

FRENCH POLYNESIA CASE STUDY

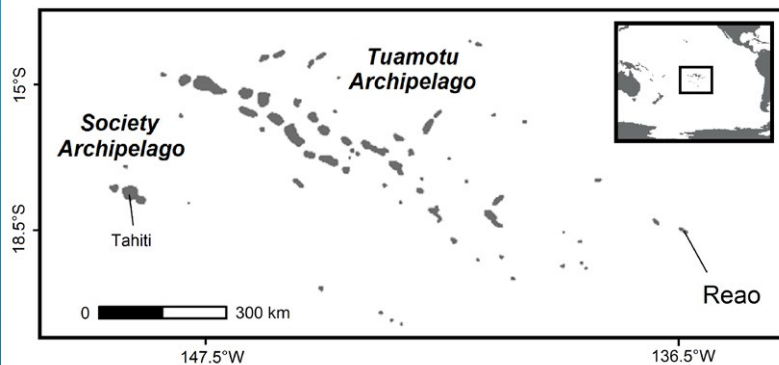
Sustainable Use, Mariculture and Conservation of Giant Clams in the Marine Regulated Fishing Area of Reao Atoll, Tuamotu



“Following the case study about seaweed culture in Zanzibar (2020), marine finfish culture in Tunisia (2021), shrimp pond aquaculture in Indonesia (2021), this case study addresses the issue of culture and conservation of a vulnerable species in tropical atoll lagoons. According to the Convention on Biological Diversity’s Aichi Targets, as well as the Sustainable Development Goals, there is a need to reconcile nature conservation and sustainable development. Marine Protected Areas (MPAs) are a key tool for achieving Aichi targets in coastal and marine ecosystems. It is also widely recognized that aquaculture is an important activity in terms of sustainable development for coastal communities, contributing to food security, poverty alleviation, economic resilience, and providing services to marine ecosystems in some cases. This document provides concrete illustrations of the value of joining efforts for conserving vulnerable species and supporting local economies. It demonstrates how aquaculture can be part of MPA objectives while identifying issues and solutions.”

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Giant clam mariculture activity © C.Wabnitz



Location of Reao within French Polynesia.

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MPA short description

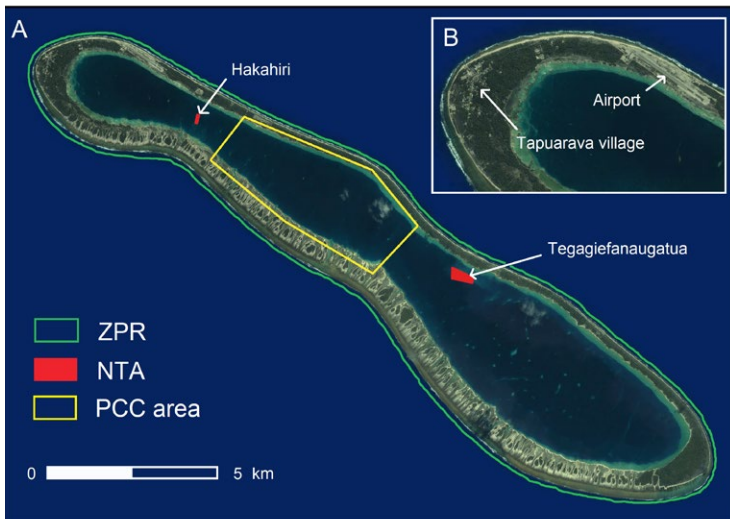
MPA location and characteristics

Reao, or the ‘beginning of the world’ in the local Paumotu language, is the easternmost atoll of the Tuamotu archipelago, located 1,400 km southeast of Tahiti. The entire atoll is recognized as a *Zone de pêche réglementée (ZPR)* – or fisheries restricted area. This is a specific French Polynesian fisheries protection status (*Délibération n° 88-184 AT du 8 décembre 1988*) equivalent to IUCN category VI. In practice, this means that resource use is permitted in line with specific conservation considerations (i.e. ban of specific fishing techniques and inclusion of no-take areas), as stipulated by French Polynesia’s marine resources department (*Direction des Ressources marines – DRM*), on 4 March 2016 (*arrêté n°238 CM*), and revised on 12 September 2017 (*arrêté n°1630 CM*). The ZPR includes Reao’s lagoon and outer reefs (including the outer reef slope), covering a total surface area of 69.72 km² (Andréfouët et al., 2005).

Environmental features of the MPA

Reao is one of a few remarkable semi-closed atolls in the eastern Tuamotu, a quite unique system characterized by a range of habitats (Gilbert & Andréfouët, 2006): sand, coral pavement, rubble (including deposits of giant clam shells), rocky floor with crustose coralline algae, massive and branching corals, as well as macroalgae (predominantly of the genus *Caulerpa*).

The special features associated with Reao’s lagoon and reefs allow a variety of organisms, particularly invertebrates, such as mollusks, to thrive in abundance. This includes first and foremost the species of giant clam known as *Tridacna maxima* (small giant clam), which is found throughout Reao’s lagoon, on hard substrate and in shallow (<10 m) habitats. The fluted giant clam (*Tridacna squamosa*), on the other hand, has only been found on the (outer) forereef (Andréfouët et al., 2014). Surveys estimate Reao’s *T. maxima* population at several tens of millions of individuals (Salvat, 1972; Gilbert et al., 2006b), with densities as high as 36.6 ind.m⁻² reported for the northern portion of the atoll. Thus, Reao’s MPA stands out as one of the areas with the highest densities of giant clams in the world (Gilbert & Andréfouët, 2006; Van Wynsberge et al., 2016). Other bivalves that are abundant in the lagoon include the oyster



A) Satellite image of the atoll with the area designated for giant clam (*Tridacna maxima*) spat collection and aquaculture (PCC area) and the two No-Take-Areas (NTA) where giant clam exploitation of any kind is prohibited; B) focus on the village and airport area at the northwestern tip of the island. ZPR = Zone de pêche réglementée.



