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CULTIVATION, SPAWNING, AND GROWTH OF THE GIANT CLAMS *TRIDACNA GIGAS*, *T. DERASA*, AND *T. SQUAMOSA* IN PALAU, CAROLINE ISLANDS

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ABSTRACT

Beckvar, N., 1981. Cultivation, spawning, and growth of the giant clams *Tridacna gigas*, *T. derasa* and *T. squamosa* in Palau, Caroline Islands. *Aquaculture*, 24: 21—30.

Larvae of the giant clams *Tridacna gigas*, *T. derasa*, and *T. squamosa* were reared in the laboratory, and juveniles were cultivated outdoors in a sunlit, flowing seawater system. Gametes were obtained from spontaneous laboratory spawnings and by induction of spawning with hydrogen peroxide. No supplemental food was added to the system. Laboratory reared *T. gigas* reached a mean length of 2.6 cm at 10 months post-fertilization; *T. derasa* were 1.1 cm mean length at 5 months; and *T. squamosa* were 6.7 cm mean length at 2 years.

Field growth studies on clams, 12—25 cm long, predict high projected growth/year: *T. gigas* grow 8—12 cm/year; *T. derasa* grow 3—6 cm/year; *Hippopus hippopus* grow 3—5 cm/year; and *T. squamosa* grow 2—4 cm/year. Instantaneous growth rates decrease with increasing length for each species. Mariculture and the seeding of overharvested reefs may now be examined for their feasibility.

INTRODUCTION

Giant clams (Tridacnidae) are probably both the fastest growing bivalves (Bonham, 1965) and the largest, attaining lengths to 1.4 m and weights to 263 kg. These coral reef dwellers have a similar mode of nutrition to the surrounding corals and house photosynthetic zooxanthellae in their brightly colored mantles (Yonge, 1936). They inhabit shallow water and are easily harvested for their highly valued shells and meats. The six species of giant clams within the family Tridacnidae are restricted to the Indo-Pacific faunal region (Rosewater, 1965). The recent decline in clam populations is probably the single most conspieuous aspect of overfishing in the entire tropical Pacific. Since 1969, over 156 000 giant clams have been taken from Swain Reefs in the Australian Great Barrier Reef (Pearson, 1977). In Ponape, *Tridacna gigas* empty shells are the only indication that it once abounded (R. Owens, personal communication, 1979). Although the Palau Islands still support all six species of giant clams, the diminishing number of *T. gigas* on reefs has been of particular local concern. Surveys have concluded that if high fishing pressure continues on Helen Reef, the clam population could become entirely depleted (Hester and Jones, 1974; Bryan and McConnel, 1976; Hirschberger, 1980).

Giant clams are functional protandric hermaphrodites (Wada, 1952). Spawning of *Tridacna maxima* (Röding), *T. squamosa* Lamarck, and *Hippopus hippopus* (Linnaeus) has been induced, using stripped gonads as a stimulating agent (Wada, 1954; LaBarbera, 1975; Jameson, 1976), but larvae were raised only one or several months past metamorphosis. Only the smallest species, *T. crocea* Lamarck, has been reared successfully (M. Murakoshi, personal communication, 1979). The two larger giant clam species, *T. gigas* (Linnaeus) and *T. derasa* (Röding), have suffered some of the highest fishing pressures and are the least studied.

Growth rates of giant clams are not well-understood, although several have speculated that length increases yearly by 5—8 cm (Bartsch and Nichols, 1945; Rosewater, 1965). Bonham (1965) used radioautography to determine the age of one *T. gigas* from Bikini Atoll and concluded that a 52 cm clam was in its ninth year. The present report describes studies concentrating on growth, spawning, and rearing of *T. gigas*, *T. derasa*, *T. squamosa*, and *H. hippopus*, conducted at the Micronesian Mariculture Center in Palau.

METHODS

T. gigas were collected from the outer reef and transported to the laboratory in baitwells filled with seawater. *T. derasa* were collected from patch reefs, whereas *T. squamosa* and *H. hippopus* were found both in lagoons and on the outer reefs. Clams were maintained in outdoor laboratory raceways with a continuous seawater flow at a salinity of 32‰ and a temperature between 27 and 33°C. After spawning trials, clams were tagged and placed in a protected cove for periodic measurement and for future use as brood stock.

