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Abstract :

A survey of small giant clams (*Tridacna maxima*), which are subject to human predation, was carried out on the resort island of Bora-Bora in French Polynesia. This paper emphasizes the impact of tourism and local activities on the *Tridacna* populations. Daily tours to the lagoon include the tasting of small giant clams. A study of clam abundance shows that the overall reef stock is still large. However a comparative analysis of the population structure of this clam, in four locations, shows a significant decrease in the average shell size of the living populations and a reduction in the average size of shells consumed by tourists. The average size of clams consumed by tourists fell from 130 mm to 108 mm in less than one year. On the fringing reef, the environmental conditions have reduced recruitment and increased natural mortality. This natural loss of giant clams along with the increasing human predation is decimating the standing stock of this area.

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Introduction

Little research has been carried out on *Tridacnidae*. The most important works are the studies by Yonge (1936) on nutrition problems and Wada (1954) on reproductive behaviours. A systematic revision by Rosewater (1965), research on the early stage of development by Labarbera (1975) and an age study by Henocque (1980), are other important contributions. Mac-Michael (1974) has studied the population structure of small giant clams at One Tree Island (Great Barrier Reef, Australia). *Tridacna maxima* (Röding, 1798) is the sole species belonging to the family *Tridacnidae* in French Polynesia. Studies on the population of the lagoon of Takapoto have been undetailed by Ricard and Salvat (1977) and Richard (1977, 1981, 1983, 1986). More recently, studies have been completed on the ecology and aquaculture of giant clams (*Tridacna gigas*). We have considered particularly the papers of Alder and Brayley (1989), Braley (1987a, 1987b), Villanoy *et al.* (1988) and Pearson and Munro (1991), which report mortality in the natural populations of giant clams.

Bora-Bora is a small island of 30 km² in area, surrounded by a large and morphologically varied reef lagoon (Pirrazzoli *et al.*, 1985). Off the west side of the island, the lagoon is subdivided into a fairly large number of distinct depressions, which are frequently deeper than 30 m. Oceanic water enters through numerous shallow passages (hoa) all around the reef belt and returns to the open sea through the wide Teavanui pass (Fig. 1). Hotels and tourism have been well-established aspect of life on Polynesian islands like Tahiti, Moorea, Bora-Bora and some atolls for more than ten years. Tour operators now offer lagoon cruises with sea-food tasting that includes small giant clams. In 1989, a study was carried out on Bora-Bora to help the Polynesian Government to prepare a General Marine Environmental Plan (PGEM in French). During this survey, local islanders complained about the stock reduction of small giant clams.

Materials and Methods

The study was carried out from 25 March to 6 April 1990. Various transects were established in order to determine the relative abundance and the demographic structure of *Tridacna maxima* in the different reefs around Bora-Bora (Fig. 2). Along 12 barrier reef transects and 39 transects of the fringing reef, the abundance was assessed according to the following code :

0 : zero	= 0 ind./m ²
1 : low abundance	= <1 ind./m ²
2 : moderately low abundance	= 2 ind./m ²
3 : moderate abundance	= between 3 and 4 ind./m ²
4 : moderately high abundance	= 5 ind./m ²
5 : high abundance	= >5 ind./m ²

(ind. = individual)

To obtain the demographic structure, measuring of the distance between the two central bifurcating spines were made for small giant clams at each study site. An allometric relationship between this parameter and greatest shell length was calculated for the clams caught. To determine the activities affecting *Tridacna maxima*, a survey was performed with tourism professionals in Bora-Bora. Figure 3 shows a map of organized boat tours and the main sites where small giant clam tasting is offered. A special stock analysis was carried out at these sites, including sampling discarded shells on the field. Clams were studied at three main sites (Fig. 2) :

- North barrier reef (A) : this site is occasionally visited by yachtsmen, who eat clams on their boats and drop the shells at their mooring sites. Sampling was done on living molluscs and on the discarded shells.

- Fringing reef (B) : directly accessible from the shore and close to an hotel.

- South barrier reef (C and C') : "jardin de corail" is the best tourism site in Bora-Bora lagoon. Tour operators organize scuba diving and clam tasting here. We sampled both the live clams close to the shore (site C), where it is easy to walk and collect them, and also, those a little offshore in the current (site C', which this is a quite dangerous swimming place for tourists). Secondly, we measured on the discarded shells along the shore which included piles that were old (about one year) and covered by algae as well as fresh shiny shells.