Wild giant clams of various colours targeted for the aquarium trade lying on a bed of green macroalgae (*Caulerpa* sp.) © C. Wabnitz

Pinctada maculata, so called tellins (*Tellina sp.*), the white strawberry cockle (*Fragum fragum*), as well as bivalves of the genus *Chama*, and the species *Ctena divergens* (Salvat, 1972). Gastropods like sea snails *Cerithium sp.* And *Astraliu confragosum* are also common, as are octopus and the sea cucumber *Holothuria atra*. Reao's lagoon is also known for a high abundance in glass anemones (*Exaiptasia pallida*), especially in the north-western part of the lagoon, and Christmas tree hydroids (*Pennaria disticha*). The former was likely introduced through pearl oyster aquaculture several decades ago, but the farms are no longer active. Finfish biodiversity and abundance is comparatively much lower than commonly found in open atolls (Adjeroud et al., 2000).



Motorized boats used by aquaculture professionals © G. Tixier

Main MPA and aquaculture facts

MPA	Type (IUCN' category)	The entire atoll is recognized as a <i>Zone de pêche réglementée</i> (ZPR), meaning that resource use is permitted in line with specific conservation considerations (IUCN category VI).
	Surface area	Reao's MPA (69.72 km ²) includes two no-take areas (0.017 and 0.146 km ²) in which giant clam fishing is prohibited. These two no-take areas protect roughly 0.5% of the exploitable population of giant clams (i.e. clams that are ≥12 cm in size).-
	Creation date	Declared 4 March 2016 (<i>arrêté</i> n°238 CM) and revised on 12 September 2017 (<i>arrêté</i> n°1630 CM).
	National status and management	Public/community-based.
Aquaculture	Type	Mariculture - intensive spat collection rafts tailored in their design to giant clams.
	Surface	Currently, regulations allow for a total surface area of 2,400 m ² to be used for spat collection, to be shared between a maximum of 30 rafts owned and managed by no more than six local aquaculture professionals.
	Creation date	Traditional spat collection techniques - typically used for oyster culture - were adapted to giant clams, trialed, and improved upon between 2001 and 2007. Technique transfer to local aquaculture professionals was initiated in 2011, with continuing capacity development and monitoring support provided by French Polynesia's marine resources department (<i>Direction des Ressources marines – DRM</i>), as well as ongoing co-design with local professionals of materials, support infrastructure and stock assessment methods. Reao was authorized for spat collection in 2010.
	Organization type	Small, family-size companies. Mariculture activities are limited to six aquaculture professionals within each lagoon authorized for spat collection (Reao and Tatakoto, as of 2020). Currently, cultured clams are destined for the marine aquarium trade, with two exporters located in Tahiti shipping live clams to Europe and the USA. Plans are underway to target the clam meat market (smoked/marinated products).
	Production	Between 2013 and 2020, an average of 8,900 +/- 3,500 spat-collected giant clams were exported annually (legal size ≥4 cm). Inter-annual variability in exported numbers reflects changing environmental conditions as well as changing numbers of professionals authorized to partake in the activity and involved in raft care.

1 IUCN uses seven MPA categories:

Protected area category and International name	Management objectives
Ia - Strict Nature Reserve	for science
Ib - Wilderness Area	to protect wilderness qualities
II - National Park	for ecosystem protection and recreation
III - Natural Monument	Managed mainly for conservation of specific natural/cultural features
IV - Habitat / Species Management Area	for conservation through management intervention
V - Protected Landscape / Seascape	for conservation and recreation
VI - Managed Resource Protected Area	for the sustainable use of natural ecosystem

Ecological and societal importance of the giant clam stocks

Giant clams play a number of significant ecological roles. For instance, they contribute to reef development and water quality. They also are important prey for and offer shelter to various invertebrates and fish (Neo et al., 2015). Recent work also suggests they can contribute significantly to carbon sequestration (Rossbach et al., 2019).

As giant clams inhabit shallow habitats, they are vulnerable to a variety of human pressures, including pollution and harvesting. Commonly referred to as *pahiva* in Reao, giant clams used to be the main protein source for the local community. Today, they remain a key target of subsistence fisheries and an important source of livelihood. They also have important cultural significance, and they are part of traditional myths (Larrue, 2006).

Giant clam specific regulations

In 1985, giant clams were listed on Appendix II of the multilateral treaty [CITES](#) (the Convention

on International Trade in Endangered Species of Wild Fauna and Flora). Thus, their international trade is closely monitored².

Tridacna maxima is currently classified as “data deficient/not evaluated” under the [IUCN Red list](#) for threatened species – however, the last assessment dates back to 1996 and likely does not accurately reflect the current situation. For instance, a more recent assessment in Singapore considers all giant clams to be highly threatened (Neo & Todd, 2013).

