

An assessment of commercial sea cucumber populations in French Polynesia just after the 2012 moratorium

Serge Andréfouët,^{1,*} Amélie Tagliaferro,¹ Laureline Chabran-Poete,¹ Joseph Campanozzi-Tarahu,² Fabien Tertre,² Gabriel Haumani² and Arsène Stein²

Abstract

Sea cucumbers were virtually unfished in French Polynesia until 2008, when their exports sky rocketed several years later, leading to the immediate closure of the fisheries in November 2012. A survey of commercial sea cucumber abundance took place around that period in 23 islands and atolls in three archipelagos (Society, Tuamotu and Gambier), which allowed the inference of the status of sea cucumbers on a wide scale. The Society Islands were severely impacted, with many sites depleted of the resource, especially high inhabited islands with lagoons. Conversely, the Gambier Archipelago and, in particular, Mangareva Island had a healthy population, characterised by a lack of dominant species and the highest species richness, with records from Mangareva only. The situation was mixed in the Tuamotu Islands. Abundances in lagoons and fore reefs were dominated by *Bohadschia* sp. and *Thelonota ananas*, respectively. The 2012–2013 moratorium was followed by a transition period where sea cucumber fishing could be performed at selected locations on certain Tuamotu atolls, but included a number of new management measures that included the monitoring of exports from the different islands. Considering the 2012–2013 survey results and the 2014–2017 fishery statistics, we discuss here several recommendations specific to the different archipelagos and islands, in the view of new management decisions.

Keywords: Gambier, Tuamotu, Society, moratorium, fishery management, sea cucumbers

Introduction and objectives

In French Polynesia, research efforts on sea cucumbers (locally called *rori*) are few. Historically, species have been recorded in several places in the course of various ecological or taxonomic surveys (e.g. Adjeroud et al. 2000). More recently, the Moorea Biocode Project³ provided the most complete inventory for one single French Polynesian island. From a commercial sea cucumber population perspective, Moorea's populations were studied in 2011 (Preuvost 2011) and the Secretariat of the Pacific Community's PROCFish project⁴ described the commercial populations of four fishing grounds in three high islands (Moorea and Tahiti in the Society Islands, and Raivavae in Austral Islands), and two atolls in the Tuamotu Islands (Fakarava, Tikehau). The PROCFish surveys occurred in 2003–2006 (Kronen et al. 2009).

It was found that the high-value species, *Holothuria fuscogilva*, would need additional specific surveys in all sites to make a conclusion regarding its population status. The high-value species, *H. whitmaei*, was generally rare or absent from most sites, and at all depths. *Thelonota ananas* could be found at all sites and in varying densities, from low to medium at Moorea and Tahiti, and to high at Fakarava. The mid-value species, *Stichopus chloronotus*, was never found in any of these surveys, suggesting it is absent from French Polynesia. The low-value leopardfish, *Bohadschia* sp., was very common at Fakarava, Tahiti and Moorea, but less so in Tikehau and Raivavae. The PROCFish surveys generally diagnosed a low potential for a commercial sea cucumber fishery in French Polynesia. When exploitation could be recommended, it was for *Actinopyga mauritiana*, which was abundant in some places, especially at Raivavae.

¹ UMR9220 ENTROPIE, IRD, Université de la Réunion, CNRS, B.P.A5, 98848 Nouméa, New Caledonia

² Direction des Ressources Marines et Minières de Polynésie française, BP 20, 98713, Papeete, Tahiti

* Corresponding author: Serge Andréfouët, serge.andrefouet@ird.fr

³ The Moorea Biocode Project aims to create the first comprehensive inventory of all non-microbial life in a complex tropical ecosystem. See: <https://mooreabiocode.org/> <https://mooreabiocode.org/>

⁴ The Pacific Regional Oceanic and Coastal Fisheries (PROCFish) project was initiated in March 2002. The coastal component of PROCFish was designed to enhance management of reef fisheries in the Pacific Islands by providing Pacific Island governments and communities with accurate, unbiased scientific information about the status and prospects of reef fisheries. See: <https://coast-fish.spc.int/en/projects/procfish>

French Polynesia has never been a significant source of beche-de-mer for the Asian market until 2008, when fishing, processing and exports of sea cucumbers became quickly organised due to the initiatives of some private investors. Because of French Polynesia's lack of regulations, and the easy access to an abundant, unfished resource, exports (frozen and dried) sky-rocketed from zero in 2007 to 126 tonnes (t) in 2011 and 2012 (Fig. 1). Considering the serious risks of a quick population collapse in many islands, and the lack of control on fisher numbers and activities, the Direction des Ressources Marines et Minières (DRMM) and the French Polynesian government established a complete moratorium on sea cucumber fishing throughout French Polynesia in November 2012, which immediately stopped new harvests, although sea cucumbers already collected could still be sold in 2013 (representing 6.8 t, Fig. 1).

In September 2012, the Living Ocean Foundation (LOF)⁵ planned three cruises in the Society (September–October), Tuamotu (November–December) and Gambier (January 2013) archipelagos on board the R/V *Golden Shadow*, a large vessel that could accommodate up to 24 divers and investigators. These cruises offered the possibility of surveying sea cucumber populations just before and after the moratorium for a vast number of islands and locations, some of which would have been difficult to access otherwise. The French Institute of Research for Development (IRD), DRMM and LOF agreed to have an onboard team dedicated to sea cucumber surveys. This team also surveyed giant clams and green snails on the same cruises, and these results are described elsewhere (Andréfouët et al. 2014a, b).

