AN ABSTRACT OF THE THESIS of Barry D. Smith for the Master of Science in Biology presented October 23, 1979.

Title: Growth Rate, Abundance, and Distribution of the Topshell *Trochus niloticus* on Guam

Approved: *Stephen G. Nelson*
Stephen G. Nelson, Chairman, Thesis Committee

Growth rates of the topshell *Trochus niloticus* Linnaeus on Guam, Mariana Islands, were studied with a mark and recapture method. A total of 598 topshells were tagged, measured, and released. Monthly measurements of the increase in diameter were made to the nearest 0.1 mm. Growth rates were determined on the basis of 322 recaptures. Although considerable variation in growth rates is evident, there is a significant negative correlation ($r = -0.69$, $p<0.01$) between growth rate and initial shell diameter. A fit of the growth data to the von Bertalanffy equation has the form $L_t = 146.5[1 - e^{-0.2462(t)}]$, when t_0 is assumed to be 0.

Spatial distribution and abundance of *T. niloticus* were surveyed at sites characterized by wide reef flats, narrow reef flats, and limestone benches. The low densities ($<0.1/20\ m^2$) of topshells found on the windward (eastern) side of the island may be related to the low-relief topography of the windward reefs. Mean abundances at various sites on the leeward (western) side of the island ranged from

0.05 to 2.13/20 m^2. Distinct zonation of size classes of topshells was found for the outer reef flat, reef margin, 6-m contour, and 12-m contour. The size distribution of _T. niloticus_ appears to be related to reef topography.

GROWTH RATE, ABUNDANCE, AND DISTRIBUTION OF THE TOPSHELL *TROCHUS NILOTICUS* ON GUAM

by

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INTRODUCTION

The topshell *Trochus niloticus* Linnaeus, one of the largest members of the family Trochidae, is widely distributed in the Indo-West Pacific region. Hedley (1917) described its range as extending from Ceylon [Sri Lanka] in the west to the Samoa Islands in the east, and from Australia and New Caledonia in the south to the Loo Choo [Ryukyu] Islands in the north. The economic value of trochus shell (Talavera and Faustino, 1931; Motoda, 1938; Gardner, 1948; Johannes, 1978) has stimulated efforts to introduce *T. niloticus* into many of the Pacific island groups (South Seas Government Fisheries Experimental Station, 1937, 1938, 1939; Asano, 1937a, 1937b; Powell, 1957; Doumenge, 1972), and successful transplantations have resulted in reproductively viable populations of this gastropod becoming established southeastwards to the Society Islands and Tuamotu Archipelago (Salvat and Rives, 1975) and northeastwards to Hawaii (Kay, in press).

The distributional pattern of *T. niloticus* in Micronesia is similar to that in the rest of the Indo-West Pacific. Indigenous populations of this topshell are found only in the Yap Islands, the Palau Islands, and Helen Reef (McGowan, 1956). Elsewhere in Micronesia, *T. niloticus* has become established subsequent to its introduction by various individuals and governmental agencies (South Seas Government Fisheries Experimental Station, 1937, 1938, 1939; Asano, 1937a, 1937b; McGowan, 1958). Van Pel (1955) reported that the first *T. niloticus* introduced on Guam were transplanted from Saipan by a local fisherman.

Studies of the growth of *T. niloticus* have been conducted at several locations all within the indigenous range of the species. Moorhouse (1932) and Asano (1940) reported on the growth rates of a narrow range of small to intermediate sizes (20-70 mm in base diameter) of *T. niloticus*, and Rao (1936), with few exceptions, focused on the intermediate sizes (30-100 mm). The absence of larger sizes (>100 mm) in these studies may have led to biases in the calculation of size-at-age and lifespan estimates.

Distribution and abundance of topshell populations have been studied only superficially. Moorhouse (1932) noted a general zonation, in which smaller sizes (≤20 mm) occupied the shingle beach and successively larger sizes (30-90 mm) were found seawards on the reef flat; he reported that no *T. niloticus* were observed in more than 1 m of water. Larger *T. niloticus* (≥50 mm) were found to depths of about 13 m by Rao (1937), and McGowan (1956) reported that, depending upon reef formation, topshells may inhabit depths of 24 m. McGowan (1958) and Devambez (1959) discussed densities of *T. niloticus* in terms of catch per unit of effort. A preliminary assessment of topshells at selected sites on Guam was presented by Stojkovich and Smith (1978).

The purpose of this study was to determine the monthly growth rate of a wide size range of *T. niloticus* on Guam and to describe the spatial distribution of this gastropod in different reef habitats.

MATERIALS AND METHODS

Growth studies were conducted at Western Shoals in Apra Harbor and at Tumon Bay (see Fig. 1). The area known as Western Shoals is a portion of a series of patch reefs rising abruptly from a deep lagoon floor (≈30 m) at the eastern end of the harbor. The patch reef is a shallow, flat platform sloping on the western side to a 5-m terrace, which is characterized by well-developed and diverse coral growth (Randall and Holloman, 1974).