Recognizing giant clams’ vulnerability in French Polynesia, several additional regulations were put in place at national and local levels, to ensure their protection and alignment with CITES listing requirements. Throughout French Polynesia, to be harvested, transported, kept or traded, *T. maxima* must be ≥ 12 cm in length. On Reao, given the atoll’s ZPR status, clam fishing and mariculture activities fall under the management of French Polynesia’s marine resources department (DRM) and are managed and governed according to a number of rules regarding exploitation zones, a maximum size of 16.9 cm and shipment quotas.

MPA management

Reao’s ZPR management plan was approved by the National Scientific Authority in 2018 and is part of the DRM and the Marine Resources Ministry’s strategy on giant clam aquaculture. It is updated when needed. Management and governance of activities within the MPA are complex and involve a large diversity of stakeholders, spanning local to national and international levels (Andrefouët et al., 2017).

There is currently no specific budget in place for Reao’s ZPR. All financial needs concerning the ZPR’s boundary delineation (beacons, displays, brochures, monitoring, etc.) are covered by the DRM’s budget. However, on location, the municipal police chief and his deputy are the ones ultimately responsible for enforcing ZPR rules as well as legal sizes and quotas of giant clam shipments.

2 <https://cites.org/eng/app/index.php>

Box: Complex multilevel and interactive management of the giant clam resource and the MPA

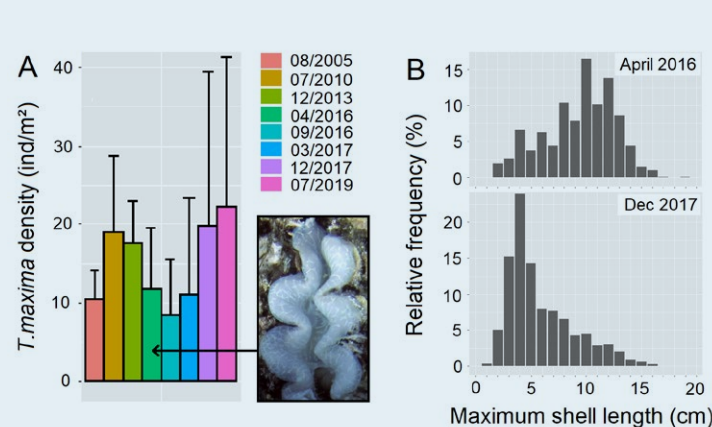
French Polynesia's marine resources department (*Direction des Ressources marines – DRM*) is tasked with coordinating activities across all stakeholders. The DRM is responsible for the overall management of marine resources (*arrêté n°1914 CM du 2011 modifié*). The DRM's role in managing mariculture activities and the MPA on Reao is multi-faceted, and includes the provision of technical assistance, monitoring of mariculture activities (e.g. spat collection and associated data, etc.) and local marine resources (e.g. giant clams and fish), providing the MPA committee and stakeholders with relevant information to support the sustainable exploitation of giant clams, data analysis, and proposing regulations suited to the evolving situation concerning resources within the MPA.

The local committee *Tomite Pahiva no Reao*: At the atoll level, discussions about the management of activities inside Reao's ZPR are led by a local committee named *Tomite Pahiva no Reao*. The committee is composed of the DRM, local authorities' deputies, and other stakeholders' representatives (*arrêté n°238 CM du 2016*). It meets once or twice a year, when a DRM representative is in Reao. At present, only giant clam exploitation is managed by the *Tomite Pahiva no Reao*. However, discussions are ongoing to extend goals of this local management committee to other fisheries resources and activities.

Regulations and export permits: Specific regulations for Reao's ZPR, particularly giant clam quotas, are promulgated by the government of French Polynesia, based on proposals submitted by the DRM. Such proposals are informed by a combination of discussions and motions coming from the local committee *Tomite Pahiva no Reao* and the municipality, but chiefly rely on scientific evidence, including in-situ monitoring findings and catch statistics. Giant clam export quotas also need to be validated by the government of French Polynesia, the High Commissioner of the French Republic in French Polynesia, and the CITES scientific authority (based in Paris). French Polynesia must be able to demonstrate that such exports will not be detrimental to the survival of the species (Non-Detriment Finding) and ensure that measures are in place within the existing management plan and regulations to support the long-term conservation and sustainable use of the species.

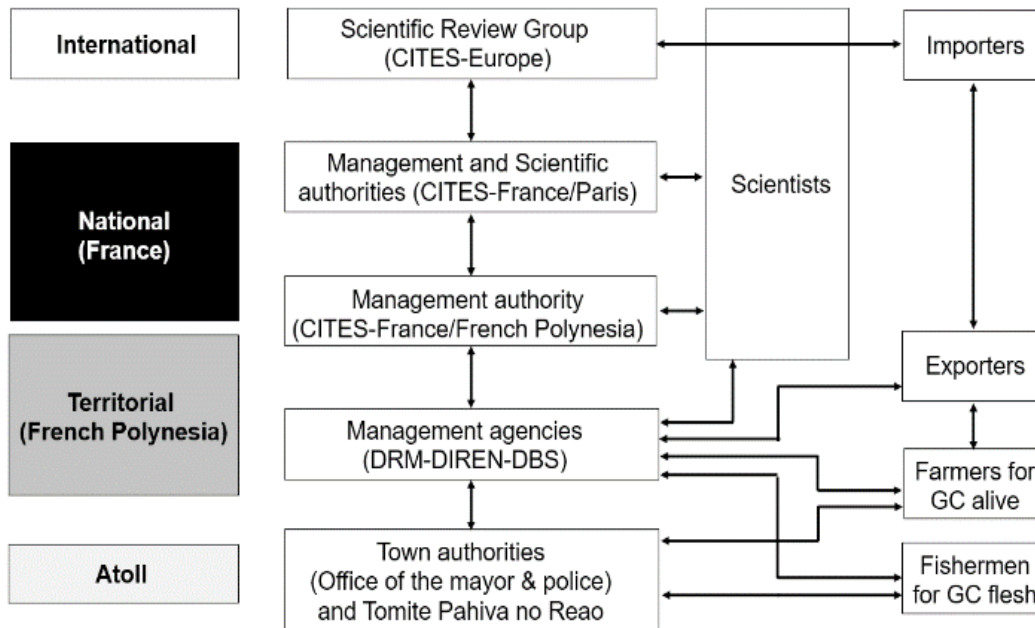
Live giant clams can only be exported by aquaculture professionals who hold a giant clam aquaculture producer license. Each professional is assigned an annual quota of wild clams – there are no quotas for spat collected clams, as long as they are ≥ 4 cm in size, to maximise survival. Every shipment of live clams (from the wild and from spat collection) is to be addressed by the aquaculture producer to his/her customer (who is either also an approved aquaculture producer or a marine licence holder). A copy of this transaction is also sent to the DRM. A commodity traceability chain is implemented for each giant clam shipment, starting with the municipal police chief at departure from Reao.