The sea cucumber census results presented hereafter were discussed with DRMM immediately after the cruises in March 2013. The trend was clear, showing a poor situation in the Society Islands, and a less dramatic one elsewhere in the Tuamotus and Gambiers. The government decided to re-open the fishery in 2014 at several Tuamotuan atolls but instated catch limits (in numbers of individuals, quotas, and periods) for all targeted species. Catches also had to be hand collected only, and in accordance with size limits per species. However, the 2012 findings were not used to guide further actions to improve knowledge about stocks and establish precise quotas for selected places, and no biological data were collected after 2012. Between 2014 and 2017, the same management measures continued, leading to exports that ranged from 3.9 t in 2014 (dried only) up to 7.6 t in 2016. However, the numbers of lagoons open to fishing increased, as

new lagoons can be opened if a local management committee is organised (9 atolls in 2014 and 2015, 13 in 2016 plus Tahaa Island in the Society Islands, and 17 in 2017). Unlike the pre-2012 period, DRMM collected detailed information on the number of fishers per island and on the number of exports per species (weight and individual counts) from each island in 2014–2017. These data helped put into perspective the pre-2012 period of fishing; for example, showing that some atolls were heavily fished for *H. fuscogilva* (Fakarava, Toau, Apataki) while other islands were targeted for *Bohadschia* spp. (Rarua, Kaukura), or *A. mauritiana* (Faaité, Makemo). At this stage it is impossible to know if this reflects the pre-2012 period, or if fishing has evolved to target lower-value species after *H. fuscogilva* or *H. whitmaei* became depleted. It is already possible, however, to see that between 2014 and 2017, there has been a decrease in the total catch of *H. fuscogilva* from Kaukura or Apataki. In 2017, the decreasing catch rate per registered fisher in several atolls may suggest that sea cucumber populations have now been impacted by the previous fishing years (Fig. 1).

In anticipation of DRMM's future surveys in places where sea cucumber fishing has become a significant source of income, and where the sustainability is at risk, we revisit here the data collected in 2012–2013 for all archipelagos and sites in order to establish a baseline and offer some recommendations.

Methods

Between September 2012 and January 2013, the three Global Reef Expedition French Polynesia cruises of LOF on board the R/V *Golden Shadow* visited 23 islands in three archipelagos: Society, Tuamotu and Gambier, including a number of rarely visited locations such as the small, mainly uninhabited remote atolls of the Acteon group or Temoe in the Gambiers. Surveys for sea cucumbers took place in 22 of these islands (Fig. 2).

Most of the stations were selected by the LOF scientific cruise director, who prioritised coral and fish surveys; hence, many stations were located on oceanic fore reefs. However, we completed lagoonal and reef flat surveys as a separate team when possible, especially for Raiatea, Fakarava, Hao and Mangareva, which were identified prior to the cruises as high priority islands for data collection by various French Polynesian institutions. Visits to these sites lasted between six and nine days, while most other islands were visited for only one (or three dive sites) to four days at most.

⁵ The Khaled bin Sultan Living Oceans Foundation is a non-profit environmental science organisation and ocean research foundation established to help preserve, protect and restore the world's oceans and aquatic resources through research, education, and outreach. See: <https://www.livingoceansfoundation.org/about/>

We focused on commercial species that are present in French Polynesia: *Holothuria fuscogilva*, *H. whitmaei*, *Thelenota ananas*, *T. anax*, *Actinopyga mauritiana*, *Stichopus chloronotus* and *Bohadschia* spp. The *Bohadschia* group included *B. argus* and green to brown specimens identified thus far as *B. vitiensis* (in Kronen et al. 2009, and G. Paulay, Curator, Florida Museum of Natural History pers. comm.), although this identification has not been confirmed genetically. Also included in this group was a *Bohadschia* specimen from Mangareva that could not be identified to species level. *Holothuria atra*, which was not fished in French Polynesia, was recorded on fore reefs or as isolated specimens on lagoons and reef flats, but these counts are not reported here. We also did not census *H. atra* when they aggregated as small individuals in the shallowest part of lagoons, sometimes reaching tens of individuals per square meter. The low number of commercial species in French Polynesia is explained by the country's position in the central Pacific, far from the center of biodiversity in Asia and the western Pacific. Several other species were also recorded, but proved to be extremely rare: *Thelenota rubrolineata* and *Holothuria edulis*.

When diving, the census was done between 30 m and the shallowest part of the visited location (i.e. generally from the deep sand plain or deep coral slopes up to the shallow spur-and-groove zone of the reef). All observed sea cucumber

