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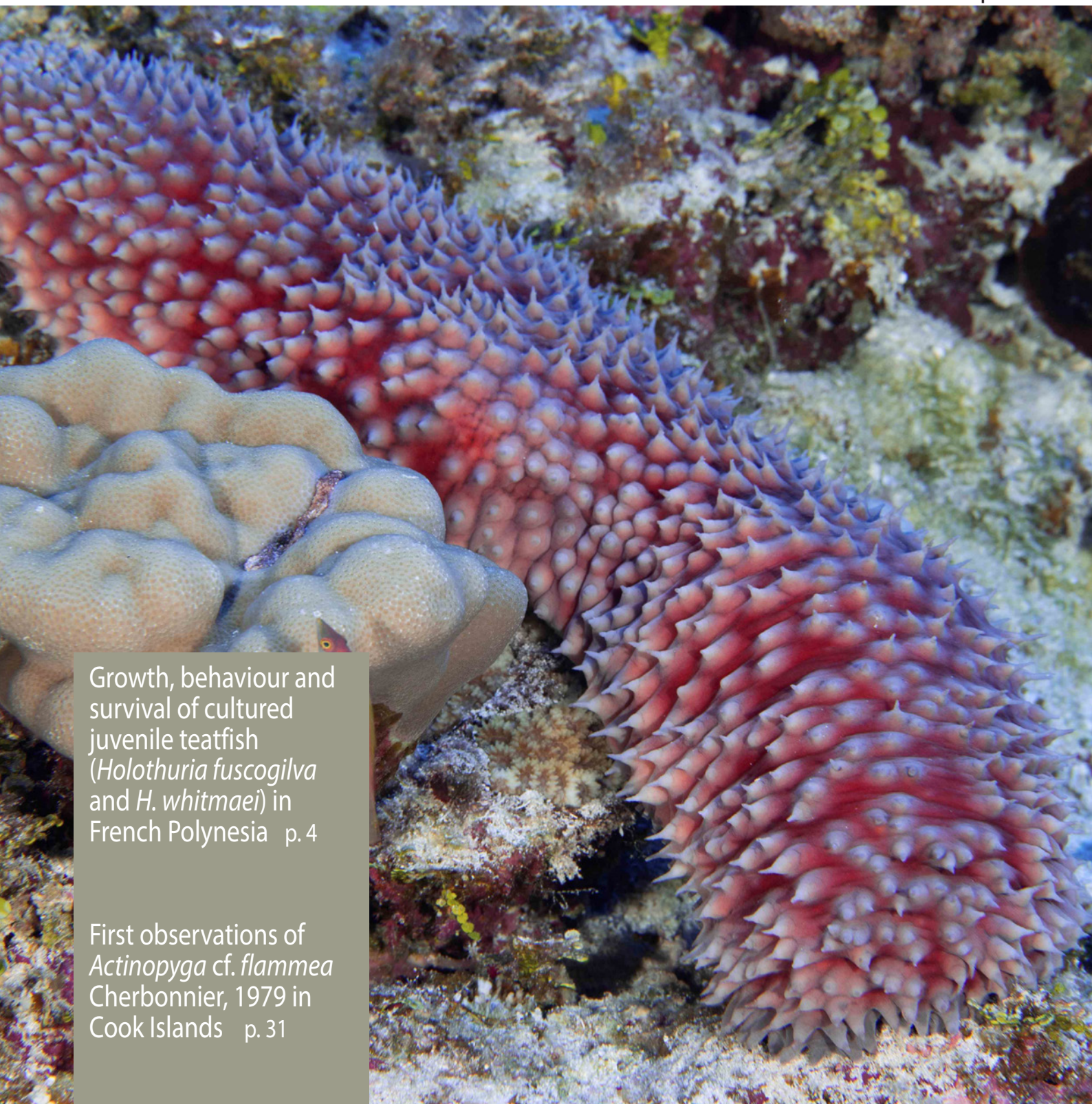

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COMMUNICATIONS

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Editorial

The 44th issue of the SPC *Beche-de-Mer Information Bulletin* includes nine original articles and scientific observations from around the world.

The first article by Burgy and Purcell (p. 4) presents the results of an aquaculture programme in French Polynesia on the white teatfish, *Holothuria fuscogilva,* and black teatfish, *H. whitmaei*. The programme aims at developing commercial-scale aquaculture for this promising sector whose products are intended for international markets, particularly in Asia.

The next article, presented by Scott and colleagues (p. 22), documents cases of skin ulceration diseases among individuals of a laboratory-held Canadian population of *Cucumaria frondosa* by comparing disease-associated symptoms with those previously described in the literature and exploring the potential co-incident causative factors.

Chammem (p. 27) provides an analysis of sea cucumber trading in Tunisia, emphasising the targeted species in the central Mediterranean Sea. Drawing insights from a diverse range of sources, it offers a detailed overview of the existing state of the sea cucumber trade in the region.

The two next articles concern *Actinopyga* species. Morejhon and Argyle (p. 31) provide the first observations of *Actinopyga* cf. *flammea* from Cook Islands, while Parrish (p. 34) makes points out a strange V-shaped sea cucumber morphology where a living adult *Actinopyga varians* in Cook Islands has a partial longitudinal split starting from the posterior end.

We then have the first report of *Holothuria spinifera* on the mid-west coast of Western Australia by Murphy and Hart (p. 35).

It is rare to have information from private companies practicing sea cucumber aquaculture. Eeckhaut (p. 39) "gives the floor" to sea cucumber aquaculture farmers and people employed by the company Indian Ocean Trepang to give some details on how sea cucumber farming works in Madagascar through the perspective of the private sector.

Also coming from Madagascar, Lavitra and colleagues (p. 48) explore local perceptions of the socioeconomic and environmental impacts of sea cucumber farming in the southwestern region during surveys of 298 households, of which 69 are actively engaged in sea cucumber farming.

Corbel and colleagues (p. 59) report of a study study that gave the first large-scale mapping (km scale) of the distribution of holothurian communities on reef flats of La Saline/L'Hermitage, Reunion Island. Fourteen different species of sea cucumbers were surveyed, three of which were dominant: *Holothuria leucospilota, Holothuria atra* and *Stichopus chloronotus*.

Finally, Cauvin (p. 65) shares some observations of the retail price of the sea cucumber *Apostichopus japonicus* at stalls in the two main fish sales markets in Tokyo, Japan.

Also included in this issue are various communications (p. 68), including those published on the web. Abstracts related sea cucumbers at the 11th European Conference on Echinoderms (Lyon, France) are reproduced on pages 68 to 73. Seven books concerning the biology, ecology or aquaculture of sea cucumbers have been published in recent months (p. 81). We mention the 17th International Echinoderm Conference that will take place in the Canary Islands as well as the opening in September of a new training position in Artisanal Mariculture Sciences and Village Farming. Congratulations to Joséphine Pierrat who presented her thesis at the University of Réunion.

Igor Eeckhaut

Cover picture: A specimen of *Actinopyga* cf. *flammea*, Photo: Kirby Morejohn

Growth, behaviour and survival of cultured juvenile teatfish (*Holothuria fuscogilva* and *H. whitmaei*) in French Polynesia

Laurent Burgy[1] and Steven W. Purcell[2]

Summary

Teatfish (subgenus *Microthele*) are a group of high-value sea cucumbers, with three of the species listed on CITES[3] Appendix II. Few studies have been made on juvenile teatfish, and their behaviour and rates of growth and natural mortality being critical knowledge gaps for aquaculture and fisheries. We present results of an aquaculture programme in French Polynesia on the white teatfish and black teatfish, *Holothuria fuscogilva* and *H. whitmaei*. The programme aims to develop commercial-scale aquaculture for this promising sector whose products are intended for international markets, particularly in Asia. From the hatchery, recently settled juveniles are grown to 1–3 g in bag nets in earthen ponds. They are then transferred to 500-m^2 sea pens in natural reef flat habitats. Survival of juvenile *H. fuscogilva* in the sea pens (>80%) has been encouraging, revealing relatively low rates of natural mortality (annually, $M = 0.31$ and 0.68 for pre-grow-out and $M = 0.15$ for grow-out) even at a juvenile stage. However, growth rates were slow, at 0.13–0.14 g/day/ind. White teatfish (*H. fuscogilva*) juveniles display camouflaging behaviour in the sea pens by attaching macroalgae and sand to their body, resulting in them resembling reef rocks. Black teatfish (*H. whitmaei*) broodstock spawned in winter and the juveniles were cultured using similar methods. They grew in sea pens at around 0.3 g/day – a rate eclipsing that of white teatfish. After three years of research and development, hatchery production increased tenfold and the grow-out phase offers promise for commercial-scale production. Although it took two years for white teatfish to reach average weights of 150 g, the aim of the programme is to improve growth rates at the different stages that would result in an economically viabile operation.

Keywords: aquaculture, Pacific, spawning, reproduction, *Holothuria fuscogilva, H. whitmaei*

Introduction

Sea cucumbers, called *rori* in French Polynesia, have been harvested in this territory for more than a century (Stein 2019). In French Polynesia, subsistence consumption of sea cucumbers occurs to a small extent (Kinch et al. 2008), while most of the exploitation is for export to Asian markets. At least 10 commercially important species are present in French Polynesian waters (Andréfouët et al. 2019), yet only five have been authorised for commercial fishing, which has been regulated since 2012 (Stein 2019). This artisanal yet lucrative activity can lead to overexploitation of natural stocks, which are fragile and subject to slow recruitment.

Teatfish are a group of at least four species of sea cucumbers that have lateral body projections, or "teats". They take a special place in Chinese cuisine, selling for USD100–400 per kg (Purcell et al. 2018), and are currently or previously harvested in at least 20 countries in the Indo-Pacific. The white and black teatfish, *Holothuria* (*Microthele*) *fuscogilva* and *H.* (*M.*) *whitmaei*, have been especially targeted by commercial artisanal fishers in French Polynesia (Stein 2019), where the back reef flats and atoll lagoons appear to be highly suitable habitats (Fig. 1). In the Polynesian language, the black teatfish is called *rori titi ʻere ʻere* while the white teatfish is *rori titi ʻuo ʻuo*. Fishing was closed in French Polynesia in 2018 over fears of overexploitation of teatfish and a few other species, although there is interest in potentially re-opening fisheries on some atolls. In recent surveys, densities of the black teatfish (*Holothuria whitmaei*) were found to be rare or absent from most sites (Andréfouët et al. 2019).

In 2019, both *Holothuria whitmaei* and *Holothuria fuscogiva* were included in Appendix II of CITES, at the request of the European Union, and endorsed by the United States of America, Seychelles, Kenya and Senegal (Di Simone et al. 2020). In this context, and in order to promote sustainable management of the resource, the Direction des Ressources Marines (DRM)[4] is undertaking initiatives on teatfish in French Polynesia. The initiatives aim to preserve wild stocks while establishing aquaculture that could promote the preservation of biodiversity and lead to more sustainable fisheries. Thus, an aquaculture sector was envisaged for the production of teatfish from hatcheries (i.e. management and reproduction of wild-caught broodstock, larval breeding and nursery rearing) up to the sea ranching phase in natural reef habitats. To do this, the mastery and output of the different stages of production had to be demonstrated.

To provide context, we note that aquaculture technology has been well developed for only a few tropical species (Purcell et al. 2012). Although all four teatfish species found in the

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[2] National Marine Science Centre, Southern Cross University, Coffs Harbour, NSW 2450, Australia
[3] Convention on International Trade in Endangered Species of Wild Fauna and Flora
[4] DRM is the government management authority responsible for fisheries in French Polynesia.

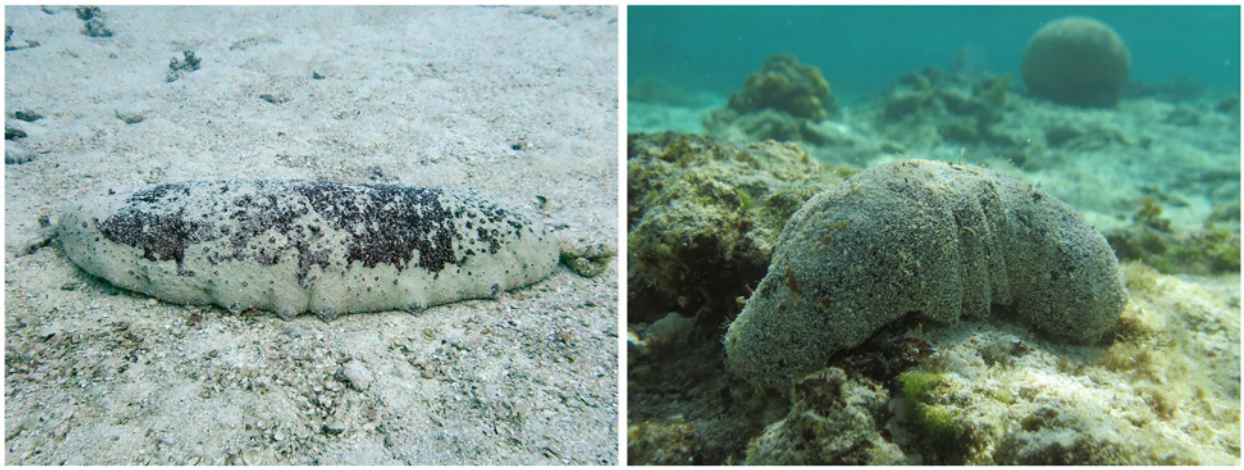

Figure 1. Left: a white teatfish, *Holothuria fuscogilva*, on lagoonal sand in French Polynesia. Image: ©S.W. Purcell
Right: a black teatfish, *Holothuria whitmaei*, on a reef flat platform in French Polynesia. Image: ©Mahanatea Garbutt

Indo-Pacific are valuable, there have been no reports of successful commercial-scale aquaculture of these species. The white teatfish, *Holothuria fuscogilva*, was cultured for several years in Kiribati, starting in the late 1990s, at an experimental scale with the assistance of Japanese aquaculturists (Friedman and Tekanene 2005). However, production numbers waned and the programme was mostly abandoned. In addition, the experience from Kiribati indicated that white teatfish were unsuitable to be grown in earthen ponds (Jimmy et al. 2012), an outcome repeated for black teatfish, *Holothuria whitmae*, in New Caledonia (Purcell et al. 2012). Thousands of hatchery-produced juvenile white teatfish were released into natural habitats in Kiribati but survival and growth monitoring was fruitless and trials to grow the animals in sea pens were thwarted by damaging storms (Jimmy et al. 2012). In New Caledonia, wild-caught black teatfish were induced to spawn in the hatchery by WorldFish in 2005 but the team was unable to get the larvae to survive through to settlement. So, the successful aquaculture and grow-out of teatfish has remained elusive.

In 2020, two years after a moratorium was set on sea cucumber fishing in French Polynesia, DRM solicited applications for collaborative research and development work on the feasibility of teatfish aquaculture. The selected company, Tahiti Marine Products (TMP), invested and launched a programme on the reproduction, breeding and sea ranching of teatfish. This work took place at the IFREMER Pacific Center, at the village of Vairao on Tahiti. This programme has been a collaboration between TMP, IFREMER and DRM. During the first couple of years, the aquaculture operation focused on white teatfish (*H. fuscogilva*) and later to also black teatfish (*H. whitmaei*). The results are, therefore, more advanced for *H. fuscogilva*.

White teatfish aquaculture development

TMP has conducted reproduction trials, larval rearing, nursery rearing, pre-grow-out and grow-out by using 50 *H. fuscogilva* broodstock that were collected under a fishery exemption permit. After three years, TMP has performed 16 reproduction trials, 8 of which resulted in the production of post-settlement juveniles.

According to research done on reproductive seasonality, white teatfish in New Caledonia spawn primarily in the summer months (Conand 1993). However, Ramofafia et al. (2000) found that this species spawned in late winter and early spring (August to October) in Solomon Islands, implying that the spawning season is not uniform across localities. During the early summer season, *H. fuscogilva* broodstock in French Polynesia were kept in sea pens and were monitored twice weekly. Since the first reproduction trials in October 2020, no mortality of broodstock has been observed.

The larval cycle follows several stages, as reported for other sea cucumbers (Fig. 2). The results of producing sea cucumber juveniles in hatcheries are highly variable. This heterogeneity in success is not due to the quality of the eggs or the broodstock; egg development is uniform, the hatching rates are excellent and the first feeding by larvae is consistent. Problems arrive later, around days 9 to 14 of the larval cycle. This could be linked to factors such as bacterial load, food type, food supply rate and human influence (e.g. different techniques or levels of hygiene). Despite this, the culture success with teatfish in French Polynesia is becoming more predictable.

The production of early-stage juveniles in French Polynesia over the last three years has increased tenfold (Fig. 3), yet there is still room for improvement. For instance, we reflect on the progress that was made by the Aquacole de la Ouenghi aquaculture company in Boulouparis, New Caledonia, in which survival rates from egg to juvenile stage increased from 1–2% to 6–8% between 2011 and 2020. In that programme, much of the improvement in the hatchery results was attributed to the careful selection of broodstock. The modest numbers of juveniles produced in 2022 related to problems of water quality and flow rate.

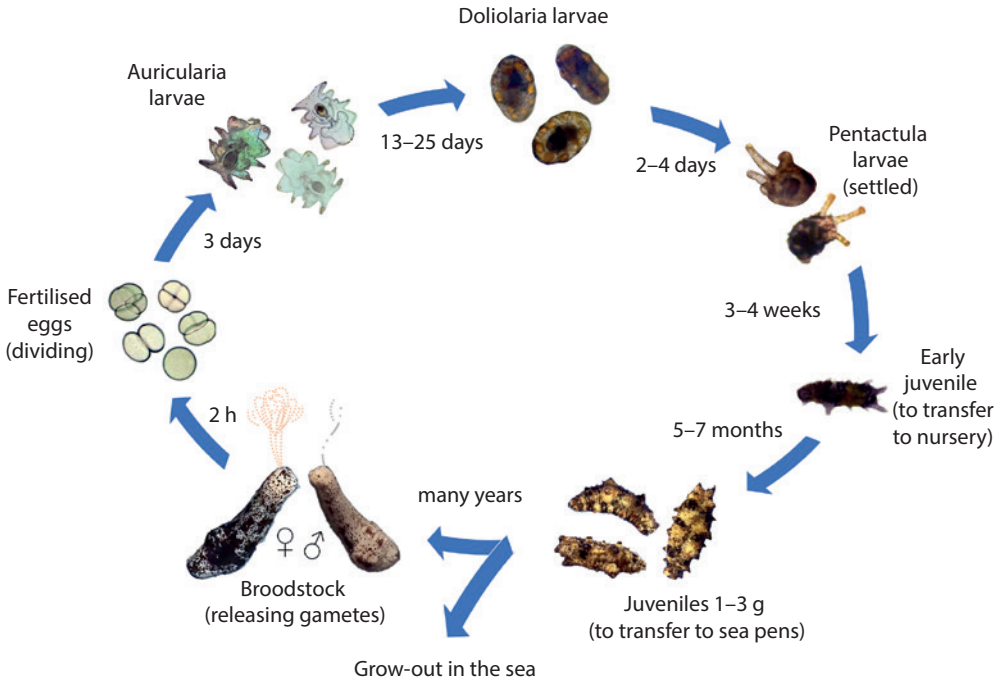

Figure 2. The life cycle of cultured white teatfish, *H. fuscogilva*, in French Polynesia.

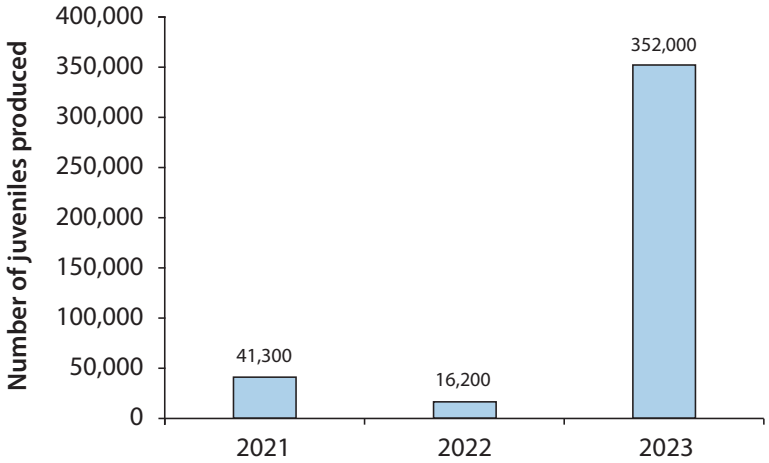

Figure 3. Recent evolution (2021–2023) of production quantities of post-settlement juveniles of white teatfish, *H. fuscogilva*, produced at the TMP hatchery in French Polynesia.

In French Polynesia, the selection of cultured *H. fuscogilva* to serve as future broodstock started with 126 animals weighing over 350 g from two different hatchery productions. Previous studies report the first sexual maturity of *H. fuscogilva* in New Caledonia to occur at around 900–950 g, with some individuals at 800 g showing mature gonads (Conand 1990). The TMP team hopes to begin the first reproduction with these selected cultured animals in 2026 when a new facility is expected to be ready at Faratea, on the east coast of Tahiti.

Nursery rearing of white teatfish

The nursery phase occurs after the hatchery phase, when sea cucumbers are at a tiny juvenile stage of 1–2 mm. Juveniles are put in bag nets (700–1000 µm mesh) that are set up in earthen ponds (Fig. 4). The preparation of these bag nets seems essential – in fact, a lack of conditioning of the bag nets and preparation of pond conditions when setting up the nursery can lead to a survival rate of less than 10%. All parameters must be considered: salinity, predation and competition, condition of the bag nets, age of the bag nets, and initial stocking density of juveniles. Juveniles stocked in the bag nets grow from <0.1 g to 2.0 g in a period of five to seven months.

Figure 4. Nursery system in earthen ponds in French Polynesia showing the bag nets supported by metal stakes in the seawater. Image: ©L. Burgy

Pre-grow-out trials of white teatfish

Pre-grow-out is the stage following the nursery, after the *H. fuscogilva* juveniles have reached 1–3 g in weight in the earthen ponds. At this stage, the juvenile white teatfish are quite spikey, with prominent papillae on the dorsal and dorso-lateral margins. The papillae tend to be dark brown in colour, with the tip being beige. The background body colour is beige and there are dark brown blotches over the body. Soon after they are transferred to the sea pens, they naturally tend to gather some macroalgae pieces and sand to adhere to their bodies, which camouflage them to the reef substratum (Fig. 5).

The pre-grow-out sea pens are located on an emergent reef flat on the western side of the Taiarapu lagoon on the western coast of Tahiti (Fig. 6). The reef sand in this habitat tends to be covered with a biofilm of organic matter and there is a scattered presence of corals (e.g. *Pocillopora* spp., *Porites* spp., and encrusting corals) and macroalgae (e.g. *Halimeda* spp., *Padina* spp. and *Dictyota* spp.). The sea pens (of varying dimensions) were made of plastic mesh (5 mm) supported upright by metal stakes. The reef habitat inside the pen is preserved in its natural state as much as possible.

Figure 5. A juvenile of *Holothuria fuscogilva*, the white teatfish, only a few grams in weight after being released in the sea pen. Notice the prominent papillae (dorsal and latero-dorsal) and the sand and macroalgae adhered to their bodies. Images: ©Matangi Moeroa

Figure 6. A 500-m^2 sea pen used for pre-grow-out of teatfish on a reef flat in Tahiti. Image: ©S.W. Purcell

The weights of white teatfish in the pre-grow-out sea pens were recorded on a monthly basis for culture production runs 6 and 8 of the programme. The pre-grow-out for these two production runs was done at two different sites: Toarahiri and Toahotu. The habitats are similar, being sandy reef flats with scattered presence of living corals. No feed was added to the sea pens, so the juveniles had only natural detritus to consume. Pooling the monthly data of the two production runs provides an average pattern of growth over nine months at the two sites (Fig. 7). After starting at 1–3 g body weight, the animals attained an average weight of around 29 g in nine months. This reveals a growth rate of 3.0 g per month, or 0.1 g per day for the pre-grow-out phase.

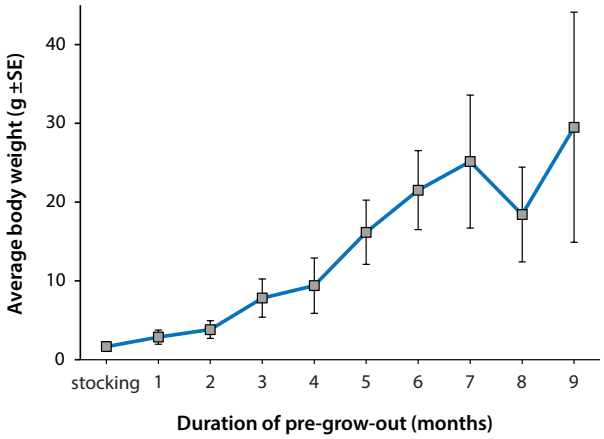

Figure 7. *Holothuria fuscogilva* (white teatfish) growth over nine months in the pre-grow-out phase in sea pens based on data from production runs 6 and 8 at Toarahiri and Toahotu, Tahiti. n = 30 individuals per sea pen

The results show that growth was relatively slow for the first two months in the sea pens, then increased and remained at a faster rate of around 3 g per month. Production run 6 was between June 2022 and January 2023, and production run 8 was between December 2022 and October 2023. The drop in average weight at month 8 seems to be linked to the vagaries of sampling. These pre-growing trials on comparable sites and at comparable densities showed similar growth rates (Fig. 8). This gives greater confidence that these growth rate findings were not just reflective of a particular batch of animals, or due to a particular season or site.

Survival of sea cucumbers in sea pens can be a major concern for commercial aquaculture operations (Purcell et al. 2012). While the walls of the sea pens in French Polynesia are not covered by water at high tide because the tidal flux is relatively small, animals could still be taken by some predators, die of natural causes, escape or not be found. Despite the TMP team's efforts to maintain the sea pens, some juveniles might have escaped at gaps that appeared after storms or large swells. In French Polynesia, the TMP team conducted some pilot studies using small sea pens measuring 12 m^2 in surface area. Using a stocking density of 1 animal per m^2, an average recapture rate of 86% was obtained. In the large-scale trials using the 500-m^2 sea pens, slightly lower recapture rates were obtained.

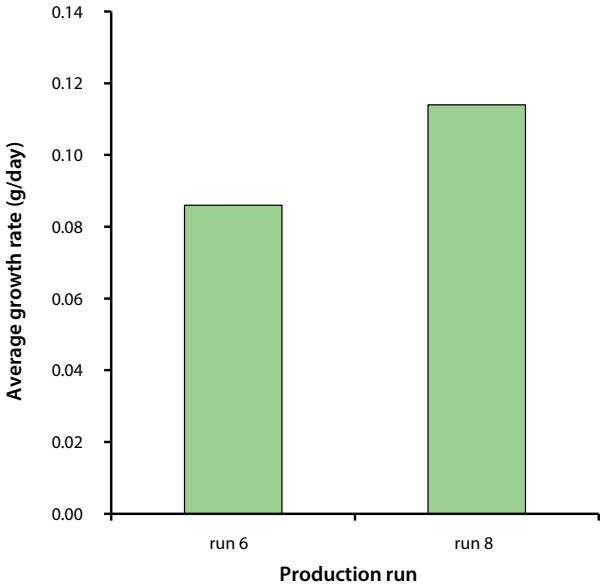

Figure 8. Average growth of juvenile teatfish in pre-grow-out phase for production runs 6 and 8.

For production run 6, the recapture rate was 60%, while the rate for production run 8 was 79%, equating to annual rates of natural mortality (M) of 0.68 and 0.31, respectively. These are still relatively high ('effective') survival rates compared to those in New Caledonia using sea pens with shorter mesh walls that are covered by water at high tide, allowing predators to enter (Purcell and Simutoga 2008). This slightly lower recapture rate in the larger sea pens compared to the 12-m^2 pens used in the pilot study might be partly explained by some animals not being found in the larger sea pens. Thus, the term "recapture rate" then takes on its full meaning.

Grow-out trials of white teatfish

After the pre-grow-out phase, *H. fuscogilva* juveniles weighting 25–40 g were transferred to grow-out sea pens of 10 mm mesh. A number of sea cucumbers in the grow-out pens were measured each month and a complete search of sea cucumbers in the pens was done at 15 months. Some enclosures were dismantled because of their poor location, particularly due to strong currents, which led to breakage. Data are presented from the remaining enclosures.

Monitoring the white teatfish in the grow-out sea pens shows fairly linear growth during the 15-month period (Fig. 9). There was an indication that growth might have slowed in the last three months, but this could be due to sampling precision. Overall, the growth rate was 8 g/ind/month, or 0.26 g/ind/day. After the 15-month grow-out period, the sea cucumbers averaged 150 g body weight, with a few being much larger (Fig. 10). Note that at this growth rate, the white teatfish would be 9–10 years old by the time they reached first sexual maturity, although it is possible that growth rates could increase later in life as pre-adults once they are a few hundred grams in weight.

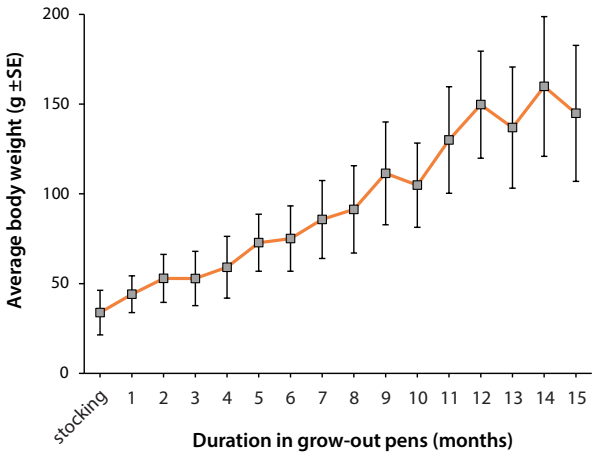

Figure 9. Growth trajectory of white teatfish over 15 months in the grow-out phase in sea pens. n = 30 individuals per sea pen

Figure 10. A large juvenile white teatfish, *H. fuscogilva*, that had been cultured in the hatchery and grown to around 250 g in weight in grow-out sea pens in French Polynesia. Image: ©S.W. Purcell

Much higher rates of growth have been found with other sea cucumber species grown in earthen ponds, where sediments are rich in nutrients (e.g. Bell et al. 2007). However, as mentioned earlier, earthen ponds seem unsuitable for the grow-out of teatfish. In sea pens, sandfish (*Holothuria scabra*) have been known to grow at up to 40–50 g/month in Madagascar, but only 9–19 g/month in New Caledonia (Purcell et al. 2012). Therefore, in comparison, white teatfish appear to have much slower growth rates in natural habitats as juveniles.

In production run 4, in which white teatfish were first stocked into sea pens in May and June 2022, the final stocking biomass after 15 months of rearing averaged 147 g/m^2 (Table 1). This appears to be under the carrying capacity limits reported for sea cucumbers in other studies (Purcell et al. 2012). At the final collection of all animals that could be found, the average recapture rate among sea pens was 83%. This outcome further reinforced the earlier finding about a relatively low natural mortality rate (M = 0.15, annually) of these larger juveniles, although we must remember that large predators were excluded from the sea pens.

The development phase of the programme ended in October 2023. Between the end of August and mid-October 2023, all white teatfish juveniles were collected from the sea pens to finalise these first production trials. A summary of results over the two years from 2021 to 2023 is given in Table 2. Considering the period of nursery rearing, pre-grow-out and grow-out, the average growth rate of the animals over the whole cycle was 0.13 g/day and 0.14 g/day. At the end of this development stage, 2801 animals had been cultured to average weights of between 95 g and 137 g.

Behaviour of white teatfish in sea pens

At the start of the pre-grow-out phase in the circular sea pens, white teatfish juveniles from 1 g to 3 g average body

Table 1. Summary of data from grow-out trials of white teatfish, *Holothuria fuscogilva*, in sea pens in French Polynesia. Spawning dates for production runs 4 and 6 were 10 February 2021 and 6 October 2021, respectively.

Production No.	Sea pen	Pen size (m^2)	Stocking date	Number of sea cucumbers stocked	Mean weight at stocking (g) (± SD)	Initial stocking density (ind m^{-2})	Initial stocking biomass (g m^{-2})	Mean end weight (g ind^{-1})	Number of individuals recaptured	Recapture rate (%)	End biomass (g m^{-2})	Total days of rearing	Growth rate (g ind^{-1} day^{-1})
4	Papehere 1	450	15 June 2022	518	28	1.2	32.1	98	493	95%	108	468	0.15
	Papehere 2	450	15 June 2022	518	28	1.2	32.1	140	495	96%	154	462	0.24
	Toarahiri 2	450	16 May 2022	566	45 (± 17)	1.0	47.4	177	421	74%	166	485	0.27
	Toarahiri 3	450	16 May 2022	614	45 (± 17)	1.0	47.5	151	483	79%	163	490	0.22
6	Toahotu 2	1700	23 Jan. 2023	1430	34 (± 8)	0.8	28.9	96	1052	74%	59	252	0.24

Table 2. Summary of aquaculture trials of white teatfish, *Holothuria fuscogilva*, in French Polynesia from spawning to final collection.

Production No.	Spawning date	Completion date	Toral duration from spawning (days)	Number of animals at completion	Mean ind. weight at completion (g)	Total weight at completion (kg)	Mean growth rate since spawning (g day^{-1} ind^{-1})
4	10 February 2021	15 September 2023	947	1792	137.3	246.1	0.14
6	6 October 2021	15 September 2023	709	1009	94.6	95.5	0.13

weight were released at the centre of the pen. The majority of these animals move very slowly. Only a small proportion of them were observed to move away quickly from the central release area, with no indication of those individuals being different from the others. Thus, there is a wide variation in potential or realised movement among individuals.

Soon after being released into the sea pens, the juvenile white teatfish appeared to be foraging on the biofilm present on the sediment. They also quickly covered themselves with sand and macroalgae, rendering them indistinguishable from overgrown reef rocks apart from their shape (Fig. 11). Only the faeces of the animals were noticeable at first glance. All of the juveniles in sea pens displayed this behaviour. This observation of camouflaging behaviour by white teatfish juveniles helps to explain why they are so seldomly found and recorded in population surveys. The TMP team also noticed that dark-coloured individuals (dark brown and dark orange) seemed to cover their bodies with dark sediments, whereas light-coloured individuals covered their bodies with light-coloured sediments, although this observation needs further investigation. Months after release, most of the animals remain in the central areas of the sea pens. Juvenile white teatfish were rarely seen climbing on the mesh walls of the sea pens.

Figure 11. One of the cultured large juvenile individual white teatfish, *Holothuria fuscogilva*, in the sea pen, well camouflaged with macroalgae attached to its body.
Image: ©Mahanatea Garbutt

Black teatfish aquaculture development

Broodstock collection

From the programme's inception, the goal of TMP and DRM was to test the feasibility of producing both white teatfish and black teatfish in French Polynesia. The rarity of black teatfish (*H. whitmaei*) around Tahiti hampered the progress of this objective. Indeed, searches for *H. whitmaei* around Tahiti and the Leeward Islands (western Society Islands) were unsuccessful. Consequently, the programme sought broodstock from a distant archipelago.

A risk analysis was requested from the Pacific Community to guide the responsible translocation of black teatfish from the Austral Islands archipelago. Biosecurity protocols proposed by the Pacific Community were used to limit the risks

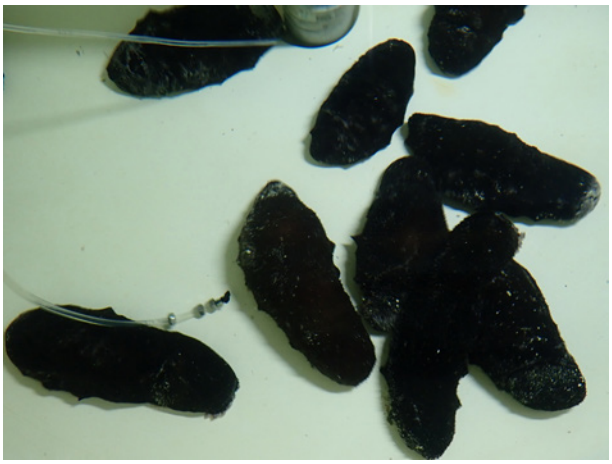

Figure 12. Some of the black teatfish (*Holothuria whitmaei*) broodstock in a tank at the IFREMER aquaculture facility at Vairao, eastern Tahiti. Image: ©S.W. Purcell

of introducing pests and disease. In 2023, TMP obtained approval to acquire 50 *H. whitmaei* broodstock from Rimatara Island in the Austral Islands (Fig. 12).

During the voyage to Tahiti, the adult black teatfish broodstock were kept in PVC tubes with shade cloth fitted to the ends to allow fresh seawater to enter. The animals survived the trip well, but the outer body wall of the animals was partly abraded by the shade cloth. This experience highlighted the need for better housing of sea cucumbers for future translocations.

Spawning of black teatfish

Aquaculture trials in Tahiti showed that *H. whitmaei* broodstock respond to similar spawning induction stress as *Holothuria fuscogilva*. This was promising for producing gametes. The larval rearing protocols developed for *H. fuscogilva* also appeared to be transferrable to *H. whitmaei* and the growth and development times of eggs and larvae are approximately the same (see Fig. 2).

Research done by Conand (1993) in New Caledonia indicate that black teatfish (*Holothuria whitmaei*) spawn primarily in winter, and this was generally corroborated by Shiell and Uthicke (2006) for black teatfish in western and eastern Australia. The first spawning of *Holothuria whitmaei* by the TMP team occurred immediately after the translocation of the broodstock to Tahiti, which was in the cool season (June). The majority of animals that spawned were male and more than 11 million eggs were produced by three females (Table 3). A second spawning was induced three months later, when the animals had

Table 3. Summary results of spawning and early juvenile production of black teatfish, *Holothuria whitmaei*, in French Polynesia.