The dead shells were randomly selected and measurements, similar to those made on living specimens, were taken. The number of measured shells in each site is indicated in Table 1, and an allometric relationship between the width from the two central bifurcating spines and the total length was calculated. Using statistical tests, we have compared the mean of each population in order to validate the variation between the different sites. The comparison test used the null hypothesis : $H_0 : \mu_1 = \mu_2$; and

$$Z_c = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_{x_1}^2}{n_1} + \frac{s_{x_2}^2}{n_2}}}$$

where \bar{x}_1 , s_{x_1} , n_1 and \bar{x}_2 , s_{x_2} , n_2 are respectively the mean, the standard deviation and the sample size of the two samples compared. The normal deviation Z_c is compared to the critical value of Z_β , where β is the error-risks ($Z(0,01)=5,14$). If $|Z_c| \leq Z_\beta$ then the means are similar and *vice et versa*.

Results

- Abundance of *Tridacna maxima*

In comparing the distribution of *Tridacna maxima* to the Bora-Bora coral area map in Galzin *et al.* (1990) we found that high densities appear on the barrier reef and in some sites in the fringing reef (Fig. 4). In the barrier reef, there is a close relationship between living coral cover and clam density. In contrast, clam density was low on most areas of the fringing reef, even with good living coral cover, and many adult and young clams were found dead in such locations.

- Demographic structure

The results of demographic structure studies are presented in Table 1, and in Figure 5. The statistical test (Z_c) used to validate the difference between the samples was found to be not significant in the analyses for the three study sites, indicating a characteristic size range for each site. In addition, Figure 5A shows a distinct low level of recruitment of young clams on the fringing reef. This might be related, in part to the harsh environmental conditions associated with the algal cover (*Acanthophora spicifera* and *Boodlea composita*) which dries out at exceptionally low tides. Another source of stress for the clam population are the activities of land reclamation and quarrying. Fifty percent of Bora-Bora's shoreline is reclaimed land and there are 12 coral quarry sites (Galzin *et al.*, 1990). Environmental disturbances associated with these activities, (lower light intensity, excessive sedimentation, low oxygen rate, etc...) contribute to the increasing the natural mortality rate of the clam population (Salvat, 1987 ; White, 1987). Moreover, fringing reefs are accessible on foot to both tourists and local inhabitants. Low density of adult stocks and low mean size of shells (75 mm) may be attributable to collecting, but low recruitment levels and natural clam mortality indicate that harsh environmental conditions must also play a part in limiting the standing stocks of giant clams.

Another interesting result is revealed in the mean size difference between living and consumed clams in sites A and C (Table 1). At both sites (A and C), the mean size of shells from consumed clams is larger indicating that human predation, which targets the largest molluscs, reduces the mean size of the live population. In the sites C and C', two other phenomena were recorded : (1) there is a reduction in the mean size of shells in the accessible living stocks (close to shore) in comparison to the inaccessible ones found offshore ($L = 79$ mm / $L = 89$ mm) ; (2) there is a reduction in mean shell size of the old discarded clams, which are bigger than the recently consumed ones ($L = 130$ mm / $L = 108$ mm). Thus some of the main characteristics of incipient overfishing can be documented at an individual site. These results are confirmed by the histograms in Figure 5B and 5C which show that sites C and C' have similar levels of recruitment but the shore population contains smaller individuals because they have been subjected to extensive collecting. The effect of this collecting activity is reflected in the reduction in size found between old and recently discarded shells along the shore

Discussion and Conclusion

This study was requested by the French Polynesian Ministry of the Environment and was included in overall management plan for the Bora-Bora lagoon. As a result of human activity, which is related to the site accessibility it appears that *Tridacna maxima* may have decreased in abundance in Bora-Bora.

Fringing reefs are characterised by low abundance, low recruitment and very small mean size of shells even in areas with large coral coverage that should be conducive to the development of thriving colonies of *Tridacnidae*. This low abundance could be due to both natural and human factors, the second amplifying the first. Initially, a ban on collection of clams on fringing reefs would help to preserve the adult stock. However, it will also be necessary to determine the extend and the causes for natural mortality of recruited individuals, in order to prepare a management plan conducive to the safeguard of the *Tridacnidae* in this zone.

For the most part, we have emphasized the effect of collecting activities of tourists on the clam communities. But inhabitant's predation and occasional major predation by large group of people from other islands visiting for, civil or religious festivities, must be taken in account in the human predation evoked in this paper.