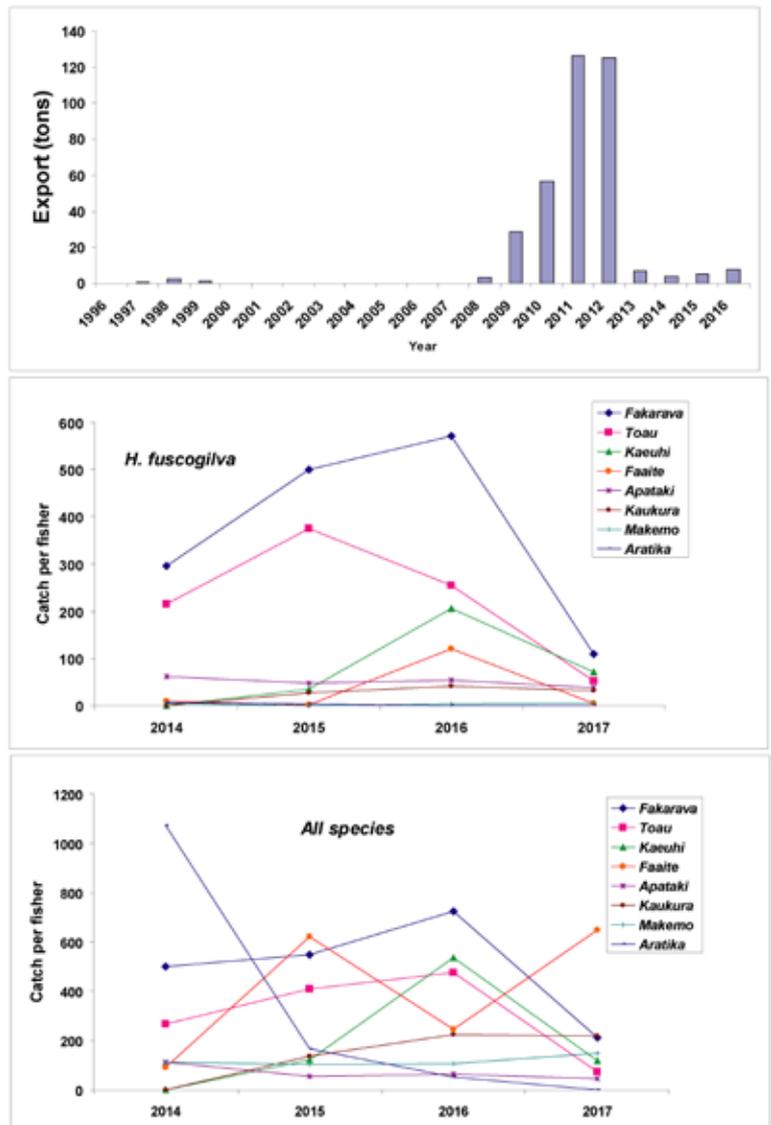


Figure 1. Statistics from Direction des Ressources Marines et Minières de Polynésie française (DRMM 2014, 2015, 2016, 2017). Top: total exports (dried specimens). Middle and bottom: for atolls with at least three years of data between 2014 and 2017, the number of catches per fisher, for *Holothuria fuscogilva* (middle) and all species (bottom).

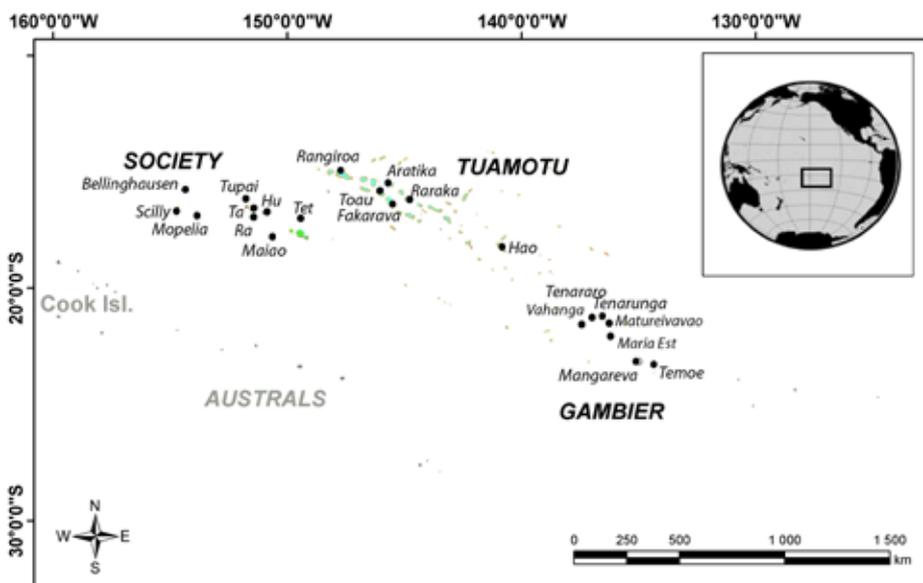


Figure 2. Study site. Ta = Tahaa, Ra = Raiatea; Tet = Tetiaroa; Hu = Huahine.

individuals were counted and photographed during a one-hour dive that was staged by depth (5 min. at 30 m, 20 m, 10 m, 5 m, 2–0 m). In the shallows (5–0 m), the exact depth was dependent on wave conditions, but if possible, we conducted surveys into the shallowest spurs and grooves to the crest to look, in particular, for specimens of *A. mauritiana*. Several 5-min. search times could be performed per depth range, especially in the shallows. The swimming speed was constant and slow, and we intentionally avoided strong currents that would significantly bias the surveys. Considering the generally very good visibility and position above the reef of the swimming surveyor (~3 m above the bottom), we estimated that each search time covered about 250 m² per minute (Andréfouët et al. 2014b), except in spur and groove areas where the surfaces covered were much smaller and less consistent.

Hereafter, densities per species are thus provided per minute of search time considering the entire dive (60 min), but a correspondence with densities per surface area is reasonably possible due to this constant speed. All searches were conducted

during daytime. The data collected (i.e. richness and species density) could be reported per depth range, per habitat (fore reef *vs* lagoon), per island, and per archipelago. Lagoonal habitats were not separated according to substrate type as search time was spent in both patches of soft and hard bottom areas. However, some species could be preferentially found on patches of soft substrate, rubble or hard bottom.

The exact fishing pressure in the islands between 2008 and 2012 is unknown (Table 1). During that time, DRMM had information only at the export level from Tahiti (i.e. global weight, and the difference between dry and frozen weights), and no information from individual islands or atolls. However, it was known that the area from the southeastern Tuamotus (from Hao) down to the southeastern Gambiers (Mangareva and Temoe) was unfished, or fished very little, as well as Aratika Atoll in the central Tuamotus, due to the mayor's decision to prohibit this exploitation. Lagoons closed to fishing at uninhabited islands or atolls, or without easy access from the outside (e.g. Tupai or Tetiaroa) were considered to be unfished, although

Table 1. Summary of information by island.

| Island/group | Abbreviation | Fished in 2014–2017 | Fished in 2012 | Lagoon sites | Ocean sites |
|----------------|--------------|---------------------|----------------|--------------|-------------|
| Gambier | | | | | |
| Mangareva | MG | n | n | 20 | 11 |
| Maria Est | M-E | n | n | 1 | 3 |
| Matureivavao | MV | n | n | 0 | 3 |
| Temoe | TE | n | n | 1 | 4 |
| Tenararo | TR | n | n | 0 | 3 |
| Tenarunga | GT | n | n | 0 | 3 |
| Vahanga | VA | n | n | 0 | 3 |
| Society | | | | | |
| Huahine | HU | n | y | 12 | 0 |
| Maiao | MA | n | ? | 0 | 2 |
| Raiatea | RA | n | y | 23 | 13 |
| Tahaa | TA | 2016–2017 | y | 0 | 4 |
| Tetiaroa | TEt | n | y | 0 | 3 |
| Tupai | TU | n | y | 3 | 1 |
| Scilly | SC | n | n | 0 | 1 |
| Mopelia | MO | n | n | 0 | 3 |
| Bellinghausen | BE | n | n | 0 | 3 |
| Tuamotu | | | | | |
| Aratika | AR | 2014–2017 | n | 2 | 5 |
| Fakarava | FA | 2014–2017 | y | 13 | 8 |
| Hao | Hao | n | n | 9 | 8 |
| Rangiroa | RG | n | y | 10 | 4 |
| Raraka | RK | 2016–2017 | y | 4 | 5 |
| Toau | TO | 2014–2017 | y | 8 | 0 |

