Pacific Community
Communauté du Pacifique

BECHE-DE-MER information bulletin

ISSN 1025-4943

Issue 42 - March 2022

First trials to induce spawning and larviculture of *Holothuria scabra* in Palau

Characterising changes in a decade of Mexican sea cucumber crime (2011–2021) using media reports

Premier inventaire des holothuries (Holothuroidea) observées sur le Mont sous-marin La Pérouse – Ile de La Réunion sud-ouest de l'océan Indien – Expédition La Pérouse 2019

Inside this issue

Editor
Igor Eeckhaut
Biology of Marine Organisms and Biomimetics
6, Av. Champ de Mars
University of Mons
7000 Mons Belgium
Email: Igor.Eeckhaut@umons.ac.be

Production
Pacific Community
BP D5, 98848 Noumea Cedex
New Caledonia
Fax: +687 263818
Email: cfpinfo@spc.int
www.spc.int

Produced with
financial assistance
from the government of Australia, the European Union, France and the New Zealand Aid Programme.

Editorial

This 42nd issue of the SPC *Beche-de-Mer Information Bulletin* includes 15 original articles and scientific observations from around the world. We continue here the formula initiated with issue #41 by including articles in English and French. Some articles appear only in one of the two languages, others in both.

The first article by Byrne et al. (p. 4) reminds us of the need for better taxonomic determination in the conservation results of sea cucumbers, and presents a case study on teatfish of the Great Barrier Reef.

The next article, presented by Bondaroff et al. (p. 11) is a very detailed analysis of sea cucumber crime in Mexico, from 2011 to 2021, using media reports.

Approximately 18 years after the publication of research papers on the sea cucumber fishery in southwestern Madagascar, Maka et al. (p. 36) review the state of the fishery today, assess management, and analyse governance of the sector. Zaidnuddin et al. (p. 46) give an update on the diversity of sea cucumbers on the reefs of Perhentian Island in Malaysia, two decades after the first survey. Mulochau et al. (p. 50) present an overview of the biodiversity of sea cucumbers observed for the first time on the submarine Mount La Pérouse (Reunion Island). This article is in French only.

The next two articles present advances in the aquaculture sector. The article from Palau by Lin and Hua informs us about the success of the first trials of spawning and larviculture of *Holothuria scabra* (p. 58), while the one by Christophersen and Sunde in Norway discusses the economic viability of producing the cold-water sea cucumber *Parastichopus tremulus* (p. 65).

Belkacem and Mezali (p. 73) conducted a taste test of a segment of the Algerian population of ready-made meals prepared with Mediterranean sea cucumbers. Two species were cooked for this purpose, *H. tubulosa* and *H. arguinensis*. In addition, Khodja and Mezali (p. 79) analyse the composition and digestibility of the integument of *Parastichopus regalis*, a deep and still unexploited species in Algeria.

The following four articles report spawning and juvenile observations: Gomez and Eeckhaut (p. 85) report on *H. scabra*'s spawnings in farmed sea pens in Madagascar and observations on juveniles that followed fertilisation; Borsa (p. 88) observes spawning of *H. leucospilota* in an urbanised bay in the southwestern lagoon of New Caledonia; and Byrne (p. 90) describes the spawning of *Stichopus chloronotus* and *H. isuga* from One Tree Reef lagoon (Australia). Also in Australia, Chai reports a *S. herrmanni* spawning event (p. 92), and Wolfe and Desbiens observe a nursery of juveniles of the same species on the outer reef crest of Heron Island on the Great Barrier Reef (p. 93).

The next contribution is by Richard (p. 95) who reports on an observation of predation by the titan triggerfish on *H. leucospilota* at Reunion Island.

Jangoux (p. 97) talks about the trepang observed at the beginning of the 19th century by Leschenault, a French naturalist who visited the island of Java in Indonesia.

Finally, we express our congratulations to Dr Emily J.S. Claereboudt who presented, at the University of Mons (Belgium), her PhD dissertation titled "Biological roles and evolution of triterpenoids in holothuroids".

It is with great sadness that we announce the death of Dr Claude Massin (25 August 1948–04 September 2021). We offer our sincere condolences to his family and loved ones. A detailed contribution by Dr Yves Samyn was published in an issue of Zootaxa in 2021 (5081(2):223–236). This contribution provides an overview of the scientific career of Claude, listing his scientific activities (academic career, participation with and organization of expeditions, scientific conferences and list of publications).

Also included in this issue are various communications (p. 101) about publications, new books, and congresses. Diverse information on holothurians is presented, most of them shared by Chantal Conand. Some interesting information that is found only on the internet is also listed at the end of this issue (p. 104).

Igor Eeckhaut

Cover picture: Captive-bred *Holothuria scabra* juveniles, 60–90-days old, photo: Tsung-Han Lin

The importance of taxonomy in conservation outcomes for beche-de-mer: the teatfish and Great Barrier Reef fishery case studies

Maria Byrne,[1] Tim O'Hara,[2] Sven Uthicke,[3] Chantal Conand,[4] Frank W.E. Rowe,[5] Hampus Eriksson,[6] Steve Purcell[7] and Kennedy Wolfe [8]

Abstract

Unresolved taxonomy has impeded the conservation and sustainable management of commercially exploited sea cucumbers, which are in a perilous state globally. The listings of 16 species as threatened on the International Union for Conservation of Nature and, most recently, of three teatfish species on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) were made possible by careful taxonomic work over decades. Efforts to achieve the CITES listings of the teatfish, and the response of a fishery to meet the challenges encompassed by this binding agreement, are presented as an insightful case study. There is a need to resolve taxonomic uncertainty for species exploited for the global sea cucumber trade and for research to address major gaps in knowledge of species' population parameters. Such work will underpin future sustainable management and conservation plans to help preserve diversity and avoid extinctions.

Keywords: commercial sea cucumbers, International Union for Conservation of Nature, Convention on International Trade in Endangered Species of Wild Fauna and Flora, *Holothuria* (*Microthele*) subgenus

Introduction

Tropical sea cucumbers are harvested globally for the high-value beche-de-mer trade, which is one of the oldest trade commodities in Australia and the Pacific (Macknight 1976; Conand and Byrne 1993). As slow-moving and easily harvested animals, many of the 80+ species of commercially important sea cucumbers are severely overharvested, and the most valuable ones tend to be at greatest risk of extinction (Purcell et al. 2014; Eriksson and Clarke 2015). High price leads to rarity over time, resulting in local extinction or the biological inability to repopulate. Extinctions at the scale of lagoon systems and regions occur when fishing is not well managed as shown for the sandfish, *Holothuria* (*Metriatyla*) *scabra*, in Palau, Papua New Guinea and Solomon Islands (Friedman et al. 2011).

Conservation efforts and management plans for beche-de-mer have been hampered by the uncertain taxonomy of many species in the trade (Uthicke et al. 2010). While fishery names can be informative, these differ across regions and so can only provide a guide to the identity of harvested species. The identity of important species in trade continues to be a challenge, including several species in the genera *Stichopus* (e.g. *Stichopus monotuberculatus* complex) and *Bohadschia*, as well as the white teatfish complex (within the subgenus *Microthele*) (Figs. 1 and 3) (Uthicke et al. 2004a; Byrne et al. 2010). Uncertain identity is an important problem to resolve because a fully characterised and vouchered taxonomy is required for conservation measures such as the listing of species on the International Union for Conservation of Nature (IUCN) and on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Teatfish names, taxonomy and CITES listings

Teatfish are among the most highly valued species of sea cucumbers in the beche-de-mer trade (Purcell et al. 2018) due to their thick body wall and flavour. They are readily recognised by the teat-like extensions along their lateral margins (Fig. 1). Considering the imperilled situation of the teatfish group and a poor taxonomic understanding, studies over decades have focused on their taxonomy and molecular phylogeny (Cherbonnier 1980; Rowe and Gates 1995; Uthicke et al. 2004a; Tanita et al. 2021). The detective work to determine the taxonomy of the teatfish species, and the campaign that led to their CITES listings in 2019 (Di Simone et al. 2019, 2020, 2021), provide an insightful case study.

In the early days of the beche-de-mer trade, the species called black teatfish included several varieties with a range of colours, from totally black, to black with large white spots,

[1] School of Life and Environmental Science, University of Sydney, Sydney, NSW, Australia. Email: maria.byrne@sydney.edu.au
[2] Marine Invertebrates, Sciences, Museum Victoria, Melbourne, VIC, Australia
[3] Australian Institute of Marine Science, Townsville, QLD, Australia
[4] Laboratoire Ecologie Marine, Université de La Réunion University, 97715 Saint Denis, La Réunion, France
[5] Australian Museum Sydney, NSW, Australia and Beechcroft, Norwich Rd, Scole, Diss, Norfolk, United Kingdom
[6] Australian National Centre for Ocean Resources and Security, University of Wollongong, Wollongong, NSW, Australia
[7] National Marine Science Centre, Southern Cross University, Coffs Harbour NSW, Australia
[8] Marine Spatial Ecology Laboratory, School of Biological Sciences, University of Queensland, St. Lucia, QLD, Australia

black and white mottled forms, and some that were mostly white (Purcell et al. 2012) (Fig. 1A–F). Clearly, this was a species complex, as also indicated by their differing reproductive biology and skeletal ossicles (Conand 1981; Cherbonnier 1980; Uthicke et al. 2004a). Scientists working in New Caledonia recognised that sympatric all-black and the mottled black-and-white forms were distinct species. The all-black species more commonly occur in shallow water while the mottled black-and-white species tends to be found at greater depths (Conand 1989).

Cherbonnier (1980) referred to the black form as *Holothuria* (*Microthele*) *nobilis* (Fig. 1A,B) and described a new species, *H.* (*M.*) *fuscogilva*, for the mottled form harvested as the white teatfish (Fig. 1D–F). This left the black teatfish as *H.* (*M.*) *nobilis*, described by Selenka in 1867, with a distribution from East Africa to Hawaii. However, the variety in Africa had large ventro-lateral white spots along the body (Fig. 1C), while the variety in the Pacific was totally black (Fig. 1A,B). Rowe and Gates (1995) pointed out that Selenka's description contained two colour forms, and molecular phylogeny confirmed the presence of two species (Uthicke et al. 2004a). As the original illustrations in Selenka's brief description depicted the black-and-white specimen, as is the specimen in the Museum of Comparative Zoology (specimen MCZ 819) (Fig. 1J), Rowe and Gates (1995) designated this to be the lectotype. Thus, the Indian Ocean black-and-white species was *H. nobilis* and the taxonomy of the totally black species in the eastern Indian Ocean, and the only form known in the Pacific Ocean, needed to be clarified. Bell (1887) described a black specimen from Samoa as *Holothuria* (*M.*) *whitmaei* (Fig. 1A,B) and Rowe and Gates (1995) noted that the holotypes of *H. whitmaei* (BMNH 1875.10.2.6) are completely black. They used this name for the all-black teatfish. Thus, there are two species harvested under the name black teatfish across regions: *H.* (*M.*) *whitmaei* and *H.* (*M.*) *nobilis* (Fig. 1A–C).