Production No.	Spawning date	Number of broodstock used	Number of spawning males	Number of spawning females	Total number of eggs (millions)	Fertilisation rate (%)	Number of juveniles produced	Survival rate (egg to end of hatchery phase)
1	9 June 2023	50	9	3	11.2	95	210,000	1.88
2	30 Sep. 2023	49	7	3	15.0	95	50,000	0.33

again been stressed by transport and a change of environment. Induced spawning attempts will be made in 2024 to examine seasonality of reproduction.

Nursery rearing of black teatfish

Holothuria whitmaei juveniles produced from the culture trials were transferred to bag nets in two earthen ponds at the aquaculture facility at Vairao. This nursery rearing trial was in progress at the time of writing this article, so few data were available. Nonetheless, it appeared that juvenile *H. whitmaei* grow faster than *H. fuscogilva* juveniles. Indeed,

Figure 13. Black teatfish (*Holothuria whitmaei*) juveniles after three months of nursery rearing in bag nets in an earthen pond at Vairao, eastern Tahiti. Image: ©L. Burgy

after three months in the nursery, *H. whitmaei* juveniles weighed, on average, 1.8 g (Fig. 13). By comparison, to reach this same body weight, *H. fuscogilva* juveniles took, on average, four to six months in the nursery.

Black teatfish (*H. whitmaei*) juveniles weighing 1–10 g are orange-beige with irregular black spots and blotches over the dorsal surface of the body (Fig. 14). The young black teatfish juveniles have numerous papillae dorsally and on the dorsolateral margins of the body but these tend to be smaller and lighter in colour compared to white teatfish juveniles of the

Figure 14. Small juvenile black teatfish (*Holothuria whitmaei*) juveniles weighing 4–6 g, cultured at the TMP hatchery in French Polynesia. Image: ©L. Burgy

same size. Presumably, the black blotches on the body of black teatfish juveniles spread across the dorsal surface as they age and the dorsal papillae become smaller relative to the body size.

Conclusions

After more than three years of research and development, TMP and its partners (DRM and IFREMER) have succeeded in demonstrating the technical feasibility of producing teatfish in hatcheries in French Polynesia. The foundations of new and sustainable aquaculture in Polynesia have been laid with major technical advances.

The first years of technology development in French Polynesia yielded hatchery survival rates (from egg to juveniles of 1–3 g) of 1–3%. The objective of the programme is to achieve 5% survival and produce several million juveniles per year. Growth rates in the pre-grow-out and grow-out phases in sea pens were rather slow, especially for *H. fuscogilva*. These growth rates should approximate natural rates of wild animals since no feed was put in pens and stocking densities were not high. More trials and research are needed on habitats that will yield consistently good survival but higher growth rates. Lessons obtained from the different phases provide hope to reducing the whole culture cycle to 24 months for obtaining large juvenile teatfish, which would make for a compelling business model.

The launch of the country aquaculture project on Faratea, Tahiti, will allow the programme to scale-up production with the construction of a new commercial hatchery and

new nursery ponds. The programme is striving to optimise production protocols to offer a new aquaculture sector for French Polynesia. The production model could ultimately be transferred to other Pacific Island countries.

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Croissance, comportement et survie en élevage des juvéniles d'holothuries à mamelles (*Holothuria fuscogilva* et *H. whitmaei*) en Polynésie française

Laurent Burgy[1] et Steven W. Purcell[2]

Résumé

Groupe à forte valeur marchande, les holothuries à mamelles (sous-genre Microthele) comptent parmi les trois espèces inscrites à l'Annexe II de la CITES. Compte tenu du peu d'études consacrées aux juvéniles d'holothuries à mamelles, on connaît encore mal le comportement et les taux de croissance et de mortalité naturelle de ces espèces, des connaissances pourtant indispensables au secteur de l'aquaculture et de la pêche. Nous présentons ici les résultats d'un programme d'élevage mené en Polynésie française pour l'holothurie blanche à mamelles (*Holohturia fuscogilva*) et l'holothurie noire à mamelles (*H. whitmaei*). Le programme vise à développer un élevage semi-commercial dans une filière prometteuse, dont les produits sont destinés aux marchés internationaux, en particulier à l'Asie. Sortis d'écloserie, les juvéniles fraîchement fixés entrent en phase de grossissement dans des filets à poche installés dans des bassins en terre, jusqu'à atteindre 1 à 3 g. Ils sont ensuite transférés dans des enclos marins de 500 m² aménagés sur des platiers récifaux naturels. Le taux de survie en enclos marins des juvéniles de *H. fuscogilva* était encourageant (> 80 %), traduisant des taux de mortalité naturelle relativement faibles (annuellement, M = 0,31 et 0,68 en phase de pré-grossissement et M = 0,15 en phase de grossissement), même au stade juvénile. Cependant, les taux de croissance étaient bas, se situant dans la fourchette 0,13–0,14 g/jour/ind. Les juvéniles de *H. fuscogilva* utilisent le camouflage dans les enclos marins, dissimulant leur corps sous des macro-algues et du sable, ce qui leur donne l'apparence de rochers coralliens. La ponte des géniteurs de *H. whitmaei* a eu lieu en hiver et les juvéniles ont été mis en élevage à l'aide de méthodes similaires. Le taux de grossissement en enclos marins se situait autour de 0,3 g/jour, un taux nettement supérieur à celui de l'holothurie blanche à mamelles. Après trois années de recherche et développement, la production en écloserie a été multipliée par dix et la phase de grossissement laisse désormais augurer une production à échelle commerciale. S'il a fallu deux ans pour que l'holothurie blanche à mamelles atteigne des poids moyens de 150 g, le programme a pour ambition d'améliorer les taux de croissance aux différentes phases du cycle d'élevage pour assurer la viabilité économique des installations.

Mots-clés : aquaculture, Pacifique, ponte, reproduction, *Holothuria fuscogilva*, *H. whitmaei*

Introduction

Les holothuries, appelées rori en Polynésie française, sont pêchées depuis plus d'un siècle dans ce territoire (Stein 2019). En Polynésie française, les holothuries sont peu consommées à des fins de subsistance (Kinch et al. 2008), la production étant destinée pour l'essentiel aux marchés asiatiques. On compte au moins 10 espèces d'intérêt commercial dans les eaux de la Polynésie française (Andréfouët et al. 2019), mais la pêche commerciale, réglementée depuis 2012, n'est autorisée que pour cinq d'entre elles (Stein 2019). Cette activité artisanale mais lucrative peut provoquer la surexploitation du stock naturel, qui est fragile et dont le recrutement est lent.

Les holothuries à mamelles forment un groupe composé d'au moins quatre espèces d'holothuries possédant de grandes protubérances latérales, appelées « mamelles ». Elles sont particulièrement prisées dans la gastronomie chinoise, se vendant entre 100 et 400 dollars des États-Unis par kg (Purcell et al. 2018), et sont ou étaient exploitées dans au moins 20 pays de l'Indopacifique. Les holothuries blanches à mamelles (*Holothuria [Microthele] fuscogilva*) et les holothuries noires à mamelles *(H. [M.] whitmaei*) ont été beaucoup pêchées par les artisans pêcheurs professionnels en Polynésie française (Stein 2019), où les platiers situés en arrière du récif et les lagons bordant les atolls semblent offrir des habitats particulièrement adaptés (figure 1). En tahitien, l'holothurie noire à mamelles et l'holothurie blanche à mamelles sont respectivement appelées *rori titi'ere'ere* et *rori titi'uo'uo.* La pêche a été interdite en 2018 en Polynésie française de crainte que les stocks soient surexploités, mais des voix s'élèvent aujourd'hui pour une éventuelle réouverture de la pêche dans certains atolls. Selon les inventaires récents, les densités de *H. whitmaei* sont faibles voire nulles dans la plupart des sites (Andréfouët *et al*. 2019).

En 2019, *H. whitmaei et H. fuscogilva* ont été toutes deux inscrites à l'Annexe II de la CITES, à la demande notamment de la France et de l'Europe. Dans ce contexte, désireuse de promouvoir la gestion durable de la ressource, la Direction des ressources marines (DRM) de la Polynésie

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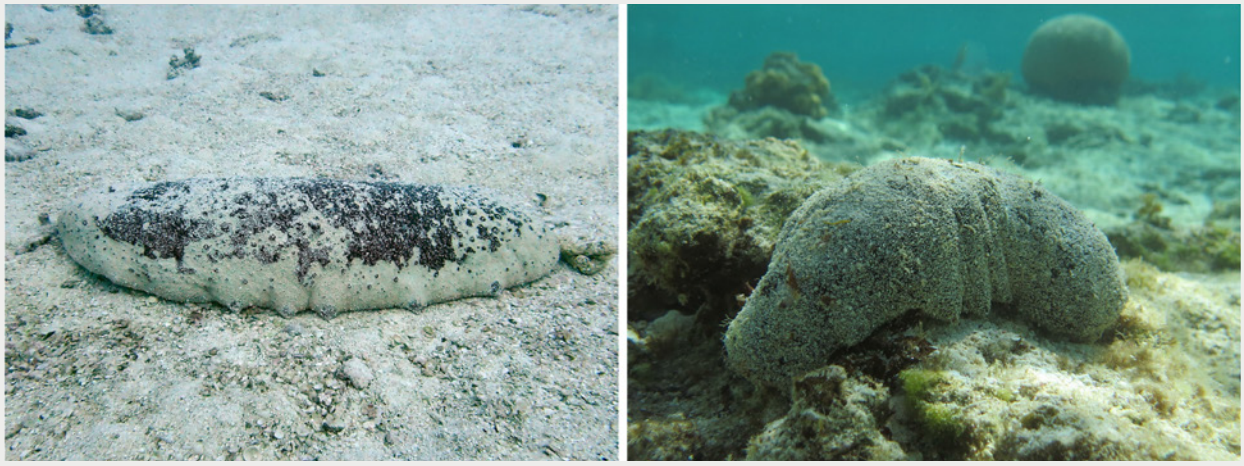

Figure 1. À gauche : une holothurie blanche à mamelles (*Holothuria fuscogilva*) posée sur une zone sablonneuse lagonaire en Polynésie française (crédit photo : © S.W. Purcell). À droite : une holothurie noire à mamelles (*Holothuria whitmaei*) sur un platier récifal en Polynésie française (crédit photo : © Mahanatea Garbutt).

française[3] met en œuvre plusieurs initiatives consacrées aux holothuries à mamelles. Leur but est de préserver les stocks sauvages, tout en créant des modes d'élevage propres à promouvoir la conservation de la biodiversité et à mieux pérenniser la ressource. Ainsi, la mise en place d'une filière d'élevage a été envisagée en vue de la production en écloserie d'holothuries à mamelles (gestion et reproduction de géniteurs prélevés dans le milieu naturel, élevage larvaire et élevage en nourricerie) avant leur transfert dans des habitats récifaux naturels pour la phase de pacage en mer. Pour mener à bien ce projet, il fallait pouvoir démontrer la maîtrise et les résultats des différentes phases de production.

Pour resituer le contexte, on notera que les techniques d'élevage ne sont bien développées que pour une poignée d'espèces tropicales (Purcell *et al*. 2012). En dépit de l'intérêt commercial que revêtent les quatre espèces d'holothuries à mamelles présentes dans l'Indopacifique, la littérature ne fait état d'aucun exemple réussi d'élevage commercial de ces espèces. Une ferme d'élevage de H. fuscogilva a été exploitée à échelle expérimentale pendant plusieurs années à Kiribati dès la fin des années 1990, avec le concours d'aquaculteurs japonais (Friedman and Tekanene 2005). Toutefois, la production s'est étiolée au fil des ans et le programme a été quasiment abandonné. En outre, l'expérience menée à Kiribati a montré que les bassins en terre n'étaient pas adaptés au grossissement de H. fuscogilva (Jimmy et al. 2012), ce qui a été confirmé pour H. whitmaei en Nouvelle-Calédonie (Purcell et al. 2012). Des milliers de juvéniles d'holothuries blanches à mamelles sortis d'écloserie ont été relâchés dans des habitats naturels à Kiribati, mais le suivi des taux de survie et de croissance n'a rien donné et les essais de grossissement en enclos marins ont été contrariés par des tempêtes destructrices (Jimmy et al. 2012). En Nouvelle-Calédonie, WorldFish est parvenu en 2005 à induire la ponte d'holothuries noires à mamelles prélevées dans le milieu naturel, mais les larves n'ont pas survécu jusqu'à la phase de fixation. Ainsi, la maîtrise de l'élevage et du grossissement des holothuries à mamelles reste difficile à acquérir.

En 2020, deux ans après l'instauration d'un moratoire sur la pêche des holothuries en Polynésie française, la DRM a lancé un appel à projets en vue de la mise en place d'un programme collaboratif de recherche et développement axé sur la faisabilité de la production aquacole d'holothuries à mamelles. La société retenue, Tahiti Marine Products (TMP), a investi dans un programme de reproduction, de sélection et de pacage en mer des holothuries à mamelles. Ce programme, lancé par TMP, a été établi au Centre Ifremer du Pacifique (CIP) dans le village de Vairao, sur l'île de Tahiti. Il s'agit d'une collaboration entre TMP, l'Ifremer et la DRM. Au cours des deux premières années, le projet aquacole s'est centré sur *H. fuscogilva*, mais il a par la suite été étendu à *H. whitmaei*. Les résultats obtenus à ce jour sont donc plus avancés pour *H. fuscogilva*.

Développement de l'élevage de l'holothurie blanche à mamelles

TMP a conduit des essais de reproduction, d'élevage larvaire, d'élevage en nourricerie, de prégrossissement et de grossissement, après prélèvement de 50 géniteurs de *H. fuscogilva* sur autorisation spéciale. En trois années de travaux, TMP a mené 16 essais de reproduction, dont 8 ont permis de produire des juvéniles après fixation.

Selon les recherches effectuées sur la saisonnalité de la reproduction, H. fuscogilva en Nouvelle-Calédonie pond principalement pendant la période estivale (Conand 1993). Néanmoins, Ramofafia et collaborateurs (Ramofafia *et al*. 2000) ont observé des pontes entre la fin de l'hiver et le début du printemps (août à octobre) aux Îles Salomon, ce qui donne à penser que la saison de ponte de cette espèce n'est pas uniforme d'un site à l'autre. En Polynésie française, au début de l'été, les géniteurs de *H. fuscogilva* ont été placés dans des enclos marins et contrôlés deux fois par semaine. Depuis les premiers essais de reproduction en octobre 2020, les géniteurs n'ont subi aucune mortalité.

[3] La DRM est le service public chargé de la gestion des pêches en Polynésie française.

Le cycle larvaire se divise en plusieurs stades, comme décrit pour d'autres espèces d'holothuries (figure 2). Les résultats de la production de juvéniles d'holothuries en écloserie sont très variables. Ces écarts de performance sont sans lien avec la qualité des œufs ou du stock de géniteurs ; le développement des œufs est uniforme, les taux d'éclosion sont excellents et les larves atteignent le premier stade d'alimentation de manière constante. Les problèmes surviennent plus tard, vers les jours 9 à 14 du cycle larvaire. Cela pourrait s'expliquer par différents facteurs, dont la charge bactérienne, les types d'aliments, la fréquence de nourrissage et le facteur humain (différentes techniques, hygiène, etc.). Malgré tout, le succès du cycle d'élevage de l'holothurie blanche à mamelles en Polynésie française est de plus en plus prévisible.

La production des premiers stades juvéniles en Polynésie française au cours des trois dernières années a été multipliée par dix (figure 3), mais il reste une marge de progression. Par exemple, nous nous penchons sur les progrès réalisés par la Société d'élevage aquacole de la Ouenghi (SEA) à Boulouparis (Nouvelle-Calédonie), où les taux de survie œufs-juvéniles sont passés de 1–2 % en 2011 à 6–8 % en 2020. L'amélioration considérable des résultats obtenus par la SEA en écloserie a été en grande partie attribuée au choix attentif des géniteurs. Les nombres modestes de juvéniles produits en 2022 s'expliquent par des problèmes de qualité et de débit de l'eau.

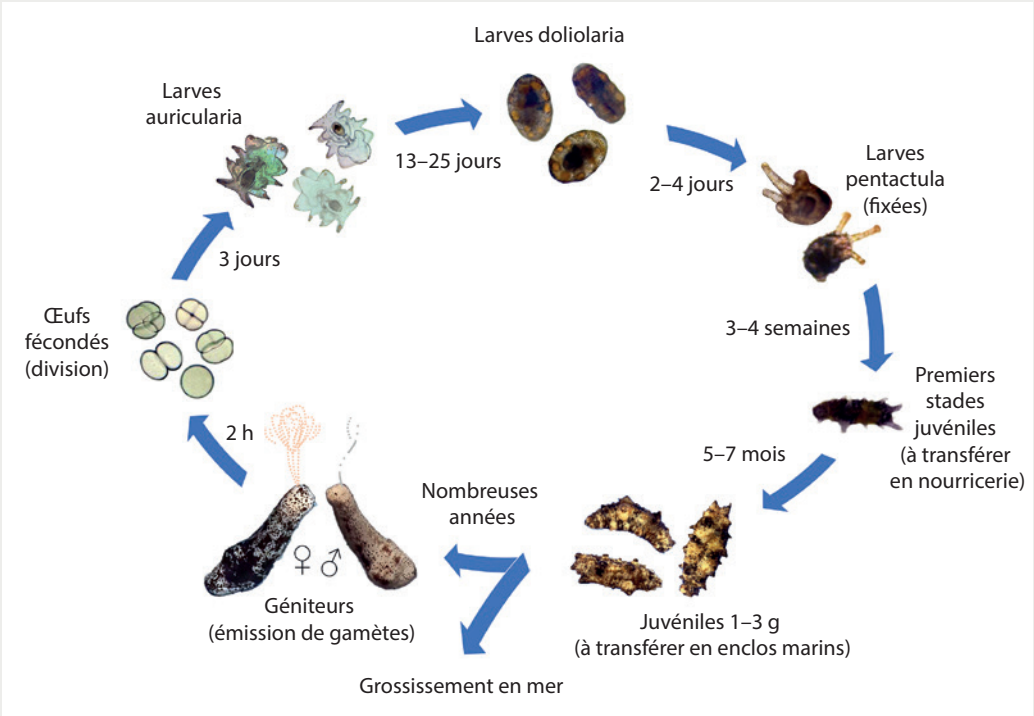

Figure 2. Cycle biologique en élevage de *H. fuscogilva* en Polynésie française.

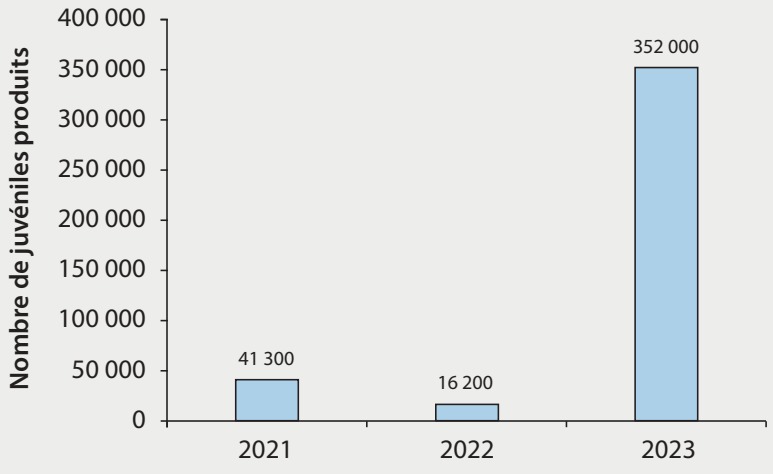

Figure 3. Évolution récente (2021–2023) du nombre de juvéniles de *H. fuscogilva* produits à l'écloserie de TMP en Polynésie française.

En Polynésie française, le choix des géniteurs de *H. fuscogilva* produits en élevage s'est porté initialement sur 126 animaux de plus de 350 g, issus de deux cycles distincts d'écloserie. Selon des études antérieures, la taille à maturité sexuelle de *H. fuscogilva* en Nouvelle-Calédonie correspondait à un poids d'environ 900 à 950 g, certains individus présentant des gonades matures à 800 g (Conand 1990). L'équipe de TMP espère lancer les premiers essais de reproduction avec les géniteurs sélectionnés en élevage en 2026, année où est prévue la mise en exploitation d'une nouvelle installation à Faratea, sur la côte est de Tahiti.

Élevage en nourricerie de l'holothurie blanche à mamelles

La phase de nourricerie intervient après la phase d'écloserie, quand les minuscules holothuries juvéniles ne mesurent encore que 1 à 2 mm. Les juvéniles sont placés dans des filets à poche (maille de 700 à 1 000 µm), installés dans des bassins en terre (figure 4). La préparation des filets à poche semble essentielle – en réalité, en l'absence de conditionnement des filets et de préparation des bassins de

la nourricerie, le taux de survie peut descendre sous la barre des 10 %. Tous les paramètres doivent être pris en compte : salinité, prédation et compétition, état et âge des filets à poche, et densité initiale de mise en charge des juvéniles. Les juvéniles transférés dans les filets passent de moins de 0,1 g à 2 g en l'espace de 5 à 7 mois.

Essais de pré-grossissement de l'holothurie blanche à mamelles

La phase de pré-grossissement succède à la phase de nourricerie, une fois que les juvéniles de *H. fuscogilva* ont atteint entre 1 et 3 g dans les bassins en terre. À ce stade, les juvéniles d'holothuries blanches à mamelles sont hérissés de grandes papilles dorsales et latéro-dorsales. Les papilles sont généralement marron foncé, la pointe étant de couleur beige. La livrée de l'animal est beige, parsemée de taches marron foncé. Peu après leur transfert dans les enclos marins, les juvéniles ont naturellement tendance à rassembler des morceaux de macro-algues et du sable qu'ils fixent en guise de camouflage sur leur corps, ce qui leur permet de se fondre dans le substrat récifal (figure 5).

Figure 4. Système de nourricerie dans des bassins en terre en Polynésie française, composé de filets à poche fixés à des pieux métalliques dans de l'eau de mer (crédit photo : © L. Burgy).

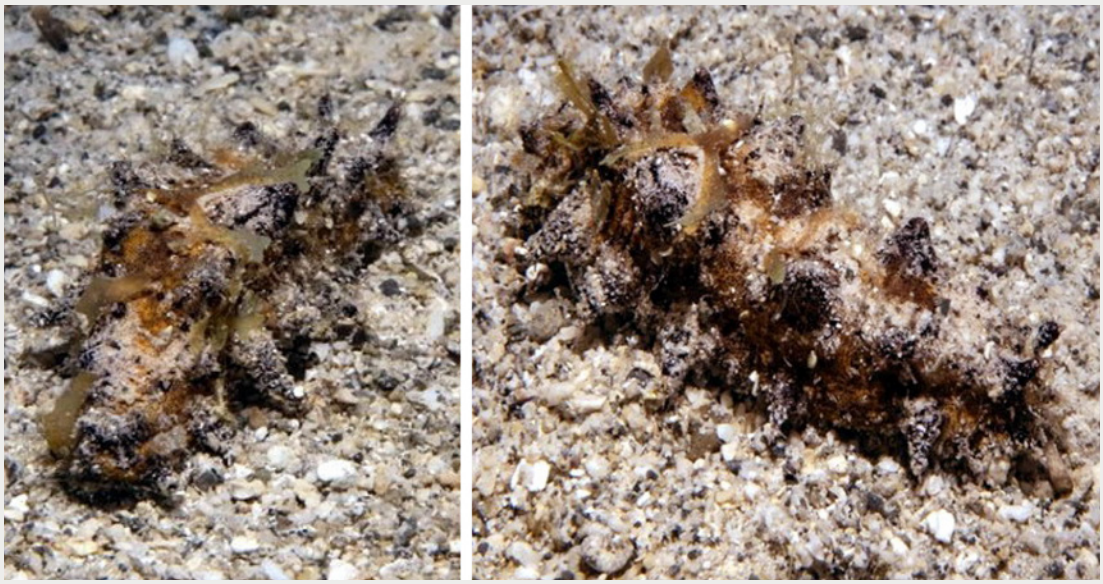

Figure 5. Juvénile de *H. fuscogilva*, pesant à peine quelques grammes, après son transfert en enclos marin. On note les papilles proéminentes (dorsales et latéro-dorsales), ainsi que le sable et les macro-algues fixés sur le corps de l'animal (crédit photo : © Matangi Moeroa).

Figure 6. Enclos marin de 500 m² utilisé pour le pré-grossissement des holothuries à mamelles sur un platier récifal à Tahiti (crédit photo : © S.W. Purcell).

Les enclos de pré-grossissement sont situés sur un platier récifal affleurant dans le lagon de Taiarapu-ouest sur la côte ouest de Tahiti (figure 6). Dans cet habitat, le sable des récifs est généralement recouvert d'un biofilm composé de matières organiques et on relève la présence éparse de coraux (par exemple, *Pocillopora* sp., *Porites* sp., et coraux encroûtants) et de macro-algues (par exemple, *Halimeda* sp., *Padina* sp. et *Dictyota* sp.). Les enclos marins (de dimensions variables) sont fabriqués à l'aide de filets en plastique (maille de 5 mm), maintenus à la verticale par des pieux métalliques. L'habitat récifal situé à l'intérieur de l'enclos est conservé autant que possible à l'état naturel.

Le poids des holothuries blanches à mamelles a été relevé à fréquence mensuelle dans les enclos de pré-grossissement, pour les essais de production 6 et 8 du programme. Pour ces deux cycles de production, le pré-grossissement a eu lieu dans deux sites distincts : Toarahiri et Toahotu. Les habitats y étaient similaires, à savoir des platiers récifaux sablonneux comptant quelques coraux vivants épars. Aucun aliment n'a été ajouté aux enclos, et les juvéniles se nourrissaient exclusivement de débris naturels. Le regroupement des données mensuelles des deux essais de production donne une courbe de croissance moyenne sur neuf mois pour les deux sites (figure 7). Transférés à un poids de 1 à 3 g, les animaux ont atteint en neuf mois un poids moyen d'environ 29 g. Le taux de croissance s'établit donc à 3,0 g par mois, soit 0,1 g par jour en phase de pré-grossissement.

Les résultats montrent que la croissance était relativement lente au cours des deux premiers mois suivant le transfert en enclos, puis a augmenté et s'est stabilisée à un rythme plus soutenu de 3 g par mois. L'essai de production 6 s'est déroulé entre juin 2022 et janvier 2023, tandis que l'essai 8 a commencé en décembre 2022 et s'est achevé en octobre 2023. La diminution du poids moyen au cours du huitième mois semble être due aux aléas de l'échantillonnage. Ces essais de pré-grossissement, menés sur des sites comparables à des densités comparables, donnent des taux de croissance similaires (figure 8). On peut donc affirmer avec davantage de confiance que ces taux de croissance ne sont pas uniquement représentatifs d'un lot d'animaux, d'une saison ou d'un site particulier.

La survie dans les enclos marins peut être une source majeure de préoccupations pour les fermes holothuricoles commerciales (Purcell *et al.* 2012). Bien qu'en raison de la faible amplitude des marées, les parois des enclos marins utilisés en Polynésie française ne soient pas immergées à marée haute, les animaux restent exposés au risque de prédation et de mort naturelle, et peuvent s'échapper ou ne pas être retrouvés. Malgré les efforts consentis par l'équipe de TMP pour entretenir les enclos marins, il se peut que certains juvéniles soient sortis par les ouvertures qui se créent après des épisodes de tempête ou de forte houle. En Polynésie française, l'équipe de TMP a mené quelques études pilotes avec de petits enclos marins d'une superficie de 12 m^2. Partant d'une densité de charge de 1 animal par m^2, un taux de recapture moyen de 86 % a été obtenu.

Dans les essais à grande échelle menés dans les enclos de 500 m^2, des taux de recapture légèrement inférieurs ont été relevés.

Lors de l'essai de production 6, le taux de recapture était de 60 %, contre 79 % pour l'essai 8, ce qui donne respectivement des taux annuels de mortalité naturelle (*M*) de 0,68 et 0,31. Ces taux de survie [effectifs] restent relativement élevés par rapport à l'expérience conduite en Nouvelle-Calédonie avec des enclos marins de hauteur inférieure, dont les parois en filets étaient complètement immergées à marée haute, laissant passer les prédateurs (Purcell and Simutoga 2008). Le fait que le taux de recapture dans les grands enclos soit légèrement inférieur à celui relevé dans les enclos de 12 m^2

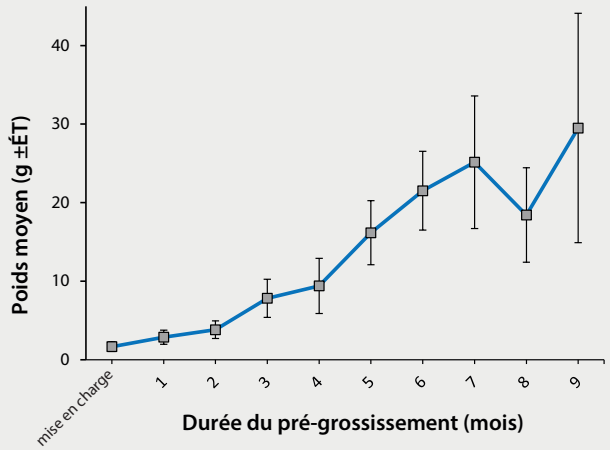

Figure 7. Croissance de *H. fuscogilva* en neuf mois de pré-grossissement en enclos marins, calculée à partir des données des essais de production 6 et 8 conduits à Toarahiri et à Toahotu, sur l'île de Tahiti. *N* = 30 individus par enclos.

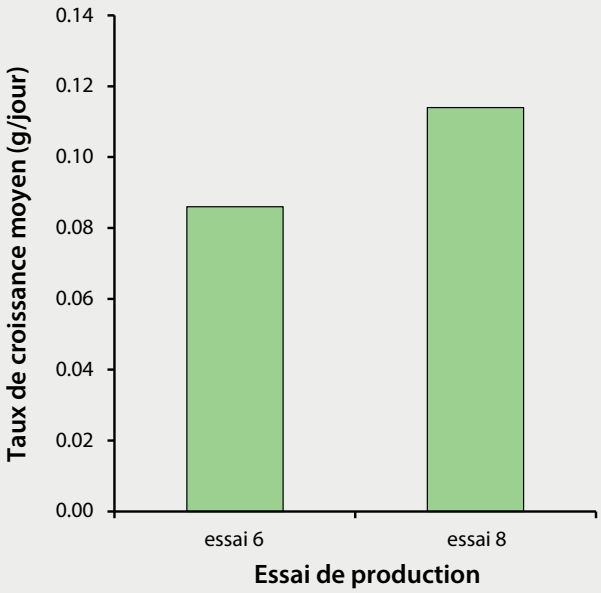

Figure 8. Croissance moyenne des juvéniles d'holothuries à mamelles pendant la phase de prégrossissement lors des essais de production 6 et 8.

utilisés dans l'étude pilote pourrait s'expliquer par l'impossibilité de retrouver certains animaux dans les enclos de plus grandes dimensions. Ainsi, le terme « taux de recapture » prend véritablement tout son sens.

Essais de grossissement de l'holothurie blanche à mamelles

Après la phase de pré-grossissement, les juvéniles de *H. fuscogilva*, pesant entre 25 et 40 g, sont transférés dans des enclos de grossissement à maille de 10 mm. Dans les enclos de grossissement, un certain nombre d'holothuries ont été mesurées chaque mois et un inventaire complet des enclos a été réalisé à 15 mois. Certains enclos, situés dans des sites inadaptés, ont été démantelés. Ils étaient en particulier soumis à de forts courants, ce qui dégradait les filets. Les données sont présentées pour les enclos restants.

Le suivi des holothuries blanches à mamelles en enclos de grossissement révèle une croissance assez linéaire au cours de la période de 15 mois considérée (figure 9). Les données semblent indiquer un ralentissement de la croissance au cours des trois derniers mois, mais cela pourrait être dû à la précision de l'échantillonnage. Dans l'ensemble, le taux de croissance était de 8 g/ind./mois, soit 0,26 g/ind./jour. Après 15 mois de grossissement, les holothuries pesaient en moyenne 150 g, certains individus affichant une croissance bien supérieure (figure 10). On notera qu'avec un tel taux de croissance, l'holothurie blanche à mamelles atteindrait la maturité sexuelle vers l'âge de 9-10 ans, même s'il se peut que les taux de croissance s'accélèrent au stade pré-adulte, quand l'animal a déjà atteint quelques centaines de grammes.

Des taux de croissance nettement supérieurs ont été observés chez certaines autres espèces d'holothuries élevées dans des bassins en terre, où les sédiments sont riches en nutriments (par exemple, Bell *et al.* 2007). Toutefois, comme mentionné plus haut, les bassins en terre ne semblent pas adaptés au grossissement des holothuries à mamelles. Il a été rapporté que, dans les enclos marins, l'holothurie de sable *Holothuria scabra* gagnait jusqu'à 40 à 50 g/mois à Madagascar, mais 9 à 19 g/mois en Nouvelle-Calédonie (Purcell *et al.* 2012).

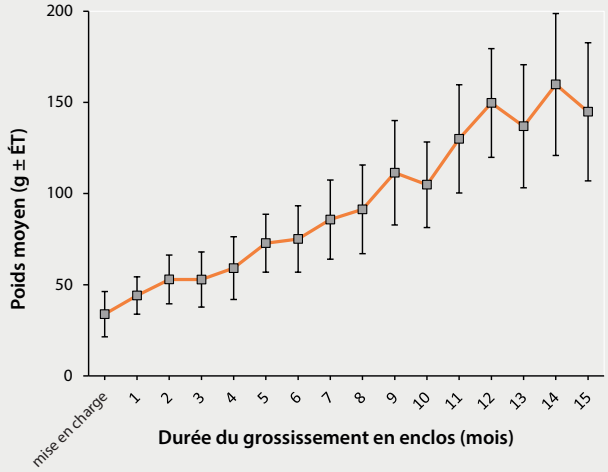

Figure 9. Courbe de croissance de l'holothurie blanche à mamelles au cours d'une période de grossissement de 15 mois en enclos marin. *N* = 30 individus par enclos.

Ainsi, par comparaison, l'holothurie blanche à mamelles au stade juvénile paraît afficher une croissance sensiblement plus lente dans les habitats naturels.

Dans le cadre de l'essai de production 4, pour lequel l'ensemencement initial des holothuries blanches à mamelles a eu lieu en mai et juin 2022, la biomasse finale des animaux mis en charge atteignait après 15 mois d'élevage une moyenne de 147 g/m^2 (tableau 1). Ce chiffre semble inférieur aux capacités de charge limites rapportées dans d'autres études pour les élevages d'holothuries (Purcell *et al.* 2012). Calculé au stade du prélèvement final des animaux qui ont pu être retrouvés, le taux de recapture moyen dans les enclos marins s'établissait à 83 %. Ce résultat corrobore la conclusion formulée ci-dessus quant au taux de mortalité naturelle relativement faible relevé chez ces juvéniles de plus grande taille (M = 0,15, annuellement), mais il faut rappeler que les grands prédateurs ont été tenus à l'écart des enclos.

La phase de développement du programme s'est achevée en octobre 2023. Entre la fin août et la mi-octobre 2023, tous les juvéniles d'holothuries blanches à mamelles ont été prélevés dans les enclos marins afin d'achever ces premiers essais de production. Une synthèse des résultats obtenus au cours de la période de deux ans comprise entre 2021 et 2023 est présentée dans le tableau 2. Si l'on prend en compte la période d'élevage en nourricerie, de pré-grossissement et de grossissement, le taux moyen de croissance des animaux au cours du cycle complet s'établissait entre 0,13 et 0,14 g/jour. À la fin de cette phase de développement, on compte 2 801 animaux mis en élevage ayant atteint des poids moyens de 95 et 137 g.

Comportement de l'holothurie blanche à mamelles dans les enclos marins

Au début de la phase de pré-grossissement dans les enclos circulaires, les juvéniles d'holothuries blanches à mamelles, pesant entre 1 et 3 g en moyenne, étaient transférés au milieu de l'enclos. La majorité des individus se déplaçaient très lentement. D'après les observations, seule une petite proportion d'individus s'éloignait rapidement de la zone centrale de lâcher, rien ne semblant distinguer ces individus

Figure 10. Grand juvénile de *H. fuscogilva* produit en écloserie et ayant atteint 250 g environ en enclos de grossissement en Polynésie française (crédit photo : © S.W. Purcell).

Tableau 1. Synthèse des données recueillies lors des essais de grossissement de *H. fuscogilva* en enclos marins en Polynésie française. Les dates de ponte pour les cycles de production 4 et 6 étaient respectivement le 10 février 2021 et le 6 octobre 2021.

Essai de production	Enclos marin	Taille de l'enclos (m^2)	Date de mise en charge	Nombre d'holothuries mises en charge	Poids médian à la mise en charge (g) (+/-DS)	Densité initiale de mise en charge (ind m^{-2})	Biomasse initiale de mise en charge (g m^{-2})	Poids médian final (g ind^{-1})	Nombre d'individus recapturés	Taux de recapture (%)	Biomasse finale (g m^{-2})	Nombre total de jours d'élevage	Taux de croissance (g ind^{-1} $jour^{-1}$)
4	Papehere 1	450	15/06/22	518	28	1.2	32.1	98	493	95%	108	468	0.15
	Papehere 2	450	15/06/22	518	28	1.2	32.1	140	495	96%	154	462	0.24
	Toarahiri 2	450	16/05/22	566	45 (± 17)	1.0	47.4	177	421	74%	166	485	0.27
	Toarahiri 3	450	16/05/22	614	45 (± 17)	1.0	47.5	151	483	79%	163	490	0.22
6	Toahotu 2	1700	23/01/23	1430	34 (± 8)	0.8	28.9	96	1052	74%	59	252	0.24

Tableau 2. Synthèse des essais de production aquacole de *H. fuscogilva* en Polynésie française, de la ponte jusqu'au prélèvement des animaux transférés en enclos.