their fore reefs could be fished. For all other locations, it can be assumed that fishing could occur, with heavier pressure in the Society Islands than in the Tuamotus due to a larger human population equipped with numerous fishing vessels and closer proximity to processing sites. There are several no-take areas in the Tuamotus, but none in the surveyed Society Islands. This is the case of the atolls of the UNESCO Man and the Biosphere (MAB) Fakareva reserve. The atolls of Fakarava, Raraka, Aratika and Toau are MAB atolls. However, possible occurrences of poaching cannot be discarded in these protected areas.

Results and discussion

Results per archipelago

In total, 68 sites were surveyed in the Society Islands (Mopelia, Scilly, Bellinghausen, Tupai, Huahine, Raiatea, Tahaa, Maiao and Tetiaroa), in which 286 commercial sea cucumbers were inventoried. Twenty-two stations (32% of the sites) had no records of commercial species. The dominant species was *B. argus*, but in low densities, and seen at 48% of the sites. *Holothuria fuscogilva* (the most valuable species) and *T. anax* were found mostly on exposed eastward facing fore reefs and in the deeper sand plains in depths of at least 30 m. *Holothuria whitmaei* was seen only once. *Thelenota ananas* was also present on fore reefs, at all depth ranges, and at most atolls and islands, but in low numbers. Tetiaroa had the highest count per dive for this species (average = 9.3). *Actinopyga mauritiana* juveniles were very abundant on algal crests, which characterise high island barrier reefs such as those of Raiatea, but they were rarely seen as adults.

In the Tuamotus, 77 sites were surveyed at Rangiroa, Aratika, Raraka, Fakarava, Toau and Hao, and 923 commercial sea cucumbers were inventoried. Twenty-two stations had no records of commercial species, but 13 of these stations were among the 17 Hao stations, and in particular among the lagoon stations. The absence of records for the lagoon was a peculiar feature for all Tuamotu atolls. Only two species were recorded in Hao (*T. ananas* and *B. argus*). The atoll's lagoon was completely depleted of sea cucumber communities as all records were from the fore reefs or the pass. Without Hao, the Tuamotu atolls had only 15% of sites without records, thus less than half that of the Society Islands. The dominant taxon overall was the genus *Bohadschia*. It was dominant in most lagoons, and generally – but not always – found in high densities around pinnacles. This genus was seen in 65% of the stations. *Holothuria fuscogilva*, *H. whitmaei* and *T. anax* were found mostly in lagoons, but never in high densities. The only exception was high numbers of *T. anax* in some

locations, particularly in the central part of Raraka lagoon, which was never fished according to our guides (themselves ex-fishers).

In total, 52 sites were surveyed in the Gambiers (Tenararo, Tenarunga, Vahanga, Matureivavao, Maria Est, Temoe and Mangareva), and 286 commercial sea cucumbers were inventoried. This is the exact same number recorded from the Society Islands, but from a fewer number of sites. The Gambiers were a relative 'hot-spot' of diversity, including several species only seen in the Acteon atolls (*T. rubrolineata*, *H. edulis*) and Mangareva (*S. chloronotus*). *Stichopus chloronotus* was abundant in Mangareva's lagoon, while it was never seen elsewhere in the other 21 surveyed islands or in any of the PROCFish surveys (Kronen et al. 2009). *Holothuria whitmaei* was also much more abundant in Mangareva than anywhere else in French Polynesia, and in shallow water (39 sightings, present in 30% of the sites). On the other hand, *H. fuscogilva* was only seen once at Temoe Atoll. Unlike the other archipelagos, there is no dominance of species or genus in the Gambiers, particularly for *Bohadschia*. In the Gambiers, 34% of the sites (18 sites, including 13 on the fore reefs) are without records, but this is because *H. atra* was not included and this was the only species (as large individuals) seen on several Gambier island fore reefs.

Overall, in all archipelagos, the majority of sites without any records were oceanic fore reefs. In both the Society and Gambier islands, 27% of the sites without records were lagoonal, while in Society Islands alone, the proportion rose to 52%.

Results per island

The average densities by species are reported for each surveyed island and per habitat Figures 3 and 4.

We also compared the average of counts (all species) per surveyed site, for both oceanic and lagoonal stations (Fig. 5). For oceanic sites and in the Gambiers, this average varies significantly between the small Acteon atolls, and the larger islands of Mangareva and Temoe. The low number of sea cucumbers found on the Acteon fore reef is attributed to very high coral cover, compared with the other sites where deep sand plains and more suitable habitats are present. The average count found for lagoonal sites in the Tuamotus are as much as three times greater than for fore reef sites (except for Hao). However, this dominance is not the case for the Society and Gambier islands where the situation is more balanced. Tuamotu lagoon ratios are especially high for Fakarava and Toau, which have been the most heavily fished atolls since 2014 (Fig. 1).

