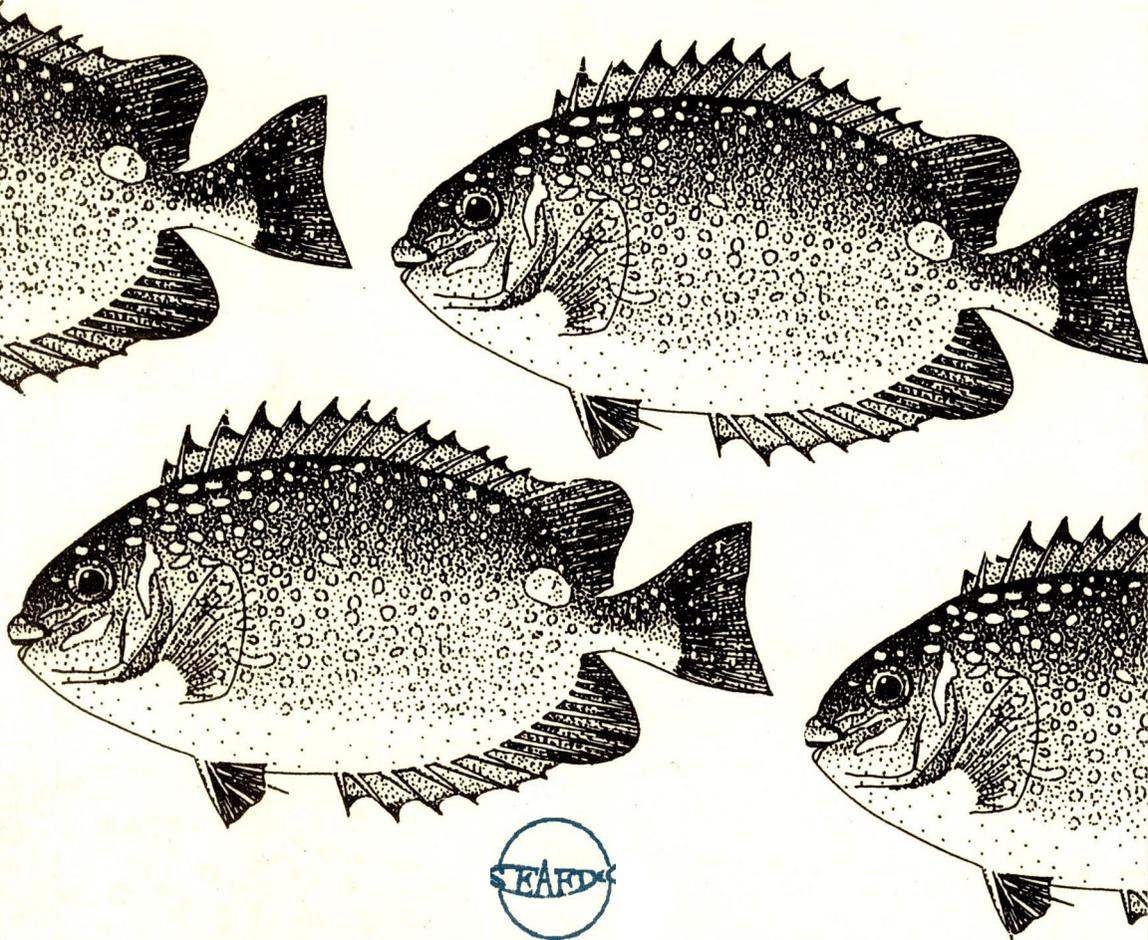


Revised Edition

April 1998

Biology and Culture of Siganids

M.N. DURAY



AQUACULTURE DEPARTMENT
SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER

ISBN 971-8511-30-X

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Published and Printed by
Aquaculture Department
Southeast Asian Fisheries Development
Center (SEAFDEC)
Tigbauan, Iloilo, Philippines

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First revision April 1998
Aquaculture Department
Southeast Asian Fisheries Development
Center (SEAFDEC)
Tigbauan, Iloilo, Philippines

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BIOLOGY AND CULTURE OF SIGANIDS

April 1998

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INTRODUCTION

Rabbitfishes (*Siganus* spp.) are widely distributed in the Indo-Pacific region, from the east coast of Africa to Polynesia, southern Japan to northern Australia (Herre & Montalban 1928); and in the eastern Mediterranean (Ben Tuvia 1966; George 1972). Woodland (1983) identified 26 species, some of which are abundant in the Indo-Malayan area but scarce in French Polynesia.

The mariculture potentials of rabbitfishes were pointed out by Ablan & Rosario in 1962. Apart from being an excellent food fish, they are used as bait to catch tuna (Wilkinson 1977) and as agents to check algal growth in tropical oyster culture (Hasse 1974). Although rabbitfishes constitute a major fishery in several Pacific countries (Manacop 1959; Lam 1974) and some species are traditionally farmed in the Philippines (Pillai 1962), commercial farming has not yet been established in any of these countries. In 1972, the Siganid Mariculture Group came up with a plan for siganid farming and research. In accord with such a plan, Lam (1974) reviewed the literature on the biology of rabbitfishes and pointed out problems requiring attention. Since then, there has been a remarkable increase in rabbitfish research.

On The Cover: Siganus guttatus (Bloch)

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BIOLOGY

Morphology

Rabbitfish are identified by their deep, compressed body, snout resembling that of a rabbit, 13 pungent spines in the dorsal fin, seven spines in the anal fin, and two spines in the ventral fin. The skin is leathery but the scales are smooth, small and closely adherent, hence the fish is often mistaken as without scales. The color is olive-green to brown depending on the species (Herre & Montalban 1928; Munro 1967).

Nomenclature and Classification

The current taxonomic classification of rabbitfishes is as follows:

- Phylum - Chordata
- Subphylum - Vertebrata
- Grade - Pisces
- Class - Osteichthyes
- Subclass - Acteropterygii
- Infraclass - Neopterygii
- Division - Halecostomi
- Subdivision - Teleostei
- Infradivision - Euteleostei
- Superorder - Acanthopterygii
- Order - Perciformis
- Suborder - Acanthuroidea
- Family - Siganidae

Family Siganidae has two genera: *Lo* and *Siganus* (*Teuthis*) with about 26 species, of which 15 are schooling (gregarious) whereas the rest occur in pairs and are coral-dwellers (Woodland & Allen 1977). Masuda et al. (1984) believed only *Siganus* occurs in the Indo-Pacific region.

Due to the close resemblance of rabbitfishes to surgeon fishes, Starks (1907) put Siganidae and Acanthuridae under Squamipinnes. He studied the skeleton of *Siganus fuscescens*, on which basis he recommended Siganidae as an independent superfamily coordinate in rank with Acanthuridae under Acanthuroidea. Day (1978) studied the group in the Indian Ocean and still used Teuthidae for Acanthuridae.

Rabbitfishes were formerly known under the generic name *Teuthis* which Woodland (1972, 1973) proposed to be suppressed in favor of *Siganus*.

Species Identification

Identification of rabbitfishes is difficult because of the few morphological differences between species. Available descriptions for species differentiation rely largely on coloration of live fish (Woodland & Randall 1979; Burgan et al. 1979). But colors change with age and emotional state of live material, as well as in death, and with method of preservation, of the fish. References for the identification of species include Herre & Montalban (1928), Fowler (1967), Woodland (1972), Rau & Rau (1980), and Masuda et al. (1980).

Distribution and Ecology

Zoogeography. Woodland (1983) discussed the zoogeography of rabbitfishes and pointed out that there are five pairs of sibling species. One of each pair has an Indian Ocean-centered distribution, and the other, a Pacific Ocean-centered distribution. The eastern and western limits of members of each pair overlap in the Indo-Malayan area. The other species are endemic to the western Indian Ocean, Red Sea, and northwestern Australian Province.

Behavioral Traits and Habitat. Gundermann et al. (1983) subdivided rabbitfishes into two groups based on behavioral characteristics, coloration, and habitat. One group includes species that live in pairs, are site-tenacious, brightly colored and associated strictly with coral reefs. These coral-dwelling species are fragile, sensitive to physico-chemical changes and usually show interspecific aggressive behavior; a typical example is *S. corallinus*. The other group includes species which school at some stage in life, move over substantial distances, and are gray or drab. They are sturdy and apparently resistant to considerable variations in salinity and temperature. These schooling species are important food fishes and currently the subject of a number of mariculture studies (Woodland & Allen 1977). Typical examples are *S. argenteus* and *S. canaliculatus*.

Larvae of rabbitfishes are pelagic and common in waters beyond the outer reef, but do not wander as far offshore as do larvae of migratory coastal species with pelagic eggs (Johannes 1978). Juveniles and adults occupy very diverse shallow water habitats (Lam 1974; Popper et al. 1979) including coral reefs (Woodland & Randall 1979), sandy and rocky bottoms with or without vegetation (Popper & Gundermann 1975; Hasse et al. 1977), lagoons and river mouths (Munro 1967), and mangrove swamps (Gundermann et al. 1983; Alcala 1979). Only *S. argenteus* has been seen in the open ocean (Laviña & Alcala 1974) (Table 1).

Table 1. Habitat of some rabbitfish

Species	Habitat	References
<i>S. argenteus</i>	Juveniles: reef & grass flats Adult: open water	dela Paz & Aragones, 1990; Alcalá 1979; Tahil 1978b Laviña & Alcalá 1974
<i>S. canaliculatus</i>	Juveniles: grass flats; mangrove Adult: mainly grass flats: also reef flats & mangrove	Burgan & Zselezky 1979 Alcalá 1979; Laviña & Alcalá 1974; Soh & Lam 1973
<i>S. corratinus</i>	Reef slopes	dela Paz & Aragones, 1990 Alcalá 1979; Horstmann 1975;
<i>S. fuscescens</i>	Reef flats; well-vegetated bottom of shallow waters; coastal waters	Woodland in Lam 1974; Okada 1966
<i>S. guttatus</i>	Juveniles: among mangrove roots in shaded areas; shallow bays, river mouths	Burgan & Zselezky 1979; Schultz et al. 1953;
<i>S. javus</i>	Adults: coastal but enter and leave rivers & estuaries Marine, brackish, and freshwaters; may enter rivers, lakes and harbors	Alcalá 1979; Herre 1953; Soh & Lam 1973 dela Paz & Aragones, 1990; Kurup & Samuel 1985; Herre 1953; de Beaufort & Chapman 1951 Lam 1974; Schultz et al. 1953 Drew in Lam 1974; Johannes 1978
<i>S. lineatus</i>	Juveniles: mangrove; dock sides Adults: reef & grass flats; along docks	Diamant 1989 Alcalá 1979; Johannes 1978 Alcalá 1979 Ben-Tuvia et al. 1973
<i>S. luridus</i>	Coral reefs	Diamant 1989
<i>S. punctatus</i>	Coral reefs	Alcalá 1979; Johannes 1978
<i>S. puellus</i>	Coral reefs; sea grass areas	Alcalá 1979
<i>S. rivulatus</i>	Shallow waters in harbors & semi-enclosed rocky pools	Ben-Tuvia et al. 1973
<i>S. vermiculatus</i>	Sand flats Mangrove	Diamant 1989 dela Paz & Aragones, 1990

REPRODUCTION

Sex Determination

There is no known external feature to distinguish the sexes of rabbitfishes except during the breeding season. Manacop (1937) enumerated some criteria for differentiation in *S. canaliculatus*: (1) males are generally smaller than females; (2) abdomen of female is distinctly plump; (3) when the abdomen is pressed, whitish fluid (milt) comes out from males and orange-colored eggs from females; (4) genital aperture of female is larger; and (5) female is less active. Helfman (1968) reported that males have a more elongated body, but measurements of body depth in relation to length in *S. canaliculatus* showed no difference between the sexes.

Sex Ratio

Monthly samplings of *S. canaliculatus* in Hong Kong (1978-1981) revealed a dominant ratio of one male to one female between March and June (Tseng & Chan 1982). However, this did not occur in all cases. In Palau, the ratio for the same species is one female to two males during the spawning season and three females to one male at other times (Gundermann et al. 1983).

Sexual Maturity

Some rabbitfish species mature in captivity when environmental conditions are favorable and food is adequate (Popper et al. 1973; Lam 1974; Soletchnik 1984; Juario et al. 1985). Sexual maturity is attained in less than a year but at different sizes in various species.

Siganus canaliculatus matures earlier than the other species (Tacon et al. 1989). Lam & Soh (1975) hinted that it matures earlier in captivity than in the wild and that males mature earlier than females. The maturation size is 10.6 cm standard length (SL) for males and 11.6 cm SL for females (Alcala & Alcazar 1979); other estimates ranged from 12 to 31 cm (Manacop 1937; Westernhagen & Rosenthal 1975; Tseng & Chan 1982; Bwathondi 1982). In terms of weight at maturity, Westernhagen & Rosenthal (1975) reported a 50-g female with 13.5 cm total length (TL). The minimum according to Tacon et al. (1989) is 32 g (14.3 cm TL) for males and 18.3 g (11.7 cm TL) for females.

Based on histological evidence (Juario et al. 1985), hatchery-bred male *S. guttatus* matures sexually in 10 months at 19 cm fork length (FL), and the female in 12 months at 21.5 cm FL. Soletchnik (1984) observed first sexual maturation in captive female *S. guttatus* at size 200 g (34 cm FL) and in hatchery-bred ones at 260 g (20-22 cm FL). For *S. rivulatus*, sexually maturity is attained at about 107g (14-16 cm) (Hashem 1983).

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Gonads

Ovary. The ovaries of *S. canaliculatus* are perciform. Their posterior portions are fused to form the oviduct which terminates immediately behind the anus (Lavina 1975; Alcalá & Alcazar 1979). There is no ovipore, thus the eggs are extruded through a rupture in the connective tissue at the end of common oviduct (Fig. 1).

The color of the ovary varies from opaque white when immature, to pinkish when developing, to golden yellow when ripe.

Testis. The testes are a pair of flattened organs which in mature fish are multilobed (Alcalá & Alcazar 1979). The sperm duct remains separate from the urinary duct but both ducts end in a common pore at the tip of the urogenital papilla (Fig. 1).

The testes vary from opaque or transparent white when immature to yellowish pink when developing, to milky white when ripe.