Tumon Bay is an extensive fringing reef system, averaging about 500 m in width. The outer reef flat is elevated and exposed during lower tides. Submarine channels originate at the reef margin and extend onto terraces at 6 m and 12 m (Randall and Holloman, 1974).

Monthly growth of Trochus niloticus was determined by a mark and recapture method. Numbered aluminum tags, 6 x 12 mm in dimensions, were cemented onto the shells with a waterproof epoxy polymer. In order to create a surface to which the polymer would adhere, a portion of the periostracum and one or more of the calcareous layers of the shell were removed. The shell layers were chiseled off larger, sturdier shells and filed off smaller, more fragile shells. In an effort to reduce stress to the animals as much as possible, the entire tagging procedure was carried out underwater. A total of 447 T. niloticus was tagged and released at Western Shoals, and an additional group of 151 topshells was tagged at Tumon Bay.

Tagged topshells were measured across the greatest diameter of the base of the shell and returned as closely as possible to the position from which they were removed. Measurements were made to the nearest

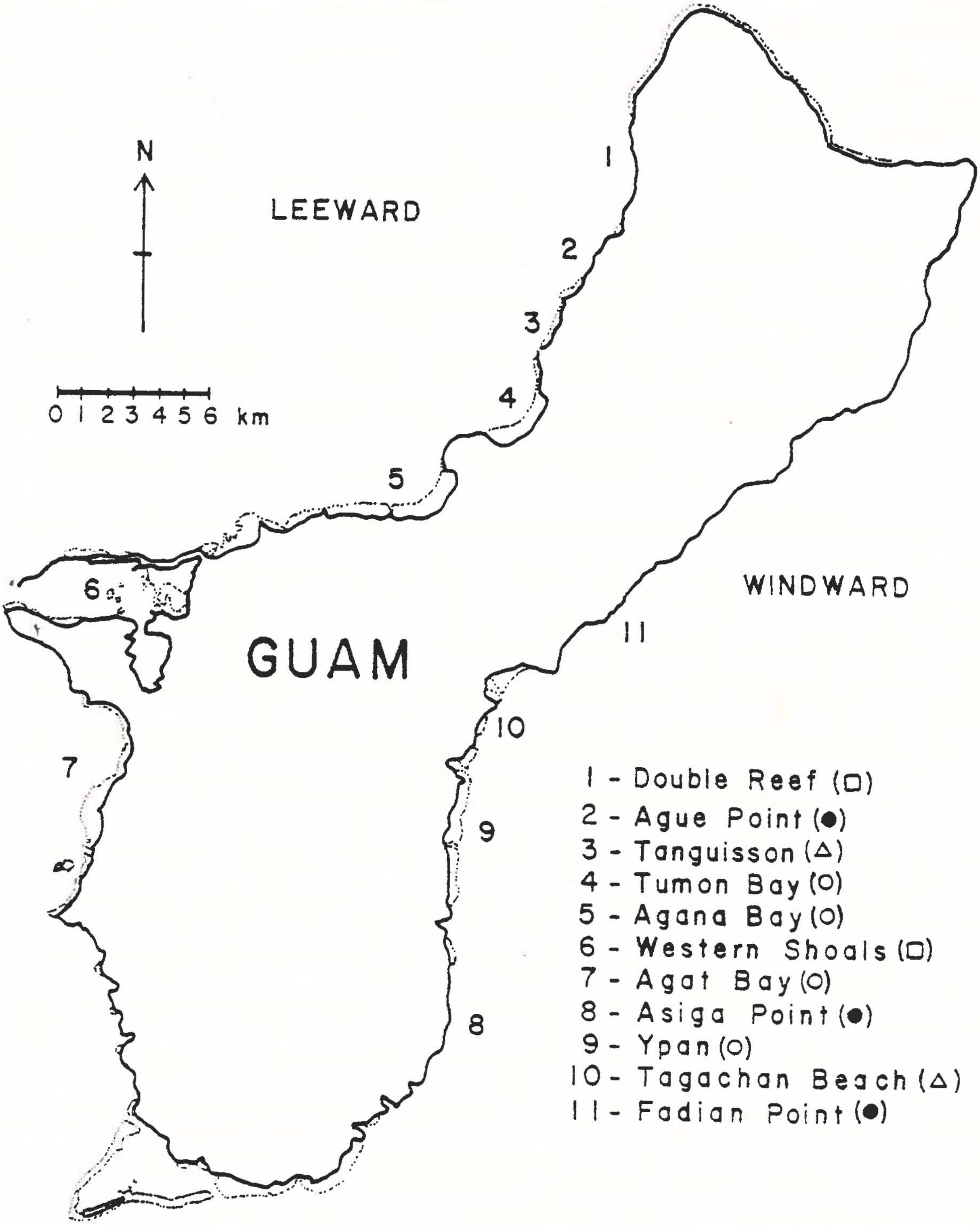

Fig. 1. Map of Guam showing sites for growth studies and distribution survey of Trochus niloticus. Habitats sampled are wide reef flat (○), narrow reef flat (△), patch reef (□), and limestone bench (●).

