Ecology of *Tridacna* in Palau[1]

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ABSTRACT: Species composition, distribution, standing crop biomass, spawning, and growth rate of Tridacnidae clams were studied in Palau, Western Caroline Islands. The population was composed of six species: *Tridacna gigas, T. derasa, T. squamosa, T. maxima, T. crocea,* and *Hippopus hippopus*. In random transects, *T. crocea* was the most frequent and abundant, while *T. derasa* and *T. gigas* made up the largest proportion of the standing crop biomass. Spawning was induced artificially in *T. squamosa* by addition of macerated gonad from one individual to an aquarium containing other individuals, but larval development was not observed. The growth rate of tagged Tridacnidae was slow and further study will be required before an estimate of biomass production can be derived.

THIS STUDY was initiated to determine the growth rate, standing crop, biomass production, and economic potential of the giant clams of Palau. It should also prove useful in outlining conservation measures.

The giant clams of the family Tridacnidae Goldfuss are widely distributed in the shallow coral reef areas of the Indo-Pacific region. Depending on the species, these sessile bivalves either rest on the botom unattached, or attach by strong bysuss threads and burrow into massive coral heads. They are found from the surface down to about 10 to 20 meters depth.

The family contains two genera, *Tridacna* Bruguière and *Hippopus* Lamarck. The former contains five species: *Tridacna gigas* (Linné), the largest, reaching 137 cm in length, *T. derasa* (Roding), *T. squamosa* (Lamarck), *T. maxima* (Roding), and *T. crocea* (Lamarck), the smallest of the group (maximum length 15 cm). The latter genus is represented only by *Hippopus hippopus* (Linné), which reaches a length of 39.7 cm. All six of the above species are found in Palau and are included in this study. Following are the Palauan equivalent names for the family Tridacnidae: Tridacnidae, kim; *T. squamosa*, ribkungel; *T. gigas*, otkang; *T. crocea*, oruer; *T. maxima,* melibes; *Hippopus hippopus*, duadeb; *T. derasa*, kisum. The taxonomy and distribution of the family have been reviewed by Rosewater (1965).

All members of the family are protandrus hermaphrodites; the gonads of larger individuals contain both male and female sex cells. Spawning, probably induced by some unknown stimulus in the environment, has been induced artificially by the addition of egg suspension from one individual to water containing another individual (Rosewater, 1965; Wada, 1954). The embryology and larval development remain unknown.

Life-span estimates of Tridacnidae range from eight years (Pelseneer, 1894) to several hundred years (Comfort, 1957). Rosewater's (1965) growth measurements on a specimen of *T. gigas* near Eniwetok Island indicate a growth rate of almost 5.1 cm per year (559 to 610 mm in 11.5 months). Bonham (1965) used radioautographs to measure strontium-90 deposited in the shells of *T. gigas* at Bikini after the 1956 and 1958 nuclear weapons tests. He interpreted the regular strontium-90 banding pattern found in the shells as annular growth lines. This method indicated a rate of growth of 5 to 8 cm per year. But reliable long-term growth measurements on many individuals of different sizes and species have not been made.

Like most lamellibranchs, Tridacnidae are filter feeders, pumping water into the mantle cavity through the inhalant siphon, removing plankton with the ciliary tracts on the gills, and

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passing water out through the exhalant siphon. In addition, the Tridacnidae are unique in their ability to "farm" part of their own food (Yonge, 1936). Zooxanthellae, contained within phagocytes in the mantle, may provide another source of energy for the clam (Muscatine, 1967).

Because of their large size, abundance, ease of harvesting, and probable high productivity, the giant clams may become an important future fisheries resource in the Indo-Pacific.

METHODS AND MATERIALS

Distribution and Standing Crop Biomass

We chose a region south of Koror from outside the fringing reef on the east to outside the barrier on the west as the location of study (Fig. 1). This region was chosen for several reasons: (1) the relatively great distance from areas of pollution runoff and high fishing pressure; (2) the assurance, since it was within the government game preserve area of Seventy Islands, that tagged clams would not be removed by fishermen; and (3) the large variety of habitats within the area.