Gonadal Maturation

The stages in gonadal development are based on macroscopic appearance, histological changes and gonadosomatic index (GSI). Laviña (1975)

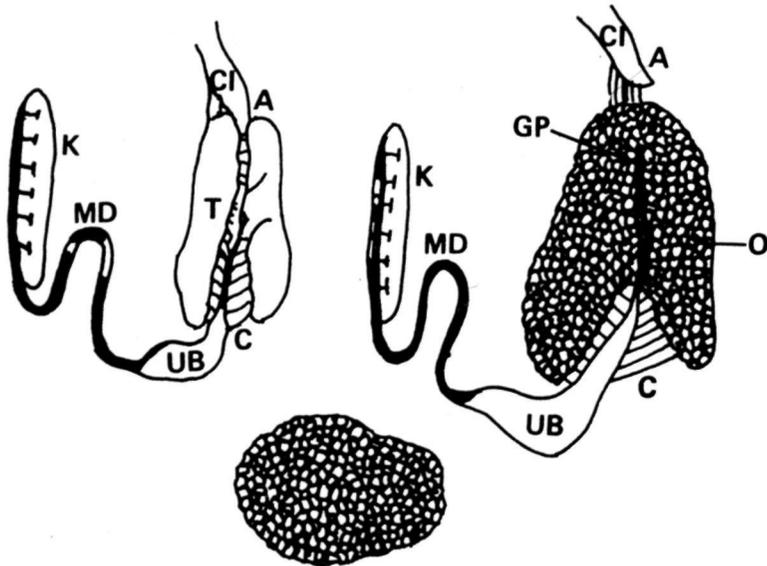


Fig. 1. *Siganus canaliculatus*: reproductive system. Top: left, male; right, female. Bottom: transverse section of fused left and right ovaries. A, anus; C, connective tissue; Cl, cloaca; GP, genito-urinary pore; K, kidney; MD, mesonephric duct; O, ovary; T, testis; UB, urinary bladder (After Alcalá & Alcazar, Silliman J. 26(2&3): 150.1979).

identified six stages in *S. canaliculatus* as follows:

- I. Immature
- II. Development virgin or recovering spent (ovary or testes)
- III. Maturing
- IV. Mature
- V. Ripe
- VI. Spent

Alcala & Alcazar (1979) separated developing virgin from recovering spent and came up with the following seven stages, each with the size range of the ovary:

- I. 14 to 70 mm (chromatin nucleolus and early perinucleolar oocytes)
- II. 14 to 238 mm (late perinucleolar and yolk vesicle oocytes)
- III. 56 to 350 mm (yolk vesicle and primary yolk oocytes)
- IV. 210 to 364 mm (secondary and tertiary yolk oocytes)
- V. 266 to 406 mm (mature oocytes)
- VI. 336 to 420 mm (ripe eggs)
- VII. 14 to 70 mm (resting or resorbing oocytes)

The maturation stages above are based on the general scheme of Yamamoto & Yamazaki (1967) for gold fish. Although Ntiba and Jaccarini (1990) also listed seven maturation stages, they based this classification on a modified Nikolsky scheme.

The stages in oocyte development in some rabbitfish species have been identified (Soh & Lam 1973; Laviña 1975; Tseng & Chan 1982; Avila 1984). Lavina (1975) suggested two gonadal cycles in *S. canaliculatus*. One cycle starts from perinucleolar stage to ripe egg stage in 4.5 months. In *S. guttatus*, vitellogenesis is completed usually within 27 to 28 days (Soletchnik 1984). In *S. sutor*, Ntiba and Jaccarini (1992) observed a strong bimodal size frequency distribution of oocytes in stage 4 and 5 suggesting that egg development is group - synchronized. They also found atresia to be prevalent in pre- and post- spawning stages.

The rate of maturation is influenced by environmental conditions (Lam 1974). Lam & Soh (1975) found that 18 h light and six h darkness retarded gonad maturation of *S. canaliculatus*. Hussein (1986) believed that gonadal maturation of *S. rivulatus* is activated by increase in temperature and prolonged photoperiod. Lavina (1975) observed that photoperiod is more positively correlated with seasonal changes in the gonads than is rainfall or prevailing wind.

In *S. guttatus*, quantity and quality of diet are important factors for maturation. Most females fed with a commercial diet containing 43% protein spawned monthly for 11 months (Soletchnik 1984). When lecithin, cod liver oil, or both were added to the diet, spawning occurred for at least four consecutive months (Hara et al. 1986c.)

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Fecundity and Gonadosomatic Index (GSI)

Estimates of absolute fecundity in *S. canaliculatus* with 11.1-11.5 cm body length vary from 166000 to 1 000 000 eggs (Alcala & Alcazar 1979; Lam 1974; Hasse et al 1977; Woodland 1979; Tseng & Chan 1982; Madeali 1985, Al Ghais, 1993). Tseng & Chan (1982) observed that larger fish give more eggs.

In *S. corallinus*, the number of oocytes per gram mature ovary ranges from 13 050 to 31 269 (Gajeelee 1988). Weight of ovary and fecundity of the fish increase with size of fish. He claimed that ovaries constituted 5.04 to 7.8% of total body weight of the fish.

A 400-g *S. guttatus* with 13.8 gonadosomatic index (GSI) spawned 0.8 million eggs; another 520-g fish with 12.6 GSI had 1.2 million (Soletchnik 1984). Hara (1987), on the basis of a weekly monitoring for 12 months of GSI and egg size in fish in Cebu-Bohol waters (Philippines), suggested that fish with GSI greater than 7.0 may spawn.

The GSI of *S. canaliculatus* was observed to be highest during new moon (Alcala & Alcazar 1979), indicating that spawning is at about this period. Aradi and Shams (1993) using GSI of 1029 males and 1297 females claimed that spawning occurred from Mar-May with a peak in April. In *S. vermiculatus*, GSI reaches its peak between November and February when the temperature is highest (Alcala 1979).

S. rivulatus has a GSI of 10.3-15.1 (Hussein, 1986). A 15-28 cm fish has a fecundity of 103, 200 to 396 600. Its relative fecundity (2160 eggs/g BW for 15 cm; 1391 eggs/g BW for 28 cm) gradually decreased as fish increased in size.

ARTIFICIAL PROPAGATION

Spawning

Natural Spawning. Natural spawning of captive fish has been observed in *S. argenteus* (Tobias 1976; Luchavez & Carumbana 1982), *S. canaliculatus* (McVey 1972), *S. chrysophilos* (Tridjoko et al. 1985); *S. guttatus* (Soletchnik 1984; Juario et al. 1985; Hara et al. 1986), *S. rivulatus* (Popper et al. 1973), *S. virgatus* (Tridjoko et al. 1985) and *S. vermiculatus* (Popper & Gtmdermann 1976). McVey (1972) opined that tidal level is the most important factor in the spawning of *S. canaliculatus*; this agrees with Manacop's (1937) contention that this species spawns when the tide recedes. Laviña & Alcala (1974) reported spawning at night in the open water near the surface.

At SEAFDEC Aquaculture Department, *S. guttatus* broodstock spawn monthly in 6-m diameter canvas tanks with little change in water

level. Natural spawning follows a lunar cycle; *S. guttatus*, for example, spawns 2-3 days after the first lunar quarter the whole year round (Hara et al. 1986c).

Induced Spawning. Rabbitfishes have been successfully induced to spawn spontaneously by hormonal treatment (Table 2). *Siganus guttatus* with oocytes ≥ 0.46 mm spawned after one injection of 500 IU human chorionic gonadotropin (HCG)/250 g fish weight; those with oocytes ≤ 0.43 mm did not spawn or spawned only after several injections (Juario et al. 1985). Ayson (1991) induced female *S. guttatus* with egg size of 0.42-0.47 mm to spawn after two injections of 2 IU HCG/g BW. He observed that the lag time from second HCG injection to spawning was inversely related to the initial egg diameter. Fertilization rate, hatching rate, total number of eggs spawned and number of larvae produced were the same as those in natural spawning. Soh & Lam (1973) observed that in *S. canaliculatus* only fish at Stage 2 oocyte development responded to HCG treatment. Thus, response of fish to hormonal injection depends on the stage of oocyte development. Harvey et al. (1985) reported that luteinizing hormone-releasing hormone analogue (LHRHa) treatment of *S. guttatus* via pellet implantation advanced spawning in both the first and second gonadal cycles following treatment, suggesting that the silastic implant may affect ovulation for as long as two months after implantation. Clomiphene citrate is also effective in inducing spawning of *S. guttatus* (Anon 1983). Lam (1974) speculated that environmental change (probably a drop in water level) is needed to stimulate spawning in rabbitfishes. Bryan et al. (1975) believed that stress and excitement due to handling triggered spawning in hormone-treated *S. canaliculatus*. Handling stress also enhanced monthly spawning in *S. guttatus* but to ensure 100% spawning exogenous gonadotropin is needed (Ayson 1989). Burgan & Zselezky (1979) claimed that reduction of water level provided adequate stress to induce spawning in *S. argenteus*.

While female fish can be successfully induced to spawn by hormonal (Harvey et al., 1985; Juario et al., 1985; Ayson, 1991), dietary (Hara et al. 1986c), and physical (Ayson, 1989, Bryan et al., 1975), manipulation; the spermiation response of mature male rabbitfish is little worked out. Using 20 μg of LHRHa, Garcia (1991) obtained highest milt production (4.9 ml/kg BW) in *S. guttatus* at 24 h after injection which coincided with low spermatocrit (68%) and sperm density (14.1×10^6 spermatozoa per μl milt). Milt production was sustained with 3 consecutive weeks of regular injection of 200 μg of LHRHa (Garcia, 1993).

Oviposition. The eggs released during one natural spawning in *S. guttatus* (Soletchnik 1984) constitute about 12% of the number of ovarian oocytes and some 5-10% body weight loss of the females every month.

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Table 2. Induced spawning of rabbitfish

Species	Hormone used	Dosage per injection	Remarks	References
<i>S. argenteus</i>	HCG	0.25 IU/g	one out of 3 spawned 96 h after first injection	Popper et al. 1979
<i>S. canaliculatus</i>	HCG	0.25-3.0 IU/g	fish spawned after 5-6 injections	Soh & Lam 1973
<i>S. guttatus</i>	HCG	0.25 IU/g	two out of 4 spawned after 5 injections	Westernhagen & Rosenthal 1976
	HCG	2.0 IU/g	one out of 4 spawned after 4 injections	Palma 1978
<i>S. luridus</i>	Clomiphine citrate	2.0/mg/g fish	fish spawned after 2 injections	Anon 1983
	HCG	2.0 IU/g	response dependent on initial oocyte diameter	Juario et al. 1985
<i>S. rivulatus</i>	LHRHa	2.0 IU/g	100% spawning	Ayson 1991; 1989
	HCG	6.7 mg/pellet/ 250 g fish	fish spawned 8-9 days after pellet implantation	Harvey et al. 1985
		0.25 IU/g	fish spawned 96 h after first injection	Popper et al. 1979
<i>S. vermiculatus</i>	HCG	0.5 IU/g	fish spawned 60 h after first injection	Popper et al. 1979
		0.25 IU/g	fish spawned 36 h after first injection	Popper et al. 1979
<i>S. argenteus</i>	HCG	2.0 IU/g	fish spawned after 2 injections	Avila 1984
			at 24 h interval	
			fish spawned 115 h after first injection, 15 h after second injection, 23 h after third injection	Popper & Gundermann 1976

Spawning Behavior

McVey (1972) noted that for *S. canaliculatus* in captivity, the female would nudge the abdomen of the male to encourage the latter to release milt. As soon as the male responded, the female would then release the eggs. Avila (1984) observed the same behavior in *S. vermiculatus* and noted that the demersal eggs get fertilized before settling on the substrate. Thus, dispersal of spermatozoa in the water column seconds before oviposition by the female assures that the maximum number of eggs is fertilized as the latter sink into the water. Wave action mixes eggs and sperm together (Lam 1974).

For *S. vermiculatus* in the wild, the smaller fish, presumed to be male, is the one which occasionally touches with its snout the anal region of the larger fish (female) (Gundermann et al. 1983). This spawning behavior is evident only on the 7th and 8th days of the lunar month.

In *S. guttatus*, Hara et al. (1986b) observed that the male chases and nudges the abdomen of the female. The male continues to swim close to the female, now and then nudging in sequence the operculum, anal region, and caudal peduncle. The female then releases its eggs, and the male, more milt, and both fish swim actively around the tank. This spawning behavior is similar to that of *S. vermiculatus* (Gundermann et al. 1983; Popper & Gundermann 1975), *S. canaliculatus* in the wild (Manacop 1937), and *S. rivulatus* and *S. luridus* in captivity (Popper & Gundermann 1975).

Lunar Periodicity

Where known, spawning rhythm in rabbitfish is lunar (Table 3). All observed spawnings took place between new moon and full moon.

Results of a one-year study on the reproductive cycle of *S. guttatus* in Cebu-Bohol waters (Philippines) concur with the earlier observation that the fish in captivity spawns during the first quarter of the moon (Hara et al. 1986c).

Spawning Seasons and Spawning Grounds

Most rabbitfishes have a definite spawning season (Table 4). Captive *S. guttatus* spawns throughout the year. Repeated spawnings by a single female were reported in *S. vermiculatus* (Alcala 1979), *S. guttatus* (Hara et al. 1986c), and possibly also in *S. canaliculatus* (ripe females were observed 1.5 months after first spawning) (Bryan et al. 1975).