0.1 mm with sliding vernier calipers. Growth was monitored at approximately 30-day intervals. Sizes of tagged shells ranged from 13.2 to 120.9 mm in diameter.

The spatial distribution of *T. niloticus* was surveyed at 10 sites (see Fig. 1). Similar habitats on the leeward (western) and windward (eastern) sides of the island were chosen for comparison. For the purposes of this study, Ypan, Agat Bay, and Tumon Bay were designated as wide reef-flat habitats; Tanguisson and Tagachan Beach were designated as narrow reef-flat habitats; and Ague Point and Fadian Point were designated as limestone-bench habitats.

Two methods were used to estimate the size-frequency distribution of *T. niloticus*. On the leeward side of the island, sites were divided into two to four sectors. The sectors were further divided into four zones representing the outer reef flat, the reef margin, the 6-m contour, and the 12-m contour. In each zone, 100-m transects were established approximately parallel to the reef margin. *T. niloticus* encountered within 1 m of the line were counted and measured in 10-m intervals of the transect. Thus, each transect consisted of ten 20-m^2 rectangular plots covering a total area of 200 m^2.

On the windward side of the island, the different reef topography required a modified sampling method. Submarine channels extending perpendicular to the reef margin were designated as transect lines. Two such channels were surveyed at each windward study site, except Asiga Point, where one channel was sampled. Each side of a channel, from the reef margin to a depth of 18 m, represented one transect. The lengths of the transects were estimated by triangulation of readings made with a hand-bearing compass. All *T. niloticus* occurring within 1 m of the upper margin of a channel were counted and measured, and the depth at which they were found was recorded.

RESULTS

Growth Rate

Considerable variation in monthly growth increments was found among Trochus niloticus of comparable sizes at Western Shoals, and there was also noticeable variation in the growth rate of given individuals over the span of several months. In spite of this variability, there is a significant negative correlation ($r = 0.69$, $p<0.01$) between growth rate and initial shell diameter (Fig. 2).

Growth studies were discontinued at the Tumon Bay site when a total of only six tagged topshells had been recovered at the end of two months. Recovery rates of tagged trochus shells at Western Shoals declined monthly but averaged about 23% for the duration of the study.

Mathematical representation of growth is an important component of assessment of many fishery stocks (Gulland, 1969). The von Bertalanffy growth model (von Bertalanffy, 1938), which expresses growth on the basis of theoretical physiological relationships, has been found applicable to most of the observed fishery growth data. The von Bertalanffy growth equation (Beverton and Holt, 1957) is $L_t = L_\infty[1 - e^{-k(t - t_0)}]$, where L_t is length at time t, t is time, L_∞ is a theoretical maximum length, K is the Brody growth coefficient (Ricker, 1975), and t_0 is the theoretical time at which length is 0. Assuming t_0 is 0, a fit of the von Bertalanffy equation to growth data T. niloticus from Western Shoals has the form of $L_t = 146.5[1 - e^{-0.2462(t)}]$. The fitted equation yields an estimated age of more than 12 years for T. niloticus at 95% of its theoretical maximum size (see Fig. 3).

