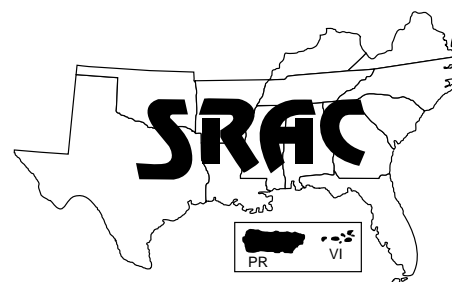


Southern
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Species Profile Mutton Snapper

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Snappers (class Osteichthyes; order Perciformes; family Lutjanidae) are important commercial and recreational food fish species throughout tropical areas of the world. In the western Atlantic, lutjanids are represented by 18 species in five genera: *Apsilus*, *Etelis*, *Pristopomoides*, *Rhomboplites* and *Lutjanus*. The mutton snapper (*Lutjanus analis*, Fig. 1) is one of 12 species in the genus *Lutjanus*.

Snappers are popular food fish and demand for them is increasing, as evidenced by burgeoning imports of several snapper species. The demand, and the relatively high value of snappers, make them interesting to aquaculturists.

Identifying characteristics

Most of the Bahamian species of *Lutjanus* have rounded anal-fin lobes; only mutton snapper and the deeper water silk snapper (*L. vivanus*) have pointed anal-fin lobes. The mutton snapper has a chevron-shaped vomerine tooth patch on the upper palate without a posterior extension, whereas the silk snapper has a posterior extension of the patch. The mutton snapper is a medium-sized fish, usually about 50 cm (19.7 inches) long. It can grow as long as 82.4 cm (32 inches) and weigh more than 11.4 kg (25 pounds).



Figure 1. Adult mutton snapper, *Lutjanus analis*. (photo by C. Manfredi)

Color and pigmentation

Young mutton snapper are olive green with broad, indistinct vertical bars on the body. The dorsal and anal fins are reddish, and there is a blue stripe below the eye. Young mutton snapper are sleek, whereas the adults develop a high back. Adult body color varies considerably from white to red. Some appear olive above the lateral line and white with a reddish hue below. The anal and ventral fins and the lower half of the caudal fin are reddish and there are blue lines and dots below, before and behind the eye. Adults have a very small subdorsal body spot about the same size as the pupil and situated above the lateral line below the anterior end of the soft dorsal fin. In young,

this spot is much larger, and the lateral line passes through its lower half. Two other inshore lutjanid species have black spots in the subdorsal area, the lane snapper, *L. synagris*, and the mahogany snapper, *L. mahogoni*. These species usually have 12 segmented dorsal-fin rays, while the mutton snapper usually has 14. The mutton snapper closely resembles *L. mahogoni*, but is distinguishable by the rows of bluish dots near the eye, which *L. mahogoni* lacks. Mutton snapper have both plain and barred color phases (Fig. 2). The fish usually is barred when feeding on the bottom, when at rest, or during encounters with other fishes; it becomes nearly uniform in color when swimming.

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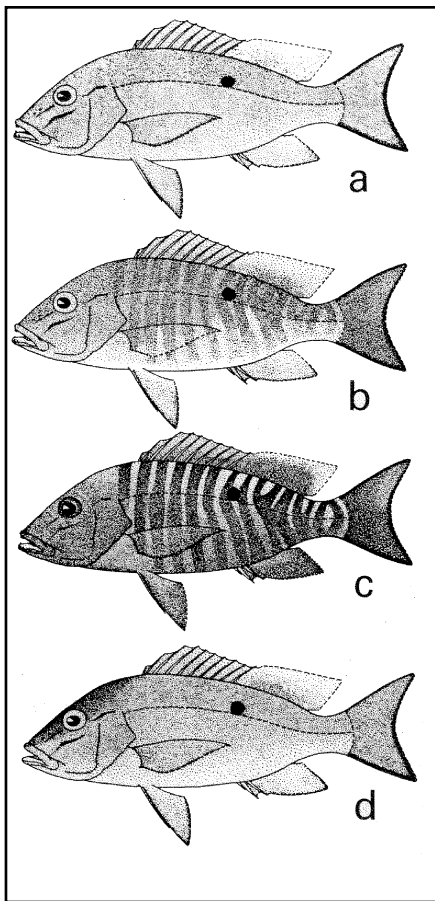


Figure 2. Color patterns in mutton snapper associated with intraspecific displacing and feeding events (Mueller, et al., 1994). Normal (a), dark barred (b, c), and dark nape (d) color patterns are transient.

Natural History

Geographic range

The mutton snapper inhabits warm, temperate and tropical waters of the western Atlantic, with distribution ranging from New England to southeastern Brazil, including the Bahamas and Gulf of Mexico. Mutton snapper are most abundant in the waters around southern Florida, the Bahamas and the Antilles.

Habitat

Mutton snapper are found in various habitats. Juveniles and small adults are found in shallow coastal waters over coral reefs, in protected bays with grass beds or mud bottoms, in tidal creeks surrounded by mangrove, and in canals. Larger adults are found in deeper waters on the continental shelf out to 91-foot (28-m) depths.

Food habits and feeding behavior

Snappers are generally nocturnal predators. During the day they form inactive schools in which dominance relationships and intraspecific aggression are rarely observed. The mutton snapper may be atypical of snappers in general, because observations of a shallow water population ranging from 6 to 25.6 inches (15 to 65 cm) in fork length (FL) in the Bahamas revealed that the fish formed dominance hierarchies and fed diurnally. A carnivorous species, the mutton snapper feeds on fishes, particularly small grunts (family Pomadasyidae), and nocturnally active crustaceans. Mutton snapper feed primarily by picking prey organisms from the surface of the substrate. They feed during all times of day. Wincrowing (the separation of prey from substrate) occurs during midday and evening, whereas midwater strikes are confined to morning and evening. When feeding on the substrate the fish have dark, barred color patterns, whereas no color changes occur during midwater strikes. Small fish less than 1 year old feed more often than medium-sized or large fish during daylight hours and have very few encounters with other mutton snapper. This suggests that small fish channel most of their energy toward feeding and growth. Differences in

feeding behavior according to fish size and time of day may reduce intraspecific competition.

Growth rates and length-weight relationships

A theoretical growth curve for mutton snapper (Fig. 3) from juvenile through adult stages was generated by measuring fish of various ages sampled from headboat landings from Jacksonville Beach, Florida to Key West from 1976 to 1981 (Mason and Manooch, 1985). In wild populations, growth in length is relatively fast for the first 2 years, but drops sharply in the third year and declines slowly thereafter. Annual growth increments were 6.3 and 5.4 inches (161 and 137 mm) for ages-1 and -2, but only 3.5 inches (90 mm) for age-3, and 57 mm for age-4 fish.¹ Growth in weight (Fig. 3) was determined from the length-weight relationship, $W = 1.0 \times 10^{-8} TL^{3.0499}$, where W = weight in kg and TL = total length in mm. Growth in weight is fastest between ages 5 and 10 years. The oldest fish examined was 14 years; it measured 32.4 inches (824 mm). Longevity was estimated at 15 to 20 years. The relationships between total length (TL), fork length (FL), and standard

¹Age-1, -2, etc. refers to age during yearly intervals. Age-0 fish are between birth and 1 year of age, age-1 fish are between 1 and 2 years old, etc.