Large schools of *S. canaliculatus* spawn as the tide recedes in tidal flats, large Enhalus flats, or wide mangrove areas accessible from the

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Table 3. Lunar periodicity in spawning of rabbitfish

Species	Lunar phase	Time of day	References
<i>S. argenteus</i>	2-4 days after new moon	early morning	Luchavez & Carumbana 1982; Burgan & Zselezky 1979; Hasse et al. 1977; Bryan et al. 1975; Manacop 1937
<i>S. canaliculatus</i>	4-7 days after new moon	midnight or early morning	Bryan & Madfaisau 1977
<i>S. lineatus</i>	3 days before full moon	late afternoon	
<i>S. luridus</i>	on or around first quarter	-	Popper et al. 1976; Popper & Gundermann 1975; Soletchnik 1984
<i>S. guttatus</i>	2-5 days before full moon	-	
	2-3 days after first quarter	-	Harvey et al. 1985
	between new moon and full moon	2200-1000 h	Hara et al. 1986c
	maximum around first quarter	1400-1800 h	Hara et al. 1986c
<i>S. rivulatus</i>	on or around new moon	early morning	Popper et al. 1979
<i>S. spinus</i>	1-4 days after full moon	-	Johannes 1978
<i>S. javus</i>	5-4 days before full moon	-	Sunyoto et al. 1990
<i>S. virgatus</i>	7 days before-7 days after full moon	-	Waspada, 1984
<i>S. vermiculatus</i>	on or around first quarter	-	Popper et al., 1976

Table 4. Spawning season of rabbitfish

Species	Spawning season	References
<i>S. argenteus</i>	Philippines: Feb-Sept	Luchavez & Carumbana 1982
<i>S. canaliculatus</i>	Singapore: Jan-Apr, peak in Feb-Mar; minor in Jul-Oct Philippines: Jan-Apr in some areas Palau: Feb-Jun, peak Apr-May; second season in Oct-Dec Hongkong: Mar-Jun Southern Arabian.Gulf: Mar-May	Soh & Lam 1973 Laviña & Alcalá 1974; Manacop 1937 McVey 1972; Drew in Lam 1974; Bryan et al. 1975; Hasse et al. 1977 Tseng & Chan 1982 Al-Ghais, 1993 Aradi & Shams, 1993
<i>S. fuscescens</i>	Japan: July-Aug Philippines: Mar-Sept (peaks Aug-Sept)	Okada 1966 del Norte & Pauly, 1990
<i>S. guttatus</i>	Philippines: whole year	Soletchnik 1984; Hara et al. 1986c
<i>S. lineatus</i>	Palau: Feb-Mar; sometimes in Aug	Drew in Lam 1974
<i>S. luridus</i>	Mediterranean: Apr-Sept	Popper & Gundermann 1975
<i>S. rivulatus</i>	Mediterranean: May-Aug	Popper & Gundermann 1975
<i>S. vermiculatus</i>	Fiji: Sept-Feb, peak in Nov-Feb	Gundermann et al. 1983

open ocean (Manacop 1937; Hasse et al. 1977). *Siganus spinus* spawns on the fringed reefs in Guam (Ikehara 1968) whereas *S. lineatus* is suspected to spawn near mangroves (Drew in Lam 1974).

S. spinus spawns in deeper water with early juveniles entering the reef flat nursery ground from March to May as they shift from a pelagic to an epibenthic mode of life (Campos et al., 1994). The juveniles remain in the reef flat until the onset of maturation (Feb-Apr) when massive emigration from the reef flat occurs.

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EGGS, LARVAE, LARVAL CULTURE

Eggs

Morphology. Ripe eggs of rabbitfishes are demersal, strongly adhesive, small, and spherical with many oil globules (Lam 1974; Leis & Rennis 1983), except those of *S. argenteus* which are free-floating and non-adhesive (Burgan & Zselezky 1979; Luchavez & Carumbana 1982). Manacop (1937) thinks that the reticulations on the egg membrane of *S. canaliculatus* is responsible for the adhesiveness of eggs. Such reticulations, however, are not evident in eggs of *S. guttatus* (Hara et al. 1986b). Avila (1984) described a thin, adhesive coating of the chorionic membrane in *S. vermiculatus*. Hasse et al. (1977) believed that this sticky layer enables the eggs to attached to floating pieces of plants for camouflage and flotation at the spawning site.

Fertilized eggs measure 0.42-0.70 mm in diameter and take 18-35 h to hatch at 22-30°C (Table 5) (Lam 1974). The eggs of *S. argenteus* said to be 0.29 mm in diameter (Luchavez & Carumbana 1982) were probably unfertilized. Westemhagen & Rosenthal (1976) observed the dependence of egg size on incubation salinity in *S. canaliculatus*.

Embryonic Development. Essentially the same embryonic development has been described for *S. canaliculatus* (Manacop 1937; Soh & Lam 1973; Westemhagen & Rosenthal 1975), *S. vermiculatus* (Avila 1984), *S. argenteus* (Burgan & Zselezky 1979; Luchavez & Carumbana 1982), *S. rivulatus* (Popper et al. 1973), *S. fuscescens* (Fujita & Ueno 1954), *S. guttatus* (Juario et al. 1985; Hara et al. 1986b) (Fig. 2). Depending on temperature, species, and locality, incubation period ranges from 18 to 35 h (Table 5), except in *S. canaliculatus* (62 h) (Manacop 1937).

Distribution. There is no available information on the distribution of rabbitfish eggs in nature, presumably due to the difficulty in sampling demersal, adhesive eggs. Eggs of *S. canaliculatus*, according to Manacop (1937), are laid on substrates but Hasse et al. (1977) failed to find any after an extensive search in *Thalassia-Enhalus* flats or in mangrove areas.

Larvae

Morphology. Newly hatched larvae are pelagic, very fragile, and measure 1.5-2.6 mm TL (Table 6). The gut is straight, the eyes are unpigmented, and the mouth still unformed. The yolk sac is oval with a single oil globule protruding at the anterior portion; in *S. guttatus* the yolk measures 0.70x0.24 mm and has two oil globules (Hara et al. 1986b). Larvae have melanophores on the snout, yolk and oil globules,

Table 5. Egg size and incubation period, temperature and salinity of rabbitfish

Species	Egg diameter (mm)		period (h)	Incubation temperature (°C)	salinity (ppt)	References
<i>S. argenteus</i>	0.62-0.68					Popper et al. 1979
	0.65		24-26	27-28	34	Burgan & Zselezky 1979
	0.29-0.70		24-26	26.4-28	34	Luchavez & Carumbana 1982
<i>S. canaliculatus</i>	-		62	-	ambient	Manacop 1937
	0.505		30	27-29	20.9-32	Westemhagen & Rosenthal 1976
	0.42-0.46		30-35	25-27	26.28.5	Soh & Lam 1973
	0.55		-	-	-	May et al. 1974
	0.65		32-34	22-23	-	Akatsu et al. 1983
<i>S. chrysoptilos</i>	0.62		24	-	-	Tridjoko et al. 1985
<i>S. fuscescens</i>	0.62-0.66		27	23.5-25.6	-	Fujita & Ueno 1954
	0.62±0.018		30-35	23-24	-	Kitajima et al. 1980
<i>S. guttatus</i>	0.46		28-31	25.27	-	Palma 1978
	0.53-0.58		-	-	-	Soletchnik 1984
	0.55		20-26	26-30	ambient	Juario et al. 1985
	0.55-0.57		-	-	-	Hara et al. 1986b
	0.54-0.60		18-20	26-28	31-34	Hara et al. 1986c
<i>S. luridus</i>	0.55-0.57		-	-	-	Alcazar & Luchavez 1986
	0.50-0.63		-	-	-	Popper et al. 1979
	0.51-0.58		18-21	26.28	ambient	Nelson & Wilkin 1994
	0.48		29-30	25.5-27	-	Hussein, 1986; Popper et al. 1973
	0.56		24	30	-	Popper et al. 1976
<i>S. vermiculatus</i>	0.52		23.24	-	-	Avila 1984
			24	-	-	Tridjoko et al. 1985

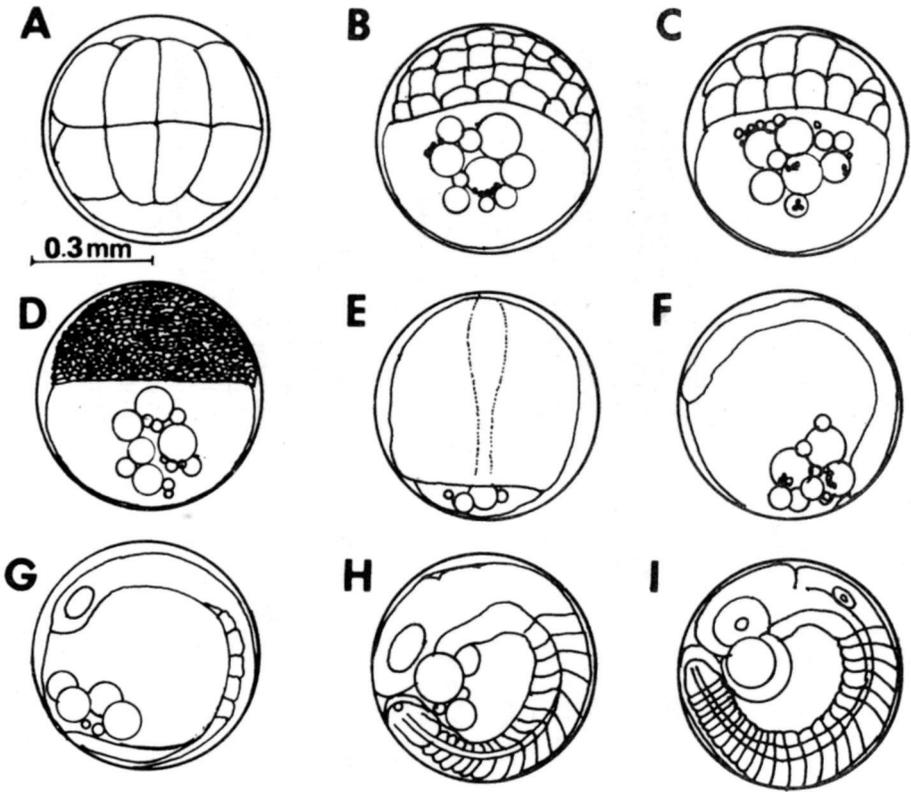


Fig. 2. *Siganus guttatus*: embryogenesis. A. 8-cell stage, 30 min after fertilization (AF). B. 32-cell stage, 70 min AF. C. Morula stage, 85 min AF. D. Blastula stage, 2 h AF. E. Embryonic shield, 5 h, 45 min AF. F. Embryonic body developed, 7 h AF. G. 6-myomere stage, 7 h, 40 mn AF. H. 16-myomere stage, 11 h, 20 min AF. I. 1.24-myomere stage, 13 h AF (After Hara et al., *Aquaculture* 59:278. 1986).

and along the ventral side of the body (Fujita & Ueno 1954; May et al. 1974; Burgan & Zselezky 1979; Hara et al. 1986b). They possess 24 myotomes (Fujita & Ueno 1954; Leis & Rennis 1983; Hara et al. 1986b).

Development. Artificial fertilization of rabbitfish eggs was reported by Manacop as early as 1937 but larval development for the first 48 h was first described much later in *S. fuscescens* by Fujita & Ueno (1954). Larvae of other species were later studied in the laboratory, and a comparison of some aspects of their development is presented in Table 6. The most detailed description is by Hara et al. (1986b) for *S. guttatus* (Fig. 3).

Table 6. Larval size at hatching and time from hatching to onset of feeding, complete yolk resorption and metamorphosis in rabbitfish

Species	TL(SL) at hatching (mm)	Onset of feeding (h)	Yolk resorption (h)	Metamorphosis	Rearing temperature (°C)	References
<i>S. argenteus</i>	2.5	48	96	-	26-27	Burgan & Zselezky 1979
	1.54-1.68	48	48	-	26-30	Luchavez & Carumbana 1982
<i>S. canaliculatus</i>	1.5	-	-	-	28	Manacop 1937
	1.55	31	42	-	-	Soh & Lam 1973
	2.10	48	48	2.1	28-32	May et al. 1974
<i>S. chrysocephalus</i>	2.3	-	-	-	-	Tridjoko et al. 1985
<i>S. fuscescens</i>	2.6	48	48	-	-	Fujita & Ueno 1954
	2.1	-	-	17	23-25	Kitajima et al. 1980
<i>S. guttatus</i>	1.5-1.6	-	-	-	-	Soletchnik 1984
	1.98	48	72	24	26-30	Juario et al. 1985
	1.50	50	72	-	-	Bagarinao 1986
	1.74	40	60	8	-	Kohno et al. 1986
	1.62-1.64	48	48	45	27-29	Hara et al. 1986c
<i>S. lineatus</i>	2.50	-	-	29	24-27	Bryan & Madraisau 1977
<i>S. luridus</i>	-	48	-	-	25-32	Popper et al. 1979
<i>S. rivulatus</i>	1.80-2.30	43	68	-	25-28	Popper et al. 1973
<i>S. vermiculatus</i>	1.8	-	-	22	30	Popper et al. 1976
	1.75	-	-	23-25	26-28	Avila 1984
<i>S. virgatus</i>	2.5	-	-	18-26	-	Gundermann et al. 1983
						Tridjoko et al. 1985

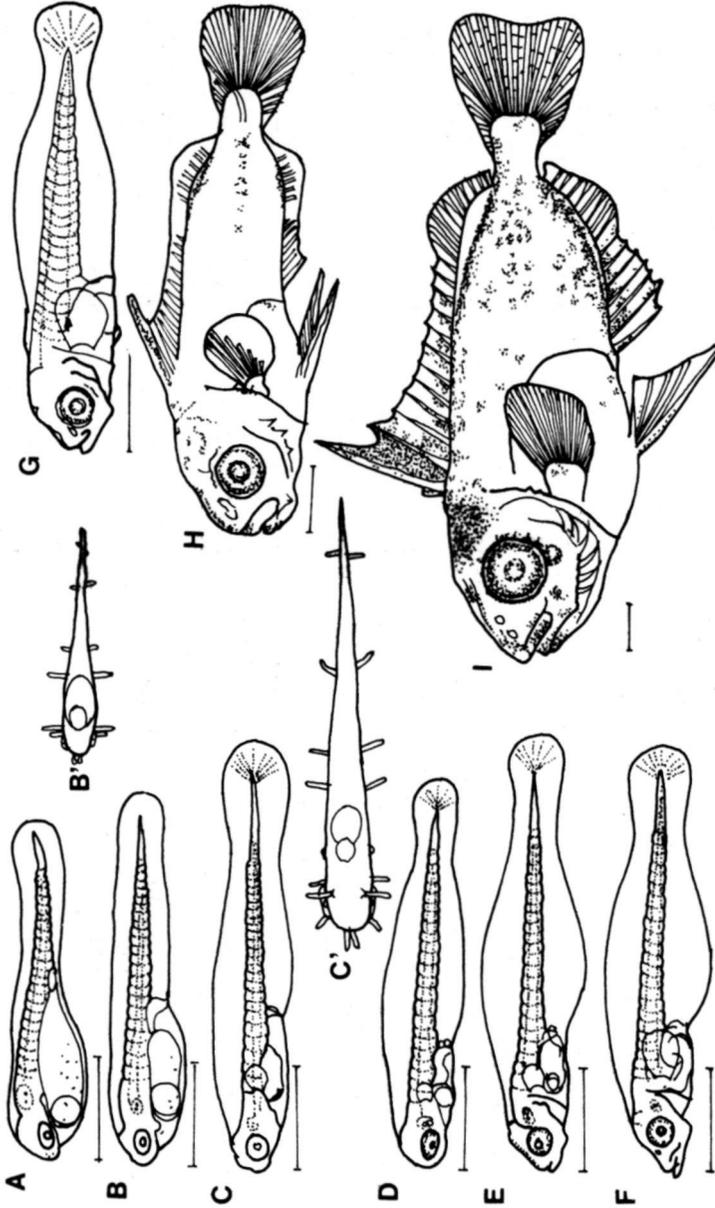


Fig. 3. *Siganus guttatus*: larval development. A. Newly hatched. 1.72 mm TL (total length). B. 6 h after hatching (AH, 2.15 mm TL. B. Same in B but schematic to show neuro-mast cupulae. C. 13 h AH, 2.80 mm TL. C. Same as in C but schematic to show neuro-mast cupulae. D. 24 h AH, 3.00 mm TL. E. 39 h AH, 2.84 mm TL. F. 2 days old, 2.75 mm TL. G. 8 days old, 4.40 mm TL. H. 13 days old, 7.92 mm TL. I. Juvenile, 17 days old, 13.07 mm TL. Scales: A-F, 0.5 mm; G-I, 1.0 mm (After Hara et al., *Aquaculture* 59:280-281, 1986).