The white teatfish appears to be a species complex (Uthicke et al. 2004a). A recent study from Japan confirmed that the

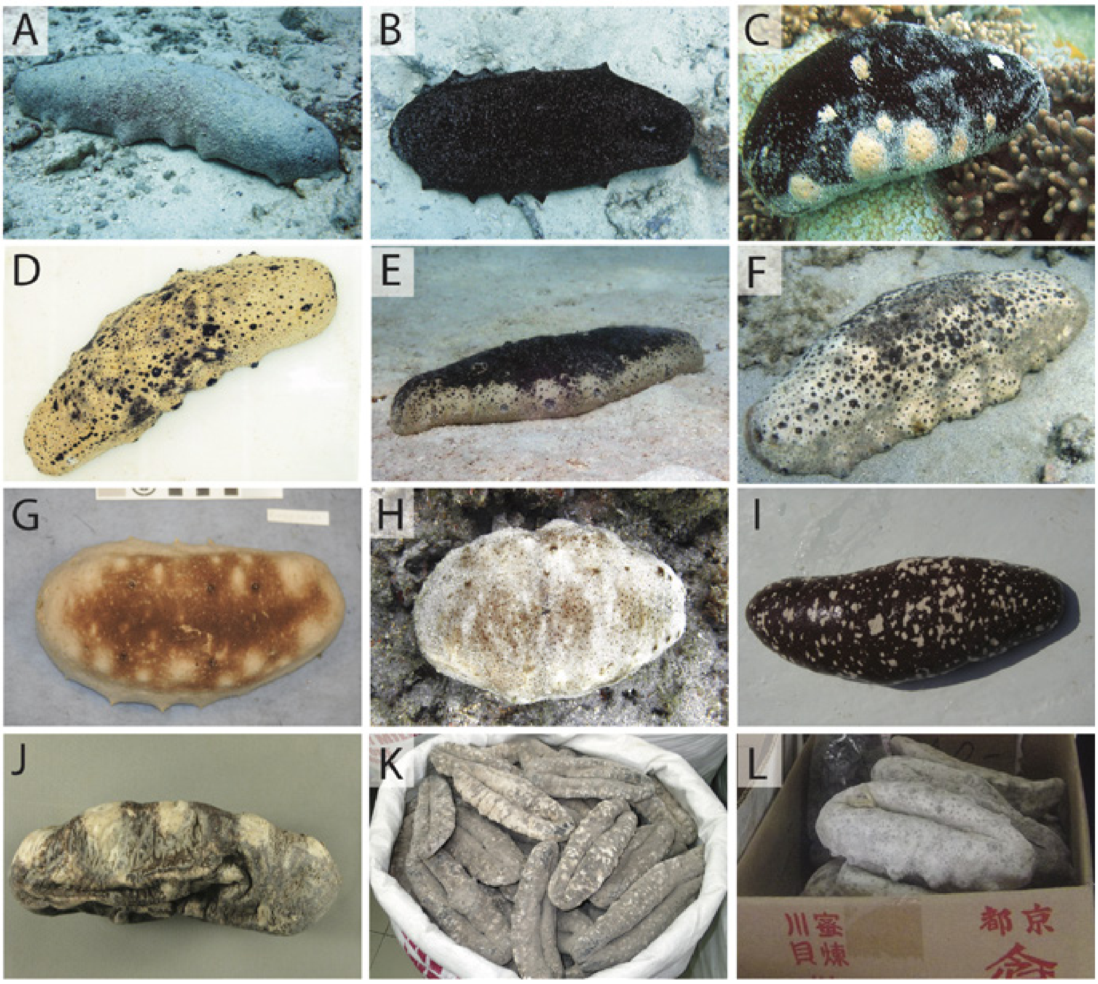


Figure 1. A,B: *Holothuria (Microthele) whitmaei*, black teatfish from the Pacific Ocean covered in sand (A) and free of sand (B) from Heron Island, eastern Australia. C: *H. (M.) nobilis* from the Red Sea. D-F: *H. (M.) fuscogilva* from Raine Island (D) and Lady Musgrave Island (E), eastern Australia, and Koniene Reef (F), New Caledonia. G-H: Unidentified light-coloured teatfish from the Red Sea (G) and La Reunion, Indian Ocean (H). I: Pentard from Seychelles. J: Lectotype of *H. (M.) nobilis* in the Museum of Comparative Zoology (MCZ 819). K-L: dried pentard (I) and *H. (M.) fuscogilva* (J) in the market. Photos: (A,B) K. Wolfe; (C,J) from Uthicke et al., 2004a; (D) M. Byrne, (E,F,K) S.W. Purcell; (G) O. Bronstein; (H) P. Bourjon; (I) T. Skewes; (L) C. Conand.

colour varieties that occur in the western Pacific, including the light and dark morphs, are all *H.* (*M.*) *fuscogilva* (Fig 1D–F) (Tanita et al. 2021). The identity of some forms of white teatfish in the Indian Ocean and Red Sea (Fig. 1G,H) remain to be confirmed. Crucially, the taxonomy of the pale-coloured, beige-blotched teatfish known as pentard (Fig. 1I) in the Indian Ocean also remains to be documented (Purcell et al. 2012, 2017).

With clarification of the taxonomy of the teatfish and other beche-de-mer species (Uthicke et al. 2004a, 2010; Byrne et al. 2010), and due to declines over global distributions, 16 species were listed on the IUCN Red List as vulnerable or endangered in 2013 (Conand et al. 2014). However, two-thirds of the 377 sea cucumber species evaluated by the IUCN panel were listed as "data deficient"; a proportion much higher than in assessments for other marine fauna (Purcell et al. 2014). Although IUCN listings are not a binding agreement, they provide a tool for conservation planning and serve as a guide to inform CITES listings. After 17 years of discussions and Conference of the Parties meetings, the three teatfish that were on the IUCN list – *Holothuria* (*Microthele*) *whitmaei*, *H.* (*M.*) *nobilis* and *H.* (*M.*) *fuscogilva* – were approved and listed under CITES Appendix II in 2019, effective from August 2020 (Di Simone et al. 2019, 2020, 2021; FAO 2019). Notably, pentard (Fig. 1I) was not listed, as it had not been formally and taxonomically described.

The CITES listings of the teatfish, as well as the IUCN listings of 16 commercial sea cucumber species, provide the impetus and framework to improve management of the beche-de-mer trade to conserve the species while sustaining their harvest (Shedrawi et al. 2019). Globally, the scientific authorities of producing countries are now required to show a non-detriment finding (NDF) to continue to their export as a wildlife trade operation. The requirement to show NDF for the teatfish will be a challenge for many fisheries (FAO 2019). This is especially the case because virtually all teatfish fisheries are already in a depleted or overharvested state (Friedman et al. 2011; Purcell et al. 2014). For instance, in Fiji, black teatfish was one of the main target species in the 1980s but fishing decimated stocks such that none were found in surveys in three-quarters of all island groups in 2009 (Pakoa et al. 2013) and 2014–2015 (Lalavanua et al. 2017). Fishers have been put on notice, for example, in Solomon Islands (Tavake 2021).

As a predominantly shallow-water reef species, black teatfish are easily fished and are, therefore, the most imperilled. This is also reflected in the fact that both the Indian Ocean (*H. nobilis*) and Pacific (*H. whitmaei*) black teatfish were evaluated at the more severe classification of endangered by the IUCN, whereas white teatfish in classified as vulnerable. In a case study from Tonga, white teatfish were found to have recovered better from a seven-year fishing moratorium than black teatfish (Friedman et al. 2011). White teatfish may have some protection due to the presence of populations in deep water (30–50 m), below the maximum depth of most fishing activity. Importantly, unlike many commercial sea cucumbers, teatfish are readily recognised in the seafood trade both in the live and dried form due to their distinct teats, which will assist in identifying black market product (Fig. 1K,L).

Queensland, Australia sea cucumber fishery

High-value teatfish and other sea cucumber species are of great socioeconomic importance to many fishing communities in developing nations (Purcell et al. 2013, Muthiga and Conand 2014). These sea cucumber fisheries also operate in a few developed nations such as Australia (Eriksson and Byrne 2015; Wolfe and Byrne 2022), and it is of interest to examine the national response to the CITES listings of teatfish.

For the fishery that operates on Australia's Great Barrier Reef – the Queensland (East Coast) Sea Cucumber Fishery – the CITES listings of the teatfish species triggered action under the Environment Protection and Biodiversity Conservation Act 1999. This act is the major legislative tool whereby Australia controls the movement of wildlife in and out of its jurisdiction.[7] The fishery must show NDF to the CITES Authority of Australia in order to continue to harvest *H.* (*M.*) *whitmaei* and *H.* (*M.*) *fuscogilva*, as a wildlife trade operation. The requirement to show an NDF to fulfil the conditions for export approval prompted the very first stock assessments for the Queensland fishery after decades of operation, which were for the two teatfish species (Helidoniotis 2021a,b). The first environmental risk assessment for the fishery was also undertaken (Pidd and Jacobsen 2021). These actions show the importance of the CITES listings in increasing awareness by fisheries management and in promoting actions to assess sustainability. While assessing stock health and ecological risks of fishing are best practice for resource managers, in this instance, the requirement to show an NDF provided the impetus to apply these measures.

As typical of global beche-de-mer fisheries, the Queensland fishery has exhibited serial replacement of priority target species over time, and shifts from shallow to deeper water harvesting (from breath-hold divers to compressed-air diving) (Eriksson and Byrne 2015), and to new species such as the burrowing blackfish *Actinopyga spinea* (Fig. 2). Early fishing effort focused on the IUCN-listed sandfish, *H.* (*M.*) *scabra*, in high catches inshore until stocks were diminished and the fishery was closed in 2000. As sandfish stocks declined, the fishery moved offshore to black teatfish, *H.* (*M.*) *whitmaei* (Roelofs 2004), with harvests largely in the northern Great Barrier Reef (Uthicke and Benzie 2001). Declines in this species with biomass estimated to have been reduced to 40% of virgin biomass prompted a fishery closure in 1999 (Benzie and Uthicke 2003). Fishing effort switched to *H.* (*M.*) *fuscogilva* in deeper water (Eriksson and Byrne 2015).

