Rearing and Larval Development of *Siganus canaliculatus* (Park) (Pisces: Siganidae)[1]

ROBERT C. MAY[2], DAN POPPER,[3] and JAMES P. MCVEY[4]

Abstract

Eggs of the siganid fish *Siganus canaliculatus*, were obtained from a hormone-induced spawning, and approximately 200 larvae were reared to metamorphosis in outdoor tanks shielded from rain by a transluscent roof. Water temperatures ranged from 28 to 32°C. Rearing was more successful in large (5,500 liter) containers than in small (500 liter) ones. Larvae fed upon cultured rotifers (*Brachionus plicatilis*) as well as copepods which become established in the rearing tanks Older larvae were fed newly hatched *Artemia* nauplii, but larval mortality associated with this diet was observed. Larvae began to metamorphose on day 23; in general, metamorphosis took place at standard lengths between 20 and 24 mm. The overall percentage survival, from hatching to metamorphosis, was approximately 0.3 %.

INTRODUCTION

Much interest has recently arisen in the mariculture of siganid fishes (Anon., 1972; Lam, 1974). Several problems, however, must be solved before the commercial mariculture of siganids can become a reality. Prominent among these is the problem of fry production, the provision of large numbers of juvenile fishes for stocking in ponds, cages or other rearing structures where growth to market size can take place. Catching wild juveniles for stocking purposes is unreliable, competes with traditional fisheries, and depletes natural populations. The only ultimate solution to the problem of fry production is to induce spawning in captive brood stock and to rear the larvae thus produced to the juvenile stage. Such a fry production scheme would also make possible selective breeding for desirable traits.

Although spawning has been induced in several siganid species (Lam, 1974), no reports of the successful rearing of siganids through the larval stage have been published. In view of the critical importance of larval rearing to an integrated siganid fish farming program, a cooperative rearing effort was initiated between the Hawaii Institute of Marine Biology, where larval rearing techniques have been under study for several years, and the Micronesian Mariculture Demonstration Center, where a program in siganid mariculture is underway. The present paper describes the initial

[1] Contribution no. 455, Hawaii Institute of Marine Biology.

[2] Hawaii Institute of Marine Biology, P. O. Box 1346, Kaneohe, Hawaii 96744.

[3] Department of Zoology, Tel Aviv University, Tel Aviv, Israel. Temporary address: c/o Fisheries Division, M. A. F. F., Lautoka, Fiji.

[4] Micronesian Mariculture Demonstration Center, P. O. Box 359, Koror, Palau, Western Caroline Islands 96940.

Micronesica 10(2):285-298. 1974 (December).

results of this cooperative effort.

Siganus canaliculatus (Park) is one of the most highly sought-after food fish in Palau and contributes substantially to the Palauan diet. The Micronesian Mariculture Demonstration Center began investigating the feasibility of culturing *Siganus canaliculatus* by collecting information from Palauan fishermen concerning occurrence and spawning habits (McVey and Madraisau, 1974). There followed a series of preliminary tests of juvenile growth rates under various captive conditions (Tsuda *et al.*, 1974); later, a technique for inducing spawning with hormone injections was developed (Bryan *et al.*, MS.), which made possible the present work on larval rearing.

METHODS

All work was conducted at the Micronesian Mariculture Demonstration Center in Palau, Western Caroline Islands. Eggs were obtained from mature *Siganus canaliculatus* injected with Antuitrin–S. Spawning occurred on 17 March 1974, and the eggs had hatched by late afternoon on 18 March. In this paper the day of hatching is referred to as day O, the following day (when the larvae were one day old) as day 1, and so forth.

Five rearing tanks were used, three circular plastic tanks containing 500 liters of water and two circular, epoxy-coated cement tanks containing 5,500 liters of water. All rearing tanks were located outdoors. A transluscent roof consisting of a wooden frame and corrugated fiberglass was constructed over the tanks to keep out rain and prevent overheating, while letting through enough sunlight for phytoplankton growth. The tanks were stocked at a density of five eggs or larvae per liter. Fertilized eggs were added to tanks 1, 2, and 4 several hours before hatching, whereas larvae were added to tanks 3 and 5, 24 hours after hatching. Prior to the spawning, blooms of mixed species of local phytoplankton had been established in each tank by adding an inoculum from a previously established culture plus inorganic fertilizer. The phytoplankton was provided in order to maintain water quality and to provide food for the planktonic animals fed to the larvae. Gentle aeration was provided in each tank. Water in the tanks remained static until day 9, when a flow of 1% of the tank volume per hour was started. This was increased to 2% on day 14 and thereafter remained at this level in tanks 2 and 5; in tank 4 the flow was raised to 6%/hour on day 20 and maintained at this level.