Science and management of Reao's giant clam stock: Local researchers are regularly asked questions concerning the sustainable exploitation of giant clam wild stocks and regularly provide advice to DRM and CITES authorities, as well as local stakeholders. Specifically, for in-situ monitoring, researchers from a number of institutions, including The French Research and Development Institute (IRD) and the Pacific Community (SPC), have conducted data collection campaigns on *T. maxima* stocks and stock recruitment in Reao lagoon in 2005 (Gilbert & Andréfouët, 2006), 2010, and 2013. They also have been involved in co-developing field protocols. Ongoing regular monitoring of wild giant clam densities is undertaken by DRM and trained community members on a set of permanently established belt-transects, selected to cover the habitats home to the largest proportion of Reao's giant clam population. Over time, the sampling scheme has undergone a number of significant changes, including the location of stations sampled and the method used for density surveys (belt-transect and quadrats). To facilitate temporal comparison of densities, recent work was undertaken to provide comparable estimates (Georget et al., 2019).



A) Temporal trend in the recorded density of giant clams showing a decline in numbers of individuals per m² following a bleaching event, and fast subsequent recovery. The picture (from Andréfouët et al., 2017) shows a bleached giant clam observed in April 2016. B) Size structure of giant clams at Reao from April 2016 to December 2017, showing high recruitment (large numbers of small clams) following the 2016 bleaching event.

Of note is that the governance framework regulating the trade of giant clams from Reao is inclusive, collaborative in nature (between local and national institutions) and adaptive – meaning feedback from assessment and monitoring is translated into policy for a wide-range of decision-makers, from customary to national levels (Andréfouët et al., 2017). As a case in point, in 2016, a heatwave associated to a strong El Niño event led to the mass bleaching of corals and giant clams in Reao's lagoon. Giant clams can also bleach as they function similarly to corals in being animal-hosts dependent on symbiotic algae for survival and growth. At the onset of the event in March, aquaculture professionals noticed that clams had lost their colour and undertook surveys. These surveys were repeated in 2017 to assess stock status and the sustainability of existing quotas. As more than 76% of clams were found bleached in March-April 2016, the exploitation of and trade in live giant clams were halted until July 2016. By then (winter) the waters had cooled and the clam population showed overall signs of good recovery from the bleaching event. Longer-term proactive measures undertaken in response to the 2016 and 2017 bleaching experiences include technical adjustments to spat collectors, development of rapid response plans at multiple policy levels, and, importantly, declaring Reao as an MPA.



Decision and action relationships linking stakeholders involved in the sustainable exploitation of giant clams in the Tuamotu atolls. CITES: the Convention on International Trade in Endangered Species of Wild Fauna and Flora; DIREN: *Direction de l'environnement* (French Polynesia's Environment department); DRM: *Direction des Ressources Marines* (French Polynesia's marine resources department); DBS: *Direction de la Biosécurité* (national biosecurity agency); GC : giant clam. (modified from Andréfouët et al., 2017).

Activities and resource use in the MPA

Reao is home to one village named Tapuarava and a total of 587 inhabitants (2017)³. There is only one primary school on the island and an infirmary with a nurse. Reao's inhabitants are greatly dependent on external supplies for food, gas, and many other commodities. Since 2010, a hybrid power plant (solar and fuel) supplies energy – affording the community an 80% saving on fuel. Regular inter-island ship visits and plane travel ensure connections with Tahiti.

Very few tourists visit the atoll, given its most eastern location in the Tuamotu archipelago. The scope of local activities is relatively limited and mostly tied to fishing, copra (the dried meat of the coconut), and handicraft making. Copra is the main production activity on Reao, with most shipments destined for Tahiti. Generating about 300 tonnes of copra per year, Reao is one of the main Tuamotu island copra producers (Polynesian Department of Marine Affairs, DPAM statistics). But production has fluctuated a lot

recently as the coconut forest is getting old and has been insufficiently regenerated. This decrease in copra activity has resulted in more individuals turning to the exploitation of marine resources as a source of income.