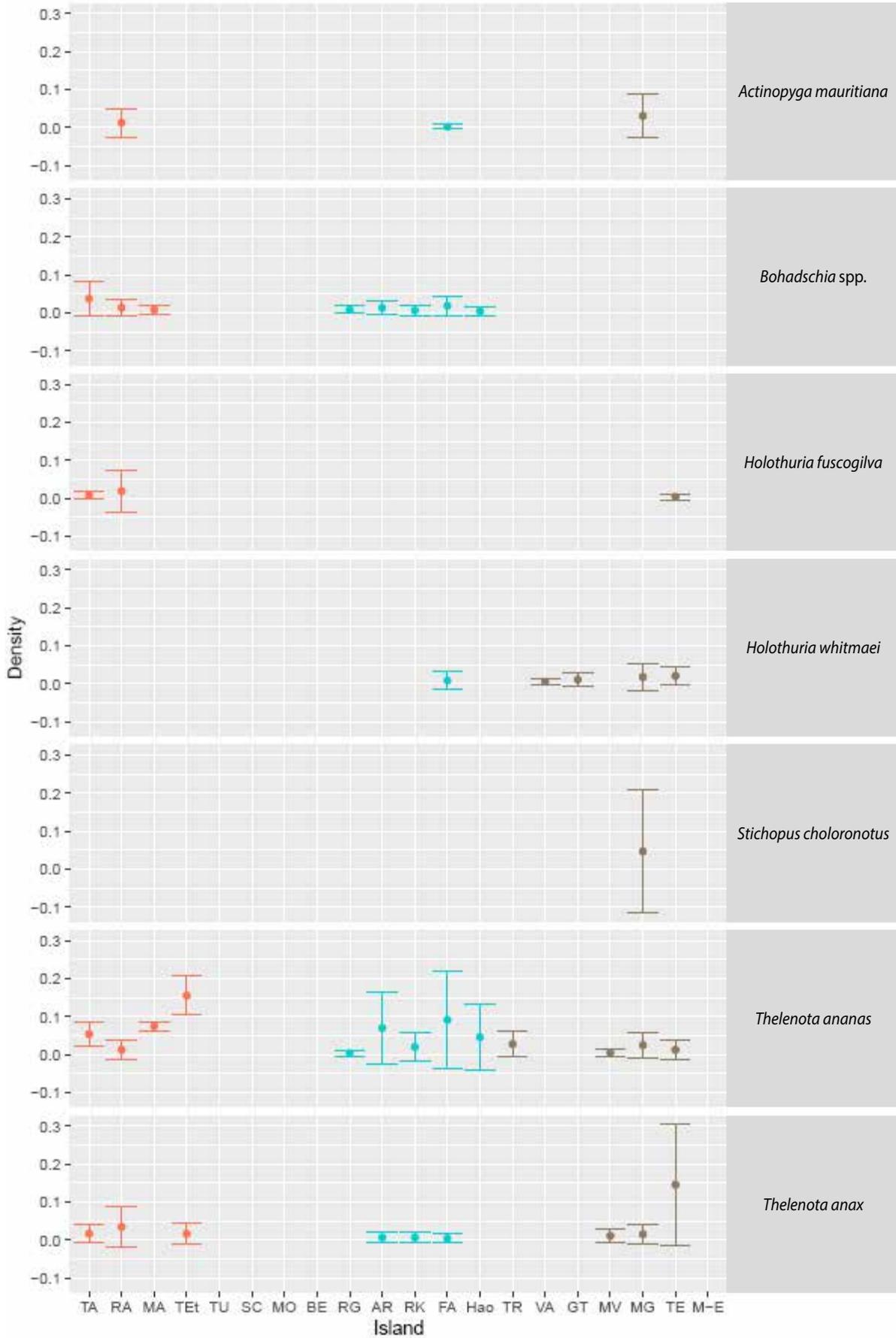


Figure 3. Density (in number of individuals per minute) per island, per species, and for ocean fore reef stations. Island name abbreviations are in Table 1.