Essai de production	Date de ponte	Date de fin	Durée totale de l'essai à partir de la ponte (jours)	Nombre d'animaux en fin d'essai	Poids médian par individu en fin d'essai (g)	Poids total en fin d'essai (kg)	Taux de croissance médian à partir de la ponte (g $jour^{-1}$ ind^{-1})
4	10/02/2021	15/09/2023	947	1792	137.3	246.1	0.14
6	6/10/2021	15/09/2023	709	1009	94.6	95.5	0.13

des autres. Par conséquent, on relève de larges écarts dans les déplacements potentiels ou effectifs des individus.

Il semble que, peu après leur transfert dans les enclos marins, les juvéniles commençaient à fouiller le biofilm présent sur les sédiments à la recherche de nourriture. Ils se couvraient aussi rapidement de sable et de macro-algues, ne se distinguant de l'environnement rocheux avoisinant que par leurs contours (figure 11). À première vue, seuls les excréments des animaux étaient visibles, trahissant leur cachette. Tous les juvéniles présents dans les enclos recouraient à cette stratégie de camouflage. Cette observation chez les juvéniles d'holothuries blanches à mamelles contribue à expliquer leur rareté dans les inventaires. L'équipe de TMP a aussi relevé que les individus de couleur foncée (marron foncé et orange foncé) semblaient recouvrir leur corps de sédiments foncés, tandis que les individus plus clairs optaient pour des sédiments de couleur claire, mais cette observation doit être confirmée par des études plus poussées. Plusieurs mois après leur transfert, la plupart des animaux restaient dans la zone centrale des enclos. On note quelques rares observations de juvéniles grimpant le long des parois grillagées des enclos.

Développement de l'élevage de l'holothurie noire à mamelles

Prélèvement des géniteurs

Depuis le démarrage du programme, Tahiti Marine Products et la DRM se sont fixé pour objectif d'évaluer la faisabilité de la production aquacole d'holothuries blanches et noires à mamelles en Polynésie française. Cet objectif a été compromis par la rareté de l'holothurie noire à mamelles aux abords de Tahiti. En effet, aucun individu de *H. whitmaei* n'a été trouvé ni dans les eaux de Tahiti ni dans celles des îles Sous-le-Vent (groupe d'îles à l'ouest des îles de la Société). Par conséquent, l'équipe du programme a dû chercher des géniteurs dans un archipel lointain.

Le programme a demandé à la CPS de conduire une analyse de risque afin d'accompagner le transfert responsable des holothuries noires à mamelles présentes dans l'archipel

Figure 11. Camouflage efficace à l'aide de macro-algues d'un grand juvénile de *H. fuscogilva* mis en élevage dans un enclos marin (crédit photo : © Mahanatea Garbutt).

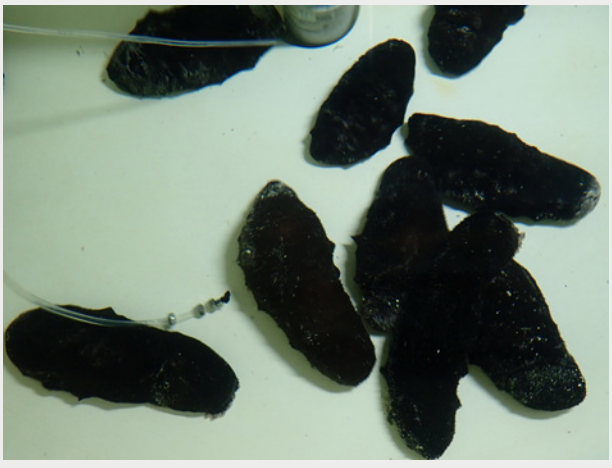

Figure 12. Quelques-uns des géniteurs d'holothurie noire à mamelles (*H. whitmaei*) conservés dans un bac des installations aquacoles du Centre Ifremer à Vairao, à l'est de Tahiti (crédit photo : © S.W. Purcell).

des Australes. Les protocoles de biosécurité préconisés par la CPS ont été utilisés pour limiter les risques d'introduction de nuisibles et de maladies. En 2023, TMP a obtenu l'autorisation de prélever 50 géniteurs de *H. whitmaei* sur l'île de Rimatara, dans l'archipel des Australes (figure 12).

Pour leur voyage vers Tahiti, les géniteurs adultes d'holothurie noire à mamelles ont été placés dans des tubes en PVC recouverts aux extrémités de toile d'ombrage, laissant passer l'eau de mer. Les animaux ont survécu au voyage, mais la toile d'ombrage a, par effet de frottement, partiellement abîmé leur tégument. Cette expérience a mis en lumière la nécessité de prévoir de meilleures conditions de transport pour les futurs transferts.

Ponte de l'holothurie noire à mamelles

Les essais de production aquacole à Tahiti ont montré que les géniteurs de *H. whitmaei* réagissaient aux mêmes types de stimuli déclencheurs de ponte que *H. fuscogilva*. C'est un résultat prometteur pour la production de gamètes. Les protocoles d'élevage larvaire mis au point pour *H. fuscogilva* semblaient aussi transférables à *H. whitmaei*, tandis que la croissance et les stades de développement des œufs et des larves sont à peu près les mêmes (voir figure 2).

D'après les recherches menées par Conand (1993) en Nouvelle-Calédonie, *H. whitmaei* pond principalement en hiver, et cette observation a été corroborée de manière générale par Shiell et Uthicke (2006) dans l'ouest et l'est de l'Australie. La première ponte obtenue par l'équipe de TMP chez *H. whitmaei* s'est produite juste après le transfert des géniteurs sur Tahiti, à savoir pendant la saison fraîche (juin). L'émission de gamètes a été observée en majorité chez des individus mâles, trois femelles ayant produit 11 millions d'œufs (tableau 3). Une deuxième ponte a été induite trois mois plus tard, alors que les animaux avaient à nouveau subi le stress du transport et d'un changement d'environnement. De nouveaux essais d'induction de ponte seront menés en 2024 afin d'étudier la saisonnalité de la reproduction.

Élevage en nourricerie de l'holothurie noire à mamelles

Les juvéniles de *H. whitmaei* produits lors des essais de production ont été transférés dans des filets à poche installés dans deux bassins en terre dans les installations aquacoles de Vairao. Les essais d'élevage en nourricerie étaient en cours à la date de rédaction du présent article ; les données disponibles à ce stade sont donc limitées. Toutefois, il apparaît déjà que les juvéniles de *H. whitmaei* ont une croissance plus rapide que ceux de *H. fuscogilva*. En effet, après un séjour de trois mois en nourricerie, les juvéniles de *H. whitmaei* pesaient en moyenne 1,8 g (figure 13). On notera à titre de comparaison que, pour atteindre le même poids, les juvéniles de *H. fuscogilva* ont dû passer en moyenne 4 à 6 mois en nourricerie.

Figure 13. Quelques holothuries noires à mamelles (*H. whitmaei*) après 3 mois d'élevage en nourricerie, où elles étaient placées dans des filets à poche dans un bassin en terre à Vairao, à l'est de Tahiti (crédit photo : © L. Burgy).

Les juvéniles de *H. whitmaei* pesant entre 1 et 10 g sont de couleur beige orangé et présentent des points et taches noirs irréguliers au niveau de la face dorsale (figure 14). Les premiers stades juvéniles sont parsemés de nombreuses papilles dorsales et latéro-dorsales, mais ces dernières sont généralement plus petites et plus claires que celles observées chez les juvéniles d'holothuries blanches à mamelles de même taille. On peut supposer que les taches noires qui apparaissent sur le corps des holothuries noires à mamelles aux stades juvéniles s'étendent sur toute la face dorsale avec l'âge et que les papilles dorsales deviennent relativement plus petites par rapport à la taille de l'animal.

Conclusions

Après plus de trois ans de recherche et développement, Tahiti Marine Products et ses partenaires (la DRM et l'Ifremer) sont parvenus à démontrer la faisabilité technique de la production d'holothuries à mamelles en écloserie en Polynésie française. Les fondements de cette nouvelle

Tableau 3. Synthèse des résultats des pontes et de la production des premiers stades juvéniles de *H. whitmaei* en Polynésie française.

Essai de production	Date de ponte	Nombre de géniteurs utilisés	Nombre de mâles ayant émis des gamètes	Nombre de femelles ayant émis des gamètes	Nombre total d'œufs (millions)	Taux de fécondation (%)	Nombre de juvéniles produits	Taux de survie (de la production de l'œuf jusqu'à la sortie d'écloserie)
1	06/06/23	50	9	3	11,2	95	210 000	1,88
2	30/09/23	49	7	3	15,0	95	50 000	0,33

Figure 14. Petits juvéniles d'holothuries noires à mamelles (*Holothuria whitmaei*), pesant entre 4 et 6 g, produits à l'écloserie de TMP en Polynésie française (crédit photo : © L. Burgy).

filière aquacole durable en Polynésie sont à présent posés et témoignent de grandes avancées techniques.

Ces premières années de développement technologique en Polynésie française ont permis d'obtenir des taux de survie de l'ordre de 1 à 3 % en écloserie (transition du stade œuf au stade juvénile, 1 à 3 g). L'objectif du programme est de parvenir à un taux de survie de 5 % et de produire plusieurs millions de juvéniles par an. Les taux de croissance relevés pendant les phases de pré-grossissement et de grossissement en enclos marins étaient relativement faibles, en particulier pour *H. fuscogilva.* Ces taux devraient être proches de ceux observés dans le milieu naturel, puisqu'aucun apport de nourriture n'a été effectué dans les enclos et que les densités de mise en charge étaient peu élevées. Il convient de mener davantage d'essais et de recherches afin de déterminer les habitats qui assureront des taux de survie constants et élevés, tout en favorisant une meilleure croissance. Les enseignements tirés des différentes phases du projet laissent entrevoir une possible réduction du cycle total d'élevage à 24 mois pour l'obtention de juvéniles de grande taille, ce qui permettrait de mettre en place un modèle d'activité performant.

Le lancement du projet territorial d'aménagements aquacoles à Faratea, sur l'île de Tahiti, permettra au programme d'étendre à plus grande échelle sa production, grâce à la construction d'une nouvelle écloserie commerciale et de nouveaux bassins de nourricerie. Le programme cherche à optimiser ses protocoles de production afin de créer une nouvelle filière aquacole pour la Polynésie française. Le modèle de production pourrait à terme être transféré à d'autres pays insulaires océaniens.

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First report of skin ulceration disease from temperate waters of the Northwest Atlantic: The case of the sea cucumber *Cucumaria frondosa*

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Abstract

Approximately 60–70 adult individuals of the dendrochirotid sea cucumber *Cucumaria frondosa* –collected in waters off the coast of insular Newfoundland in eastern Canada – presented injuries consistent with skin ulceration disease (SKUD). An examination of 31 individuals that were suspected to be diseased revealed some cases of white-coloured lesions or ulcerations on the body wall, evisceration of internal organs, liquefaction of the dermis, and loss of podia attachment strength. Another 11 diseased individuals were quarantined and, eventually, exhibited liquefaction of the entire body and died. To our knowledge, this is the first time a condition consistent with SKUD has been reported in temperate–subpolar waters of the Northwest Atlantic and, the first time in *C. frondosa*, which is a commercially valuable species.

Keywords: dendrochirotida, health, outbreak, skin disease, SKUD

Introduction

The dendrochirotid sea cucumber *Cucumaria frondosa* (Gunnerus, 1767), commonly known as the orange-footed sea cucumber, occurs in the cold waters of the Arctic and North Atlantic (Mercier et al. 2023). In the northwest Atlantic, this species is commercially fished in the Canadian provinces of Quebec, New Brunswick, Nova Scotia, Newfoundland and Labrador, and in the French territorial waters of Saint-Pierre-et-Miquelon (DFO 2021; Gianasi et al. 2021; Mercier et al. 2023). The species has also been used for generations by some indigenous communities as part of a subsistence fishery in the Canadian Arctic (Mercier et al. 2023; Hamel and Mercier 2024).

There are multiple diseases described in holothuroids such as acute peristome edema disease, viscera ejection syndrome, and off-plate syndrome (Smith et al. 2022). Skin ulceration disease (SKUD), which can also be referred to as skin ulcer syndrome or SUS, has been described in tropical and temperate species (Delroisse et al. 2020). This disease is typically fatal; its common symptoms include anorexia, skin ulcers, swollen oral region, evisceration, general atrophy, and increased mucus secretion (Becker at al. 2004; Delroisse et al. 2020; Smith et al. 2022). Moreover, white spots can appear on the dermis, the dermis and connective tissue can be destroyed (i.e. liquefaction), and ulcers can enlarge over time, perforating the body wall (Delroisse et al. 2020).

SKUD was described in several species, all of which are commercially exploited: *Holothuria scabra* in the Indo-Pacific (Delroisse et al. 2020), *H. arguinensis* in the northeast Atlantic (Cánovas et al. 2019), and *Apostichopus japonicus* in the temperate western Pacific (Deng et al. 2009; Shao et al. 2013). Moreover, the disease was described in captive and cultivated sea cucumbers and, in some instances, wild sea cucumbers in Portugal (Cánovas et al. 2019; Delroisse et al. 2020).

This skin disease was first detected in juveniles of *A. japonicus* and was originally thought to be linked with elevated temperatures and high stock densities (Zhang and Liu 1998). Many factors induce the disease including bacteria, viruses, and parasites (Delroisse et al. 2020; Smith et al. 2022). Specifically, *Vibrio sp., Shewanella sp.,* and *Pseudoaltermonas sp.* are bacterial pathogens that have been put forward as causative agents of SKUD in sea cucumbers (Shao et al. 2013; Cánovas et al. 2019; Smith et al. 2022). Some suspected causative agents may be species specific; for example, certain types of bacteria or a diet containing high levels of animal organic matter (i.e. an inappropriate diet; Delroisse et al. 2020). Environmental and physiological stressors, such as high stocking density or thermal stress, may also be a proxy for SKUD outbreaks, as Zhang and Liu (1998) found the disease in *A. japonicus* under high stocking conditions and Delroisse et al. (2020) found it in *H. scabra* after prolonged exposure to low temperatures.

In this report, we document suspected cases of SKUD among individuals of a laboratory-held population of *C. frondosa* by comparing disease-associated symptoms with those previously described in the literature, and exploring potential co-incident causative factors. Also, we discuss the possible progressive deterioration of infected individuals, starting with the appearance of exposed collagenous connective tissue, then perforation on the body wall leading to evisceration, and ultimately liquefaction of the entire body wall.

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Methodology

More than 600 adult individuals of the sea cucumber *Cucumaria frondosa* were collected by hand via scuba at depths of ~10–15 m in Tors Cove, Newfoundland and Labrador, Canada (N47°12'44"; W52°50'39") between 2022 and 2023 for various fundamental and applied studies. In the laboratory (Ocean Sciences Centre, Memorial University), the collected individuals were transferred to independent flow-through tanks supplied with unfiltered ambient seawater. These sea cucumbers experienced the natural photoperiod through large windows and, as suspension feeders, they had access to ambient levels of food particles. Throughout the study period – from the beginning of March to the end of November 2023 – seawater temperatures in flow-through tanks were recorded using a temperature logger (HOBO Pendant Temperature/Light 64K Data Logger UA-002-64).

In the laboratory, *C. frondosa* were maintained at densities between 20 and 30 individuals per square metre and monitored regularly for mortality. These conditions would be typical in nature, with densities upwards of 50 individuals per square metre recorded in eastern Canada (Hamel and Mercier 1996; So et al. 2010; Gianasi et al. 2021; Hamel et al. 2023). Water flow and seawater temperature were monitored regularly.

All individuals showing signs of body-wall damage or signs of disease were taken out of the holding tank (~60–70 individuals over the study). A subset of these individuals (n = 31) was photographed and preserved in 70% ethanol. Another subset (n = 11) was quarantined in a separate holding tank to examine the disease (degradation) progression. The whole wet weight of some of these individuals (n = 24) was determined using a digital balance (Optima OPD-A).

Results and discussion

All unhealthy individuals of *Cucumaria frondosa* that were isolated and examined (i.e. those showing signs of abnormal body-wall conditions) lost podia attachment strength, and some exhibited swelling of the oral region (specifically the introvert, the collar of flexible tissue behind the buccal tentacles and associated structures that can be pulled into the body cavity by retractor muscles; see Mercier et al. 2023). For comparison, a healthy unaffected individual exhibited an unblemished body wall and tended to retract its introvert when disturbed (Fig. 1A). An external examination of the subset of 31 unhealthy individuals revealed that 84% (n = 26) presented white-coloured lesions or ulcers on the dermis (Fig. 1B–C). Fifty-four percent of individuals (n = 17) eviscerated internal organs (e.g. the digestive tract, gonads, respiratory tree) through a perforation of their body wall (Fig. 1D). Moreover, 10% (n = 3) exhibited liquefaction of the dermis (Fig. 1E–F). These dermal injuries tended to expose the white-coloured collagenous connective tissue underneath the dermis (Fig. 1B–F). These symptoms – white-coloured lesions and a swollen oral region – were consistent with those previously described in SKUD-affected individuals of other holothuroid species (Delroisse et al. 2020; Smith et al. 2022).

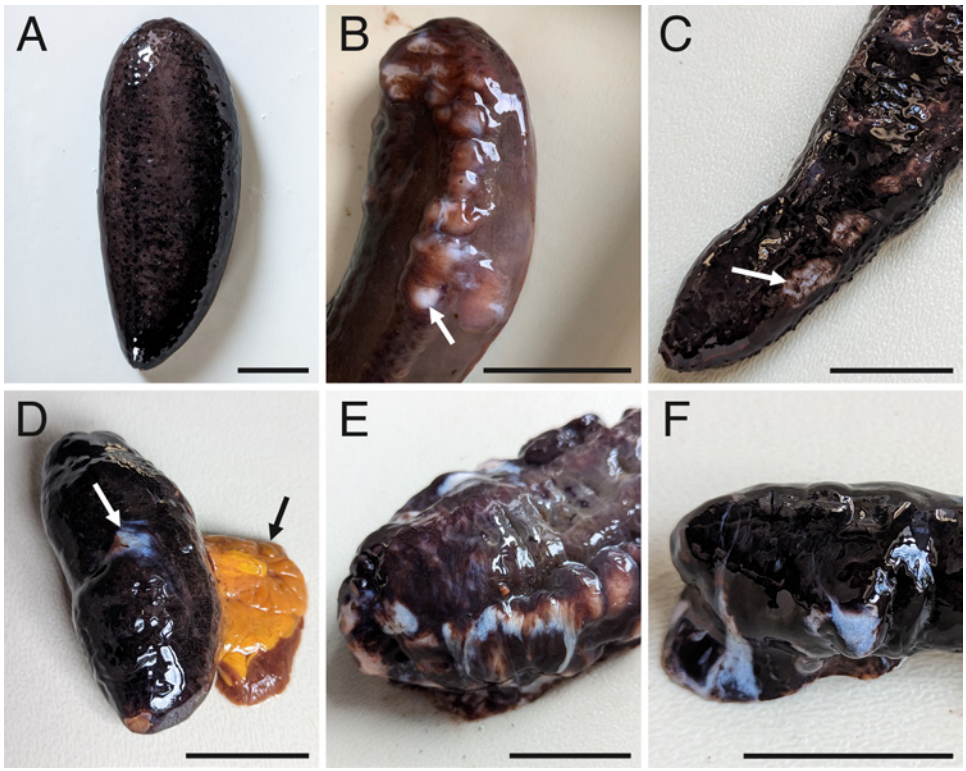

Figure 1. (A) A healthy unaffected *Cucumaria frondosa* individual; (B–C) individuals displaying white-coloured lesions or ulcers (white arrows), exposing the collagenous connective tissue underneath; (D) a case of evisceration through a perforation of the body wall (black arrow) and early signs of liquefaction of the dermis (white arrow); and (E–F) liquefaction of the dermis. Scale bars represent 3 cm.

In the laboratory, affected *C. frondosa* individuals tended to be observed from the same tanks, such that multiple independent tanks were affected. One characteristic aligning with previously described SKUD symptoms in sea cucumbers was the initial appearance of lesions or ulcers near the cloaca and the oral region, later spreading to the rest of the body (Delroisse et al. 2020). Among the 26 individuals with lesions or ulcers on the dermis, 42% (n = 11) had lesions near the oral region, 12% (n = 3) had lesions near the cloaca, 12% (n = 3) had lesions only around the mid-body section, 8% (n = 2) had lesions on both ends, and 27% (n = 7) had lesions all over the body. However, the sequence of events related to the appearance and spread of lesions and ulcers was not observed in the present study.

Affected individuals of *C. frondosa* tended to be smaller in size, with an average wet weight (± standard deviation) of 112 ± 60 g (n = 24), compared to the average size of sea cucumbers in the laboratory (wet weight of ~180 g). SKUD was found to affect smaller individuals (juveniles) of both *Holothuria scabra* (Becker et al. 2004) and *Apostichopus japonicus* (Zhang and Liu 1998), although small adult individuals of *C. frondosa* discussed here were substantially larger than those juveniles.

Individuals with only lesions or ulcers responded sluggishly to haptic stimulation, suggesting that this may be the initial phase of disease. Eviscerated individuals usually had some damage to the body wall, which could be a combination of white-coloured lesions or ulcers, perforation through the body wall, or early signs of liquefaction of the dermis. Individuals with near-complete liquefaction of the dermis were not responsive to haptic stimulation, indicating that this could be a late phase of disease. Delroisse et al. (2020) described SKUD in stages (I–IV), which is comparable to the progression seen in the present study. Quarantined individuals of C. frondosa (n = 11) eventually exhibited liquefaction of the entire body, death and decomposition over time (with an associated putrid smell). None of the infected individuals in quarantine survived, and less than three to four weeks elapsed between the first symptoms and mortality. Mortality was also the usual outcome for sea cucumbers affected by SKUD in previously studied species (Delroisse et al. 2020, Smith et al. 2022).

Although the causative agent for SKUD is unknown, there are some proposed hypotheses regarding what the agent(s) may be, such as pathogens and thermal stress (Zhang and Liu 1998; Delroisse et al. 2020). Although not observed as a causative or potentially correlated stressor in other studies, it should be noted that this outbreak was also co-incident with the physiologically demanding breeding season of *C. frondosa* in insular Newfoundland (i.e. between February and May; Mercier and Hamel 2010), with spawning observed in mid-April 2023 in the laboratory population. The latter outbreak event in the fall was co-incident with temperature changes: a spike to 12.6°C occurred on 22 September (from 4.4°C on 21 September and back down to 2.2°C on 23 September), followed by prolonged warmer temperatures through October (an average of 8.5 ± 1.5°C) compared with cooler temperatures in August (2.8 ± 0.8°C; Fig. 2). However, the thermal regime experienced by the individuals overall was similar to that of every other year, possibly being a bit colder than usual. Unlike experimental cases in which SKUD was induced by thermally shocking juveniles of *H. scabra* (Delroisse et al. 2020), the observed temperatures during the study period were not novel to the cold-temperate *C. frondosa*. Moreover, this species has been kept in the same laboratory for the past two decades, with no occurrence of this disease before the recent cases reported here.

As a response to a possible outbreak, any transfer of organisms or materials (e.g. live rock, kelp, or other décor) between affected and unaffected tanks was halted. Moreover, a protocol of soaking equipment (e.g. waterproof gloves and nets) with a multi-purpose disinfectant (Virkon) was implemented during the middle of the study period to minimise the transfer of the putative pathogen from one tank to another, and all individuals suspected of exhibiting signs of SKUD were quarantined in isolated holding tanks or discarded. These procedures showed no indication of eliminating the disease from the laboratory-held population. The conditions observed in *C. frondosa* included the loss of podia attachment strength, presence of white lesions, swollen oral region, evisceration and liquefaction. These symptoms are similar to those described in SKUD cases in other sea cucumber species (Delroisse et al. 2020; Smith et al. 2022). The population size of *C. frondosa* in the laboratory increased by about 500% with a moderate increase in stocking density (i.e. about 50% increase) around the time of the initial outbreak, which could have been one of the main inducing factors. The second outbreak coincided with a temperature spike (+8.2°C peak occurring over <24 h before returning to normal) followed by a seasonal increase (+5.7°C in October), although the increase was not outside of the normal range experienced by individuals housed in the laboratory. Thermal stress is thought to be an abiotic factor in SKUD onset, as well as stocking density (Delroisse et al. 2020), although their correlation with the outbreak in the current study is tenuous.

Geographically, documented cases of SKUD in *Actinopyga japonicus*, *Holothuria arguinensis* and *H. scabra* were previously reported from the Pacific in China, northeast Atlantic in Portugal, and from the Indo-Pacific in Australia, Indonesia, Madagascar, Malaysia and Vietnam, respectively (Delroisse et al. 2020). The suspected outbreak in *C. frondosa* (this study) represents the first report of SKUD in temperate–subpolar waters of the northwest Atlantic and the first time for this suspension-feeding dendrochirotid sea cucumber.

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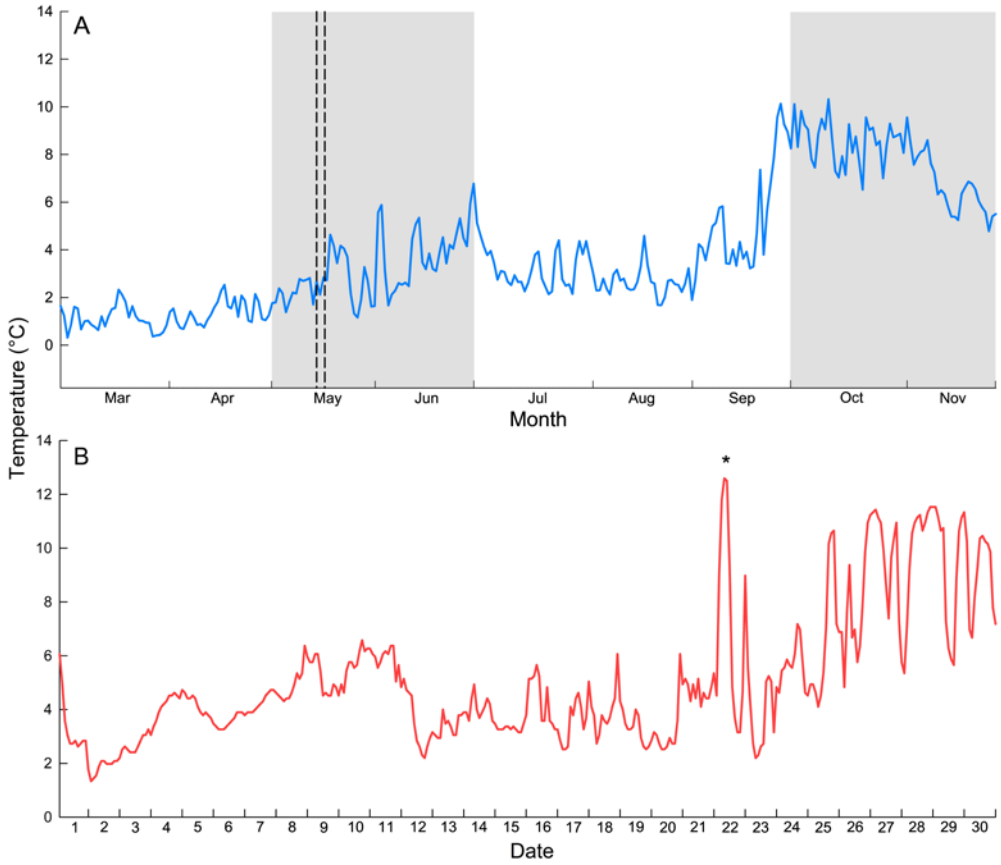

Figure 2. Figure 2. (A) Mean daily temperature from 1 March to 30 November 2023, and (B) temperature recorded every two hours for the month of September 2023. Grey areas in panel A indicate suspected outbreaks of skin ulcerating disease (SKUD) in laboratory-held individuals of *Cucumaria frondosa*; dotted lines in panel A are dates when population size and stocking density was increased; * in panel B indicates the highest temperature measured for the entire study period.

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The sea cucumber trade in Tunisia: Insights from the central Mediterranean Sea

Hayfa Chammem[1, 2]

Abstract

This contribution provides a comprehensive analysis of sea cucumber trading in Tunisia, emphasising targeted species in the central Mediterranean Sea. Drawing insights from a diverse range of sources, it offers a detailed overview of the status of the sea cucumber trade in the region. The findings shed light on the dynamics of sea cucumber commerce in Tunisia, addressing key aspects such as species preferences, market trends, and the role of social media in shaping trade practices. This analysis contributes valuable insights for policy-makers, researchers, and industry stakeholders involved in the sustainable management and development of sea cucumber resources in the central Mediterranean.

Keywords: Sea cucumber fishery, Tunisia, central Mediterranean Sea, market trends, trade practices, species preference

Introduction

In the Mediterranean, the exploitation of sea cucumbers is relatively limited, and is not a thriving industry. Moreover, fishing, processing and marketing persist, frequently involving illegal and unregulated practices with no form of control. According to Rakaj and Fianchini (2024), insights from the literature reveal evidence of local sea cucumber consumption and exportation in Italy before the World War II. In this era, *Holothuria poli* and *H. tubulosa* were especially exploited.

Today, Turkey is the leading Mediterranean country for the harvest and export of sea cucumbers, mainly to Singapore and Hong Kong (Aydin 2008; Conand et al. 2014; Rakaj and Fianchini 2024). The sea cucumber fishery in Turkey mainly targets *H. tubulosa, H. poli* and *H. mammata* (Aydin 2008; Sicuro et al. 2012; González-Wangüemert et al. 2018).

In Tunisia, there are some references to the exploitation of *Holothuria tubulosa, H. poli, H. sanctori* and *H. forskali*, although information is scarce (Telahigue et al. 2014; Ben Mustapha and Hattour 2016a,b; Sellem et al. 2017; Sellem et al. 2019). Sellem et al. (2019) have delved into the diversity of sea cucumbers in Tunisian lagoons, providing a more nuanced perspective on the prevalence and ecological significance of these species in Tunisia.

Nonetheless, there is little information regarding sea cucumber stocks and fishery activities in the country. This study seeks to explore the current status and potential of sea cucumber fisheries in the region, underscoring the importance of implementing sustainable management practices in the face of increasing exploitation pressures.

Methodology

Facts presented in this study regarding target sea cucumber species in Tunisia are sourced from a review of available articles, checklists, reports, and social networking platforms such as Facebook. Data on total production and commercialisation were gathered from authoritative sources, including Tunisia's National Institute of Statistics and the Department of Fisheries and Aquaculture.

Results

Sea cucumber trading in Tunisia

Recent holothurian production data for Tunisia is presented in Table 1. Findings from the Tunisian National Institute of Statistics reveal a dynamic pattern in the marketing of beche-de-mer over time.

Exportation of this product started in 2013, but was notably absent in 2014 and from 2016 to 2019. Each year, the export of beche-de-mer was limited to one or two markets, spanning different countries across Asia, Europe, Africa and America where Hong Kong consistently stands out as the main destination for exports.

Sea cucumber production has been disorganised over the years, marked by a significant surge in 2020, reaching a total of 23,412 kg. The lowest production was about 120 kg while the largest was about 20,700 kg, which was destined for Turkey. This could be linked to external factors such as the fishing regulations implemented by Turkey during the same period which suggest a possible influence of these regulations on the trade dynamics. Turkey's measures, including a prohibition on fishing during the reproductive period, restrictions on specific fishing gear usage, and the implementation of quotas (Rakaj and Fianchi 2024), likely prompted changes in sea cucumber production patterns. The surge in production may be a response to increased demand or altered trade dynamics resulting from Turkey's efforts to

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restore and preserve wild stocks. It also serves Turkey's strategic goal to maintain its position as the primary exporter of sea cucumbers in the Mediterranean, ensuring control over its market.

Data on sea cucumber commercialisation, collected from the Tunisian National Institute of Statistics (on foreign trade) and the Department of Fisheries and Aquaculture, reveal that the most exploited species are *Holothuria tubulosa, H. poli* and *H. mammata.* Typically, these sea cucumbers are captured through diving, dredging or even by hand, as they mainly inhabit the shallow waters of coastal lagoons. These species are exported in raw, frozen and dried forms, yet, there is a lack of information regarding the processing method.

Through a basic Facebook search for pages related to sea cucumber commercialisation in Tunisia, over 10 pages were found to be devoted to selling Tunisian beche-de-mer. These pages offer raw, dried and powdered products, tailored to customer demand. It is worth noting that these pages do not represent formal company entities, but rather private enterprises. However, a fair number of Tunisian companies have been operating legally since 2016.

From the published photos, it was possible to discern that the main harvested and exported species are *Holothuria poli* and *H. tubulosa,* originating from diverse coastal regions spanning the northern to southern parts of Tunisia (Fig. 1).

There is currently limited demand for products derived from sea cucumbers in Tunisia because the exploitation of these creatures has only recently begun. Therefore, within their profiles, these pages provide information on the curative and gastronomic values of sea cucumbers, often sharing recipes associated with their culinary use.

Coastal lagoon fishing spotlight: Holothuria poli

Tunisia's sea cucumber fishery is chiefly concentrated in lagoons, notably the Bizerte Lagoon in northern Tunisia and the Boughrara Lagoon in the south, both intricately connected to the Mediterranean Sea. Sellem et al. (2019) identified seven holothurian species within these ecosystems, with the predominant species being *H. poli*. In Sidi Daoud Lagoon, over 43.7% of sea cucumbers were *H. poli,* thus showcasing its prevalence (Ben Mustapha and Hattour 2016a). Chammem (2021) reported that more than half of the *H. poli* specimens collected from northern Tunisia were found in Bizerte Lagoon (Fig. 2).

The adaptability of *H. poli* was evident in various environmental conditions, thriving in both coastal and open sea environments, thereby demonstrating its robust capacity to endure diverse biotic and abiotic factors. Classified as an euryoecious species, *H. poli* exhibited wide ecological range, colonising habitats from the Red Sea to the Mediterranean Sea.

On the other hand, despite its smaller size, *H. poli* is a widely cultivated and popularly exploited sea cucumber in the Mediterranean, offering nutritional richness with high protein and mineral content and a low-fat profile (Benedetto and Jay 2011; Sellem et al. 2017; Rakaj et al. 2019). Biandolino and colleagues (2022) further report on the health benefits of consuming *H. poli,* emphasising its valuable nutritional contributions and indicating a low risk of chronic systemic effects.

Table 1. Beche-de-mer production in Tunisia (in kilograms), 2010–2023.

National Institute of Statistics – Tunisia														
INFORMATION BY PRODUCT														
Export by product in quantity (kg) 030819-others ``Beche- de-mer´´														
Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Turkey	-	-	-	-	-	-	-	-	-	-	20700	-	-	-
Senegal	-	-	-	-	-	-	-	-	-	-	-	-	-	200
Canada	-	-	-	120	-	-	-	-	-	-	180	-	-	-
Unites States	-	-	-	250	-	-	-	-	-	-		-	-	-
United Arab Emirates	-	-	-	-	-	235	-	-	-	-	-	-	-	-
Hong Kong	-	-	-	-	-	-	-	-	-	710	1455	749	1895	1613
Singapore	-	-	-	-	-	-	-	-	-		225	-	-	-
Undetermined countries	-	-	-	-	-	-	-	-	-	-	852	500	-	-

Source: Tunisian National Institute of Statistics - Exports

Figure 1. The three forms of exported sea cucumber, as found on Facebook: powdered, dried and raw.

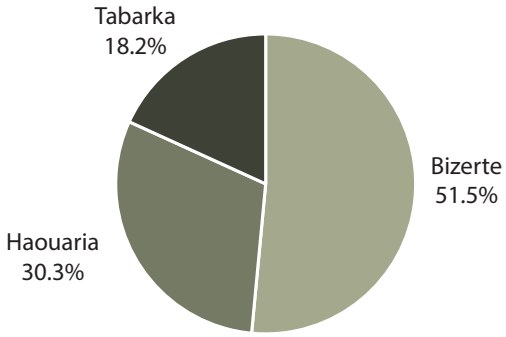

Figure 2. Percentages of *Holothuria poli* collected at different stations from northern Tunisia.
Source: Chammem 2021

Discussion

The sea cucumber fishery in Tunisian lagoons is of ecological importance, particularly for *H. poli.* This species, however, is under threat from overexploitation, illegal fishing and habitat destruction. Coastal lagoons in Tunisia face challenges such as illegal fishing and environmental degradation due to industrial and harbour-related activities that lead to wastewater and sewage pollution (Ben Garali et al. 2009; Guetat et al. 2012; Ben Mustapha and Hattour 2016a,b).

Recognising the vital ecological role of holothurians in marine ecosystems is crucial to establishing a structured framework for sea cucumber management and exploitation in Tunisia, and to ensuring the persistence of stocks.

Sea cucumber exploitation in Tunisia began in 2013 as a response to illegal fishing pressure in lagoon environments. Despite its recent introduction, commercialisation remains limited and disorganised. To ensure sustainability, it is recommended that measures such as restricting harvesting in terms of number, times and space be implemented. Critical components include controlling the number of catches and maintaining detailed biological records, including systematic classification, age at maturity, and biometric data. Ben Mustapha and Hattour (2016a) suggested limiting catches to 50 individuals per day for three months, only during a specific period each year. Furthermore, harvesting is strictly forbidden from June to August, corresponding to the reproduction season of sea cucumbers.

Knowledge about sea cucumber biological diversity, stock status, and processing methods is significantly limited in Tunisia. Additionally, data related to their reproduction, recruitment, growth and mortality is largely absent. To address this, it is recommended that states regulate fishing efforts, allowing only licensed fishermen to collect holothurians in well-defined periods and areas.