Spawning occurred either spontaneously or was induced by using macerated gonad (fresh or frozen) and hydrogen peroxide. Macerated gonad was introduced into the raceways near the incurrent siphons of 6—12 brood clams. Hydrogen peroxide was tested by squirting 20—30 ml of a 3% solution directly into the clams' incurrent siphon.

Following spawning, fertilized eggs were removed from the raceways in buckets and transferred to 1000 l indoor containers filled with 25 μm filtered seawater. Trochophores and veligers were maintained in these tanks; they were not fed, but 100 l were replaced with fresh seawater every other day. No aeration was provided. Prior to development of the larval foot (pediveliger stage), veligers were removed to an outdoor rearing system. The free-swimming veligers were transferred by siphoning the 1000 l tanks and trapping the larvae on a 70 μm Nitex filter.

The outdoor flow-through rearing system, consisting of a series of seven clear, circular, fiberglass, 30 l tanks on a gravity-flow system, had a constant seawater flow of 1.5 l/min. The system was screened from the sun by a translucent blue plastic roof. From 4000-6000 veligers were placed in each tank. Temperature in the tanks fluctuated daily from 27 to 33°C. Algal overgrowth in the tanks was retarded by placing black plastic under the tanks and 1/4-in. Vexar screen over them, but algal overgrowth continued to be a serious problem. Gas bubbles that developed in the tanks were removed daily by rinsing with seawater.

Pediveligers settled and metamorphosed without a special substrate and juveniles were maintained in this system and measured periodically. In September 1979, they were transferred into 1000 l cement tanks receiving seawater continuously (15 l/min) and direct sunlight for several hours each day. The final length measurements were taken on clams from these tanks in March 1980.

Growth of laboratory reared *T. squamosa* in the field was compared with that in the outdoor laboratory system. Clams in the field were held in a cage made from a Nestier tray covered with 1/4-in. Vexar screen. These clams (N=11) were placed in 3 m of water in the lagoon for 2 months.

Field growth studies were conducted on the four largest species of Tridacnidae, collected from numerous reefs in Palau. Clams were brought to the laboratory for tagging. The shells were scrubbed clean of organic matter, dried, and tagged using plastic tags attached to the shell with underwater epoxy (Aquatapoxy). Clams were double-and triple-tagged, and after initial measurements they were placed in about 3 m of water in a cove protected by high islands. Three of the four clam species occur naturally in this cove. Measurements were made every few months on about 80 clams with initial lengths of 12—27 cm. Shell length was measured with calipers along the longest axis. Because of shell irregularities, every clam was measured four times on each date and the longest length recorded. This method gave measurements that were repeatable with an accuracy of ± 0.2 cm. With double-and triple-tagging, less than 10% of the clams lost all tags.

RESULTS

Spawning and cultivation

Freshly collected *T. gigas*, with shell lengths of 45—75 cm, were induced to spawn sperm, using fresh or frozen macerated gonad; however, no eggs were released. These clams were held in raceways for 2 months. On nine occasions they spawned spontaneously, always beginning in late afternoon. This behavior was unique for *T. gigas*; other species exhibited different temporal patterns of gamete release. Eggs were released on three of these occasions but two batches degenerated for unknown reasons. In October 1978, fertilization and development proceeded normally. Larval density was adjusted to 1/ 2 ml. Trochophores hatched 16 h after fertilization, and at 20 h postfertilization larvae were in the trochophore—veliger transitional stage. Pediveligers settled on tank sides and bottom 7 days after fertilization, and by day 10 metamorphosis had occurred. Laboratory reared *T. gigas* attached themselves to coral placed in the tanks (Fig. 1). Mortality was greater than 99% from egg to juvenile stage. After 10 months in the system, these clams had a mean length of 2.6 cm (Fig. 2), and at 17 months, five remaining *T. gigas* had a mean length of 8.3 cm.

T. derasa were induced to spawn in March 1979, using hydrogen peroxide as a stimulating agent. Hydrogen peroxide has been used to induce spawning in gastropods and bivalves (Morse et al., 1977) but has never been used previously to induce spawning in giant clams. On two consecutive afternoons, 20—30 ml of H_2O_2 were squirted into the incurrent siphon of 10 specimens ranging in length from 30 to 45 cm. On the first day one clam reacted within

Fig. 1. Laboratory reared *T. gigas* at 4-1/2 months, 0.8 cm long, attached to coral (March, 1979).