This region we divided into 224 numbered areas, each of approximately 1.00×10^6 square meters. Each of these 224 areas was further divided into 64 numbered sections of approximately 2.43×10^4 square meters, thus designating a total of 14,336 (224×64) numbered sections. Using a table of random numbers (Ostle, 1960), we selected sampling sites from these numbered sections, rejecting any sections that proved deeper than 18.3 meters (10 fathoms).

When approaching a selected sampling section by boat we located position by taking compass bearings from known landmarks. After anchoring we descended with SCUBA and, beginning at the anchor and proceeding clockwise, marked off with string a square transect (usually 100 m^2) along the bottom. Then we carefully worked along the bottom, identifying and measuring all clams within the transect area.

We measured the greatest shell length of each clam with sliding meter stick calipers and recorded notes on a plastic writing board (Fig. 2). In addition to these random sites, we made a 1600 m^2 transect in the area of tagged clams (see section on growth rate below).

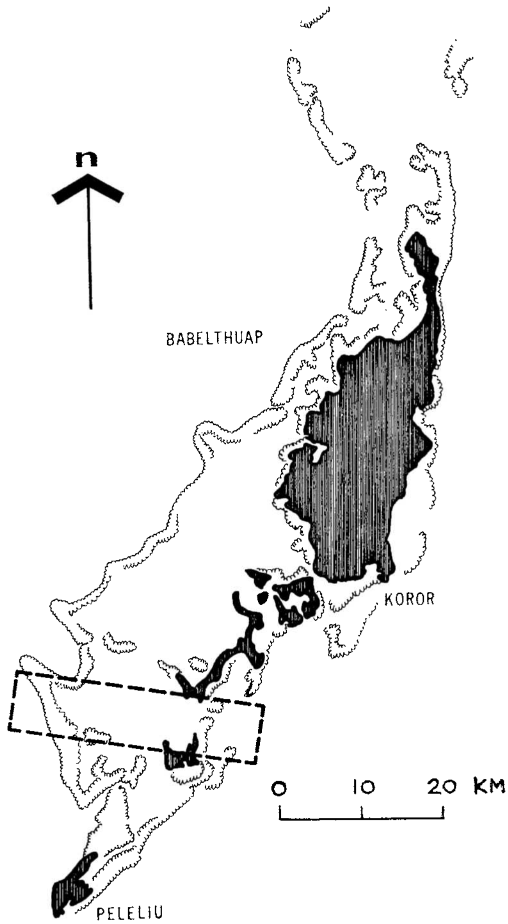

FIG. 1. Palau, Western Caroline Islands. *Dotted line* indicates area of study.

To determine the ratio of shell length to wet and dry weight of clam body, we transported live clams to the laboratory and recorded the total wet weight, wet weight of body without shell, and dry body weight of each. We determined dry weights by drying the clam bodies to constant weight in an oven at $120 \pm 1°C$.

Growth Rate

We selected a small coral reef in the Seventy Islands area as a sampling site for growth measurements on Tridacnidae. This reef, typical of the many small reef areas found inside the Palau lagoon, rises from an 18-meter deep sand bottom to the surface at low-low tide and is

FIG. 2. Author recording data underwater on plastic writing board. Depth 8 meters. *Arrow* indicates looped tag in *Tridacna squamosa*. Photograph by Peter Wilson.

protected from surf action by surrounding islands. Using SCUBA and a hand drill we drilled a 3-mm hole in the dorsal edge of each clam shell near the lip and inserted numbered yellow plastic spaghetti tags, tying each into a loop with monofilament line (Fig. 2). We tagged 70 clams in this manner between May 24 and September 20, 1967.

Spawning

We induced spawning reactions in *T. squamosa* following the procedure of Wada (1954). We collected three individuals from Malakal Harbor on February 28, 1968 (29.6, 15.1 and 10.2 cm length) and placed them in a 20-gallon aerated saltwater aquarium at 26.5°C. We added approximately one gram of macerated gonad from a fourth clam (length 28.8 cm) to the aquarium and after the clams had spawned removed them from the acquarium. We placed pieces of glass, shell, and stone in the bottom of the aquarium to serve as settling areas for developing larvae and examined these objects (and the water) microscopically at intervals for three weeks.

RESULTS AND DISCUSSION

Distributions and Habitats

Tridacna squamosa and *Hippopus hippopus* occupy much the same habitat and were often found together. They were widely distributed in relatively shallow water both in the lagoon and on the barrier and fringing reefs. The former were more often associated with coral areas of *Acropora* sp., and the latter with sandy areas between scattered coral heads.