Efforts should prioritise technical support for stock assessments, training, and promoting sea cucumber breeding, especially among young researchers. The Higher Institute of Fisheries and Aquaculture in Bizerte has commendably initiated sea cucumber aquaculture, focusing on *Holothuria forskali*, and is actively studying diversity, abundance, exploitation and processing in Bizerte Lagoon. While this initiative is commendable, it needs to be funded and implemented nationwide. Otherwise, a common management approach involves licensing exporting agents for overseeing beche-de-mer exports and limiting illegal trade. Agents must submit detailed reports, and fishers and customers need to be educated about sea cucumber conservation and good management.

Conclusion

Sea cucumber exploitation in Tunisia began in 2013, and is marked by challenges and opportunities. Achieving sustainable management is imperative, and there is a critical need for controlled harvesting practices and thorough data collection. The lack of understanding about sea cucumber biology and reproduction underscores the importance of regulatory measures, technical support for stock assessments, and targeted training for researchers. Although commendable efforts are underway, a comprehensive, well-funded and nationwide approach is essential for the effective and responsible management of sea cucumber resources in Tunisia.

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First observations of *Actinopyga* cf. *flammea* Cherbonnier, 1979 in Cook Islands

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Species: *Actinopyga* cf. *flammea* Cherbonnier, 1979

Context: *Actinopyga flammea* was first described by Cherbonnier in 1979 in New Caledonia, where it was found at 40–45 m depth on the outer reef among coral debris, and brown and coralline algae (Cherbonnier, 1979). A holotype specimen is held in the echinoderm collection of the Muséum National d'Histoire Naturelle in Paris, France (MNHN-IE-2013-17833; Cherbonnier 1979).

Since its description, records of this species in the scientific literature have been rare. Purcell et al. (2012) described a similar species, tentatively named *Actinopyga* sp. aff. *flammea*, that is fished in New Caledonia, Fiji and Tonga (Purcell et al. 2012). Purcell et al. (2012) wrote that this species closely resembles, but differs genetically from, the *A. flammea* described by Cherbonnier (1979), however details of this genetic analysis were not provided in the report.

It has been suggested that some *Actinopyga* species may be considered as species complexes (Alcudia-Catalma et al. 2020). For example, high genetic diversity was observed in the mitochondrial COI gene region between *Actinopyga echinites* specimens from different geographic locations (Bohol and Ilocos Norte in the Phillipines; Alcudia-Catalma et al. 2020). In contrast, a different study found both *Actinopyga flammea* and *A. caerulea*, to be indistinguishable from *A. palauensis* when comparing mitochondrial COI sequences (Michonneau et al. 2015), although this was limited to an analysis of one individual per species. Further investigation is required to resolve the genetic and morphological diversity within and between *A. flammea* and closely related species.

Both *Actinopyga flammea* and *A.* sp. aff. *flammea* (*sensu* Purcell et al. 2012) are considered rare species, inhabiting waters between depths of 35 m and 60 m (Bhatnagar et al. 1984; Purcell et al. 2012; Pakoa et al. 2013; Motuhi 2016). Their presence in fisheries catches is likely a result of an increase in deep-water harvest effort (Pakoa et al. 2013). *Actinopyga* sp. aff. *flammea* is fished in low numbers in Fiji and Tonga (Pakoa et al. 2013; Purcell et al. 2012; Ravinesh et al. 2016; Moore et al. 2017). In Fiji, it is considered a "high-value species", fetching USD 5–15 USD per fresh specimen (Pakoa et al. 2013; Purcell et al. 2012), although Purcell et al. (2014) noted that this value is much lower than the highest valued species, *Holothuria scabra*.

Aside from its commercial exploitation, *A. flammea* has been reported to be highly ichthyotoxic and used as a fish poison by fishers in the Philippines (Motuhi 2016). Multiple novel triterpenoid saponin compounds have been isolated and characterised from *A. flammea* as part of a bioprospecting study in New Caledonia (Motuhi et al. 2016) following an earlier discovery of triterpenoid saponins from this species (Bhatnagar et al. 1984).

In the Cook Islands, shallow-water sea cucumbers, including *Holothuria* spp. and *Actinopyga varians*, are harvested locally for subsistence and by fishers in small quantities for local artisanal sale. Sea cucumbers are harvested by hand, with gleaning focused in lagoons and on reef flats and reef crests. Underwater breathing apparatuses, trawling and dredging are not used, and harvesting sea cucumbers for commercial export does not occur. Harvests confined to shallow waters and limited resource survey efforts at depth are the likely reason *A. flammea*/*Actinopyga* sp. aff. *flammea* have not been previously recorded in the Cook Islands.

Date of observations: 5 December 2023

Location: Fore reef slope, 50 m depth, west coast, Atiu, Cook Islands (approximate coordinates: -19.978810°, -158.141161°)

Approximate sizes: 30–35 cm

Observation: One exploratory 83-minute scuba dive was conducted by one diver. The dive started at 54 m depth and finished in 3 m depth. Two specimens of what were identified as *A.* cf. *flammea* were observed (Fig. 1). Identification was based on morphology consisting of a reddish-pink body covered in blue-grey conical papillae as described by Cherbonnier (1979) and Purcell (2012). The specimens were located within 5 m of each other, at a depth of ~50 m.

The habitat was a steep reef, with a slope greater than 45 degrees. The substrate comprised coral pavement, sand, algae and hard corals.

These are the first records of the species in Cook Islands.

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Figure 1 a and b. Two specimens of *Actinopyga* cf. *flammea*. Images © Kirby Morejohn, Ministry of Marine Resources, Cook Islands.

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Variation in a *varians*: A mutant *Actinopyga varians* from Cook Islands

Michael Parrish

Species: *Actinopyga varians*

Date of observation: 28 November 2023

Location: West coast of Atiu, Cook Islands (approximate coordinates S 20°0'4.10", W 158°8'32.55")

Depth: < 0.3 m

Habitat: Reef flat with coral pavement and sand substrate

Total length: 24 cm

Note: An adult *Actinopyga varians* was observed on the reef flat on the western side of Atiu, Cook Islands. The sea cucumber had a partial split longitudinally starting from the posterior end. The two posterior ends each had a terminal anus; one end had three teeth and the other had five teeth. There was a difference in length of 4 cm between the two posterior ends. The longer of the two posterior ends was lighter in color than the rest of the cucumber (Fig. 1A and B).

Figure 1. A: An adult *Actinopyga varians* with longitudinal split resulting in two posterior ends; B: terminal anus on each posterior end; one with three teeth, the other with five teeth. Images: © Kirby Morejohn, Ministry of Marine Resources, Cook Islands

Confirmation and extended range of *Holothuria spinifera* in the Abrolhos Islands, Western Australia

Dave Murphy[1]* and Anthony Hart

Abstract

This is the first known reporting of *Holothuria spinifera* from Western Australia. An individual sample was collected by fishers and researchers from the Abrolhos Islands on 30 January 2023, at a depth of 18 m and a GPS location of S28° 25.7, E113° 46.7. A morphological, anatomical and endo-skeletal description was carried out on the individual. This study extends the known distribution of *Holothuria spinifera* to the southwestern part of Western Australia.

Keywords: *Holothuria spinifera,* Abrolhos Islands, Western Australia, trawl fisheries, ossicles

Introduction

Holothuria spinifera Théel, 1886 is a filter feeding scavenger, sifting through the sediment on the seabed with its tentacles. It can completely burrow in the daylight and is generally more active at night or on incoming tides. The animal reproduces bi-annually. Reproduction peaks in September and October, with a minor peak in February and March. It is known to have prolonged spawning in India from November to March. *Holothuria spinifera* is a sea cucumber species that is commercially harvested and reported from East Africa, Middle East, India, Southeast Asia, Indo-Pacific, and northern Australia. Its common name is brown sandfish. In India it is known as *cheena attai* or *raja attai*.

Methodology

A collaboration with Australia's Department of Primary Industry and Regional Development fisheries researchers and fishers of the Abrolhos Islands Mid-West Trawl fishery allowed the collection and study of bycatch within this fishery. Samples were sent to the laboratory in Perth for further identification and analysis. The specimen was caught in a fishing trawl and immediately sorted on deck, individually bagged and labelled, and then frozen.

A small slice of flesh (15 mm x 3 mm) from the specimen's dorsal side, anus, mouth and body wall papillae (spots) were placed into separate Eppendorf vials and soaked in bleach for 20 minutes. After 20 minutes, the bleach was drained and the remaining sample washed about five times with fresh water. Using a pipette, the ossicles were extracted and drops then placed under a compound microscope. High-definition photos were taken of the ossicles in each sample. These photos were used to compare the descriptions of ossicles from the published species identification paper "Commercially Important Sea Cucumbers of the World, FAO Species Catalogue for Fishery Purposes No. 6".

Results and discussion

Description

Holothuria spinifera can reach 30 cm (live length), with an average wet weight of 300 g. This species has a cylindrical, sausage shape, with a pimpled, rough dorsal surface, and a

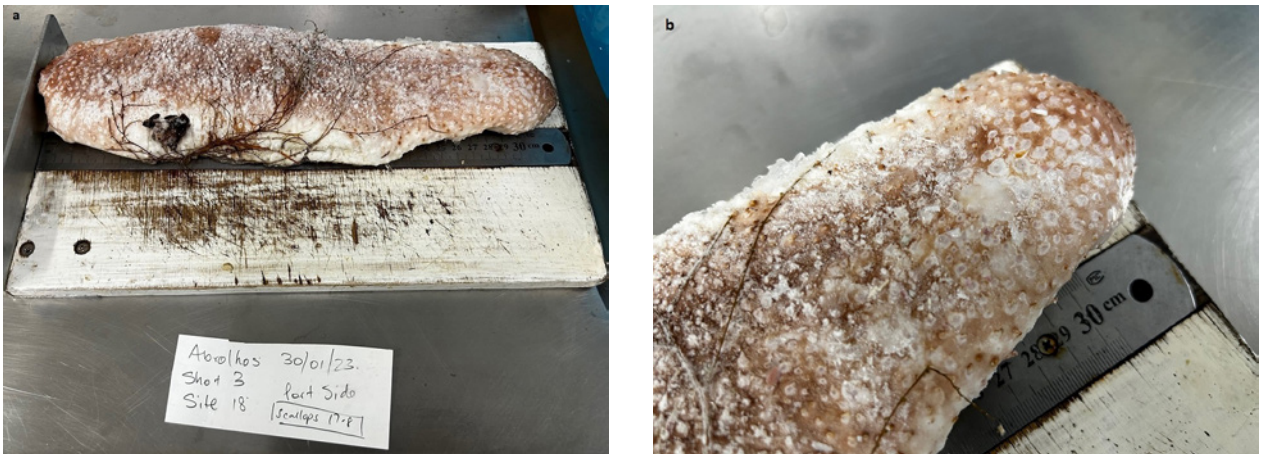

Figure 1. (a) Dorsal view of a *Holothuria spinifera* specimen from the Abrolhos Islands in Western Australia. (b) Close-up view of the dorsal surface texture and colouration.

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smoother ventral surface. The dorsal surface ranges in colour from tan to darker brown, which may have a slightly mottled appearance; the ventral surface is cream coloured to white.

This species is generally found in shallow waters from 2 m to 10 m in sandy and coral rubble bottoms but have also been recorded in other areas of the Indo-Pacific Ocean in depths ranging from 10 m to 60 m. This report identifies *Holothuria spinifera* from outside of its known distribution at about 60 km off the west coast of Western Australia in the Abrolhos Islands (S28° 25.7', 1E 13° 46.7'). It was found at a depth of 18–20 m in a substrate consisting primarily of sand.

This specimen was caught on 30 January 2023 as bycatch in the Abrolhos Islands Mid-West Trawl fishery, which is a significant fishery operating off the coast of Western Australia (see Figs 2 and 3). Situated in the ecologically diverse Abrolhos Islands, this fishery focuses on harvesting the highly valued Abrolhos scallops (*Amusium balloti*). With scallop trawling as the primary fishing method, the industry contributes to the local economy and sustains fishing communities while striving to balance economic benefits with environmental sustainability.

On return to the laboratory, the sample maintained its composition and good quality until it was slightly thawed, photographed, processed and analysed under a compound microscope. Its identification as *Holothuria spinifera* was confirmed by comparing the ossicles of compound microscope photos (Fig. 4) with the descriptions in the FAO guide as shown in Figure 5. Photographs of the ventral mouth and anal ossicles, as shown in Figure 4a and 4d, match the plates of ventral podia from the FAO guide (see Fig. 5a, areas circled in red). Also, supporting evidence shows the photographs of the dorsal side and dorsal wall ossicles (Fig. 4b and 4c), showing the smooth buttons of the dorsal body wall, with six to eight internal segments within the ossicles matching the description shown in the FAO guide.

The Western Australian Sea Cucumber Fishery comprises eight sea cucumber species that inhabit the tropical shallow continental shelf waters of Australia's North Coast Bioregion, and are taken predominately by diving and wading (Hart et al. 2022). However, >99% of the harvest consists of two main species, *Holothuria scabra* (sandfish) and *Actinopyga echinites* (deepwater redfish). The brown sandfish, *Holothuria spinifera*, has not been recorded from catches in the Western Australian Sea Cucumber Fishery.

Sandfish and redfish stocks are assessed each year using annual indices of biomass derived from a population model that uses fine-scale catch, effort and fishery-independent

Figure 3. Location of site at the Abrolhos Islands where this specimen of *Holothuria spinifera* was caught in a scallop trawl.

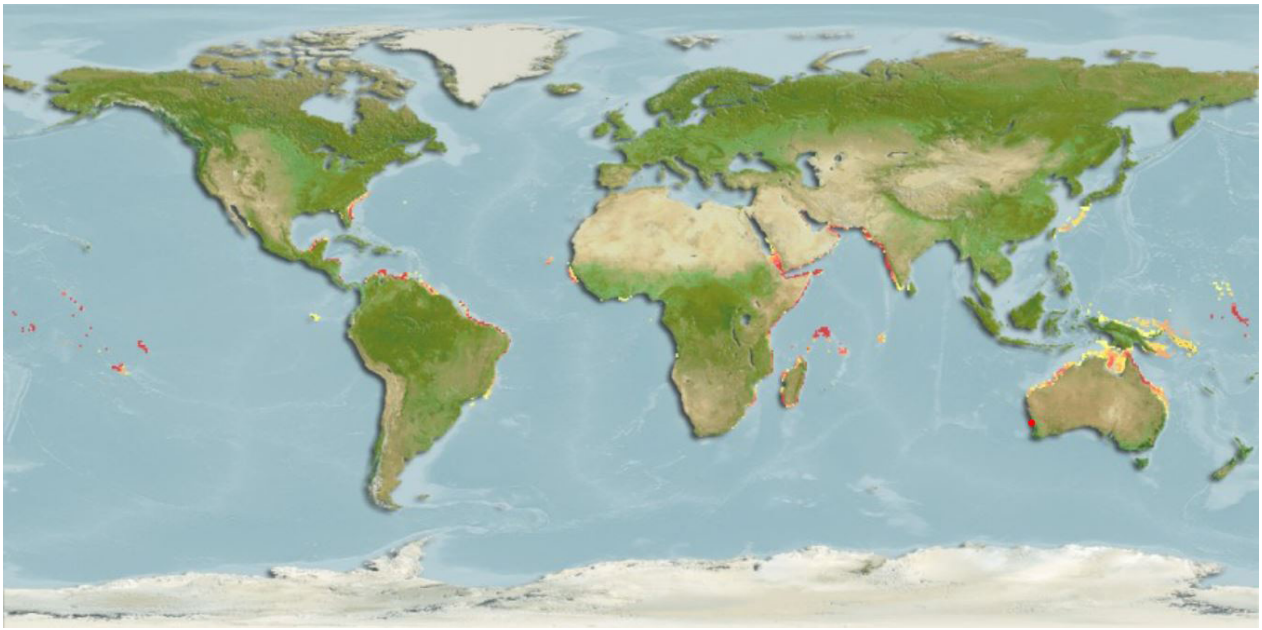

Figure 2. Computer-generated native distribution map for *Holothuria spinifera*, indicating suitability of habitat for probable occurrence from SeaLife Base (Palomares and Pauly 2023).

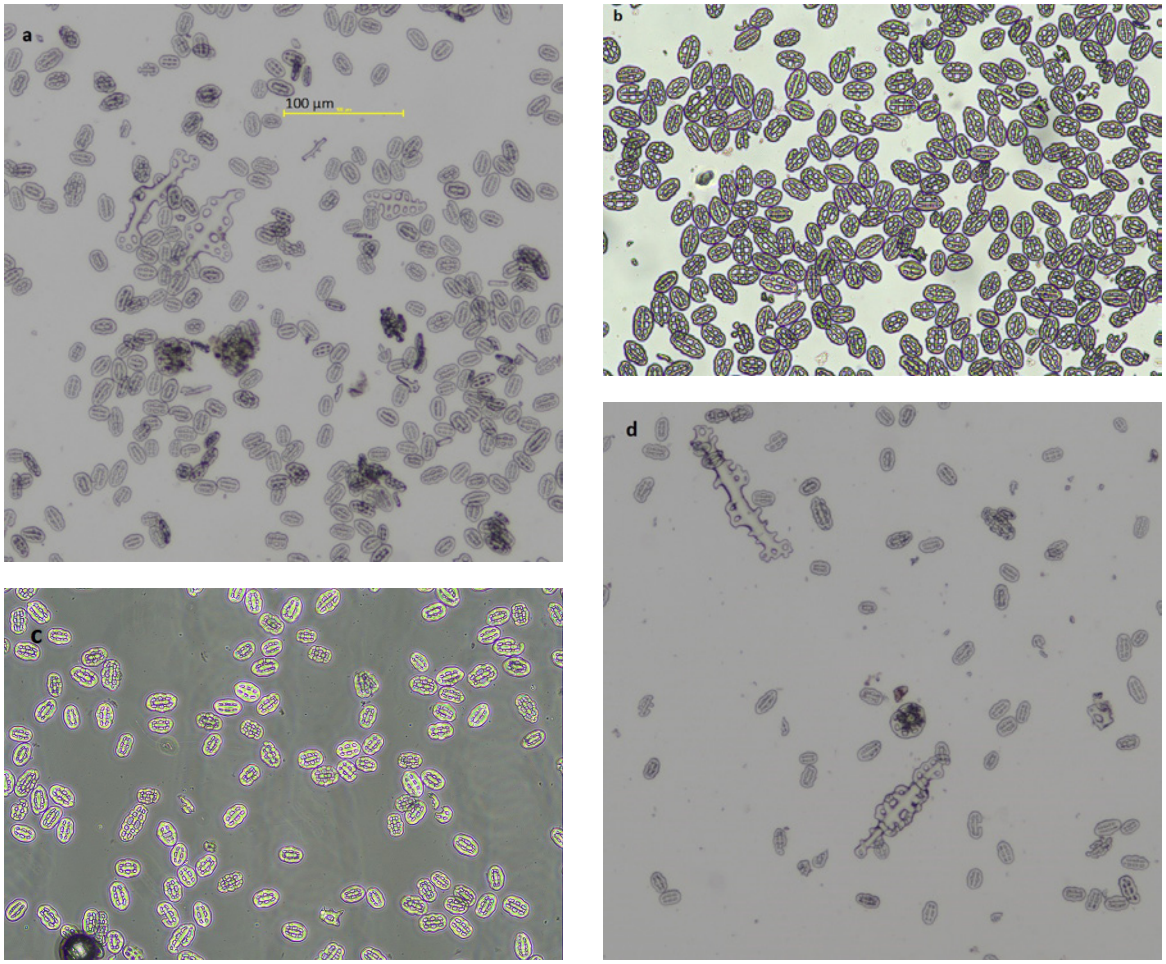

Figure 4. Photographs of ossicles from the specimen *Holothuria spinifera* that was caught in a scallop trawl; a. mouth ossicles, b. dorsal ossicles, c. dorsal wall ossicles, and d. anal ossicles.

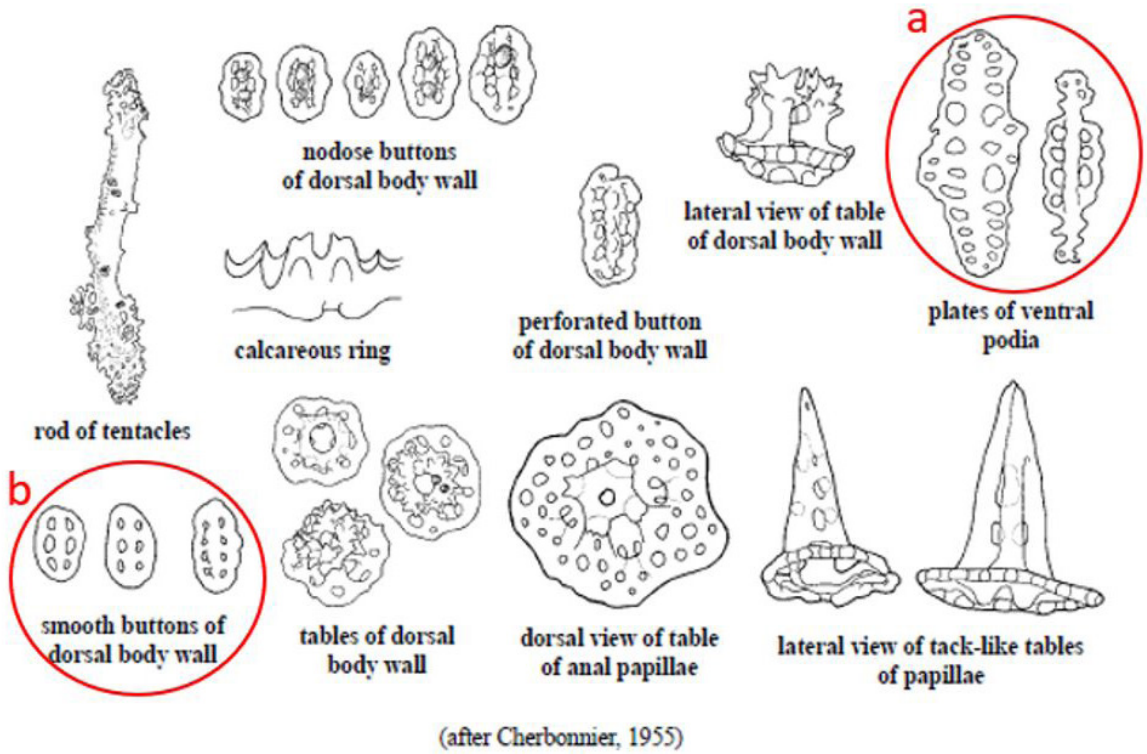

Figure 5. Artist impressions and descriptions of ossicles from *Holothuria spinifera* as described in Purcell et al. (2012). The ossicles enclosed by the red circles were the key identifiers for the sample of *Holothuria spinifera* for this study.

survey abundance data. These are compared with specified reference points, such as biomass targets, thresholds and limits developed using the population models. If the threshold or limit reference points are breached, the prescribed management action (involving fishery closures) is implemented according to the harvest strategy. More information on these stocks can be found here: https://fisheries.msc.org/en/fisheries/western-australia-sea-cucumber/@@assessments

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Indian Ocean Trepang (Madagascar) – A private company involved in the blue economy or blue grabbing?

Igor Eeckhaut[1]

Abstract

Indian Ocean Trepang is the only private company in southwestern Madagascar that produces juvenile sea cucumbers that are then given to villagers to farm. Sea cucumber enclosures are currently the only efficient tools that make it possible to limit the movements of sea cucumbers and to make it known that the enclosure is being used by farmers. A recent paper describes the problems that resulted with the privatisation of marine spaces in southwestern Madagascar, but the private sector was not consulted to provide a broader view of the problems. The floor here is given to sea cucumber aquaculture farmers and people employed by Indian Ocean Trepang, including an expert in village farming, to give some details of how sea cucumber farming works in Madagascar from the perspective of the private sector.

Introduction

The "blue economy" concept seeks to promote economic growth, social inclusion, and the preservation or improvement of livelihoods while at the same time ensuring environmental sustainability of the oceans and coastal areas. (World Bank 2017:6). The scope of the blue economy includes a wide range of economic sectors, mainly fisheries, artisanal mariculture and tourism. Blue grabbing, on the other hand, is defined as the "actions, policies or initiatives that deprive small-scale fishers of resources, dispossess vulnerable populations in coastal areas, and/or undermines historical access to areas of the sea" (Bennett et al. 2015:61). Blue grabbing is a form of "accumulation by dispossession" in which commonly held spaces and resources are enclosed and privatised (Baker-Médard and Kroger 2023). The dispossession of marine spaces and marine resources from coastal resource users allows private entities to secure capital investment in ocean-based production (Baker-Médard and Kroger 2023). People who previously relied on commonly held resources not only lose access to these resources, but are often forced to become wage-earners to survive (Baker-Médard and Kroger 2023).

With the overexploitation of natural populations of sea cucumbers, the aquaculture of these animals has developed in various countries over the past 30 years (Hamel et al. 2022). Sea cucumber aquaculture includes three phases: the production of 1) young juveniles from embryos in the hatchery, 2) aged juveniles in the nursery and 3) marketable adults at sea (Hamel et al. 2022). In Madagascar, this economic activity has developed for 25 years, mainly in the south where a private company, Indian Ocean Trepang, supplies juveniles to fishing villagers, either directly or through non-governmental organisations such as Reef Doctor or Blue Venture (Eeckhaut 2021). The fattening of the sea cucumber *Holothuria scabra* in enclosures is, therefore, done partially through "company farming", where company employees are paid for grow-out work, and through "village farming", where assisted villagers are paid for production (Eeckhaut 2021). In 2021, there were two company farm sites in Madagascar: the Mangrove site consisting of 101 ha of enclosures, and the Andamilamy site with 96 ha. Village farming sites included 37 ha of enclosures at sea (Eeckhaut 2021). In 2021, 227 people were employed by IOT, including 143 permanent employees who were divided into various departments: hatchery, nursery, sea pens, factory, logistic, security, maintenance and administration (Eeckhaut 2021).

A recently published paper describes the problems that have resulted with the privatisation of marine spaces in southwestern Madagascar (Baker-Médard and Kroger 2023). Indeed, the appearance of fences at sea, whether managed by villagers or IOT, implies restricted access to these sites, and that villagers must fish elsewhere. Furthermore, the appearance of this new economic activity has generated a situation of violence that did not exist before. It is, in fact, extremely easy to pillage the enclosures because the sea cucumbers are in abundance in one place. Knowing that a bag can be filled in a few minutes, and that each bag is equivalent in value to an amount sufficient to purchase a zebu (a type of cow that is often kept in hot countries), the temptation to pillage the enclosures has become quite strong in this extremely poor region of Madagascar. On multiple occasions, thieves have been arrested and brought to justice. The culmination of this violence came in March 2019, when dozens of people looting the IOT enclosures clashed with gendarmes and, after provoking the gendarmes, six of them died during the shootout that followed (Manase 2019).

Baker-Médard and Kroger (2023) interviewed 12 fishermen, who described IOT as an entity that kills people, hides bodies, and only thinks of making a profit to the detriment of human life, and with no consideration for artisanal

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fishermen. Regrettably, however, no one from IOT was consulted during the authors' research to provide a broader and more objective view of the problem. The aim of this article is to give some details on how sea cucumber farming works in Madagascar from the perspective of the private sector. For this, we give the floor here to sea cucumber aquaculture farmers and people employed by IOT.

Methodology

Following a similar method as that used by Baker-Médard and Kroger (2023), we interviewed 12 sea cucumber farmers working in IOT farming sites: three women and three men in each of the villages of Sarodrano and Andrevo. We also interviewed four people working for IOT: Loïc Gaumez, Rijaniaina Ratsimbazafy, Moustapha Dieng and Dr Benjamin Pascal. Their background and responsibilities are detailed below.

Loïc Gaumez is responsible for IOT's research and development as well as farming production. Loïc has worked at IOT since 2019. He has a master's degree in marine biology and has been trained in aquaculture and water management. Part of his job at IOT concerns the grow-out of sea cucumbers in the offshore enclosures. He organises and plans the production in both the company farm enclosures and village enclosures. He is also involved in maintaining good relationships with the farmers who work with IOT. With his colleague Rija, he is very involved in establishing and maintaining a relationship of trust with the farmers.

Rijaniaina Ratsimbazafy is the head of the nursery and co-head of village grow-out at IOT. Rija graduated in fisheries and aquaculture production from the Fisheries and Marine Sciences Institute of the University of Toliara. He has a particular interest in aquaculture, especially sea cucumber farming. His professional experiences are mainly focused on sea cucumber farming, starting as a breeding technician in the private company Madagascar Holothurie, then as a consultant and trainer in the Sea Cucumber Community Support Project for training fishermen in southwestern Madagascar on the popularisation of sea cucumber farming in fishing villages.

Moustapha Dieng has been the managing director of IOT since December 2018. His role consists of defining, with the shareholders, the company's main guidelines. He develops and monitors IOT's budget to optimise costs, directs the production of juvenile sea cucumbers, and monitors their growth in the offshore enclosures He ensures good collaboration with village farmers (around 25% of the total growing areas at sea), organises the harvesting of adult cucumbers, and monitors the processing of cucumbers in the factory and marketing of the dried sea cucumbers. He also ensures good relations with various institutions (e.g. universities, government, non-governmental organisations, aquaculture farmers' associations).

Dr Benjamin Pascal has been working with coastal communities in southwestern Madagascar since 2003, first as part of his research on social and territorial dynamics, which gave rise to the production of a doctoral thesis, then as part of various projects within NGOs and associated commercial companies. He was actively involved in the development and promotion of village models of sea cucumber and algae production in the southwest. He has worked in partnership with Madagascar Holothurie and then with IOT since 2008, and continues to act as a consultant for IOT preparing the development of new sites, ensuring mediation with local populations, and advising on the social and institutional integration of activities.

Results

Interview with farmers

In response to the question "Are you satisfied with your collaboration with IOT?", all 12 farmers answered positively. When asked if sea cucumber farming is profitable for them and if this activity should continue in the future, everyone also answered in the affirmative. Zizy, a 47-year-old woman, stated that "It suits our life; sea cucumber farming brings us a lot of money and it must continue." To the question, "During attacks on IOT farms, when shots were fired, who were the perpetrators of these shots?", everyone indicated that thieves are responsible. Madame Vola, aged 37, said that "Those who attack are the first responsible for the shots; they do it so that the security team is afraid and so they can enter the enclosures easily." When women were asked if they were afraid of the IOT team, everyone answered in the negative. A specific question to the six women was, "Do you feel left out in relation to farming work?" Their answers indicated that they do not feel left out. Madame Deha, 33, responded: "We don't feel left out, the work we are given is less hard". A specific question to the six men was "How are women integrated into the work of the enclosures?". Jean-Jacques, a 39-year-old man, responded: "As women are less physically strong, we gave them less physical work, seeding, brushing and maintenance."

Interview with Loïc Gaumez

Can you explain, in detail, the differences between the two types of farming production?

We have developed two offshore production systems. The first is the company farming system that consists of the company managing the breeding. Currently, this represents a total area of 220 ha on two sites. The second is the village farming system, which is carried out by communities in the Atsimo-Andrefana region, and consists of 67 ha divided among six villages. The development of an income-generating activity was always the objective of the research initially, and subsequently of the different IOT departments, so that the coastal community can be integrated into the project and can also benefit from it. The partnership system between farmers and IOT is managed by a contract. IOT provides the equipment for production, the enclosures and guard towers (managed by the villagers), and the juvenile sea cucumbers that are given to villagers free of charge (the

juveniles are produced in the IOT hatchery). After a growth period of 13–16 months, depending on the farmer's choice, IOT buys back the entire production according to a price scale based on the return rate and the time spent in the enclosures. In other words, the higher the return rate, the better the price, which allows farmers to value their security efforts and their involvement. The longer the time, the better the price. For example, a 13-month enclosure with a return rate of less than 30% (very bad), the unit price of caught cucumbers is MGA[2] 2500, whereas if the grow-out period is 16 months, the rate of return is greater than 50%, and the unit price is MGA 4000. In order to limit theft and optimise production, the farmers' areas are collectivised so that the income among them is equal.

How does IOT access various marine spaces?

It is not possible to own any particular part of the sea: the marine space is public domain managed by the national government It is, however, possible to carry out aquaculture production activities after requesting a marine concession from the State. This generally takes approximately a year and a half. IOT begins by discussing the project with the local community (Fig. 1). During these discussions, we present the project to community members and discuss the impacts on their marine space. Once the community agrees to participate in the project, we launch a social and environmental impact study, which is carried out by independent experts and scientists. Once the study is finalised, this triggers a request for opinion from the Maritime Spatial Planning commission, which is made up of the Ministry of Decentralisation and Territorial Planning, and the Ministry of Fisheries. If opinions are positive, this leads to a request for an environmental permit issued by the National Office for the Environment (ONE). With the environmental permit, ONE also delivers its environmental specifications. In order to obtain the environmental permit, ONE organises a public consultation with participants, including representatives of the three ministries mentioned above and ONE, as well as regional representatives of each entity. Once the environmental permit has been issued with its specifications, a request for production authorisation is made to the Minister of Fisheries and the Blue Economy. And once this authorisation has been obtained, its duration is 10 years and must be renewed thereafter. In addition to these steps, IOT requests the opinion of the mayor and the municipal council. Subsequently, a memorandum of understanding is signed with the community so that IOT's commitments are well known to everyone, and the rules that govern the activity are clear. It is a long procedure that is essential to preserve the Malagasy maritime public domain.

The birth of this new economic activity aroused bad intentions in the minds of certain people, and numerous thefts were committed in the enclosures. What were the impacts of these thefts on sea cucumber production?

The theft of sea cucumbers from offshore production enclosures began very early on when farming was set up during the research phase in the early 2000s. It has continued during the creation of Madagascar Holothurie and IOT. This is currently the biggest challenge in sustaining the industry, much more than biological problems such as predation at sea or ecological problems such as temperature variations. Groups of people coming from inland, sometimes armed with rifles or bladed weapons, regularly attacked production sites, both village sites and IOT sites. This insecurity has, at certain times, led to the establishment of gendarmerie forces in villages and on sea cucumber growing sites. In 2019, when events led to the tragic deaths of some looters, IOT was on the verge of bankruptcy. Out of 100 animals placed at sea, around 20 were found, while during the research period as well as today, more than 50% of the reared animals were found in the fences. Thefts continue, and are still the main factor that will decide the success or failure of village farming. For example, Tables 1 and 2 summarise the events that we have observed on our company farm sites in 2023. Thirty-three intrusions were recorded on the two farming sites (19 in Andamilamy and 14 in Sarodrano). Sixty thieves were arrested by the guards (36 in Andamilamy and 24 in Sarodrano). All of the thieves were men who did not practice sea cucumber farming, and mostly came from the countryside. Although many men were arrested, many others were able to flee. In the bags of arrested or fleeing thieves, 2648 individuals of *Holothuria scabra* were found (1095 in Andamilamy and 1553 in Sarodrano). The arrested thieves were taken to the gendarmerie in Tuléar (most of the time) or Manombo.

What do you think of the production system contracted with communities?

Village production has been in the DNA of our activity since the initial development of sea cucumber aquaculture in Madagascar. The beginnings were difficult from a technical point of view because the breeding procedures were poorly understood. But over time, we developed a reliable method of production. It is normal that for some villagers, the changes imposed – such as no access to certain fishing zones – have destabilised the relationship of trust they had with us. But from 2020, we deployed a new method that has already proven successful in our farm enclosures. This new method has a reduced sea cucumber density within the pens, which means that the sea cucumbers are of a uniform size when harvested This development has made it possible to increase farmers' income and eliminate many problems, such as the purchase of animals, which was previously correlated with a minimum fresh individual weight of 400 g. Currently, the new system is showing very good results for the villagers. IOT is proactive in its relationships with communities, whether as sea cucumber producers or not. We have frequent discussions and are always available for feedback or requests for help.

[2] MGA = Malagasy ariary in which MGA 1 = USD 0.00022

Figures 1 and 2. The Indian Ocean Trepang team discusses aquaculture projects with locals from different villages along the west coast of Madagascar.

Table 1. Characteristics of thefts at the Andamilamy farming site

Date	Time of theft	No. of thieves on the run	No. of thieves arrested	No. of sea cucumbers taken	Continuation
21/01/23	03h45	Unknown number	_	78	None
25/01/23	04h00	-	2	132	Gendarmerie
26/02/23	02h20	12	-	95	None
4/03/23	23h00	-	2	-	Gendarmerie
6/03/23	22h35	8	-	unknown	None
25/03/23	-	-	4	276	Gendarmerie
6/04/23	01h00	-	1	5	Gendarmerie
20/04/23	00h15	-	1	20	Gendarmerie
15/05/23	22h15	4	-	101	None
12/06/23	22h20	1	-	12	None
19/06/23	22h50	-	1	51	None
19/07/23	01h50	-	3	58	Gendarmerie
21/08/23	16h00	-	1	77	Gendarmerie
29/08/23	-	-	4	-	Gendarmerie
27/11/23	-	-	1	6	Gendarmerie
28/11/23	21h30	-	1	2	Gendarmerie
5/12/23	22h15	-	2	7	Gendarmerie
26/12/23	22h50	-	2	175	Gendarmerie Manombo
20/12/23	Day time	-	11	unknown	Gendarmerie Manombo

Table 2. Characteristics of thefts at the La Mangrove (Sarodrano) farming site

Date	Time	No. of thieves on the run	No. of thieves arrested	No. of sea cucumbers taken	Continuation
11/03/23	01h00	Unknown number	-	7	None
26/03/23	05h30	Unknown number	-	16	None
17/04/23	20h17	-	2	36	Gendarmerie
12/05/23	07h00	-	2	51	Gendarmerie
20/05/23	00h00	-	2	141	Gendarmerie
4/07/23	12h35	-	1	9	Gendarmerie
13/07/23	23h00	Unknown number	-	50	None
5/09/23	03h45	-	2	44	Gendarmerie
16/09/23	23h00	Unknown number	-	136	None
27/10/23	-	-	6	690	Gendarmerie
13/11/23	23h00	-	2	113	Gendarmerie
17/11/23	23h30	-	2	99	Gendarmerie
29/11/23	23h30	-	3	62	Gendarmerie
16/12/23	01h40	-	2	99	Gendarmerie

Interview with Rijaniaina Ratsimbazafy

What do you think of the production system contracted with communities?