The original experimental design called for three feeding regimes in each of two tank sizes, a total of six treatments. Because of a limited supply of food and limited number of tanks with phytoplankton blooms, the number of tanks was reduced to five and the feeding regimes were as listed in Table 1. The main cultured food used was the rotifer, *Brachionus plicatilis*, which was added to the tanks only once because its rate of reproduction is high and its density usually increases, despite grazing by larval fishes, until the phytoplankton supply has been exhausted. Rotifer stocking densities varied from tank to tank (Table 1) because numbers available were limited.

Table 1. Tank volume and initial feeding regimes.

Tank Number	Volume (liters)	Food type	Initial Food concentration (No./ml)	Age of larvae (days) when food added
1	500	rotifers	1	0
2	500	oyster eggs	10	3–6
		rotifers	0.5	0
3	500	rotifers	1	4
4	5,500	rotifers	0.07	0
5	5,500	—	—	—

Eggs of the oyster *Crassostrea echinata*, collected in Palau, were artificially fertilized and added to tank 2 after rinsing. In addition to the items specifically added as food, copepods (mainly *Euterpina* sp. and *Oithona* sp.) were inadvertently transferred from the spawning tank along with the siganid eggs and larvae and became established in all rearing tanks. These copepods constituted the only animal food available to the larvae in Tank 5 during the first week, as no rotifers or oyster eggs could be provided.

Artemia salina nauplii were first offered to the larvae on day 8. From day 8 to day 19, *Artemia* (24 to 48 hours old) were offered at a daily rate of approximately 20 nauplii/liter; after day 19 this was gradually increased to a maximum of 150 naupii/liter on day 25. *Artemia* additions were discontinued on day 29, and from then on the fish were fed only trout chow and the green alga, *Enteromorpha* sp.

Tank temperatures were recorded two or three times per day. Salinities were measured daily with a refractometer. Zooplankton densities were estimated daily by averaging values from several 1 ml surface samples taken from different sectors of the tanks. Phytoplankton densities were estimated from single hemacytometer counts. Small numbers of larvae were sampled daily from days 1 to 10, and at three-day intervals thereafter, to provide a series for descriptive purposes. Heavier sampling was conducted on days 0, 10, 20 and 30 to provide data on growth rates. On days 20 and 30, the sampled larvae were anaesthetized with MS 222 (tricaine methanesulfonate) and returned to the tank after measurement. Lengths referred to are standard lengths (SL), measured from snout to top of notochord or to the end of the hypural elements. Larvae were periodically dissected and their gut contents examined to reveal food preferences.

RESULTS

Water Quality

Mean temperatures in containers with static water varied from 29.2 C in the morning to 30.8 C in the afternoon, and in flowing water they varied from 28.7 C to 30.3 C. Maximum temperatures recorded in tanks 1, 2 and 3 were 31.0, 32.0, and

33.0 C, respectively, while in Tanks 4 and 5 the maximum respective temperatures were 31.5 and 32.5 C. The salinity varied between 30.5 and 33.8‰.

The phytoplankton in tanks 1, 2, and 4 was profuse at the beginning of the experiment. A mixture of species was present, dominated by unidentified green flagellates (7–14 μm in diameter) present at a density of about 10^4 cells/ml. Within a week the water in tanks 1 and 2 was nearly devoid of phytoplankton because of grazing by rotifers, while the water in tank 4 remained green until the system was opened on day 9. Additional phytoplankton was added to tanks 1 and 2 on days 7 and 8 to make up for the loss due to grazing by rotifers. On day 7, rotifer densities rose to 30/ml and 20/ml in tanks 1 and 2 respectively (compared to a maximum of 2/ml in tank 4), and an attempt was made to reduce the rotifer densities in these tanks by cropping with a fine mesh-plankton net. The phytoplankton in tanks 3 and 5 never reached the densities observed in the other tanks, probably because the cultures, having been started earlier than the others, were senescent at the beginning of the experiment. Additional phytoplankton added to these tanks on several occasions was insufficient to create the desired bloom. In addition to the numerically dominant green flagellates, in all tanks two unarmored dinoflagellates, *Gyrodinium* sp. and *Gymnodinium* sp. became established, reaching densities of the order of 10^3/ml.

Survival

Larvae survived to metamorphosis only in the large tanks (Tanks 4 and 5). Because of the large tank sizes no quantitative survival data were collected for the early stages of development, but visual estimates were made of relative survival rates. Toward the end of the first week of larval development it became apparent that more larvae were present in Tank 5 than in Tank 4, perhaps because the former was stocked with larvae while the latter was stocked with eggs whose hatching rate was unknown. The great number of larvae in Tank 5 declined noticeably after day 10; the low level of food originally in that tank, along with intense grazing pressure from the large larval population, apparently resulted in eventual starvation of most of the larvae. By the third week the relative survival rates in the two large tanks had reversed themselves, significantly more larvae being present in Tank 4 than in Tank 5. From then on, survival was excellent in Tank 5, the food available being adequate for the few larvae present.