Cupulae on free neuromasts were first observed and recorded in *S. guttatus* by Hara et al. (1986b). These appear 6 h after hatching (TAH) and disappear after 39 h. Their presence makes the larvae highly sensitive and difficult to capture with pipettes. When handled, the larvae die. Cupulae were also seen in larval *S. fuscescens* (Pantoja & Kadowaki 1988). Kohno et al. (1986) showed that in *S. guttatus* the dorsal and ventral fin rays begin to develop at 3.93 mm TL, the notochord flexion is completed at about 6.5 mm TL, and the adult complement of fin rays is attained at about 8.0 mm TL. The premaxillae appear at 4.12 mm TL and, as in adult, occupy most of the gape at about 6.5 mm TL. The jaw and pharyngeal teeth start to develop at 4.0-4.5 mm TL, thus there is a change in the feeding habit of the larvae at 7.0-8.0 mm TL.

Hara (1987) also studied the development of head armor or shield and melanophore. The head armor is believed to improve survival of larvae by enhancing flotation and apparently increasing their size to deter predators.

Behavior. Newly hatched larvae of *S. lineatus* and *S. canaliculatus* orient themselves head down, frequently wriggling downward in short burst in the water column (Bryan & Madraisau 1977; Westemhagen & Rosenthal 1975). They aggregate near the surface and on day 1 are difficult to pipette out. Snatch-feeding at few seconds interval at the sides and bottom of the rearing container occurs on day 2 in *S. argenteus* (Luchavez & Carumbana 1982). Larvae of *S. guttatus* on day 12 nibble on algae growing on walls of the tank and on day 15 show aggressive behavior (Juario et al. 1985). They chase and sometimes apparently bite each other's tail or eye region. This behavior becomes more overt as the larvae grow bigger (May et al. 1974). Larvae on day 18 begin to stay deeper in the water column and on day 23 until metamorphosis start to school and swim continuously in search of food.

Larvae of *S. guttatus* exhibit phototaxis and rheotaxis at 2.7 mm TL and 2.6 mm TL, respectively; phototaxis disappears at 9.2 mm TL. The larvae also settle on tank bottom at 19.6 mm TL (Hara 1987).

Growth and Survival. Four species of rabbitfish have been monitored for their growth and survival, i.e., from hatching to metamorphosis (Table 6). *Siganus canaliculatus* larvae with an initial SL of 2.1 mm grow up to 21.8 mm SL by day 33 (May et al. 1974) or from 2.6 mm to 100.8 mm TL on day 90 (Akatsu et al. 1983). Larvae of *S. lineatus* grow from 2.5 mm to 20.3 mm SL on day 33 (Bryan & Madraisau 1977;) and those of *S. fuscescens*, from 2.1 mm to 9.5 mm on day 17 (Kitajima et al. 1980). For *S. guttatus*, size increases to 19.5 mm and 18.3 mm TL are attained on day 35 respectively from 1.62 mm (Hara et al. 1985b) and 1.98 mm TL (Juario et al. 1985).

Metamorphosis usually involves rapid and obvious changes in external appearance. The larval stage when the body is highly transparent and the abdomen is silvery gives way to the juvenile stage when the

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entire body turns light brown as in the adult. This transformation starts on day 23 or 25 for *S. canaliculatus* (May et al. 1974; Akatsu et al. 1983) and day 17 (Juario et al. 1985) or day 24 (Hara et al. 1986b) for *S. guttatus*. Bryan & Madraisau (1977) noted distinct changes in the gastrointestinal tract and feeding behavior during metamorphosis in *S. lineatus*. They described the three stages as follows: (1) darkhead carnivorous stage (premetamorphosis) - the gut longer than SL; (2) brown-head omnivorous stage (concurrent with metamorphosis) - the gut single-coiled and about 18% longer, convoluted into a reversing coil as in the letter "S", and about 25% longer than SL; and (3) juvenile - herbivorous stage (post-metamorphosis) - the gut coiled and about 63% longer than SL. Completely metamorphosed *S. guttatus* is about 8.0 mm TL (Kohno et al. 1986).

The survival rate is 16% from day 0 to day 35 for *S. lineatus* (Bryan & Madraisau 1977); 9% for *S. vermiculatus* in 80 m³ concrete tank (Popper et al. 1976; May et al. 1974); 2-3% on day 46 for *S. fuscescens* (Kitajima et al. 1980); 0.7-37.4% on day 35 (Juario et al. 1985), 4.5-30.1% on day 21 and 3.5-16.6% on day 45 (Hara et al. 1986c) for *S. guttatus*. The survival rate of *S. guttatus* larvae in 500-l tanks is only 0.2-31.6% as against 4.3-38.0% in 5-ton tanks.

To understand the survival mechanism of *S. guttatus*, development of feeding structures and the feeding ecology of the larvae were studied by Ordonio-Aguilar (1995). Its small size at hatching (1.42 mm TL) was offset by the rapid growth rate during the first 16 h although body mass decreased during the first hour after hatching implying yolk loss and tissue catabolism.

At initial opening, the mouth size of *S. guttatus* was only 0.080 mm at 30.5 h TAH (Ordonio-Aguilar 1995). Initial feeding occurred 1.5 h after mouth opening with preference to small rotifers (80-120 μ m). This feeding limitation is offset by the fact that *S. guttatus* larvae are diligent feeders.

Migration. The postlarvae of *S. vermiculatus* migrate during and after metamorphosis from oceanic to coastal waters where they are caught before or on the night of the newmoon (Gundermann et al. 1983). Such a shoreward migration of postlarvae seems to follow a lunar cycle which coincides with the lunar spawning cycle. Most of the fry are collected off attractors in creeks with salinities of 12-15 ppt. Thus the migration is towards brackishwater.

Kishimoto (1984) reported that large groups of pelagic juveniles of *S. argenteus*, *S. canaliculatus*, and *S. spinus* come to settle in coral reef areas during flood tide on the 6th lunar month.

The running distance of larval *S. guttatus* under laboratory conditions average 58.2 cm/min on day 2 1/2 and 70.6 cm/min on day 6 1/2 (M.N. Duray, unpubl. data).

Environmental Conditions for Rearing

There is little available information on the optimum salinity, temperature, and water quality requirements for rabbitfishes during embryonic and larval development. In *S. guttatus*, naturally spawned eggs are more tolerant to salinity changes than inductively spawned eggs (Duray et al. 1986). Eggs transferred to different salinities at gastrula stage also had higher hatching rate and gave more viable larvae than those transferred at blastomere stage. Hatching rate was highest at 24 ppt. Percentage viable larvae was highest also at 24 ppt and lowest at 8 ppt. Larvae from eggs hatched at lower salinities were longer than those from eggs hatched at ambient and higher salinities; the same is true in *S. canaliculatus* (Westemhagen & Rosenthal 1975).

Young and Dueñas (1993) found that naturally spawned eggs of *S. guttatus* tolerate a salinity range of 3 to 71 ppt with 90% hatching rate; inductively spawned eggs tolerate salinities up to 68 ppt. They observed that 50% of the larvae from inductively spawned eggs are normal at 7- 62 ppt or 90% at 10-51 ppt for those coming from naturally spawned eggs. Thus, they recommend 14-37 ppt for the maintenance of yolk-sac larvae. Westemhagen & Rosenthal (1975) reported the narrower salinity tolerance range of 15.8 to 32.2 ppt for the eggs and larvae of *S. canaliculatus*. For *S. virgatus*, Tridjoko (1988) found 30°C and 26 ppt are best for hatching (\bar{x} =86%).

Salinity tolerance and resistance tests conducted on *S. guttatus* of various ages show 0-day-old larvae to be more resistant than 7- or 14-day old to high and low salinity levels (8 to 37 ppt). Older larvae (21-, 28-, 35-day-old) are tolerant of abrupt salinity changes (2 to 55 ppt) (C. Dueñas, unpubl. data). However, Hara et al. (1986c) did not observe significant differences in the survival of *S. guttatus* larvae reared at 20 and 32 ppt. Westemhagen & Rosenthal (1975) considered 32 ppt the optimum for hatching eggs and rearing larvae of *S. canaliculatus*. Lower salinity (20.9 ppt) suffices for successful incubation but is unfavorable for growth and rearing. However, Burhanuddin (1987) considered 20 ppt optimum for growth of *S. vermiculatus* larvae.

Survival of *S. guttatus* larvae is improved when rearing is at lower temperatures (22-26°C) even at ambient salinity (Kohno et al. 1988) but with provision of small-sized *Brachionus* (Duray 1986; Hara et al 1986c). In *S. randalli* oxygen consumption which peaked at hatching was higher in embryos incubated at 30°C than those at 27°C (Collins & Nelson, 1993). Rates of oxygen consumption did not vary with age of the larvae but varied between spawns. They further observed that rates of yolk depletion was also higher at 30°C. Larvae maintained at 30°C completed eye pigmentation 3 h ahead than those maintained at 27°C but the larvae had less endogenous reserves. Continuous (24h) lighting

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period also gives better survival of larvae (Duray & Kohno 1988). The feeding and water management scheme used by Hara et al. (1986c) gives consistently fair survival.

Respiratory rates of larval *S. randalli* at various developmental stages were monitored (Nelson & Wilkins 1994). Larval metabolism increased steadily during embryonic stages and a rapid burst of activity immediately after hatching. Respiration rates stabilized from shortly after hatching until the initial feeding. For post-yolk-sac larvae, respiration rates scaled isometrically with larval dry mass. Daily growth of feeding larvae was estimated to be 27-28% of their dry mass.

FRY AND FINGERLING CULTURE

Juvenile

Larvae attain the juvenile stage once they have acquired the full complement of spines and fin rays characteristics of the adult of the species. Juveniles also closely resemble the adults in body shape and color, and may or may not live in the same habitat as the adults (Table 1). The period during which the juvenile stage is reached varies with the species: 22.0 mm after 45 days from hatching in *S. guttatus*, 20-24 mm after 21 days in *S. canaliculatus*, and 9.5 mm TL after 11 days in *S. fuscescens*. Rate of transformation is affected by temperature, type of food given, etc.

Groups of juvenile rabbitfishes occur in certain coasts at predictable times of the year (e.g., Guam: April to May, last lunar quarter). Each individual generally measures 10 mm. Age of the fish can be determined through its scale. Hussein (1986b) claimed that scale formation in *S. rivulatus* does not start at once and that scales in the posterior body area may virtually secrete the first scales. The juvenile stage begins about 4-12 months from spawning and may last until the first sexual maturity (Rosario 1974; Tseng & Chan 1982; Alcalá 1979; Juario et al. 1985).

Tolerance to Environmental Factors

Rabbitfishes are generally tolerant of wide salinity changes (Ben-Tuvia 1966; Lam 1974; Tobias 1976; Alcalá 1979). Pillai (1962) remarked that rabbitfishes may not tolerate low salinity and high temperature. Carumbana & Luchavez (1979a), however, observed *S. guttatus* juveniles (37-43 mm SL) to be tolerant of these conditions. Mortality was 28%

for *S. guttatus* after 2 days in freshwater, whereas *S. spinus* (9.3-10.1 mm SL) had total mortality in 3 days in 2 ppt. The lower lethal salinity range for *S. argenteus* is 4-7 ppt (Tobias 1976). *Siganus canaliculatus* can tolerate abrupt transfer to a salinity at least 1/3 that of seawater and thrive in as low as 5 ppt if gradually acclimatized (Lam 1974; Miranda 1984). However, the optimum for growth and survival of the species is 10 ppt (Laviña & Alcalá 1974). For *S. vermiculatus*, the tolerance range is 10-50 ppt (Gundermann et al. 1983).

Rabbitfishes are generally capable of adapting to reduced oxygen concentration (Ben-Tuvia et al. 1973; Carumbana & Luchavez 1979a). The lower limit is 2 ppm for *S. canaliculatus* (20-30 mm SL) (Laviña & Alcalá 1974; Lam 1974), 0.7 ppm for *S. guttatus*, 1.0 ppm for *S. argenteus*, and 2.0 ppm for *S. vermiculatus* (Carumbana & Luchavez 1979a; Tobias 1976). The variation in tolerance to low oxygen is related to the differences in metabolic rate among species.

Juveniles can tolerate temperature changes between 23 and 26°C (Drew in Lam 1974; Alcalá 1979). Lam (1974) reported *S. canaliculatus* to be sensitive to high pH, but Gundermann et al. (1983) credited the species with tolerance to a wide range of pH, perhaps because of the differences in the size or age of the fish used. Other species like *S. luridus* and *S. rivulatus* are also tolerant of rough handling and over-crowding (Ben-Tuvia et al. 1973).

Growth and Survival

Many studies on the growth of rabbitfish have conflicting results perhaps due to variations in culture system and diet (Catanaoan 1965; Westemhagen & Rosenthal 1975; Tahil 1978a; Carumbana 1983). Growth of fry and fingerlings is generally slow and the average growth rate of the same species varies with the holding system (Table 7). It should be pointed out that during culture, growth may be faster at some periods and slow in others. Horstmann (1975) gives the highest values at 5.0-6.5 g/week for all the species studied. Growth of *S. guttatus* in cages is slow in early juvenile phase but rapid in pre-adult phase (Tahil 1978a; E. Laviña, pers. comm.). In *S. rivulatus*, growth in length also increases rapidly in the first 2 years and thereafter decreases markedly; growth in weight shows the opposite trend (Hashem 1983). For *S. virgatus* in floating cages, however, growth in weight is increased if pellets, fish chow and *Sargassum* are given as supplemental food (Ismael 1976). The growth pattern is isometric in *S. javus* and *S. vermiculatus* and allometric in *S. canaliculatus*, *S. virgatus*, *S. chrysospilos* (Merta 1982; Panggabean 1983), *S. corallinus*, and *S. guttatus* (Djamali 1978). Lazarus & Reddy (1986-87) also reported significant deviations in the cubic values of length-weight in *S. canaliculatus* and *S. javus* from the coastal waters of Madras.