Village sea cucumber farming is one way to add income to fishermen and reduce fishing pressure and effort in the marine environment. The current observation that stocks of fishery products are weakening is proven by the reduction in the number and size of fishermens' catches. Village sea cucumber farming is an income-generating activity that can reach more than the basic minimum wage per month in certain fishing villages, and the work does not require a lot of time; just maintaining the enclosures and guarding them. The popularisation of sea cucumber farming is one of the solutions for sustainable development, especially at the level of fishing villages because, in addition to the direct impacts of income generated by breeding and/or the establishment of a fishing society production that gives work to locals, there is also the impact on the natural environment with the reduction in anthropogenic pressures, and especially the capture of juveniles for regenerating natural stocks. However, to sustain the sector, we must always be available and attentive to the problems that farmers encounter, especially social problems at the village level, and be responsive to finding adequate solutions. All of these efforts are currently creating better relationships with the communities, which means that current production is growing positively, even with the new models of collective farms that we have initiated.

Interview with Moustapha Dieng

In a recent scientific article, IOT was described as a mafia entity that was unscrupulous with people's lives and the development of fishing communities in southwest Madagascar. How do you feel about this description?

I am both surprised and amazed by this article, especially since no one has asked for IOT's opinion. The vision of IOT and its leaders is the opposite of what this article describes. Since 1999, I have lived in Madagascar and I have worked for companies involved in the collection and export of seafood products (e.g. fish, octopus, squid, crab, lobster). In the mid-2000s, we increasingly noticed a scarcity of resources and several ways have been explored to help fishermen to protect the resource (e.g. biological rest for certain species such as octopus) and, have an alternative income to fishing. Thus, the idea was born to launch into seaweed and sea cucumber aquaculture with an inclusive model allowing 25% of sea cucumber areas to be entrusted to fishermen farmers. This model has been so successful that the allocated areas continue to grow, thanks to the support of the Pole Intégré de Croissance project, which finances the equipment to build the sea pen enclosures in the villages. We went from 80 farmers in 2009 and 4.5 ha of surface area at sea, to 237 farmers in 2019 and 30 ha of surface area, up to 570 farmers in 2023 and 67 ha of surface area. With these farmers, IOT now has 196 permanent employees and 73 seasonal employees.

Most villagers are interested in farming sea cucumbers, and we have more demand from new farmers. This successful model is also supported by organisations such as the World Bank and United States Agency for International Development, which take charge of financing the construction of new offshore enclosures for new village farmers. These organisations are deeply concerned about current social issues such as gender equity and child labour, and to obtain these funds we must scrupulously respond to a set of criteria to which we fully adhere for the positive development of the fishing communities who work with us. In December 2023, we finished a public consultation in Befandefa, where the communities granted us 220 ha and allocated 30 ha for themselves. About 250 families in this remote and isolated area will benefit from an alternative source of income.

It is a fact that the installation of enclosures at sea (both village farming and company farming) are the basis for the violence that did not exist before. What were and what will be the measures taken by IOT to limit or stop this violence?

IOT's leaders favour dialogue in all circumstances to avoid conflicts. As proof, in 2019 when the company had all the authorisations required to build the rest of its enclosures in Andrevo, part of the population questioned the agreements reached in 2017. Consequently, we preferred to renegotiate for two years rather than force the matter. Also, to try to remedy the problems that the use of surface areas at sea can cause, we decided in 2021, apart from the legal rebates paid to the municipalities and the region, to pay a voluntary contribution to the villagers of MGA 50 per sea cucumber caught in our own enclosures. This contribution amounted to MGA 15,732,200 in 2021 (approximately EUR 3500), MGA 17,067,800 in 2022 (approximately EUR 4000) and MGA 15,557,450 in 2023 (approximately EUR 3500).

IOT has no problem with the fishing communities who have understood the project and its benefits. On the contrary, the Vezo community is asking for more enclosures in order to reap more benefits. The violence around sea cucumber farms is mainly caused by people from the land (i.e. non-fishermen) who engage in two illegal activities: 1) violent theft (in which the thieves are sometimes armed) in our enclosures and in those of village farmers, and 2) fishing with prohibited nets and fishing techniques. Finally, there has never been violence between individual villagers or farmers and IOT staff, although the defence and security forces have responded to the violence of thieves attacking the IOT enclosures.

Interview with Dr Benjamin Pascal

The installation of sea cucumber enclosures at sea for village farming and company farming has posed problems: placing fences in the sea means that certain fishing areas are no longer accessible to villagers, and there is the pillaging of enclosures by thieves. Today, we find ourselves with a situation where, on the one hand, enclosures and guarding are essential to ensure the economic viability of

the activity but on the other hand, these enclosures have developed an insecurity that did not exist before. What is your opinion of this situation, and what are some possible solutions to reduce or stop the violence and insecurity?

It must be understood that the areas of the enclosures are typically sandy-muddy flats with scattered seagrass beds. These areas are not very strategic or suitable for the activities of the Vezo and Sarà fishermen. These areas are instead used by migrants who come from inland to practice small-scale fishing on foot, which targets poorly valued resources (e.g. juvenile fish, crustaceans and shellfish mainly transformed into feed). It is, therefore, these groups of migrants who see their fishing zones as becoming restricted by the installation of enclosures. For their part, the indigenous Vezo and Sarà fishermen living near the farms have also sometimes expressed a certain dissatisfaction with IOT (notably at the time of the planned extension of the enclosures). But rather than restrictions on access to fishing zones, restrictions on movement by canoes or an estimated lack of economic benefits, were deplored. Their demands were heard and taken into account by IOT, which 1) modified the layout of certain enclosures to provide access or circulation routes considered strategic; 2) developed and implemented procedures to authorise the crossing of the enclosures by canoes at high tide; 3) strengthened land compensation mechanisms to increase benefits to communities; and 4) reviewed and revalidated the protocols of understanding between IOT and local residents.

For 10 years, IOT has faced several forms of demands revealing distinct strategies.

- From the point of view of the natives,[3] it is quite logical (and even quite typical in this type of project) to minimise constraints (here desire to control the expansion of enclosures or the extent of restrictions on usage rights and access) while maximising benefits (capture of economic benefits at the village level, including village enclosures, jobs and other associated income). The expression of their demands seems above all to be aimed at a negotiation objective (the constraints experienced or felt must justify the increase in compensation obtained). These demands do not mean, however, that most local fishermen want the withdrawal of sea cucumber farms. Likewise, the intervention of the gendarmes to secure the enclosures was perceived by these communities as legitimate and necessary to respond to thefts deemed unacceptable.[4]

- Concerning migrants, we are dealing with demands that may seem just as legitimate (due to a real loss of access to fishing zones) but which, in my opinion, reflect a more ambiguous reality. In recent years, there has been a notable increase in migrant activities on the outskirts of farms, motivated both by living conditions that have become difficult in their villages of origin, and by the opportunities sought on the coast (fishing and/or employment at IOT). As a result, competition for access to and pressure on adjacent fishing zones have increased. Already stigmatised for these unsustainable fishing practices, this migrant population is also considered the main accomplice and provider of the thieves arrested in the enclosures. However, since the establishment of gendarmes at the enclosures, thefts have become riskier, with more frequent arrests and convictions, and even deaths following clashes with the police. For all these reasons, the living conditions of these migrants continue to be difficult. Many of them perceive themselves as victims without fully taking responsibility for publicly increasing their demands.

- Finally, in a country where the armed response of the police is widely acclaimed to respond to organised gang thefts and rural insecurity, it seems quite revealing that several notables and public figures have attempted to throw fuel the fire by denouncing these clashes between thieves and the police as a desire for intimidation for the monopolisation of marine spaces. By drastically reducing thefts, the intervention of the gendarmes led to a drying up of a financial windfall benefiting mafia networks by ensuring concealment, and who had every interest in orchestrating a targeted denigration campaign to delegitimise IOT's rights to defend these enclosures.

After a critical period, violent clashes between thieves and the police have now become rare. Thieves continue to try their luck but they no longer bring weapons with them and no longer offer resistance when arrested. Maintaining a well-organised security system involving the police continues to be a necessity to deter attempts at theft with the use of violence. However, it seems equally essential that IOT continue to improve its image among local populations that are perceived to be a serious development partner. This involves maintaining a continuous and transparent dialogue with local residents as much as building positive interdependence. In particular, the strengthening of compensatory mechanisms, part of which has every interest in being indexed to productive performance in order to constitute an economic incentive for the defense of the model. Some mechanisms are already in place but there is probably a lack of visibility and supervision to produce the expected effects in terms of local development and ownership. In the same way, the development of village sea cucumber farming, particularly in its collective forms, today appears to be one of the best ways to strengthen support for the long-term implementation of IOT.

[3] The concept of indigenous is found locally in the Malagasy term *tompontany* ("master of the land"), which expresses the precedence of certain groups and the prevalence of their rights over a territory. The term can be applied to marine spaces and related to a type of collective land right. In the marine areas considered here, it is essentially Vezo and Sarà groups that can be considered as *tompotany*.

[4] The provision of gendarmes to deal with rural insecurity is also a request regularly made to IOT or other economic operators in the coastal villages where the company operates.

Ultimately, the insecurity and violence that have affected the development of the sector depend on factors that go well beyond the scope of expertise and prerogatives of IOT. Whether it is social dialogue, poverty reduction, maintaining order, rendering justice or even the development of appropriate regulatory frameworks, the necessary adjustments to create the conditions for harmonious development depend, above all, on the will and capacity of public authorities to act. Beyond the advocacy carried out by IOT, the upcoming completion of a doctoral thesis dedicated to the land and socioeconomic issues associated with the development of sea cucumber farming therefore seems to me to be a good initiative to shed new light on decision-makers on the issues at hand.

Discussion

The problems generated by the establishment of enclosures at sea managed by farmers or managed by IOT are very real: they have led, and still lead, to violence today. To say, however, that IOT is solely responsible for this violence and that, in the extreme, IOT staff are killing looters and hiding their bodies is entirely false. The farming system was created by researchers, particularly Malagasy-Belgian ones, in the early 2000s and adopted by fishing villagers, by non-governmental organisations, by the private sector and by the Ministry of Fisheries. Everyone is responsible for the development of this system and, therefore, for the violence generated, but the looters themselves are the main individuals responsible for the insecurity and violence.

Interviewing a few farmers out of hundreds and repeating this in a scientific article, certain targeted phrases are not a right method to describe the role of the private sector in sea cucumber farming. We demonstrate here, through the absurd, by interviewing 12 farmers, that we can have a completely different story from that obtained with another sample of farmers (see Baker-Médard and Kroger 2023). It is certain that after 10 years of practice, a serious study on the villagers' acceptance of this farming method, highlighting the positive and negative points, is welcome. Such research has begun with the work of Lavitra et al. (2024) in this issue of the *Beche-de-Mer Information Bulletin*.

Holothuria scabra farming is complex. This species, unfortunately, requires an enormous surface area at sea to be aquacultured and to allow the company producing juveniles to reach an acceptable profitability threshold. The maximum biomass that can be reached on 1 m^2 is 700 g of *H. scabra* (Lavitra et al. 2010), which means that after 10–14 months, depending on the location, one 700-g individual (or two individuals of 350 g or seven individuals of 100 g) can be harvested. A density of 1 individual/m2 means that 1 ha can produce 5000 individuals, using a mortality rate of 50%. These individuals will donate some 100 kg of exported trepang, which will bring in around EUR 15,000 to the exporting company. The villagers, for their part, can earn EUR 2500–5000 from this sum.

The enclosures are currently the only tools that make it possible to both limit the movements of sea cucumbers, and make it known that the plot of sediment belongs and is exploited by farmers. IOT is currently testing community enclosures that limit theft between farmers and appears to be having some success. These community enclosures will, however, not prevent looters coming from the land. We cannot blame these looters who are extremely poor and who try their luck by stealing cucumbers; however, if we want the farming system to develop because they really allow honest villagers to earn a sum of money that they find interesting (see Lavitra et al. this issue) we must try to stop these thefts. This must involve preventing theft by making the system better understood by all, by repression, where punishment is fair in relation to what is stolen, and by an increasing the standard of living of all, including the people of the countryside. But, all of this cannot be done in one day.

To better know the multiple social aspects of sea cucumber farming, a PhD dissertation in sociology will be funded by an ARES-CCD project (Belgium) for four years, starting in September 2024. The dissertation will debate the significant changes in land relations caused by sea cucumber farming, their legitimacy, the nature of the impacts (both positive and negative), on those who depend on these marine spaces, and will discuss the relevance of the model and its approaches and consider that there is monopolisation of spaces and associated benefits.

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Local perceptions of the socioeconomic and environmental impacts of sea cucumber farming in southwestern Madagascar

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Abstract

This study explores local perceptions of the socioeconomic and environmental impacts of sea cucumber farming in southwestern Madagascar. Among the 298 households surveyed, 69 were actively engaged in sea cucumber farming, participating in sales six to nine times annually, with each farmer selling 43–158 adult sea cucumbers per period. Repurchase prices per village ranged from MGA[5] 33,660,000 to MGA 150,534,200 per year, corresponding to an average selling price of MGA 2,078,378 per farmer per year. Sea cucumber farming significantly enhances household living conditions, as indicated by impacts such as furniture acquisition, fishing gear, and home construction. Two primary challenges faced by sea cucumber farmers are theft in sea pen enclosures and conflicts over marine space initiated by non-sea cucumber farmers. Regarding environmental impacts, villagers found it challenging to respond comprehensively, primarily noting the attraction and aggregation of various marine animals around sea cucumber enclosures, including juvenile sea cucumbers, finfish, gastropods, bivalves, octopus, shrimp, and squid. In conclusion, sea cucumber farming contributes positively to the standard of living for village farmers in southwestern Madagascar. The engagement of sociologists is imperative for addressing social challenges and fostering the development of this sector.

Keywords: sea cucumber farming, socioeconomic impacts, environmental impacts, household perceptions, southwestern Madagascar

Introduction

In Madagascar, particularly in the southwest region, sea cucumber fishing constitutes one of the economically viable activities that are actively pursued by coastal communities (Rasolofonirina et al. 2004). However, the overexploitation of sea cucumbers since the beginning of 1990 has led to a decline in holothurian stocks that is evident through the shift in quality, decrease in product size, and various signs of illegal harvesting practices (Rasolofonirina et al. 2004). To address this problem, a sea cucumber mariculture project was launched in Madagascar in 1999, funded by the Belgian universities University of Mons and Université libre de Bruxelles (Jangoux et al. 2001). Under this project, the hatchery in Toliara (Aqua-Lab) was established and became operational in 2003. Aqua-Lab has produced up to 200,000 of juveniles of the most valuable sea cucumber, *Holothuria scabra* (Eeckhaut et al. 2008). The second phase of the project was initiated in 2004 and included the establishment of sea cucumber farming pens in Belaza, 20 km south of Toliara city (Eeckhaut et al. 2008). The end of the Belgium funds in March 2008 led to the creation of a tripartite partnership between the Belgium universities, Institut Halieutique et des Sciences Marines (IH.SM), and the private company Copefrito SA, which further resulted in the establishment of a private company named Madagascar Holothurie – the first trade company based on sea cucumber aquaculture (involving coastal villagers) in Madagascar (Eeckhaut et al. 2008).

In response to the objective set by the three parties, a new partnership emerged between local communities, non-governmental organisations, and the private sector. This partnership pioneered a form of community-based mariculture, in which hatchery-reared juvenile sea cucumbers were reared by coastal communities in sea pens (Robinson and Pascal 2009). The results of this test phase prompted the partners in 2012 to establish a new private company named Indian Ocean Trepang to further advance and develop sea cucumber farming on an industrial scale (Todinanahary et al. 2016; Eeckhaut 2021). Community-based sea cucumber farming with IOT began in 2015. Initially, the project targeted 25 households within two villages (Ambolimailaky and Andrevo), resulting in the production of 1.2 t of fresh products. By 2020, the initiative had expanded to involve 228 households from seven villages, resulting in a substantial increase in production to 56.1 t of fresh products.

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[5] 1000 malgache ariary (MGA) = 0.35 Australian dollars as of 26 February 2024

Despite increased efforts in sea cucumber farming over the last two decades, research addressing the impacts of these activities remains limited, especially in Madagascar. The present study aims at evaluating local perceptions regarding the socioeconomic and environmental impacts of community-based sea cucumber farming in southwestern Madagascar. The primary objective is to contribute to the development of this sector in Madagascar.

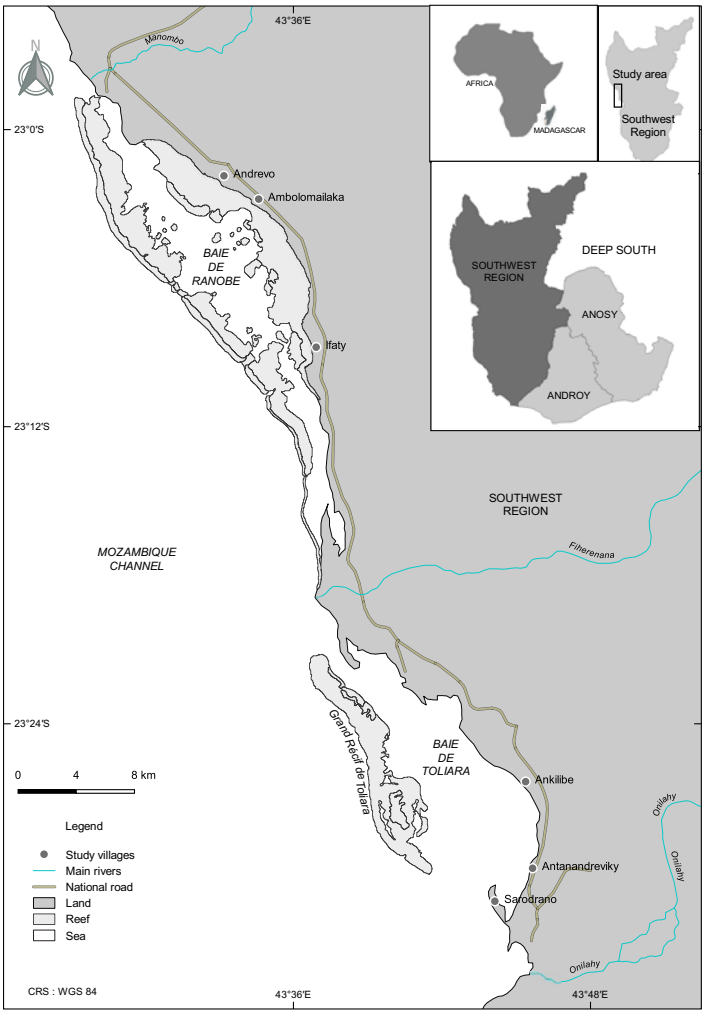
Methodology

Study area

Our study area was in the central part of the southwest region of Madagascar, delineated in the north by the Manombo River, and in the south by the Onilahy River. The study area encompassed six coastal villages along the shores of the Bay of Toliara and the Bay of Ranobe (Fig. 1). The study villages included Andrevo, Ambolomailaka, and Ifaty in the Bay of Ranobe, and Ankilibe, Antanandreviky and Sarodrano in the Bay of Toliara (Fig. 1).

Data collection approaches

The study was conducted along with an assessment of the impact of seaweed farming (not addressed in this article) in southwestern Madagascar, and focused on the six villages mentioned above. Our data collection approach combined individual surveys to collect quantitative data, and focus group discussions to collect qualitative data (Lambert and Loiselle 2008).



Figures 1. Study area and villages.

Individual surveys

We used a semi-structured interview format for the individual surveys, and targeted heads of households who are engaged in either seaweed or sea cucumber farming. In total, 298 individuals were interviewed between July and October 2022. The survey spanned approximately seven days per village, and questions were related to key household characteristics including age, gender, ethnic group, marital status, residence status, child in charge, and principal economic activity. These formulated questions aimed at exploring farmers' perceptions of the socioeconomic and environmental aspects of sea cucumber and seaweed farming. The date of the surveys, number of surveyed households, and the village the survey was conducted in are detailed in Table 1.

Of the 298 households surveyed, we interviewed 199 households engaged only in seaweed farming (66.78% of household respondents), 69 households engaged only in sea cucumber farming (23.15% of household respondents), and 30 households practicing both activities (10.07% of household respondents). This information is summarised in Table 2. Although the survey focused on both seaweed and sea cucumber, this article focuses on cucumber farming as mentioned above. As such, the results presented in this study will be derived from the 69 surveyed households practicing only sea cucumber farming.

In addition to individual surveys conducted with heads of sea cucumber farmer households, interviews were carried out with the managers and technicians of the local company Indian Ocean Trepang (IOT) to obtain insights into its sea cucumber farming operational model. Data on the income of each farmer in the study sites were also directly collected from IOT.

Focus group discussions

In addition to individual surveys, we held focus group discussions with 10 individuals (men and women) who were not involved in mariculture (either sea cucumber or seaweed farming). The discussion was held in an open manner, and participants were encouraged to express their points of view on the issues related to sea cucumber farming and its impact on their daily lives. In total, six focus groups discussion were conducted in six villages.

Data analysis

The data collected from the 69 sea cucumber farmer interviews were entered into an Excel database with 18 columns. These columns encompassed characteristics of the survey population (8 columns) and outcomes related to the perception of sea cucumber farming on the head of household's quality of life (10 columns). Subsequently, the file was converted to CSV format and processed using R software version 4.2.1.

R software played a pivotal role in data synthesis, graph generation, and summarisation of survey population characteristics. It was also crucial in conducting statistical analyses, particularly for comparing the average yearly incomes of sea cucumber farmers in the three villages: Andrevo, Ambolimailaka, and Sarodrano + Antanandreviky.

Given that the data did not follow a normal distribution (pShapiro-Wilk < 0.05) and the variance was not homogeneous (pLevene < 0.05), even after transformation, the non-parametric Kruskal-Wallis test was utilised instead of ANOVA. The significance level for all analyses was set at 5%.

Results

Characteristics of the surveyed population

Table 3 presents the characteristics of the surveyed population. The 69 households engaged in sea cucumber farming were distributed across the villages of Andrevo (24), Ambolimailaka (38), Antananreviky (02), and Sarodrano (05).

Only responses from adults (men and women aged 20 and older) were considered. The greatest number of responses came from individuals aged 30–59 (72.5% of responses). The number of men who were heads of household is higher (72.5%) than that of women (27.5%). Regarding the various ethnic groups, 5 out of 18 Malagasy ethnic groups were present during the survey, in which the Vezo ethnic group (which are known fishers) were the predominant group (75.4%). The majority of these people were married through a traditional wedding (87%) and most of them resided in the village (94.2%). More than 56.5% of households had more than four children under their care.

Among the 69 households engaged in sea cucumber farming, only 2 (2.9%) identified sea cucumber farming as their primary economic activity. The remaining households practiced it as a secondary activity with their main activity focused on fishing (78.3%), mixed with selling (8.7%), fish mongering (5.8%), and other undefined activities (4.3%).

Operating model, and technical and organisational practices

IOT is the only private company in Madagascar involved in the large-scale production of the sea cucumber *Holothuria scabra*. The different stages of sea cucumber production, from larval rearing in the hatchery to exportation, are summarised in Figure 2.

Table 1. Summary of data collection

Date of survey (year 2022)	Number of surveyed households	Village
25–31 July	21	Ankilibe
4–11 August	103	Sarodrano
19–26 August	27	Antanandreviky
27 August–2 September	45	Ambolimailaka
3–6 September, and 24 September–3 October	84	Andrevo
13–19 October	18	Ifaty
Total	**298**	**6**

Table 2. Number of surveyed households per village per farming activity.

Village	Number of surveyed households			
	Sea cucumber farmers	Seaweed farmers	Seaweed and sea cucumber farmers	**Total**
Andrevo	24	60	0	84
Ambolimailaky	38	2	5	45
Ifaty	0	18	0	18
Ankilibe	0	21	0	21
Antanandreviky	2	18	7	27
Sarodrano	5	80	18	103
Total	**69**	**199**	**30**	**298**
Percentages	*23.15%*	*66.78%*	*10.07%*	*100%*

The sea cucumber farming model in the coastal villages of southwest Madagascar is a mix of company farming and village farming. For the company farming model, IOT supplies juvenile sea cucumbers produced from its hatchery to fill their own pens. The company covers all the expenses, including staff, inputs, and infrastructure. For the village farming model, IOT supplies juveniles to village farmers for free and the cost of these juveniles is deducted at the time of harvest because those local farmers resell the juveniles that they farmed back to IOT. The company also provides the equipment needed to construct the pens, such as plastic netting and galvanised tubes. IOT also ensures that the farmers monitor the sea cucumbers by establishing a kind of contract to engage the resale back of adult sea cucumbers back to them. The farmers must maintain the pens that were provided to them (e.g. brushing them to prevent clogging) and monitor sea cucumber growth and health.

To recruit farmers, IOT advertises the number of farmers needed in its intervention villages. Interested villagers submit their expressions of interest and the selection occurs with the presence of the president and vice-president of the sea cucumber farmer association, as well as IOT technicians.

Once the farmers are identified and the pens are built in each village, IOT distributes sea cucumber juveniles weighing an average of 50 g each. Previously, this size was much smaller (around 20 g), but IOT decided to increase the size to reduce mortality rates in the pens, likely due to predators. The growth period at the village level varies from 9 to 14 months and, based on various parameters such as the sediment quality and water temperature, generally lasts around 14 months. So, for the first delivery of juveniles in the new pens, the first sale occurs at 14 months. A delivery of juveniles is made every two to three months to ensure that the sale will not occur until 14 months. This system allows the farmers to sell adult sea cucumbers every two to three months after the first sale (14 months' duration). Sometimes, the sale depends on the availability of commercially sized cucumbers, weighing no less than 400 g fresh weight.

Table 3. Characteristics of the surveyed population.

Sample characteristics		Frequency (n)	Percent (%)
Village	Andrevo	24	34.8
	Ambolimailaka	38	55.1
	Antanandreviky	2	2.9
	Sarodrano	5	7.2
Age	20–29	17	24.6
	30–59	50	72.5
	>60	2	2.9
Gender	Male	50	72.5
	Female	19	27.5
Ethnic group	Vezo	52	75.4
	Masikoro	7	10.1
	Mahafaly	4	5.8
	Tandroy	2	2.9
	Tanalana	4	5.8
Marital status	Married	60	87
	Single	6	8.7
	Widowed	3	4.3
Residence status	Resident	64	94.2
	Migrant	4	5.8
No. of children	0	5	7.3
	1–3	25	36.2
	4–6	23	33.3
	>7	16	23.2
Principal economic activity	Fishermen	54	78.3
	Sales	6	8.7
	Fishmongers	4	5.8
	Sea cucumber farming	2	2.9
	Other	3	4.3

Juvenile sea cucumber deliveries to farmer, and adults repurchased by IOT

Details of the deliveries of juveniles and the purchases of adult sea cucumbers by IOT from the farmers in the studied villages from 2020 and 2021 are presented in Table 4. In this table, data from the villages of Sarodrano and Antanandreviky are combined, just as they are in the IOT database. The data encompass all farmers involved in sea cucumber farming, whether exclusively sea cucumber farmers or engaging in both sea cucumber and seaweed farming. The number of farmers remained constant 45, 50 and 40 for the respective villages of Andrevo, Ambolimailaka, and Sarodrano + Antananderviky over the two years under consideration.

In total, IOT delivered 452,216 juveniles to village farmers, with quantities ranging from 65,789 to 87,835, depending on village context and year. Annually, each farmer received between 1390 and 2196 juveniles.

The frequency of transfers from IOT to farmers varied from five to seven times per year, with the number of juveniles ranging between 199 and 439 per farmer per delivery. The number of market-size sea cucumbers sold by farmers per year and per village varied between 13,464 and 54,131, or between 299 and 1353 per farmer per year. Sales occurred six to nine times per year, resulting in each farmer selling 43 to 158 adult sea cucumbers per repurchase period.

During the first half of 2020, the buying price for an adult sea cucumber was approximately MGA 4000 for an individual weighing around 400 g in fresh weight. This price was reduced to MGA 2500 in the second half of 2020, and has remained constant throughout 2021. This price adjustment is attributed to IOT deducting the price of one juvenile (MGA 1500) at the time of delivery. With variations in price and diverse pricing based on the size of adult sea cucumbers, the total sum of repurchase prices for adult individuals returned for each village ranged from MGA 33,660,000 to MGA 150,534,200 per year. This results in a total of MGA 748,000 to MGA 3,763,355 per year per village farmer.

It is also noted that due to the loss and mortality of juveniles, the number of adult individuals purchased back is consistently lower than the number of juveniles delivered. This ratio varied from 20% to 70%.

The variation in the average amount received by each farmer for every sale of marketable-size sea cucumbers is depicted in Figure 3. Our observation highlights that farmers in Sarodrano + Antanandreviky received a higher income than those in Ambolimailaka and Andrevo during 2020 (Fig. 3A) and 2021 (Fig. 3B), respectively. Nevertheless, statistical analysis indicates that during 2020, there is no significant difference ($p_{kw = 0.509}$) in the average sum received per farmer per purchasing period, despite a substantial sum received by

Figures 2. Stages of sea cucumber production from larval production to export.

farmers in Sarodrano + Antanandreviky (MGA 532,802) compared to Ambolimailaka (MGA 343,242) and Andrevo (MGA 273,935) (Fig. 3A). However, a significant difference is observed during 2021 (pkw = 0.001), where the amount received was significantly higher in Sarodrano + Antanandreviky (MGA 390,547) than in Ambolimailaka (MGA 217,034) and Andrevo (MGA 106,458) (Fig. 3B).

Figure 4 illustrates the distribution of income received by farmers during sales in 2020 and 2021. In Andrevo for 2020 (Fig. 4A), the amount varied between MGA 65,279 and MGA 618,933, and ranged from MGA 49,583 to MGA 211,333 in 2021 (Fig. 4B). Ambolimailka showed an average distribution between MGA 153,520 and MGA 553,500 in 2020 (Fig. 4C) and MGA 112,202 to MGA 295,990 in 2021 (Fig. 4D). In Sarodrano + Antanandreviky, the sum received per farmer per sales season varies from MGA 188,840 to MGA 904,300 in 2020 (Fig. 4E) and from MGA 157,927 to MGA 640,122 in 2021 (Fig. 4F).

Perceived impacts of sea cucumber farming on farmers' quality of life

Based on the results of our survey, farmers reported 10 impacts of sea cucumber farming that have contributed to improving their household living conditions (Fig. 5). The most perceived impacts were acquisition of home furniture (19.12%), acquisition of fishing gear (16.67%), construction of home (16.67%), and home appliance purchase, educational support with nutritional enhancement, each representing 12.25% of all responses.

Table 4. Delivered juveniles and repurchased adult sea cucumbers by Indian Ocean Trepang.

Village	Andrevo		Ambolimailaka		Sarodrano and Antanandreviky	
Year	**2020**	**2021**	**2020**	**2021**	**2020**	**2021**
Number of farmers	45	45	50	50	40	40
Total number of juveniles delivered	85,585	66,453	65,789	69,488	87,835	77,066
Average number of juveniles per farmer	1902	1477	1316	1390	2196	1927
Frequency of delivery	6	6	6	7	5	6
Average number of juveniles per farmer per delivery	317	246	219	199	439	321
Total number of adults sold	22,798	13,464	28,718	23,100	44,268	54,131
Average number of adults sold per farmer	507	299	574	462	1107	1353
Frequency of selling	6	7	7	8	7	9
Average number of adults sold per famer per selling	85	43	82	58	158	150
Total amount per year (MGA)	76,777,500	33,660,000	85,728,000	57,750,000	150,534,200	135,327,500
Average amount per farmer per year (MGA)	1,706,166	748,000	1,714,560	1,155,000	3,763,355	3,383,187
Price per piece of adults (MGA)	3368	2500	2985	2500	3400	2500
Ratio adults/juveniles (%)	26.6	20.3	43.7	33.2	50.4	70.2

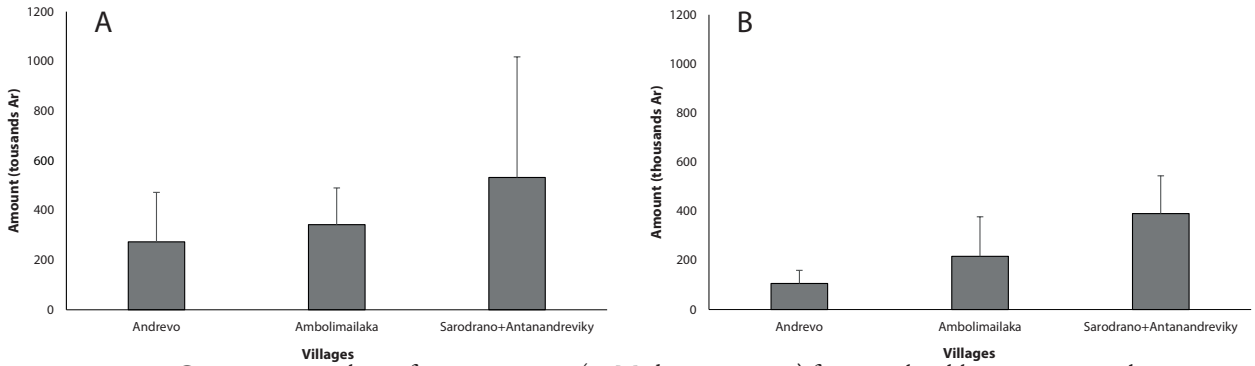


Figure 3. Comparative analysis of average income (in Madagascar ariary) from marketable-size sea cucumbers: A) Year 2020 and B) Year 2021.

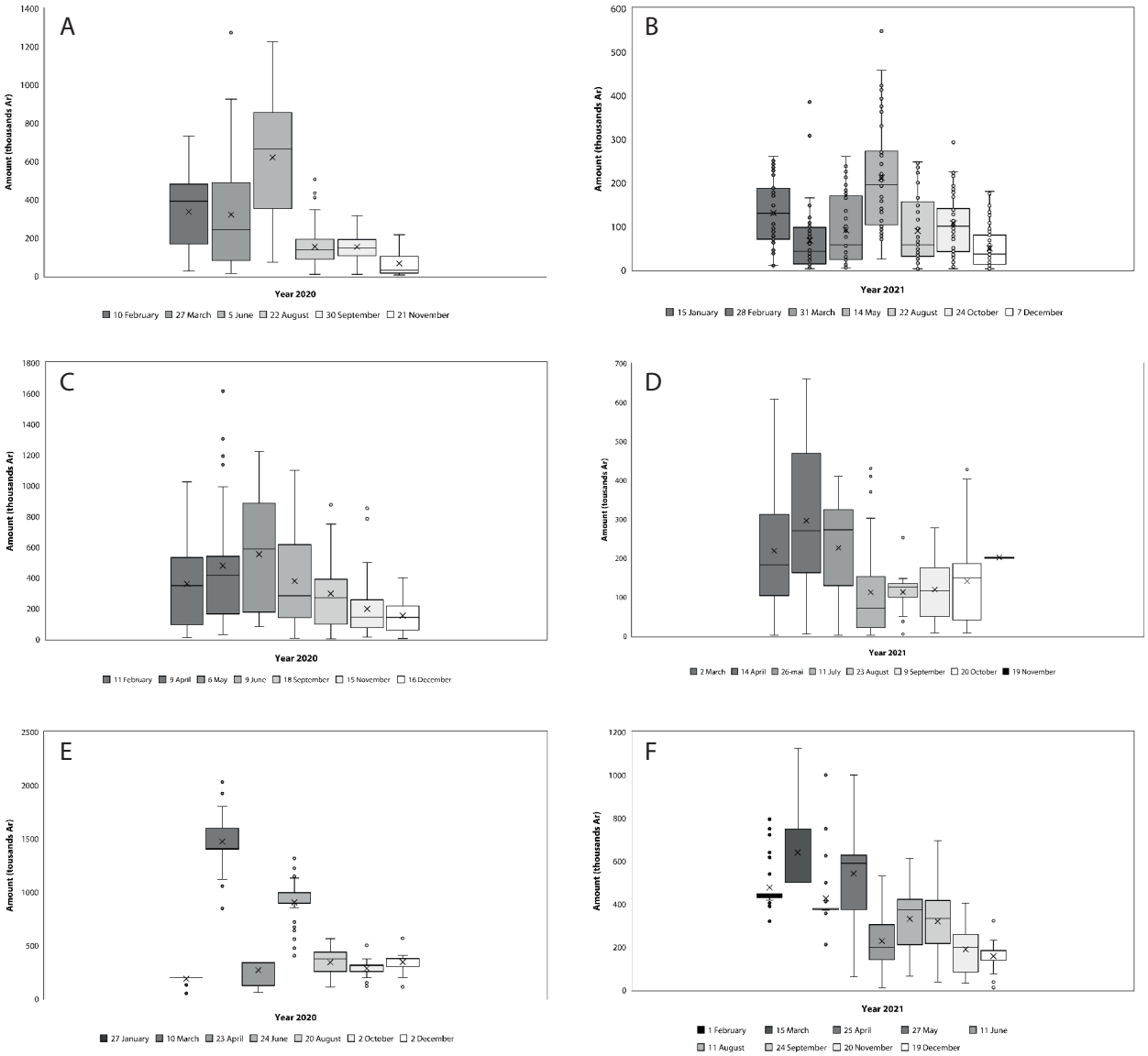


Figure 4. Distribution of income received by farmers during the sales seasons in 2020 and 2021 across different villages. Graphs indicate the average amount received by one farmer in one year (bars indicate standard deviation). A) Sarodrano, 2020; B) Sarodrano, 2021; C) Ambolimailaka,2020; D) Ambolimailaka, 2021; E) Sarodrano + Antanandreviky, 2020; F) Sarodrano + Antanandreviky, 2021.