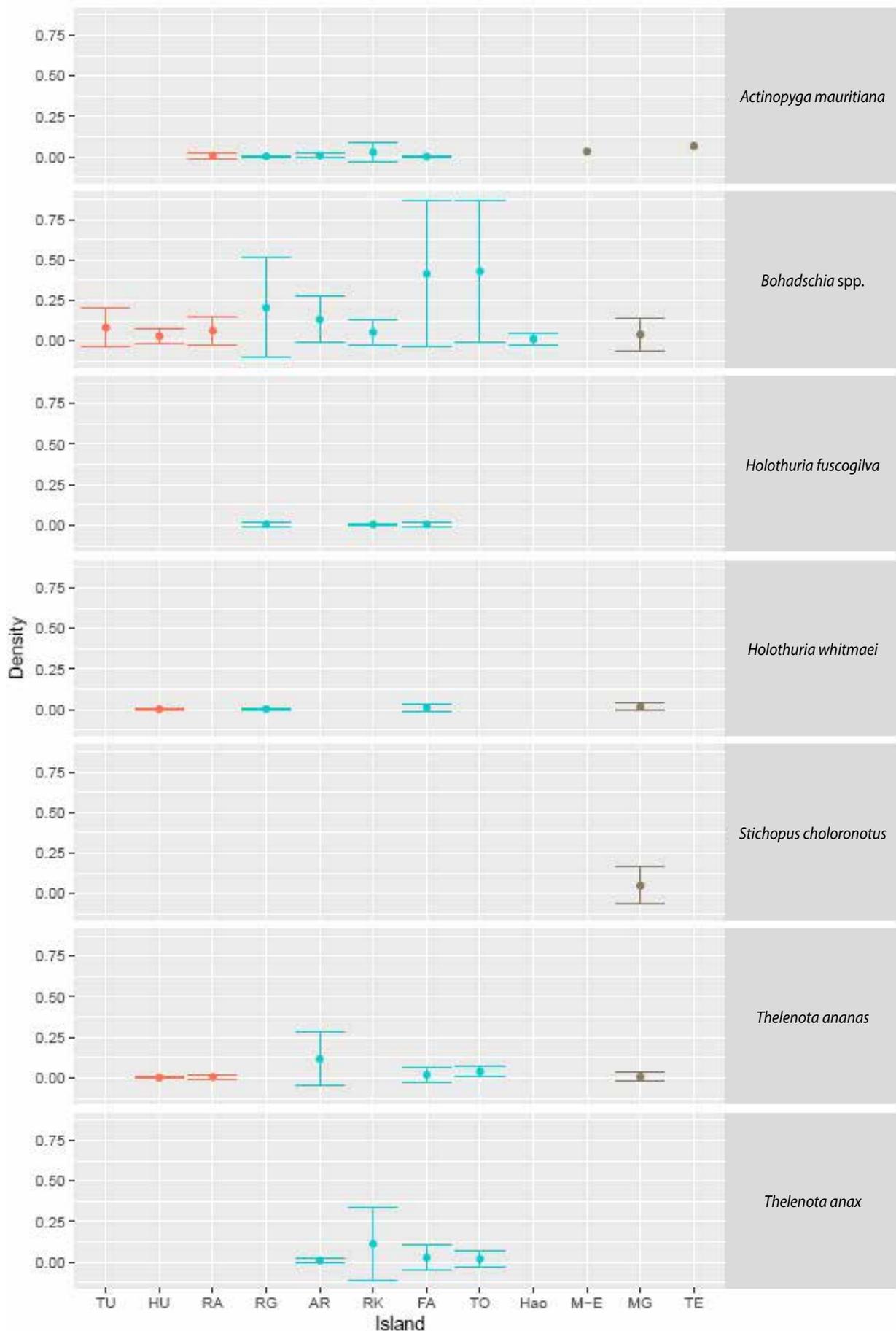


Figure 4. Density (in number of individuals per minute) per island, per species, and for lagoonal stations. Island name abbreviations are in Table 1.

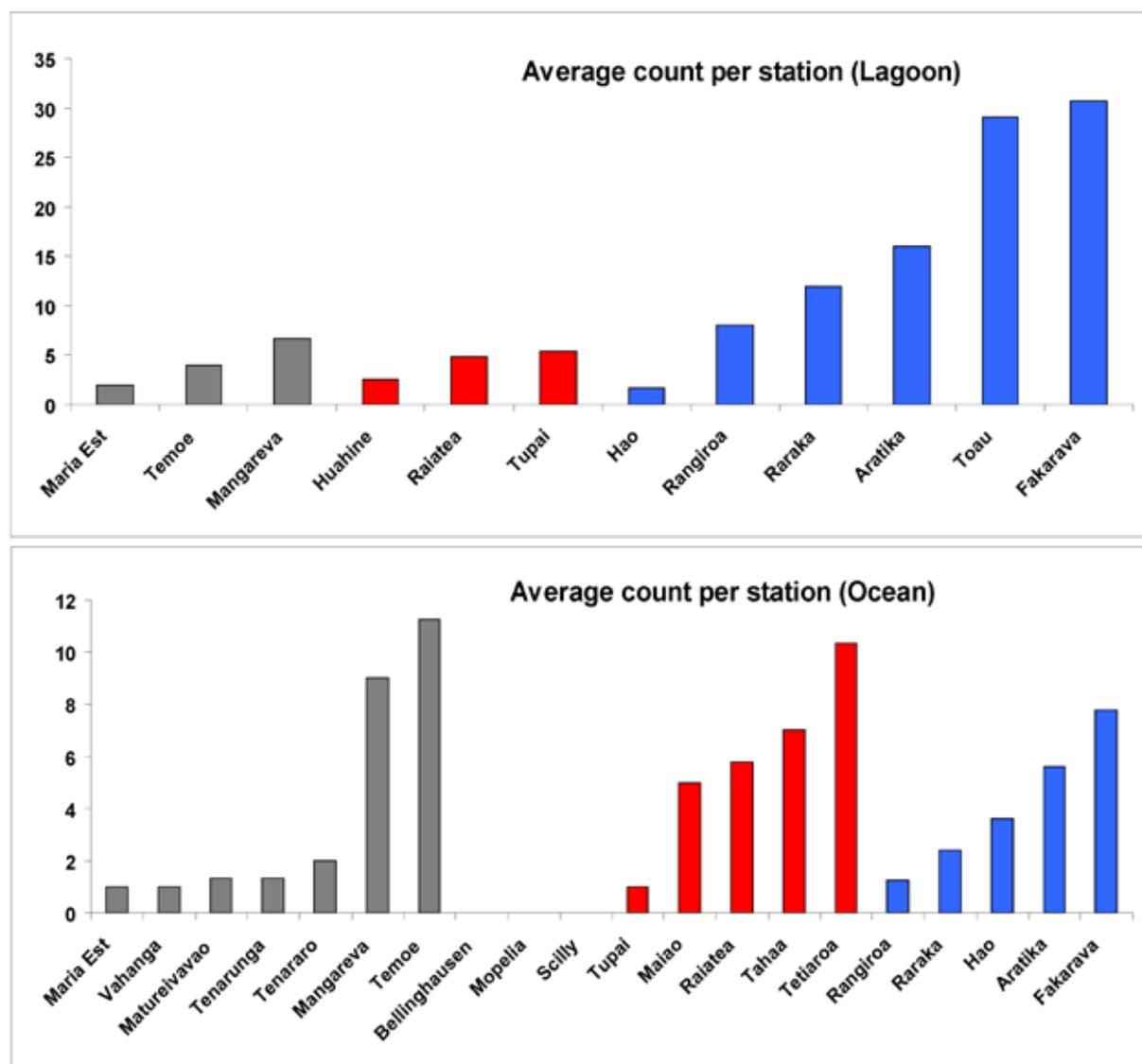


Figure 5. Histograms representing the average count (or ratio between the total counts and the number of stations) per station for each island, for lagoonal and oceanic stations. If no census took place at lagoonal or oceanic sites, the island is not shown. Zero values report a lack of sightings. Grey = Gambiers, red = Societies, blue = Tuamotus.

An archipelago-scale gradient of fishing impact

The total number of records per dive and the density of sea cucumbers per search time were lowest in the Society Islands. Also, 32% of the sites were completely depleted, and the highest proportion of sites without records was lagoonal sites. There was also an almost complete absence of valuable species in shallow areas. *Bohadschia* spp. densities were low, especially compared with the Tuamotus. These observations confirm that the islands have been impacted by the 2008–2012 period of open fishing. Within the most studied islands in the Societies, Raiatea exhibited patterns that confirmed the assumption that fishing activities had reduced sea cucumber densities in the Society island. Valuable specimens could be found, but only at depth (~30 m), which is unreachable by most free divers who opportunistically began fishing for sea cucumbers

in 2008. Densities were also higher on the exposed fore reefs, which are more difficult to exploit due to their exposure to swells generated by the easterly trade winds (Fig. 6).