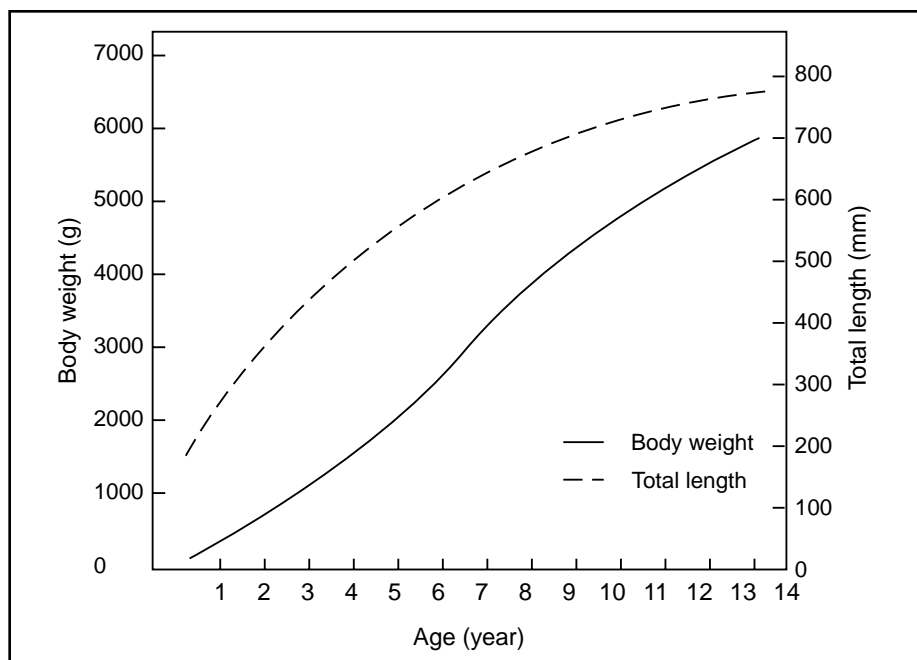


Figure 3. Theoretical growth curves for wild populations of mutton snapper based on fishery samples (Mason and Manooch, 1985).

length (SL), based on wild-caught specimens, were described as follows: $SL = -0.2 + 0.85 FL$, and $TL = 0.7 + 1.09 FL$.

Reproduction and spawning

Large spawning aggregations of mutton snapper occur seasonally off the coasts of Cuba, the Turks and Caicos, and the U.S. Virgin Islands. In the continental U.S., the last known spawning aggregation of mutton snapper is located in the Riley's Hump near the Dry Tortugas area off Key West, Florida. May and June are the principal spawning months for mutton snapper populations in this aggregation, which is heavily fished by commercial and recreational anglers.

Captive, wild-caught broodstock held in outdoor tanks under ambient photo-thermal conditions in the central Bahamas matured and spawned in association with increasing photoperiod and water temperature conditions in the spring and early summer.

It is known, however, that reproductive seasonality in a given lutjanid species may vary among populations, from extended summer spawning to year-round spawning with pulses in spring and fall, possibly depending upon habitat (oceanic island or continental, for example). Spawning seasonality of a captive mutton snapper broodstock, therefore, cannot be reliably predicted from seasonal considerations alone, and studies are needed to determine the effects of artificial temperature and photoperiod regimes on gonadal maturation of captive adults as a basis for controlled breeding programs.

Ovarian biopsies of many lutjanid snappers show more than one size of oocytes, a pattern assumed to indicate multiple spawnings by individual females during the reproduction season. However, in mutton snapper, only one size group of eggs has been observed, suggesting that females release eggs once during the spawning season.

Juveniles and adults

Little is known about the life history of mutton snapper from juvenile to adult stages, including patterns of movement and migration. Natural distributions of juveniles

and adults suggest that the young recruit into shallow inshore waters, gradually moving into deeper offshore areas with maturity. Large fish roam greater distances, whereas small individuals remain close to shelter. Recruitment of juveniles (< 7 cm fork length) to seagrass beds in Florida and Cuba has been reported to peak during August and September. From hatchery observations, sexual maturity appears to occur at the age of 3 years and at a size of 18 to 18.5 inches (45.5 to 47.0 cm) total length and 3.5 to 4.5 pounds (1.58 to 2.04 kg) in females, and 14.8 to 18.3 inches (37.5 to 46.5 cm) total length and 3.7 to 4.0 pounds (1.69 to 1.83 kg) in males. This is consistent with data from fishery samples.

Culture Techniques

Broodstock procurement

Mutton snapper broodstock are generally caught by hook-and-line or by traps from spawning aggregations off the Florida Keys, although specimens have been obtained from the Indian River Lagoon Estuary in Florida. Juveniles or subadults could be captured and grown in captivity until they reach sexual maturity.

In first-generation, hatchery-reared mutton snapper, first maturity occurred at the age of 3 years and at a size of 18 to 18.5 inches (45.5 to 47 cm) total length and 3.5 to 4.5 pounds (1.58 to 2.04 kg) in females, and 14.7 to 18.3 inches (37.5 to 46.5 cm) total length and 3.7 to 4.0 pounds (1.69 to 1.83 kg) in males.

Spawning behavior

While spawning behavior in natural aggregations has not been documented, limited information is available from observations of captive broodstock during induced spawning in tanks. About 3 hours before spawning, males began following and circling the female. The color of both male and female spawners darkened at this time. In less than 1 minute, the female released eggs at the water surface, her dorsal surface frequently exposed, while males circled rapidly below.

Induced spawning

Hormone-induced spawning of a captive mutton snapper broodstock was first reported by Watanabe et al. (1998). In this study, wild-caught subadults were reared under ambient photoperiod and temperature in outdoor, 15-m³, flow-through seawater (36 to 38 ppt) tanks. Fish were fed frozen squid and a commercially prepared striped bass diet containing 38 percent protein. During their third year in captivity fish reached first maturity and were induced to spawn by hormone treatment. A female (1.79 kg; 46 cm FL) with mature, vitellogenic-stage oocytes with a mean oocyte diameter of 382 μm (range = 225 to 475 μm and a unimodal egg diameter-frequency distribution) was induced to spawn by injection of the mammalian hormone human chorionic gonadotropin (HCG). Two intramuscular injections were used: a first (priming) dose of 500 IU/kg body weight was followed 24 hours later by a second (resolving) dose of 1,000 IU/kg body weight. At the time of the second injection, three males also were injected with HCG (500 IU/kg body weight.) to stimulate spermiation. Water temperature averaged 28.5 °C during the hormone induction period. Voluntary spawning occurred 33 hours after the first injection, with a total of 534,781 eggs released. Overall fertilization rate was 75.7 percent, producing 404,829 fertilized eggs.

