SPECIAL TRAITS AND PROMISES OF THE GIANT CLAM (*TRIDACNA MAXIMA*) IN FRENCH POLYNESIA

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Introduction

Naturally drawn to the sea, Polynesians are traditionally fishers and lagoon or coastal seafood consumers. With an increasing population in the Society Islands (Fig. 1) and a corresponding increase in the demand for lagoon seafood products, certain islands have diversified their economic activities to meet the demand for seafood. In some French Polynesian islands, fishers are frequently seen collecting and cleaning giant clams on site before draining and freezing them for export to Tahiti, or exchanging them when ships arrive. In fact, many artisanal fisheries have developed over the past 30 years, targeting both fish and invertebrates; an activity that has been boosted by the arrival of ships with cold storage rooms and, more recently, by inter-island air transport.

French Polynesia's geographic distribution is wide and sparse (118 islands scattered out over an EZZ of some 5 million km^2), and its population spread is also very uneven: 87% of the population lives in the Society Islands with 75% on just two islands in the Windward group: Tahiti and Moorea (Anon 2002a). Modern transport methods, however, have made it possible to reduce the isolation of certain French Polynesian islands and have opened the door to new forms of inter-island exchange.

Recent work by the Ministry of Marine Affairs (MER) and the Fisheries Department (SPE) will make it possible to sustainably develop and manage the artisanal fisheries sector. Since 2001, the SPE has funded and participated in efforts to manage, exploit and repopulate certain echinoderm and mollusc species in French Polynesia's lagoons and reefs. Giant clams (Tridacnidae) are the primary molluscs of commercial interest. *Tridacna maxima* is the only one of the eight tridacnid species (Rosewater 1965) found in French Polynesia. Because of the popularity of its meat, *Tridacna maxima* is covered by a programme funded entirely by the second phase of the France/French Polynesia development contract.

A special context

The lagoon invertebrate populations of the eastern Tuamotu Islands include large numbers of giant clams, a vital protein and cultural resource for these atolls. Each island has its own name for giant clams, which are most commonly called *pahua* in French Polynesia as a whole, and kohea in the eastern Tuamotu Islands. Giant clam meat is eaten raw, cooked or sometimes smoked and dried.

Tridacna maxima is still abundant in French Polynesia, although this abundance is uneven. It reaches outstanding levels (Tab.1) in some of the Austral Islands (Raivavae and Tubuai) and in the closed atolls of the eastern Tuamotu Islands, including Fangatau, Fakahina, Tatakoto, Pukarua, Reao, Napuka, and Vahitahi (Salvat 1972; Andréfouët et al. 2005; Gilbert et al. 2005; Gilbert et al., in publication).

In contrast to the giant clam's abundance and dominance in the lagoons of these islands, its abundance in other French Polynesian

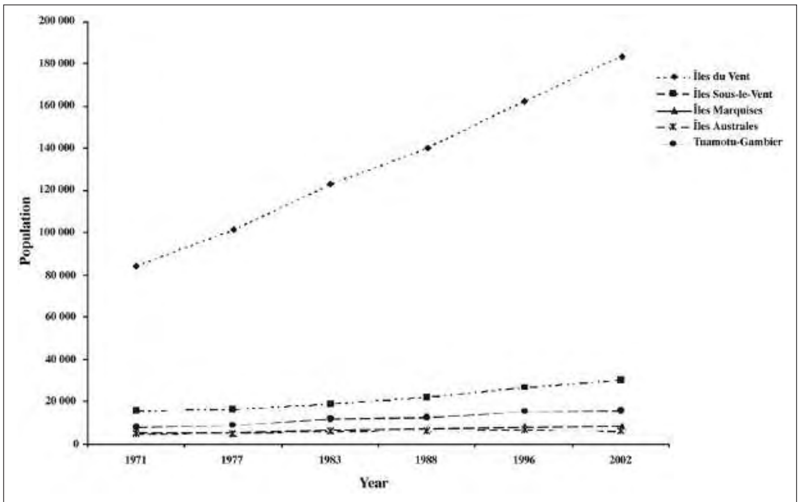

Figure 1: Demographic changes by island group from 1971 to 2002 (source: Institut Pacifique de Polynésie française.