It is worth noting the case of Scilly, Mopelia and Bellinghausen, the three westernmost Society atolls. The seven stations on these atolls, all oceanic, show no records at all, although other teams have seen a couple of *T. ananas* when doing their own survey (e.g., IRD's Research Fellow Sylvain Petek sponge survey), and we saw a few *B. argus* and *H. atra* in the lagoons when collecting other samples. The paucity of echinoderms at these atolls may be general and unrelated to fishing in this western part of the archipelago, as previous expeditions in Scilly have also reported a lack of echinoderms (Salvat 1983).

In the Tuamotus, the pattern varied among atolls. Hao lagoon densities were surprisingly very low

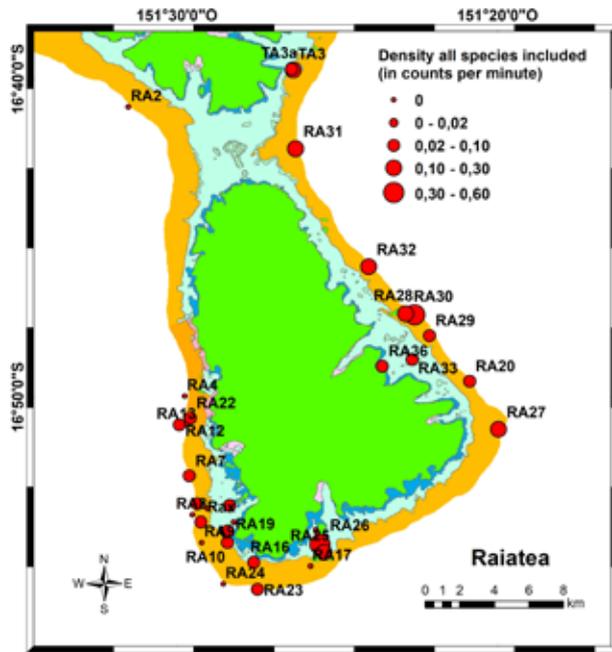


Figure 6. Survey stations at Raiatea, with densities of commercial species.

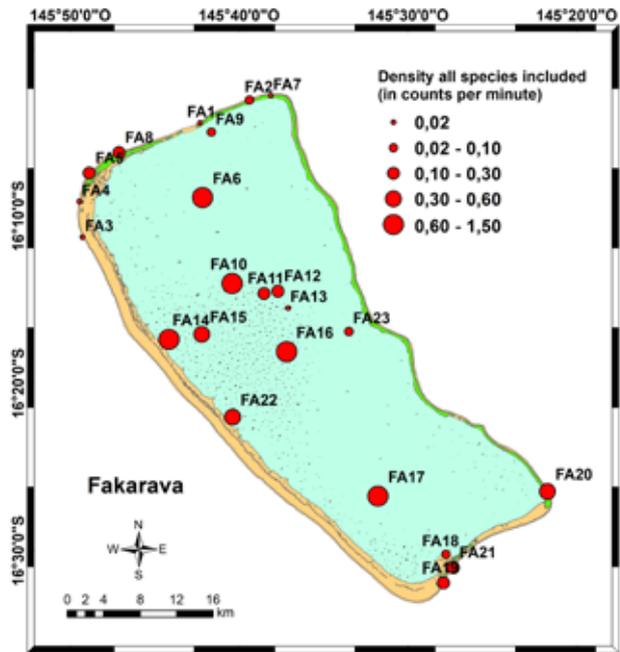


Figure 7. Fakarava survey stations, with densities of commercial species. Villages are near FA27 and FA19.

(Figs. 3, 4 and 5). Local inhabitants confirmed that sea cucumbers vanished almost entirely from the lagoon but this occurred two decades ago, and the reason why is unclear. A large specimen of *B. argus* could still be found near the Hao pass in very shallow water (0–5 m), confirming that significant fishing had not taken place there recently. *Thelenota ananas* was the most dominant species on the fore reefs of all atolls. Aratika, which was never fished, had high densities of *T. ananas* even at sites close to the pass and village, and in shallow water (5 m). Although this would need further investigation, a distance-to-village effect seems to be confirmed when looking at the densities of all species at Fakarava (Fig. 7).

The case of *T. fuscogilva* in Tuamotu is interesting, as DRMM data show contrasting catch levels between atolls, even between large ones. For instance, very few were harvested from Makemo (10 individuals in 2017, DRMM 2018), while several thousands of individuals came from Fakarava and Toau per year since 2014, and probably much more before 2012 (Fig. 1). The differences between Makemo and Fakarava atolls, both of similar sized atolls, can likely be explained not by environmental features or habitat quality, but rather by fishers' habits. In Makemo, the primary catch is *A. mauritiana*, suggesting that gleaning in shallow outer reef flats is the dominant mode of fishing there, whereas in Fakarava, fishers free-dive deep in the pass area and lagoon in search of the most valuable species, *H. fuscogilva*. Both our data and the PROCFish data do not suggest a particularly high potential for *H. fuscogilva* at Fakarava (or elsewhere), but aggregations have likely been missed in the surveys.

We found a healthy population of sea cucumbers in the Gambiers, especially in Mangareva's lagoon where the species richness was high, including the presence of the only *S. chloronotus* population we observed during the three cruises. Despite an overall low density and number of records, these observations confirmed the lack of significant fishing because the high-value *H. whitmaei* was fairly abundant in shallow reefs even those close to the main village. All other commercially important species (*T. ananas*, *T. anax*, *A. varians*) were present. Based on the data collected, the Gambier and Society islands have several common characteristics, but the abundance of *H. whitmaei*, and the absence of fishing, suggests that the sea cucumber population at Mangareva is not impacted. Temoe is also likely to be non-impacted considering the records.