Recent attempts to develop husbandry methods for captive mutton snapper broodstock indicate that gonadal development may be inhibited by handling stress, such as occurs during gonadal biopsy. Furthermore, onset of puberty in captive, first-generation (F₁), hatchery-reared mutton snapper broodstock was accompanied by heightened aggression and territoriality, causing the death of some brooders. This is consistent with field observations showing that in mutton snapper, intraspecific aggression is more prevalent among older, larger fish. Efforts to spawn F₁, hatchery-reared adults have had limited success. The injection of one F₁ female with late vitellogenic-stage oocytes with HCG (500 IU/kg) did produce final maturation and ovulation, but with an apparent "over-stimula-

tion” of the ovary. A large number of hydrated eggs were found in her body cavity post-mortem. This “eggbound” condition has been observed in a variety of fish species (e.g., red drum) following HCG treatment. This problem has hampered the spawning of captive mutton snapper broodstock.

Recently, tank- or strip-spawning has been successful with wild adults treated with hormones within several weeks of capture. Females with mean oocyte diameters of at least 300 μm have been strip-spawned after a single injection of 1,000 IU/kg of HCG. Wild-caught adults also have been induced to spawn with superactive analogues of mammalian gonadotropin-releasing hormones, but with variable fertilization success. Four females with late vitellogenic stage oocytes (450 to 500 μm diameter) were implanted within several weeks of capture with a sustained-release LHRH-a (Luteinizing hormone-releasing hormone analog) pellet (34 to 38 g/kg). Pellet implantation induced final maturation and ovulation in all females. One female produced 40,000 eggs, of which 90 percent (36,000) were fertilized. A second female spawned 4 million eggs, but with only 1.25 percent (50,000) fertilized. The other two females

released significant numbers of hydrated eggs, but without fertilization. Instead of sustained-release pellets, two females were given an intraperitoneal injection of LHRH-a in aqueous solution. Both spawned within 24 to 72 hours, but without fertilization. There should be more studies of sustained-release LHRH-a pellet implants for induced spawning of mutton snapper.

The lack of a reliable controlled reproduction system is the primary bottleneck to both hatchery research and the commercial grow-out of mutton snapper. Mature adults for use in induced spawning trials are available only seasonally, and in limited numbers.

Fecundity

Fecundity values for mutton snapper range from a minimum of 373,000 for a 2.3-kg female (186,500/kg) to a maximum of 1,370,000 for a 2.27-kg female (603,000/kg). Under voluntary tank spawning induced by hormone injection, a female with a body weight of 1.79 kg (49.5 cm total length) released 534,781 eggs (298,760/kg body weight). Buoyant eggs were spherical, translucent, and contained a single oil droplet. Mean diameter of fertilized eggs (measured 1 hour after fertilization)

was 783 μm (range = 725 to 875 μm).

Eggs and larvae

Clarke et al. (1997) describe the development of larvae and juveniles in the laboratory. Newly hatched larvae measure 2.2 to 2.5 mm standard length (SL), have unpigmented eyes, lack a functional mouth, and have a large, elliptical yolk sac that protrudes in front of the snout (Fig. 4). A single oil globule (130 to 220 μm diameter) is located at the front of the yolk sac.

Under an incubation temperature of 27.5 to 28.5 $^{\circ}\text{C}$, yolk is resorbed, eyes are fully pigmented, the mouth is formed, and feeding begins by 24 to 48 hours post-hatching (~2.6 to 2.8 mm standard length (SL)) (Fig. 4). Notochord flexion begins at 11 to 12 days post-hatching when larvae are about 4.4 mm long (Fig. 5); it is completed 16 to 18 days after hatching when larvae are about 6 mm long (Fig. 6). Transformation from the larval to juvenile stage begins when fish are about 10 mm long, or day 13 to day 19. At this time scales develop and pigmentation appears over the lateral surfaces of the body, starting behind the pectoral-fin base (Fig. 7). Juveniles are fully-scaled by day 28 at 14 to 15 mm long.

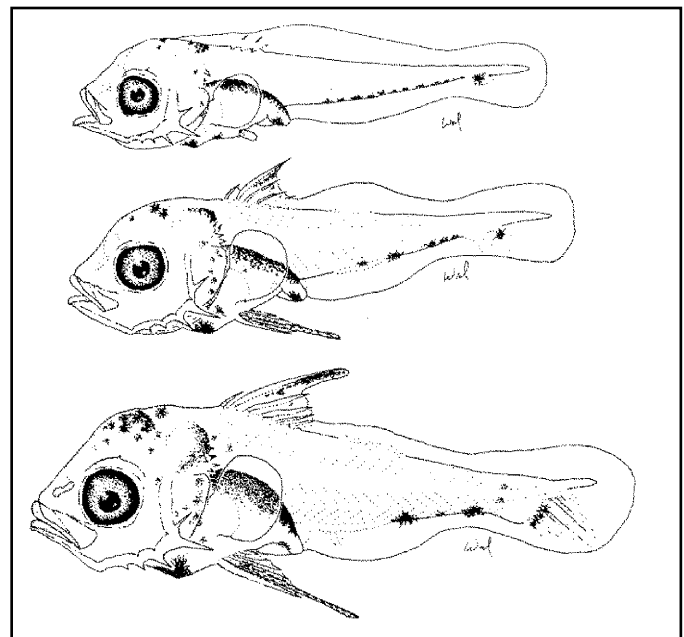
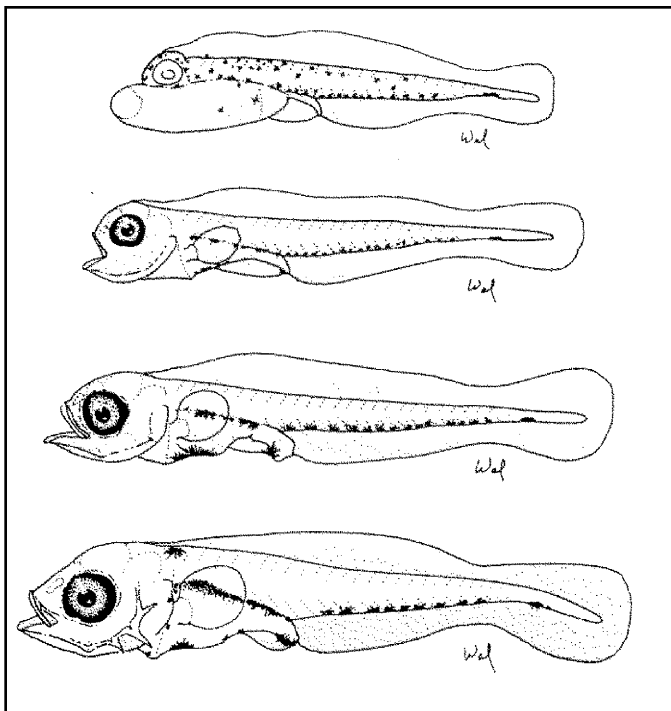


Figure 4. Mutton snapper yolk sac larvae (2.2 mm) (top) and pre-flexion larvae (2.7 to 3.5 mm) (Clarke et al., 1997).