Giant clam fishing and meat consumption

Giant clams are either consumed locally (≤ 2 tonnes of meat consumed annually (Municipal police chief) or sent to customers in Tahiti. Over the last 5 years, meat exports have averaged around 2 tonnes annually. Giant clam fishing is a family-based artisanal activity, mostly practiced from shore. Large specimens may be caught by (breath hold) divers. Local consumption of giant clams is not restricted, but export of wild giant clam meat to other islands in French Polynesia (mostly Tahiti) is regulated. Before being expedited, the Reao municipal police chief or

3 Last official recording in 2017: <https://www.ispf.pf/bases/Recensements/2017/Presentation/conference-de-presse>

his deputy check shipments' weight and assess these against local quotas. The current total annual export quota of around 3.2 tonnes of wild giant clam meat (equivalent to around 48,000 individual clams and US\$ 21,000 to 24,000 per year) is shared among fishers and local families. Based on 2005 data (Gilbert & Andréfouët, 2006), the total annual meat shipment quota represents about 0.66% of Reao's ZPR's giant clam stock above the legal harvest size of 12 cm.

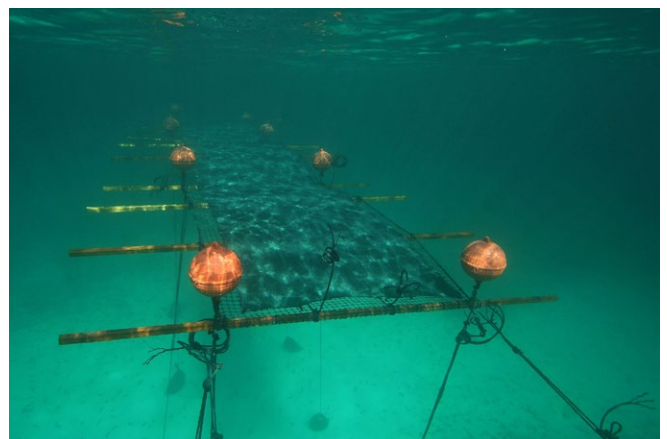
Other fishing activities

Other fishing activities that take place on Reao are listed below.

- **Seasonal finfish capture:** This fishing activity is practiced using traditional dead coral rock traps or wire mesh traps in or upstream of shallow lagoon channels *hoa*. Wild fish are trapped and caught to serve locally or for export to Tahiti. Mean annual catches over the last 5 years amount to around 12 +/- 3 tonnes (DPAM statistics) and consist of a diversity of species including parrotfish (Scaridae), wrasses (Labridae), jacks/scads/runners (Carangidae), butterflyfish (Chaetodontidae), milkfish (Chanidae), and surgeonfish/tangs/unicornfish (Acanthuridae). Pufferfish *hive* (Tetraodontidae), butterflyfish *korai* and milkfish *pai* are reserved for local use only.
- **Finfish spearfishing, net fishing and trolling:** This activity is mostly undertaken by men and takes place either in the lagoon at peak seasons (September to February) or on the outer reef with fishers mostly targeting high value fish such as jacks/scads/runners, groupers (Serranidae), Napoleon wrasse (*Cheilinus undulatus*), wahoo (*Acanthocybium solandri*) and yellowfin tuna (*Thunnus albacares*). Most catches are destined for the Tahitian market or used to barter for food with the regularly visiting schooner.
- **Gleaning for octopus and rough turban snails:** This activity is mostly undertaken by old men and women. Catches are consumed locally or exported to Tahiti and are dominated by octopus exports to Tahiti (1 to 7 tonnes per year).
- **Shell harvesting for handicrafts:** shells are harvested on the reef and on beaches, mostly by women, to make necklaces and handicraft for tourists in Tahiti and to adorn traditional dance costumes.

Aquaculture activities within the MPA

Mariculture infrastructure in Reao consists of intensive spat collection rafts and rearing rafts. Spat collection rafts are similar to those used for mussels and oysters but tailored in their design to giant clams. The activity, currently, mainly targets the aquarium trade (Gilbert et al., 2006b; Remoissenet & Wabnitz, 2012). The culture techniques were tested before their transfer to aquaculture professionals (Remoissenet et al., 2010) and have been improved upon and further refined by local professionals on their own or in partnership with DRM and others.



Freshly submerged spat collection raft tailored in its design to giant clams © DRM

Reao was authorized for spat collection and giant clam farming in 2010⁴. There is a quota of six registered aquaculture professionals (small family-size company) per atoll. Aquaculture professionals also harvest wild live coloured giant clams for export (≥ 12 cm).

Spat collection

Spat collection devices are described in detail in a published [manual for aquaculture producers](#). They are based on raft techniques that support a high level of recruitment (100 to 500 ind.m⁻²). Once juvenile clams have reached 3 cm, survival of settled spat is $\geq 90\%$ – unless there is an extreme climate event, raft accident, or predator invasion. Although a total of 2,400 m² of spat collection have been authorized across

30 devices and six aquaculture professionals, only eight devices have been deployed so far, covering 729 m². To date, a mean of 9,463 spat-collected giant clams (legal size ≥ 4 cm) have been harvested annually between 2013 and 2020 and sent to Tahiti, mainly for export (Table 1).

Once spat have recruited onto the raft, the producer must protect and take care of them as well as of the raft on a regular basis. After about one year, once recruits have reached the minimum legal size (4 cm), they can be detached carefully from the raft and sold. Currently, cultured live clams are mostly sold to Tahitian wholesalers who export them on to Europe and the USA for the aquarium trade. A few are sold for local restocking at the minimum legal size of 7 cm (for better survival).

Table 1: Wild and spat collected giant clams *Tridacna maxima* exported from Reao since 2013 (DRM and customs office data).