[9] https://www.awe.gov.au/environment/epbc/about

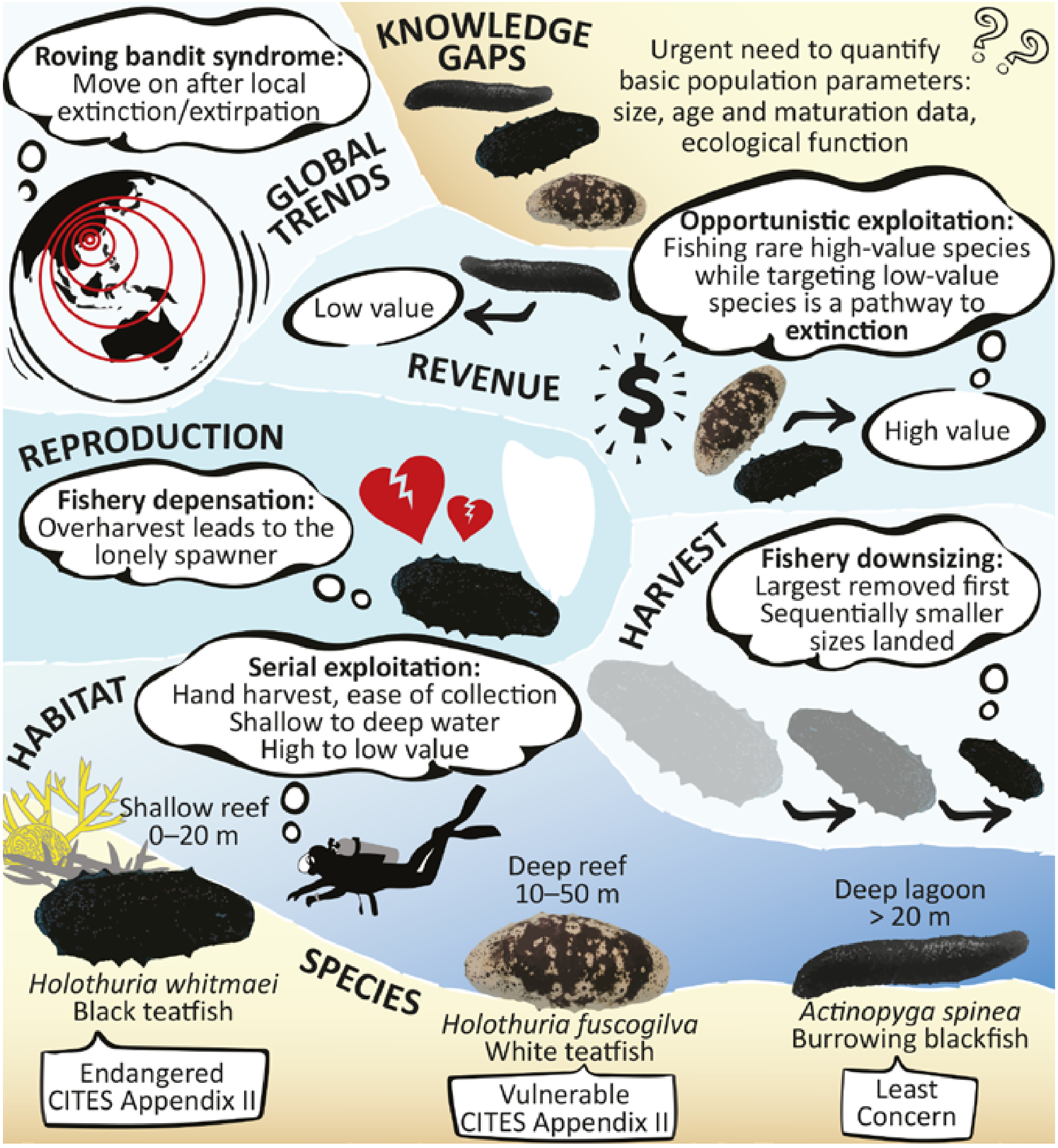


Figure 2. Schematic of conservation challenges for sea cucumber fisheries, with the Queensland fishery providing a model to illustrate the problems faced by fisheries of slow-moving marine invertebrates, globally, and the challenge to achieve sustainability. All images by Kennedy Wolfe, except scuba diver (StockVector), globe (modified from FreeSVG), reef (modified from IAN symbols library; ian.umces.edu/media-library/symbols/) and dollar sign (SeekPNG). From Wolfe and Byrne (2022), with permission, license number 5240450385318.

After 20 years, the black teatfish fishery reopened in 2019, as surveys in the northern Great Barrier Reef indicated that this species had recovered (Knuckey and Koopman 2016). Recent fishing, however, has concentrated on unfished grounds in the southern Great Barrier Reef. Despite the indication of recovery, which provided the rationale to restart harvesting, the recent stock assessment indicates otherwise (Helidoniotis 2021a). The biomass estimate for this assessment (40–42% of virgin biomass, Helidoniotis 2021a) is comparable to that determined 20 years ago by Benzie and Uthicke (2003). This indicates that black teatfish stocks have not recovered after 20 years of fishery closure despite the potential buffer of no-take areas within the Great Barrier Reef Marine Park in adjacent unfished zones (Wolfe and Byrne 2022). This points to inherent biological and ecological traits of *H. whitmaei* that result in retarded recovery (Fig. 2). Due to the naturally low density of this species (Benzie and Uthicke 2003), it is likely to be vulnerable to low spawner density (Fig. 2), leading to reproductive failure (i.e. fishery depensation). This phenomenon is a concern for commercial sea cucumber species (Bell et al. 2008). The slow growth, longevity and paucity of juveniles in *H. whitmaei* populations indicate intermittent and unpredictable recruitment and thereby slow population growth (Uthicke et al. 2004b). Given its close relatedness, *H. fuscogilva* is likely to have a similarly slow population growth.

The CITES listings for teatfish species provided an important opportunity for Australia as a developed nation to lead by example in the conservation and protection of these imperilled species. In consideration of fishery trends and submissions provided during the public consultation process, the CITES Scientific Authority of Australia did not make a positive NDF for *H. whitmaei* due to uncertainties regarding harvest (DAWE 2021). Thus, after just two years of reopening, the harvesting of black teatfish has again ceased, although the fishery for *H. fuscogilva* continues. In this recent assessment (November 2021), the Department placed conditions on the fishery with respect to *H. fuscogilva* as well several IUCN-listed species (e.g. *Thelenota ananas*, *Stichopus herrmanni*) and heavily targeted species (*Actinopyga spinea*) (DAWE 2021). These conditions must be addressed over the next three years, with fishery reassessment scheduled for 2024, when the export of black teatfish can again be considered.

Conclusion

Taxonomic advances for the three teatfish species currently described have resulted in global recognition of their perilous state and urgent need for protection. However, the taxonomy of the teatfish group has yet to be fully resolved, particularly for species in the Indian Ocean and Red Sea (Fig. 1G,H). The taxonomy of the pale-coloured, beige-blotched teatfish pentard (Fig. 1I) urgently needs to be documented. We also need improved taxonomy of other sea cucumber species to ensure that global protection efforts are effective for differentiating species at-risk. Specific attention is needed for several unresolved species of *Bohadschia*, including one harvested in high numbers in Sri Lanka (Fig. 3A) – *Actinopyga* species and the *Stichopus monotuberculatus* complex (Fig. 3B) (Byrne et al. 2010) as well as sandfish in the Indian Ocean.

High uncertainty of biological traits (e.g. growth, age and longevity) and the lack of empirical demographic data on key population parameters for the teatfish species (see Wolfe and Byrne 2022) and many other sea cucumbers make it difficult to formulate reliable fishery models to inform sustainable harvest strategies and prevents conservation measures such as CITES listings because of being "data deficient". Thus, together with attention to taxonomy, there is an urgent need for targeted species-level research on commercial sea cucumbers and collaboration among science, management and stakeholders to sustain their harvest. We emphasise the need to apply conservative fishery regulations on sea cucumbers to redress the global patterns of decline and depletion.

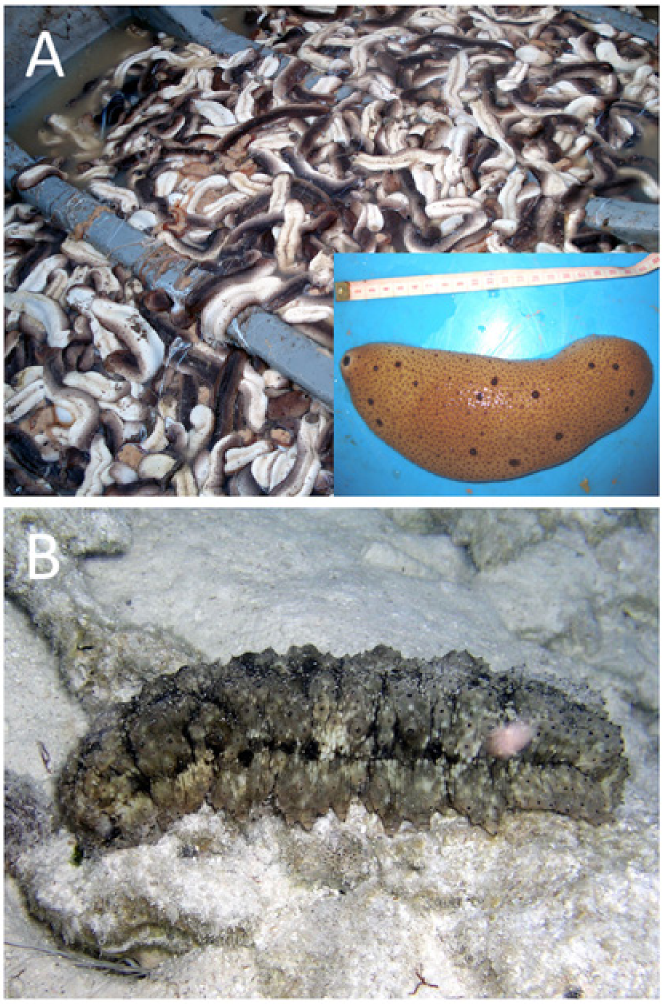


Figure 3. Further taxonomic studies are needed. A: An undescribed species in the genus *Bohadschia*, which is harvested in Sri Lanka. B: *Stichopus monotuberculatus* from Heron Island, eastern Australia. Photos: (A) D.C.T. Dissanayake; (B) S.W. Purcell.

Acknowledgements

Thanks to Omri Bronstein, Tim Skewes, D.C.T. Dissanayake and P. Bourjon for providing photographs.

References

Bell F.J. 1887. Studies in the Holothurioidea.VI. Descriptions of new species. Proceedings of the Zoological Society of London 1887:531–534.

Bell J.D., Purcell S.W. and Nash W.J. 2008. Restoring small-scale fisheries for tropical sea cucumbers. Ocean and Coastal Management 51:589–593.

Benzie J.A.H. and Uthicke S. 2003. Stock size of bêche-de-mer, recruitment patterns and gene flow in black teatfish, and recovery of overfished black teatfish stocks in the Great Barrier Reef. Australian Institute of Marine Sciences. Fisheries Research and Development Corporation, Canberra Project 1998/133.

Byrne M., Rowe F.W. and Uthicke S. 2010. Molecular taxonomy, phylogeny and evolution in the family Stichopodidae (Aspidochirotida: Holothuroidea) based on COI and 16S mitochondrial DNA. Molecular Phylogenetics and Evolution 56:1068–1081.

Cherbonnier G. 1980. Holothuries de Nouvelle-Calédonie. Bulletin du Museum National d'Histoire Naturelle, Paris 2:615–667.

Conand C. 1981. Sexual cycle of three commercially important holothurian species (Echinodermata) from the lagoon of New Caledonia. Bulletin of Marine Science 31:523–543.

Conand C. 1989. Les Holothuries Aspidochirotes du lagon de Nouvelle-Calédonie: biologie, écologie et exploitation. Etudes et Thèses. Paris: ORSTOM. 393 p.

Conand C. and Byrne M. 1993. A review of recent developments in the world sea cucumber fisheries. Marine Fisheries Review 55:1–13.

Conand C., Polidoro B.A., Mercier A., Gamboa R., Hamel J.-F. and Purcell S.W. 2014. The IUCN Red List assessment of aspidochirotid sea cucumbers and its implications. SPC Beche-de-mer Bulletin 34:3–7.