An analysis of flourishing barrier reef clam stocks makes it possible to measure the impact of human predation to the exclusion of other factors. The exploitation of *Tridacna maxima* causes a reduction in the mean size

of shells of living clam shells which is also reflected in the reduction in size of clams consumed by tourists. At present this predation is not significant in terms of overall abundance, but the rapid diminution in mean shell size is a point of concern.

In order to prevent the decrease of a small giant clams stock, a combination of methods (management plans, restriction on commercial trade, marine reserves, education, ...) will be required to safeguard coral reefs from the impact of human shell predation (Wells and Alcala, 1987). Studies are need to establish a size and number limit for collecting in order to ensure that giant clam stocks are not overexploited.

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	N	Lc(mm) μ et (∂)	Lt* (mm)
North barrier reef (A):			
Living population	47	24,42 (2,36)	90,68
Discarded shells	32	28,56 (2,81)	105,12
Fringing reef (B) :			
Living population	42	20,05 (2,01)	75,44
South barrier reef :			
Shore population (C) :	100	21,34 (2,12)	79,94
Offshore population (C') :	123	24,10 (2,29)	89,94
Recent shells discarded :	79	29,55 (0,90)	108,57
Old shells discarded :	80	35,83 (1,55)	130,47

Tab 1 : Population structure of *Tridacna maxima* in the three sites analysed. (N = number of shells measured ; Lc = width between the two central bifurcating spines (μ = middle-size ; ∂ = variance) ; Lt = total length estimated with the linear relation between the total length and the width between the two central bifurcating spines)