This relative situation persisted until the fourth week, when fish began dying in Tank 4. Eighty-two fish were lost between days 20 and 30 in this tank, including 15 metamorphosed fish, while in Tank 5 only five fish died during the same period. The mortality in Tank 4 was associated with additions of large numbers of *Artemia* nauplii and ceased when the diet was switched to trout chow (Fig. 1). Mortality during this period included large, well-developed larvae and metamorphosed juveniles as well as small, stunted individuals. The latter, generally measuring less than 12 or 13 mm (SL), were emaciated and frequently contained stones in the urinary bladder. On day 30, fish from Tank 5 were counted and transferred to a new tank.

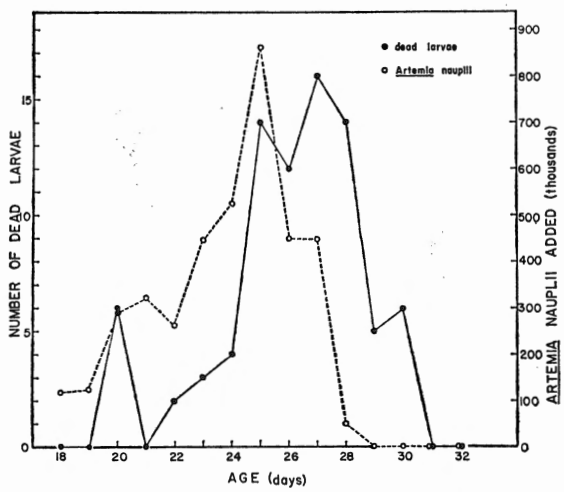

Fig. 1. Numbers of dead larvae found in Tank 4, and numbers of *Artemia* nauplii added as food, between days 18 and 32.

At this time there were 97 fish in Tank 5 and approximately the same number (by visual estimate) in Tank 4, yielding a survival rate to day 30 of about 0.3 % in each tank. If the rate of hatching in Tank 4 was considerably below 100 %, as is strongly suspected, then survival from hatching to day 30 was higher than 0.3 % in that tank.

Survival in the small tanks was poor. On day 10 Tanks 1 and 3 (both fed rotifers) were terminated because of low survival, there being only 9 and 13 larvae surviving in them, respectively. Larvae in Tank 2 (fed oyster eggs plus rotifers) survived better, but their numbers declined precipitously during the third week, only a single larva remaining alive on day 20 when the tank was terminated.

Feeding

Larvae had absorbed their yolk and possessed functional eyes and mouths by day 2. Gut contents of larvae examined on day 3 consisted almost entirely of green plant material, although some copepod nauplii were also taken. Similar unidentifiable green plant material was found in larval guts up to day 9 and probably reflects direct consumption of phytoplankton. Larvae began feeding on rotifers at least by day 4; early larvae in Tank 2 consumed both oyster eggs and rotifers. The only animal food found in larvae from Tank 5 was copepod nauplii, but larvae in Tank 4 ate both rotifers and copepod nauplii, with the latter predominating.

Larvae consumed *Artemia* nauplii when first offered them on days 8 and 9. Gut contents showed that larvae in Tank 4 continued to eat rotifers, copepod nauplii, and copepodites in addition to *Artemia,* indicating opportunistic feeding. On day 13 and thereafter an overfeeding syndrome was noted in which some of the smaller larvae acquired orange, swollen abdomens and swam in a frantic and disoriented

manner within an hour after *Artemia* had been added to the tank. Within 30 minutes most of the larvae had recovered and could be seen trailing long, orange fecal strands. In order to avoid overfeeding of this sort, from day 15 on the *Artemia* nauplii were added to Tanks 4 and 5 at a slow rate throughout the day by siphoning through a narrow tube from an aerated bucket suspended over the tanks. This reduced but did not entirely eliminate the overfeeding syndrome. As mentioned above, larval mortality in Tank 4 between days 20 and 30 was associated with a high rate of consumption of *Artemia* and stopped when *Artemia* feeding was discontinued. Occasionally during this period, dead larvae with large numbers of *Artemia* naupii in their guts (273 nauplii were counted in one larva) were found about one hour after *Artemia* had first been added to the tank. Such larvae sometimes had large numbers of *Artemia* eggs in addition to nauplii in their guts (one larva contained 59 eggs). Other dead larvae found early in the morning contained only well-digested material in their guts, so that chronic effects from feeding on *Artemia*, as well as acute overfeeding, may have contributed to mortality.