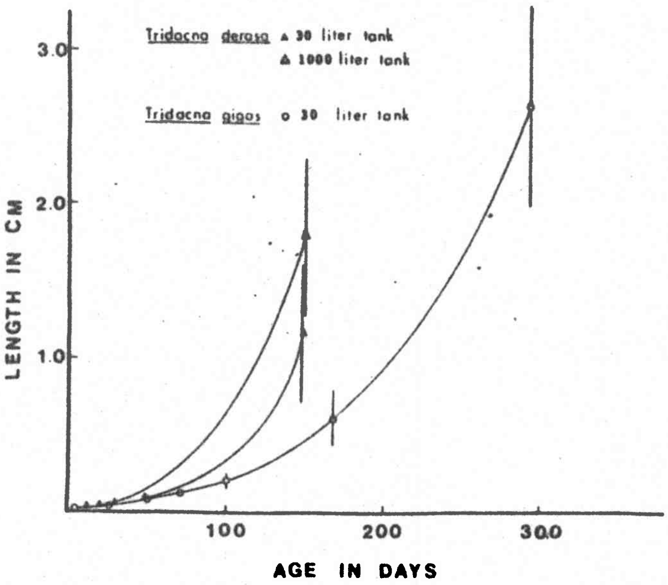

Fig. 2. Growth of laboratory reared larvae and juveniles of *T. gigas* (October 1978—August 1979) and *T. derasa* (March 1979—August 1979). Points are mean shell lengths of *N*= 15—20 clams, with 1 S.D. Curves fitted by eye.

15 min and another within 90 min by spawning sperm. On the second afternoon, within 1 h after addition of H_2O_2, all clams began releasing gametes copiously. The reaction was not typical of the genus because some individuals released egg and sperm simultaneously, but fertilization and normal development followed. *T. derasa* pediveligers were first observed on day 5 and by day 6 all larvae had reached this stage. On day 11 the newly metamorphosed juveniles all contained three to eight cells of zooxanthellae. Pediveligers held in indoor tanks with no water exchange did not metamorphose and eventually died. After 2 months there were between 300 and 500 juveniles surviving in each 30 l tank. At 5 months *T. derasa* in the 30 l system had a mean length of 1.1 cm and juveniles reared in a 1000 l cement tank were 1.7 cm (Fig. 2).

T. squamosa spawned spontaneously (W. Hamner, personal communication, 1979) in March 1978, and larvae were handled similarly to the other species. Laboratory reared juvenile *T. squamosa* grown in cages in the lagoon for 2 months had faster growth than laboratory reared ones. Mean length increased 0.31 cm for 22 laboratory reared clams over 2 months, while 11 ocean reared clams increased 0.85 cm in length during the same time. After 1 year of laboratory rearing, *T. squamosa* (Fig. 3) had a mean length of 2.8 cm. The 2-year-old clams (*N*=6) had a mean length of 6.7 cm and a maximum length of 9.2 cm.

Sunlight may be the single most critical factor influencing the growth of giant clams. Their unique symbiosis with the photosynthetic zooxanthellae has been long known (Yonge, 1936) but poorly understood. Considerable