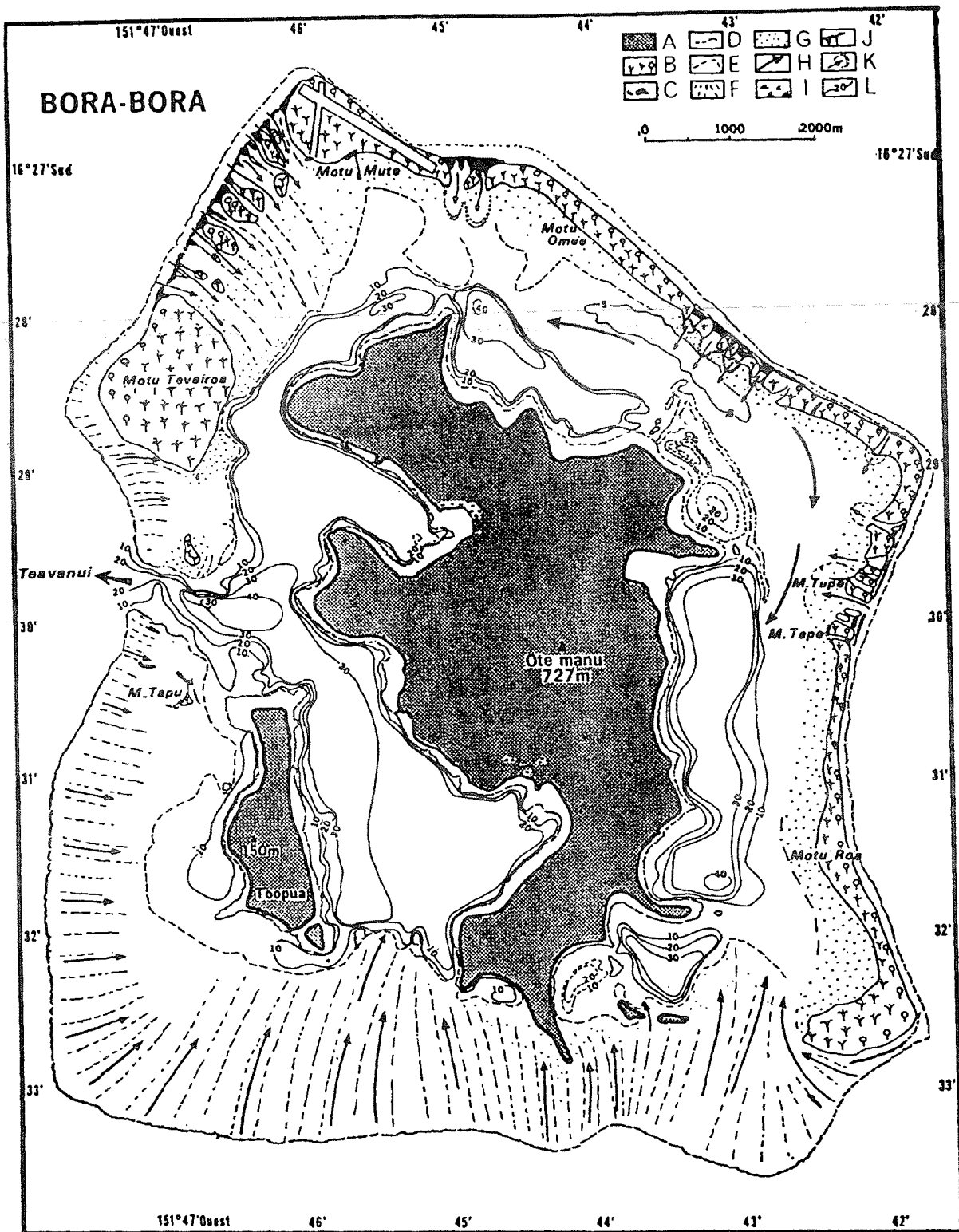


Fig 1 : Geomorphological and location map of Bora-Bora (Guilcher *et al.*, 1969). (A=volcanic islands ; B=coral island with vegetation (motu) ; C=exposed coral conglomerate ; D=outer edge of the present reef ; E=inner edge of the present reef ; F=radial lines on the reef ; G=sand ; H=direction of the main current ; I=marshes ; J=sand and gravel spits ; K=detritic delta ; L=isobathe in the lagoon (meters)).