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Table 7. Average growth rate of rabbitfish in different holding systems.

Species	Holding system	Culture period	Wet weight Initial (g)	Wet weight Final (g)	Weight gain per week*	References
<i>S. canaliculatus</i>	tanks	5.5 mo	4.0	4.0	1.6	Al Aradi et al. 1980
	pond	-	-	-	2-2.25	Son & Lam 1973
	floating cage	4 mo	10.0	114.0	6.5	Horstmann 1975
	concrete tank	3 mo	0.34	7.85	0.63	Rosario 1974
	floating cage	6 mo	61.0	79.9	0.79	Baga & Sacayanan 1980
	aquaria	4 mo	0.76	7.89	0.44	Carumbana & Luchavez 1979a
	floating cage	2 mo	3.76	12.93	1.15	Carumbana & Luchavez 1979a
	tank	6 mo	0.49	1.34	0.04	Miranda 1984
	floating cage	9-11 mo	-	-	3.30	Lam 1974
	cage	2 mo	7.5-24.0	-	-	James et al. 1980
<i>S. guttatus</i>	cage	4 mo	4.7	52.2-96.6	2.8-5.3	Kungvankij et al. 1990
	cage	30 days	29.8	60.97	7.79	Ismael & Soeharmoko 1989
	floating cage	3 mo	12.0	75.0	5.20	Horstmann 1975
	floating cage	6 mo	15.49	33.56	0.75	Tahil 1978a
	fish pen	6 mo	15.47	34.47	0.79	Tahil 1978a
	floating cage	2 mo	4.55	29.2	3.07	Carumbana & Luchavez 1979a
	pond	6 mo	1.64	62.45	2.37	Miranda 1984
	floating cage	52 days	0.15	13.78	1.83	Ponce 1983
		4 mo	12.09	77.7	4.1	Toledo 1992
				(formulated) feed		

table 7, continued...

Table 7 (cont.)

Species	Holding system	Culture period	Wet weight Initial (g)	Wet weight Final (g)	Weight gain per week*	References
<i>S. javus</i>	pond	6 mo	4.27	40.8 (lumut)	1.8	Toledo 1992
		5 mo	11.02	49.5	1.83	Luchavez 1986
		2 mo	2.25	38.9	1.39	Luchavez 1986
	tank pond	1 mo	2.57	14.6	1.55	Luchavez 1986
		6 mo	1.33	16.2	3.39	Luchavez 1986
		180 days	3.0-4.2	5.15	0.16	Miranda 1984
<i>S. lineatus</i>	pond	52 days	0.15	16.1-42.8	0.67-1.78	Ganzon-Naret 1991
		42 days	4.74	9.97	1.31	Ponce 1983
	floating cage	30 days	23.57	12.75	1.33	Basyari & Tanaka 1989
		30 days	23.57	13.0	1.28	Ismael & Soeharmoko 1989
<i>S. punctatus</i>	pond	52 days	0.15	7.29	0.95	Ponce 1983
		1 mo	-	-	3.50	Drew in Lam 1974
<i>S. randalli</i>	pond	3 mo	8.0	68.0	5.00	Horstmann 1975
		112 days	13.6	121.7	6.75	Brown et al. 1994
<i>S. rivulatus</i>	pond	2 mo	7.3	28.5	1.93	Ben-Tuvia et al. 1973
		6 mo	3.0	102.0	4.95	Lichatowich et al. 1984b
<i>S. spinus</i>	pond	1 mo	0.91	3.7	0.69	Ben-Tuvia et al. 1973
		3.3 mo	5.0	71.0	0.50	Chervinski 1972
	floating cage	4 mo	15.0	98.0	0.90	Hortsmann 1975
		4 mo	15.0	97.0	5.12	Hortsmann 1975
<i>S. vermiculatus</i>	pond	45 days	0.26	4.5	0.70	Westmhagen 1974
		4 mo	0.76	8.89	0.51	Carumbana & Luchavez 1979a
<i>S. vermiculatus</i>	pond	6 mo	2.0	175.0	1.52	Lichatowich & Popper 1975
		6 mo	1.47	5.37	0.16	Miranda 1984
<i>S. vermiculatus</i>	pond	6 mo	1.64	62.65	2.38	Miranda 1984

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According to Miranda (1984), the suitable stocking rate in ponds is 50 fish/m². Growth is faster but survival is lower when rice bran is fed. *Lumot* (filamentous green algae) is a better food than *lab-lab* (a complex of blue-green algae, diatoms, bacteria others).

Growth is faster in *S. vermiculatus* and *S. guttatus* than in *S. canaliculatus* in both pond (Miranda, 1984) and floating cage cultures (Horstmann 1975; Carumbana & Luchavez 1979a; Ponce 1983); however Westemhagen & Rosenthal (1975) believe otherwise, i.e., that *S. guttatus* is a slow grower than *S. canaliculatus*.

In tanks, *S. canaliculatus* fingerlings (13 g) fed commercial seabream diet (55% crude protein) showed superior growth at 30 fish/m³ and a feeding rate of 2.3% BW (El-Sayed et al., 1993). At 45 and 60 fish/m³, optimum growth and feed utilization efficiency was obtained at 4-5% BW.

Growth and survival rates of *S. canaliculatus* juveniles decrease at salinities higher than 32 ppt or lower than 10 ppt (Carumbana & Luchavez 1979a). Better growth of *S. rivulatus* is obtained at 30 ppt than at 20 and 50 ppt, but these salinity levels have no significant effect on the growth of *S. luridus* (Popper & Gundermann 1975). Growth and survival of *S. argenteus* are also better at 20 ppt than at 10 and 30 ppt.

Mangaoang's (1982) study based on otoliths of three species shows that captive fish have lower growth rates than those in the wild. Ntiba and Jaccarini (1988) also used otolith microbands as a measure of age in days for *S. sutor* in Kenyan shores. Gundermann et al. (1983) claim, however, that growth rate is the same for wild and pond-cultured *S. vermiculatus*. Data on growth of wild juveniles are nil. Laviña & Alcalá (1974) attempted to determine growth rate of wild *S. canaliculatus* by the capture-recapture method. One fish grew 1.4 cm when recaptured after 14 days, and another, 0.90 cm after 27 days.

The culture methods in different holding systems for the different species need to be standardized. Since growth is generally slow at the early stages, application of thyroxine and other growth-promoting substances at this stage may be tried.

Fry Grounds and Seasonal Occurrence

Rabbitfish fry are collected in the vicinities of sea grass communities and reef flats. They usually appear in various sizes, usually 1.0-cm long, according to Urmaza (1983), and in dense schools. Their appearance is closely related to the lunar cycle (Table 8). Aragonés (1987) reported a size of 2-3 cm SL for *S. canaliculatus*, 2-4 cm SL for *S. spinus*, 4.6-5.6 cm SL for *S. argenteus* caught in northern Philippines. Blanco & Villadolid (1939) enumerated the important fry grounds in the Philippines.

Table 8. Seasonal occurrence of rabbitfish fry

Species	Season	Lunar phase	Length (cm)	Reference
<i>S. argenteus</i>	Guam: Apr-May	± 2 days of 3rd quarter new moon	5.4-6.4	Tobias 1976
	Philippines: May-June : Mar-May	3rd quarter-new moon	2.6	Burgan & Zselezky 1979
<i>S. canaliculatus</i>	Mediterranean: Jul-Sept	-	4.6-5.6	Aragones 1987
	Philippines: May-Jun	2 days after new moon	6.0-7.0	Al-Arabi et al. 1980
	: Mar-Sept	3rd quarter to new moon	2.0-3.0	Laviña & Alcalá 1974
	Indonesia: Aug-Sept; May	-	2.0-3.0	Aragones 1977 Hutomo & Martosewojo 1977
<i>S. fuscescens</i>	Western Caroline: Apr-May	around new moon	2.0-3.0	Hasse et al. 1977
	Philippines	2-3 days after new moon	2.0-3.0	Laviña 1975
	Philippines: year round	-	-	dela Paz & Aragones, 1990
	Mediterranean: summer and fall: May-Sept	3-5 days before full moon	3.0 g*	Lichatowich et al. 1984b
	Guam: Apr-May	1-2 days after 3rd quarter	1.5-2.0	Lichatowich et al. 1984 b
<i>S. rostratus</i>	Guam: Apr-May; Jun-Oct	± 2 days after 3rd quarter	8.0	Tsuda & Bryan 1973
	Philippines: year round	3rd quarter to new moon	4.5	Tsuda & Bryan 1973
<i>S. spinus</i>	Philippines: Mar-Apr; Sept-Nov.	-	2.0-4.0	dela Paz & Aragones, 1990
<i>S. virgatus</i>	Fiji: Oct-Mar	1st day of new moon	-	dela Paz & Aragones, 1990
Mixed species	Philippines: May-Jun	2-3 days after new moon & full moon	2.5-3.0 1.0-4.0	Gundermann et al. 1983 Tahil 1978b; Calvelo & Ginon 1974; Blanco & Villaloid 1939

*No data on length.

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Capture of Fry

Juveniles are collected by push nets, scoop or seine nets, throw nets, lift nets, and fyke nets (Pillai 1962; Anon 1979; Lichatowich et al. 1984a; Wijeyaratne et al. 1996). In Pangasinan, northern Philippines, juveniles are caught by bag nets in deep waters and by beach seine and fish corral in the reef flats (Aragones, 1987; 1989). In the reef flat, they are exploited by gill net and by spearfishing (Campos et al. 1994). The bamboo trap *bubu* (Ismael & Nuraini 1983; Conrad 1987) is used, for example, in grass beds (*Halophylla*). Artificial light is used at times to attract the fish. Filamentous green algae are also used as lures (Pillai 1962; Ben-Tuvia et al., 1973; Ablan & Rosario 1962) and the fish are then scooped by nets. In Okinawa, the traditional food *shuk-garasu* is offered when juveniles come close to shallow corraline areas. The fish are then caught by dip net or drain net (H. Kohno, pers., comm.). Ungson (1990) estimated about 12.2 million fry caught in Ilocos Norte, Philippines in 1987.

Lichatowich et al. (1984a) reported the use of a mobile fyke net for mass collection of fry. Daily catches ranged from 800 to 1,200 per set for 5,000-7,000 individuals.

Transport and Handling of Fry

Fry transported over long distances are packed in earthenware pots or double-layered plastic bags placed in buri or pandan bags for further protection. Plastic bags of size 50 x 75 cm are most convenient. The bagged fry or fingerlings are supplied with oxygen. Each bag may contain 200 fry (1-cm long) or less if fry are bigger. If the destination is to a nearby farm, the fry is just placed in fine mesh bamboo or cane baskets and towed to the pond (Urmaza 1983).

Ayson et al. (1990) using 2.1 cm TL *S. guttatus* (47 days old) recommend a packing density of 100 fish/L for 8 h transport, 300 fish/1 for 2 h at 28°C and 32 ppt transport water; and 200 fish/1 for 4 h transport at 20°C and 20 ppt. On the other hand, Sulaeman & Burhanuddin (1990) recommends 50 juveniles *S. javus* (8g)/bag in 4 h transport and 30 fish/bag in 6 h. A dose of 10-15 mg clove oil/1 of water was found as a safe dose of anesthesia for transporting *S. guttatus* (Burhanuddin & Thamrin, 1989).

Culture

Some rabbitfishes are traditionally farmed in the Philippines with encouraging results (Pillai 1962; Ponce 1983; Urmaza 1983). They are either monocultured or polycultured with milkfish. Rabbitfish ponds yield 1051 kg/ha (Anon 1976). The methods employed in rabbitfish pond

culture are generally similar to those for milkfish except that the ponds are much deeper.

The ideal pond for rabbitfish is one that directly draws brackishwater from a river. A fishpond that relies on its water supply from an adjacent fishpond usually fails. A slight rain or even a shower can kill the fish if pond water is shallow and not replenished with fresh brackishwater (Urmaza 1983).

The *nursery pond* is the smallest lot (1/5 of the total pond area) among the three rearing ponds. This is usually located adjacent to the river to allow immediate water entry during high tide. The fish is reared in the nursery for about a month at a stocking rate of 200 000-300 000 fish/ha.

The *transition pond* (1/4-1/3 of total fishpond) is located adjacent to the nursery and grow-out pond to facilitate transfer of fish. The fish is reared for a month at a stocking rate of 60 000 - 100 000 fingerlings/ha.

The grow-out pond is the rearing area where the fish is grown to marketable size. The fish is reared for 3-4 months at a stocking rate of 1500-2000 fingerlings/ha depending on the volume of food in the pond and the size of fish at stocking.

The food recommended in the rearing pond includes such filamentous algae like *Cladophora linum*, *Chaetomorpha* sp., and *Enteromorpha tubulosa*. To prepare the food for the fry, the algae are planted uniformly in small clumps in the entire pond. This is done in the late afternoon or early evening to prevent the algal material from floating the next day. The pond is ready for stocking when the algae have grown halfway from the pond bottom to the water surface (Urmaza 1983).

Rabbitfishes can also be reared in floating cages. Carumbana & Luchavez' (1979b) manual for this type of culture is available. The cage may be big or small, depending on the financial capability of the fish farmer. Most cages are made of bamboo and nylon nets (5-mm mesh). The cages are anchored firmly to the bottom with the bamboo frame serving as float. At least two cages are needed for a 10-month rearing (Ben-Tuvia et al. 1973; Horstmann 1975; Tahil 1978a; Al-Aradi et al. 1980; Baga & Sacayanan 1980; Bwathondi 1982).

The cages should be placed in well-protected areas where the water is subject to ample air circulation and has a depth of at least 3 m at the lowest tide. The area should be free from pollution. The water temperature should be 28-32°C, and salinity of 15-27 ppt.

Farming of rabbitfish is profitable (Masajo & Librero 1976). However, it has its economic limitations (Laviña & Alcalá 1974; Ben-Tuvia et al. 1973; Tsuda et al. 1976; Westernhagen & Rosenthal 1975). In general, rabbitfishes grow slowly but mature early. They are also difficult to handle; once pricked by the strong spine, a person feels a burning sensation and suffers from severe headache (Herzberg 1973). A benefit-

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cost-ratio of 2.03 was reported by Soriano et al. (1995) in culturing *S. guttatus* in cages. At a stocking rate of 50 fish/m³ and using commercial feeds supplemented with natural food, they reported 108.07 g highest mean weight and 9.78 cm length increment. Duray and Juario (1995) reviewed production of siganids.