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Table 1: Mean density (ind/m²) on Moorea (Society Islands), Tubuai, Raivavae (Austral Islands), Takapoto, Anaa (western Tuamotu Islands), Reao, Pukarua, Fangatau and Tatakoto (eastern Tuamotu Islands)

	Moorea (Laurent, 2001)	Takapoto (Laurent, 2001)	Anaa (Laurent, 2001)	Reao (pers. observ.)	Pukarua (pers. observ.)	Fangatau (Gilbert et al., submitted)	Tatakoto (Gilbert et al., submitted)	Tubuai (Gilbert et al., submitted)	Raivavae (pers. observ.)
Area and/or number of samples	20 000 m^2	1150m^2/6	2735m^2/14	3200m^2/303	1305m^2/173	86m^2/343	70m^2/281	2950m^2/326	5485m^2/313
Sampling method	PCQM***	T*	T*	T*	T*	QSM**	QSM**	T*	T*
Mean density (ind/m^2)	0.035	0.14	0.02	8.15	13.06	44.09	87.37	2.53	1.31

* Transect Sampling Method

** The samples are located in the live giant clam strata (for more details please refer to the methodology described in Andréfouet et al., 2005)

*** Point Centered Quarter Method

lagoons is much lower (Tab. 1), and certain lagoons are currently experiencing declines, sometimes significant, in their populations. While this is in part due to natural causes (Addessi 2001), the increase in fishing pressure, in response to the growing human population pressure, is certainly a major cause. While in the past, large numbers of giant clams could be found in the lagoons of the Society Islands, they are becoming increasingly scarce as they continue to be a popular species at the Tahiti market. With about 50 tonnes of meat marketed each year on this island (Anon 2002b), this "new" financial resource provides significant and direct income to the communities on the outer islands. Income generated from the giant clam market for all fishers has been roughly estimated to be between XPF 20 and 25 million annually. This is a fairly significant supplement to traditional resources, which are often limited to copra harvests (eastern Tuamotus) and agriculture (Austral Islands). In some cases, giant clams can account for the equivalent of nearly 40% of copra income.

As is notably the case on Bora Bora and Rangiroa, the harvesting of giant clams to supply the Tahiti market runs the risk of overexploitation, even in the richest islands, and in spite of regulations governing the minimum harvest size (a 1988 resolution set the minimum shell length at 12 cm for fishing, transport, holding, marketing and consumption). SPE has had to respond to the concerns of mayors and inhabitants of the islands involved. Against this background, several studies have been carried out since 2001. One study was a local market survey conducted by a consulting firm (Pacific Consulting). A range of other studies and surveys were carried out by various research institutions: studies on genetics (École Pratique des Hautes Études-French National Centre for Scientific Research), natural stocks (Institute of Research for Development and the University of French Polynesia), natural stock dynamics, a fisheries survey (Institute of Research for Development and the French National School of Agricultural Sciences in Rennes), a survey on fishers and related populations (University of French Polynesia), and a study on harvesting techniques, aquaculture, transport and reseeding (SPE).

Unique stocks worldwide

A 1994 synopsis of existing data on giant clam stocks (all species combined) by Lucas (1994) showed that stock status varies significantly, depending on the country. The general trend, however, is towards a decline in stocks. Because of *T. maxima*'s size and the way it attaches itself, it continues to be the least endangered species worldwide.

Quantitative and qualitative inventories have occasionally been conducted in order to better understand stock status and to recommend management measures, notably in Palau, Micronesia (Hardy and Hardy 1969), One Tree Island, Australia (McMichael 1974), Rose Atoll, American Samoa (Green and Craig 1999), Milne Bay Province, Papua New Guinea (Skewes et al. 2003), and Reao, Takapoto and Anaa islands in French Polynesia (Salvat 1971, 1972, 1973; Richard 1977, 1982, 1989; Laurent 2001).