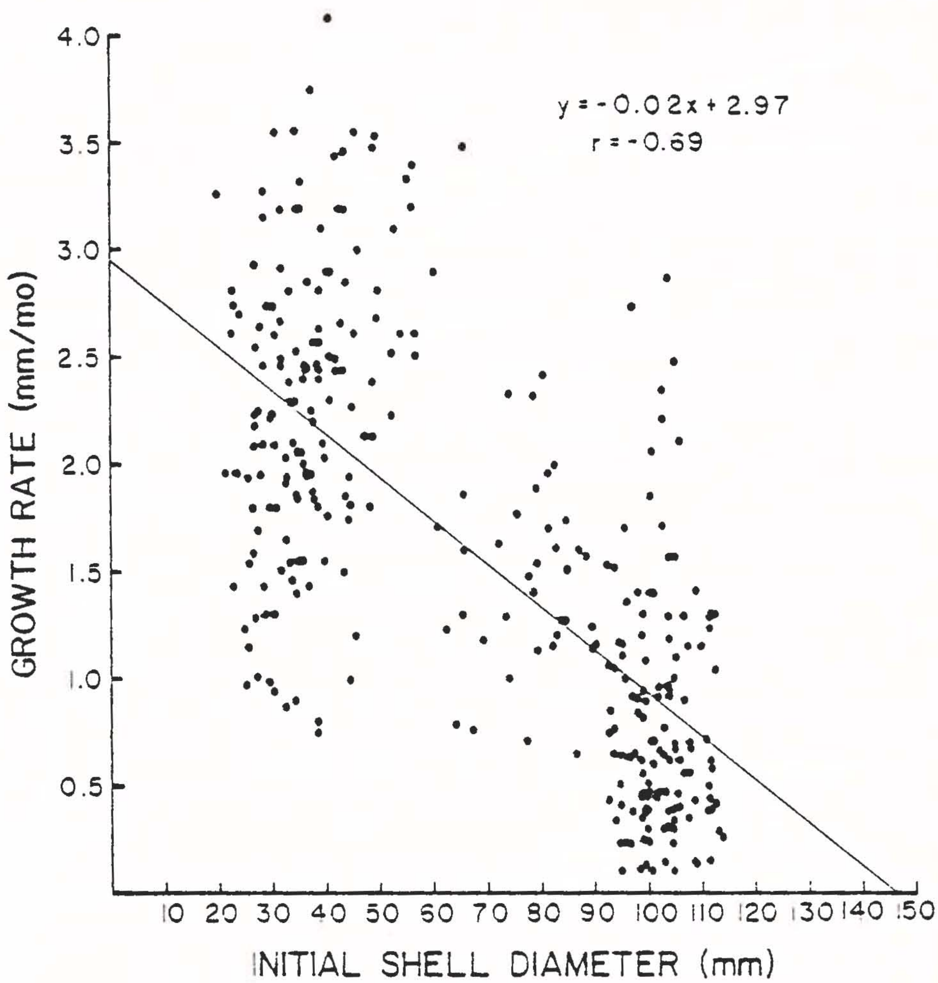

Fig. 2. Relationship of growth rate and maximum shell diameter of <u>Trochus niloticus</u>.

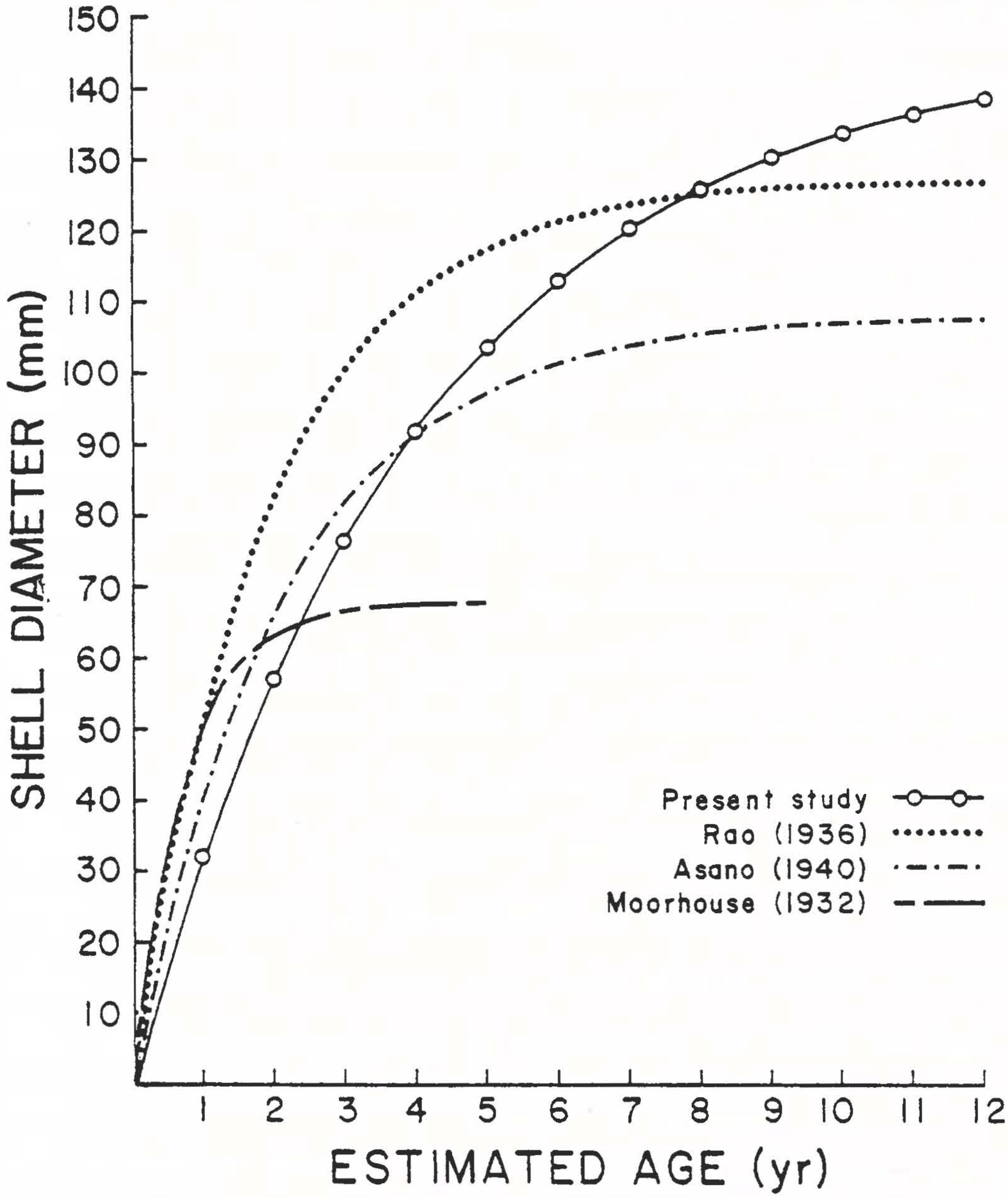

Fig. 3. Comparison of von Bertalanffy growth curve in the present study to growth curves calculated from data in previous studies of Trochus niloticus. Calculations are based on a 30-day month. Seven data points of Asano (1940) were re-calculated to correct apparent printer's errors.