Figure 5. Mutton snapper flexion larvae (top to bottom, 4.6, 4.9 and 5.8 mm) (Clarke et al., 1997).

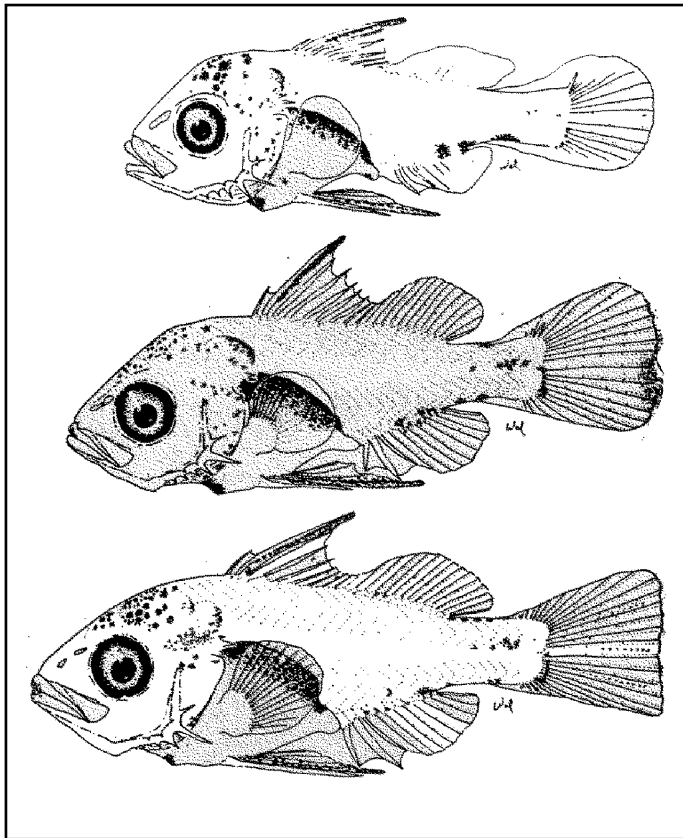


Figure 6. Mutton snapper postflexion larvae (top to bottom, 6.2, 8.1 and 9.8 mm) (Clarke et al., 1997).

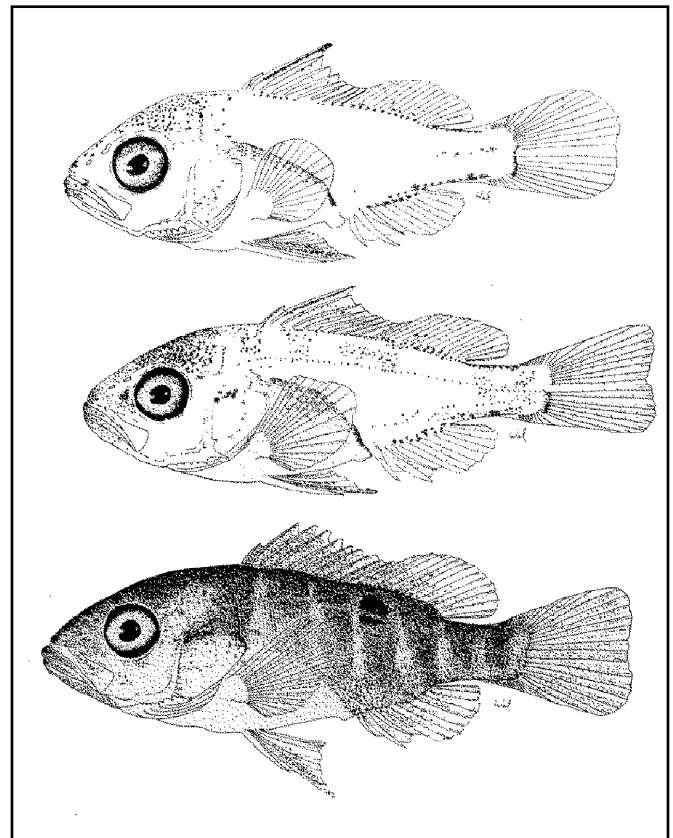


Figure 7. Mutton snapper postflexion larva (top, 11.5 mm), transforming juvenile (middle, 15 mm) and juvenile (bottom, 18.5 mm) (Clarke et al., 1997).

Larval culture

After the first spawning of captive mutton snapper broodstock, the survival and growth of larvae, from egg to metamorphic stages, were studied under pilot-scale hatchery conditions (Watanabe et al., 1998). The rearing unit consisted of an outdoor, above-ground, rectangular, 30-m³ tank (7.5 m long, 4.5 m wide, and 0.9 m deep) constructed of framing lumber, lined with black, high-density polyethylene, and enclosed by a polyethylene greenhouse. Light intensity at the water surface between 8:00 a.m. and 3:00 p.m. was approximately 7,000 to 12,000 lux (less than 5 percent of direct sunlight). A minimum level of aeration for dispersion of eggs and larvae was used.

The feeding regimen used during the pilot-scale trial is summarized in Figure 8. One week before spawning, the rearing tank was filled with unfiltered seawater and fertilized with ammonium phosphate (50 g or 1.7 mg/L), monopotassium phosphate (15 g or 0.5 mg/L), urea (2.5 g or 0.08 mg/L), Fe-EDTA (7.5 g or 0.25 mg/L), and a trace metal mix (0.5 g

or 0.017 mg/L). It was then inoculated with the microalga *Nannochloropsis oculata* (150 x 10³ cells/mL) and, after 5 days, with ss-type rotifers *Brachionus plicatilis* (1 individual/mL). On the day of spawning, fertilized eggs (approximately 1 to 2 hours post-fertilization) were stocked into the rearing tank at a density of 10.5 eggs/L. Larvae were fed ss-type rotifers until day 28 (Fig. 8). Rotifers were grown at 22 ppt salinity in a batch culture system and fed *N. oculata* and baker's yeast (*Saccharomyces cerevisiae*) at an approximate 1:1 ratio. Rotifer and algae concentrations in the rearing tank were monitored daily and replenished as available. Rotifer population was kept at an average of 18 individuals per milliliter (range = 12 to 27) from day 0 to day 8; rotifer population then declined to an average of 8 individuals per milliliter (range = 1 to 15) until day 28. Algae was maintained at approximately 25 x 10³ cells per rotifer per mL.