In 2003, remote sensing was used to estimate giant clam stocks in French Polynesia (as part of the SPE's giant clam programme: Andréfouët et al. 2005), using a refined version of the method initially proposed by Green and Craig (1999). Nowadays, a rising number of studies on tropical coastal systems (coral reefs, mangroves, sea grass beds: Green et al. 2000) include high resolution remote sensing, particularly for inventories of commercially sensitive species, habitats or invasive species (Bour et al. 1986; Long et al. 1993; Mumby et al. 1997; Andréfouët et al. 2004). Maps and numerical and weight estimations have been made for giant clam stocks from Fangatau, Tatakoto and Tubuai (Gilbert et al. submitted for publication) (Tab. 2), and similar work is currently underway on Reao, Pukarua, Fakahina and Raivavae.

Recorded densities in the Tuamotus were set at some 224 specimens/m^2 in Reao Atoll in the eastern Tuamotus (Salvat 1967). Since that time, Andréfouet et al. (2005) and Gilbert et al.

(2005) have reported maximum densities on Fangatau and Tatakoto of some 136 specimens/m² and 544 specimens/m², respectively (Fig. 2). At present, these two atolls have the highest densities of giant clams recorded anywhere in the world. These densities are linked to an aggregative spatial structure (Fig. 2) specific to *T. maxima* in certain semi-enclosed lagoons in the eastern Tuamotus. These agglomerations sometimes lead to the emergence of small biodetritic islands made of shells, locally called mapiko (Fig. 3). In contrast, in many other areas of the world (e.g. Papua New Guinea, Samoa, Fiji, Australia) and in most lagoons in French Polynesia, densities are much lower, at most a few specimens per square meter, and frequently, the figures are given in hectares (Lucas 1994; Green and Craig 1999; Skewes et al. 2003; Andréfouët et al. 2005).

A survey by SPC's PROCFish project, which covers most Pacific Island countries, is designed to obtain up-to-date information on the status of invertebrate and fish resources. The PROCFish team has conducted surveys on the islands of Raivavave, Tikehau, Tahiti and Fakarava in French Polynesia (Kim Friedman, pers. comm.). Comparative surveys of the countries studied by PROCFish, combined with the studies carried out by the SPE, will make it possible to determine where Polynesia fits, in terms of its nearshore resources, within the greater regional Pacific context.

Table 2: Numerical and weight estimations of giant clam stocks from Fangatau, Tatakoto and Tubuai

	Total number of giant clams (millions)	Total weight (tonnes)	Total weight of saleable meat (L > 12 cm) (tonnes
Fangatau	23.6 ± 5.3	9 194 ± 2 158	1 162 ± 272
Tatakoto	88.3 ± 10.5	13 135 ± 1 573	1 485 ± 177
Tubuai	47.5 ± 5.2	19 729 ± 2 109	2 173 ± 232

FRAGILE GIANT CLAM POPULATIONS

Giant clam stock biomass and structure in French Polynesia's atolls, as studied by the SPE, cannot be considered critical at this time but the situation could change rapidly. We cannot predict how these exceptional giant clam populations grouped together in the shallow parts of the lagoon will react to sustained exploitation. Giant clams' shallow water distribution combined with their sedentary behaviour and the fact they are easily found by fishers, render them particularly vulnerable to fishing efforts. To this must be added other specific traits linked to their biology and method of reproduction. Giant clams, which are known to have erratic recruitment, maximise their chances of reproduction by synchronised spawning (Munro and Gwyther 1981; Braley 1985). It would appear that there are

Figure 2 (top): Unusually high densities found in the reserve set up at Tatakoto (Photo Y. Chancerelle)

Figure 3 (bottom): Emerged area in Fangatau lagoon made of dead giant clam shells or Mapiko (Photo A. Gilbert)

chemical mediators or pheromones in the eggs and ovarian tissue (Wada 1954). The zones with the densest number of giant clams are the areas where mass spawning can be observed (Shelley and Southgate 1988), a phenomenon we also observed in situ. In sedentary organisms, which spawn en masse, the total stock's contribution to reproduction depends a great deal on these zones of high density. But it is precisely in such areas that fishing efforts are the highest. As soon as a high aggregation area becomes depleted, there is, in addition to the changes in mean density, an underlying effect on the population's spatial structure, which probably affects pre-dispersion processes that depend on density. Fishers then unwittingly target those specimens that have the best chance of reproducing, a recurrent phenomenon that contributes to overharvesting in benthic fisheries (Orensanz et al. 2004).