DAWE (Department of Agriculture Water and the Environment). 2021. Assessment of the Queensland sea cucumber fishery, November 2021. Canberra: Department of Agriculture Water and the Environment, Commonwealth of Australia.

Di Simone M., Conand C. and Horellou A. 2020. Three species of teatfish to be protected by CITES. SPC Beche-de-mer Information Bulletin 40:3–4.

Di Simone M., Horellou A. and Conand C. 2019. Towards a CITES listing of teatfish. SPC Beche-de-mer Information Bulletin 39:76–78.

Di Simone M., Horellou A. and Conand C. 2021. The listing of three sea cucumber species in CITES Appendix II enters into force. SPC Beche-de-mer Information Bulletin 41:3–4.

Eriksson H. and Byrne M. 2015. The sea cucumber fishery in Australia's Great Barrier Reef Marine Park follows global patterns of serial exploitation. Fish and Fisheries 16:329–341.

Eriksson H. and Clarke S. 2015. Chinese market responses to overexploitation of sharks and sea cucumbers. Biological Conservation 184:163–173.

FAO (Food and Agriculture Organization of the United Nations). 2019. Food and Agriculture Organization expert advisory panel assessment report: COP18 proposal 45. p. 62–105. Report of the Sixth FAO Expert Advisory Panel for the Assessment of Proposals to Amend Appendices I and II of CITES Concerning Commercially Exploited Aquatic Species FAO Fisheries and Aquaculture Report No 1255. Rome: FAO.

Friedman K., Eriksson H., Tardy E. and Pakoa K. 2011. Management of sea cucumber stocks: Patterns of vulnerability and recovery of sea cucumber stocks impacted by fishing. Fish and Fisheries 12:75-93.

Helidoniotis F. 2021a. Stock assessment of black teatfish (*Holothuria whitmaei*) in Queensland, Australia. Fisheries Queensland, Department of Agriculture and Fisheries, State of Queensland.

Helidoniotis F. 2021b. Stock assessment of white teatfish (*Holothuria fuscogilva*) in Queensland, Australia. Fisheries Queensland, Department of Agriculture and Fisheries, State of Queensland.

Knuckey I. and Koopman M. 2016. Survey to estimate the biomass and recovery of black teatfish (*Holothuria whitmaei*) in Zone 1 of the Queensland Sea Cucumber Fishery (East Coast). Queenscliffe, Australia: Fishwell Consulting.

Lalavanua W., Mangubhai S., Vandervord C., Dulunaqio S., Fox M., Naisilisili W., Jupiter S., Tuinasavusavu I. and Vodivodi T. 2017. Sea cucumber species richness and densities within locally managed marine areas. p. 4–15. In: Mangubhai S., Lalavanua W. and Purcell S.W. (eds). Fiji's sea cucumber fishery: Advances in science for improved management. Suva, Fiji: Wildlife Conservation Society (Report No. 01/17).

Macknight C.C. 1976. The voyage to Marege. Macassan trepangers in northern Australia. Melbourne, Australia: University Press. 175 p.

Muthiga N. and Conand C. 2014. Sea cucumbers in the western Indian Ocean: Improving management of an important but poorly understood resource. Zanzibar, Tanzania: Western Indian Ocean Marine Science Association Book Series, 74.

Pidd A. and Jacobsen I. 2021. Level 1 Ecological Risk Assessment Queensland Sea Cucumber Fishery (East Coast), August 2021. Sustainable Fisheries Strategy 2017–2027. Fisheries Queensland, Department of Agriculture and Fisheries.

Pakoa K., Saladrau W., Lalavanua W., Valotu D., Tuinasavusavu I., Sharp M. and Bertram I. 2013. The status of sea cucumber resources and fisheries management in Fiji. Noumea, New Caledonia: Secretariat of the Pacific Community. 62 p.

Purcell S.W., Samyn Y. and Conand C. 2012. Commercially important sea cucumbers of the world. FAO Species Catalogue for Fishery Purposes. No. 6. Rome: FAO. 150 + p. 30 colour plates.

Purcell S.W., Mercier A., Conand C., Hamel J.-F., Toral-Granda M.V., Lovatelli A. and Uthicke S. 2013. Sea cucumber fisheries: global analysis of stocks, management measures and drivers of overfishing. Fish and Fisheries 14:34–59.

Purcell S.W., Polidoro B.A., Hamel J.-F., Gamboa R.U. and Mercier A. 2014. The cost of being valuable: Predictors of extinction risk in marine invertebrates exploited as luxury seafood. Proceedings of the Royal Society B Biological Sciences 281:20133296.

Purcell S.W., Ngaluafe P., Wang G. and Lalavanua W. 2017. Market value of flower teatfish (“pentard”): A highly exploited Indian Ocean holothuroid. SPC Beche-de-mer Information Bulletin 37:53–56.

Purcell S.W., Ngaluafe P. and Williamson D.H. 2018. Chinese market prices of beche-de-mer: Implications for fisheries and aquaculture. Marine Policy 91:58–65.

Roelofs A. 2004. Ecological assessment of the Queensland’s east coast beche-de-mer fishery. A report to the Australian Government Department of Environmentand Heritage on the ecologically sustainable management of a highly selective dive fishery. Queensland Government Department of Primary Industries and Fisheries. 43 p.

Rowe F.W.E. and Gates J. 1995. Zoological catalogue of Australia. Vol. 33. Echinodermata. Melbourne, Australia: CSIRO Publishing.

Selenka E. 1867. Beiträge zur Anatomie und Systematik der Holothurien. Zeitschrift der Wissenschaftlichen Zoologie 17:291–374.

Shedrawi G., Kinch J.P., Halford A.R., Bertram I., Molai C. and Friedman K.J. 2019. CITES listing of sea cucumber species provides opportunities to improve management of the beche-de-mer trade. SPC Fisheries Newsletter 159:6–8.

Tanita I., Nishihama S. and Hayashibara T. 2021. Identification of species of teatfish (Holothuroidea: Holothuriida) in Japan based on mitochondrial cytochrome oxidase subunit I (COI) sequences, morphology, and ossicles. Plankton and Benthos Research 16:200–209.

Tavake S. 2021. MFMR will strictly monitor the harvesting of endangered beche-de-mer species. In: Solomon Islands Broadcasting Corporation [online].

https://www.sibconline.com.sb/mfmr-will-strictly-monitor-the-harvesting-of-endangered-beche-de-mer-species/

Uthicke S. and Benzie J.A.H. 2001. Effect of beche-de-mer fishing on densities and size structure of *Holothuria nobilis* (Echinodermata: Holothuroidea) populations on the Great Barrier Reef. Coral Reefs 19:271–276.

Uthicke S., O’Hara T.D. and Byrne M. 2004a. Species composition and molecular phylogeny of the Indo-Pacific teatfish (Echinodermata: Holothuroidea) bêche-de-mer fishery. Marine and Freshwater Research 55:1–12.

Uthicke S., Welch D. and Benzie J.A.H. 2004b. Slow growth and lack of recovery in overfished holothurians on the Great Barrier Reef: Evidence from DNA fingerprints and repeated large scale surveys. Conservation Biology 18:1395–1404.

Uthicke S., Byrne M. and Conand C. 2010. Genetic barcoding of commercial beche-de-mer species (Echinodermata: Holothuroidea). Molecular Ecology Resources 10:634–646.

Wolfe K. and Byrne M. 2022. Overview of the Great Barrier Reef sea cucumber fishery with a focus on vulnerable and endangered species. Biological Conservation 266:109451

Characterising changes in a decade of Mexican sea cucumber crime (2011–2021) using media reports

Teale N. Phelps Bondaroff,[1] Felix Morrow,[2] Abigail Bennett,[3] Carmen Pedroza-Gutiérrez,[4] Meredith L. Gore[5] and Jorge A. López-Rocha[6]

Abstract

This paper uses over a decade's worth of media coverage of sea cucumber crime (smuggling and poaching) in Mexico, in order to characterise the spatio-temporal magnitude of the problem and to better understand the *modus operandi* of those engaged in this form of wildlife crime. Towards this goal, we analysed and mapped incidents of crime relating to sea cucumbers taken from Mexican waters between 2011 and 2021; these were compiled from news media reports, government press releases and social media. The 97 incidents analysed revealed 125 arrests, with an average of 1.29 arrests and 1037 kg of sea cucumbers seized per incident. Mexican and United States authorities seized 100.6 tonnes of sea cucumbers, valued at an estimated USD 29.5 million. A qualitative review of these incidents reveals a number of key practises, including false identification, mislabelling, misreporting, stockpiling and invoice manipulation and fraud as means of laundering illicit catches. Also documented is corruption, the use of clandestine drying sites, and private vehicles for transportation. Media coverage of sea cucumber poaching and smuggling operations in Mexico frame the crime as being organised and conspicuous for its association with armed violence.

Keywords: Illegal fishing, sea cucumbers, wildlife crime, illegal, unreported and unregulated (IUU) fishing

Introduction

The poaching and smuggling of sea cucumbers threatens the stability of their populations, marine ecosystems and legal fisheries by undermining conservation and management measures. A better understanding of the nature of sea cucumber crime is, therefore, critical to combatting this ruinous type of wildlife crime. Wherever there are sea cucumber fisheries, wildlife crime will inevitably emerge (Conand 2018). Surveying instances of sea cucumber crime globally reveals certain regions and countries as conspicuous hotspots. Mexico is one country with a globally recognized sea cucumber fishery and a considerable number of documented instances of sea cucumber crime.

Sources report extensive illegal activity in Mexican sea cucumber fisheries with sizable quantities of Mexican sea cucumbers having been seized by law enforcement in recent years. Such is the scale of illegal sea cucumber fishing in Mexico, Cisneros-Montemayor et al. (2013) estimated that the illegal catch may well be twice that of reported catches. Calderon-Aguilera (2019) noted that official sources reported the confiscation of 1,024,813 individual sea cucumbers in the Gulf of California between 2013 and 2018, and posited that the illegal catch was certainly much larger. Between 2013 and 2015, Gamboa-Álvarez et al. (2020) observed an increase in seizures of illegally caught *Isostichopus badionotus* from the Campeche Bank, with 34.1 t seized in 2014. One news story, relying on documents obtained through transparency laws, reported that between 2007 and 2016, the Secretary of the Navy (SEMAR), seized nearly 42 t of illicit sea cucumbers (Alvarado et al. 2016). However, this same article notes databases maintained by the Federal Attorney for Environmental Protection [Procuraduria Federal de Protección al Ambiente] (PROFEPA) only record the seizure of 3164 kg over this same period (Alvarado et al. 2016).

This paucity of detailed data is echoed by Vidal-Hernández et al. (2019:227), who noted that "actors within the local fisheries sector estimate that over 70% of the trade in this resource is illegal and that trade authorities have no accurate data for the amount that leaves the state by land, sea, and air." They further remark that "there is also no documentation of the structure of the state's sea cucumber market network (i.e. how it operates and who participates), be it legal and/or illegal" (Vidal-Hernández et al. 2019:227). Given that sea cucumber populations in Mexico have been severely depleted, and that illegal extraction is a substantial cause of this depletion (Calderon-Aguilera 2019), a deeper understanding of this phenomenon is needed. A previous attempt to better understand Mexican sea cucumber crime was conducted by Calderon-Aguilera (2019), who tabulated 11 instances of sea cucumber crime in Baja California from 2013 to 2018, amounting to the confiscation of over 26.6 t of sea cucumbers. We seek to build on this work with a more comprehensive look at this form of wildlife crime.