Newly hatched, San Francisco Bay (SFB) strain *Artemia* nauplii were fed at 1/L from day 7 to day 9.

One-day-old, enriched *Artemia* (SFB strain) were added three times daily (9:00 a.m., noon and 4:00 p.m.) from day 10 to day 20, in total numbers increasing from 0.21 x 10⁶ to 23.5 x 10⁶ per day during this period. Nauplii were enriched with a commercial fatty-acid booster for 15 to 22 hours before being fed to larvae. From day 21 to day 25 post hatching, larvae were fed enriched, Great Salt Lake (GSL) strain *Artemia* in numbers increasing from 24.3 x 10⁶ to 66.9 x 10⁶ per day.

On day 24 post hatching, *Artemia* were added to the rearing tank later in the day and an artificial, pelleted diet (Nippai ML-400; 52 percent protein, 12 percent fat; particle size = 400 to 850 µm) was fed hourly from 7:00 a.m. to noon and at 3:00 p.m. Transition to a larger feed (Nippai ML-800; 48 percent protein, 8 percent fat; particle size = 800 to 1,500 µm) was begun on the 29th day and fish were fed every 2 hours from 7:00 a.m. to 7:00 p.m.

Seawater (36 to 38 ppt salinity) exchange began on day 1 post hatching at a rate of 10 percent per day and was gradually increased to

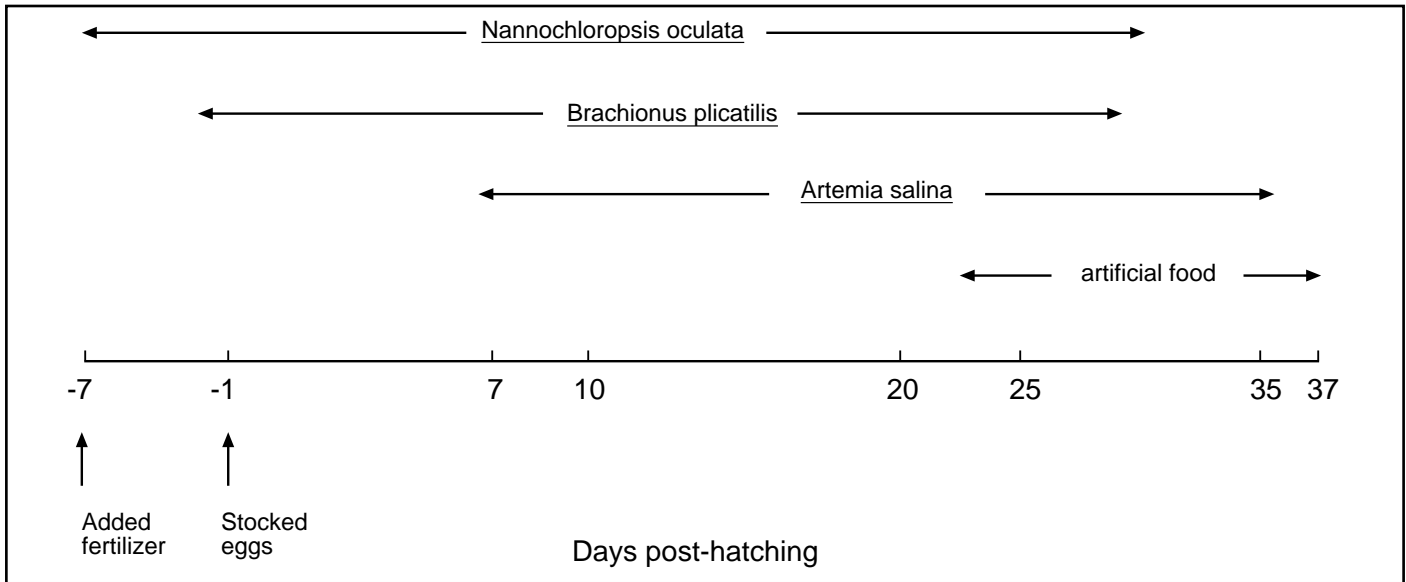


Figure 8. Feeding regimen used during pilot-scale culture of mutton snapper from egg to metamorphic stages in a 30-m³ tank.

150 percent per day by day 37. Surface skimmers were used to reduce oily surface film. Mean water quality values (range) were as follows: temperature 28.7 °C (26.8 to 30.4 °C); dissolved oxygen 6.1 mg/L (4.1 to 7.9 mg/L); salinity 37.5 ppt (36 to 39 ppt); and total ammonia nitrogen 0.12 mg/L (0.01 to 0.27 mg/L).

Under an incubation temperature of 27.7 °C, hatching began 17 hours post-fertilization. On day 2 post hatching, larval density was 8.61 larvae/L. From then on larval survival declined gradually to 29.3 percent (2.52 fish/L) by day 20, then declined more slowly to 14.3 percent (1.23 fish/L) by day 38 (Table 1), when a total of 36,900 post-metamorphic juveniles were produced. Timing of metamorphosis varied among individuals from approximately day 30 to day 38. Larval notochord length (Table 1) on day 2 was 2.66 mm, increasing slowly to 4.94 mm by day 21. Growth was rapid after day 21, with larvae reaching 22.2 mm standard length (SL) (range = 18.5 to 25.8 mm) by day 38, when fish averaged 0.309 ± 0.015 g (SD).

The survival rate (14.2 percent) of mutton snapper larvae to the post-metamorphic stages in this study surpassed rates attained in previous rearing attempts with larval lutjanids, including mangrove snapper, yellowtail snapper, and red snapper. It is comparable to rates attained in commercial hatcheries in Europe for sea bream, *Sparus aurata*, (i.e., 10 to 20 percent at weaning

onto formulated feeds). Relatively high survival of larval mutton snapper in this study may have been related in part to the use of *Artemia* enriched with n-3 highly unsaturated fatty acids, particularly docosahexaenoic acid (DHA), and the supplementation of live feed (*Artemia*) with an artificial diet beginning on day 24, which was associated with a dramatic increase in larval growth (Table 1) and a stabilization in survival after day 20. Because larvae readily accepted the

artificial diet on day 24, it is likely that mutton snapper larvae could be weaned at an even earlier age. High survival of larval mutton snapper through metamorphic stages in this study was also probably related to species-specific behavioral characteristics. Rotifers elicited a strong feeding response in first-feeding mutton snapper, resulting in efficient prey capture and consumption. In addition, there was little cannibalism among larvae.

Table 1. Survival and growth of larval mutton snapper from hatching through metamorphic stages during pilot-scale culture in a 30-m³ tank. Fertilized eggs were stocked at a density of 10.5 eggs/L.