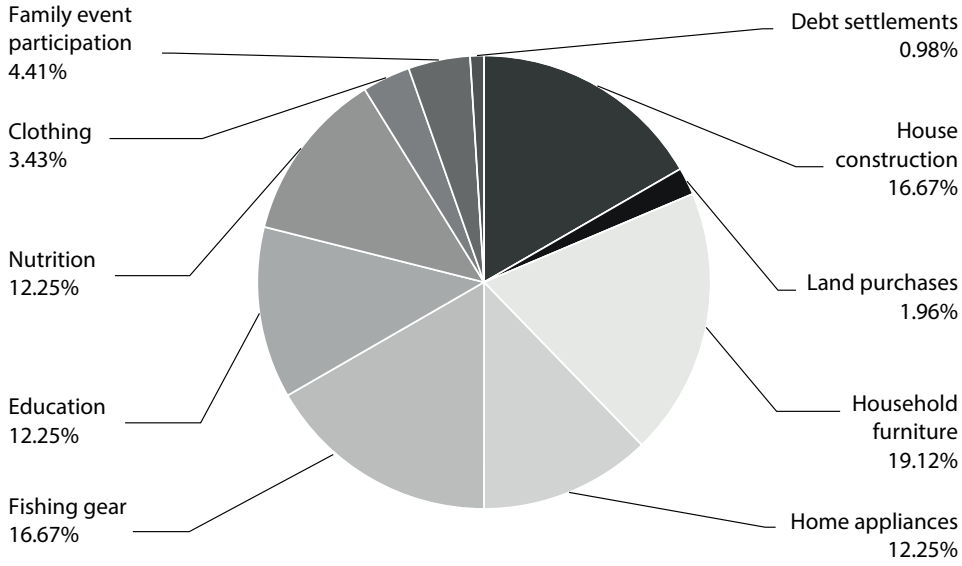


Figure 5. Impacts of sea cucumber farming on the farmers' household living conditions.

(a) Household furniture

Household furniture includes the acquisition of chests, wardrobes, glass tables, mirrors, formica shelves, formica sideboards, lounge chairs, plastic chairs, beds, mattresses, and specific kitchen utensils. Of the 69 sea cucumber farmers surveyed, 39 (56.5%) reported being able to purchase household furniture as a result of sea cucumber farming. The most commonly acquired items were lounge chairs (27.3%), glass tables (14.8%), sideboards (12.5%) and formica shelves (10.2%). While the majority of households acquired only one type of furniture (41%), others opted for two types (23.1%), and a smaller percentage bought three types (17.9%). Notably, 2 out of the 39 farmers who reported purchasing household furniture were able to specify having acquired six different types.

(b) Fishing gear

Of the all 69 farmers surveyed, 34 (49.3%) reported acquiring fishing gear through sea cucumber sales. The most common items purchased were pirogues (27 farmers), fishing nets (22 farmers), and masks for snorkeling (7 farmers). Other equipment included spear guns (4 farmers), fins (3 farmers), and a wetsuit (1 farmer). Over half of the farmers (52.9%) simultaneously purchased two types of fishing gear, with one farmer obtaining an impressive five types. While 27 farmers mentioned buying pirogues with proceeds from sea cucumber farming, the total acquired was 59, as some farmers bought 1 (15), 2 (5), 3 (5), 6 (1), and even up to 13 pirogues (1). Fishing nets were acquired by 22 farmers, and individual purchases ranged from 1 to 20 nets, resulting in a total of 109 nets for the surveyed households.

(c) House construction

Among the 69 sea cucumber farmers, 34 (49.3%) were able to build a house from the proceeds of sea cucumber farming. The majority of these houses are constructed with sheet metal (59.5%) and rush (29.7%). Others were built using permanent construction materials (2 farmers), planks (1 farmer), and mud (1 farmer). Three farmers were able to build two houses. One of them constructed both a sheet metal house and one with permanent construction materials, while the other two built one house made of rush and the other made of sheet metal.

(d) Home appliances

Among all sea cucumber farmers, 25 (36.2%) reported purchasing household appliances. Appliances included flat-screen TVs, phones, radios, speakers, boomboxes, walkmans, DVD players, solar panels, batteries, stabilisers, converters and generators. The most frequently acquired household appliances were batteries and solar panels (50%) for lighting purposes, followed by TVs, speakers (10% each) and radios (7.1%).

(e) Education

Twenty-five of the 69 sea cucumber farmers surveyed (36.2%) indicated that they used the proceeds from sea cucumber farming to help pay for their children's education. This financial support encompasses diverse expenses, including school fees, school supplies (e.g. notebooks, pens) and uniforms.

(f) Nutrition

Twenty-six farmers (37.7%) mentioned that the money generated from sea cucumber farming also played a role in improving their daily diet. Responses included purchasing a bag of rice directly for food security or being able to afford zebu meat, something that they were unable to purchase before.

(g) Family event participation

Nine farmers reported using money earned from sea cucumber farming to support various family events, including engagements, funerals, circumcisions and soron'anake. Soron'anake is a tradition observed in certain Malagasy tribes whereby a man must offer a zebu to his wife's family. This ritual, performed in the traditional way and involving the eldest member of the wife's family, is crucial for a man to establish his parental rights in the context of traditional customs. Failure to complete this tradition would result in the children born to the couple being considered as belonging to the family of the wife rather than the husband.

(h) Clothing, land purchases and debt settlements

Seven farmers (10.1%) mentioned buying clothing using funds generated from sea cucumber farming, while only four purchased land. These instances entailed the purchase of land for cultivation and were exclusive to the village of Ambolimailaka. Additionally, two farmers disclosed using funds from sea cucumber farming to settle their debts.

Problems related to sea cucumber farming and perceptions of local villagers of its environmental impacts

For those who practice sea cucumber farming, two major issues were highlighted. All heads of households interviewed (i.e. 69 out of 69) reported problems with theft in their sea cucumber pens despite using guards. Another issue stated by all farmers in Andrevo is the conflict over marine space, which has been primarily initiated by non-sea cucumber farmers.

Non-farmer responses varied from village to village. In Sarodrano, non-farmers, especially fishermen, stated that they had no issues with the development of sea cucumber farming. Their primary concern lies with the restriction of fishing areas near the shore. Non-farmers acknowledge the tangible benefits sea cucumber farming to the practitioners, including improved housing and access to education for children, acquisition of materials and goods, and a more consistent income stream.

For the residents of Antanandreviky, the concerns were severe, primarily linked to the marine space occupied by sea cucumber farming enclosures, involving not only local farmers but also IOT. Sea cucumber farming is expanding across a considerable marine area directly opposite their village. Consequently, women expressed dissatisfaction with the increased distance they had to cover to fish along the shoreline due to the enclosures (for shellfish, octopus, and other sea cucumber species) because of the establishment of sea cucumber farms. Men were significantly inconvenienced because of their pirogues, which have difficult navigating around the enclosures. Villagers also associated sea cucumber farming with additional challenges, such as the unsettling feeling of fear when encountering IOT farm guards, who restrict villagers from approaching the pens, especially at night.

In Ambolimailaka, non-sea cucumber farmers do not have any issues with sea cucumber farmers. Unlike Antanandreviky and Sarodrano, where the coastline is extensive, the only concern that was the increasing interest in the activity, despite limited marine space. These individuals also recognised that sea cucumber farmers have a better quality of life than fishermen.

In Andrevo, the issue is social conflict, with those who lack access to sea cucumber farming envious of farmers who have advantages that result in a better life. A tragic conflict occurred between the Masikoro and Vezo tribes, in which the Masikoro – harbouring jealousy towards the improved living conditions of Vezo farmers – lead to provocations and deaths. The situation escalated when the Masikoro attacked the village to pilfer sea cucumbers, resulting in their confrontation with the enclosure guards, ultimately causing a minor civil war, where families of the deceased sought revenge.

Another challenge is the frequenting of bars by male sea cucumber farmers. At times, their behaviour reflects affluence, which triggers jealousy among non-farmers. And, this contributes to the prevalence of polygamy.

With regard to the environmental impacts of sea cucumber farming, villagers had difficulty answering this question. Their responses were confined to the attraction and aggregation of various marine animals around the sea cucumber enclosures. The most frequently mentioned groups of animals included juvenile sea cucumbers, finfish, gastropods, bivalves, octopus, shrimp and squid.

Discussion

Sea cucumber farming is emerging as a supplementary endeavour for farmers because it demands only a few hours of work per week, primarily during low spring tides for paddock maintenance. This flexibility enables farmers to allocate time to other activities, particularly their primary pursuit, fishing (78.3%), which aligns seamlessly with sea cucumber farming. In southwestern Madagascar, sea cucumber farming stands out as a pioneering development. Our study underscores that the production model for 2022 remains consistent with Todinanahary et al.'s 2016 description of employing a mixed model that combines the "company farm" concept with that of "village farming".

In this context, the private company IOT ensures the sustainability of production, provides technical support to farmers, and invests in production materials, while farmers manage their plots following farming protocols (Todinanahary et al. 2016). This adopted mixed model emerges as a promising solution, enabling IOT to thrive while actively involving village farmers in local development. It is crucial to emphasise that, currently, village farmers are unable to independently secure the supply of juveniles. They remain reliant on IOT's hatchery. The hatchery and pre-grow out phase demand not only substantial investment in capital but also cutting-edge technology. Village sea cucumber farming in Madagascar stands out as a success story and can serve as a model for other coastal regions and countries (Kunzman et al. 2023).

In terms of socioeconomic impacts, the influence of sea cucumber farming on improving the standard of living for village farmers is evident. The average selling price of sea cucumbers from farming is MGA 2,078,378 per farmer per year, with the amount received ranging from MGA748,000 per farmer per year in Andrevo in 2021, to MGA 3,763,355 per farmer per year in Sarodrano + Antananderviky in 2020. This average selling price of sea cucumber (MGA 2,078,378) per farmer per year is equivalent to MGA 173,198 per farmer per month, which is not far from the minimum monthly wage set in Madagascar (MGA 250,000) according to Decree n°2023 - 563. It is noted that sea cucumber farming is not a full-time pursuit, indicating its beneficial nature for those engaged in the activity. One sea cucumber farmer family spends about three hours per day during each of the eight working days per month (Todinanahary et al. 2016), resulting in an average of 15% of the legal working time (8 hours per days, 20 days per month).

This practice indeed contributes to improving the living conditions of village farmers, as stated by the farmers themselves from their individual testimonials and through focus group discussions. The reported benefits were also supported by non-governmental organisations such as Blue Ventures and IOT (Baker-Médard and Kroger 2023). The same authors also highlight that some individuals perceive advantages in aquaculture, believing that positive outcomes are attainable with a different approach (Baker-Médard and Kroger 2023).

We gathered 10 responses from village farmers regarding the improvements in their lives due to sea cucumber farming. The most frequently mentioned improvements include the purchase of household supplies, acquisition of fishing equipment, house construction, procurement of household appliances, educational support, and nutritional improvement. These responses closely align with priorities reported by practitioners of seaweed farming in Kenya, particularly in the village of Kibuyuni on the southern coast of Kenya. The

key improvements outlined in the Kenyan study encompass constructing modern housing for the family (17%), funding family education (17%), addressing family medical needs (17%), acquiring clothing (17%), ensuring food and nutrition (17%), making business investments (4%), covering farm work expenses (4%), investing in livestock (4%), and settling family debts (3%) (Mirera et al. 2020).

Despite these advantages, some emerging social challenges – including theft, conflicts over the use of marine space, disputes between farmers and non-farmers, and behavioral shifts linked to wealth – occurred as a result of sea cucumber farming. Authors such as Baker-Médard and Kroger (2023) have raised these issues, highlighting concerns that the practice tends to disproportionately benefit recent arrivals, causing tensions and marginalisation, especially among original residents reliant on traditional fishing practices compared to newcomers engaged in aquaculture. The same authors report frequent violence related to sea cucumber theft, involving armed guards and resulting in numerous deaths, creating an atmosphere of fear in the region. A more comprehensive sociological study is recommended to address these problems.

The encountered challenges predominantly have social dimensions. To improve this situation, in depth sociological studies or targeted interventions are proposed. This underpins the importance of involving sociologists in the development of this sector. Within a new "Artisanal Mariculture and Village farming" certificate (Eeckhaut et al. 2023) funded by the Belgian ARES-CCD, a social research initiative has been launched. We also advocate for the integration of financial education for village farmers. In response to the shortage of juveniles distributed by IOT, and to expand this activity across Madagascar, we advocate the Ministry of Fisheries' support for the development of sea cucumber hatcheries in the country. A sea cucumber development plan has already been drafted for Madagascar (MPEB 2021).

Finally, regarding the environmental impacts of sea cucumber farming, limited studies have explored these impacts to date (but see Plotieau et al. 2013 for an impact on sediment quality), highlighting the necessity for more comprehensive research in this field. Initially, concerns about plastic pollution resulting from enclosure construction material were anticipated. However, Rabemanantsoa's study (2021) revealed that fishing constitutes the primary source of 30% of all plastic waste in southwest Madagascar, including items such as ropes, net fragments, sandals, floats, mosquito nets, wires and plastic bottle pieces. Surprisingly, the majority of plastic waste is attributed to everyday consumer goods, particularly plastic bags and packaging. Contrary to expectations, sea cucumber farming minimally contributes to plastic waste, and plastic waste from aquaculture is not prominently observed in the reef ecosystem, aligning with Kunzman and colleagues' findings (2023). Beyond scientific investigations, a hotelier's observation from four years ago highlighted negative impacts linked to sea cucumber farming, notably habitat change (from a sandy to a muddy beach) and nocturnal disturbances during sea cucumber sale/purchase periods, impacting local tourism. These observations emphasise the importance of a comprehensive environmental assessment, transcending farmers' perspectives, to gain a nuanced understanding of the ecological implications of this activity.

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Holothurian communities of Reunion Island's reef complex within the Natural Marine Reserve

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Abstract

One of the long-term objectives of the management plan for Reunion Island's Natural Marine Reserve is to monitor holothurians, a taxon that plays a major role on the reefs. This study gave the first large-scale mapping (km scale) of the distribution of holothurian communities on the reef flats of La Saline/L'Hermitage. Surveys used the fixed-point method in seven habitats. Of the 14 species of sea cucumbers surveyed, three were the most abundant: *Holothuria leucospilota*, *Holothuria atra* and *Stichopus chloronotus*. *Synapta maculata* almost disappeared. In terms of habitat, 87% of holothurian individuals were found in the back reef zone in areas of high eutrophication, with a maximum recorded at the Planch'Alizés site (1015 ind./100 m²). Rare specimens were concentrated on the outer reef flat, inner reef flat, and inner reef flat, detritic zones.

Introduction

Reunion Island is a volcanic island in the western Indian Ocean, located around 700 km east of Madagascar and 170 km west-southwest of Mauritius at S 21° 07' and E 55° 32'. Together with Mauritius and Rodrigues, Reunion lies within the Mascarenes Archipelago. It has a coastline of around 210 km, with only 25 km of discontinuous coral ecosystems on the west coast (Montaggioni and Martin-Garin 2020). The total surface area of the coral reefs is 12 km² (Montaggioni and Faure 1980).

The main reef complexes of Reunion Island are the fringing reefs of L'Hermitage/La Saline (the largest), Saint-Leu, L'Étang-Salé and Saint-Pierre. They are exposed to strong hydrodynamic conditions, such as the swell generated by the southeasterly trade winds during the dry season or by tropical cyclones during the wet season. The tides are semi-diurnal, with a maximum tidal range of 0.9 m (Chabanet et al. 2000). In addition, the reef is an interface between the watershed and the oceanic environment due to its narrowness. It is, therefore, directly or indirectly impacted by human activities, such as increased run-off and eutrophication (Tessier et al. 2008).

Since the early 1970s, signs of degradation of benthic populations have been observed (Faure 1982; Cuet et al. 1988). Now, the coral reefs of Reunion Island are monitored by a number of scientific organisations and associations including Tropical Marine Ecology of the Pacific and Indian Oceans, associations such BestRun and l'Agence de Recherche pour la Biodiversité de La Réunion, the Natural Marine Reserve of Reunion and Vie océane. They are also studied by participatory science associations such as Reef Check (Corbel and Neff 2022).

Worldwide, 1774 species of sea cucumbers have been recorded (WoRMS 2023). At Reunion Island, four of the seven known orders are represented (Miller et al. 2017; Purcell et al. 2023). Sea cucumbers have been extensively studied there, especially for their reproductive (Uthicke 1994; Gaudron et al. 2008; Conand et al. 2016) and their feeding behaviour (Kolasinski et al. 2010; Cuvillier 2016). The recent PhD thesis of Pierrat (2023) analysed the genetic, feeding and environmental factors driving the heterogeneous distribution, over space, of *Holothuria atra*, *H. leucospilota* and *Stichopus chloronotus* as these species were found in patches and reach very high densities (> 1 individual/m²) at some locations. However, most of the studies to date, have given scattered information about diversity and abundance (Conand 2003; Conand et al. 2010; see also Pierrat 2023) and no large-scale (kilometric) data is available on sea cucumber distribution. *Holothuria atra* and *H. leucospilota* are known to be the two dominant species on Reunion Island (Conand and Mangion 2002; Pierrat 2023). New information is needed to optimise benthic communities' monitoring and protection, and the present study aims at giving a first overview of the distribution of sea cucumber populations over the L'Hermitage/La Saline coral reef complex.

Methodology

The study site is the largest reef formation on Reunion Island (150 ha of reef flats, 81 ha of back reef areas) and extends over 8 km from the mouth of Saint-Gilles ravine to Trois Bassins ravine. Its area represents 48% of the coral reefs on the island (Naim et al. 2000). At its centre, L'Hermitage pass divides the complex into two sectors: L'Hermitage (north) and La Saline (south). The reef habitats (146 types) defined by Nicet et al. (2017) were simplified in order to give an easy-reading mapping. This simplification led to the definition of seven main habitats (Fig. 1).

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Data were acquired with several field surveys. The BestRun Association agreed to share their field data acquired in October and November during the UTOPIAN project,[8] for habitats "Inner reef flat" (137 stations), "Inner reef flat detritic" (87 stations), "Outer reef flat" (51 stations), "Inner reef flat with dense coral colonies" (43 stations), and "Back reef with coral colonies" (23 stations). The MAREX firm agreed to share their field data acquired for "Back reef with seagrass on detritic substrate" (49 stations) in February. The field survey for this study was targeted on the back reef (241 stations) in March. All of these surveys used the fixed-point method, named CORRAM (COral Reef Monitoring Network) funded by l'Initiative Française pour les Récifs Coralliens (IFRECOR) (Pinault et al. 2017; Pinault and Broudic 2023; Kolasinski et al. 2024).

The fixed-point method used here is a rapid assessment method because the number of metrics surveyed was low (species and numbers of holothurians and sea urchins, depth, habitat and current assessment). The data collected and pooled were then interpolated, using a large number of stations, to produce an accurate map. The first step was to determine the position of the survey sites in each habitat, using QGIS (QGIS Association 2022). A 50-m grid was positioned over the entire study area, creating a surface area of 2500 m^2. The GPS coordinates of the centres of each grid square will be recorded and will define the station to be studied. In total, 631 sites were studied (Fig. 2), and each represents an area of 100 m^2. Habitat type was confirmed *in situ* by visual check. In the event of any change, the habitat type was moved to the nearest corresponding substrate. All visible holothurians were identified and counted (Fig. 3A). In the event of very high abundance (i.e. >100 individuals over ¼ of the circle), count was stopped at the first quarter (Fig. 3B). If any doubt arose about the identification of a specimen, a photo was taken for later analysis. Inverse distance weighted spatial interpolation was used in this study to produce distribution maps of holothurian populations.

Results

Species richness

Across the entire reef complex, 45,162 individuals were counted. A list of 14 species recorded and their abundance are presented in Table 1. *Holothuria leucospilota*, *H. atra* and *S. chloronotus* were the three most abundant species, accounting for 97% of all individuals on the reef complex. *Stichopus maculata*, formerly abundant on fringing reefs (Conand and Mangion 2002; Conand 2003), accounted for only 19 individuals. The back reef, with a surface of 63 ha, had the highest species richness with 10 species (Fig. 4). It was the most common habitat, with 241 sites recorded. The back reef with coral colonies, covering 13 ha, had the lowest richness, with four species recorded, but was also the least common habitat, with only 23 sites. The back reef with seagrass on detritic substrate, had the smallest surface area (5 a) but has a richness of 6 species.

Spatial distribution of holothurian populations

Distribution is variable both inter- and intra-habitat. Figure 4 shows the results for all species and highlights "patches" of individual density. The majority of species were found in the La Saline sector, in the back reef habitat of the post-reef zone. This density is variable, both between and within habitats, but also between sectors. It also shows the "rare" species, from which the dominant species *Holothuria leucospilota, H. atra and Stichopus choloronotus* have been removed to highlight them. Their spatial distribution is different. These species are close to the reef crest on the outer reef flat. Several aggregation zones have been observed, with densities ranging from 0 to 1015 individuals/100 m^2, divided into four groups (Fig. 5):

1. ≥ 1000 individuals/100 m^2 at Planch'Alizés
2. Between 500 and 1000 individuals/100 m^2 between MNS La Saline, Bodega and Lux sites
3. Between 200 and 500 individuals/100 m^2 at MNS La Saline and MNS L'Hermitage sites
4. ≤ 200 individuals/100 m^2 at Passe de L'Hermitage site.

Discussion

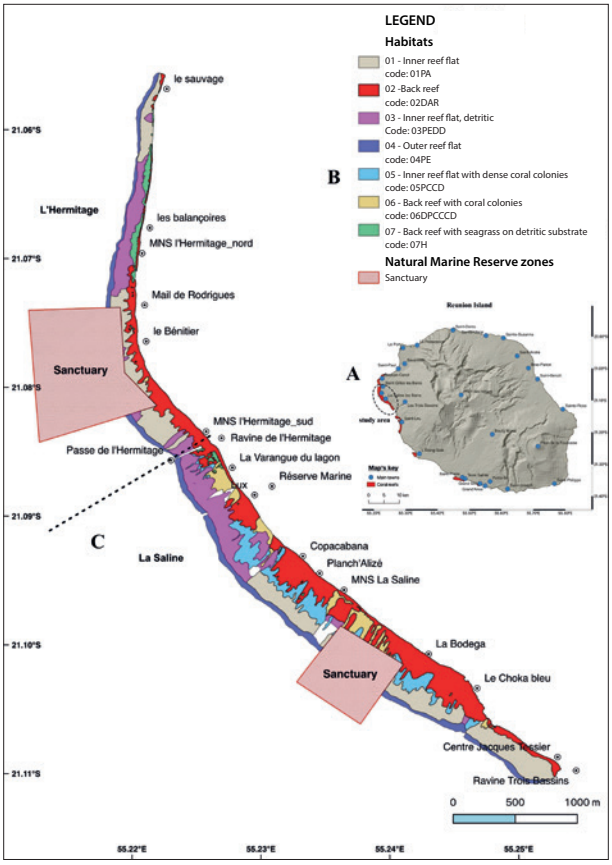
Species richness

In 2002, 17 species of Holothuroidea were reported on the reefs of Reunion Island (Conand and Mangion 2002; Conand 2003; Conand et al. 2010). In 2018, it reached 38 species (Conand et al. 2018). This difference corresponds to an increased sampling effort between these dates, and the inclusion of reef slopes.

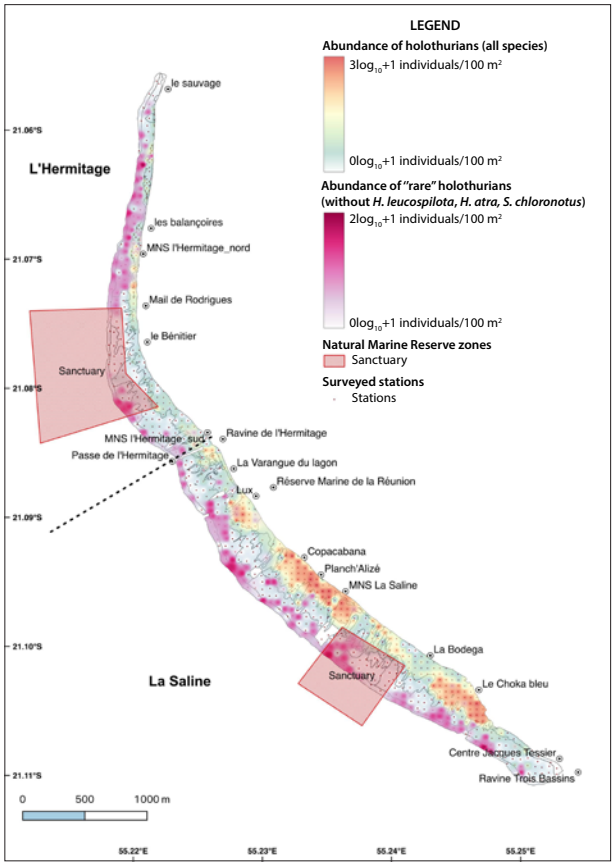
Community spatial pattern

Three species of holothurian massively dominate the La Saline/L'Hermitage reef complex: *Holothuria leucospilota, H. atra and Stichopus chloronotus*. The collapse of *S. maculata* populations could be linked to the upsurge in sea turtle populations since 2007, particularly *Chelonia mydas* and *Eretmochelys imbricata*, which have increased significantly (Soria et al. 2015). A green turtle has been observed feeding on two specimens of *S. maculata* (Mulochau et al. 2021). The density of *S. chloronotus* on Reunion is among the highest worldwide (Pierrat 2023; Pierrat et al. 2023). It has a dominant asexual mode for reproduction (Pirog et al. 2019; Pierrat 2023). Pierrat et al. (2023) analysed a multiseasonal monitoring that revealed the three species have their own dynamics, with *H. leucospilota* increasing in density, *H. atra* remaining stable, and *S. chloronotus* decreasing since the 1990s. *Stichopus chloronotus* seems to be a specialist while the two other are generalists. The drastic diminution of *S. chloronotus* populations could be linked to over 30 unstudied factors such as illegal harvesting, disease, predation and climate change (Pierrat 2023).

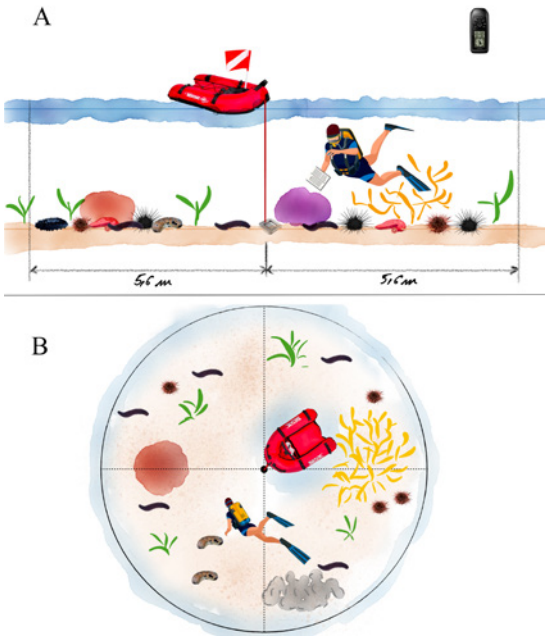
[8] The UTOPIAN project aims to map the state of health of Réunion's coral reefs. It is a scientific project for the conservation of natural environments led by the BestRun Association (ecology students) and the University of La Réunion.



Figures 1. A: Reunion Island; B: coding system; C: simplified habitat map (Nicet 2016) of the La Saline/ L'Hermitage reef complex.



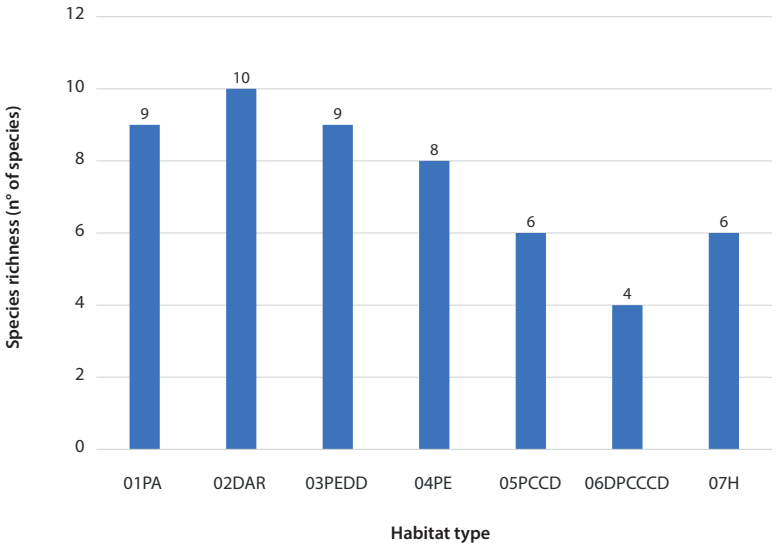
Figures 2. The spatial distribution of all holothurian communities, as well as that of "rare" specimens, where *Holothuria leucospilta, H. atra* and *Stichopus chloronotus* have been removed from the calculation to highlight them. The stations surveyed are indicated by black dots.



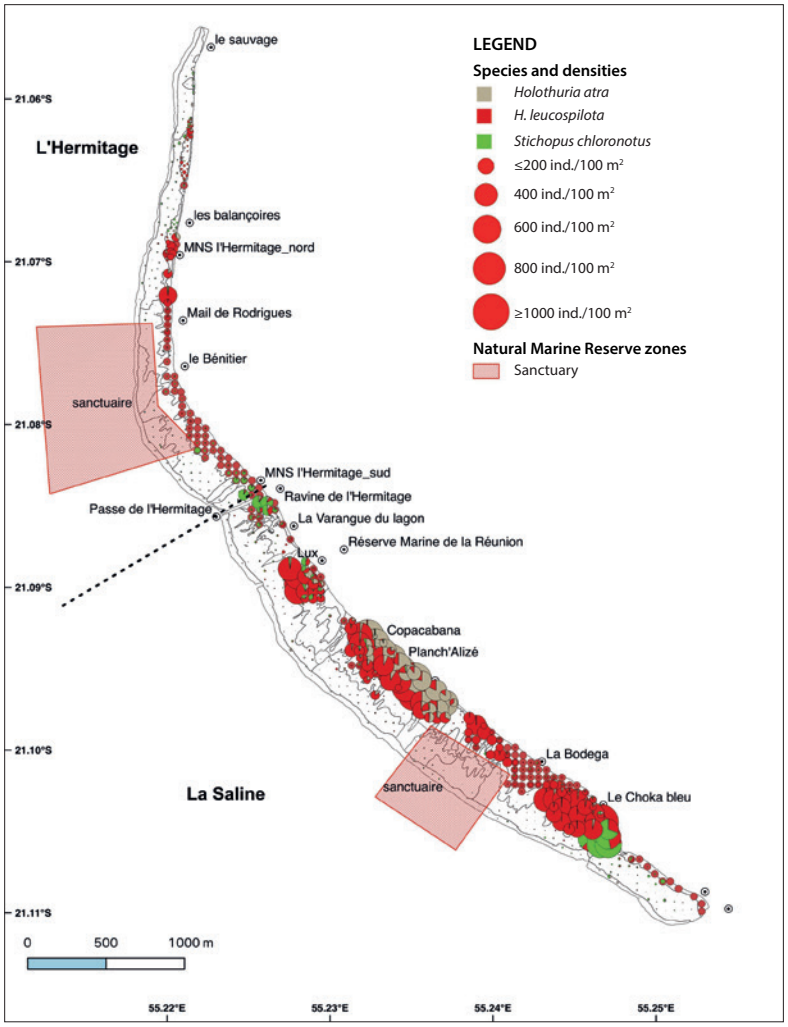
Figures 3. Survey method for "fixed point" stations. A: profile view of the station and the radius of 5.6 m. B: top view of the station with subsampling by one-fourth of the circle.

Table 1: Species abundance at all sites.

Species	Abundance
Holothuria leucospilota	**23,984**
Holothuria atra	**13,818**
Stichopus chloronotus	**5850**
Actinopyga mauritiana	981
Actinopyga echinites	213
Holothuria cinerascens	111
Holothuria nobilis	107
Holothuria verrucosa	53
Synapta maculata	19
Holothuria cf. *pervicax*	12
Holothuria flavomaculata	11
Bohadschia vitiensis	2
Actinopyga spp.	1
Actinopyga capillata	1



Figures 4. Holothurian species richness by habitat.
01PA: Inner Reef flat; 02DAR: back reef; 03PEDD Inner Reef flat, detritic;
04PE: Outer reef flat; 05PCCD: Inner reef flat with dense coral colonies;
06DPCCCD: Back reef with coral colonies; 07H: Back reef with seagrass on detritic substrate.



Figures 5. Spatial distribution of communities of the three dominant holothurian species on the La Saline/L'Hermitage reef complex.

The Holothuroidea community on the reef is spatially heterogeneous and an aggregative phenomenon has been documented elsewhere (e.g. Shepherd et al. 2003; Taddei 2006; Shiell and Knott 2010; Obura 2014)such as diver efficiency and diver error; and 2. This was confirmed during this study, with the presence of areas with very high densities such as Trou d'eau, Planch'Alizés, Lux, Passe de L'Hermitage sites and, to a lesser extent, between the Mail de Rodrigues and MNS L'Hermitage sites. The highest density was found at Planch'Alizés, where up to 1015 individuals/100 m^2 (*H. leucospilota* and *H. atra* combined) were noted. Although it is difficult to compare these data with previous studies, the value obtained in this area is equivalent to that recorded 30 years ago, which was 1100 individuals/100 m2 (Naim and Cuet 1989). The mapping carried out in this study enables the identification of those high-density spots.

Most individuals (83%), mainly from the three dominant species, were found in the reef flat zone. In contrast, the "rare" species (Table 1 and Fig. 4) were found on the back reef, which has a more complex structure and is subject to strong hydrodynamics.

One hypothesis that has been put forward, is the possible correlation between the level of enrichment of the site and the densities of *Holothuria leucospilota*, *H. atra* and *S. chloronotus*, with higher abundances in eutrophic zones (Mangion et al. 2004). In our study, patches of high abundance are actually located in areas known for their eutrophication feature, which include the sites of Planch'Alizés, Trou d'eau and Passe de L'Hermitage (Cuet et al. 1988; Naim 1993; Guigue et al. 2015; Tedetti et al. 2020)Indian Ocean. The distribution pattern described in this study is probably a multifactor effect, including nutrient enrichment, water flow, reproduction mode, and others that have yet to be identified.

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Observations récentes sur le prix de vente au détail de l'holothurie (*Apostichopus japonicus*) sur des étals des deux principaux marchés de ventes de produits halieutiques de Tokyo du Japon, Tsukiji et Toyosu en juillet 2023

Bruce Cauvin[1]

Introduction

Apostichopus japonicus est une espèce d'holothurie présente dans la zone nord-ouest de l'Océan Pacifique plus particulièrement en Mer Jaune, en Mer du Japon et dans la Mer d'Okhotsk. Cette espèce est présente sur les côtes des provinces de Chine comme Hebei, Shandon ou Liaoning au niveau de l'île de Dalian. Elle est observée au Japon jusqu'à l'île de Tanegashima.

La couleur du corps peut être variable, avec des individus rouges, verts, noirs et même blancs (albinos). De petits points bruns à grisâtres peuvent être présents sur le dos et sont plus nombreux sur le ventre. Le corps est carré en section transversale et légèrement effilé aux extrémités antérieure et postérieure. De grandes papilles coniques sont présentes en deux rangées sur la face dorsale. Sur la face ventrale, les podia sont alignés en trois rangées longitudinales irrégulières. La bouche est antéro-ventrale avec 20 tentacules. L'anus est postérieur et terminal, sans dents (Purcell *et al.* 2023). Surexploitée dans de nombreuses localités, cette espèce est classée en danger sur la Liste rouge de l'UICN.

Le prix observé à Hong Kong en 2022 était en moyenne équivalent à 1600 Euros au kilogramme de produit séché et conditionné (Purcell *et al.* 2023). Présente à la vente notamment sur les marchés de produits halieutiques de Tokyo (Japon) cette espèce est vendue au détail jusqu'à près de 400 000 yens par kilogramme en juillet 2023 (équivalent 2560 Euros).

Observations du prix de vente au détail sur les marchés de Tsukiji et Toyosu (Tokyo, Japon) en juillet 2023

Fondé en 1935, le marché de Tsukiji était le principal marché aux poissons de Tokyo et le plus grand marché au gros du monde pour les produits d'origine halieutique. Situé à environ 2 kilomètres à l'est du marché de Tsukiji, inauguré en 2018, le marché aux poissons de Toyosu remplace désormais le marché de Tsukiji en tant que plus grand marché aux poissons au Japon et dans le monde, il accueille plus de 600 vendeurs qui proposent une grande variété de produits, allant des poissons classiques tels que le thon aux espèces plus exotiques comme l'oursin ou l'holothurie.

Marché de Tsukiji

Le 14 juillet 2023, au niveau du cours des devises, 1 euro (EUR) s'échangeait à 160 yens et 1 dollar des États-Unis (USD) à 139 yens. Sur la partie extérieure du marché de Tsukiji, le kilogramme de l'espèce d'holothurie *Apostichopus japonicus* se négociait au détail jusqu'à 240 000 yens pour un kilogramme de produit sec, soit l'équivalent de 1500 EUR et de 1727 USD par kilogramme (Figs 1, a-c).