In general, overexploitation is linked to a combination of factors, including in French Polynesia:

- an increase in human population and fishing pressure;
- an increase in fishing effort, which is related to the availability of more effective fishing equipment (boats and diving equipment);
- the development of storage, transport and intra/inter-island communication resources;
- the difficulties that regulatory authorities face, and even a lack of response of their part, when confronted with regulation violations and unsustainable exploitation.

CITES AND INTERNATIONAL MANAGEMENT TOOLS

When overexploitation has been noted in most regions, it has led to measures designed to ensure the regeneration and protection of stocks.

At the international level, since 1983, all giant clam species have been listed in Appendix II of the Convention on the International Trade in Endangered Species (CITES), and are considered endangered species by the IUCN (World Conservation Union). Appendix II means that the listed species is not threatened with extinction, but could be at risk of becoming so unless the trade is regulated. International trade is permitted in Appendix II-listed species, provided strict authorisation and monitoring systems are in place. For that reason, export permits at departure and import permits at arrival are mandatory for every commercial operation.

Other regional initiatives have been undertaken. It is recommended that marine refuges or restricted use areas be established in all areas where stocks are at very low levels (Mitchell et al. 2001). It may take many decades to replenish stocks if the part of the reef involved is isolated or currents are not favourable (Braley 1994; Munro et al. 1993; Lucas 1994; Mitchell et al. 2001; Wells 1997). Reserves where fishing is prohibited have been set up

Figure 4 (top): Aerial photo of the enclosed eastern area of Tatakoto that has been declared a reserve (Photo A. Gilbert)

Figure 5 (bottom): Buoy marking the southern boundary of Tatakoto reserve (Photo F. Faana)

at Rose Atoll in American Samoa (Green and Craig 1999), Papua New Guinea (Kinch 2002), and Tatakoto in the Tuamotus (Figs. 4 and 5) (Gilbert et al. 2005).

Setting a minimum size that corresponds to sexual maturity is a frequently used measure that allows giant clams to reproduce at least once before they are harvested. Initial maturity has been observed in the eastern Tuamotus at between 5 and 6 cm (pers. observ.). The minimum size for this species varies depending on the region: 18 cm on Guam and Niue, 16 cm in Samoa, 15.5 cm in Tonga, and 12 cm in French Polynesia (SPC 2005).

Another approach consists of concentrating adult genitors so as to increase the probability of gamete fertilisation and increase recruitment within and outside the zone (Lucas 1994). Finally, while giant clam farming is highly developed in the Pacific (Bell 1999), specimens from hatcheries are rarely used for ecological purposes (e.g. repopulation) and are mainly destined for the aquarium trade (e.g. *T. maxima* is highly sought after for its colours), or the food market, in the case of larger species.

A resource management plan backed up by an innovative spat production technique

Stock surveys are a necessary but inadequate approach to implementing sustainable exploitation plans. Stock dynamics (i.e. growth, natural mortality and recruitment) are also very important (Beverton and Holt 1957). Stock dynamics have been studied in situ during tagging/recapture experiments on Fangatau, Tatakoto and Tubuai (Faben 1965; Pauly 1983; Pearson and Munro 1991). The initial results showed wide variability, both within a single lagoon and between islands (Gilbert 2005).