Aggressive behavior (chasing and biting) was noted in Tank 4 as early as day 15, and the behavior became more overt as the larvae grew. Only one case of actual cannibalism was observed (on day 17). Cannibalism is hindered in *Siganus canaliculatus* by the small mouth and formidible spines of this species, but conspecific biting does occur and may have caused significant mortality in Tank 4. Such behavior probably reflects a lack of food, and it was for this reason that greater numbers of *Artemia* were provided after day 20. Aggressive behavior was seldom noted in Tank 5, where the larval density was much lower during the third and fourth weeks of development. A high incidence of slightly deformed tails was noted among fish in Tank 4 between days 20 and 30, perhaps reflecting biting at earlier stages of development; tail structure in larvae from Tank 5 showed no such abnormalities.

The larger larvae in Tanks 4 and 5 consumed small bits of finely ground trout chow as early as day 20, but this food was not offered regularly until the *Artemia* regime was discontinued on day 29. At that time fish of all sizes began consuming small pieces of trout chow and thereafter were successfully maintained on this food. Two metamorphosed fish in Tank 4 were seen feeding on *Enteromorpha* on day 23, and the rate of feeding on this alga increased with time. By day 25, even some untransformed larvae occasionally nibbled on *Enteromorpha.* Gut content analyses showed that larvae as small as 15.0 mm (SL) would take at least some *Enteromorpha.* Fecal pellets voided by larvae and juveniles feeding on this alga consisted of apparently undigested thalli. One metamorphosed fish (20.0 mm, SL) dissected on day 27 had its gut crammed with *Enteromorpha* from esophagus to anus, all of which appeared undigested. In most of the dissected larvae and juveniles which contained algae, the gut contents were dominated by animal food, mainly *Artemia* nauplii and copepods.

Growth

Newly hatched larvae had a mean standard length of 2.1 mm. On day 10 the

larvae sampled from Tank 4 had attained a mean length of 4.3 mm (the largest larvae in the tank were not included in the sample), while the mean for those from Tank 5 was only 3.3 mm. The few remaining larvae in Tanks 1 and 3 had mean lengths of 3.8 and 3.5 mm, respectively. The mean length was significantly greater in Tank 3 than in the other tanks, and significantly greater in Tank 1 than in Tank 5; other differences in length were nonsignificant (SNK test; Sokal and Rohlf, 1969, p. 242 ff.). On day 10, 8 out of the 11 larvae sampled from Tank 4 possessed the large, pigmented dorsal and ventral spines which are characteristic of larval siganids (see Fig. 7), while none of the larvae in Tank 5 and only a small proportion of those in the small tanks, had developed these spines (Table 2).

Table 2. Growth and development to day 10.

Tank Number	No. larvae sampled	Mean standard length (mm)	No. with pigmented spines
1	9[1]	3.8	4
3	13[1]	3.5	2
4	11	4.3	8
5	10	3.3	0

[1] Includes all larvae suviving to day 10.

The difference in growth rate between the two large tanks, stemming from a lower food supply and higher larval density during the first week in Tank 5, persisted even until the final measurement on day 30 (Fig. 2). On day 30, the mean standard length of the fish measured in Tank 4 was 27.3 mm while that of fish in Tank 5 was

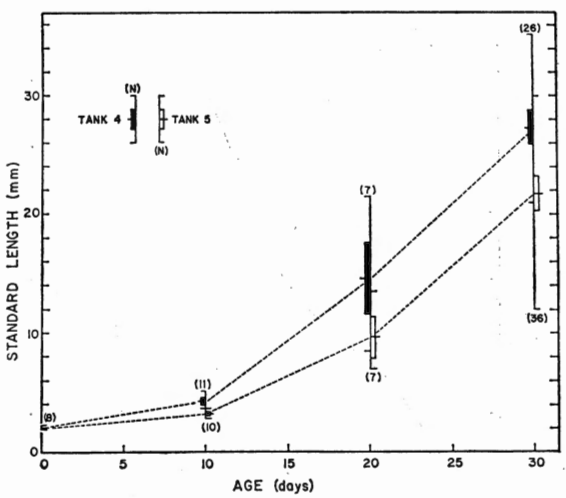

Fig. 2. Standard length as a function of age in Tanks 4 and 5. Ranges and means are plotted; bars indicate 2 standard errors on either side of the mean. Numbers of fish measured are given in parentheses, and mean lengths for each tank are connected by dashed lines.

21.8 mm, and the maximum lengths in the two tanks were 35.0 and 30.0 mm, respectively. These figures yield average growth rates of 0.84 and 0.66 mm/day in Tanks 4 and 5 for the first 30 days of development, and maximum rates of 1.10 and 0.93 mm/day.

Variability in size increased with age (Fig. 2). After one month, when there were many large, healthy, transformed fish in Tank 4, some small, emaciated larvae were also present in the same tank and were dying by slow attrition. They often had stones in the urinary bladder. Since abundant food was usually present in the tank, this slow growth and starved appearance may have been due to an internal disorder rather than to competition.