Marché de Toyosu

Le 18 juillet 2023, au niveau du cours des devises, 1 euro s'échangeait à 156 yens et 1 dollar des États-Unis à 139 yens. Sur le marché moderne de Toyosu (Figure 2), le kilogramme de l'espèce d'holothurie *Apostichopus japonicus* se négociait au détail jusqu'à près de 400 000 yens (399 600 yens) pour un kilogramme soit l'équivalent de 2562 EUR et de 2875 USD par kilogramme pour des individus secs et calibrés entre 17 et 20 grammes (Figure 3).

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Figures 1. Holothuries et ormeaux conditionnés et séchés à la vente sur un étal du marché de Tsukiji (prix affichés en yens/kg) – 14 juillet 2023.

Figures 2. Le marché de Toyosu (Tokyo, Japon) – 14 juillet 2023.

Figures 3. Holothuries et ormeaux conditionnés et séchés à la vente sur un étal du marché de Toyosu (prix affichés en yens/kg) – 18 juillet 2023.

COMMUNICATIONS

Conference and meeting abstracts

Abstracts of the 11th European Conference on Echinoderms

An innovative strategy for the isolation of circulating pigmented cells: The case of sea cucumber coelomocytes

Estelle Bossiroy,[1] Noé Wambreuse,[1] Frank David,[2] Céline Vanwinge,[3] Jérôme Delroisse,[1] Igor Eeckhaut[1] and Guillaume Caulier[1]

The immune system of sea cucumbers, which are marine invertebrates belonging to the phylum Echinodermata, relies on circulating cells known as coelomocytes. These cells are found in the fluids of the coelomic cavity and the ambulacral system of these organisms. In some sea cucumber species, hemocytes are the predominant type of coelomocytes in the ambulacral fluid and are stored in large numbers in an organ of this system, the Polian vesicle. Hemocytes have been recently studied for their role in encapsulating foreign particles (Caulier et al., 2020). Interestingly, they are easily distinguishable from other coelomocytes due to their intense red color. It has long been assumed that this pigmentation was due to the presence of hemoglobin. However, our pigment analysis using HPLC revealed a high concentration of carotenoids in the ambulacral fluid and Polian vesicle, suggesting that these pigments are responsible for the hemocyte pigmentation. A comparative transcriptomics approach did not reveal a notable elevated expression of genes coding for globins relative to other coelomocytes, in contrast to the expression of genes involved in carotenoid metabolism. This finding corroborates the hypothesis that the observed pigmentation likely does not originate from hemoglobin. Additionally, hemocytes exhibit strong autofluorescence, and we took advantage of this property to isolate hemocytes using a combined approach of spectral flow cytometry and FACS. We successfully obtained a pure and viable cell population that can be processed for downstream analyses. This strategy could be extended to other pigmented cells and offer new perspectives for a more targeted study of hemocytes and their function(s) in the immune response of sea cucumbers.

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Saponins: Multitasking chemical signatures in asteroids and holothuroids

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Organisms live in a world of odors and flavors where each living or inert entity releases distinct molecules in the environment. Marine organisms, in particular, rely on environmental chemical cues during their entire life, from early developmental to adult stages (Hay, 2009). Particularly, the phylum Echinodermata presents specific chemicals for each class (Kornprobst, 2005). Saponins are triterpenic or steroidic glycosides that are produced by all investigated species of holothuroids and asteroids (Caulier et al., 2011). Due to their amphiphilic properties, these molecules can interact with sterols in biological membranes, rendering saponins noxious and repellent to most organisms (e.g., ichthyotoxic effect). Despite this role of chemical defense, sea cucumbers and seastars harbor diverse symbiotic communities composed of crustaceans, polychaetes and even carapid fishes that developed biological adaptations to resist to saponins. Not only symbionts may benefit from the chemical defense of their hosts to reduce their predation rate, they can also use saponins as kairomones to specifically recognize their host by chemical communication (Caulier et al., 2013). Recently, we even discovered that holothuroids use saponins as an aggregation pheromone, having a particularly important role in their reproduction (Claereboudt et al., 2023).

This study highlights the diverse functions of saponins in seastars and sea cucumbers, ranging from repellent allomones to attractive pheromones and kairomones. These essential metabolites have been strongly selected throughout evolution, with each species possessing its unique chemical signature allowing it to interact with the environment.

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The echinoderm abyssal biodiversity of the Clarion Clipperton Zone

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The Clarion-Clipperton Zone (CCZ) covers about 6 million km2 of the Pacific seabed and it's the largest polymetallic nodule province in the world. Other important occurrences are known from the Peru Basin and specifically from the DISturbance and re-COLonisation Experimental Area (DEA). CCZ is targeted for commercial-scale mining in the coming years, however there is a lack of adequate baseline information that may result in serious species declines before they are even discovered and described. The restricted knowledge on these dark taxa ensures that they remain in the shadows of research and conservation policies. Therefore, Echinodermata (Asteroidea, Crinoidea, Echinoidea, Holothuroidea, Ophiuroidea) collected during ten scientific cruises across the CCZ and the DEA were examined. More than 850 specimens were sorted and identified to the lowest possible level through imagery to propose primary species hypotheses, and the ensuring data were integrated with barcoding information (COI). Neighbour-joining trees were constructed, while tree- and distance-based methods of species delineation (ASAP, BINs, GMYC, mPTP) were employed to propose secondary species hypotheses (SSHs) among the echinoderms collected. Concordant results from the species delimitation analyses revealed 87 deep-sea echinoderm SSHs, uncovering an unexpectedly high diversity and showing that diversity of even the most conspicuous invertebrates in abyssal plains has so far been considerably underestimated. As a result, a curated DNA reference library for the CCZ-DEA echinoderms was created in BOLD, including DNA sequences, photographs, collection, and taxonomic data. This study provides the foundation for biogeographic and functional analyses that will aid policy-making as commercial ventures affect dark abyssal biodiversity.

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Conservation of commercially exploited sea cucumbers (Holothuroidea): Recent advances and knowledge gaps

Chantal Conand,[1] Steven Purcell,[2] Jean-François Hamel,[3] Annie Mercier,[4] Marie Di Simone,[5] Arnaud Horellou,[5] Kim Friedman[6] and Alessandro Lovatelli[6]

Sea cucumbers have been harvested, particularly by the Chinese, for human consumption for thousand years. To service modern Asian seafood markets, fisheries have progressively expanded to countries around the tropical Pacific, then into the Indian Ocean and more recently across the world. The tropical fisheries are generally artisanal and multispecific, whereas temperate ones are often monospecific and industrialized. The number of exploited species has increased greatly in recent decades and the dried products (bêche de mer or trepang) can be classified according to their value. Harvesting often follows a 'boom-and-bust' cycle, with a rapid or steady increase in production, followed by over-exploitation and stocks collapsing. Illegal harvesting (IUU) is often observed, especially in low-income countries where fishing has been banned. Conservation issues have therefore been raised and research developed at both the specific level, relating to taxonomy, biology, and ecology and at the ecosystem level, regarding biodiversity, fisheries and markets. Advances in holothurian conservation is coming from the efforts of international bodies, including FAO, CITES, IUCN, as well as from regional ones such as SPC and WIOMSA, and national research and fisheries administrations. Present knowledge gaps are analyzed through the following questions: What are the main threats to the fishery, past and emerging? What biological and ecological data are most needed for conservation planning? For which species/groups are these data most lacking and why? Are there geographic areas that are especially data poor? What are the most effective processes for conserving sea cucumber populations?

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Comparative and morpho-functional investigation of the stone canal in Holothuroidea

Guillaume Corbisier,[1] Guillaume Caulier,[2] Jean-Francois Hamel[3] and Annie Mercier[4]

Among the most enigmatic structures of echinoderms is the stone canal, which is part of the ambulacral system. It is typically connected to the exterior in echinoderms, however in the majority of Holothuroidea, this canal is opening in the main body cavity. While the morphology and function of the stone canal in Asteroidea and Echinoidea have been studied for the past two centuries, no consensus has been reached regarding its function. Most commonly, it is described as a pressure regulator, with ciliary inflow occurring at the surface of the apex of the stone canal. An excretory function has been hypothesized, however a bidirectional flow has also been suggested (Binyon, 1964).

Despite these hypotheses, the function of the stone canal remains poorly understood, and its function in the Holothuroidea class has not been investigated. The morphology of the stone canal in sea cucumber is also understudied, and only limited information is available on it (Erber, 1983).

To address these gaps in research, 6 species of sea cucumber have been studied and various morphological and in vivo analyses have been conducted. Morphological results have led to the discovery of an asymmetric canal inside the peduncle of the stone canal that can play a part in generating a bidirectional flow through ciliary movement. To strengthen this assumption, in vivo analyses were conducted using microbeads and carbon particles to track the movement within the organisms at different time points. Injections were made in the ambulacral system and inside the body cavity. Particles were tracked for 72 hours. These analyses have confirmed the existence of a bidirectional flow, where particles inside the body cavity entered the stone canal and particles inside the ambulacral system migrated to the body cavity via the stone canal.

These findings represent a step towards understanding the functions of the stone canal and further research may shed light on the various functions of this organ and on the broader concept of excretion in echinoderms.

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Mechanically tunable collagen scaffolds for tissue engineering applications inspired by sea cucumbers

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As the average human lifetime increases, so does the incidence of failing tissues and organs in the elderly. Thus, it becomes essential to develop strategies for regenerating replacement tissues in the lab. However, there are still major challenges to effectively engineer artificial tissues and organs with complex 3D structures – most notably the temporal and spatial regulation of tissue scaffold mechanics. To address this challenge, we take inspiration from a unique biological model – the mutable collagenous tissue (MCT) of sea cucumbers (Bonneel et al., 2023). MCT is a collagen-based tissue that can be stiffened and softened through the addition of effector proteins. We hypothesize that sea cucumber-sourced collagen will enable dynamic modulation of mechanical properties for tissue engineering applications, providing several functional advantages over current mammalian-sourced collagen. In particular, MCT scaffolds will provide the ability to tune local mechanical properties in a controlled manner that is not possible with current natural or synthetic tissue scaffold materials.
Yet, harnessing MCT as a dynamically mechanoresponsive scaffold first requires an in-depth understanding of the molecular and structural mechanisms underlying mechanical mutability. Here, we undertook a comparative compositional and structural investigation of two distantly related sea cucumber species–*Holothuria forskali* and *Cucumaria frondosa*. For both species, it is known that the effector protein tensilin can rapidly induce a transformation between the soft and standard (stiffer) mechanical states of the dermis (Bonneel et al., 2023). However, the other effector proteins, including softener, have only been partially purified based on their activity, and their identity and sequence remain unknown. Proteomic analyses coupled to transcriptomics first allowed us to investigate the specific molecular components of the MCT from the dermis of *H. forskali*. Then, we investigated the mechanical, compositional, and structural differences between *H. forskali* and *C.*

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frondosa dermis using a range of cross-disciplinary techniques including histology, tensile testing, FT-IR spectroscopy, X-ray diffraction and confocal Raman spectroscopy. This multi-length scale approach provides new insights into the similarities and differences between MCT from these two species, furthering our understanding of the mechanisms of tunability in this distinctive mechanically adaptive collagenous tissue.

Dietary effect of fermented feed sources on growth performance of juveniles sea cucumber *Holothuria scabra*

Lisa F. Indriana,[1,2,3] Andreas Kunzmann[2] and Matthew J. Slater[1]

Sea cucumber *Holothuria scabra* is one of the marine species with a high economic value that has the potential as a source of luxury seafood. A suitable diet is still a limiting factor in the growth of farmed sea cucumbers, particularly in large-scale cultivation. The objective of this study is to evaluate the effect of fermented diet on the growth and survival of early juveniles of *H. scabra*. Seven treatments were conducted with 4 replicates each, with the following main components: seagrass *Enhalus acoroides* (control), seaweed *Halimeda* sp., *Ulva* sp., *Padina* sp., *Sargassum* sp., microphytobenthos, and moss. Juveniles with an initial average wet weight of 0.16-0.18 g were maintained in experimental tanks in East Lombok, Indonesia. There were significant differences in the growth rate of juvenile *H. scabra* fed different fermented diets ($p<0.05$). The highest and the lowest values of growth rate (0.09±0.023 and 0.01±0.001 g d-1) were observed in treatments fed with klekap and *Ulva* sp., respectively. Specific growth rates of the diet *Halimeda* sp.,(3.17±0.183 % d-1) and control *Enhalus* sp., (4.17±0.058 % d-1) are statistically significantly different ($p<0.05$). The survival rates of the dietsmicrophytobenthos, *Halimeda* sp. and moss were significantly lower than the control feed (*Enhalus* sp.) which had the highest value of 80.63 ± 4.38%.

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Holothuroid phylogeny inferred from mitogenome data

Andreas Kroh[1] and Mike Reich[2,3,4]

Over the last decade an increasing number of mitochondrial genomes for echinoderms have been published and currently more than 230 echinoderm mitogenomes representing ca. 200 different species are available. Thanks to high-throughput sequencing it is now easier than ever to assemble mitochondrial genomes. Because of the high number of mitochondrial copies per cell, mitochondrial reads typically represent a few percent of the sequence data from most sequencing experiments, even if mitochondrial DNA was not the focus of the experiment in question. These data can often be used to assemble complete mitochondrial genomes of high quality and high genomic coverage (sequencing depth). Using published and newly assembled mitochondrial genomes from around the half of the known families of the major groups of sea cucumbers (Apodida, Elasipodida, Holothuriida, Molpadida, Synallactida, Dendrochirotida), we examined the phylogeny of the Holothuroidea and compared the results with phylogenomic analyses based on nuclear markers from transcriptomic data and morphological data.

This is a contribution to the efforts for the revised *Treatise on Invertebrate Paleontology, Part U, Echinodermata 3, Asterozoa – Echinozoa*.

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Longitudinal gradient in the population size structure of the sea cucumber *Cucumaria frondosa* in the Northwest Atlantic

Kevin C.K. Ma[1], Robert Trenholm,[1,2] Jean-François Hamel[3] and Annie Mercier[1]

In response to declines in finfish fisheries, commercial harvests of underutilised species such as whelks and sea cucumbers were developed in many jurisdictions to generate or maintain economic growth. The sea cucumber *Cucumaria frondosa* is an abundant benthic echinoderm found on the continental shelves of eastern Canada and several other countries in the North Atlantic, making it a good candidate for a commercial fishery. On the St. Pierre Bank off the southern coast of insular Newfoundland (NAFO Division 3Ps) in Canada and France (Saint-Pierre-et-Miquelon), the biomass of sea cucumbers was estimated around 255,000 metric tonnes in 2016. In this study, this stock was assessed by examining the population size structure from three areas across a longitudinal gradient. We found an increasingly greater proportions of smaller individuals in the eastern area of the fishing ground. This pattern remained robust even after accounting for individual variability in size, which can range between 10 and 20% depending on the metric tested (e.g., body length, whole wet weight). Differences in size structure among populations were linked with local fluctuations in primary production (a proxy for food availability), temperature, and current velocity at the seafloor. These findings advocate for the importance of using site-specific size structure in the future management across the whole distributional range of *C. frondosa* in the Northwest Atlantic.

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The sea cucumbers of the Algerian coastal waters: Taxonomy, ecology and their nascent fisheries and illegal trade

Karim Mezali

The present work aims to provide an overview of the various studies carried out on sea cucumber species from the Algerian coastal areas. The main contributions relate to the discovery of the new genus *Paraleptopentacta* and the separation of the new species *Holothuria algeriensis* formerly called *Holothuria tubulosa* "B" (Mezali et al., 2020, 2021). Various studies have focused on the reproduction of *Holothuria sanctori* and *Holothuria poli*, the population dynamics of *Holothuria tubulosa* and *Holothuria poli*, the feeding behavior and the analysis of the digestive contents of some species of the genus *Holothuria,* as well as the species *Parastichopus regalis* (Mezali et al., 2022). The biochemical aspect was approached by elucidating the proximate composition of the species of the genus *Holothuria* as well as the characterization of the saponins present in the tegument and Cuvierian tubules of *Holothuria sanctori*, *Holothuria algeriensis* and *Holothuria arguinensis*. In Algeria, the harvesting of sea cucumbers is growing rapidly and is capable of extracting significant amounts of these benthic animals (Mezali and Slimane-Tamacha, 2020). Hence, there is an urgent need for effective management in order to avoid destruction of the stock.

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Study of sea cucumber photoreception

Youri Nonclercq,[1] Patrick Flammang,[1] Igor Eeckhaut[1] and Jérôme Delroisse[1]

It has been known that echinoderms, despite lacking complex eye structures, exhibit photosensitivity mediated by opsins, photoreceptor proteins also found in other bilaterians. Recent studies on sea urchins, sea stars, and brittle stars, have revealed opsins in various body parts such as tube feet, spines, and the nervous system (Ullrich-Lüter et al., 2011; Delroisse et al., 2014). The eyespot located at the sea star arm tips has also been studied extensively. Some species have even demonstrated low-resolution extraocular spatial vision (e.g., Sumner-Rooney et al., 2020). However, photoreception in sea cucumbers has remained largely unexplored, with only sporadic data available, such as observations of species moving away from a light source or retracting their oral tentacles under strong light exposure. To fill this knowledge gap, we conducted a comprehensive investigation of sea cucumber photoreception using a multidisciplinary approach. Firstly, we analyzed genomes and transcriptomes of multiple holothuroid species, revealing the presence of six ancestral opsin types in this group. Secondly, we highlighted the expression of rhabdomeric opsins, commonly found in protostome eyes, in oral tentacles and tube feet of *Holothuria (Panningothuria) forskali*, a European species belonging to the Holothuriida order. Our investigation also focused on the Apodida order, a group of sea cucumbers with snake-shaped bodies lacking tube feet. Previous authors have proposed the presence of visual-like structures at the base of the tentacles and/or in association with the oral nerve ring in different spe-

cies (e.g., Ludwig, 1889; Yamamoto and Yoshida, 1978). Our study revealed the expression of ciliary opsins, typically found in vertebrate eyes, in the neuroepithelial structures forming eyespots at the base of tentacles in the tropical species *Euapta godeffroyi*. We also detected the expression of ciliary opsins in the sensory cupules of *Oestergrenia digitata*, a burrowing European species. Until now, the functions of these cupules located on the inner surface of tentacles had remained unexplored. Finally, ethological tests conducted on both Holothuriida and Apodida species revealed that *H.(P.) forskali* and *E. godeffroyi* moved away from a light source, while *Synapta maculata* exhibited a movement toward it, specifically in response to blue and green lights. These findings provide new insights into the mechanisms and evolution of photoreception in sea cucumbers.

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What drives the patchy distribution of tropical sea cucumbers? A multispecific monitoring study

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Three species of sea cucumbers, *Holothuria atra*, *Holothuria leucospilota* and *Stichopus chloronotus*, are patchily distributed within coral reefs of Reunion Island. They exhibit high density (> 1 ind.m^2). Factors involved in the distribution and spatio-temporal dynamics of these populations are not well understood yet. The aim of this study is to identify the key factors which drive the dynamics of sea cucumbers populations of Reunion Island. Sea cucumber populations and sedimentary factors (substrates composition, total organic matter, fine particles, chlorophyll *a*, Δ13C and Δ15N) were monitored along a back-reef and shore-to-ocean gradient during four consecutive seasons. Feeding behaviour was assessed by measure of motility and excretion rate. Multiseasonal monitoring revealed that the three species have their own dynamics, with an increase of density for *H. leucospilota*, a stability observed for *H. atra*, but a decrease for *S. chloronotus*, since 1990s. Meanwhile, the use of asexual reproduction has ceased for *H. atra* and *H. leucospilota*, and some signs of decline for *S. chloronotus* were observed. *Stichopus chloronotus* seems specialist while the two other generalists. Sedimentary factors with signs of anthropogenic disturbances (high organic matter, chlorophyll *a* and Δ13C) was related to *H. atra* distribution, while seagrasses variable was correlated with *H. leucospilota*. Conspecific attraction may drive the high-density patchy distribution of these two species. Finally, no sedimentary factor was correlated with *S. chloronotus*. The drastic diminution of the populations of *S. chloronotus* could be linked to unstudied factors such as illegal harvesting, diseases, predation or climate change. Further studies should focus on other environmental factors in other reef compartments to fully explain to patchy distribution of sea cucumbers at Reunion Island.

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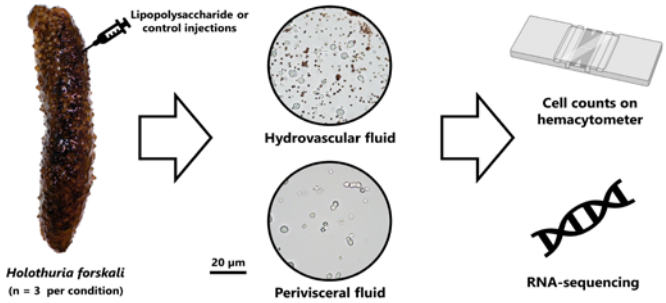
Divergent function between perivisceral fluid and hydrovascular fluid under immunological stress in sea cucumbers (*Holothuria forskali*)

Noé Wambreuse,[1] Estelle Bossiroy,[1] Jérôme Delroisse,[1] Céline Vanwinge,[2] Igor Eeckhaut[1] and Guillaume Caulier[1]

Echinoderms have two main coelomic cavities in their body plan: the general perivisceral cavity containing the different organs and the hydrovascular cavity constituting a unique vascular system also known as the water vascular system. These two cavities are filled with a fluid whose composition is close to that of seawater, but which contains a large amount of metabolites and cells. These cells are called coelomocytes and constitute the main actor of echinoderm immunity. Different cell types have been described based on morphological criteria; it appears that sea cucumbers show the greatest diversity among the five classes of echinoderms at six to seven different types. While the immune response of perivisceral coelomocytes has already been studied in different species, the immune response of hydrovascular coelomocytes remains understudied and the differences in their immune response have not been investigated yet. In the present study, we investigated the transcriptomic response of coelomocytes to injections of lipopolysaccharide (LPS) – a molecule that mimics a bacterial infection – in the sea cucumber *Holothuria forskali*. Coelomocytes from both fluids were studied distinctly to compare their immune response. In addition, we attempted to correlate gene expression with the proportion of different coelomocyte types in each fluid by counting the cells (Fig. 1). Our results revealed 17,646 differentially expressed genes (DEGs) between control and LPS-injected individuals (by considering both fluids) and 5524 and 6420 DEGS specific to the perivisceral and hydrovascular fluid, respectively. Regarding the comparison of the two fluids, 2853 genes were DEGs when considering all individuals (*i.e.*, control and LPS-injected individuals). Interestingly, the same analysis resulted in only 179 DEGs in control individuals but in 2773 DEGs in stressed individuals. These results suggest that in immunoquiescent conditions, the coelomocytes from both

fluids have a similar function but that this function tends to change following the immunological stress. Furthermore, this change coincides with an increase in the concentration of hemocytes as a result of immunological stress that occurs only in the hydrovascular fluid. Finally, the functional annotation of DEGs offers precious information about the specific functions of coelomocytes in both fluids. This research raises interesting questions about the function of the hydrovascular system and coelomocytes and provides valuable data for comparative immunology.



Figures 1. Experimental design: 6 specimens were selected (3 control injection individuals and 3 lipopolysaccharide injection individuals); their hydrovascular fluid and perivisceral fluid were harvested; coelomocytes were counted on a hemacytometer before performing the RNA-sequencing analysis

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Bonding with sea cucumbers: Identification of tube foot adhesive proteins from transcriptomic data

Alessandra Whaite,[1] Baptiste Herlemont,[1] Jérôme Delroisse[1] and Patrick Flammang[1]

Many marine invertebrates produce adhesives that act in the presence of water, and this has raised growing scientific interest because of the potential to mimic such adhesives for use in human medicine and dentistry. In echinoderms, adhesive secretions are mostly within the tube feet, which are the external appendages of the water-vascular system, a distinctive feature of the phylum (Flammang et al., 2016). Tube feet are involved in tasks that require temporary adhesion underwater, such as locomotion, maintenance of position, and feeding. Although tube feet are present in every extant echinoderm species, adhesion has only been studied in detail in asteroids and regular echinoids. Within the tube feet, duo-gland adhesive systems release proteinaceous secretions from adhesive cells, while de-adhesive cell secretion allows detachment.

In our laboratory, we have been studying tube foot adhesion in echinoderms for many years. However, it is only recently that some adhesive proteins have been characterized in the sea urchin *Paracentrotus lividus* (Pjeta et al., 2020) and in the sea star *Asterias rubens* (Algrain et al., 2022). In contrast, very little information is available on adhesive proteins produced by sea cucumber tube feet. Taking a bioinformatics approach, we have utilised existing transcriptome data and knowledge of adhesive protein attributes in other echinoderms to identify key proteins involved in adhesion in the sea cucumber, *Holothuria forskali.* More specifically, Blast searches were used to identify proteins similar to adhesive proteins from *P. lividus* and *A. rubens* in the body wall transcriptome of *H. forskali*. The list of candidate proteins was further refined by differential transcriptomics, comparing the expression levels of their coding mRNAs in the ventral (with tube feet) and dorsal (without tube feet) body wall. This allowed us to establish a short list of about 10 adhesive protein candidates which were then further validated by confirming they are expressed in tube feet but not in other organs using PCR. Once fully characterized, these proteins could offer novel features and/or performance characteristics for applications in wet environment adhesion.

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Summaries of posters

Nutritional quality and culinary and nutraceutical valorization of sea cucumbers from the Mostaganem region (Algeria)

Nour El Houda Belkacem,[1] Ihcene Khodja[1] and Karim Mezali[1]

Sea cucumbers have a high level of proteins including collagen and a low lipid level represented by unsaturated fatty acids (omega-3, omega-6) thus constituting a perfect combination for human consumption in addition to their high level of vitamins and minerals. In addition, numerous species of the Holothuroidea contain many bioactive molecules such as saponins that have a wide range of biological activities (anticancer, antiviral, antifungal, ...).

Our work focuses on the valorization of "sea cucumbers" from the Mostaganem region (Algeria), which is a resource caught illegally and exported abroad via intermediaries at very low prices. In this study, we propose processing of fresh "sea cucumbers" into dry products called "bêche-de-mer" that we valued in two ways: 1) Culinary valorization imitating the recipes of various dishes commonly consumed in Algerian cuisine ["bourek" (very fine paste composed of wheat flour filled with the stuffing of chopped sea cucumber), "sea cucumber with white sauce and mushrooms", "sausages" and "marinated sea cucumber salad"] and 2) Nutraceutical valorization in the form of powder and food supplement.

Through this study, we aim to contribute to food security with a product rich in protein and which enters the purchasing power of the Algerian population, especially since its manufacturing process is not very expensive

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Distributional congruence and species richness of echinoderms in the East Pacific

Andrea A. Caballero-Ochoa,[1,2] Blanca Estela Buitrón-Sánchez[3] and Francisco A. Solís-Marín[4]

The biogeographic patterns of echinoderms throughout the eastern Pacific have not been well documented. In this work, more than 100,000 records contained in the Global Biodiversity Information Facility (GBIF) repository databases were analyzed and validated in order to identify the distributional congruence and record the areas with highest specific richness. A total of 893 species of echinoderms distributed in the region were recorded for the first time. Five areas with the highest richness were located: 1) the Gulf of California; 2) the Bay of Panama, including the Malpelo and del Coco Islands; 3) the Galapagos Islands; and finally, near the Strait of Magellan, 4) the Chilean Fjords. Separately, changes in latitudinal gradient were identified, one in a hot zone, another in a temperate zone and finally in a cold zone, each area with the corresponding endemic species were mapped. Fourteen consensus areas were identified, which show the distributional congruence of the species; each area was assigned to each identified pattern, as well as the species that support the area and their percentage of species richness. The patterns were: Bering Strait, British Columbia nested with California (USA), Gulf of California, Panama Bay, Galapagos Islands and the Chilean-Patagonian region. It is necessary to continue with the analyses of the biogeographic patterns of the area to evaluate the possible common histories of the biota and the ecological processes that could be involved.

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Can holothurians from the deep-sea of New Caledonia be used to monitor microplastic pollution?

Valentin Dettling,[1,2] Claire Laguionie-Marchais,[1] Jean-Baptiste Fini[2] and Sarah Samadi[1]

Plastic production has risen exponentially since the early 1950s. Plastics represent the vast majority of total marine litter, while they mostly stem from mismanaged land-based litter. Most of the plastic pollution is today believed to be due to microplastics, microparticles resulting from the weathering and breakdown of larger plastics. Microplastics display a wide variety of toxicity and can easily be ingested by a broad range of organisms. Moreover, microplastics can sink onto the seafloor due to their density or to biofouling or marine snow. As such, several studies have shown that microplastics can accumulate in the sediments, and that the deep seafloor could constitute a major microplastic sink, rendering them bioavailable to benthic organisms.

Most holothurian species are benthic organisms present at all depths and latitudes. A vast majority of species are deposit-feeders, with high bioturbation and sediment-filtering rates, comprised between 9 and 82 kg per individual per year. Hence, we hypothesise that holothurians could be a relevant model organism to study microplastics pollution. Research in shallow water ecosystems has already demonstrated the presence of microplastics in several families of holothurians.

In this project, we will investigate microplastic pollution temporal trends, using a time-series collection of deep-sea New Caledonia holothurians of the *Muséum National d'Histoire Naturelle*. The sampling strategy of the collection specimens will be presented, as well as preliminary analyses of microplastic contents found in holothurians. This project also ambitions to determine the potential uptake and biodistribution of microplastics by holothurians, and investigate microplastics ingestion physiological consequences. Altogether, these experiments will enable to obtain a better understanding of the impact of microplastic pollution on holothurians, an important ecological and economical class of organisms.

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Autotomy in the apodid sea cucumber *Chiridota laevis*

Sara Jobson,[1] Jean-François Hamel[2] and Annie Mercier[3]

This study characterizes the autotomic ability in the apodid sea cucumber *Chiridota laevis.* Although this species has been documented in temperate benthic marine environments for over a century, basic information regarding its regenerative capacity is absent from the literature. Our initial investigations of *C. laevis* demonstrated that it can undergo remarkably rapid transversal fission. This unique behaviour and its relationship to various triggers were investigated from ecological and evolutionary perspectives. Experimental results confirmed that this mid-body splitting behaviour is indeed true autotomy (i.e. an active defense mechanism in response to physical stimuli) as opposed to reproduction through fission. Physical triggers were explored, along with the autotomic breakage planes and kinetics of the healing process post splitting. Preliminary results suggest that autotomy is closely linked with season and possibly ontogeny and reproductive maturity. The findings will directly address knowledge gaps in the field of regenerative biology, while providing useful information about an interesting and valuable model organism for evolutionary biology research.

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IceDivA Project: The study of diversity of deep-sea holothurians in the North Atlantic Ocean using molecular approaches

Elham Kamyab,[1]* Sahar Khodami,[1] Frederic Bonk,[1] Sven Rossel,[1] James Taylor,[2] Saskia Brix[2] and Pedro Martínez Arbizu[1]

Monitoring the unexplored diversity of deep-sea marine ecosystems has been challenging due to the limited accessibility and size variety of organisms from different taxa. During the IceDivA expeditions (Icelandic marine Animals meets Diversity along latitudinal gradients in the deep sea of the Atlantic Ocean; SO280 and 286), we assessed deep-sea planktonic and benthic fauna presented in abyssal plains east and west of the Mid-Atlantic Ridge. Within IceDivA, we identified sea cucumbers using targeted sanger-sequencing (COI barcoding) as well as, for the first time, proteomic fingerprinting using MALDI-TOF MS analysis for holothurians. The preliminary results related to holothurian identification showed that sea cucumbers have a patchy distribution along deep-sea basins. Moreover, initial morphological observations and comparison of our sequences to public DNA repositories (i.e., BOLD and NCBI) showed that among 28 specimens, most of the samples belonged to the order *Elasipodida*. In parallel, MALDI-TOF MS analysis was able to differentiate between the proteomic fingerprints of most of the species in correspondence to the COI barcodes. Finally, in order to complete the assignment and provide accurate identifications at species level, a combination of molecular methodologies with classical taxonomic identifications is necessary.

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Molecular diversity and structure-activity relationship of saponin in Indo-Pacific sea cucumber *Bohadschia argus*

Elham Kamyab,[1]* Matthias Y. Kellermann,[2] Miriam Reverter,[3] Dimas Praditya,[4] Arlette W. Storjohann,[5] Matthias Köck,[6] Joachim Wink,[7] Eike Steinmann,[4] Deniz Tasdemir[5] and Peter J. Schupp[2,8]

Sea cucumbers are slow moving benthic invertebrates that contain triterpenoid saponin glycosides in abundance (Kamyab et al., 2020). Sea cucumber saponins are chemically highly diverse with variations in their aglycones or sugar moieties (Popov, 2002; Kalinin et al., 2008). In this study, we investigated the chemical structure and bioactivity of different saponin glycosides isolated from Indo-Pacific sea cucumber species, *Bohadschia argus* which appeared to be highly active in initial bioactivity screening. Using Feature-Based Molecular Networking (FBMN), we first identified the major saponin compounds present both in the whole organism as well as in its Cuvierian tubules (CTs, specialized structure that often accumulates a cocktail of saponins). In addition, four already identified saponin compounds were isolated and their structures were elucidated as bivittosides C, D and argusides B and C by high-resolution MS and MS/MS experiments combined with nuclear magnetic resonance (NMR) spectroscopy. Finally, we were able to draw structure-activity relationships between different saponins and their antibacterial, antifungal, anti-viral, and anticancer activities. It showed that the observed bioactivities were influenced by the presence or absence of hydroxyl groups at C-12 and C-17 in the aglycone moiety, as well as by changes in the sugar moiety specifically in the second sugar unit of the saponins. In conclusion, we revealed that *B. argus* contains structurally diverse saponins, with specific structural features being correlated to different bioactivities. This highlights the importance of studying the structural characteristics and the biological activities of saponins to identify the main bioactive moieties of the molecules useful for possible industrial productions.

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Comparative taxonomic analysis of *Holothuria (Thymiosycia) decorata* and *H. (Mertensiothuria) hilla*

Jinho Lee[1] and Taekjun Lee[1,2]

Holothuria (*Mertensiothuria*) *hilla* is a common sea cucumber in the northwest Pacific, and it extends its reach to regions such as Korea, Japan, Hawaii, the Indo-Pacific, Australia, and Zanzibar in East Africa. Several species have been synonymized with *H.* (*M.*) *hilla*. However, *H.* (*M.*) *hilla* collected from the northwest Pacific, particularly the adjacent waters of Korea and Japan, exhibit distinct morphological differences compared to specimens from the Indo-Pacific region.

In this study, we conducted a comprehensive investigation into the species history based on previous articles and analyzed their morphological characteristics. Additionally, we obtained DNA barcoding sequences from both *H.* (*M.*) *hilla* and *H.* (*Thymiosycia*) *decorata*. The results of this study revealed significant differences in the morphological characteristics of ossicles between these two species. Furthermore, the DNA barcoding analysis clearly indicates that *H.* (*M.*) *hilla* and *H.* (*T.*) *decorata* are different at the species level. Based on the results in this study, we suggest recognizing *H.* (*T.*) *decorata* as a separate species.

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An investigation of the molecular and structural properties of the mutable collagenous tissue in the European sea cucumber *Holothuria forskali*

Némo Lemaire,[1] Nathalie Singh,[3] Amy Lin,[3] Rudy Wattiez,[2] Jérôme Delroisse,[1] Matthew J. Harrington[3] and Patrick Flammang[1]

The mutable collagenous tissue (MCT) found in echinoderms, including sea cucumbers, is a unique connective tissue that can rapidly change its mechanical properties in response to certain stimuli. This tissue is constantly switching between different stiffness states! In sea cucumbers, the tissue properties are modulated by the release of molecular factors in the extracellular matrix, leading to the formation of transient cross-bridges between collagen fibrils. Surprisingly, despite this unique ability, there have been relatively few studies on the molecular and structural characteristics of MCT compared to other collagen-based connective tissues.

The present project aims to explore the molecular composition and the structure of the MCT constituting the dermis of the European sea cucumber *Holothuria forskali.* Proteomic analyses coupled to transcriptomics allowed to investigate the specific molecular components of the MCT. Obtained results showed an interesting combination of alpha 1, 2 and 5 chains in purified collagen fibrils. Furthermore, Raman and ATR-FTIR spectroscopy showed bands consistent with type I collagen, corroborating SEM observations of the fibrils. Additionally, characterization of the collagen structure and organization in the dermis of *H. forskali* was performed using polarized light microscopy and X-ray diffraction in comparaison with another species, *Cucumaria frondosa*. Preliminary data seem to indicate a species-specific preferential alignment of collagen in holothuroids. Understanding the molecular and structural properties of MCT could have potential applications in the medical and engineering fields as an inspiration for memory-shaped material with reversible viscoelastic state.

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First observations and morphological descriptions of biogenic calcareous microcrystalline structures in an echinoderm

Kevin C. K. Ma,[1] Fei Gao,[2] Jean-François Hamel[3] and Annie Mercier[1]

Biogenic calcareous microcrystalline structures (or microcrystals) have been observed in many animal taxa, including Porifera, Anthropoda, Mollusca, and Chordata (from Tunicata to Mammalia). In mammals, these microcrystals and other types of urinary crystals are morphologically complex and often associated with urine as a by-product of metabolism. In this study, different tissues (e.g., skin, muscles, intestine, gonad) of the holothuroid *Cucumaria frondosa* were analysed to isolate calcium-based microcrystals. We found microcrystals—classified as calcium carbonate or calcium oxalate dihydrate—from the circular muscle, the cloaca, the Polian vesicle, the respiratory tree, the retractor muscle, the skin, or the tentacle in all examined

individuals. Notably, they were absent from the ampulla, genital papilla, the gonad, the intestine, longitudinal muscle, and the stomach. Calcium carbonate microcrystals varied in shape and size: rhombohedral (20 to 50µm) or barrel-shaped (12 to 142µm). While calcium oxalate dihydrate were either octahedral (5 to 50µm) or dodecahedral in shape (12 to 70µm). We suspect that the accumulation of these microcrystals in tissues of holothuroids could be related to tissue fatigue and, as is the case for mammals, a method to diagnose disease, which could make echinoderms a new model taxon to study the evolution and function of biogenic microcrystals.