[1] Director of Research, OceansAsia, Victoria, BC, Canada. Email: teale@oceansasia.org
[2] Researcher, OceansAsia, Victoria, BC, Canada
[3] Assistant Professor, Department of Fisheries and Wildlife, College of Agriculture and Natural Resources, Michigan State University, Unites States
[4] Senior Researcher, Escuela Nacional de Estudios Superiores, Unidad Mérida, Universidad Nacional Autónoma de México, Mexico
[5] Associate Professor, Department of Geographical Sciences, University of Maryland, College Park, Maryland, United States
[6] Senior Professor, Unidad Multidisciplinaria de Docencia e Investigación, Facultad de Ciencias, Universidad Nacional Autónoma de México, Sisal, Yucatan, Mexico

The goal of this paper is to use media coverage to characterise the spatio-temporal magnitude of the problem and to help gain a better understanding of the *modus operandi* of those engaging in sea cucumber crime in Mexico. Using open-access online search engines, we conducted a detailed search for all publicly available Spanish- and English-language news stories, government press releases, and social media posts documenting seizures, arrests and other illegal incidents, published between 1 January 2011 and 1 December 2021, involving Mexican sea cucumbers. Incidents of sea cucumber crime published in the media were then qualitatively studied and quantitatively coded. We reviewed the details of incidents in order to better understand the *modus operandi* of criminal operations involving sea cucumbers, and the incidents were then mapped in order to better understand spatio-temporal features. Incidents were also tabulated in a database to allow for a quantitative review.

In addition to better understanding sea cucumber crime in Mexico, it is our ambition that this paper may also contribute insight into methods that can be employed to study other forms of wildlife crime. Government reporting of wildlife crimes is inconsistent. A further challenge of studying illicit activities is that they are covert by nature. Some stages of wildlife crime, such as poaching, occur in remote locations characterised by limited human interface, and as a result, it can be difficult to directly observe. Clandestine stages of wildlife crime supply chains only come to light when they are interrupted by law enforcement authorities. These seizures and arrests may occur in different jurisdictions from whence originated the trafficked wildlife. The transboundary and clandestine nature of wildlife crime make it challenging to characterise the supply chain and *modus operandi* of offenders.

Media coverage offers one means of tracking wildlife crime along various stages of the illicit supply chain. Basic descriptive information about the "how", "where", "when" and "who" of wildlife crime is reported in media stories. Media coverage is also catalogued, so that decades of coverage can be compiled into a single dataset. Characterising media coverage of wildlife-related issues has become a commonly employed tool in conservation social science and criminology (e.g. Gore et al. 2005; Muter et al. 2013), and can offer a retrospective set of data chronicling conservation activity. Media coverage can, but does not always, influence public perceptions concerning wildlife (Gore and Knuth 2009) because the media does not cover every wildlife-related event. The strength of analysing media coverage is the novel set of data that is produced. A secondary goal of this paper is to demonstrate the effectiveness of using news media reports in order to better understand wildlife crime.

We begin with an overview of sea cucumber fisheries in Mexico, providing a brief history of the various fisheries, outlining relevant laws and regulations, and shining a light on instances of violence associated with the fishery. The paper then examines social drivers and factors motivating illegal sea cucumber fishing in Mexico. Before detailing our methods, we examine the Mayorquin case – a multi-year, multi-million-dollar sea cucumber smuggling operation that transported at least USD 13 million worth of sea cucumbers from Mexico to the United States, and then to Southeast Asian markets, between 2010 and 2012. The results are presented in two broader sections. We begin with a qualitative review of the *modus operandi* of sea cucumber criminals, before exploring elements of the documented incidents (arrests, weights and values of seizures, species, and associated species/products), and conclude with an analysis of the geographic distribution of sea cucumber crime in Mexico.

Sea cucumber fisheries in Mexico

Mexico's four coastal regions (Gulf of California, Pacific Ocean, Gulf of Mexico and Caribbean Sea) are home to 113 species of sea cucumbers (Solís-Marín et al. 2014; Solís-Marín et al. 2013). Major sea cucumber fisheries operate in two primary regions: the waters around the Baja California Peninsula (the Gulf of California and the Pacific, hereafter the Baja California Peninsula), comprising the Mexican states of Baja California and Baja California Sur; and the waters off the Yucatan Peninsula, comprising Campeche, Yucatan and Quintana Roo (Bennett and Basurto 2018) (see Fig. 4). The dramatic increase in interest in sea cucumbers in Mexico is linked to increasing demand from Southeast Asian markets, and has made sea cucumbers a highly lucrative opportunity for fishers. The high value of sea cucumbers has led to their being dubbed "oro negro" or black gold (Bennett and Basurto 2018; see also Calderon-Aguilera 2019). Consulting daily landings and payment records from a Yucatan fishing cooperative, Bennett and Basurto averaged the mean daily earnings per boat at USD 459, but noted that this went up to USD 737 during sea cucumber fishing season (2018). In good years, fishers could earn upwards of USD 1628 per day during the sea cucumber fishing season. By comparison, lobster fishing only earned fishers USD 150 per day (Kaplan-Hallam et al. 2017). Sea cucumber fishing quickly increased in importance. As Vidal-Hernández et al. (2019:227) note,

> "an estimated 23400 people along the coast of the state of Yucatan depend on the 6000 fishers who participate in the sea cucumber fishing season each year; in other words, 75% of the fishers and one-third of the coastal population. It is clearly an important regional fishery."

In both regions, fishing is typically carried out from small outboard motor-equipped boats, crewed by three to four fishers using semi-autonomous hookah-type diving gear in waters between 10 and 20 m (López-Rocha and Velázquez-Abunader 2019; Gamboa-Álvarez et al. 2020). Sea cucumbers are typically boiled, dried and salted before export, while lesser quantities are frozen (Solís-Marín et al. 2013:43). As Pedroza-Gutiérrez and López-Rocha note, "one major characteristic of the fishery is that the catch is male dominated, it is very rare to see a female fisher and even rarer to see a female diver" (2021:15). Processing, on the other hand, is mostly performed by women, who are seasonally and often informally employed, and who are "without any voice or influence in the fishery organization" (Pedroza-Gutiérrez and López-Rocha 2021:15).

Baja California Peninsula

The Gulf of California is home to 64 species of sea cucumbers, and 53 species can be found living in the waters of the Pacific coast of the Baja California Peninsula (Solís-Marín et al. 2013). The main species of sea cucumbers that have been exploited in this region are *Isostichopus fuscus* and *Parastichopus parvimensis*. There are five other species of commercial interest: *Apostichopus californicus*, *Holothuria impatiens*, *H. inornata*, *H. parinhabilis*, and *H. paraprinceps* (Rivera-Téllez and López-Segurajáuregui 2021). The first records of captures for *I. fuscus* and *P. parvimensis* date from 1988 (Singh-Cabanillas and Vélez-Barajas 1996). Catches of *I. fuscus* increased rapidly until they reached 2000 t per year in 1991. They then decreased until 1994, when the Mexican government declared *I. fuscus* an endangered species in NOM–059, and as a result, the fishery was closed (SEMARNAT 2020). The administration of *I. fuscus* was transferred from the National Aquaculture and Fisheries Commission [Comisión Nacional de Acuacultura y Pesca] (CONAPESCA) to the Secretariat of Environment and Natural Resources [Secretaría del Medio Ambiente y Recursos Naturales] (SEMARNAT). Illegal fishing persisted, however, despite this closure.

In 2007, the *I. fuscus* fishery was reopened, with a restricted fishing season (June to September) and a quota system. Subsequently, in 2010 and 2019, changes were made to the species protection category, designating it as a species subject to special protection (DOF 2010, 2019). This category allows for the use of the species, but it is managed by the General Directorate of Wildlife of SEMARNAT, and not by CONAPESCA. The conservation and legal extraction of *I. fuscus* is currently managed under a federal management plan in 37 federal areas in Baja California and the Gulf of California, including Sinaloa, Colima, Jalisco and Oaxaca. This management plan also recognises that illegal fishing is the main problem in the fishery (SEMARNAT 2020). At the moment, "*P. parvimensis* is not considered to be at risk or threatened" (Toral-Granda 2008, cited by Vidal-Hernández et al. 2019:227).

The Yucatan Peninsula

Of the 14 species of sea cucumbers foundoff the coast of the Yucatan Peninsula, five are commercially exploited: *Astichopus multifidus*, *I. badionotus*, *Holothuria floridana*, *H. mexicana* and *H. grisea*. Of these, *I. badionotus* and *H. floridana* are the most significant commercial species and are the only species for which fishing permits are issued (see Gamboa-Álvarez et al. 2020; Gore and Bennett 2021). Fishing for *I. badionotus* and *H. floridana* started in 2006 and continued in 2010–2012, with permits and quotas being implemented by CONAPESCA (Bennet and Basurto 2018; Pedroza-Gutiérrez and López-Rocha 2021).

Initial permits were "development" permits intended to explore the potential and sustainability of the fishery, and were granted from 2000 to 2012 (DOF 2015). The first commercial permits were issued in 2013 for *I. badionotus*, and a management plan was published in 2015 (Pedroza-Gutiérrez and López-Rocha 2021). The commercial fishery was managed across four fishing zones in Yucatan through vessel permits, quotas, size limits and closed seasons (open seasons have typically run for 10–14 days, 1–2 times per year) (see Pedroza-Gutiérrez and López-Rocha 2021; Bennett and Basurto 2018). The Mexican National Fisheries Institute [Instituto Nacional de Pesca] (INAPESCA) collects the necessary information to recommend whether and when to open fishing seasons based on sea cucumber abundance, size and density determined through transect surveys. CONAPESCA determines regulations and recommendations, and communicates them through the Official Journal of the Federation [Diario Oficial de la Federación] (DOF) (Pedroza-Gutiérrez and López-Rocha 2021:10).

Significant interest in *I. badionotus* and incomplete enforcement of the fishery's regulations led to overexploitation. This in turn, led to the fishery's closure in 2019, after nine years of operation. Yet despite these closures, populations of *I. badionotus* show no signs of recovery (Pedroza-Gutiérrez and López-Rocha 2021; see also Glockner-Fagetti et al. 2016; Bennett and Basurto 2018; López-Rocha and Velazquez-Abunader 2019; Gamboa-Álvarez et al. 2020). In Baja California and the Yucatan Peninsula, illegal fishing has remained a constant problem leading to criminal code amendments to expand the ability of regulators and police to crack down on illegal fishing.

Fisheries enforcement and monitoring in Mexico

As with many sea cucumber fisheries, enforcement of sea cucumber fishing regulations in Mexico has been challenging and unfortunately inadequate. In Mexico, in addition to government authorities such as CONAPESCA, municipal, state and Federal Police, environmental protection and protected area authorities (e.g. PROFEPA, the National Commission of Protected Natural Areas [Comisión Nacional de Áreas Naturales Protegidas, CONANP]), and military (e.g. SEMAR), fishing cooperatives play an important role in the monitoring and enforcement of formal fishery regulations and local rules (Mendez-Medina et al. 2020; McCay et al. 2014). The role of cooperatives in fisheries monitoring and enforcement has been particularly well-documented in the Yucatan Peninsula sea cucumber fishery (Bennett and Basurto 2018; Kaplan-Hallam 2016; Pedroza-Gutiérrez and López-Rocha 2021).