Metamorphosis

Metamorphosis in *Siganus canaliculatus* involves a rapid and obvious change in external appearance: the larval condition, comprising a highly transparent body and silvery abdomen, gives way to the juvenile condition, in which the entire body is light brownish in color and is covered with numerous small, white spots. The change can take place in a matter of hours, perhaps even quicker. The first metamorphosed fish was seen in Tank 4 on the morning of day 23, and by late afternoon a second appeared. The numbers of metamorphosed fish rose to 12 on day 24, 16 on day 25, 20 on day 26, and 30 on day 27, after which it became difficult to estimate the numbers with any accuracy. No metamorphosed fish were present in Tank 5 until day 28, when one was seen in the morning and two in the afternoon; two more had metamorphosed by afternoon on day 29, and on day 30, when all fish were

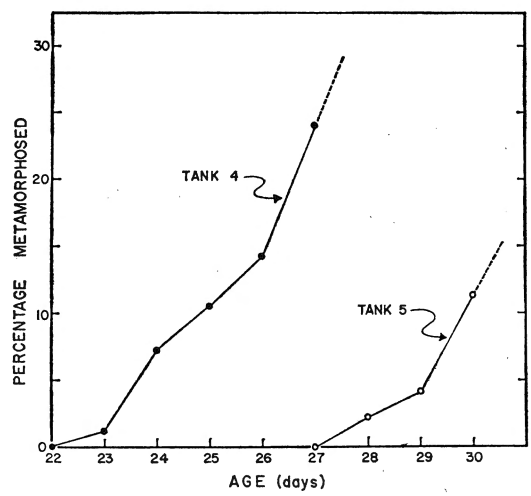

Fig. 3. Percentage of metamorphosed fish as a function of age in Tanks 4 and 5. Counts of metamorphosed fish were not made after day 27 in Tank 4 or after day 30 in Tank 5.

transferred out of Tank 5, 11 metamorphosed fish were present among a total of 97 fish. Figures for the total number of fish alive on day 30, along with mortality data between days 20 and 30, permitted computation of the percentages of metamorphosed fish in the two tanks as a function of age (Fig. 3). The size at metamorphosis was variable. The smallest metamorphosed fish examined was 17.5 mm (SL), but non-metamorphosed larvae as large as 24.5 mm were also seen. In general, metamorphosis took place at standard lengths between 20 and 24 mm.

Metamorphosis involved changes in behavior and internal anatomy as well as in external appearance. On the day of their first appearance (day 23), metamorphosed fish were seen eating *Enteromorpha.* On subsequent days other metamorphosed fish showed the same tendency to feed on and congregate near clumps of this alga, although they also commonly made excursions to feed at the *Artemia* siphon. As mentioned above, some non-metamorphosed larvae later also began eating *Enteromorpha*, perhaps as a result of social facilitation. Metamorphosed fish tended to school separately from larvae and spent more time near the bottom; they remained in a given area longer than larvae and in general swam in a less hurried manner. The relative length and degree of coiling of the gut increased at about the time of metamorphosis. Fish with long, coiled guts often had considerable animal matter (mainly *Artemia* nauplii) in their guts, but usually at least some *Enteromorpha* was present.

The pelagic larval stage of *Siganus canaliculatus* has never been studied in the field, but metamorphosed juveniles are known to invade shallow waters in Palau between March and October. During this time large schools of thousands of juveniles can be seen grazing in sheltered inlets and bays. A collection of such juveniles was made in March of 1973, and individuals from this collection were reared to sexual maturity at the Micronesian Mariculture Demonstration Center and induced to spawn in less than a year. A certain number of these fish died at the time of collection and were preserved in formalin. When measured a year later they had a mean standard length of 26.0 mm (N=75, range=23.5—28.8 mm). Many of the metamorphosed fish measured in tank 4 on day 30 were larger than this (Fig. 2), indicating that further rearing to maturity should present no problems.

Notes on larval development

The following descriptive notes were made in the course of this rearing trial and and refer to development at temperatures of 28–31.5°C. Fertilized eggs were approximately 550 μm in diameter, and embryonic development was similar to that described for *S. rivulatus* (Popper *et al.*, 1973) and *S. fuscescens* (Fujita and Ueno, 1954). Hatching occurred about 24–26 hours after spawning at 29–30°C.

Pigmentation at hatching was somewhat variable, but in general a few pigment spots were present on the snout, on the eye, and on the yolk sac (Fig. 4), and in some specimens a line of melanophores extended along the ventral margin of the musculature (Fig. 5). The eyes became gradually pigmented during the second day after hatching,

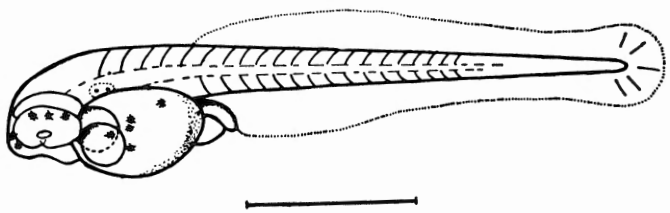

Fig. 4. Newly hatched larva. Horizontal line, 0.5 mm.