Abundance and Distribution

Densities of *Trochus niloticus* were found to be greater on the leeward side of Guam than on the windward side. A summary of the mean abundances of topshells occurring on transects on the leeward side of the island is presented in Table 1. On the windward side, only six topshells were encountered in a total area of 4152 m^2 surveyed.

Data on sizes of *T. niloticus* occurring on transects at Tanguisson, Tumon Bay, Agana Bay, and Agat Bay were analyzed to determine if any distributional patterns were evident. For each site, the data from transects within a given reef zone were combined. Analysis of variance (Sokal and Rohlf, 1969) of the pooled data indicated significant differences ($p<0.01$) among reef zones at each site (see Table 2). The mean shell diameters of *T. niloticus* on transects on the leeward side of the island are given in Table 2. An attempt was made to identify the source of variation among the zones. The Student-Newman-Keuls (SNK) procedure is an a posteriori method using the range to test all possible comparisons of means (Sokal and Rohlf, 1969). Results of this analysis indicate that there is a great deal of overlap in size distribution of *T. niloticus* at Tanguisson, but there are four distinct zones at Tumon Bay and three at Agat Bay and Agana Bay (see Table 2).

Analysis of variance of size distribution among bays indicates significant differences among outer reef flat zones ($F_s = 3.788$, $p<0.05$) and among 6-m contour zones ($F_s = 3.426$, $p<0.05$). No significant variation was found among reef margin zones ($F_s = 0.765$, $0.50<p<0.75$) and among 12-m contour zones ($F_s = 0.446$, $0.50<p<0.75$). Comparison of mean shell sizes among bays with the SNK procedure reveals no

Table 1. Densities of *Trochus niloticus* in 20-m^2 rectangular plots on the leeward side of Guam. Values are means $\pm$ standard errors, with the number of plots sampled given in parentheses.

Site	Outer Reef Flat	Reef Margin	6-m Contour	12-m Contour
Double Reef[a]	---	---	0.15 $\pm$ 0.08 (20)	0.10 $\pm$ 0.07 (20)
Tanguisson	0.05 $\pm$ 0.03 (40)	0.13 $\pm$ 0.05 (40)	0.18 $\pm$ 0.07 (40)	0.25 $\pm$ 0.09 (40)
Tumon Bay	2.45 $\pm$ 0.65 (40)	0.95 $\pm$ 0.20 (40)	0.40 $\pm$ 0.09 (40)	1.65 $\pm$ 0.22 (40)
Agana Bay	0.45 $\pm$ 0.11 (40)	0.28 $\pm$ 0.10 (40)	0.78 $\pm$ 0.19 (40)	0.63 $\pm$ 0.16 (40)
Agat Bay	0.65 $\pm$ 0.18 (40)	2.13 $\pm$ 0.44 (40)	2.03 $\pm$ 0.35 (40)	0.33 $\pm$ 0.33 (40)

[a]The outer reef flat and reef margin zones were not sampled at this site.

Table 2. Mean diameters (mm) of *Trochus niloticus* on transects on the leeward side of Guam. Values are means ± standard errors, with the sample sizes given in parentheses. Results of analysis of variance of diameters among reef zones are given; all F_s values indicated significant differences ($p<0.01$). Analysis of means with the SNK procedure indicated no significant differences ($p>0.05$) between underlined means.

Site	Outer Reef Flat	Reef Margin	6-m Contour	12-m Contour	F_s
Double Reef[a]	---	---	123.5 ± 3.6 (3)	110.0 ± 1.7 (2)	
Tanguisson	31.0 ± 5.7 (2)	73.0 ± 10.5 (5)	97.5 ± 10.7 (7)	108.2 ± 8.0 (10)	7.260
Tumon Bay	32.5 ± 0.7 (98)	65.4 ± 1.7 (38)	104.1 ± 3.7 (16)	110.7 ± 1.2 (66)	990.366
Agana Bay	32.9 ± 1.8 (18)	63.5 ± 2.4 (11)	105.5 ± 2.2 (31)	109.0 ± 2.1 (25)	255.259
Agat Bay	38.4 ± 2.2 (26)	64.2 ± 1.5 (85)	109.8 ± 0.9 (81)	113.6 ± 1.9 (13)	390.668

[a]The outer reef flat and reef margin zones were not sampled at this site.