Enforcing harvesting regulations at sea is a challenge for authorities, given limited resources and assets, and in consideration of the geography and size of fishing areas in both Baja California and Yucatan Peninsula sea cucumber fisheries. As a result, instead of enforcing harvesting volumes, CONAPESCA officials "monitor volumes transported out of fishing communities…At roadside checkpoints, CONAPESCA inspected vehicles and weighed sea cucumber to verify that invoices matched the amount of sea cucumber being transported" (Bennett and Basurto 2018:64).

In 2017, the Mexican criminal code was amended to include Article 420 (II Bis), which made it illegal to:

> In a fraudulent manner, capture, transform, stockpile, transport, destroy or trade with the aquatic species called abalone, shrimp, sea cucumber and lobster, within or outside the closed season periods, without the corresponding authorization, in a quantity that exceeds 10 kilograms of weight (Government of Mexico, Código Penal Federal, Book 2, Title 25, Chapter 2).[7]

As Mexican law currently stands, those harvesting and transporting sea cucumbers require the proper documentation and official invoices, "which are documents provided to permit holders (e.g. co-ops or patrons) according to the quotas authorized in their permits," which "restricts permit holders from selling volumes greater than their harvest quotas" (Bennett and Basurto 2018:64).

In Yucatan, fishing cooperatives have aided in the monitoring and enforcement of sea cucumber regulations by alerting authorities to the presence of poachers (often non-local fishers) in local fishing grounds, attempting to prevent local fishers from targeting sea cucumber without permits, and lobbying state and federal government (including the national legislature) to invest in enhancing enforcement capacity. Enforcement and governance activities by fishing cooperatives play out differently along the Yucatan Peninsula coast, depending on local social and institutional dynamics. In various efforts to lobby government on issues relating to improving the regulation (management and enforcement) of sea cucumber fisheries, local cooperative fishers have employed a variety of forms of activism, including blocking highways, government buildings and ports to prevent un-permitted boats from accessing fishing grounds (Bennett and Basurto 2018; Tierra Fértil 2016).

A sporadic history of conflict and violence

Local monitoring and enforcement efforts by fishers have at times led to violent conflicts between legal and illegal fishers and fishers from other states and communities. For example, in 2014, when fishing cooperative members approached boats poaching sea cucumbers in Yucatan, the poachers kidnapped a cooperative member. The cooperative member was later returned to his community with serious injuries (see Bennett and Basurto 2018). Conflict has also been driven by territorial struggles over fishing grounds. For example, fishers from both sides of the Yucatan-Campeche border have had multiple violent confrontations over sea cucumber fishing territory, resulting in burned boats and even deaths (Michel 2014; Yucatan Times 2016).

Fishing cooperative members are not deputised and, therefore, do not carry firearms, although sea cucumber poachers are very often armed. This has sometimes led to fishers being vulnerable to attack and robbery. For example, on 29 April 2015, 10 armed men entered the mouth of the port of El Cuyo, Yucatan on a barge, and attacked three guards protecting a cold storage facility. The criminals absconded with 3.5 t of dried sea cucumber (Jimémez 2019). In another incident, in June 2016 at sea off the coast of Dzilam de Bravo, a group of armed men robbed eight fishers at gunpoint. The armed men allegedly stole half a tonne of sea cucumbers, robbed the fishers and threw them into the sea, leading to the drowning death of two fishers (Tierra Fértil 2016). Property damage, shootings, injuries and fatalities resulting from conflicts between fishers and poachers have been widely reported (Kaplan-Hallam et al. 2017; Medina 2021; Escalante Rosado 2018). Further confounding matters is the fact that port officials are not permitted to carry firearms, leaving them vulnerable and unable to safely engage with armed actors. Only officers from the Navy (SEMAR) are armed.

Even interactions among illegal fishing crews working on the same fishing vessel have led to injury and death. When poachers are approached by authorities, they attempt to flee quickly, and in at least one incident, have sunk their own vessel to avoid apprehension (Ruido 2019). When poaching operations are interrupted, divers may be quickly pulled to the surface of the water, leading to decompression injuries and death. To avoid detection from authorities, illicit fishers experiencing decompression injuries may avoid seeking medical assistance, and in some instances, they have been abandoned at sea by their accomplices.

The risks of decompression sickness are not limited to illicit sea cucumber fisheries. The general risks of decompression sickness and other associated safety issues are increased when depleting sea cucumber populations (as a result of poor regulation, overfishing and illegal fishing), leading to fishers diving deeper and seeking out less exploited, and often more dangerous, fishing areas (see Escalante Rosado 2018; Kaplan-Hallam et al. 2017). Gamboa-Álvarez et al. (2020) report that between 2012 and 2014, there were 468 injuries and 26 deaths caused by decompression sickness from sea cucumber fishing in the Yucatan Peninsula. This rate of injury is considerable given that the region only employs 6000 fishers, 4500 of whom target sea cucumbers (Vidal-Hernández 2019). Hutchim-Lara et al. (2018) report 166 cases from 2014 to 2016 in the Yucatan Peninsula, which they note is striking, given that the fishery was only open for ~17 days per year. Nor has the situation improved in recent years. Pedroza-Gutiérrez and López-Rocha (2021) report 10 cases of decompression sickness and one death in 2017.

In addition to violent confrontations between poachers and legal fishers, the sea cucumber fishery has had a range of socio-economic impacts on local communities. Disruptions caused by a rapid influx of money and outsiders have been documented in a number of sea cucumber fisheries, such as those in Papua New Guinea and Fiji (see Busilacchi et al. 2018; Hair et al. 2019; Cakaunivere 2016; Chen 2003). In Mexico, communities with rapidly emerging and evolving sea cucumber

[7] Translated from Spanish, original reads: "De manera dolosa capture, transforme, acopie, transporte, destruya o comercie con las especies acuáticas denominadas abulón, camarón, pepino de mar y langosta, dentro o fuera de los periodos de veda, sin contar con la autorización que corresponda, en cantidad que exceda 10 kilogramos de peso."

fisheries have experienced an observed rise in antisocial or "deviant" behaviours, such as drug use, prostitution and theft (Kaplan-Hallam 2016; Bennett and Basurto 2018; Kaplan-Hallam et al. 2017; Gamboa-Álvarez et al. 2020).

Select social drivers of sea cucumber crime

The decision to engage in illegal fishing is driven by a range of socioeconomic factors. Demand for luxury seafood products, such as sea cucumbers, expanded dramatically after the 1970s, alongside Chinese economic development. Rapid urbanisation in China and the rise of a growing middle class, along with the depletion of traditional fisheries, led to increased seafood consumption, such that per capita seafood consumption grew by 665% from 1970 to 2013 (4.53 kg to 34.67 kg) (Food and Agriculture Organization of the United Nations quoted by Fahrenbruch 2018). Chinese seafood imports grew by over 3300% over this same time period. Roving bandits fanned out through the world to uncover easily exploitable fisheries to satisfy this demand (Fahrenbruch 2018), and some of them found Mexico.

In the context of Mexican sea cucumber fishing, economic opportunity, historical processes of neoliberalisation and globalisation, changes in the role of local fishing cooperatives, and difficulty monitoring and regulating an expanding fishery, are all drivers of illegal fishing. Prior to the 1980s, the Yucatan Peninsula fishing industry was relatively small and consisted of locally owned cooperatives. In this period, fishing primarily met local demand, creating food and employment for the region (Pedroza-Gutiérrez and Salas 2011). This changed with the neoliberalisation of the fishery, which led to deregulation, privatisation, and increased private investment. The opening of fisheries to the global market and the reduction in state support for cooperatives, specifically the lowering of financial support to help fund large capital expenditures such as boats, led to actors from outside of communities arriving and taking a greater role in fisheries. Whereas early fisheries development approached investment and commercialisation through strong relationships between the state and fishing cooperatives, neoliberal reforms in the fishery sector helped enable a rise in the private sector, which consists of private fishing firms and patron-client relationships (Young 2001; Bennett 2017).

Patron-client relationships, in particular, serve as mechanisms facilitating investment in capital and migrant fishing labour that can lead to rapid increases in (often illegal) fishing effort in local communities, especially in the context of high market demand (Bennett and Basurto 2018; Pedroza 2013). During the early development of the sea cucumber fishery in Yucatan, some fishing cooperatives argued that the fishery should be modelled after another valuable benthic fishery in the region – the spiny lobster fishery – through spatial fishing concessions, with priority given to cooperatives over the private sector. However, the private sector was able to secure substantial access to fishing permits (Bennett, unpublished interview data).

The neoliberal regime resulted in a decline in regulation, and the state left fishing cooperatives as the primary moderating force in fisheries (Kaplan-Hallam 2016). The decline of fishing cooperatives in communities that previously have largely been locally fished, has diminished local monitoring and enforcement capacity. As fishers increasingly come from outside of communities and/or are not linked to local cooperatives, the ability for cooperatives to identify and prevent illegal fishing is greatly diminished. Further, issues of real and perceived corruption of regulators allow for illegal fishing and lead locals to not report observed crimes (Kaplan-Hallam 2016). The combination of deregulation and increased investment lead to an intensification of extraction and production and, as a result, ecological decline in sea cucumber populations (Kaplan-Hallam 2016; Pedroza and Salas 2011).

The weakening of local regulatory capacity, increased costs of fishing (costs of fuel and permits and increasing scarcity of sea cucumbers), a lack of economic opportunities in fishing communities and nearby agricultural communities, and the high price of sea cucumbers incentivized local and outside fishers to operate outside of the legal fishery. The sea cucumber boom created economic prosperity and wealth and the bust that soon followed threatened that prosperity. The economic insecurity created by the ecological decline of sea cucumber populations has driven fishers to engage in illegal fishing to maintain their economic standing and avoid poverty. Further, global demand and profitability remain high, making illegal sea cucumber fishing a worthwhile endeavour for organised crime. Given all of these factors driving illicit sea cucumber fisheries, how has this crime manifested in Mexico?

Methods

Sampling

Building on the method employed in the analysis of sea cucumber crime in India and Sri Lanka (Phelps Bondaroff 2021), we assembled a database of seizures and other illegal incidents involving sea cucumbers in, and pertaining to, Mexico, from 1 January 2011 to 1 December 2021. This timeline is as reasonably far back as one can go given the method, and also, within the context of sea cucumber fisheries in the Yucatan, captures two years before the issuance of the first commercial fishing permits, the height of commercial fishing, and two years after the complete closure of the fishery.