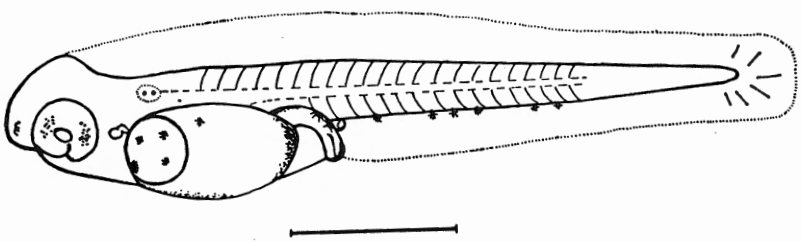

Fig. 5. Larva 24 hours after hatching. Horizontal line, 0.5 mm.

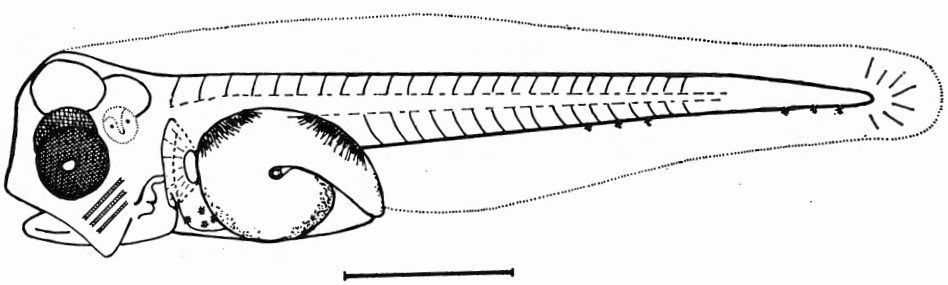

Fig. 6. Larva 3 days after hatching. Horizontal line, 0.5 mm.

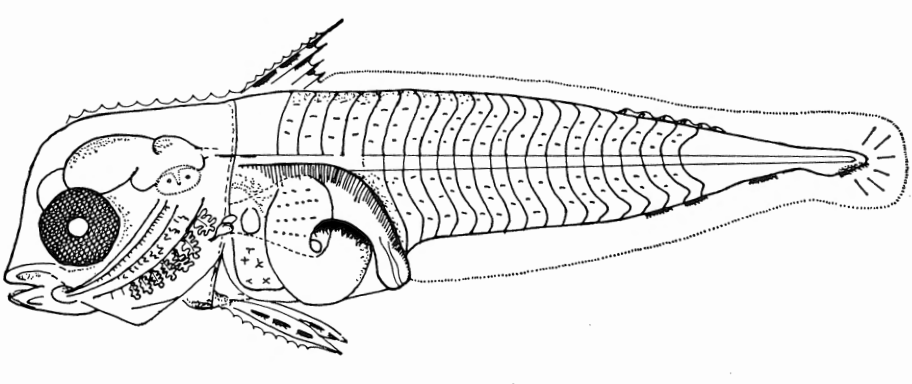

Fig. 7. Larva 9 days after hatching. Horizontal line, 1.0 mm.

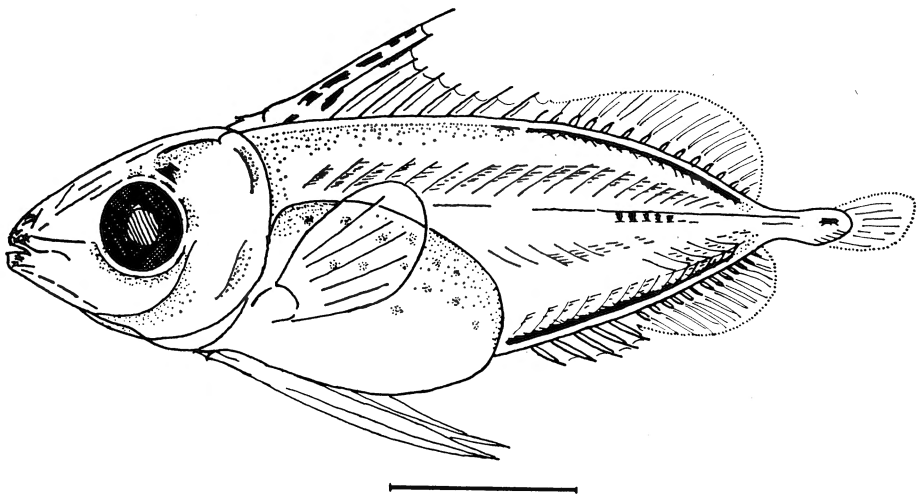

Fig. 8. Larva 16 days after hatching. Drawn from a preserved specimen with slightly deformed tail. Horizontal line, 2.0 mm.