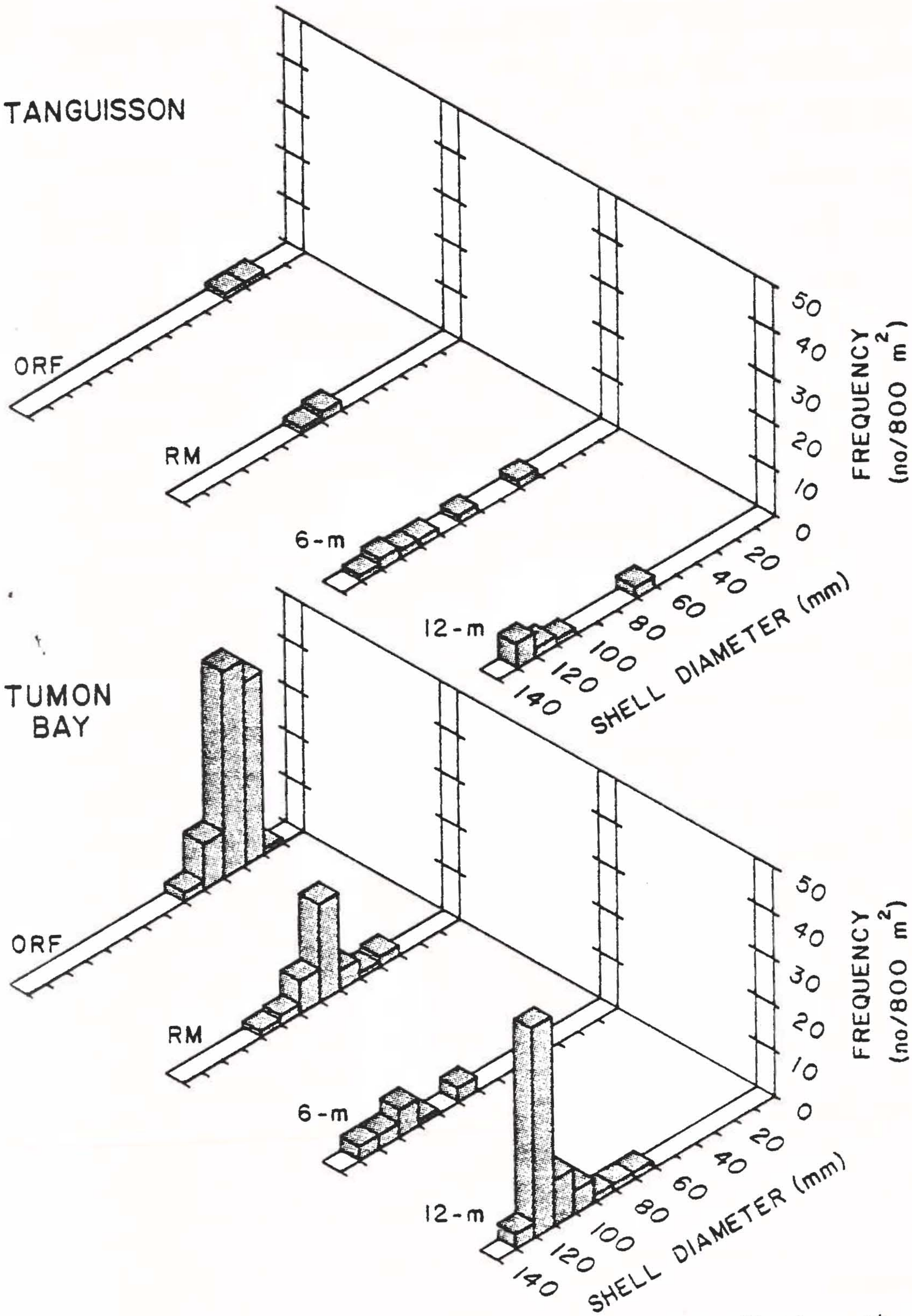

Fig. 4. Size-frequency distributions of Trochus niloticus at Tumon Bay and at Tanguisson. Zones are outer reef flat (ORF), reef margin (RM), 6-m contour (6-m), and 12-m contour (12-m).