Age (d post-hatching)	Survival (larvae/L)	(%) ^a	Notochord length ^b (mm)
2	8.61	100	2.66 ± 0.32
5	6.85	79.6	2.96 ± 0.25
6			3.03 ± 0.27
7	6.56	76.2	
8			3.39 ± 0.22
10	5.38	62.5	
11			4.12 ± 0.53
15	4.72	54.8	
16			4.67 ± 0.56
20	2.52	29.3	
21			4.94 ± 0.35
25	2.16	25.1	
26			9.68 ± 1.54
31			16.2 ± 1.40
38	1.23	14.3	22.2 ± 3.61

^a Percentage of larval density on day 2 post-hatch.

^b n = 20, except for day 38 post-hatch when n = 100.

Juvenile grow-out

Commercial production trials with mutton snapper have begun at the Grassy Key Aquatic Center, Inc. (GKAC) in Key West, Florida. At GKAC, fertilized eggs were obtained by HCG-induced spawning of wild adults collected in June and July 1999 from the Riley's Hump spawning aggregation. Larval rearing trials were conducted in 2.25-, 4- and 20-m³ tanks. Larval feeds consisted of the microalgae *Isochrysis galbana* (C-Iso strain), rotifers, *Brachionus plicatilis* (L-strain), *Artemia* nauplii, and enriched metanauplii and sub-adults. Traditional live feeds were supplemented with induced tank blooms of wild zooplankton, particularly copepods of the genus *Acartia*. A combination of enriched frozen *Artemia* and various commercially prepared starter diets was used to wean 4-week-old postlarvae to dry feeds. Fifteen thousand fingerlings (average weight = 10 g; range = 5 to 35 g) were reared through 120 days.

On day 97 post hatching, hatchery-reared juveniles (n = 1,390; average weight = 10.5 g, range = 4.8 to 18.4 g) from the 1 June 1995 spawn were stocked into two, outdoor, 14.4-m³ fiberglass tanks (diameter = 3.5 m; depth = 1.4 m) at a density of 48.3 fish/m³ (695 fish/tank, 0.51 kg/m³). Both tanks were supported by a common water recirculation system consisting of a high-rate sand filter to remove solids and a "fluidized bed" biofilter. Tanks were covered by 70 percent light-occluding shade cloth. Fish were hand fed to satiation three times daily for the first 90 days of the study, then once daily. The feed was a commercially prepared mahimahi grower containing 56 percent protein and 14 percent fat. Fish were grown under ambient

photoperiod and temperature conditions through late November.

Mutton snapper juveniles proved extremely hardy under the culture conditions of the recirculating seawater tank system. There was no evidence of disease and few deaths despite marked fluctuations in water temperature (average = 25.7 °C, range = 18 to 31 °C), salinity (average = 24.1 ppt; range = 18 to 30 ppt) and pH (average = 7.4; range = 6.8 to 7.7) (Table 2).

Average dissolved oxygen concentration was 5.88 (range = 5.00 to 6.20 mg/L) and average total ammonia-nitrogen concentration was 0.34 (range = 0.10 to 1.0 mg/L). At the end of the 168-day grow-out study, fish averaged 140.8 grams (30 to 300 g) for an average daily weight gain of 0.78 grams/day and a specific growth rate of 1.55 percent per day. Feed consumption averaged 1.58 percent body weight

per day, while overall feed conversion ratio (dry weight fed/wet weight gain) was 1.2. Final survival was 97.8 percent, while final biomass density was 6.65 kg/m³ (Table 2). Abnormalities were observed in a small percentage of individuals, including scoliosis (5.0 percent) and gill plate deformities (2.4 percent). Studies are needed to determine growth rates of mutton snapper from juvenile through full marketable sizes.

F₁ progeny from this grow-out study were transferred to outdoor seawater tanks 3.7 to 6.1 meters (12 to 20 feet) in diameter at various locations in Florida and North Carolina and held under non-standardized conditions. Post-experimental body weights and lengths of F₁ fish of different ages are shown in Figure 9. While preliminary, the data reveal that growth rates of captive, hatchery-reared mutton snap-

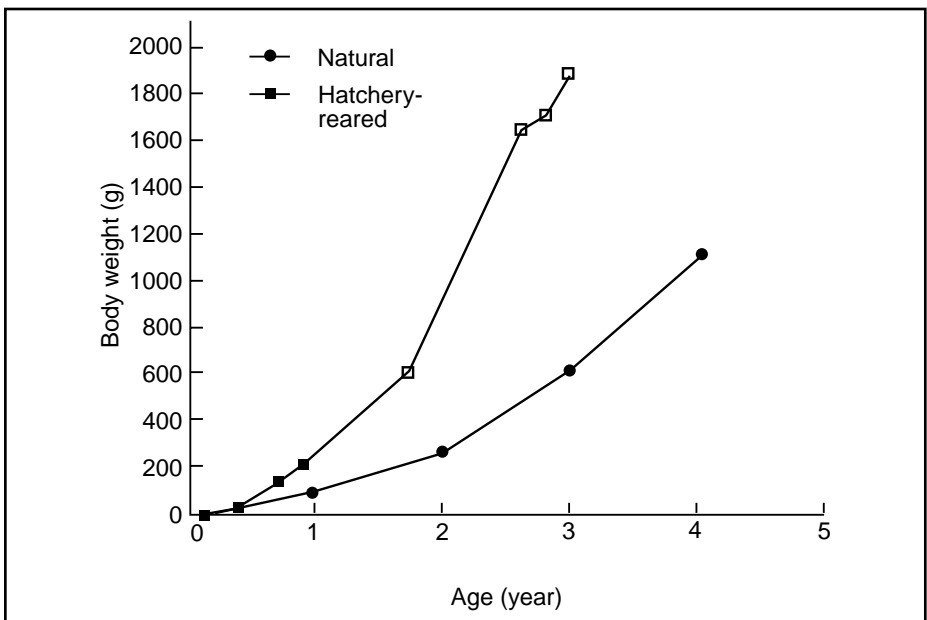


Figure 9. Comparison of growth of hatchery-reared mutton snapper in seawater tanks with growth of fish in wild populations. For hatchery-reared fish, data are for culture in recirculating tanks (closed squares) (Watanabe et al.,1998), and for fish held at various locations under non-standardized conditions (open squares). Growth of wild fish (closed circles) is based on fishery samples as described in the text (Mason and Manooch, 1985).

Table 2. Growth, survival, and biomass density during pilot-scale grow-out of juvenile mutton snapper in recirculating seawater tanks. Two 14.4-m³ tanks were each stocked with 695 juveniles (age = 97 days post-hatching) and grown for 168 days.

Age (d post-hatching)	Experiment day	Body weight ^a (g)	Total length ^a (mm)	Survival ^a (%)	Biomass ^a (kg/m ³)	N ^b
97	0	10.5 + 2.5	88.7 + 8.9	100	0.507	51
186	89	68.7 + 18.8	157 + 13.6	99.9	3.31	144
265	168	140.8 + 46.2	207 + 7.8	97.8	6.65	1,037

^a Values represent averages for two tanks.