and by the third day the mouth was open (Fig. 6). The lower jaw at this stage was 0.18 mm long and the mouth 0.12 mm wide. Pectoral fins developed during the third day and one turn was seen in the gut; gill arches started to form on the same day. The gill cleft was visible on the fifth day. Buds of the ventral fins, and the first of the dorsal spines, were present on day 7. The second dorsal spine, as well as the ventral fin spines, were apparent on day 9, and a mesial, serrated ridge appeared on the head at that time (Fig. 7). The posterior tip of the notochord began to flex upward on day 9. By day 13, two anal spines had formed and a lateral patch of pigment spots was apparent just anterior to the caudal peduncle. From this stage on, the abdomen gradually acquired more pigmentation and the snout became more elongated (Fig. 8), an appearance which was retained until metamorphosis (see above). As the larvae developed, the dorsal and ventral spines decreased in relative size: between days 10 and 16, the length of the largest of these spines equalled between 20 and 30% of the standard length of the fish, whereas after day 20 they equalled only about 15% of the standard length.

DISCUSSION

The results of this work suggest several guidelines for future rearing trials with *Siganus canaliculatus*. Stocking rearing tanks with hatched larvae rather than with unhatched eggs seems beneficial, because the demersal and adhesive qualities of the eggs make it difficult to aerate them adequately in large rearing tanks to assure optimal hatching. Larvae can be transferred on day 1 with no ill effects. Since adult *Siganus canaliculatus* will spawn in 500 liter tanks, the eggs can be left in the spawning tank, where adequate aeration can be provided, until hatching occurs.

Large tanks were decidedly better than small tanks for rearing larval *Siganus canaliculatus*. Popper *et al.* (1973) also obtained better results with large-volume containers in rearing trials with *Siganus rivulatus*, and recent successful rearing work with several other marine fishes has involved tanks of relatively large capacity (e. g., Liao *et al.*, 1970; Barnabé, 1974; René, 1974. The advantages conferred by large containers are many. The large water volume has a great buffering capacity, damping temperature fluctuations and probably maintaining a more constant and favorable chemical environment. Larvae in large containers have more freedom to swim continuously without contacting tank walls. Finally, a natural food chain develops in large containers, increasing the availability of food to larvae.

It is clear that an abundant supply of suitable food is essential for successful larval rearing. A great variety of cultured organisms has been used in attempts to feed marine fish larvae in captivity (May, 1970), but few have met with notable success. The rotifer, *Brachionus plicatilis,* has been used for this purpose increasingly in recent years (e. g., Harada, 1970; Theilacker and McMaster, 1971; Howell, 1973) and is attractive because of its appropriate size and ease of culture. Larval *Siganus canaliculatus* will consume this rotifer and can be reared on it, at least for a time. Over-reproduction of the rotifers may become a problem, however, and some means of cropping the rotifer population seems necessary. There was some indication that oyster eggs are a useful food for early larvae of *Siganus canaliculatus*, but logistic problems associated with oyster collection in Palau militate against further use of this food source, at least in the near future. Cultured copepods have been suggested as an ideal food for rearing larval marine fishes, because they ordinarily dominate the larval diet in nature (May, 1970). The fortuitous establishment of copepod populations in the rearing tanks during the present experiment suggests that this food can be easily cultured in Palau and should be exploited in future work, especially since the larvae seemed to prefer copepods to rotifers. Furthermore, copepod nauplii are smaller than rotifers and therefore are more suitable for first-feeding larvae. Further development of food production capabilities will probably be the key to increasing larval survival rates in future rearing trials with *Siganus canaliculatus*.

There is strong circumstantial evidence in the present study that prolonged feeding with *Artemia* nauplii is deleterious to larval *Siganus canaliculatus*. The reason for this is unclear; it could involve a basic nutritional inadequacy in *Artemia* nauplii, contamination by some toxic agent, or an inability on the part of the larvae to fully digest *Artemia*. Certain other fishes, notably clupeoids, also do poorly on prolonged *Artemia* regimes, while still others, such as certain flatfish, survive and grow quite well on an exclusive diet of *Artemia* (May, 1970). In the present instance a major problem with *Artemia* nauplii was that it led to overfeeding. Some two-week old *Siganus canaliculatus* larvae were definitely highly stressed after gorging themselves on *Artemia*, and autopsies of dead larvae three and four weeks old suggested that overfeeding on *Artemia* may have contributed to mortality. Larvae of the atherinid fish, *Leuresthes tenuis*, also apparently died from stuffing themselves with *Artemia* nauplii after food had been withheld for several days (May, 1971). Restricting the

supply of *Artemia* is no solution to this problem, as it has the equally undesirable effect of increasing competition between larvae and fostering cannibalism. In future work with *Siganus canaliculatus* it may be advisable to use *Artemia* nauplii only as a supplement to other foods, or to use it for only a short period of time.