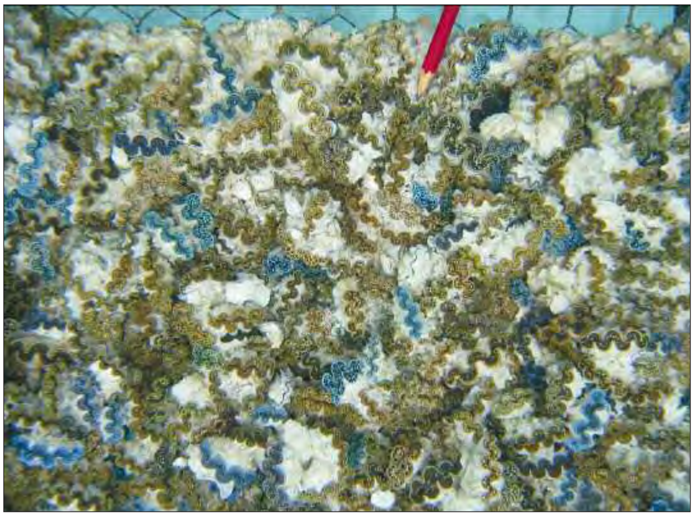
Studies have also been conducted on this fishery in order to gain an overall view of the ecosystem. Exports were monitored on Tatakoto and Fangatau and are being estimated on Tubuai (Fig. 6). In 2004, exports reached 16.4 tonnes of marketable meat on Tatakoto, and 5.5 tonnes on Fangatau. On Tubuai, depending on the survey, estimates reached between 8 and 30 tonnes (Lehartel 2003; Larrue 2005). The price depends on the distribution network used and varies between XPF 300 and 500/kg. Monitoring of fishers has shown that the catch per unit of effort (CPUE) in kg of marketable meat/man-hour) are between 2.7 kg/hour and 4.9 kg/hour (Fig. 7). Collec-tion site depths and differences in population structures (density and size) make it possible to explain these differences in CPUE between islands and even between sites on the same island.

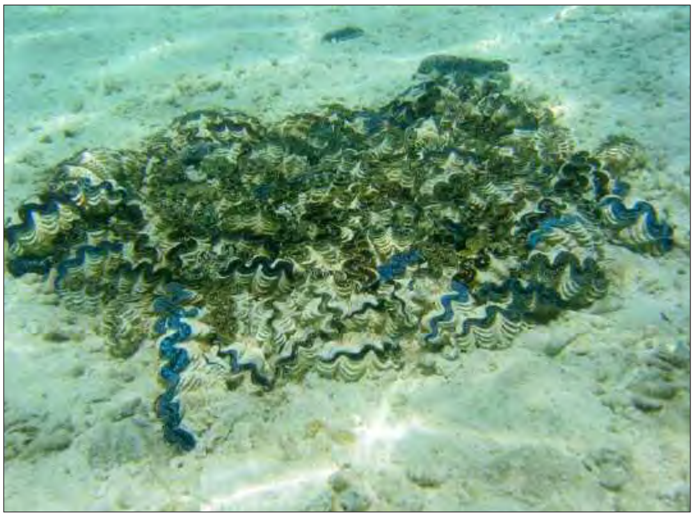
These data were used to formulate some initial recommendations. Beverton and Holt's model (1957) made it possible to analyse yield per recruit and, through that, biomass per recruit as a percentage of biomass per recruit in an untouched state. Some interesting preliminary diagnostic information is available. However, the specific characteristics of invertebrate biology and fisheries make it difficult to apply the con-

Figure 6 (top): Monitoring giant clam exports from Tatakoto by weighing before maritime shipping (Photo A. Gilbert)

Figure 7 (bottom): Giant clam fishers-gathers in Fangatau lagoon (Photo A. Gilbert) cepts and models used for finfish fisheries management, and so care should be taken with regards to the results from the Beverton and Holt model. Most invertebrate species have strong spatial structures, with adult stages that are only slightly, if at all, mobile but with large-scale larval dispersion. These characteristics contribute to a spatial structure of meta-populations, the dynamics of which have only just begun to be modelled. Given that, work should continue and a precautionary principle should be applied to promote a homogenous distribution of the fishing effort (i.e. through a rotation strategy, or *rahui* zones used in the past by the elders), in order to preserve source subpopulations (i.e. identify refuges for reproduction zones or *tapu* zones used in the past by the elders) and to monitor the integrated response of the system (i.e. monitoring the spatial structure by means of a co-management system). This group of measures should make it possible to apply the adaptive management needed for sustainable exploitation of this resource. In the same way as what has been done with giant clams elsewhere in the Pacific, a co-management project for giant clam stocks and fisheries is being conducted in the lagoons of Fangatau, Tatakoto and Tubuai.