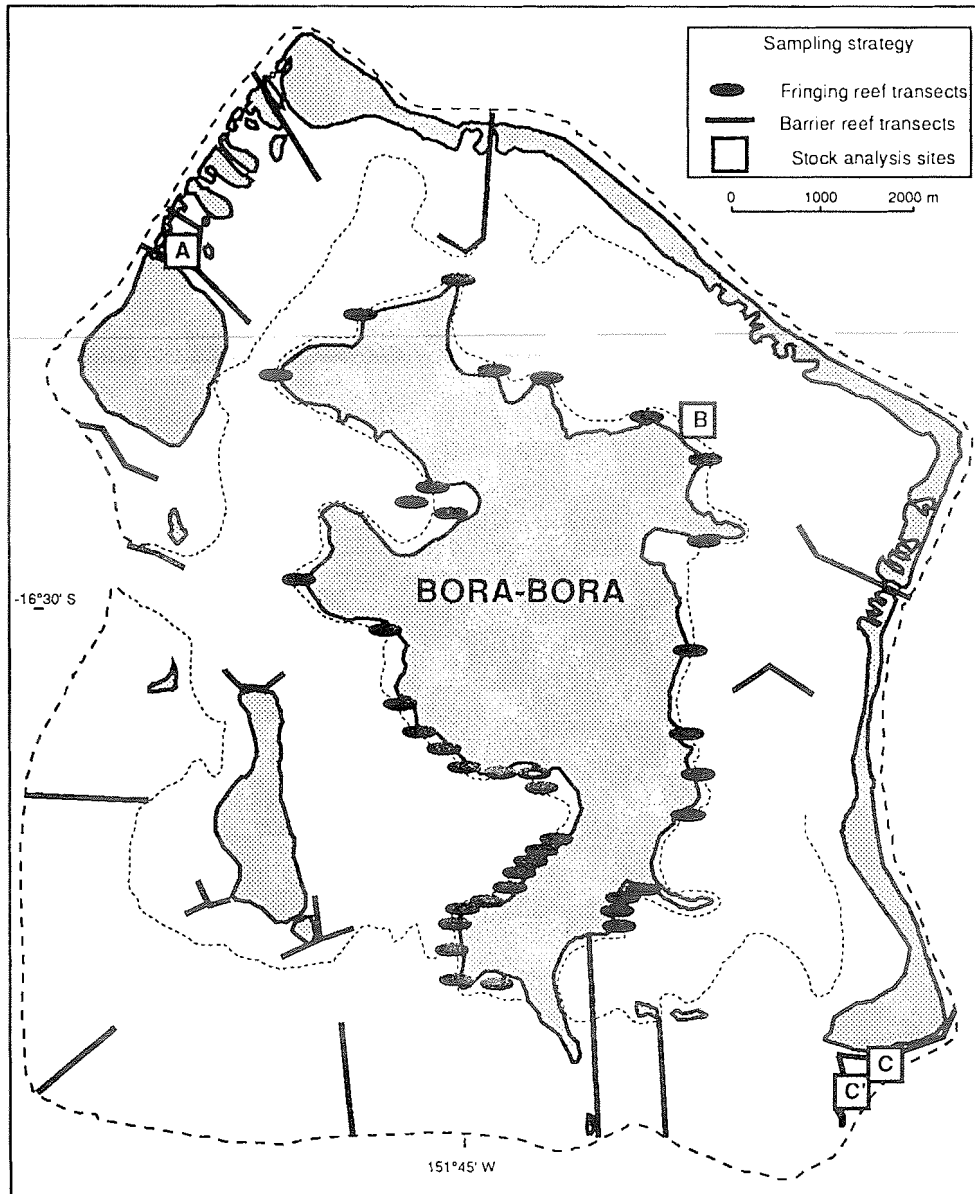


Fig 2 : Location of the 39 fringing reef transects, the 12 barrier reef transects and the four stock analysis sites.

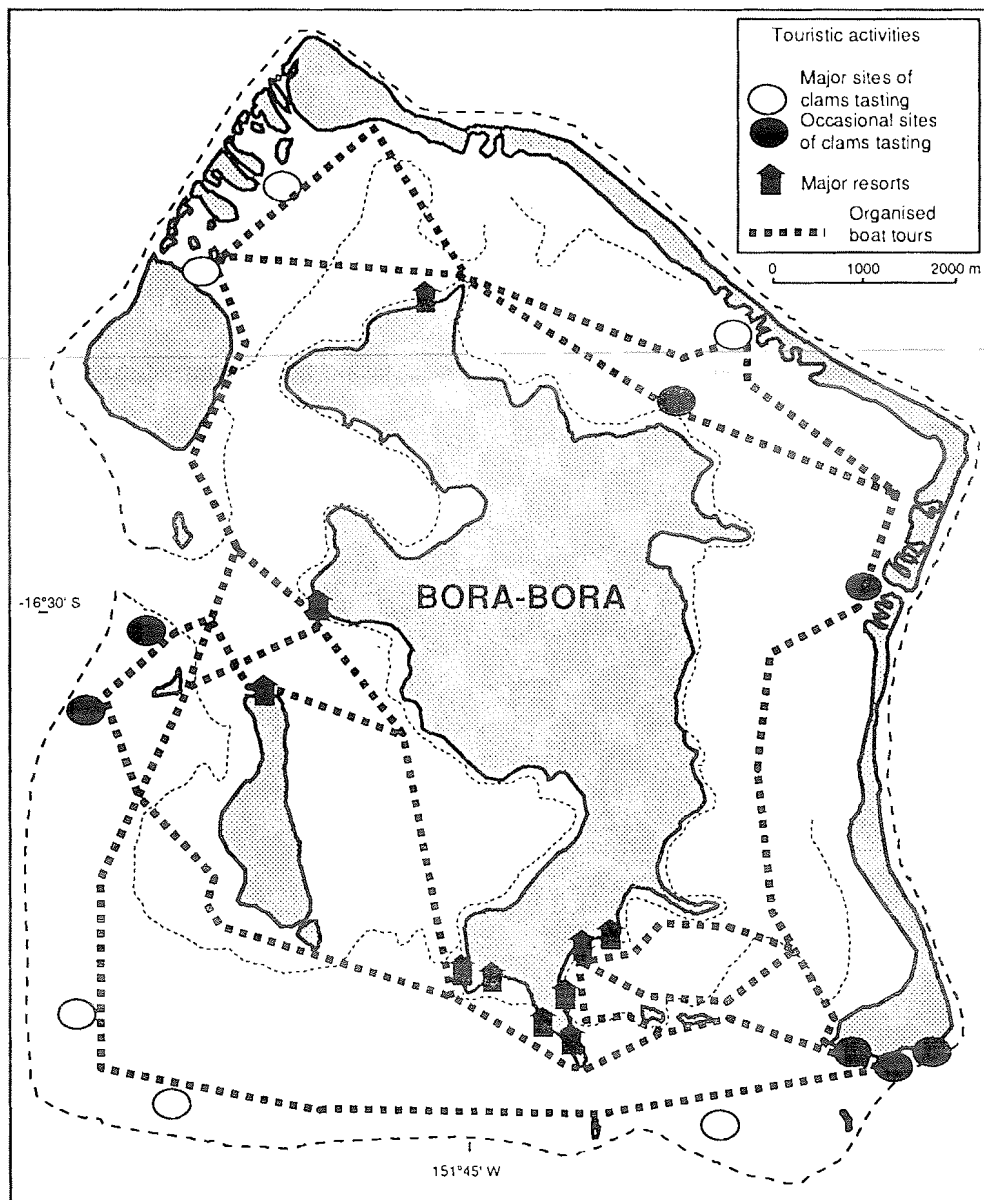


Fig 3 : Map indicating the tourist activities in the lagoon of Bora-Bora in relation to the small giant clams.