It is significant that *Siganus canaliculatus* was reared to metamorphosis in outdoor tanks at temperatures between 28 and 32°C in Palau. This implies that marine fish hatcheries may prove feasible in Micronesia and other developing areas where water temperatures are high and where, for a variety of reasons, elaborate indoor rearing facilities are impractical. A simple transluscent roof was an indispensible aid in the present work, as it allowed natural illumination to stimulate phytoplankton growth and for the most part eliminated the drawbacks of completely exposed tanks in the tropics (namely, overheating and dilution from rain water). In spite of the roof, afternoon water temperatures occasionally reached very high levels; some form of tank insulation, and the capability to decrease light penetration through the roof on extremely sunny days, may be useful measures for eliminating overheating. In view of the high temperatures which can be expected in future hatchery work with tropical species, it would be useful to define the upper lethal limits for the larval stages so that appropriate measures can be taken when these limits are approached.

ACKNOWLEDGEMENTS

We wish to thank Beketaut Madraisau and Patrick Bryan for their considerable help in conducting this experiment. This work was supported by the Division of Marine Resources, Trust Territory of the Pacific Islands, and by grants to the Hawaii Institute of Marine Biology and the Micronesian Mariculture Demonstration Center from the Sea Grant Program of the National Oceanic and Atmospheric Administration, U. S. Department of Commerce.

REFERENCES

Anonymous, 1972. Plans for a siganid fish farming program. Proposed by Siganid Mariculture Group, at the Siganid Mariculture Implementation Conference. Hawaii Institute of Marine Biology, University of Hawaii, Honolulu, Hawaii, Nov. 1–5, 1972. iii+23 pp.

Barnabé, G. 1974. Mass rearing of the bass *Dicentrarchus labrax*. p. 749–753. *In* J. H. S. Blaxter (ed.), Early Life History of Fish. Springer-Verlag, Berlin.

Bryan, P., J. P. McVey and B. Madraisau. MS. Hormone-induced spawning of *Siganus canaliculatus*.

Fujita, S., and M. Ueno. 1954. On the development of the egg and prelarval stages of *Siganus fuscescens* (Houttuyn) by artificial insemination. Jap. J. Ichthyol. 3(3–5):129–132.

Harada, T. 1970. The present status of marine fish cultivation research in Japan. Helgol. wiss. Meeresunters. 20(1–4):594–601.

Howell, B. R. 1973. Marine fish culture in Britain VIII. A marine rotifer, *Brachionus plicatilis* Muller, and the larvae of the mussel, *Mytilus edulis* L., as foods for larval flatfish. J. Cons. 35(1):1–6.

Lam, T. J. 1974. Siganids: Their biology and mariculture potential. Aquaculture **3**(4): 325–354.

Liao, I. C., Y. J. Lu, T. L. Huang and M. C. Lin. 1970. Experiments on induced breeding of the grey mullet *Mugil cephalus* Linnaeus. Indo-Pac. Fish. Counc. 14th Sess., Bangkok, Thailand, Nov. 18-27, 1970. (mimeo), 26 pp.

May, R. C. 1970. Feeding larval marine fishes in the laboratory: a review. Calif. Coop. Oceanic Fish. Invest., Rep. 14:76–83.

May, R. C. 1971. Effects of delayed initial feeding on larvae of the grunion, *Leuresthes tenuis* (Ayres). Fish. Bull., U. S. 69(2):411–425.

McVey, J. P., and B. Madraisau. 1974. Observations on the spawning behavior and juvenile behavior of the rabbitfish *Siganus canaliculatus* in the Palau Islands. International Symposium on Indo-Pacific Tropical Reef Biology, Agana, Guam, June 23-July 5, 1974. (Abstract), p. 33.

Popper, D., H. Gordin and G. Wm. Kissil. 1973. Fertilization and hatching of rabbitfish *Siganus rivulatus*. Aquaculture 2(1):37–44.

René, F. 1974. Rearing of gilt-head *Sparus auratus*. p. 747. *In* J. H. S. Blaxter (ed.)., Early Life History of Fish. Springer-Verlag, Berlin.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco. xxi+776 pp.

Theilacker, G. H., and M. F. McMaster. 1971. Mass culture of the rotifer *Brachionus plicatilis* and its evaluation as a food for larval anchovies. Mar. Biol. 10(2):183–188.

Tsuda, R. T., P. G. Bryan, W. J. FitzGerald and W. J. Tobias. 1974. Juvenile-adult rearing of *Siganus* (Pisces: Siganidae) in Guam. South Pacific Commission Seventh Technical Meeting on Fisheries, Nuku'alofa, Tonga, July 15–19, 1974. (mimeo), 6 pp.