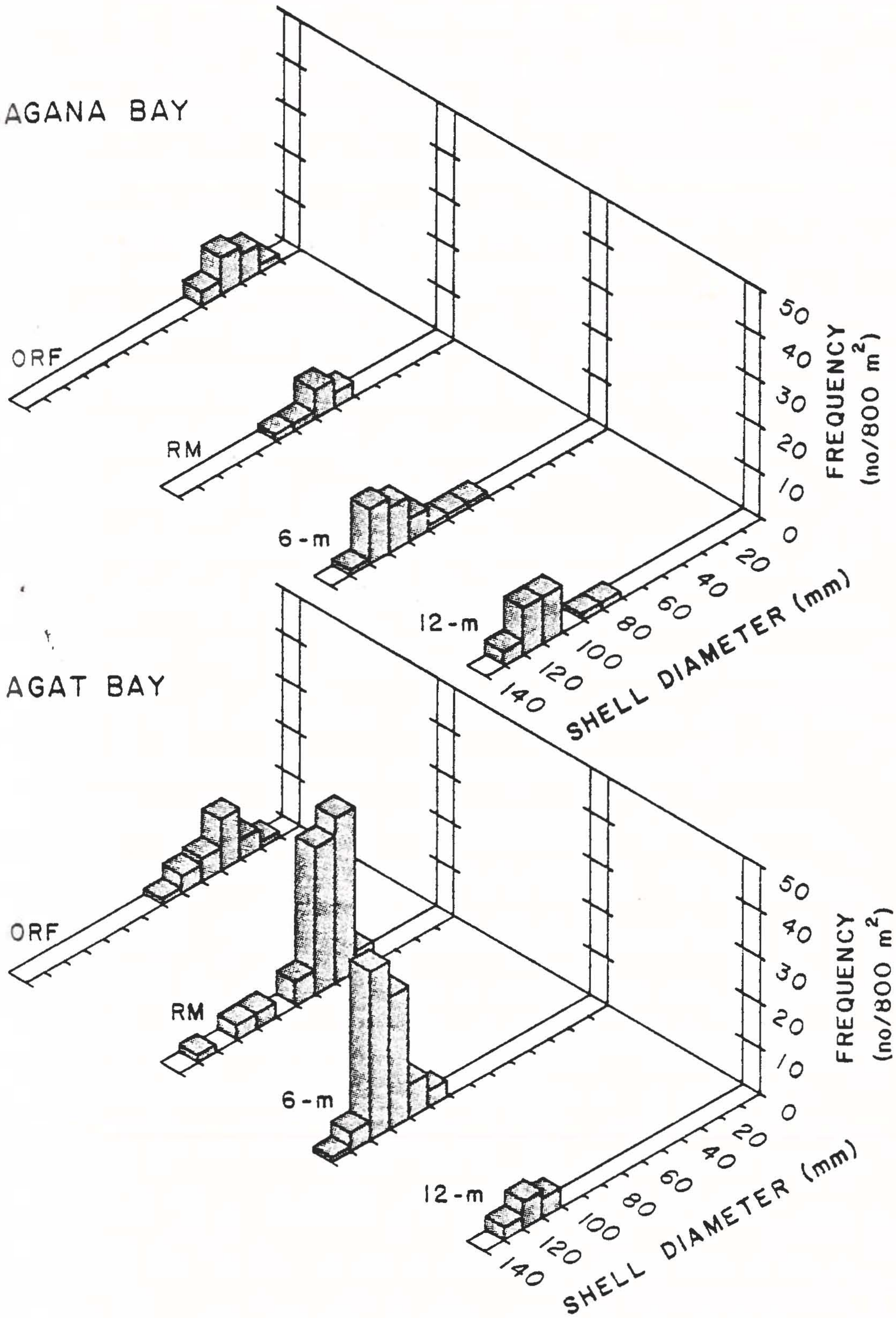

Fig. 5. Size-frequency distributions of Trochus niloticus at Agat Bay and at Agana Bay. Zones are outer reef flat (ORF), reef margin (RM), 6-m contour (6-m), and 12-m contour (12-m).

significant differences in size distributions of *T. niloticus* among the Tanguisson, Tumon Bay, and Agana Bay study sites. Thus, Agat Bay is the apparent source of statistical differences found by analysis of variance of shell size data. Size-frequency distributions for these four sites are summarized in Figs. 4 and 5.

DISCUSSION

Growth Rate

The theoretical maximum diameter of 146.5 mm predicted by the von Bertalanffy model is a good approximation of the maximum sizes reported for *Trochus niloticus*. Individuals measuring 142 mm (Hedley, 1917) and 141 mm (Devambez, 1959) have been examined, and Angot (1958) and Cernohorsky (1972) described the maximum attainable size as being up to 150 mm. The largest topshell occurring on transects in the present study was 132 mm in diameter.

When the growth data of Moorhouse (1932), Rao (1936), and Asano (1940) are fitted to the von Bertalanffy equation and compared to the present study (Fig. 3, Table 3), the disparity among theoretical maximum diameters and growth coefficients is striking. The theoretical maximum diameters predicted from data from previous studies are well below actual sizes attained by *T. niloticus*. Growth coefficients from the data of Rao and Asano are similar, but they indicate a faster rate of growth than either of these investigators postulated.

A growth rate of about 25 mm in diameter per year was the concensus among the early reports on *T. niloticus*. Results of the present study indicate that this rate is a good estimate during the first three years of growth, but during the fourth year, the annual growth increment decreases to about 15 mm and continues to diminish in the following years (see Fig. 3). In spite of the lack of data from larger size classes, Rao (1936) and Rao and Raja (1936) noted the negative correlation of growth rate and shell diameter, and they predicted the

Table 3. Comparison of von Bertalanffy model parameters in the present study to parameters calculated from data in previous growth studies of *Trochus niloticus*. Calculations are based on a 30-day month.

	Sample Size n	Growth Coefficient k	Maximum Diameter L_∞ (mm)	Correlation Coefficient r
Present Study	322	0.2452	146.5	-0.6932
Asano (1940)[a]	32	0.4724	107.7	-0.6821
Rao (1936)	301	0.5212	127.2	-0.7733
Moorhouse (1932)	178	1.3607	67.8	-0.5827

[a]Seven data points were re-calculated to correct apparent printer's errors.

lifespan of _T. niloticus_ to exceed 10 years in the Andaman Islands. Data from _T. niloticus_ on Guam indicate an age of about 15 years for an individual of 142 mm in diameter.