Data were drawn from publicly available news stories that were identified through a series of English and Spanish language keyword searches.[8] Several rounds of searches were conducted using the Advance Search feature on Google, with and without the region filter being set to Mexico. Searches for "Mexico" plus "sea cucumber", "trepang", "bêche-de-mer", "beche-de-mer", "pepino de mar" and "pepinillo de mar" were also conducted in English and Spanish through Google News. A detailed search for the term "pepino de mar" was also conducted on the Mexican government's website (www.gob.mx). Finally, we used the Advanced Search feature on Twitter to identify any tweets from fishery-focused Mexican and US government law enforcement agencies, departments and ministries, that contained the terms “sea cucumber” or “pepino de mar”.[9] When an incident was identified, where possible, triangulation was used to confirm the details of the incident, and news stories reporting arrests and later stories documenting successful prosecutions were combined.

Identifying information was recorded for each entry, including date, location, agencies involved, method of transport, weight and/or number of sea cucumbers seized, species, state of seizure (live, fresh, dry, frozen, mixed), value of seizure (as estimated by the authorities), associated commodities (other wildlife products or other illicit products such as weapons or drugs), the number of people arrested (along with their nationalities, names, and ages), and any other seizures (vessels, fishing gear, vehicles). We also recorded the declared origins of the sea cucumbers, any transit points, and the declared destination, along with any legal consequences or sanctions, apart from initial arrests and seizures, including any fines or jail time, as well as any associated crimes (traffic violations, drug trafficking, weapons, etc.). Qualitative descriptions from news reports were also collected and served to inform our understanding of the *modus operandi* of illicit sea cucumber operations.

Arrests or seizures that occurred in different locations but on the same day were recorded as separate entries; this was done to allow us to map individual incidents. Likewise, seizures that occurred at the same location on the same date, but for which different details were provided, were treated as separate entries (Ángeles Rivero 2018). Thus, when federal police seized 17 t of dried *I. badionotus* at the Cancun International Airport on 20 May 2015, two entries were made in the database because 11 t were bound for Hong Kong, while 6 t were being shipped to Florida in the United States (Government of Mexico 2015a)

Calculating values

Knowing the state and species of the sea cucumbers that were seized allows for an estimate of weight when only a number of animals was reported. While weights or numbers were provided for most incidents, the level of precision varied considerably. In some instances, the state of the sea cucumbers could be observed from photos or inferred from context, such as when authorities interdicted a vessel that was actively fishing, they were assumed to be fresh (see for example Lizárraga 2020), or when sea cucumbers were reported as being transported in boxes by truck, they were assumed to be dried, as processing typically takes place on the beach or in port (see for example Government of Mexico 2013c). In this way, we were able to identify the state of every seizure.

In five incidents, both the weight and number of sea cucumbers seized were reported, such as the 21 May 2014 seizure of 55,960 individuals of *I. fuscus*, or 2.5 t, from a warehouse in Ensenada, Baja California by PROFEPA agents; the more precise number was used for the purposes of calculations and analysis (Government of Mexico 2015b).

We drew on the literature for average live/fresh weights of individual sea cucumbers, and used the following for our analysis: *I. fuscus* (385.9 g) (Herrero-Pérezul and Reyes-Bonilla 2008; see also Reyes-Bonilla et al. 2018), *Isostichopus badionotus* (551.9 g) (an average wet weight from DOF 2015; Pedroza-Gutierrez and López-Rocha 2021; Hernández-Flores et al. 2018; López-Rocha 2012; de Jesús-Navarrete et al. 2018; Poot-Salazar et al. 2015:18), *Holothuria floridana* (63.6 g) (Ramos-Miranda et al. 2017), and *H. mexicana* (97.9 g) (Guzmán et al. 2003). When the species was unknown, we used an average of all four weights (274.8 g).

Sea cucumbers typically retail in a dry state and, therefore, in order to calculate the value of seizures and compare incidents, we estimated dry weight for each seizure when a dry weight was not reported. Sea cucumbers lose considerable weight when they are processed and dried. We drew upon the literature in order to convert live/fresh weights to dry weights. For *I. fuscus*, we relied on the wet-to-dry recovery rate of 8%, calculated by Acosta et al. (2021), meaning that an average of 8% of the initial weight of the animal remains after processing. For *I. badionotus*, we used a wet-to-dry recovery rate of 7% (DOF 2015). As we were unable to locate literature specific to *H. floridana* and *H. mexicana*, we relied on the wet-to-dry recovery rate of 12% (Ngaluafe and Lee 2013), an average calculated from analysing 10 tropical species. When the species was unknown, we used the wet-to-dry recovery rate of 12%.

Calculating values

Unlike with most crime reporting, the value of the seizures was seldom reported (only in eight incidents). Consistent with most crime reporting, when the value of a seizure was reported, it was not very reliable (Murtha 2016; and see Coomber et al. 2000). Prices vary at various stages of the fisheries supply chain. For example, Bennett and Basurto reported that a 2012 survey of fishers in Yucatan found that a kilogram of fresh sea cucumbers could be sold for USD 2.0–3.7, while dried sea cucumber could sell for USD 20–26 per kilogram (SAGARPA 2015 cited by Bennett and Basurto 2018; see also Vidal-Hernández 2019). Informal contractual relationships between buyers and sellers, as well as the legal status of a catch, also influence prices. Wholesale and retail prices in Southeast Asian markets, as well as online prices are considerably higher; quality specimens of *I. fuscus* can fetch up to USD 1030 per kilogram in some markets (Purcell 2014, cited by Calderon-Aguilera 2019:42). Further complicating matters is the fact that length, weight and the quality of processing also affect prices (see for example Purcell 2014; Purcell et al. 2018a; Purcell et al. 2018b; Purcell et al. 2017; Govan 2019). Thus, it was unclear as to what prices were used by authorities to calculate seizure values, and as a result, the reported value of seizures was discarded.

Instead, we searched the literature for average market prices for the four target species. We used the average Hong Kong market prices from Purcell et al. (2018b) for *H. mexicana* (USD 117) and *I. badionotus* (USD 313). As market prices were unavailable for *H. floridana* and *I. fuscus*, we calculated prices for these species in the following way. First, we averaged available prices from online sellers for each species, three *H. floridana* (USD 290.7) and six for the *I. fuscus* (USD 460.5).

When we compared the market price used by Purcell et al. 2018b for *I. badionotus* (USD 313) with an average of five online prices for the *I. badionotus* adjusted to 2018 prices using a 2.4% average beche-de-mer price growth rate (Purcell et al. 2018b) (USD 334.9), we found that market prices were 93.5% of online prices. We recognize that as a result, we used slightly inflated values for our price calculi for *H. floridana* and *I. fuscus*, as compared with previous market prices from the literature.

Method of transportation

Incidents with identified transportation methods were placed into six categories: air, fishing vessel, ship, vehicle, private facility and container. Incidents were placed into these categories reflecting the last known intended method of transport. Thus, if a truck was stopped while entering the parcel area of an airport, the incident would be categorised as "air ", whereas if a car was stopped at a highway checkpoint, the incident would be classified as "vehicle". Boats were placed into two separate categories: fishing vessel and ship. "Fishing vessel" describes instances where people were caught in the act of fishing illegally or having just caught illegal sea cucumbers. "Ship" describes instances when illegal product were seized from a boat being used to ship the product. The category of "container" includes incidents where sea cucumbers were seized in a shipping container, but the method of shipment was unclear, such as a shipping container in a port town that could be loaded onto a truck or a vessel where no indication was given in reports.

For the purposes of analysing methods of transport, two incidents were excluded. The first involved a woman walking through the United States border crossing into Baja California with the equivalent of 1.13 kg of dry sea cucumber in her bag (Rohrlich 2019). The second was an incident that occurred in July 2021, where a man was arrested with a small bag of sea cucumbers on a beach near Loreto, Baja California Sur, while he was illegally gleaning (BCS Noticias 2021).

Limitations and sources of error

There are a number of limitations and potential sources of error in addition to those highlighted above. Wherever possible, we used triangulation to mitigate potential ambiguities in news stories and government press releases, and we conducted multiple rounds of searches using a range of search terms and on a number of platforms in order to maximise the number of news stories and reports we encountered. Because our approach relies on analysing news, social media posts and government press releases, it typically captures newsworthy incidents; as a result, many routine administrative actions are likely to be missed. This method relies on issues being problematized and, therefore, reported on by the media, and as such it is possible that incidents that occurred close to the origin of fisheries may not have been sufficiently problematized to be considered an issue worthy of media coverage.

Many news media platforms archive stories for a limited period, and may only archive significant stories. As a result, the further back in time one goes, the fewer stories one is likely to encounter. We observed a lower diversity of sources in earlier years, and this likely indicates that some older incidents may have been missed. Likewise, smaller local news media platforms, the type that are most likely to report less significant incidents such as those involving only a few individuals or smaller seizures, may not publish their content online, or may have only started doing so in more recent years, and are also less likely to be indexed by the search engines that we used. One way we sought to mitigate this potential source of error was by investigating any "recommended stories" links, hyperlinks referring to previous related news stories that are often shared at the bottom of news stories.

Information was not always provided for all categories in the database, as entries were based on government press releases, tweets and news media stories. Some categories were more likely to be reported than others. For example, only 30 incidents had transit points or the declared destinations, legal sanctions or punishments were only available for 11 incidents, and reporting of the details about suspects (first names, ages, nationalities) was inconsistent. On the other hand, location was almost always reported, the weight or number of sea cucumbers seized was reported in most stories (91 of 97), and the species was noted in 47 incidents.

Similarly, the terminology used to describe seized sea cucumbers was not always consistent or clear for the purposes of calculating weight. For example, a 26 July 2021 news story recorded the seizure of 290 kg of cooked semi-dry (*semiseco cocido*) and 214.4 kg of cooked sea cucumbers by SEMAR and CONAPESCA personnel from vehicle stops in Hidalgo and Bustamante, Ensenada (Borbolla 2021). Other common terms used to describe sea cucumbers were stewed (*sancochado*) and pre-cooked or parboiled (*pre-cocido*) (See for example Larios Gaxiola 2015; Government of Mexico 2016b). These incidents were evaluated on a case-by-case basis, with the incident being assigned the nearest reasonable state (dry or wet).

In some cases, it was evident that values had been rounded, while in other cases, seemingly highly precise numbers were provided. For example, on 10 September 2015, a joint operation of SEMAR, CONAPESCA, and the Tax Administration Service led to the seizure of a reported 11 t of sea cucumber (*I. badionotus*, *H. mexicana* and *H. floridana*) from a shipping container in the port in Progreso, Yucatan (Government of Mexico 2015c). These numbers are considerably less precise when compared with, for example, a 13 March 2016 news story that reported the seizure of 144.94 kg of dry, and 191.42 kg of raw/fresh *H. floridana*, by a joint operation, from a processing camp on the Island of Jaina, Campeche (Chi Segovia 2016). Rounding could also be observed with the reporting of numbers seized.