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Investigating the mystery of beaching events involving sea cucumbers

Annie Mercier[1] and Jean-François Hamel[2]

Most reports of stranding in echinoderms relate to mass mortalities of sea stars and sea urchins, while documentation of sea cucumber beaching events (i.e. wash-ups of live or dead individuals along the shores) have received less attention. The present study compiles and analyses the reported cases of sea cucumbers washing up on shores around the world over the past century. Although they are still mostly anecdotal, being issued by the general public, media, and research scientists alike, they appear to have increased in frequency, particularly over the last decade. The details and magnitude of documented stranding events were examined in an attempt to draw some preliminary interpretations regarding their potential causes and ecological significance. While parallels can be draw across events, taxa-specific ecophysiological aspects also seem to be emerging, pointing to a diversity of mechanisms. As our understanding of sea cucumbers and other echinoderms grows, we can start to define with a little more certainty the potential triggers leading to this sometimes sad finality and be on the look-out for an intensification of certain types of beaching events under the influence of climate change.

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Anal teeth in modern and fossil holothuriid sea cucumbers (Echinodermata: Holothuroidea: Actinopoda)

Mike Reich,[1,2,3] Gustav Paulay,[4] Andreas Kro,[5] Viola Winkler[6] and Hans Hagdorn[7]

The Holothuroidea are probably the most morphologically diverse, but also the least understood clade of the present-day echinoderms. This concerns not only the size of adults or their mode of life, but also their hard part morphology. The calcareous ring surrounding the pharynx in the mouth area and the ossicles of the body wall are functionally almost indispensable and, with a few exceptions, present in all species. An additional rigid test or anal teeth, as well as phosphatic deposits in the body wall, in contrast, are limited to some holothuroid groups; chitinous tentacle-sheaths have so far only been recorded from one species.

The five anal teeth or the plates that surround the anus ring-like also belong to the morphologically almost unknown and rarely studied hard part structures of sea cucumbers. Although first mentioned in the 18th century, the knowledge about this distinct morphological structure in terms of anatomy, stereom differentiation, function etc. is insufficient. The taxonomic distribution of those calcareous elements is variable and particularly well developed in a few clades of actinopodid sea cucumbers (Holothuriida, Molpadida, Dendrochirotida), but unknown in detail.

Our study presents for the first time an overview of the anal teeth of various members of the Holothuriidae — *Actinopyga, Holothuria* (*Microthele*), *Holothuria* (*Platyperona*) —obtained by light, laser scanning and scanning electron microscopy, as well as x-ray computed tomography. The modern examples are compared with the only distinct fossil anal teeth known so far (from the Middle Triassic/Anisian 'Muschelkalk' of southern Germany). The latter finds confirm that anal teeth have been present in Holothuriida (clade Pneumonophora) for at least 243 million years.

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Morphological and molecular phylogenetic analysis of sea cucumbers (Holothuroidea) collected on the Kyushu-Palau ridge

Chongzhen Yuan,[1] Chunsheng Wang[1, 2, 3, 4] and Dongsheng Zhang[1, 2, 3]

In contrast to other echinoderms that can be more readily collected, members of the class Holothuroidea present challenges in preservation due to their susceptibility to damage and difficulty in preservation. Despite their broad distribution, there remains a paucity of DNA molecular data for sea cucumbers. Further research employing morphological and molecular phylogenetic identification techniques is necessary to address this deficiency.

During the DY68 voyage, multiple sea cucumber samples were collected in the Kyushu-Palau Sea area. After morphological identification and molecular phylogenetic analysis, 14 sea cucumber species of the Psychropotidae family of the Elasipodida order were found, including 9 known *Benthodytes* species and 1 new species, and 5 *Psychropotes* species. Based on the results of molecular phylogenetic analysis using COI and 16S, we found that the branches of the *Benthodytes* genus were inlaid by the branches of the *Psychropotes* genus to form a paraphyletic group, suggesting that the *Benthodytes* genus can be further divided into two genera. In addition, based on the results of morphological identification, we found that the presence or absence of dorsal appendages cannot be used as a basis for classification, suggesting that the classification of the Psychropotidae family requires other morphological evidence.

The findings of this study will augment the currently limited sea cucumber DNA molecular database, facilitating future taxonomic efforts.

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New books

The world of sea cucumbers – Challenges, advances, and innovations

By: Annie Mercier, Jean-Francois Hamel, Andrew Suhrbier and Christopher Pearce (eds). 2023. Language: English. ISBN print: 978-0323-9537-71; eBook ISBN: 978-0323-9537-88

Description

The world of sea cucumbers: Challenges, advances, and innovations provides broad coverage of sea cucumber biology, ecology, fisheries, aquaculture, and trade while also bringing forward novel cultural, socioeconomic and scientific topics related to commercial and non-commercial species worldwide. Written by international experts in their respective fields, the book offers a unique outlook into the fascinating world of sea cucumbers while also providing valuable information to various stakeholders and researchers. Commercial fisheries and aquaculture programs are addressed, especially as they relate to emerging species, but the book also covers novel, understudied or lesser-known biological, ecological, and commercial aspects.

The involvement of indigenous peoples and minorities in various community-level initiatives and on the cultural significance/impact of sea cucumbers in many regions are also examined. Finally, breakthroughs and emerging biotechnologies centred on sea cucumbers are presented.

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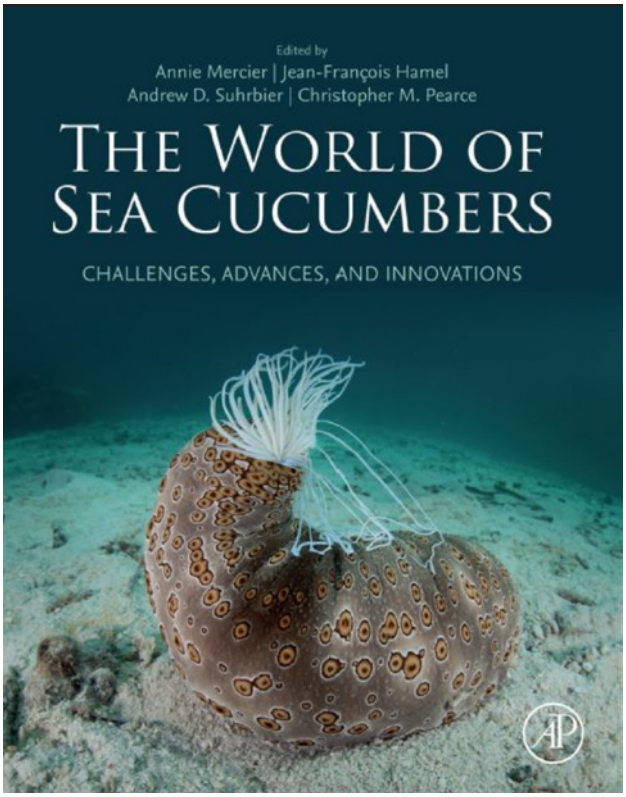
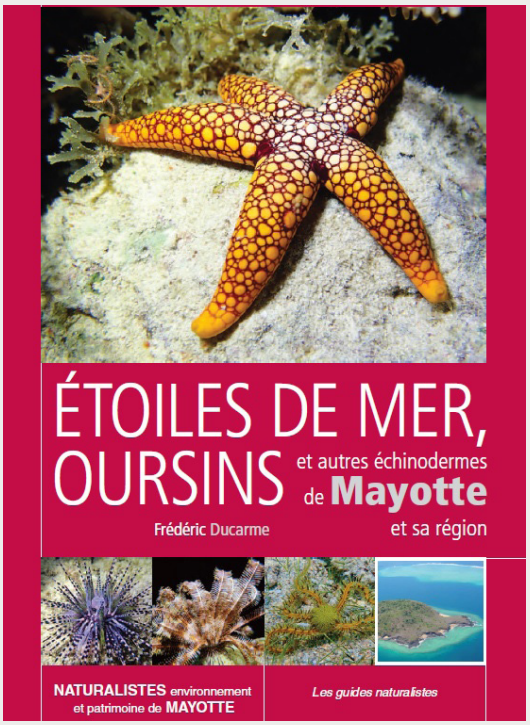


Étoiles de mer, oursins et autres échinodermes de Mayotte et sa région

By: Frédéric Ducarme. 2023. Language: French. ISBN/EAN: 978-295-21543-52

L'océan Indien est sans doute le moins étudié et donc le moins bien connu des trois principaux bassins océaniques de notre planète. Par conséquent, il souffre d'un important retard en termes de bibliographie, autant en quantité qu'en qualité, entre autres du faite qu'une trop large part de la littérature lui attribue encore à tort de nombreuses espèces endémiques du Pacifique du fait de confusions ou d'anciens signalements d'espèces désormais séparées en plusieurs taxons.



Après l'ouvrage de Chantal Conand *et al.* portant sur la Réunion (2016), ce travail se propose de dresser un inventaire illustré des 137 espèces d'échinodermes observés pendant 5 ans sur l'île de Mayotte, de jour comme de nuit, à travers tous les écosystèmes côtiers et jusqu'à 130 mètres de profondeur, complété par une synthèse bibliographique englobant tout l'océan Indien occidental de l'Afrique du Sud au Kenya et listant 130 espèces supplémentaires.

Le volume se découpe en chapitres thématiques introductifs (biogéographie, ethnoécologie, pêche, menaces, risques...) puis en cinq sections de fiches illustrées, suivant les 5 classes d'échinodermes. Riche de plus de 1000 photos, il a bénéficié de la contribution de plusieurs photographes sous-marins célèbres comme Gabriel Barathieu (« *Underwater photographer of the year* 2017 »).

Concernant les holothuries, l'ouvrage recense 80 espèces dont 49 font l'objet d'une fiche détaillée.

L'ouvrage est disponible à la commande auprès des Naturalistes de Mayotte : naturalistes.mayotte@wanadoo.fr

The Indian Ocean is probably the least studied and least well known of our planet's three main ocean basins. As a result, it suffers from a significant backlog in terms of bibliography, both in quantity and quality, notably since too much of the literature still wrongly attributes to it many species endemic to the Pacific, due to confusions or old records of species now separated into several taxa.

Following on Chantal Conand et al.'s book on Reunion Island (2016), this book presents an illustrated inventory of the 137 species of echinoderms observed over 5 years on the island of Mayotte (Comoros archipelago), by day and night, across all coastal ecosystems and at depths of up to 130 meters, supplemented by a bibliographic synthesis covering the entire Western Indian Ocean from South Africa to Kenya and listing a further 130 species.

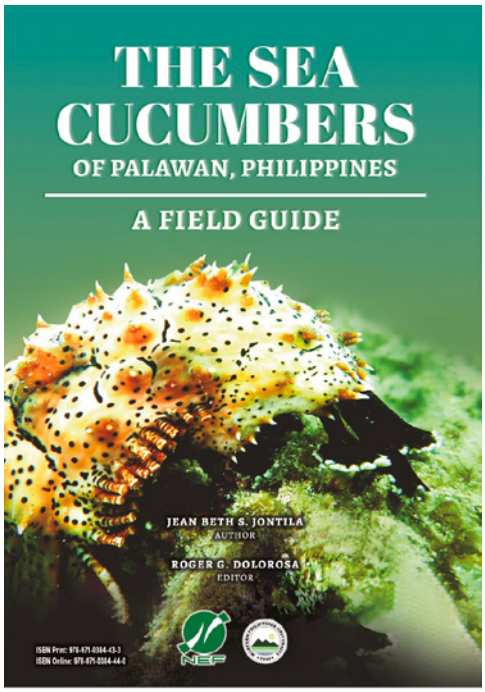
The book is divided into introductory thematic chapters (e.g. biogeography, ethnoecology, fisheries, threats, risks) and then into five sections of illustrated fact sheets, according to the five classes of echinoderms. Featuring over 1000 photos, it has benefited from the contributions of several famous underwater photographers, including Gabriel Barathieu ("Underwater photographer of the year 2017").

Regarding sea cucumbers in particular, the book lists 80 species, 49 of which are described in detail.

Although the book is only available in French so far, names and pictures can be easily understood by foreigners. It can be ordered from Les Naturalistes de Mayotte: naturalistes.mayotte@wanadoo.fr.

The sea cucumbers of Palawan, Philippines: A field guide

By: Jean Beth S Jontila. 2023. Language: English. ISBN print: 9789710384433; ISBN online: 978-971-0384-44-0



This beautiful book on the sea cucumbers of the Palawan region of the Philippines is a very important resource for educators, researchers and managers. The very high diversity of sea cucumbers in this region is an ecologically and economically important asset for the community, and this this book is an important contribution to convey the ecology and conservation status of these animals.

This book is very well illustrated for each of the 50 species included. These beautiful images will be of great assistance in identifying species in the field. The book includes very useful information on the local distribution of the species and their key features, and is also very useful for instructors with information and images that can be used in teaching and in field practical exercises.

The Sea Cucumbers of Palawan, Philippines: A Field Guide is especially important for the fisheries and conservation of the commercial species processed into trepang or beche-de-mer. Many of the commercial species are of conservation concern and the book provides information on their IUCN and CITES status. This is crucial to create awareness in the community to protect these valuable resources.

I commend the authors for producing this very timely and highly engaging field guide.

Dr Maria Byrne
Professor of Marine Biology
University of Sydney, Sydney, Australia

A practical guide on safe hookah diving – Diving for sea cucumbers and other organisms

By: Giampaolo Buonfiglio and Alessandro Lovaltelli. 2023. Languages: English and Spanish. English version ISBN: 978-92-5-137476-4; Spanish version ISBN: 978-92-5-138077-2

A French version will soon be available.

English version freely available at: https://www.fao.org/documents/card/en?details=CC3789EN

Spanish version freely available at: https://www.fao.org/documents/card/en/c/CC3789ES

Abstract

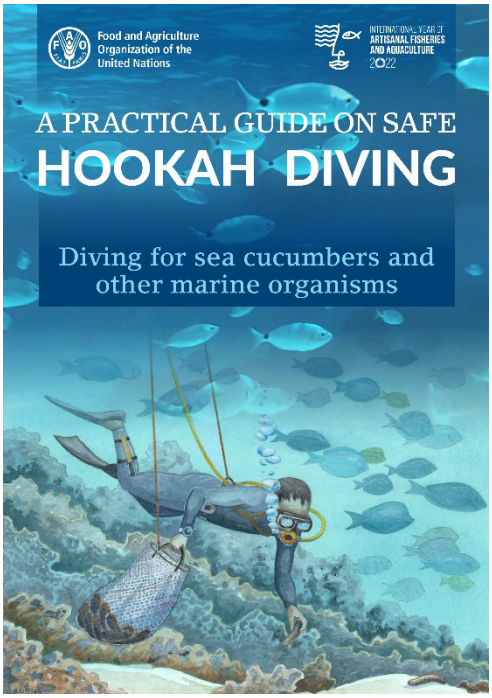
The gathering of commercial benthic organisms from the seabed by underwater fishers is a growing activity in many regions in Africa, Asia, Pacific, Latin America and the Caribbean. Sea cucumbers are particularly targeted, as they are in great demand and command high market prices in Asian markets. Fishing and trading of these holothurians have attracted the interest of many people, particularly trade intermediaries, who often employ local fishers with little or no underwater diving experience. Generally poorly equipped, the fishers are often forced to work long hours with no concerns over their state of physical health and psychophysical suitability for the strenuous and dangerous activity of diving.

In many regions, sea cucumber fishers operate with compressed air supplied by hookah systems frequently powered by unsuitable or improvised compressors. Furthermore, because of the declining number of specimens in shallow waters in many fishing grounds, divers increasingly search for resources at greater depths and for prolonged periods, often unaware or ignoring dive decompression tables and other safe diving practices. Working under such poor conditions, often with inadequate

support from the boat assistant, makes hookah diving a risky and unsafe activity. It may lead to accidents that may result in the death or permanent disability of fishers, who generally operate in locations far from medical facilities capable of providing hyperbaric treatment and first aid.

This guide aims at providing fishers, as well as fishery extension officers, with a tool to acquire the basic knowledge needed to carry out hookah diving safely. Through simple language and numerous illustrations, the guide describes the basic rules of diving, the potential risks associated with this activity and what to do to minimize them, as well as other useful tips to improve hookah diving operations. The guide, however, is not intended as a comprehensive manual for commercial divers. Rather, it is strongly recommended that fishers who want to engage in hookah or SCUBA diving receive appropriate training by a qualified diving instructor.

The guide is divided into two parts. The first part is intended for fishery extension officers to help them understand the risks of hookah and SCUBA diving and to provide them with information that should increase good practices for this type of fishing. The second part is intended for the fishers themselves; it outlines the risks associated with hookah diving and recommends practices that should help prevent any work-related accident associated with this diving practice.



Commercially important sea cucumbers of the world

By: Purcell S.W., Lovatelli A., González-Wangüemert M., Solís-Marín F.A., Samyn Y. and Conand C. 2023 second edition.
Language: English. ISBN: 978-92-5-138077-2

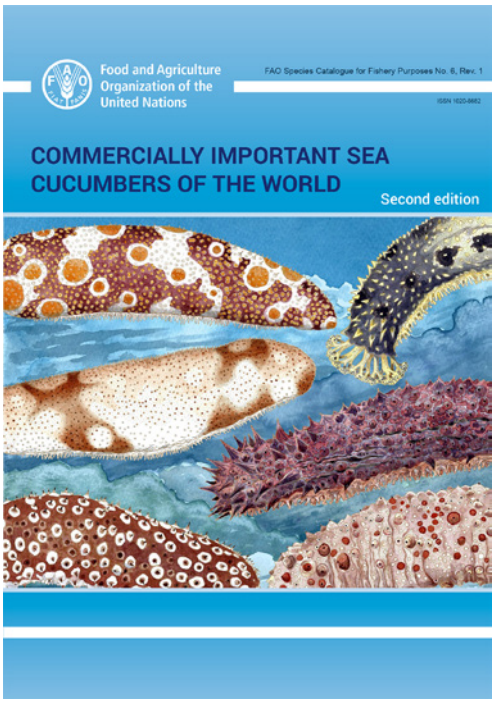
Freely available at: https://www.fao.org/documents/card/fr?details=CC5230EN

Abstract

Sea cucumbers are harvested and traded in more than 70 countries worldwide. They are exploited in industrialized, semi-industrialized, and artisanal (small-scale) fisheries in polar regions, temperate zones and throughout the tropics. In some fisheries, more than 20 species can be exploited by fishers and should be distinguished from each other by fishery officers and scientists. The processed (cooked and dried) animals, often called bêche-de-mer or trepang, are exported mostly to Asian markets and need to be distinguished to species level by customs and trade officers. This book is intended as an identification tool for fishery managers, scientists, trade officers and industry workers to distinguish various species exploited and traded worldwide.

This book provides identification information on 58 species of sea cucumbers that are commonly exploited around the world. There are many other species that are exploited either in a small number of localities or in relatively small quantities, which are not presented. Species in some regions with active fisheries are also not represented due to limited information available (e.g. Mediterranean species). The accounts are based on more than 170 reports and research articles and by comments and reviews by taxonomists and field workers.

Two-page identification sheets provide sufficient information to allow readers to distinguish each species from other similar species, both in the live and processed (dried) forms. Where available, the following information for each species has been included: nomenclature together with FAO names and known common names used in different countries and regions; scientific illustrations of the body and ossicles; descriptions of ossicles present in different body parts; a colour photograph of live



and dried specimens; basic information on size, habitat, biology, fisheries, human consumption, market value and trade; geographic distribution maps. The volume is fully indexed and contains an introduction, a glossary, and a dedicated bibliography. Readers are encouraged to base their identifications on a combination of morphological features, samples of ossicles from different body parts and information on what habitat and locality the species was found.

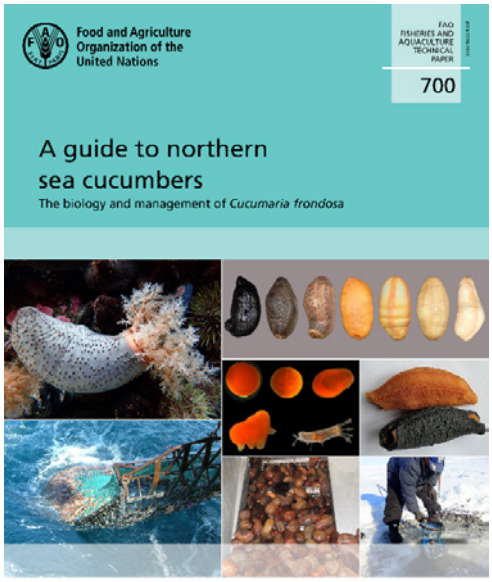
A guide to northern sea cucumbers – The biology and management of *Cucumaria frondosa*

By: Annie Mercier, Heather Penney, Kevin C.K. Ma, Alessandro Lovatelli and Jean-Françoise Hamel. 2023. Language: English. ISBN: 978-92-5-138196-0.

Freely available at: https://www.fao.org/documents/card/en?details=cc7928en

Abstract

This document synthesising knowledge on the northern sea cucumber *Cucumaria frondosa* was prepared for all stakeholders, including industry participants, government scientists, policymakers, and academic researchers. Its aim is to highlight the uniqueness of this marine resource to guide the industry forward and to emphasize areas that deserve further investigation. Available data from eastern and northern Canada, eastern United States of America, Greenland, northern Europe and the Russian Federation are presented. Topics covered include the taxonomy, distribution, biology, and ecology of the species, the natural threats it faces, the current harvesting, processing and marketing practices, and the prospects for aquaculture development. Relying on a knowledge base gathered over more than 40 years, this contribution compares *C. frondosa* with other common commercial species of sea cucumbers to tease out the major aspects that set it apart. A final segment provides a number of key recommendations for its management and conservation.



Guide méthodologique pour le suivi des populations d'holothuries (Echinodermata) des écosystèmes côtiers des Outre-Mer français

Par: Joanna Kolasinski, Alexis Cuvillier and Thierry Mulochau.

Disponible gratuitement à: http://ifrecor-doc.fr/files/original/700482df5bd00aec3fa0195b48b05d3e.pdf

Les holothuries ou « concombres de mer » sont des échinodermes présents des tropiques aux milieux polaires, des premiers mètres de la colonne d'eau jusqu'aux écosystèmes profonds. Ces organismes sont connus pour leur rôle écologique majeur dans les cycles biogéochimiques et plus particulièrement pour leur fonction clé dans le maintien de la santé des écosystèmes marins. Les holothuries sont des organismes essentiels des écosystèmes coralliens en représentant l'un des phylums les plus importants dans les processus de recyclage de la matière organique et de bioturbation des sédiments. De récents travaux ont démontré leur influence sur le contrôle des communautés micro-algales, bactériennes et autres invertébrés sessiles, le cycle des nutriments et la productivité des récifs et des habitats associés. Ces organismes pourraient également jouer un rôle dans l'atténuation locale des effets de l'acidification sur les récifs coralliens. La raréfaction ou la disparition de ces organismes, qu'elle soit d'origine naturelle ou anthropique, peut donc avoir des conséquences significatives sur le fonctionnement, la productivité et la résilience des écosystèmes récifaux.

Du fait de leur forte valeur commerciale, les holothuries sont aujourd'hui surexploitées dans plusieurs régions. Des *hot spots* géographiques présentant un risque élevé de surpêche sont identifiés sur la côte est de l›Afrique, les côtes de Madagascar et de l'Inde, en Mer Rouge, dans le Pacifique occidental, en Asie et sur la côte ouest de l›Amérique du Sud. La pêche mondiale s›étant rapidement développée, les prix du marché, qui varient en moyenne de 15 à 385 dollars US le kg, ont pour la plupart

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augmenté de six à douze fois au cours des deux dernières décennies. La pêche non-régulée ou illégale de ces espèces s'intensifie également et est aujourd'hui considérée comme un pillage des écosystèmes à large échelle, aboutissant à certains endroits à un effondrement des populations. Face à ce risque, des recommandations spécifiques ont été émises par la Convention sur le commerce international des espèces de faune et de flore sauvages menacées d›extinction (CITES) à destination des institutions compétentes sur la gestion de ces ressources. Les actions prioritaires identifiées concernent la mise en place de mesures commerciales, l'évaluation des pêcheries, l'acquisition de connaissances ainsi que la sensibilisation du public.

À ce titre, plusieurs travaux visant la mise en place de statut de protection pour les espèces d'holothuries sont engagés. En 2013 l'UICN a classé sur sa liste rouge 7 espèces dans la catégorie « en danger » et 9 espèces dans la catégorie « vulnérable » face au risque d'extinction. Parmi ces espèces 75% sont classées « en déclin démographique » par l'IUCN. Il est également à noter que 66% des espèces appartenant à la Classe des Holothuroidea listées par l'UICN sont classées dans la catégorie « Données insuffisantes », reflétant le manque de connaissances très important concernant ce groupe d'echinoderme. Plus récemment, la France s'est particulièrement impliquée dans les travaux de la CITES visant le classement d'espèces d'intérêt commercial sur les Annexes de la Convention. À compter du 28 août 2020, 3 espèces supplémentaires figurent sur l'Annexe II de la Convention (*Holothuria nobilis, H. fuscogilva, H. whitmaei*), portant à 4 le nombre total d'espèces bénéficiant de ce classement.

Les Outre-Mer français abritent de grandes surfaces de récifs coralliens et d'habitats associés (e.g. herbiers, mangroves), qui sont considérés comme « zones sources » de diversité et d'abondances en holothuries. Ces écosystèmes, et notamment ceux bénéficiant d'un statut de protection (e.g. parc naturel marin, réserve naturelle nationale) jouent probablement un rôle essentiel dans le maintien des populations d'holothuries à l'échelle locale et régionale. L'évaluation des populations en leur sein est une première étape indispensable à la mise en place de mesures de mesures de gestions adaptées pour enrayer leur déclin.

L'objectif de ce guide méthodologique est d'harmoniser les protocoles de suivi pour les gestionnaires d'espaces naturels à l'échelle des outre-mer français en tenant compte des contraintes inhérentes aux aspects logistiques et financiers. Il est à noter que ce guide n'a pas vocation à évaluer la gestion des pêcheries. Par ailleurs, ce guide pourra évoluer ces prochaines années pour intégrer les développements technologies d'acquisition de données sous-marines.

Upcoming conference

17th International Echinoderm Conference

15–19 July 2024, Puerto de la Cruz, Tenerife

It has been five years since the last International Echinoderm Conference, which took place in Nagoya, Japan. We are very pleased to announce that the 17th International Echinoderm Conference will be held in Spain for the first time. For this special event, we've chosen the beautiful city of Puerto de la Cruz, on the island of Tenerife, to share some unforgettable moments with you. There are plenty of accommodations in Puerto de la Cruz and everything is within walking distance. In addition, Tenerife is well connected to European airports.

For more information see: https://wp.ull.es/iec17tenerife/

Training opportunity

Applications are open for the certificate in the Science of Artisanal Maricultures and Village Farming

The certificate (delivered by Belgian and Malagasy universities) aims to train those who have a Master's or engineering degree in artisanal maricultures, in particular those concerning the aquaculture of holothuroids (sea cucumbers), algae, corals and spirulina.

There will be two types of training: 1) a year-long training course (60 credits) in the four disciplines mentioned above, and 2) a short training course of two to three months (19 credits) in one of these disciplines. Practical training will take place entirely at the Fisheries and Marine Sciences Institute at the University of Tuléar (IH.SM; Madagascar). Theoretical training will be carried out online.

A maximum of 15 candidates per year will be trained. The first round of training will begin in September 2024. Scholarships will be awarded to 10 candidates from developing countries. The scholarship includes the cost of travel and a living allowance (~ EUR 250 per month).

Additional information and application forms can be found at: https://www.bio-mar.com/services-4

Résumé de thèse

Thèse en écologie marine pour obtenir le grade de Docteure de l'Université de la Réunion, soutenue le 23 juin 2023

Compréhension de la dynamique spatiale et temporelle de populations d'holothuries à La Réunion : facteurs génétiques, alimentaires et environnementaux

par Joséphine Pierrat

Keywords: Sea cucumbers, feeding, metabarcoding, ecotoxicology, population ecology, genetic structure

Résumé

Les récifs coralliens de La Réunion comptent environ 40 espèces d'holothuries dont trois (*Holothuria atra*, *Holothuria leucospilota* et *Stichopus chloronotus*) sont dispersées, avec des densités très élevées (> 1 ind./m²) par endroits. L'objectif de l'étude était de comprendre les facteurs génétiques, alimentaires et environnementaux à l'origine de cette distribution hétérogène dans l'espace et le temps. L'échantillonnage s'est déroulé sur les récifs de l'Hermitage/La Saline et de l'Étang-Salé et s'est étendu de l'hiver 2019 à l'hiver 2021. Dans un premier temps, les individus ont été génotypés à l'aide de marqueurs microsatellites spécifiques. La richesse clonale de *H. atra* et *H. leucospilota* était maximale (R = 1), impliquant un mode de reproduction principal de type sexué. La structure génétique des différentes populations de *H. leucospilota* à travers le récif de l'Hermitage/La Saline était homogène, probablement en raison de flux larvaires réciproques. La richesse clonale de *S. chloronotus* était plus faible (R = 0,24), induisant un rôle prépondérant de la reproduction asexuée pour cette espèce, également démontré par une faible connectivité à l'échelle intra-récifale uniquement. Dans un second temps, l'évolution spatio-temporelle de la densité, de saisons en décennies, a montré que les populations de *H. leucospilota* semblaient désormais stables, à densités élevées, alors que celles d'*H. atra* et de *S. chloronotus* ont diminué depuis deux ans. Paradoxalement, peu de corrélations ont été trouvées entre caractéristiques sédimentaires et densité de *S. chloronotus* et *H. leucospilota*, tandis que *H. atra* semblait liée à des caractéristiques sédimentaires anthropisées. Dans un troisième temps, les analyses sur le comportement alimentaire ont révélé que le taux d'ingestion et la vitesse de déplacement étaient les plus élevés chez *S. chloronotus*, suggèrant que cet espèce ingèrait plus de sable pour se nourrir, en couvrant une plus grande surface pour satisfaire ses besoins nutritifs. Cette espèce semble donc être spécialiste alors que les deux autres peuvent être considérées plutôt comme généralistes. Puis, les analyses de métabarcoding ont permis d'identifier plus de 29 000 ASVs bacteriens dans le régime alimentaire des holothuries. Les fractions ingérées et assimilées étaient très variables

Abstract

Coral reefs at Reunion Island comprise 40 species of sea cucumbers, 3 of them – *Holothuria atra*, *H. leucospilota* and *Stichopus chloronotus* – being patchily distributed, reaching very high densities (> 1 ind./m²) at some locations. The aim of this study was to understand genetic, feeding and environmental factors driving this heterogeneous distribution over space and time. Sampling was conducted in the Hermitage/La Saline and Etang-Salé reefs, from winter 2019 to winter 2021, along a north–south gradient. Individuals were genotyped using microsatellite markers. Clonal richness of *H. atra* and *H. leucospilota* were maximal (R= 1), meaning that sexual reproduction was the main mode of reproduction used. Genetic structure of scattered *H. leucospilota* populations were similar, probably due to larval fluxes. Clonal richness of *S. chloronotus* was lower (R= 0.24), meaning that asexual reproduction dominated for this species. A mild connectivity was found at the intra-reef scale, whereas inter-reef connexions were not detected. Spatio-temporal monitoring for density, from seasons to decades, show that populations of *H. leucospilota* have reached high densities and seem to be stable now, whereas the density of *H. atra* has declined and that of *S. chloronotus* has drastically decreased for two decades. Length variations of individuals were congruent with the main mode of reproduction identified for each species. Few correlations were found between sedimentary characteristics and *S. chloronotus* and *H. leucospilota* density, while *H. atra* density seems related to sediments exhibiting an anthropogenic signature. The ingestion rate and speed of *S. chloronotus* were the highest, suggesting that this species needs to ingest more sand and forage over a greater surface area to fulfill its daily nutritive requirements, compared to the other two species. Consequently, *S. chloronotus* appears to be a specialist while the other two can be considered as generalists. Metabarcoding analyses have identified more than 29,000 ASV in the diet of sea cucumbers. Benthic bacteria communities showed significant spatiotemporal variations, without any general trend, with dominant phyla of Planctomycetota, Pseudomonadota and Cyanobacteria. Ingested and assimilated fractions were highly variable

selon les espèces, les saisons et les sites. La structure des communautés de bactéries benthiques a montré des variations spatio-temporelles significatives, sans patron particulier, les phyla dominants étant Planctomycetota, Pseudomonadota et Cyanobacteria. Les Pirellulales ont été les plus assimilées par les trois espèces. Les Shingomonadales et les Spirochaetales ont été principalement assimilées par *H. atra*, les Spirochaetales et les Chloroplastes par *H. leucospilota*, et les Sphingomonadales et les Rhodobacterales par *S. chloronotus*. La distribution hétérogène des holothuries à La Réunion ne semble donc pas liée avec la distribution variable des bactéries benthiques. Dans un dernier temps, deux nouveaux biomarqueurs liés aux dommages oxydatifs des protéines (l'activité du protéasome et le niveau des produits finaux oxydatifs avancés) ont été comparés à l'acétylcholinestérase dans les tissus des holothuries. Ils ont révélé un stress physiologique le plus élevé chez *H. leucospilota*. Cependant, celui-ci pourrait être considéré comme relativement faible car les niveaux d'acétylcholinestérase étaient plus élevés qu'en 2005, signifiant une possible diminution de la pollution du récif par les pesticides depuis cette date. Une quantification directe des pesticides reste nécessaire. *Holothuria leucospilota* est à la fois sensible et résistante, capable de présenter une large gamme de valeurs pour un biomarqueur, mais possède des populations prospères. L'espèce *H. leucospilota* pourrait être considérées comme une indicatrice de la pollution par les pesticides. En conclusion, la distribution inégale de *S. chloronotus* pourrait s'expliquer par la reproduction asexuée plutôt que par la qualité de l'alimentation bactérienne. La distribution de *H. atra* semble en lien avec des marqueurs de pressions anthropiques. Enfin, celle de *H. leucospilota* n'a pu être liée à aucun patron particulier de communautés bactériennes, ni à la reproduction, ni à aucun facteur environnemental évalué dans cette étude. De futures études devraient se concentrer sur le phénomène d'attraction conspécifique et sur les patrons de recrutement de ces espèces. Enfin, d'autres fractions du régime alimentaire des holothuries, telles que les microalgues ou les bactéries de la colonne d'eau, pourraient être explorées.

among species, seasons and sites. Pirellulales were the most common among the three species. Shingomonadales and Spirochaetales orders were mostly assimilated by *H. atra*, Spirochaetales and Chloroplasts by *H. leucospilota*, and Shingomonadales and Rhodobacterales by *S. chloronotus*. The patchy distribution of sea cucumbers in Reunion Island seems to be unrelated to the variable distribution of benthic bacteria. Two new biomarkers linked to oxidative protein damage (activity of the proteasome and advanced oxidative end products level) were compared to acetylcholinesterase biomarker in sea cucumber tissues. They revealed that *H. leucospilota* had the highest physiological stress in the reef. However, the latter could be considered as low because the acetylcholinesterase levels were higher than in 2005, possibly meaning a decrease in reef pollution by pesticides since then. Direct pesticide quantification is still needed. *Holothuria leucospilota* is both sensitive and resistant, able to register a large range of biomarker values but with thriving populations. Consequently, *H. leucospilota* could be considered as an indicator of pollution by pesticides. In conclusion, the patchy distribution of *S. chloronotus* could be explained by asexual reproduction more than by bacterial food quality. The distribution of *H. atra* seems related to anthropogenic disturbances. Finally, the distribution of *H. leucospilota* could not be linked to any bacterial community pattern or reproduction or environmental factors assessed in this study. Further studies should focus on conspecific attraction and on the other fractions of the diet of sea cucumbers such as microalgae or bacteria from the water column.

Sea cucumbers in the news

Aomori sea cucumber fishermen hit hard by China's seafood import ban - The Japan Times

By Kahoku Shimpo, 30 October 2023 (Sent by Poo Sze)

https://www.japantimes.co.jp/news/2023/10/30/japan/society/aomori-sea-cucumber/

Sea cucumber toner that sold out in six days and had a waitlist of 35,000 is back in stock - and shoppers claim it cures acne and eczema and say their skin is "the best it's ever been" | Daily Mail Online

By Rebekah Absalom, 31 October 2023 (Sent by Bruce Cauvin)

https://www.dailymail.co.uk/femail/article-12692327/bescher-beauty-sea-cucumber-collagen-toner.html

Indonesian fishing vessel allegedly intercepted in Australian waters carrying 250 kilograms of sea cucumber

By Matt Brann, 1 March 2023

https://www.abc.net.au/news/2023-03-01/sea-cucumber-bust-alleged-illegal-fishing-indonesia-darwin/102038946?utm_source=abc_news_web&utm_medium=content_shared&utm_campaign=abc_news_web

Stakeholders finalize first national Fisheries Management Plan for Sustainable Sea Cucumbers

In: FAO Liberia Newsletter May 2023 Issue #2

https://www.fao.org/3/cc5927en/cc5927en.pdf

Madagascar interdit la pêche de l'holothurie pour lutter contre le braconnage

By Fabrice Floch, 20 February 2024

https://la1ere.francetvinfo.fr/reunion/madagascar-interdit-la-peche-de-l-holothurie-pour-lutter-contre-le-braconnage-1466469.html

Sea Cucumber Smuggler Nabbed at South Florida Airport, Feds Say

By Izzy Kapnick, 8 December 2023

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