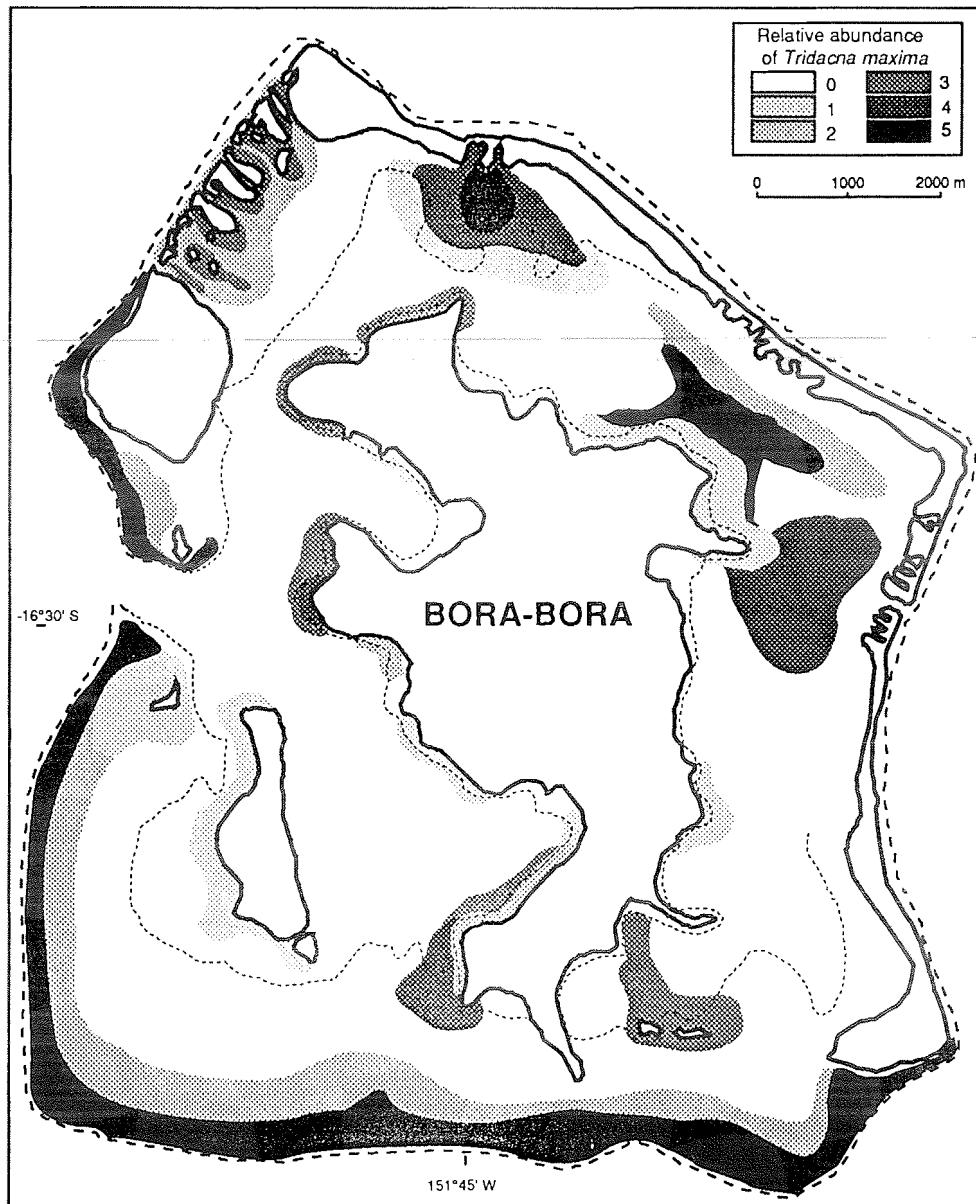


Fig 4 : Relative abundance of *Tridacna maxima* in the lagoon of Bora-Bora according to the code established.