^b n = number of fish sampled.

per are much higher than growth rates of fish in natural populations (Fig. 9). Growth and feed conversion can likely be improved with optimum environmental and nutritional conditions. The relationship between fork length (FL) and body weight based on F₁ hatchery-reared progeny is shown in Figure 10.

Environmental and nutritional requirements of juveniles

Successful spawning and rearing of mutton snapper larvae through metamorphic stages have made it possible to conduct experimental studies with hatchery-reared juveniles. Under controlled, laboratory conditions, growth and feed utilization of juveniles (mean weight = 12.2 g) were compared for 40 days using four isonitrogenous diets (45 percent crude protein) of varying lipid content (6, 9, 12 and 15 percent) with energy:protein ratios (E:P; kJ/g protein) of 33.9, 36.3, 38.8 and 41.2, respectively. Growth on these diets was compared at temperatures of 25 and 30 °C. Salinity was 36 to 38 ppt and photoperiod was 12 L:12 D.

A clear departure in growth rates among the dietary lipid and temperature treatments were observed by day 14 (Fig. 11, top). Growth increased with decreasing dietary lipid (Fig. 11, top) and was higher at 30 than at 25 °C (Fig. 11, bottom). This suggests that rearing temperatures (average = 25.7 °C) used during preliminary grow-out studies of juveniles (Watanabe et al; 1998) were less than optimum. These growth trends were related primarily to feed consumption, which decreased with increasing dietary lipid from 1.57 percent per day in the 6 percent diet to 0.95 percent per day in the 15 percent diet and was higher at 30 °C (1.36 percent per day) than at 25 °C (1.03 percent per day).

Feed conversion ratio (FCR) and protein efficiency ratio (PER) were not significantly affected by dietary lipid and E:P ratio, but were higher at 30 °C (FCR = 2.60; PER = 0.88) than at 25 °C (FCR = 3.38; PER = 0.69). Maximum growth and energy retention in juvenile mutton snapper using a diet containing 45 percent crude protein was obtained at dietary lipid levels of 6 to 9 percent

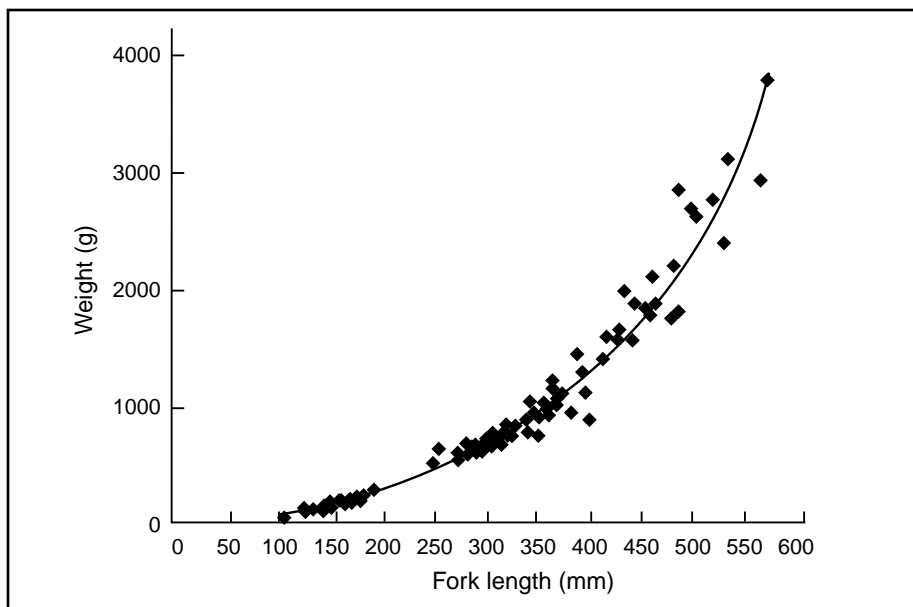


Figure 10. Relationship between fork length (L) and body weight (W) in F₁ hatchery-reared mutton snapper: $W = -4 \times 10^{-8} L^4 + 7 \times 10^{-5} L^3 - 1.5995L$ (n = 298; R² = 0.9828).

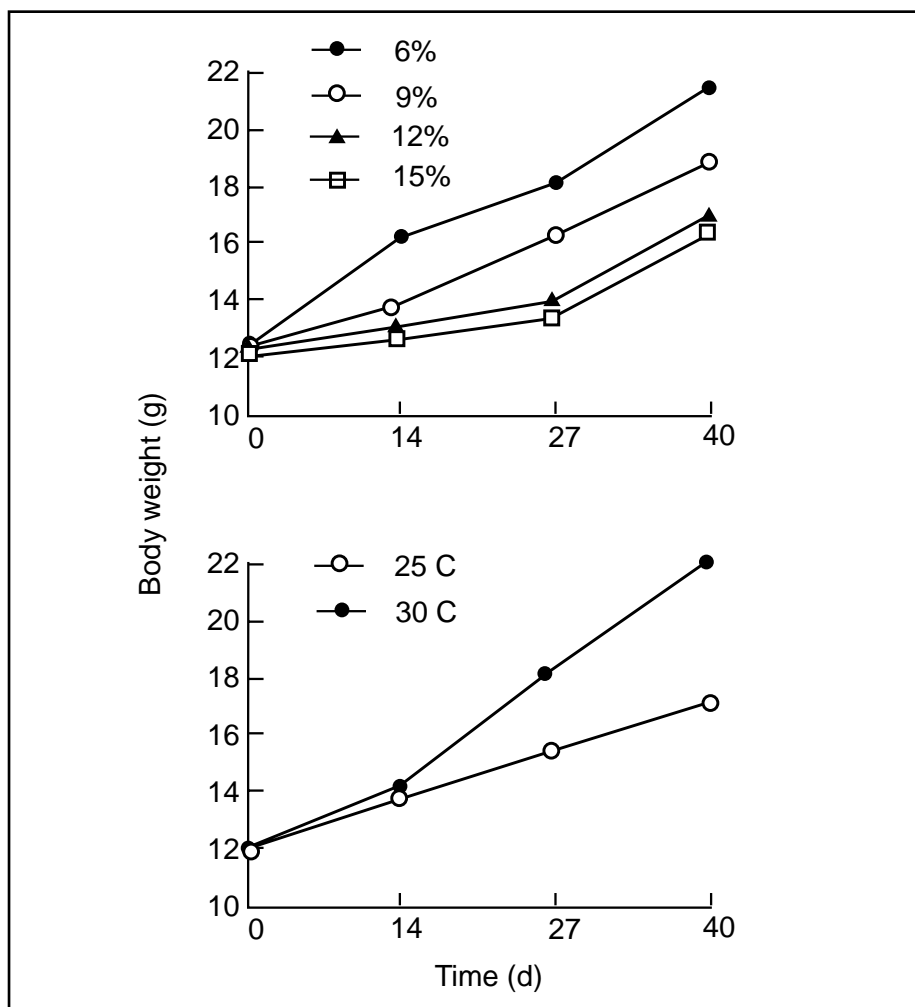


Figure 11. Growth of juvenile mutton snapper fed four isonitrogenous (45 percent CP), semi-practical diets with different crude lipid levels and E:P ratios at 25 and 30 °C (Ellis et al., 1999). Top graph shows growth at different lipid levels integrated for both temperatures, while bottom graph shows growth at both temperatures, integrated across all dietary lipid levels. Plotted points represent means (n = 6 in top graph; n = 11 in bottom graph).