NUTRITION AND FEEDS

Morphology of Digestive Tract

The description of the digestive tract presented below is mainly Bryan's (1975) and is based on *S. spinus*.

Dentition. The upper jaw overlaps the lower jaw upon closure of the mouth. The upper teeth (32) are more pointed than the lower ones (36) (Fig. 4A). *Siganus fuscescens* has 25 to 30 conical teeth on both jaws (Suyehiro 1942).

Gill Arches and Pharyngeal Teeth. There are four distinct gill arches; the fifth is modified into pharyngeal tooth plates (Fig. 4B). The gill rakers of the first and second arches are long and pointed. The central axis has lateral processes which in turn may branch in the second arch. The rakers of the third and fourth arches become progressively broader and have serrate upper margins. The lower pharyngeal elements of the fifth arch have fine spine-like projections oriented posteriorly (Fig. 4C). The upper pharyngeals have thicker thorn-like spines.

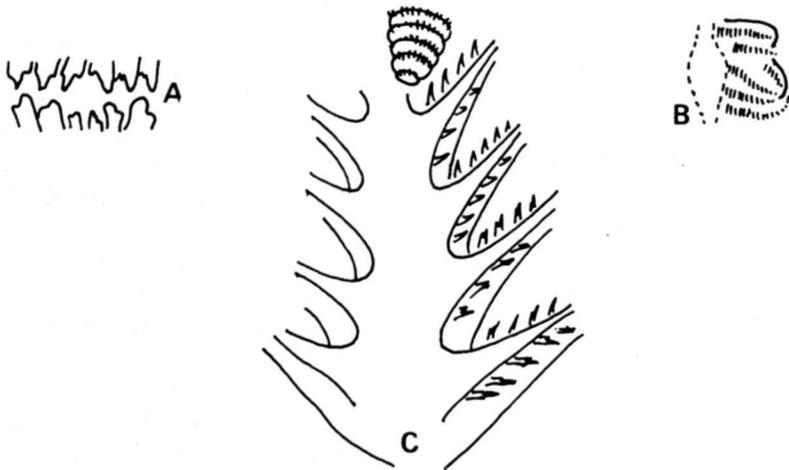
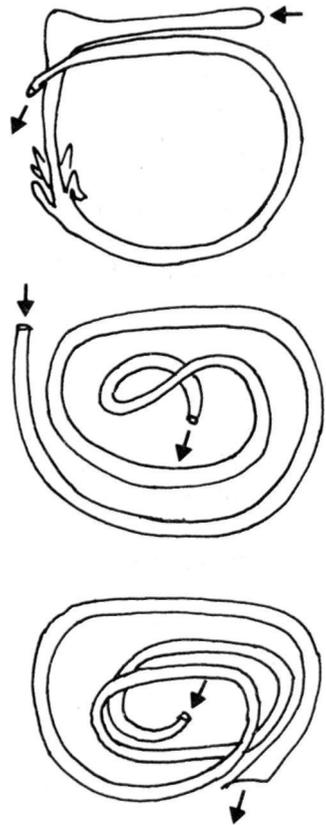


Fig. 4. *Siganus spinus*: dentition, gill arches, pharyngeal elements. A. Median teeth of upper and lower jaws. B. Upper pharyngeals. C. Pharyngeal apparatus showing gill arches 1-4 and lower pharyngeal bones (After Bryan, Pac. Sci. 29:273.1975).

Gastrointestinal Tract. The U-shaped stomach typically lies on the left side of the body and is divisible into cardia and pylorus (Fig. 5). The cardiac wall is about 0.5 mm thick, becoming thicker to about 1.0 mm as the cardia constricts and merges into the pylorus. The pylorus constricts near the pyloric caeca of which there are usually five. The larger lobe of the liver lies on the left side of the body, the smaller lobe on the right. The gallbladder also lies on the left side in the upper intestinal region. The pancreas is well-developed and lies along the stomach and intestine.

The intestine is rather broad, extremely long, and winding. The intestinal wall is about 0.8 mm thick, becoming thinner in the lower regions. The inner lining is provided with numerous tiny papillae. The length of the gastrointestinal tract of *S. spinus* (102-155 FL) is 3.5-4 times longer than the FL of the body. The anus opens just in front of the anal fin, with the peritoneal cavity stretching just beyond.

Fig. 5. *Siganus spinus*. Coiling pattern of gastrointestinal tract (After Bryan, Pac.Sci. 29:273. 1975).



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The gastric and intestinal juices and bile of rabbitfish are bactericidal and bacteriostatic against *Enterobacter* sp., *Pseudomonas aeruginosa* and *Proteus vulgaris* (Encabo 1976).

Development of the Digestive System

The digestive tract of *S. guttatus* has been studied morphologically (Hara 1987) and histologically (Avila & Juario 1987). Starting as a straight tube, the gut begins to coil 8-9 h TAH in synchrony with yolk resorption. The liver starts to develop on day 1 as a loose meshwork of primordial cells ventral to the anterior gut and enveloping the yolk sac. It increases in size as the yolk becomes smaller and is differentiated toward day 5. The yolk is resorbed earlier than the oil globule in day 2 and day 3 larvae; this implies that the former is used primarily for organogenesis, and the latter, as energy reserve (Kohno et al. 1988).

Histochemical studies on the intestinal bulb of *S. rivulatus* showed variation in enzyme activities (Rizkalla et al., 1988). There was weak lipolytic and moderate proteolytic enzymic activities and the strong activity of B-glucuronidase (for carbohydrate digestion) agrees with other workers (e.g., von Westernhagen, 1974; Lundberg & Lipkin, 1979) that *S. rivulatus* is an herbivore.

In juvenile *S. fuscescens* (about 19.0 mm TL), the digestive tract forms a loop and the pyloric appendages appear in the constricted portion of the stomach (Kitajima et al. 1980) (Fig. 6).

Larval Food and Feeding Habits

Larvae of *S. guttatus* grow fast within the first 24 h. The mouth opens at 36 h TAH, the larvae learn to feed at 60 h TAH, and the yolk is completely resorbed at 72 h TAH (Bagarinao 1986). Irreversible starvation was estimated to be 60 h TAH (Bagarinao 1986). For *S. javus*, Diani et al. (1990) estimated it to be 48 h TAH. The provision of suitable food during this period is needed for the larvae to survive further. Kohno et al. (1988) proposed that the transition of larval growth from endogenous to exogenous feeding be divided into 7 phases as follows:

1. rapid growth due to rapid yolk resorption (hatching to about 15 h TAH);
2. slow growth and organogenesis based mainly on yolk energy (to about 50 h TAH);
3. slow growth based on energy of yolk, oil globule and exogenous food (to about 70 h TAH);
4. slow growth based on energy from oil globule and exogenous food (to about 120 h TAH);
5. slow growth based on energy from oil globule and certain amount of feeding (to about 120 h TAH);

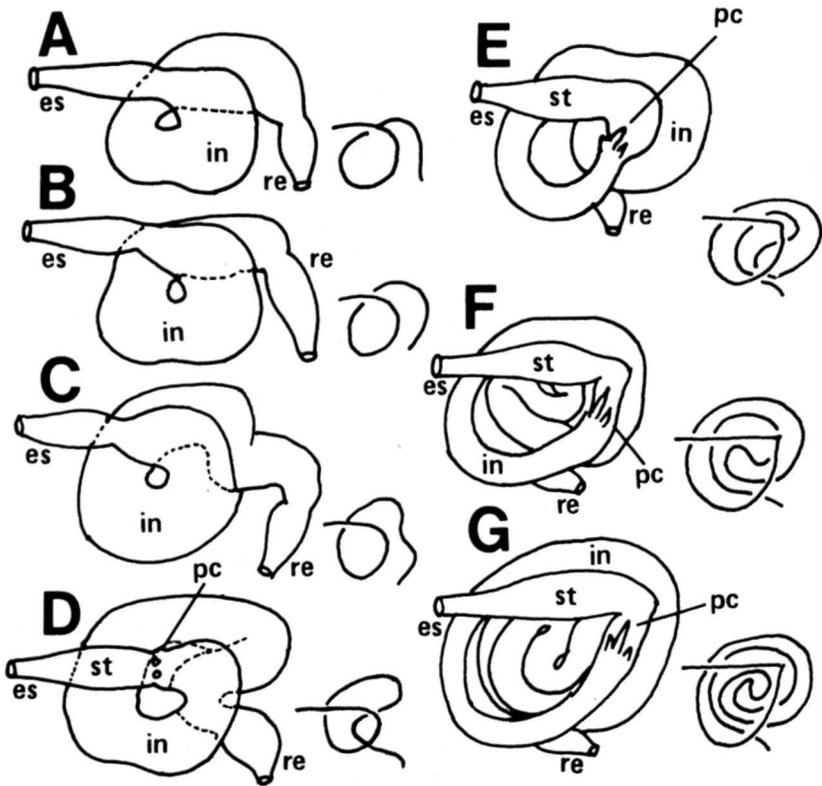


Fig. 6. *Siganus fuscescens*: development of intestinal tract. A. Larva, 14 days old, 6.5 mm total length (TL). B. Juvenile, 20 days old, 12.7 mm TL. C. Juvenile, 22 days old, 16.0 mm TL. D. Juvenile, 24 days old, 19.0 mm TL. E. Juvenile, 234 days old, 23.4 mm TL. F. Young fish, 30 days old, 27.5 mm TL. G. Adult, 205 mm TL. *es*, esophagus; *in*, intestine; *re*, rectum; *st*, stomach; *pc*, pyloric caeca (After Kitajima et al., *Bull Nagasaki Pref. Inst. Fish.* 6, 1980).

6. accelerated growth and effective swimming and feeding based only on exogenous food (to about 150 h TAH); and
7. same mode as in the preceding but with accelerated increase in food consumption (beyond 150 h TAH).

The relatively short time from initial feeding to oil globule exhaustion suggests that rabbitfish larvae are more difficult to rear than either milkfish or sea bass.

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Yolk and oil globule resorption as well as the growth and initial feeding habits of *S. javus* was discussed by Diani et al. (1990). Yolk was completely resorbed 41-57 h TAH and the oil globule at 88-106 h TAH. Mouth opening and eye pigmentation occurred at 41 h TAH and first feeding on oyster trochopores was at 57 h TAH.

The larvae of *S. guttatus* consume their yolk and start to feed on day 2. Nevertheless, high mortality occurs during the first few days, particularly on days 3 to 4 (Juario et al. 1985; Hara et al. 1986c) due to insufficient suitable food. Feeding with *Brachionus* (less 90 microns in size) at 10-20 individuals/ml improves the survival rate of the first-feeding larvae (Duray 1986; Hara et al. 1986a). *Chlorella*, *Tetraselmis* and *Isochrysis* as the sole food for the larvae will not support life beyond 4 days TAH (Duray 1986). Soh & Lam (1973) also observed that *S. oramin* larvae did not feed on green algae and died of starvation. For *S. guttatus*, mixed phytoplankton or *Isochrysis* alone plus small-sized *Brachionus* gave better survival than did *Tetraselmis* + *Brachionus* or *Chlorella* + *Brachionus*. Copepod nauplii are smaller than *Brachionus* and thus are more suitable for the first-feeding larvae (May et al. 1974) but their mass production is still a problem. Avila & Juario (1987) pointed out that the quality of the diet of the spawners is also an important factor in the survival performance of the larvae.

In the hatchery, rabbitfish larvae are fed with *Brachionus*, *Artemia* nauplii, and artificial diet (May et al. 1974; Bryan & Madraisau 1977; Palma 1978; Luchavez & Carumbana 1982; Juario et al. 1985; Hara et al. 1986c). Weaning *S. guttatus* at early stage (D10-D15) has very limited success (Duray, unpubl. data). However, Gomez (1988) successfully weaned 25-day old *S. guttatus* over to microparticulate diets with lipid from different sources; survival ranged from 78.6 to 83.8%. Parazo (1991) recommended a diet with 40% protein and estimated energy content of 3971 kcal kg⁻¹ for hatchery use in *S. guttatus*. Feeding rate she used was 4.5 g per tank per day.

A feeding scheme for *S. guttatus* for 35 days of rearing (Juario et al. 1985) is shown in Fig. 7A. This is slightly different from that used by Hara et al. (1986c) (Fig. 7B) which consistently gave fair survival until metamorphosis. The feeding regime used by Popper et al. (1973) for *S. lineatus* utilizes copepod nauplii and adults on days 12 to 24 and *Artemia* nauplii every third day.

Dietary problems resulting from the use of live food are encountered in a number of larval fish (Watanabe et al. 1983). Polyunsaturated fatty acids, which are essential for normal growth and development, are deficient in natural food. The nutritional requirements of larval siganids are still not known. May et al. (1974) observed over-feeding of larval *S. canaliculatus* an hour after *Artemia* had been added to the tank; this later led to mortality due to contamination with some toxic agent or inability of the larvae to fully digest the *Artemia*. Improved growth of *S.*

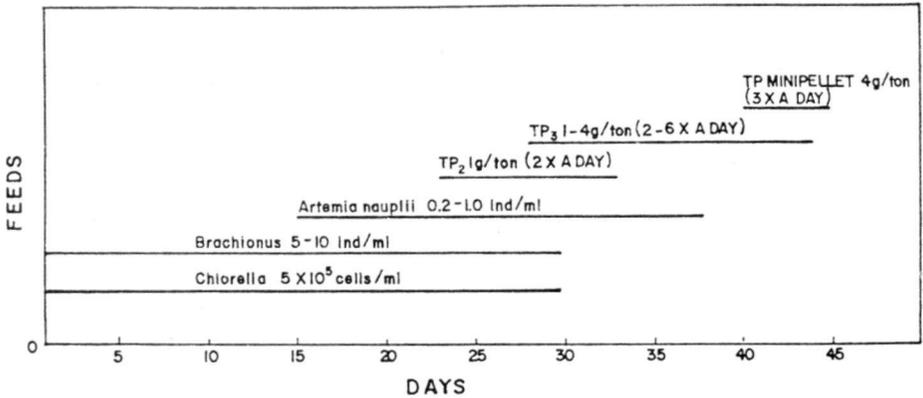
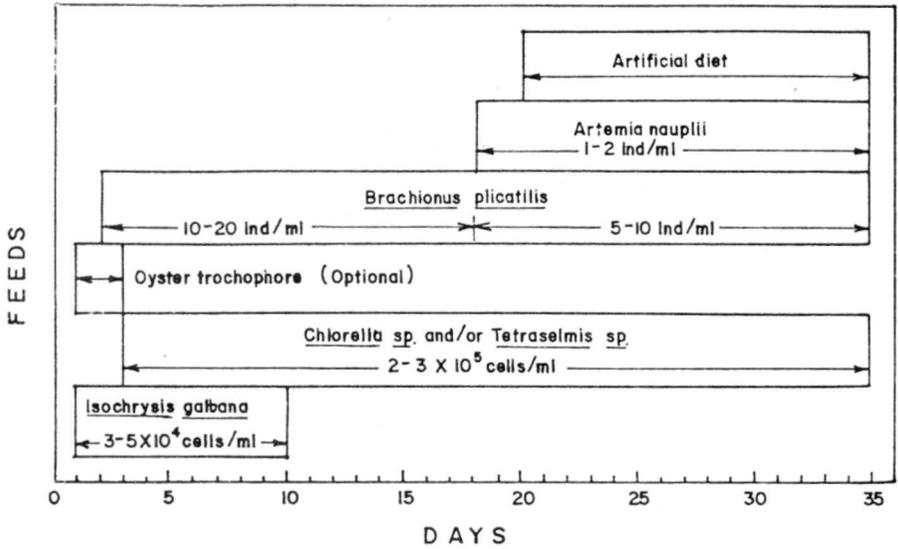


Fig. 7. *Siganus guttatus*: feeding schedules for larvae. A, after Juario et al., *Aquaculture* 44:93. 1985; B, Illustrated based on data (Table 6) in Hara et al., *Aquaculture* 59:267. 1986).

guttatus was reported by Sorgeloos et al. (1988) when the *Artemia* was first given enrichment diets. In nutritional studies, Dhert et al. (1992) suggested to subject the fry to salinity stress to evaluate their physiological condition. They also observed that mortalities of *Siganus* larvae were reduced after a short (n-3) HUFA boosting of the larval food but prolonged HUFA-enrichment did not improve larval quality nor metamorphosis.