	Wild harvested Legal size ≥ 12 cm	Collected spat on artificial devices Harvest size ≥ 4 cm	Total Giant clams
2013	946	11 276	12 222
2014	16 314	14 822	31 136
2015	9 332	7 396	16 728
2016	13 028	5 600	18 628
2017	13 734	9 594	23 328
2018	11 993	6 080	18 073
2019	17 460	10 264	27 724
2020	10 177	10 668	20 845
Annual mean	11 623	9 463	21 086

On-growing rafts

Once clams have reached 4 cm they can be detached from the collecting raft and sold or placed on rearing rafts for grow-out. Rearing rafts are designed to give clams more space. They are similar in design to spat collecting devices but made of untreated wood or plastic crates instead of shade cloth. On rearing rafts, clams take around 4 years, one year faster than wild clams, to grow to 12 cm. In practice, spat-

collected clams are mostly kept on collecting rafts until they are detached for export. While high densities reduce clams' growth, high densities also protect individuals from biofouling and reduce the amount of effort the farmer needs to expend to take care of clams.

Spat-collected clams, which are locally considered as farmed clams (as per the Food and Agriculture Organization's (FAO) definition of aquaculture), are classified as wild clams (W

4 Arrêté n°2079 CM replaced by Arrêté n°259 CM of 10 March 2016.



Diver working on a spat collection raft © DRM

code) by [CITES](#), rather than farmed clams (F code for hatchery produced clams) or ranched clams (R code). Work is underway to see whether this latter code could eventually be used to classify spat collected giant clams from French Polynesia.

Location of mariculture activities

Mariculture activities can only take place in authorized zones. Reasons for the restrictions in activity space include: (i) minimizing conflict with other lagoon users, and (ii) limiting infestation and proliferation of glass anemones (*Exaiptasia pallida*), a pest for aquarists, by banning aquaculture activities in the northern part of the atoll where they are abundant.

Giant clam fishing - aquarium trade

The six registered aquaculture professionals share an annual total quota of 24,000 individual



Cleaning of clams before sale © DRM



Spat collection raft with giant clams © DRM

live clams to be sold for export on the aquarium trade market. The equivalent local income for the overall quota is around US\$ 75,000 per year. Due to constraints in air freight availability, the quota has never been reached. Aquaculture professionals use part of these earnings to invest in maintenance, repair and new spat collecting devices, as well as other aquaculture materials.

Based on 2005 abundance estimates (Gilbert & Andréfouët, 2006), current live giant clam shipments to Tahiti represent 0.33% of Reao's ZPR ≥ 12 cm giant clam population.

Main challenges and development perspectives

While six aquaculture professionals, including one woman, are legally authorised to culture giant clams, in practice, only one farmer has consistently been active in Reao since 2012. Between 2012 and today, two other individuals were active consistently over two years. Three further individuals took up the activity last year. Several challenges associated with giant clam mariculture, and possibly linked to the high turnover rate, are highlighted below.

- The activity requires initial investment and availability of resources (boat) that some farmers lack on this remote atoll. Some logistic and technical support was initially provided by the Pacific Community (SPC) and DRM in 2012, but was a one-off to kickstart activities. As farmers have come and gone, individuals that took up

mariculture after 2012 may have lacked the resources to ensure the financial sustainability of their operations.

- The activity requires regular monitoring of rafts, often consisting of several hours spent swimming and free-diving, and some farmers, older individuals in particular, ultimately lacked the required gear, motivation and energy to carry out such work consistently. This issue is amplified by the fact that most spat collection devices are located some ways from the village.
- The strong 2016 El Niño saw a large number of giant clams bleach, resulting in major losses for farmers. Although high recruitment followed the bleaching event, the possible vulnerability of the activity to rising temperatures, and a repeat bleaching event in 2017, may have discouraged individuals potentially interested in taking up mariculture.
- Fluctuations in market prices, air freight availability and small volume demand can considerably reduce the financial viability of operations, especially considering the livelihood-setting of most community members on the atoll.

While the sale of clams for the aquarium trade can be considered as relatively lucrative, it remains a niche activity and only targets colourful giant clams. Some work is planned to develop several on-site value-added activities for farmed giant clam meat (salting, smoking or bottling them). The processing, which could involve women, needs to be validated for health and safety as well as gustative purposes before the project can be implemented.



Control of clams' legal harvest size before export © C. Wabnitz

Interactions between aquaculture activities, the MPA and local communities

Negative interactions

- **Interactions between giant clam farmers, fishers, the community and ZPR status**

The legal status of the ZPR is currently imperfect, as the restriction is based on

fishing techniques (on-foot fishing and dive fishing) rather than targeted species.

Fishers mostly abide by the relevant regulations linked to the MPA, including Reao's MPA quota for meat export. Overall, fishers who are most active disapprove of wild live giant clam quotas, as these

are shared among the six aquaculture professionals only. The meat quota allocations among families, on the other hand, are relatively well accepted. Broadly speaking, fishers, representing around 54 families, are less concerned with giant clam stock surveys and conservation measures than aquaculture professionals and their 14 associated families.

Aquaculture professionals use boats, sell live giant clams at a higher price than fishers who sell clams just for meat, and may employ several individuals to assist with relevant farming activities. Consequently, they are locally 'perceived' as prosperous operators exploiting the resource to the detriment of fishers targeting giant clams for meat. Conversely, aquaculture professionals criticize fishers' lack of involvement around MPA monitoring, and their relative lack of respect vis-à-vis legal size limits.