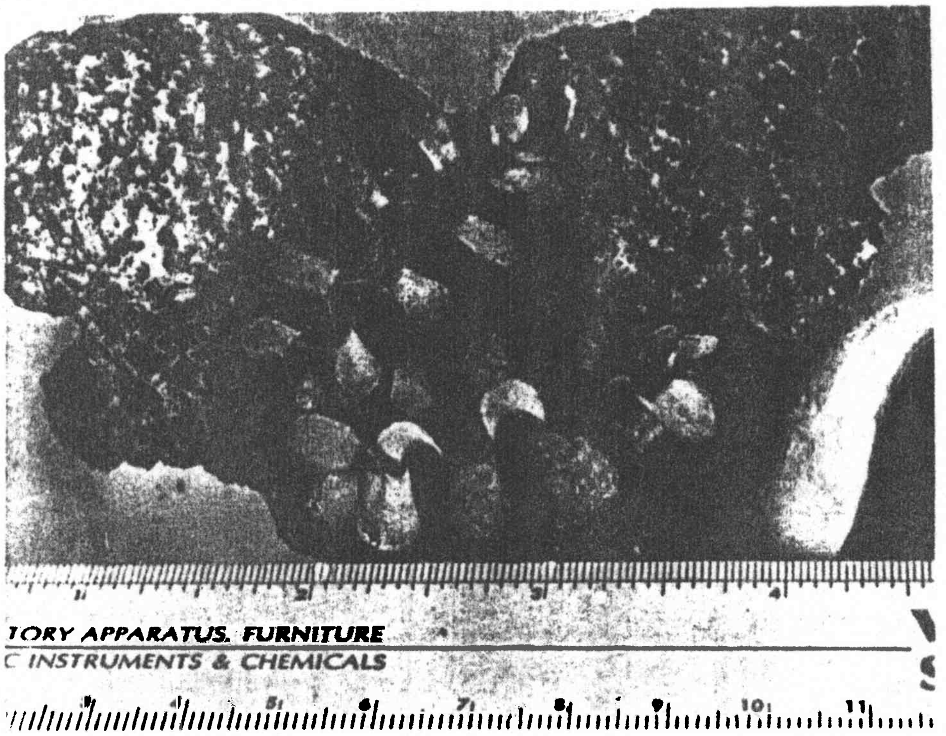

Fig. 3. Laboratory reared 1-year-old *T. squamosa*, 3.7 cm long and 4.1 cm long, attached to coral (March 1979).

size variation was noted between tanks where amount of sunlight was the most obvious variable. Tanks receiving the most sunlight had clams with a mean length of 0.2 cm, whereas those clams receiving the least sunlight were only 0.13 cm mean length. *T. squamosa* juveniles raised indoors under artificial light had retarded growth and higher mortality compared with clams reared outdoors.

Field growth studies

There was considerable variation in growth even between similar-sized clams of the same species, but some trends were apparent. Instantaneous growth (K) was calculated from measured increases in shell length during 4—11 months of growth, using the equation

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$$K = \ln L_2 - \ln L_1 / T_2 - T_1 .$$

Projected growth/year (Table I) was calculated from these instantaneous growth rates. *T. gigas* had the highest projected growth, ranging from 8—12 cm/year. Similar-sized specimens of the other species grew as follows: *T.*

TABLE I

Instantaneous growth (K) and projected growth/year of clams measured August 1978—April 1979, and some through August 1979 (Mean length is initial length of animal and represents an average when more than 1 clam was within a 1 cm interval. *T. gigas*, $N=18$; *T. derasa*, $N=14$; *H. hippopus*, $N=16$; *T. squamosa*, $N=29$. Measurement error ± 0.2 cm)

T. gigas			*T. derasa*			*H. hippopus*			*T. squamosa*		
Mean length (cm)	K ($\times 10^{-3}$)	Projected growth/ year (cm)	Mean length (cm)	K ($\times 10^{-3}$)	Projected growth/ year (cm)	Mean length (cm)	K ($\times 10^{-3}$)	Projected growth/ year (cm)	Mean length (cm)	K ($\times 10^{-3}$)	Projected growth/ year (cm)
14.0	1.64	8.4	13.0	1.23	5.8	11.9	0.91	4.0	13.2	0.78	3.8
17.0	1.95	12.1	15.6	0.95	5.4	16.1	0.71	4.3	16.4	0.43	2.6
18.8	1.76	12.1	19.3	0.62	4.4	18.1	0.74	5.3	17.6	0.45	2.9
19.8	1.19	8.6	20.2	0.86	6.3	21.9	0.41	3.3	19.8	0.33	2.4
20.2	1.39	10.3	22.2	0.48	3.9	22.8	0.3	2.5	20.5	0.25	1.9
21.5	1.39	10.9	22.8	0.76	6.3	24.1	0.29	2.6	21.3	0.23	1.8
22.2	1.16	9.4	23.6	0.57	4.9	26.1	0.31	3.0	22.8	0.3	2.5
23.4	1.16	9.9	24.4	0.43	3.8	27.8	0.31	3.1	23.4	0.13	1.1
24.1	1.11	9.8	25.9	0.27	2.6				24.7	0.0	0.0
			26.8	0.25	2.4				25.4	0.06	0.6
			27.5	0.21	2.1				27.3	0.0	0.0