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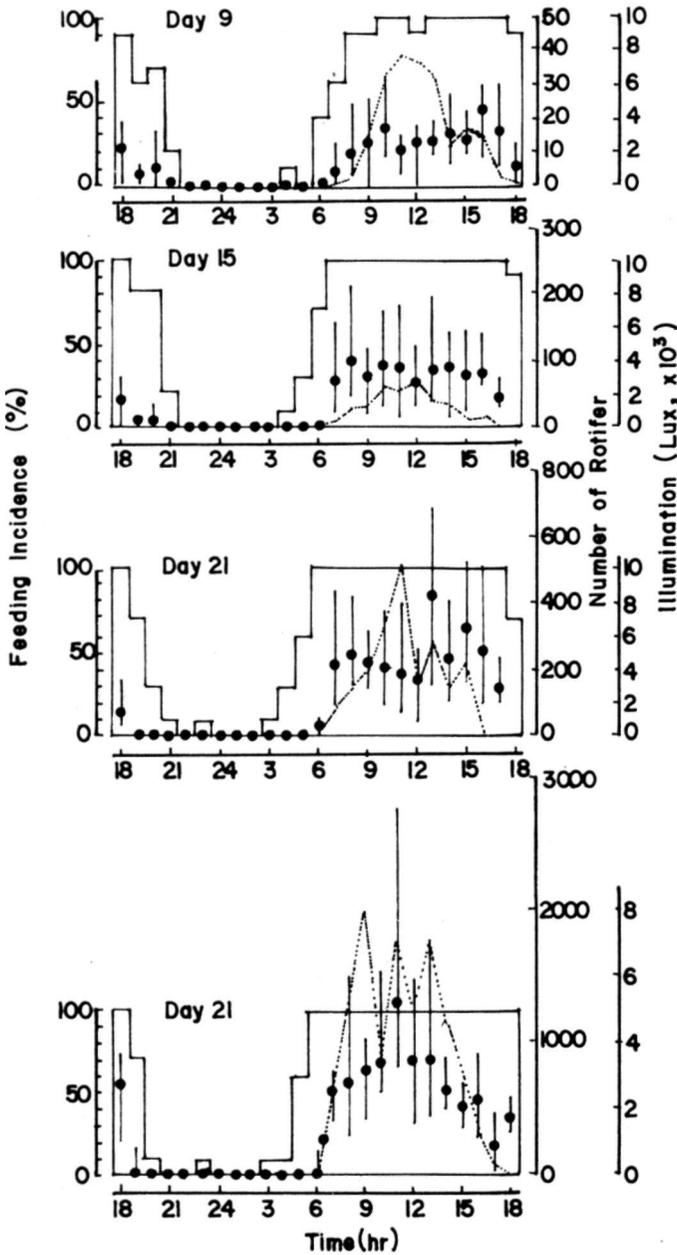


Fig. 8. *Siganus guttatus*: hourly changes in feeding incidence of (% larvae and juveniles with rotifer in digestive tract: left ordinate, block space) and in number of rotifers eaten by (right ordinate, solid circles with bars representing means and ranges) larvae and juveniles of different ages, shown with illumination intensity (broken line) After Hara, S., doctoral dissertation, University of Tokyo, p. 154. 1987).

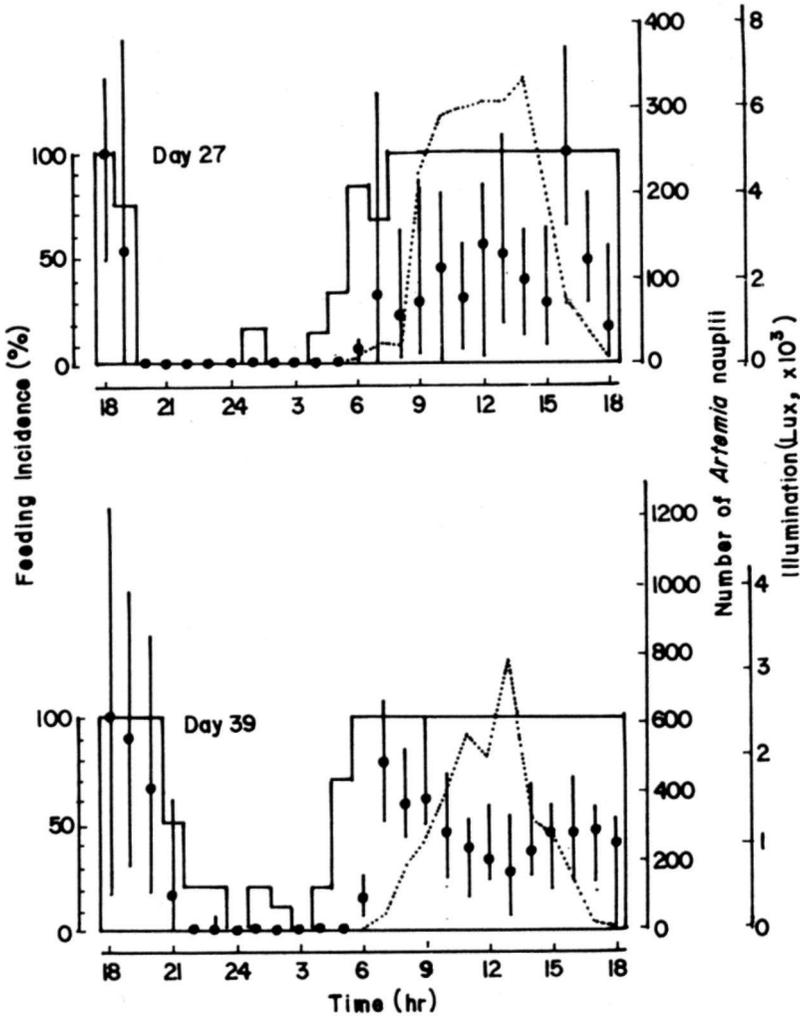


Fig. 9. *Siganus guttatus*: hourly changes in feeding incidence of (% juvenile with *Artemia* nauplii in digestive tract; left ordinate, block space) and in number of *Artemia* eaten by (right ordinate, solid circles with bars representing means and ranges) juveniles of different ages, shown with illumination intensity (broken line) (After Hara, S., doctoral dissertation, University of Tokyo, p. 155. 1987).

The larvae of *S. guttatus* at 2.6 mm TL feed initially on rotifer and, at 4.4 mm TL (day 12), on brine shrimp. A change in feed preference coincident with full osteological development of the feeding apparatus occurs at about 7.0-9.5 mm TL (Hara et al. 1986a). *S. javus* larvae initially fed on trochopores at 2.7 mm size and changed to rotifers at 3.21 mm and to *Artemia* at 4-5 mm TL (Waspada & Taufik, 1990).

Larvae of *S. guttatus* also exhibit diurnal feeding at day 9 (3.7 mm TL), day 15 (5.8 mm TL), and day 21 (7.9 mm TL) (Fig. 8, 9). For all age

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groups, the percentage of larvae with food in the gut decreases in the evening and reaches zero at 2200 h. The time of active feeding (i.e., 50% of larvae with food in the gut) shifts earlier in the day with larval age. Satiation occurs at 8:00-10:00 A.M. in larvae of all age groups, about 20 min for day 9 and day 15 larvae and 30 min for day 21 larvae and juveniles. Average rotifer/*Artemia* consumption increases with larval age (Hara, 1987). Digestion time for rotifer decreases with larval growth: 3.0 h for day 9 larvae and only 1.5 h for day 21 larvae and juveniles. Complete disappearance of rotifers in the gut takes 6.5 h for day 9 and 15 larvae and 3.5 h for day 21 larvae (Fig. 8). The same follows for *Artemia* as feed: 5.0 h for day 15 and 21 larvae and 2.5 h for day 27 larvae (Fig. 9).

Day 3 larvae of *S. rivulatus* start to nibble on the walls of tank and on small particles in the water column. Larvae of *S. lineatus*, on the other hand, consume phytoplankton on days 1 to 2, begin feeding on small *Brachionus* in the afternoon of day 2, and feed strictly on *Brachionus* on day 3. *Brachionus* intake reaches the maximum on day 10 and declines thereafter (Popper et al. 1973). Larvae of *S. argenteus* prefer phytoplankton over *Brachionus* on day 2 but consume both on day 3. They exhibit a snatching-feeding behavior at few seconds intervals near the sides and bottom of tanks (Luchavez & Carumbana 1982).

Food and Feeding Habits of Juveniles

Whereas rabbitfishes larvae are zooplankton feeders, the juveniles and adults are primarily *herbivorous* (Suyehiro 1942). They feed by nibbling on the marine vegetation, often browsing in schools with heads directed downward (Munro 1967) during the day and in the evening (Gundermann et al. 1983).

Analysis of gut content showed that the algae preferred by captive fish were not always those found in greatest quantity in the gut of wild fish (Westernhagen 1973a&b, 1974; Bryan 1975; Tobias 1976; Merta 1982). Tobias (1976) and Tsuda & Bryan (1973) observed that the algal species consumed by adult fish were rejected by the juveniles. Juvenile and adult *S. spinus*, juvenile *S. argenteus* (Tsuda & Bryan 1973; Bryan 1975) and juvenile *S. guttatus*, *S. virgatus* and *S. canaliculatus* (Westernhagen 1973b, 1974) prefer *Enteromorpha* sp. in the laboratory but take this only in small amounts in nature. However, *Enteromorpha* is a very important diet of *S. rivulatus* and *S. argenteus* in the Elat Gulf, Middle East (Lichatowich et al. 1984b). Feeding *S. javus* juveniles with a variety of natural food (*Oscillatoria*, *Phormidium*, *Chaetomorpha*, *Enteromorpha*, *Gracilaria*, *Halophila*, and *Cymodocea*) given individually and also as mixed food, Balasubrahmanyam and Natarjan (1985) observed that fish fed with *Enteromorpha* and *Gracilaria* increased 74% to 185% BW in 30 days. Fish fed with the other food died in a week with

no appreciable growth. Fish fed with mixed natural food showed 225% to 315% increase in weight. However, Rizkalla et al. (1988) observed that in *S. rivulatus*, macrophytes (brown and red algae) constitute 62.68% of their diet; blue-green (*Oscillatoria*, *Lyngbia*, *Phormidium*) about 17.14%; diatoms (*Navicula*, *Nitzchia*, *Licmophora*) about 6.82%, and detritus around 13.09%. Selectivity index was 0.81 for macrophytes, 0.66 for blue-green and 0.53 for diatoms. Bryan (1975) and Stergiou (1988) point out that although fish in the laboratory displays food preference, algal availability and various other factors determine the composition of the diet ingested by fish in the wild.

Lundberg & Lipkin (1979) tabulated the diet composition of three species (*S. rivulatus*, *S. luridus*, *S. argenteus*) in the Gulf of Elat, as did Tobias (1976) for *S. argenteus* in Guam. Both found that the algal species ingested by the fish directly reflect algal availability in the specific area. Paul et al. (1990) observed that adult and juvenile *S. argenteus* preferred *Caulerpa racemosa* and *Cladophoropsis membranacea* than any of the other algae present. These workers believed that the secondary metabolites in the algae account for their low palatability. Likewise, calcified and tough seaweeds have low feeding preferences to these species. On the other hand, *S. canaliculatus* in Banten Bay, West Java prefers *Enhalus*, *Acoroides*, *Enteromorpha*, and *Caulerpa* (Merta 1981). In the eastern Mediterranean, *S. luridus* feeds on a diverse assemblage of benthic algae. On annual basis, *Dictyota*, *Cystoseira*, *Sphacelaria* and *Gelidium* predominate in the diet. Feeding remains intense throughout but it declines during the spawning period in summer (Stergiou 1988).

Some species (e.g., *S. canaliculatus*, *S. spinus*, *S. guttatus*) in captivity accept various kinds of food (Horstmann 1975; Tahlil 1978a; Carumbana & Luchavez 1979a).

Juveniles and adults in the wild feed on any algae that they could physically bite on and ingest (Bryan 1975; Westernhagen 1973a; Tsuda et al. 1976). Fish feed at an angle to the substrate (Burgan et al. 1979). They feed actively in the early morning and become inactive at night (Popper & Gundermann 1975; Burgan & Zselezky 1979; Hasse et al. 1977). Hernandez and Jarre (1990) conducted bihourly for 24 h collection at Bolinao, Pangasinan, northern Philippines and observed that *S. fuscescens* feeds primarily at daytime. Its diet consists mostly of seagrass (60-70%). They likewise estimated that the average daily consumption of a 27.9 g *S. fuscescens* is about 35% BW. Salita-Espinosa et al. (1992) estimated the ingestion rate of *S. fuscescens* (0.24 g DW) to be 207 cal/fish/day while a 0.741 g fish about 299 cal/fish/day.