The distribution of *T. crocea* is highly clumped because of its habit of burrowing into scattered massive coral heads (*Porites* sp.) and limestone rock, where it attaches by strong bysuss threads. The clams were found in the bays, in the lagoon, and on the reefs, mostly in shallow water, but in one case down to 8 meters depth.

Tridacna derasa was found mostly in the lagoon, from the surface down to 20 meters, and often in association with areas of old *Acropora* sp.

Tridacna maxima and *T. gigas* were very seldom found in the bays, sometimes in the lagoon, but mostly in the transparent water of the barrier and fringing reefs. Both were often found in areas of surf action. An apparent environmental dimorphism was found in *T. gigas*. Individuals growing inside the lagoon had comparatively thin shells (valves), whereas those growing in areas of turbulent surf action on the outer reefs had much heavier, thickened shells. They were found from the surface down to 20 meters.

Distribution and growth may also be affected by the velocity of tidal currents and the rate at which food plankton is carried past the inhalant siphon of the clam. Motoda (1940) determined the differences in seasonal hydrographic conditions between the bay, the lagoon, and the open sea in Palau. He found that the primary difference among these three areas was in depth of transparency of the water. He attributed this difference to the amount and nature of silt and microorganisms. The transparency in the bay was 8 to 11 meters, in the lagoon 11 to 28 meters, and in the open sea 17 to 36.4 meters, all with little seasonal variation.

Differences in temperature, oxygen content, pH, and specific gravity were not appreciable. In the lagoon area, with which the present study is concerned, Motoda (1940) found that the annual monthly temperature varied between 28° and 30.1°C, with little variation down to the measured depth of 30 meters. Density was

TABLE 1

SPECIES AND STANDING CROP BIOMASS OF CLAMS IN EIGHT TRANSECTS TOTALING 1100 m^2

SPECIES	NUMBER OF INDIVIDUALS	ESTIMATED TOTAL WET WEIGHT OF CLAM BODIES ($kg/1100\ m^2$)	TOTAL WET WEIGHT OF CLAM BODIES (g/m^2)
Tridacna derasa	6	6.20	5.6
Tridacna gigas	2	3.20	2.9
Tridacna squamosa	7	2.60	2.4
Hippopus hippopus	4	2.54	2.3
Tridacna crocea	153	1.89	1.7
Tridacna maxima	6	0.74	0.7
Total	178	17.17	15.6

24.43 to 25.59 (σ_t), pH 8.25 to 8.35, and oxygen content 3.7 to 4.1 cc/liter.

These rather uniform hydrographic conditions indicate that the limiting depth for growth of Tridacnidae (10 to 20 meters) is determined primarily by the transparency of the water and the lack of sufficient light for photosynthesis by zooxanthellae at greater depths. In the inner bays, where transparency is less, we found Tridacnidae limited to shallower water (about 10 meters), whereas in the more transparent water near the barrier reef Tridacnidae were found down to 20 meters depth.

Again, considering the rather uniform hydrographic conditions, the horizontal distribution of Tridacnidae varied greatly between species and appeared to be determined by specific biohabitats, benthic topography, and associations with corals and other organisms. As noted above, the distributions of clams are not random, and that of *T. crocea*, in particular, is highly clumped. Future studies should attempt to determine the degree of clumping in the distribution of each species.

Standing Crop Biomass

Studies on seven random transects and one transect in the area of tagged clams were completed; the results are combined in Table 1. In the eight transects covering 1100 m^2 we found 178 clams totaling 17.17 kg wet body weight, or a mean specific density of 15.6 g/m^2. *Tridacna crocea* was the most abundant and most frequently encountered of the six species; while *T. derasa* made up the largest percentage of the total biomass.

The wet and dry body weights of clams of various lengths varied only slightly between species and have been combined graphically in Figures 3 and 4.