At the same time, trials have been carried out on giant clam collecting, farming, transport and on restocking, using harvested giant clams. Low species richness and the giant clam's dominance in Fangatau and Tatakoto lagoons seem to indicate that Tridacna maxima is predominant in the pelagic larvae pool and, therefore, has an excellent capture or collection potential (local term from the pearl oyster industry). With a mean density of more than 400 specimens/m^2 (Fig. 8) and a collection rate of more than 80% two years after the installation of the collectors, this method is very promising. This is the first successful use in the world of giant clam collection techniques. This spat collection method has a number of economic advantages over other Pacific producers where a hatchery phase is required (Tisdell and Tacconi 1992). The growth rate was also encouraging with a mean size of more than 3 cm at the end of the first year of farming. Using collected spat may, then, facilitate the development of giant clam resources.





The low level of genetic differences between Tridacna maxima populations in French Polynesia (Planes et al. 2004) also makes it possible to plan transfers with no genetic risks. The low epibiont colonisation of young collected spat (7 cm or less), the existence of the same epibionts in the island groups where transfers are planned (Fauchille et al. 2004), and the possibility of conducting freshwater treatments before dry transfer, make it possible to limit the ecological risks during inter-island transfers. Inter-island transport trials involving an external freshwater treatment have been carried out using the Ellis method (2000), with a particularly high survival rate of 95% after 10 hours of dry transport (Yan 2005).

Finally, in Tatakoto and Fangatau lagoons, reseeding trials (Fig. 9) that used more than 36,300 spat

Figure 8 (top): Giant clam spat collected (Photo L. Yan)

Figure 9 (bottom): Small island of restocked giant clams (Photo A. Gilbert)

provided good prospects for reseeding projects. Survival rates in these two lagoons were 31% and 71%, respectively, more than 20 months after reseeding, and respective maximum rates during trials to improve the techniques were 57% and 91%. In addition, we noted that the new spat attached themselves to reseeded giant clams at a mean rate for both lagoons of 8.3% and 2.7%, and a maximum rate of 55% and 15%, respectively. This means that what is involved is not merely reseeding, but an actual lagoon restocking method. However, this method must be mastered in high island lagoons before the technology can be transferred.

Whether destined for ecological or fisheries (repopulation) projects, "ecotourism" (developing lagoons in front of hotels) or the aquarium fish trade, these giant clam collection and reseeding methods offer an alternate way to exploit and develop this resource, and offers a new economic activity for isolated island groups in the eastern Tuamotus. However, modifying local regulations and CITES permits is the final step to be taken before this new source of income can be fully developed. The economic development potential of the collection sector is also a tool that supplements management. Besides repopulation, it can contribute to raising an entire community's awareness of the richness and importance of this extraordinary resource, and can lead to sustainable exploitation.

Conclusion

The giant clam stocks of the populated islands in the Society group have clearly been over-harvested, but certain islands in the eastern Tuamotu and Austral Islands still have exceptional giant clam concentrations. French Polynesia has recorded giant clam stocks whose abundance, coverage and densities are the highest of any coral reefs in the world today. This is certainly one of the reasons for the success of an innovative technique for spat collection, an emerging sector of activity. But even in the case of these exceptional sites, the risk of overexploitation cannot be ruled out over the medium- to long-term due to the current rate of meat exports from the outer islands to Tahiti and projected increases in demand. Stock dynamics, and fisheries and population dynamics studies were carried out on three islands in French Polynesia in order to provide the initial information needed for sustainable exploitation. These studies allowed preliminary use of the Beverton and Holt model but this model is based on certain assumptions and does not take into account the importance of stocks' spatial structures. So, while taking a precautionary approach and giving due consideration to the giant clam's specific biological traits, management must take into account this spatial component. The methods proposed seem to be relatively well-adapted to the local context as they are similar to traditional management methods used in the past (e.g. the *rahui* strategy (rotation), the *tapu* (total fishing prohibition: reproduction refuges) and tomite toohitu strategies (using councils of elders to co-manage community property). However, the only way to ensure that future recommendations are followed is to have the involvement and support of local communities. Scientific and technical efforts currently underway must be backed up by meetings with island communities, listening to them, engaging in discussions, and attempting to find mutually acceptable solutions. The SPE should promote a changeover to multi-sectoral collaboration, the only realistic way to integrate and implement future recommendations with a view to involving all stakeholders in a joint project to sustainably co-manage stocks and fisheries.

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