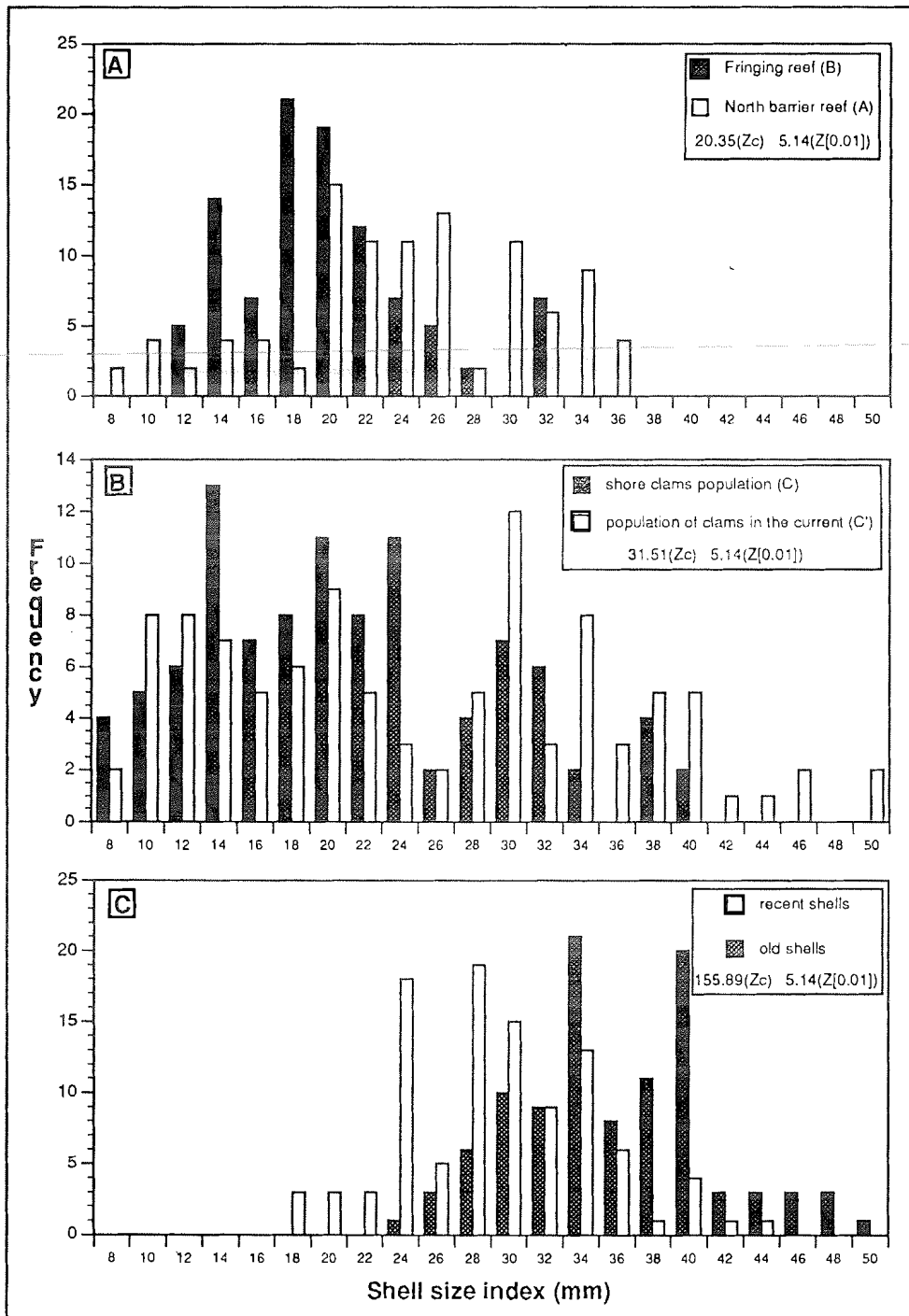


Fig 5 : Comparaision of the distribution of the size frequencies of clams from different sites and statistical test on the middle-size (Z_c) :

A : Comparison between living populations in the fringing reef (B) and in the barrier reef (A).

B : Comparison between the living population near the shore (C) and the living population in the current (C').

C : Comparison between the size frequencies of shells collected one year ago and the shell recently collected.