Consequences for management

Even if the sampling could not be perfectly replicated the same way within the various islands during the LOF expeditions, the global image drawn by the results and by DRMM fishing statistics led us to recommend, in 2013, that both the Society and the Gambier islands should be declared as no take-areas and remain closed to fishing, although for different reasons. In the Society Islands, this is to allow the population to recover from four years of unregulated and intense exploitation, and in the Gambiers it is to leave intact an untouched population that possibly may include several cryptic species. Hence, a programme focused on the biodiversity of sea cucumbers could be a priority at Mangareva (or the Gambiers as a whole). In contrast,

Tuamotu's atolls showed similar species richness between islands, but with evidence of different levels of harvest; none of the atolls were depleted. So, we confirmed that the Tuamotu's could have controlled exploitation. These recommendations from 2013 still remain valid. Four years was likely not enough to rebuild the Society Islands' populations, but revisiting some sites in the near future could determine whether there was recovery, or not.

Mangareva appeared as the hot-spot for sea cucumbers French Polynesia, and a dedicated survey coupled with a population genetics study will certainly bring interesting results. Beyond Mangareva, this statement can be extended to the Gambier region, with the only observations of *T. rubrolineata* in this region. This species is also absent from the Moorea Island Biocode records. Although one specimen was genetically identified as *T. rubrolineata* using bar-coding markers (G. Paulay, pers. comm.), some apparent morphological and color variations could warrant further investigations on the isolation of these populations. Furthermore, it has been recently confirmed with genetic tools that a *Bohadschia* individual sampled during the LOF expedition is a new endemic species (G. Paulay pers. comm., and unpublished data).

The next critical step from a fishery perspective is to ensure that exploitation in the Tuamotus remains sustainable. In addition to the continued monitoring of catches, exports and fisher licenses, periodic surveys of populations seem necessary to establish more soundly what could be the total allowable catch per species and per island open to fishing. This would need to be linked with a socioeconomic survey to understand fisher habits. A co-management framework with the participation of fishers was successfully established in New Caledonia for the exploitation of *H. scabra* in the shallow seagrass beds of the Plateau des Massacres near the Boyen tribe in the North Province (Léopold et al. 2013). Every year, a survey provides information on the state of the population and a quota is dynamically established for a given temporary period of fishing by local authorities. The quota is also distributed among the fishers, who endorsed and respected the process, which has demonstrated its efficiency both ecologically for *H. scabra* populations and economically for the fishers. A similar procedure would make sense in the Tuamotus, especially because each island that is open to fishing has a local committee monitoring quotas and the way they are distributed among fishers. However, the challenges of conducting multi-species surveys every year for (thus far) 17 atolls and islands would likely be quite significant. Instead, a rotational procedure may be more feasible, with a subset of four atolls investigated every year, and a definition of quotas valid for four years for instance, with a particular focus

on the large atolls that are more heavily fished such as Fakarava, Toau or Apataki. The present state of knowledge and data, as summarised here, is clearly insufficient to establish precisely quotas for a sustainable fishery at each island and new initiatives for data collection are therefore recommended.

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References

- Adjeroud M., Andréfouët S., Payri C. and Orrem-puller J. 2000. Physical factors of differentiation in macrobenthic communities between atoll lagoons in the Central Tuamotu Archipelago (French Polynesia). *Marine Ecology Progress Series* 196:39–48.
- Andréfouët S., Bruckner A., Chabran L., Campanozzi-Tarahu J. and Dempsey A. 2014a. Spread of the green snail *Turbo marmoratus* in French Polynesia 45 years after its introduction and implications for fishery management. *Ocean and Coastal Management* 96:42–50.
- Andréfouët S., Van Wynsberge S., Fauvelot C., Bruckner A.W. and Remoissenet G. 2014b. Significance of new records of *Tridacna squamosa* Lamarck, 1819, in the Tuamotu and Gambier Archipelagos (French Polynesia). *Molluscan Research* 34:277–284.
- DRMM 2014. Bulletin statistique: synthèse des données de la pêche professionnelle de l'aquaculture et de la perliculture Edition 2014, Papeete. <http://www.ressources-marines.gov.pf/cdi/bulletin-statistique/> (accessed July 2018). 52 p.
- DRMM 2015. Bulletin statistique: synthèse des données de la pêche professionnelle de l'aquaculture et de la perliculture Edition 2015, Papeete. <http://www.ressources-marines.gov.pf/cdi/bulletin-statistique/> (accessed July 2018). 56 p.
- DRMM 2016. Bulletin statistique: synthèse des données de la pêche professionnelle de l'aquaculture et de la perliculture, Papeete, <http://www.ressources-marines.gov.pf/cdi/bulletin-statistique/> (accessed July 2018). 56 p.

- DRMM 2017. Bulletin statistique: synthèse des données de la pêche professionnelle de l'aquaculture et de la perliculture, Papeete. 59 p.
- Kronen M., Friedman K.J., Pinca S., Chapman L.B., Awira R., Pakoa K., Vigliola L., Boblin P. and Magron F. 2009. Polynésie française - Rapport de Pays: profils et résultats des enquêtes réalisées à Fakarava, Maatea, Mataiea, Raivavae, et Tikehau (septembre–octobre 2003, janvier–mars 2004, avril–juin 2006). Noumea, New Caledonia: Secretariat of the Pacific Community.
- Léopold N., Cornuet N., Andréfouët S., Moenteapo Z., Duvauchelle C., Raubani J., Ham J. and Dumas P. 2013. Co-managing small-scale sea cucumber fisheries in New Caledonia and Vanuatu using stock biomass estimates to set spatial catch quotas. *Environmental Conservation* 40:367–379.
- Preuvost M. 2011. Estimation des stocks d'holothuries commerciales dans le lagon de Moorea et recommandations de gestion associées. Master 2 Université de Perpignan, PGEM Moorea-CRIOBE. 31 p.
- Salvat B. 1983. La faune benthique du lagon de l'atoll de Scilly, archipel de la Société. *Journal de la Société des Océanistes* 39:5–15.