- **Environmental effects of mariculture activities and their mitigation**

Spat collection and rearing rafts are currently partly made of plastic. Although the number of rafts dedicated to giant clam mariculture is very low, their presence in Reao's ZPR nevertheless may represent a threat to the environment. To avoid gear loss and waste when materials are substituted or when a farmer decides to quit, spat collection and rearing rafts are initially georeferenced. Work is also underway to replace plastic ropes and artificial shade cloth with natural or bio-sourced materials in support both of a more circular economy and to lower the activity's carbon footprint.

Positive interactions

- **Mariculture activities, resource management and conservation**

Giant clam-focused mariculture activities are an essential component of the strategy

developed to protect and restore the atoll's giant clam stock (i.e. to help buffer extreme natural mortalities, and enhance natural recruitment). Mariculture may contribute to the renewal of wild giant clam populations. Importantly, associated activities increase the involvement of local stakeholders in management and conservation activities in the following ways:

1. Mariculture supports restocking efforts of giant clams simply by providing stock. After their third year of activity, aquaculture professionals are required to contribute a portion of their cultured clams to restocking efforts. The clams destined for restocking are placed in the two no-take areas.
2. Farmed clams may contribute to the dynamics of the overall giant clam population in Reao's ZPR by increasing the number of clams present. Giant clam spat collection and rearing rafts are strategically positioned in the lagoon to be exposed to water quality and other environmental conditions that promote clams' optimal growth. These conditions may indirectly also support their reproductive potential as greater variability in temperature and stronger current, for instance, are known to lead to more spawning events. However, given the small size of the cultured clams, their contribution to the overall stock of gametes is likely to be negligible, and the gametes released will essentially all be male (Menoud et al., 2016). As a note of interest, aquaculture professionals increasingly place several wild big blue-coloured giant clams on their collecting rafts to increase spat settlement (Dumas et al., 2014) and in the hopes of enhancing their rafts' blue-coloured giant clam ratio.
3. Mariculture promotes better monitoring of giant clam fishing activities as part of CITES requirements (sustainable exploitation, Non-Detriment Finding, etc.). The harvest and trade of giant clams are part of an ongoing, regular, and detailed monitoring program

(*Bulletin statistique de la Direction des ressources marines*; Andrefouët et al., 2017; Van Wynsberge & Andrefouët, 2017).

4. As the success of mariculture activities depends on the health of the wild broodstock, aquaculture professionals feel a personal sense of commitment to support the conservation of natural habitats. As a case in point, sediment removal for infrastructure development with potential impacts on natural habitats and biodiversity, including giant clams, has been the topic of focused and heated debates in the *Tomite Pahiva no Reao*. Having the *Tomite* as part of Reao's ZPR management structure also has fostered discussions around the sustainability of fishing activities targeting species other than giant clams and environmental conservation more broadly.
 5. The development of mariculture activities has resulted in the involvement of a variety of actors and stakeholders (aquaculture professionals, fishers, the Reao municipality, the DRM, and scientists) in resource management and conservation. However, this collaboration remains fragile and weaknesses in the current management framework will need to be resolved in the future.
 6. Mariculture has led to the development of two ZPR "no-take areas". These two areas are home to high giant clam densities that may benefit the entire lagoon ecosystem. They also represent the focal areas for restocking activities with cultured clams. Current efforts are underway to develop a carbon budget for the atoll, with initial findings indicating that Reao's giant clam population may be acting as a carbon sink, an essential function that should benefit from protection.
- **Mariculture activities, Reao's social-ecological system and its resilience**

Compared to activities such as tourism or pearl farming, mariculture probably

provides negligible benefits in terms of income generation across French Polynesia more broadly. However, it represents an important livelihood opportunity for Reao's inhabitants where few alternatives exist (subsidized copra but no tourism, or pearl oyster farming). Mariculture activities targeting the live aquarium trade allow for a significant proportion of exploited giant clams to be sold live at much higher prices than if harvested for their meat, thereby increasing local income opportunities from this resource.

The contribution of Reao's giant clams to the aquarium trade also supports the promotion of French Polynesia's natural marine heritage. Advertisement of this image helps maintain tourism receipts and travel by visitors between Tahiti and its outer islands. This in turn helps support the local airline, which represents a vital link between Tahiti and remote communities, such as Reao, on this unprofitable line.

Mariculture activities on Reao benefit all genders. If diving for coloured clams is mostly undertaken by men, both women and men are involved in the construction and maintenance of spat collection rafts on land. Women are also the ones mostly responsible for cleaning, sorting, and packaging giant clams before shipments are expedited onwards to Tahiti.

Mariculture activities on the atoll play a sentinel role regarding ecosystem and climate change effects. Scientists have been key to the acquisition of knowledge on status and dynamics of the lagoon, its giant clam resource and habitats. However, researchers' involvement in monitoring is complicated due to Reao's remoteness and is therefore facilitated and undertaken in close collaboration with the DRM and local stakeholders. Specifically, during the 2016 bleaching event, the resource was closely monitored by aquaculture professionals and the municipal police chief (Andrefouët et

al., 2017). These events have led all groups (scientists, managers, aquaculture farmers, local authorities) to work together to co-

produce approaches and practices, including anticipatory measures that support adaptive capacity and resilience.

