 1976; Tucker 1984, 1989). It grows slowly, reaching only 8 ounces (220 g) and 7.8 inches (198 mm standard length) in the third year in nature. Growth rate might be doubled or tripled in culture (Petrocci, 1995).

A few other western North Atlantic serranids have been studied. Gags were induced to ovulate, and eggs and early larvae were described (Roberts *et al.*, 1983). Red groupers were induced to ovulate, larvae were raised, and six juveniles fed pinfish (*Lagodon rhomboides*) in aquaria during the period from 66 to 557 dah reached about 8.5 inches in length (Colin *et al.*, 1996). Sand perch (*Diplectrum formosum*) were induced to ovulate with HCG, and larval development was described (Manrique, 1987a, 1987b).

Ages (months) at which some serranids reach 1 pound in nature are: black grouper, 17; gag grouper, 18; red grouper, 27; and black sea bass, 51.

Marketing

Nearly all groupers large enough to eat are preferred food fish. Groupers usually are very easy to catch, and stocks in many areas have been depleted by overfishing. As numbers of the largest species drop below a threshhold, the next largest common species is targeted, and so on. In the Caribbean, the sequence usually is: Nassau grouper→red hind (*E. guttatus*)→coney (*E. fulvus*) and graysby (*E. cruentatus*), with weight decreasing from 30 to 50 pounds to a few ounces over the years. The usual minimum market size for groupers in the U.S. is 4 pounds, but smaller fish can be sold in specialized markets, especially in large cities. Recent wholesale prices for dead groupers in the eastern U.S. range from $2.30 to 3.25 per pound, depending on species and season. Groupers yield about 36 to 40 percent skinless, boneless fillet, which is at least as good as channel catfish, tilapia and hybrid striped bass. Fillets typically sell for $7 to 9 per pound wholesale and $11 to 14 per pound retail. In the Bahamas, live Nassau groupers are sold for $5 to 6 per pound by dealers who buy directly from fishing boats. In Hong Kong, live groupers weighing 1 to 4 pounds are worth $10 to 20 per pound wholesale, depending on species.

Economics

Grouper farming fluctuates because of variability in the (mostly decreasing) supply of wild juveniles and the lack of sustained hatchery production for most species. Inconsistent quantity and quality of trash fish and the lack of economical compound feeds also has been a handicap in some areas. The extended larval period and variable survival make the effort and cost of producing juvenile groupers 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 grow-out 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 grow-out, but there has to be good water exchange and a minimum of 10 to 15 feet 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.

Li (1995) reported that when four grouper species (typically 1,350 juveniles stocked in a 9.8-foot x 9.8-foot x 9.8-foot cage) were grown out in China, FCR with trash fish was 7 to 8, survival was 60 to 70 percent, monthly weight gain was 0.9 to 3.0 ounces (25 to 84 g), harvest size was 1.2 to 3.1 pounds (550 to 1,400 g), and time required was 16 to 18 months (final age about 19 to 21 months). Greasy groupers performed best, reaching 3.1 pounds in 16 months (about 19 months old). In 1995, costs and revenues per 35 cubic feet (1 m^3) of cage volume were $27.16 and $56.46 for greasy grouper and $22.06 and $58.01 for redspotted grouper.

In 1994 in Thailand, a 2.9-pound live grouper could sell for as much as $20.78, about 2.5 times the price of a 1.1- to 1.8-pound dead grouper (Ruangpanit and Yashiro, 1995). Four-inch juveniles (age 3 to 4 months) stocked at 8 to 12 per cubic yard (10 to 16/m^3) in 23.5- to 42-cubic-yard cages reached 1.3 to 1.8 pounds in 7 to 8 months and 2.6 to 3.1 pounds in 12 to 14 months (at about 15 to 18 months old). A cage could produce at least 660 pounds of 2.6-pound fish with a value of $3,431 per cycle. Costs were: cage, $61.76; juveniles, $294.12; feed, $423.53; and labor, $141.18. Net income was $2,510.78.

Liao (1995) reported that the price of wild 1-inch groupers in Taiwan was as low as $0.20 to 0.40 in fall and winter, but 2.4- to 3.5-inch juveniles could be sold for $2 to 3 in the spring when demand was high. To grow groupers from 2.4 inches (age 3 months) to 0.9 to 1.8 pounds in ponds, stocking density was 8,100 to 28,300 fish per acre (20,000 to 70,000 fish/ha), FCR was 4 to 5 for trash fish and 1.2 to 1.4 for moist pellets, time required was 10 to 14 months (final age about 13 to 17 months), and harvest density was 8,900 to 26,700 pounds per acre (10,000 to 30,000 kg/ha).

With one larval rearing tank, six nursery tanks, six phase-I grow-out tanks, and 24 phase-II grow-out tanks, it would be possible to raise 120,000 pounds of Nassau groupers worth at least $360,000 in 2 years, as shown in Table 1. Hatchery costs would be less than $1.00 per weaned, 70-day-old, 2-inch juvenile. In nursery tanks, those early juveniles would be raised to robust 5-inch juveniles (pellet size increasing from 1/16 to 3/32 inch). During grow-out, those juveniles would be raised to 9 inches (pellets up to 5/32 inch) in the first phase and 17.5 inches (pellets up to 3/8 inch) in the second. The culture period would be about 115 days shorter for 3-pound 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 4 pounds. Overall feed cost would be $0.319 to 0.638 per pound of fish (feed, $0.25 to 0.50 per pound; overall FCR, 1.275; overall PCR, 0.757). The 4-pound groupers would be worth at least $3.00 per pound whole and at least $7.00 per pound as fillets.

A proposed $36.3 million dollar recirculating intensive tank farm (including hatchery and processing plant) in the southern U.S. that can produce 17.2 million pounds of live marine warmwater fish per year with gross sales of $50.3 million has been estimated to have $18.7 million in annual operating costs and $2.9 million in depreciation. Itemized operating costs would be: feed, 33 percent (assuming $0.25 per pound); utilities, 12 percent; labor, 40 percent; marketing, sales and freight, 10 percent; and miscellaneous, 5 percent.

Table 1. Production of Nassau groupers from eggs to 4 pounds in 2 years in facilities designed for raising groupers intensively.								
Phase	**Tank size (m^3) (gal.)**	**No. tanks**	**No. stocked**	**Days**	**Survival (%)**	**Final density (no./m^3) (no./gal.)**	**Final weight (g) (lb.)**	**Final density (kg/m^3) (lb./gal.)**
Hatchery	60 16,000	1	300,000	70	10	500 1.89	2 0.004	1.0 0.008
Nursery	18.9 5,000	6	5,000	60	~100	264 1	25 0.055	6.6 0.055
Grow-out I	37.8 10,000	6	5,000	100	~100	132 0.5	180 0.397	23.8 0.198
Grow-out II	75.7 20,000	24	1,250	500	~100	16.5 0.0625	1,814 4.0	30.0 0.25

Conclusions

For fish farming in the southeastern United States and Caribbean, Nassau groupers, gags, black groupers and jewfish are good candidates. In the U.S., grow-out 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 (e.g., 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 species are fragile, and reported survival from eggs to juveniles often has been 1 percent or less. 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 year-round 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 grow-out operations. In the future groupers likely will be vaccinated for major diseases such as vibriosis.

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