Although growth rates of _Trochus niloticus_ varied considerably at Western Shoals, a great deal of this variability is evident in previous reports (Rao, 1936; Asano, 1940). Moorhouse (1932) found that individuals of similar size varied by as much as 5 mm after six months of growth. Such variability in growth rates is not uncommon among marine gastropods. Growth rates for _Strombus gigas_ Linnaeus varied by as much as 17% in three months (Randall, 1964). Yamaguchi (1977) reported that increments for _Cerithium nodulosum_ Bruguière varied by a factor of more than two. Differential growth rates of two populations of _Cabestana spengleri_ (Perry) in New Zealand were attributed to different conditions of nutrition between two localities (Laxton, 1970).

The scatter of points in Fig. 2 appears to indicate a bimodal distribution in the sizes of shells studied. This pattern is an artifact of the numbers of animals recaptured in the intermediate size range. _Trochus niloticus_ of intermediate sizes inhabit the very heterogeneous environment of the reef-margin zone (see Figs. 4 and 5). Enhanced by this habitat, the cryptic coloration and habits of the intermediate size classes were probable causes of their low recovery rates.

Recovery of tagged animals is a problem of the mark and recapture method in general. Moorhouse (1932) deemed a preliminary growth study to be a failure because of the rapid disappearance of tagged topshells.

Rao (1936) lost 200 tagged animals in a one-month period. Possible explanations of the loss of the tagged T. niloticus at the Tumon Bay site include migration of the topshells, predation, and harvest for consumption by humans.

Abundance and Distribution

Different sampling methods were adopted for estimation of abundance and distribution of Trochus niloticus in order to accommodate differences in reef topography between the leeward and the windward sides of Guam. The description by Tracey et al. (1964) of the windward reef-front zone south of the Ylig River was found to be generally applicable to the Fadian Point, Tagachan Beach, Ypan, and Asiga Point study sites. The reef-front zone at these sites consists of a nearly flat pavement coated with calcareous algae and containing scattered colonies of corals.

A preliminary survey along depth contours at Ypan indicated that T. niloticus were restricted to the upper margins of submarine channels. These channel margins are characterized by rock outcrops and greater coral cover than is found along the contours of the terrace. The six living topshells occurring on transects on the windward side of the island were recorded at Ypan. Several empty shells were noted on Tagachan Beach transects, but there was no indication of the presence of T. niloticus at Asiga Point and Fadian Point. Low-relief topography similar to these windward study sites was found to be unfavorable habitat for T. niloticus in other areas of Micronesia (McGowan, 1958).

Mean abundances of *T. niloticus* on transects on the leeward side of Guam (Table 1) suggest that a wide reef-flat system is more favorable to perpetuation of a large population than a narrow reef-flat system. Evidence in support of this hypothesis is provided by the data from the Ague Point study site, where there is no reef-flat development. Although no *T. niloticus* were encountered in the 1600-m^2 area sampled, the observation of a living individual topshell in an area adjacent to a transect indicates that the reef front here is suitable habitat for adult topshells. It is conceivable that this individual was recruited from the fringing reef north of the study site.

McGowan (1956) considered the reef flat to be a "nursery" which contributed all the recruits to the population of *T. niloticus* inhabiting the reef front. Size-frequency distributions (Figs. 4 and 5) support this opinion. The planktonic larvae of *T. niloticus* apparently settle on the outer reef flat, and juvenile topshells migrate to the reef margin and deeper water as they increase in size and age. With rare exceptions, individuals smaller than 50 mm in diameter are not found in water deeper than 3 m (Rao, 1937; McGowan, 1956; Stojkovich and Smith, 1978).

An examination of Table 2 and Figs. 4 and 5 reveals a greater segregation of sizes of topshells among reef zones on Guam than on the Australian Great Barrier Reef (Moorhouse, 1932). This trend towards distinct zonation was noted in a study by Stojkovich and Smith (1978).

The pattern of size distributions of *T. niloticus* among the bays on the leeward side of the island may be attributed to differences in reef development. Tanguisson, which is characterized by a narrow reef front (Randall and Holloman, 1974), has considerable overlap in the mean size distribution of topshells. At Tumon Bay and Agana Bay, where reef flats are wider and where reef front terraces are more developed (Randall and Holloman, 1974), more distinct zonation of size classes is apparent. The presence of extensive sand-floored areas with scattered, irregular rocky zones on the terrace at Agat Bay (Randall and Holloman, 1974) causes a shift in the size distribution of topshells. Because *T. niloticus* has been found to avoid moving on sand (Nakajima, 1920), the sand tracts at Agat Bay probably constitute barriers to the migration of larger individuals to deeper contours, except on localized mounds that extend from the reef margin.

The data from the present study of growth and distribution of *T. niloticus* should be of value as a guideline in the development of management and conservation strategies for the species in Micronesia. Existing programs of management and conservation of topshells for this region are arbitrary regulations based upon scanty data from studies conducted in other areas. If introductions of topshells are desired in the future, these data indicate that such schemes should be developed on a regional basis, with consideration given to reef structure at each proposed site.

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