Box: Impact of the COVID-19 pandemic on the aquaculture sector and the MPA

The Covid-19 pandemic has led to three suspension periods for international flights, and a number of restrictions for local flights. These decisions have had significant bearing on giant clam exports, with production declining to 2/3 of its potential in 2020. This has profoundly impacted moral among aquaculture professionals, with little to no investment in collecting devices, despite the French government providing some subsidies. The DRM was unable to travel to Reao for 16 months, but thanks to the strong collaborative partnerships forged and capacity building undertaken over the years, the monitoring of live giant clam and clam meat expeditions proceeded successfully. As of April 2021, the activity is progressively recovering.

Conclusion: SWOT matrix⁵

Giant clam mariculture activity, in part to align with CITES requirements, led to the implementation of an MPA that has strengthened exchanges between local stakeholders and across groups (scientists, managers, aquaculture farmers, and local authorities) as well as supported local livelihoods. The local committee established to oversee the management of the MPA and giant clam-related activities is contributing to the protection and sustainable use of the resource. This case study highlights several important gaps, including the need to develop a value-added market for cultured clam meat, and the official recognition of spat-collected giant clams as distinct from wild-sourced

individuals in international statistics. A number of important scientific gaps also remain to support the continued sustainable and adaptive management of mariculture including the modelling of clam recruitment as well as the sensitivity and resilience of the wild giant clam broodstock to rising temperatures, which fishing and mariculture activities depend on. This case study also highlights how MPA management activities can inform the evidence-base to support sustainable aquaculture activities, and in turn how aquaculture can act as a sentinel to identify threats, in particular linked to climate change, to the local ecosystem to inform more adaptive MPA management.

⁵ Osita, I., Onyebuchi, I., Justina, N. (2014). [Organization's stability and productivity: the role of SWOT analysis](http://journalijiar.com/uploads/2014-10-02_231409_710.pdf). *International Journal of Innovative and Applied Research* 2(9): 23-32. http://journalijiar.com/uploads/2014-10-02_231409_710.pdf

	Strengths	Weaknesses
PRESENT	<p>Mutual benefits</p> <ul style="list-style-type: none"> Aquaculture and CITES requirements led to the establishment of the MPA, and now the MPA supports the sustainable exploitation of giant clams. <p>Aquaculture professionals' involvement</p> <ul style="list-style-type: none"> Aquaculture professionals are strongly involved in and empowered by their role in giant clam resource management within Reao's MPA. Aquaculture professionals provide critical assistance in the collection of regular field data. These data, together with other variables, help support wild giant clam stock assessments undertaken by the DRM and partners, which in turn inform resource management decisions. <p>Local governance</p> <ul style="list-style-type: none"> Reao's MPA giant clam committee fosters discussions between representatives of all stakeholder groups. Giant clam aquaculture and Reao's MPA have raised the local community's awareness around the need to balance conservation and sustainable use and stimulated interest in the designation of the MPA for all reef resources. The governance framework characteristic of Reao's trade in giant clams is inclusive and collaborative in nature as well as adaptive. 	<p>Atoll situation</p> <ul style="list-style-type: none"> Reao's geographic remoteness (and associated cost of access) limits the DRM's and its partners' ability to deploy supportive actions and the undertaking of scientific assessments on a more regular basis. <p>Governance and regulations</p> <ul style="list-style-type: none"> Current role of local authorities, and mostly municipal police are not officially integrated in existing regulations and depend on the will of the municipality. Regulations are still incomplete regarding traceability mechanisms of giant clam aquaculture activities, and the development of cultured giant clam meat exploitation, among others. MPA status still needs to be clarified (focus on targeted resources rather than specific fishing techniques). Further efforts should be made to resolve conflicts between fishers and giant clam aquaculture professionals. <p>Aquaculture professionals' involvement</p> <ul style="list-style-type: none"> The involvement of aquaculture professionals in the MPA varies, but broadly speaking is greater than that of fishers. A few show strong engagement, regularly encouraging others to be more vocal and more involved as MPA management is linked to quota decisions, regulating of other activities, etc.
	FUTURE	<p>Stronger governance and regulations</p> <ul style="list-style-type: none"> A contract between the DRM and Reao's municipality regarding the DRM's capacity to delegate certain key responsibilities could constitute major progress in support of effective enforcement, traceability of operations, and ultimately the sustainability of both fishing and mariculture activities. With the local governance tools in place (cf Box link), restocking activities from spat collection could be a catalyst to unify all stakeholders. The extension of MPA regulations to all reef resources, integrating the same governance process (Fishery/Aquaculture), could contribute to greater resilience of the entire social-ecological system. <p>A new tool</p> <ul style="list-style-type: none"> The establishment of a Marine Education Area (designation specific to French Polynesia) involving scholars with expertise on MPAs, including monitoring of the giant clam resources, their role within the ecosystem, and ecosystem carbon budget, represents a unique opportunity to learn about and from this marine resource, its social-ecological system, and its governance framework. It also draws attention to this Reao case study. <p>Stronger and broader responsibility for the aquaculture sector</p> <ul style="list-style-type: none"> The aquaculture professionals are in a position to continue contributing to the acquisition of crucial data and support the co-development and co-production of approaches and practices that support adaptive capacity and resilience.

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Graphs regarding the wild giant clam density and size structures at Reao were generated using the software SPOTIL (DRM-IRD-IFREMER).

Warning: This document was edited for scientific purposes, as part of a collection of case studies providing useful background information about various sites in the world where Marine Protected Areas are established together with marine aquaculture production. Each case study is subject to be updated on a regular basis, according to new developments occurring in the region concerned. This document has no legal status.



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