The relative scarcity of *T. gigas* found in our transects may result from fishing pressure on this particular species. According to reliable local informants, the number of *T. gigas* has markedly decreased in the last few years due to overfishing for export of the large shells. Large

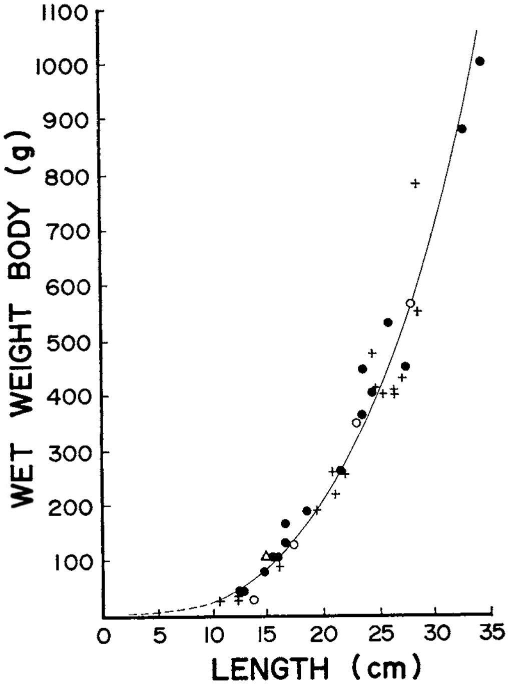

FIG. 3. Wet body weight of Tridacnidae in relation to greatest shell length. ●, *Tridacna squamosa;* ○, *Tridacna derasa*; △, *Tridacna maxima*; +, *Hippopus hippopus*.

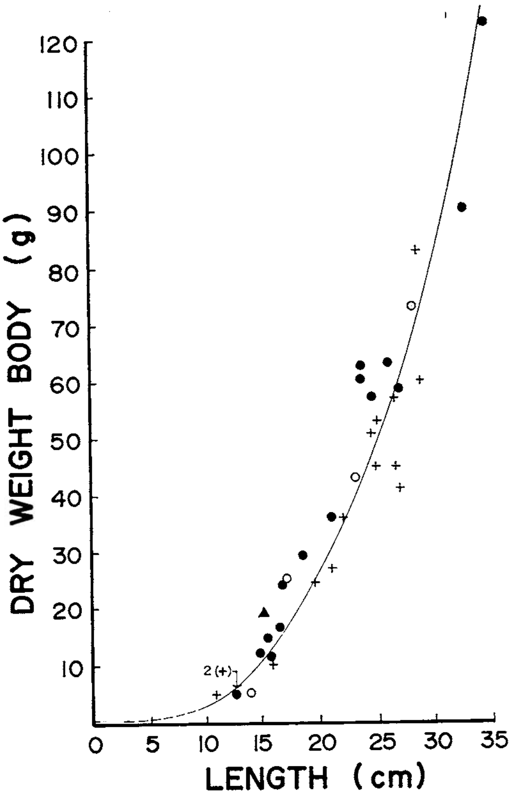

FIG. 4. Dry body weight of Tridacnidae in relation to greatest shell length. ●, *Tridacna squamosa*; ○, *Tridacna derasa*; △, *Tridacna maxima*; +, *Hippopus hippopus*.

T. gigas formerly occurred in much greater numbers and were even abundant in the T-Dock region of Koror. In areas farther away from Koror, they still occur in abundance.

Growth Rate

Preliminary growth measurements of tagged clams indicated that growth proceeds slowly. In fact, growth over a 7- to 11-month period was not great enough to exceed the experimental error in measurement using sliding meter stick calipers. For example, measurements on 15 tagged *T. squamosa* indicated growth of 0.7 ± 0.6 cm. In some cases, the length at recovery was less than the length at tagging, which we attribute to error in caliper measurement. The growth rate probably varies with size, species, and habitat, but a true growth curve cannot be derived until more individuals have been recovered. The large variation attributed here to experimental error in measurement indicates that further measurements must be made over a longer period of time. Future tagging and measurement of the clams should be done at yearly intervals for at least five years. This would provide a more valid indication of growth rate and an estimate of biomass production.

Spawning

Approximately one minute after the addition of macerated gonad to the aquarium containing three individuals of *T. squamosa*, all three clams began rapid contractual closure of the valves, which proceeded at intervals for 30 minutes to 2 hours. On many of the contractions, a white cloud was expelled through the exhalant siphon into the water. During a period of three weeks, no larvae were detected in the water or on objects placed in the bottom of the aquarium.

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