Liver cells of *S. guttatus* regain their structural integrity earlier when fed with *Chaetomorpha* two weeks after starvation; other diets (trash fish, fish pellets, sucrose, pork lard) give inferior results or

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deleterious effects (Avila 1986). Segner (1985) also reports a slight improvement in the liver cells of newly metamorphosed fish fed with *Chaetomorpha* instead of *Artemia*.

For a better understanding of the dietary requirements of siganids, nutritional and enzymic studies were conducted. Parazo (1989) observed that the specific growth rate of juvenile *S. guttatus* increases with protein and energy levels. She postulated that the fish is capable of utilizing dietary fat and carbohydrates to the extent of sparing protein for growth. In pond, Ganzon-Naret (1991) obtained highest weight gain of *S. guttatus* fed *lumut* supplemented with a diet containing 30% protein. However, survival was highest for those fed sole *lumut*. For *S. canaliculatus*, Yousif et al. (1996) reported that a diet containing 480 g kg⁻¹ protein and P:E ratio of 27.16 mg crude protein kJ⁻¹ gave the maximum growth and best feed utilization efficiency for fry (2.5 g) while for fingerlings (11.5 g), it was from a diet containing 360 g kg⁻¹ protein and P:E ratio of 20.48 mg crude protein k J⁻¹. While body composition of fry was not affected by the feeding regime, this affected the fingerlings. For *S. javus*, better growth is obtained with diet containing 35-46% instead of 29 or 58% protein (Basyari & Tanaka 1989); *S. canaliculatus* also gives poor growth rate when fed low protein diets or just seaweeds (Bwathondi 1982; Ismael et al. 1986; Basyari & Tanaka 1989; Meyers et al. in Tacon et al. 1989; Tacon et al. 1990). However, rapid growth is attained if supplied with a more balanced formulated feed (Kungvankij et al. 1990).

The effect of dietary fat level on *S. canaliculatus* was evaluated by Osman et al. (1996). At 25% crude protein, diet containing 5% level (sunflower oil) gave the best growth and feed utilization efficiency for fry (2.45g) after 70 days culture. Fingerlings (11.0 g) fed diets containing 0, 5 or 10% fat level grew similarly. Carcass fat increased with fat level in the diet. Optimum level was estimated to be 8% for fry and 3% for fingerlings.

Tacon et al. (1989) reported that *S. canaliculatus* fed formulated diet (32% protein) gave the highest daily weight gain and specific growth rate, followed by those fed frozen *Leignathus splendens*; growth was negative in fish given only *Gracilaria/Eucheuma*. However, Ismael (1976) observed growth increment to be better in *S. virgatus* fed *Sargassum* sp. instead of pelletized diets.

Although siganids are primarily herbivores, some species are capable of omnivory (Lam 1974), implying the presence of carbohydrases and proteases. Amylase, maltase, sucrase, techalase and laminarinase were detected in *S. canaliculatus* (Sabapathy & Teo 1993). The characteristics of trypsin, chemotrypsin and leucine aminopeptidase in the intestine of *S. canaliculatus* point out that this species could utilize any protein component of the feeds (Sabapathy & Teo 1993, 1995). *S. rivulatus* also showed various digestive enzymes in the intestinal linings (Rizkalla et al, 1988).

Stimulatory effectiveness of amino acids on the olfactory response in *S. fuscescens* was reported by Ishida and Kobayashi (1992). L-serine is the most potent both as chemosensory and olfactory stimulant. L-proline and L-glutamic acid are the most potent gustatory stimulants while L-alanine, L-glutamine, L-arginine and L-lysine are the most potent olfactory stimulants.

Broodstock Nutrition

There is not much information available for species other than *S. guttatus*. Kanazawa (1984) suggested a feed formula for *S. canaliculatus* and *S. spinus*, but this is yet to be tested for its efficiency. *Siganus guttatus* fed commercial pellets (42% protein) at 2% of body weight have been maintained in tanks (Juario et al. 1985). The fish spawns monthly at a high protein diet (Soletchnik 1984), but there is a decline in fertilization and hatching rates and larval quality with the age of spawner (Juario et al. 1985). Soletchnik (1984) suggests that broodstock be maintained on a diet low in energy and protein content but high in ash. For spawning purposes, the fish should be fed with a diet high in energy and protein content but low in ash. A single female spawned for four successive months when fed with a diet to which was added 10% pollack or cod liver oil (Hara et al. 1986c). Diets rich in cod liver oil alone or in combination with soybean or lecithin induced repeated spawning for 13 consecutive months. Broodstock of *S. guttatus* fed with formulated diet containing 18% fat from these sources also spawned more eggs and gave better larval survival than those fed diets with only 12-15% fat (Duray et al. 1994). Larvae from these broodstock were larger at hatching. There was no remarkable effects on fertilization, yolk volume and hatching rates at these three dietary levels.

Ayson and Lam (1993) reported that larvae from spawners injected with 10 and 100 µg thyroxine (T₄)/g BW were relatively longer and survived better than those from the control and those injected only with 1 µg T₄/g BW 7 days after hatching. They hypothesized that T₄ is converted into T₃ (triiodothyronine) and these hormones in maternal circulation were transferred into the oocytes and consequently into the larvae. Larval length at hatching was significantly improved by injecting T₃ to the mother fish two days before spawning (Ayson et al. 1993).

FISHERIES

Traditional rabbitfish fishery has existed in countries such as Guam and the Philippines where the market value of the fish is high. In the Philippines, rabbitfishes are among those caught in insular demersal fishing (Smith et al. 1980); the average catch for 1968-72 accounted for

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1% of the total commercial fisheries production (Calvelo & Ginon 1974). From 7620 metric tons production in 1980 from capture fishery, it went up to 19314 tons in 1982 and decreased to 14748 tons in 1989 (Lopez, 1991). Lovatelli (1990) claimed that siganids constitute 5.7% of the total fish production in the Philippines. Campos et al. (1994) estimated 96 tons for 1987-1988 catch of *S. fuscescens* alone in Cape Bolinao, Pangasinan from spearfishing, gill nets, and fish corrals. In Palau, the catch for *S. canaliculatus* in 1968 was 500 metric tons (Helfman 1968). Singapore produced about 10 tons in 1990 (FAO, 1990). *S. canaliculatus* farmed in Saudi Arabia and United Arab Emirates yielded 9 tons in 1986. Siganid production was reviewed recently by Duray and Juario (1995).

DISEASES AND PARASITES

A monogenetic trematode causing tissue ischemia, a respiratory disease, was reported in *S. canaliculatus* by Paperna (1972). Amicrosporidian infestation of the gills leads to death in the same species (Lam 1974). Exophthalmia, bloated stomach, body lesions and fin rot are also encountered in captive rabbitfishes (Westernhagen 1973; Lam 1974; Tahlil 1978a; Carumbana & Luchavez 1979a; S. Hara, pers. comm.). Nodular enlargement in the liver of *S. luridus* caused by sporozoans was also noted by Paperna (1979). The ectoparasite *Caligus epidemicus* was also observed in *S. guttatus* broodstock (G.L.Po, pers comm.). Nelson (1990) also reported *Caligus* infestation in *Siganus* spp. broodstock in Guam. Immersion in freshwater for 60-90 sec followed by stocking of mosquito fish in holding tanks controls the infection. Captive fish at SEAFDEC Aquaculture Department were also infested by nematodes causing poor appetite of fish. Cammallanid nematodes were found also in *S. luridus* and *S. rivulatus* caught in the northern Gulf of Elat (Fusco & Overstreet 1979). The larval nematode *Hysterothylacium* caused massive necrosis and fibrosis of the liver (Diamant & Paperna 1986).

Mass mortality of cultured *S. canaliculatus* in cages was reported in the northeast coast of Singapore (Foo et al. 1985). Some fish changed in body coloration, moved sluggishly and later became blind. Prior to death, the fish exhibited violent movement, convulsion, and seizure. Mortality was due to a Gram-positive bacterium with characteristics similar to those of *Streptococcus faecium*. *Pseudomonas putrefaciens* also caused a disease outbreak among *S. rivulatus* stock in Saudi Arabian mariculture facility in the Red Sea. Chief clinical signs of the disease were discoloration, hemorrhagic necrosis on the body and mouth, frayed fins, and exophthalmia (Saeed et al. 1987). Aerobic heterotrophic bacteria recovered from cage-reared *S. rivulatus* in Jeddah, Saudi Arabia were estimated at 6×10^5 super (5)/g compared to

surrounding water (3.3×10 super (4)/ml) and to open ocean (6.6×10 super (2) /ml) (Mudarris 1993).

Diamant & Paperna (1986) reported 35 species of parasites in *S. argenteus*, *S. luridus* and *S. rivulatus* in the Gulf of Elat. Of these, the *myxosporeans* *Ceratomyxa* and *Zschokkella* produced acute desquamation of gallbladder epithelium and chronic congestion and distention of the hepatic biliary canaliculi.

Abundance and host relationships of the acanthocephalan *Sclerocollum rubrimaris* revealed that *S. rivulatus* and *S. argenteus* are primary definite hosts and *S. luridus* is an accessory host (Diamant 1989). High parasite abundance in March-May correlated with the period of extensive algal grazing prior to spawning by the host fish. In *S. rivulatus*, parasite abundance increased with host size; the reverse was true in *S. argenteus*. The infection patterns varied with parasite specificity and host habitat, feeding habit and diet preference.

A survey of helminth parasitic infestations on Arabian Gulf fishes (El. Naffar et al. 1992) showed 72.2% incidence. Of these, 11.1% were monogeneans, 43.3% digeneans and 5.6% acanthocephalans. Of *S. javus* examined (n=50), 14% had digeneans and of *S. canaliculatus* (n=40), 25% had monogeneans and 12.5% acanthocephalans.

GENETICS

Lam (1974) pointed out the possibility of hybridization of rabbitfish since artificial fertilization is not a problem. *Siganus fuscescens* has $2n=48$ chromosomes (Kitada et al. 1979). There are 23 pairs of telocentric chromosomes. Chromosomal length varies from 1.5 to 2.0 mm, the largest pair being the subtelecentric chromosomes which are peculiar to the Siganidae. Sex chromosomes are not heteromorphic. *S. javus* has 48 seriated telocentric chromosomes which in haploid state vary in length from 2.7 to 5.38 μm (Choudhury et al. 1979).

The immunochemical techniques used by Macaranas & Cierte (1984) confirmed the taxonomic relationships in the Siganidae based on electrophoretic analyses. Macaranas & Benitez (unpubl. data) also associated the changes in the pattern of lactate dehydrogenase isozymes with the morphogenetic changes during the early development of rabbitfish.

Frequencies of electromorphs encoded by 14 polymorphic loci were used to estimate genetic distances among siganid samples collected from western Pacific ocean (Lacson & Nelson, 1993). *S. randalli* and *S. vermiculatus* were found to show the lowest levels of genetic divergence relative to all other pairs of species studied. *S. randalli*, *S. guttatus*, and *S. vermiculatus* comprised one of three clusters discerned in all resultant topologies. *S. argenteus*, *S. fuscescens* and *S. spinus*

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(fusiform-bodied species) formed a second ball cluster that was clearly separable from the remaining species (*S. doliatus*, *S. javus*, *S. punctatus* and *S. vulpinus*) studied.

PROBLEM AREAS

The five major problem areas identified by the Siganid Mariculture Group continue to be worked out.

Species Survey

Dr. D.J. Woodland has revised the family Siganidae so that problems in species identification are already resolved. However, surveys are needed to identify the factors affecting the market value and acceptability of various species (Lam 1974).

Juvenile-to-Adult Farming

A number of studies on farming juveniles in different holding systems have yielded conflicting results (see page 24, 25). Since the fish in captivity accepts any kind of food, cheap and locally available feed should be tried. There is also a need to study the nutritional requirements and the growth and survival of fish under different feeding regimes. Culture techniques in ponds, cages and pens should be developed.

Fry Production

Natural or induced spawning is not a problem, especially in *S. guttatus* (Hara et al. 1986c), but there is still much to be done. Mass production of other species should be tried. The effects on fry survival of environmental factors, natural food and type and size of tanks, and the nutritional requirements of larvae need to be investigated. Food requirements of broodstock in relation to fish size should also be studied.

Fry are available in great quantities during particular periods but methods for their capture, handling, and transport should be standardized. Fry collecting grounds should be identified and described.

Diseases

The limited space and high stocking density in intensive culture systems result in mass infection or infestation of the cultured fish with parasites. Control measures must be provided to avoid fish mortalities.

Production Economics

There is a dearth of information on the economics and sociocultural aspects of rabbitfish farming. There is a need for more efforts in this field.

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ACKNOWLEDGMENT

The author thanks the following: Dr. Jesus V. Juario, Dr. Hiroshi Kohno, Dr. Teodora U. Bagarinao, and Dr. Irineo J. Dogma Jr., technical reviewers; the SEAFDEC BRAIS Project leader and staff; Ms. A.T. Arisola for assistance in library work; Mr. ET Ledesma for the illustrations; the staff, Development Communication, Training and Information Division for producing this revised monograph.

Biology and Culture of Siganids

SEAFDEC Aquaculture Department

Tigbauan, Iloilo, Philippines

APRIL 1998

The Southeast Asian Fisheries Development Center (SEAFDEC) is a regional treaty organization established in December 1967 for the purpose of promoting fisheries development in the region. Its Member Countries are Japan, Malaysia, the Philippines, Singapore, Thailand, Brunei Darussalam, and the Socialist Republic of Viet Nam.

Representing the Member Countries is the Council of Directors, the policy-making body of SEAFDEC. The chief administrator of SEAFDEC is the Secretary-General whose office, the Secretariat, is based in Bangkok, Thailand.

Created to develop fishery potentials in the region in response to the global food crises, SEAFDEC undertakes research on appropriate fishery technologies, trains fisheries and aquaculture technicians, and disseminates fisheries and aquaculture information. Four departments were established to pursue the objectives of SEAFDEC.

- The **Training Department** (TD) in Samut Prakan, Thailand, established in 1967 for marine capture fisheries training
- The **Marine Fisheries Research Department** (MFRD) at Changi Fisheries Complex, Singapore, established in 1967 for fishery post-harvest technology
- The **Aquaculture Department** (AQD) in Tigbauan, Iloilo, Philippines, established in July 1973 for aquaculture research and development
- The **Marine Fishery Resources Development and Management Department** (MFRDMD) in Kuala Terengganu, Malaysia, established in 1992 for the development and management of the marine fishery resources in the exclusive economic zones (EEZs) of SEAFDEC Member-Countries.