and E:P ratios of 33.6 to 36.3 kJ/g protein. As observed in commercial scale tests, juveniles fed a diet containing 55 percent protein and 10 percent lipid had a feed conversion ratio of 1.2. This suggests that increasing dietary protein while maintaining a gross energy level of 15 to 16 kJ/g of diet would lower the E:P ratio and improve feed conversion and growth.

Markets for existing commercial landings and value

Commercial landings of snapper (*Lutjanidae*) in the southeastern U.S. have remained relatively stable over the last 10 years. In 1998, 10,631,000 pounds (4,832 metric tons, mt) of snapper, with a dock-side value of \$10,365,000, were landed. Red snapper and vermilion snapper were the primary species harvested, representing 48.5 percent (5,161,000 pounds; 2,341 mt) and 15.3 percent (1,630,000 pounds; 739 mt), respectively, of the total harvest weight (NMFS, 1999). All other snappers (including the mutton snapper) represented 36.1 percent (3,840,000 pounds, 1,745 mt) of the total harvest weight.

Domestic harvest of snapper, although relatively stable, is inadequate to meet demand, and imports of snapper into the U.S. have risen dramatically during the last decade (Fig. 12). In 1989, only 2,517 pounds (1.1 mt) was imported; it had a value of \$4,289. In 1998, snapper imports (primarily fresh product) climbed to 25 million pounds (11,374 mt), valued at \$38.7 million (NMFS, 1999). Much of the imported snapper comes from countries in the Caribbean or along the Gulf of Mexico, with some product originating in Asia and the Pacific. There is excellent potential for replacing imported snapper with a cultivated, domestic product.

The mutton snapper resembles and is often marketed as the red snapper (*L. campechanus*). Taste and appearance are indistinguishable between these species once filleted. The flesh is firm, white, and ideally suited for baking and broiling. Cheek and throat meats from larger fish are gourmet items. Considered one of the most delicious saltwater

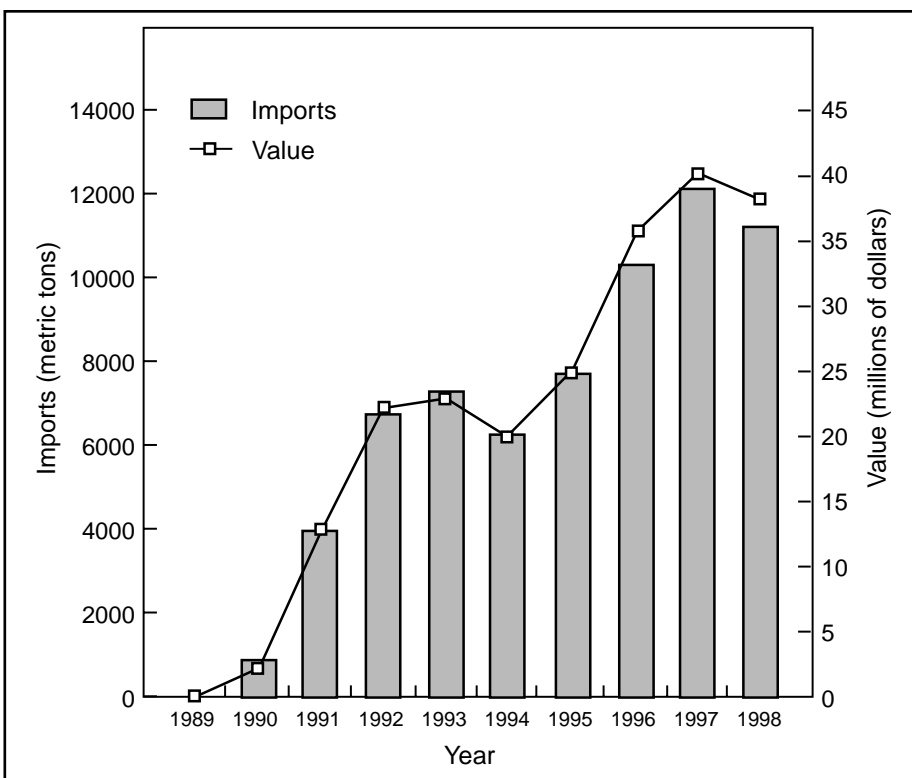


Figure 12. Imports of snapper (*Lutjanidae* spp.) to the U.S. from 1989 to 1998.

fishes, filets of mutton snapper sell for about \$12 a pound in Miami seafood markets. Prices are expected to climb as demand increases and stocks wane.

Snappers, including the mangrove snapper, *L. argentimaculatus*, and John's snapper, *L. johni*, command high market prices in Southeast Asia and are cultured in floating net cages and brackishwater ponds in Singapore, Indonesia and the Philippines. Seed for farms comes entirely from wild fry, so the supply is limited and unreliable. This is a major constraint to snapper aquaculture in these regions.

Prospectus

Commercial marine finfish culture in the U.S. can be successful if the species is in demand, has high value, and can be easily reared through larval stages and grown to marketable sizes in intensive recirculating systems or in offshore cages. These systems need little land, can be operated away from the high-priced coastal zone, and mitigate land-use conflicts and problems of effluent discharge requirements. The mutton snapper is a prime, new candidate for commercial aquaculture in the U.S.

Preliminary studies show that larvae can be reared in significant quantities using current marine finfish culture techniques, and that juveniles are extremely hardy during grow-out in recirculating seawater tanks. The potential for pond and net pen culture also should be examined. While further studies on optimum environmental and nutritional conditions are needed, the development of reliable methods for controlled breeding of captive broodstock seems to be the key to commercial culture of this species. There are no reliable data on the potential cost of producing mutton snapper, so economic analysis is another important area for future research. However, there seem to be few unusual problems with mutton snapper culture that would add significantly to the cost of production. Costs may be in line with those for red drum under similar conditions. The selling price for mutton snapper is high relative to the potential cost of production, so other than the usual problems encountered in developing a commercial venture, there appear to be few obstacles to profitable commercialization of mutton snapper aquaculture.

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