derasa, 3—6 cm/year; *H. hippopus*, 3—5 cm/year; and *T. squamosa*, 2—4 cm/year. The larger the maximum size attained by the species, the faster the growth, but growth differences among the four species are due in part to age differences. *T. gigas* (maximum length 137 cm) at 20 cm shell length would be young clams approximately 2—4 years of age, whereas *T. squamosa* (maximum length 40 cm) would be sexually mature adults perhaps 8—13 years of age. Instantaneous growth rates decrease with increasing shell length for all species (Table I). This supports an earlier study with *T. maxima* in Australia which demonstrated that growth rate decreased with increasing age (McMichael, 1974). Therefore, growth of *T. squamosa* above 24 cm was difficult to detect in the present study.

Most clams were collected from the outer reef where the strong current may induce thick shell growth. In a protected cove with a slower current, a faster increase in shell length might be expected. Growth of young *T. gigas* is, however, impressive.

DISCUSSION

Giant clams appear amenable to culturing. They spawn prolifically in the laboratory, have a short larval life, require little maintenance during grow-out, and obtain nutrition from the photosynthesis of their symbiotic zooxanthellae. Larvae settle on tank bottoms without a special substrate and, after metamorphosis, grow remarkably fast. Although young clams attach by byssal threads, they readily reattach if removed carefully. Therefore, "spot" handling of juveniles would not be a factor limiting cultivation as Yamaguchi (1977) suggests. Clams grown to a suitable "escape" size in the laboratory could be transferred to a clam "farm" in the ocean where they might have higher growth rates.

At present, the major factors limiting giant clam cultivation include: high larval mortality, filamentous algal overgrowth in the rearing tanks, and uncertain availability of spawners. Further investigations of these problems are needed. *T. derasa* had less than 3% survival from veliger to juvenile stage. Future studies on larval nutrition requirements and improved rearing techniques should result in increased survival rates. As a means of controlling algal growth, the feasibility of culturing algal grazing *Trochus niloticus* juveniles (Heslinga and Hillman, 1981) with tridacnid juveniles should be investigated. Although the spawning periodicities of giant clams are undetermined, temporal trends are emerging from laboratory trials. *T. squamosa* spawned from February to March at Eniwetok (Rosewater, 1965), July in Fiji (LaBarbera, 1974, 1975), and February (Hardy and Hardy, 1969) and March in Palau. This species may have a peak breeding season in winter (Yamaguchi, 1977). *H. hippopus* spawned in June (Jameson, 1976), July (Yamaguchi, 1977), and April in Palau. The peak breeding period in Australia was the summer months of January to March (Stephenson, 1934). The peak breeding period of *H. hippopus* appears to be in summer. *T. gigas* and *T. derasa* were induced to spawn only in Palau. *T. derasa* spawned in March and April and *T. gigas* spawned in July, September, and October. Tridacnidae may also have a lunar spawning cycle. Five of eight spawnings (spontaneous and induced) by *T. gigas*, *T. derasa*, and *H. hippopus* were on or near new moon. These spawnings were in the afternoon on a rising tide. The only in situ spawning observation on *T. gigas* was made the day before new moon in the late afternoon (G.A. Heslinga, personal communication, 1979).

T. gigas and *T. derasa* larvae followed the stereotypic development pattern described by Jameson (1976). Larval and juvenile growth of *T. squamosa* in the present study was similar to that of the species in his study. However, growth of *T. gigas* and *T. derasa* juveniles was much faster than the other four species. This may have been because *T. gigas* and *T. derasa* were exposed to more sunlight. *T. derasa* juveniles reared in 1000 l tanks in direct sunlight had the most rapid growth (Fig. 2).

Application of these techniques to tridacnid mariculture and conservation looks promising. Conservation practices should be initiated by consolidating some of the now scattered clams into breeding units, encouraging higher juvenile recruitment by increasing the probability of successful fertilization. Breeding populations could be introduced to areas where clams are now extinct and regulations imposed to restrict harvesting. Additionally, juveniles reared in the laboratory could be used to reseed selected reefs.

The studies reported here could be applicable in many areas of the tropical Pacific, where giant clam populations are rapidly declining. Improved and expanded culture techniques could insure preservation of this valuable resource, and could eventually permit profitable export of both meat and shells. Active support and interest of local Pacific Island governments will be important prerequisities in the development of a successful giant clam mariculture industry.

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