We also noted inconsistencies and errors in press releases and news stories. One prominent example was a widely reported incident that occurred on 22 May 2013, when PROFEPA officers seized a shipping container that was being used to transport a variety of illicit marine wildlife products at Ensenada (Baja California) Customs. Along with licit cover products, the container reportedly contained 898,660 dried *I. fuscus*, 78,676 seahorses, along with shark fins and nearly 1000 boxes of dry and frozen totoaba (*Totoaba macdonaldi*) fish maw (swim bladders), mixed in with other legal marine products. However, the same press release later noted that 686 kg of *I. fuscus* and 197 kg of seahorses (*Hippocampus ingens*), and 21 boxes of dry swim bladders and 955 boxes of frozen swim bladders, presumably from totoaba. The press release mentioned that the entire value of the illicit cargo exceeded MXN 2 million (~USD 160,300) (Government of Mexico 2013a; Madrigal 2013; CITES 2014). Something is off with these numbers, however. If we were to estimate the weight of 898,660 dry *I. fuscus* using a per sea cucumber dry weight of 31 g, the result would be well over 27 t of sea cucumbers. This weight is approaching the maximum weight for a 40-foot shipping container without factoring in the weight of the rest of the licit and illicit cargo. Likewise, the value of the cargo seems incredibly low, as 27 t of dried *I. fuscus* would have exceeded USD 10 million, and given that at the time, a single totoaba swim bladder fetched over USD 100,000, the value of 955 "boxes" of totoaba would be astronomical (see Alvarado Matrínez and Martínez 2018; Guilford 2015). In this instance, given the unlikelihood that PROFEPA counted every sea cucumber and the aforementioned discrepancies between weights and numbers, we opted to include the much more conservative weight estimates in our dataset. Where errors or discrepancies in news stories and press releases could not be corrected through triangulation, we opted for the more conservative number.

Corruption is another factor that could influence reported values. In one instance in May 2018, law enforcement allegedly seized 600 kg of sea cucumber in Chicxulub, near Progreso, Yucatan, but only 402 kg were eventually presented to the authorities. The local media story suggested that the sea cucumbers could have gone missing as a result of corruption (Chavarría 2018). We should note that we attempted to be as conservative as possible when calculating weights and values, however, while the use of averages (as described above) allows for comparison over time and between regions, it reduces the precision of values.

Mayorquin case

One of the challenges with studying illicit activities is that they are, by their very nature, covert. When Hong Kong reports that volumes of sea cucumber imports are 1.3 times greater than the total of all global exports, we know that the scale of sea cucumber crime is extensive, and that there is a considerable number of successful sea cucumber poachers and smugglers (Anderson et al. 2011). Because we must rely on reports of instances when illicit activities are disrupted by law enforcement, we can only estimate the actual scale of criminal enterprises. Clearly for every smuggler stopped at a roadblock with a truck full of wildlife products, or a traveller caught with sea cucumbers in their luggage, there are numerous successful smuggling operations, and it is difficult to conceive of the scale and structure of the broader network within which these individuals operate. However, there are instances when a network is successfully identified, disrupted and dismantled by law enforcement, which provides us a glimpse of the scale and structure of their operations.

Therefore, before examining instances where law enforcement apprehended sea cucumber poachers and smugglers in Mexico, we would be remiss if we did not highlight one particularly salient case, notably the Mayorquin sea cucumber smuggling ring. We must also highlight this case because court proceedings revealed that the perpetrators successfully smuggled sea cucumbers from Mexico to Southeast Asia on at least 16 occasions. Because they were successful, these instances were not captured by our method.

Ramon Torres Mayorquin (father) and David Mayorquin (son) operated a seafood company, Blessings Inc., out of Tucson, Arizona (United States). Through this company, the two smuggled Mexican sea cucumbers from Mexico and into Southeast Asian markets. According to court documents, David Mayorquin handled the ordering of sea cucumbers from Mexico, primarily from the Yucatan, and arranged for products to be sold to Southeast Asian markets, while Ramon Torres Mayorquin received sea cucumbers in Mexico and arranged the practical aspects of moving product across the United States border (US Department of Justice 2018; Hickok 2018). The sea cucumbers were brought into the United States through the Otay Mesa port of entry in California. Once there, Ramon Torres would falsify invoices that included using a "non-existent address", and substantially undervaluing the sea cucumbers. In two instances, the coordination of the payment of bribes to Mexican officials were recorded by the courts, although the defendants were not charged with bribery.

In this way, between 23 January 2010 and 22 July 2012, 16 instances of illicit product with falsified documents were recorded. In total, the court recorded 128,610.5 kg of sea cucumbers (dry), with a total misreported value of USD 733,704 trafficked out of Mexico. The court estimated that the actual value of the over 128 t of sea cucumbers was close to USD 17.5 million when sold to Southeast Asian markets.

The Mayoquins did not have the proper licences or documentation to establish the legality of their products, and they intentionally misreported the value of their shipments (US Department of Justice 2018). Thus, in 2010, they exported 21,780 kg of sea cucumbers from Mexico into the United States in five shipments, and claimed the value to be USD 1.60/kg. In 2011, they exported 54,376 kg of sea cucumbers into the US in six shipments and claimed the value to be USD 1.30/kg. When they made five shipments of sea cucumbers from the United States to Taiwan and Hong Kong in 2012, totalling 52,454.5 kg, they claimed a value of USD 12.00/kg. All of these reported values were as little as one-tenth the actual value of the products (Department of Justice 2017; United States Department of Justice 2018).

On 8 March 2018, David Mayorquin, Ramon Torres Mayorquin and the company Blessings Inc. pled guilty to a 26-count indictment for illegally importing USD 13 million worth of sea cucumbers from Mexico; sea cucumbers that were sold for an estimated USD 17.5 million to Southeast Asian markets. The indictment resulted in the guilty parties forfeiting illegally procured product and profit, and they were required to pay USD 973,490 in fines, USD 237,879 in forfeited assets, and USD 40,000 in restitution to the Mexican government. A large portion of the fine was paid into United States government conservation funds (US Department of Justice 2018). No jail time was awarded to either David or Ramon Mayorquin, despite a number of the charges carrying maximum sentences of between five and twenty years. In addition, the fines were far less than the alleged profits earned by the conspirators over the duration of their operation. Both Mayorquins and Blessings Inc were placed on five years of probation (Putnam 2018; US Department of Justice 2018).

The Mayorquins moved a considerable amount of illicit sea cucumbers out of Mexico and were highly organised and used falsified documents extensively. A more in-depth examination of other incidents across Mexico will help establish whether this case was an outlier or the norm.

Results and discussion

From news media stories, government press releases, and tweets, we identified 97 instances of sea cucumber crime in Mexico between 1 January 2011 to 1 December 2021 (Table 1). These incidents resulted in 125 arrests and the seizure of the equivalent of 100,611 kg of dried sea cucumbers, with an estimated value of USD 29.55 million (Table 1). The number of incidents was generally on the rise until 2020, when there was a dramatic decrease (Fig. 1). The majority of these incidents (91) occurred in Mexico, while 6 incidents occurred in the United States. Note that our analysis and mapping of Mexican incidents sometimes exclude these US incidents. The average weight of each of these six incidents was 28.3 kg, and seizures ranged from 0.8 kg to 78 kg. Five people were arrested in four of the six seizures. Three of the seizures in the US occurred at the San Ysidro port of entry, the land crossing between Baja California, Mexico and California, United States. In all but one instance, the sea cucumbers being smuggled were dry, and in three instances, the species was identified as *I. fuscus*.

Modus operandi

Reviewing individual incidents qualitatively allowed us to gain a better understanding of the *modus operandi* of illicit sea cucumber operations. Here, we will highlight a number of salient observations from the incidents examined. Laundering, false labelling, and the bribing of officials have been common practice among those seeking to smuggle sea cucumbers out of Mexico. However, illegal actions have altered according to the availability of sea cucumbers, and the status of the legal fishery.

When the Yucatan Peninsula fishery was open, cooperatives provided one of the avenues and entities used to launder sea cucumbers. Each fishing season, the principal buyers would go to the cooperatives to auction the catch and associated invoices before they would start fishing. Invoices are required in order to legally sell and transport sea cucumber catches in Mexico. Buyers would store the illegal catch for the entire year and, when the season reopened, they would use the invoices to launder the product. A portion of the sea cucumbers stored would be sold using these recently acquired invoices. Thus, the fishing seasons served both as a time to fish, but also as an opportunity to launder sea cucumbers that were caught illegally out of season or above quotas from the previous season (Pedroza-Gutiérrez and López-Rocha 2021). Elsewhere, Bennett and Basurto (2018) described how when a local harvest exceeds the amount that can be legally transported out of the region, "some permit holders re-used invoices that were not

Table 1: Incidents, weight, arrests, value and boats seized, 2011–2021.

Year	Number of cases	Weight (dry) (kg)	Number of arrests	USD	Boats seized
2011	5	1402	34	450,935	2
2012	2	6	6	1448	0
2013	8	8466	15	2,322,474	9
2014	10	16,643	3	5,258,682	0
2015	9	31,009	15	8,713,030	2
2016	9	6815	6	2,006,994	1
2017	11	10,349	8	3,825,755	0
2018	14	1938	9	532,954	1
2019	14	19,643	19	5,062,481	0
2020	5	582	4	170,278	0
2021	10	3761	6	1,201,923	0
Total	**97**	**100,613**	**125**	**29,546,953**	**15**

inspected upon initial use," while others "froze and stored sea cucumber with the intention of selling it under future quotas during subsequent seasons". Bennet and Basurto (2018:64) describe the rise of an informal market for invoices, whereby "permit holders often sold their invoices to prospecting buyers prior to each season".

Smuggling and mislabelling have evolved with regulatory changes in the fishery. When the legal fishery was in operation, sea cucumbers would often be labelled as another type of seafood (one for which a legal fishery existed). However, in 2019 the Yucatan Peninsula fishery closed and smugglers began falsely labelling sea cucumbers more broadly as seafood and non-seafood products. This is evidenced in the Mayorquin case and in a variety of incidents that we documented. In one incident, a government press release reported that on 30 March 2019, the Mexican Navy seized approximately 12 t of sea cucumbers that had been labelled as peanuts from a shipping container in the port in Manzanillo, Colima (Government of Mexico 2019a). In another incident, 1116 kg of *Holothuria mexicana* and *H. floridana* that were falsely labelled as bonito were seized by authorities at the International Airport in Merida, Yucatan on 16 April 2016 (Government of Mexico 2016c).

Another seemingly common practice is under-reporting or misreporting. In these incidents, those shipping sea cucumbers may have the appropriate paperwork and permissions, but their paperwork does not correspond with the actual state, quantity or weight of the shipment. For example, on 8 April 2014, PROFEPA officials at the Mesa de Otay border crossing in Tijuana, Baja California, seized a shipment of 10,582 individuals of (700 kg) of *I. fuscus*, which exceeded the declared amount by 1759 units and whose state allegedly did not match the accompanying paperwork (Government of Mexico 2014). In another incident in Tijuana, this one on 10 November 2014, PROFEPA was alerted by some irregularities in the documents accompanying a shipment purporting to contain 32,000 dried *I. fuscus*. Upon inspection, officials counted 58,115 sea cucumbers, and so they seized the shipment and arrested the manager of the shipping company (Government of Mexico 2016a).

A number of other factors and *modus operandi* complicate the effective enforcement of sea cucumber fishing laws. As Gore and Bennett (2021:9) note, "illegal fishing and fish trade activity occurs in the same places and often appears quite similar to legal activities." The authors also elaborate how:

> ...permitted and non-permitted fishers may be fishing in the same areas and authorities lacking specific training may be unable to visually recognize the difference. Boat owners who possess legal permits may simply exceed harvesting quotas or copy permits to use more vessels. Vessels permitted to harvest sea cucumber may also harvest other species for which they are not permitted during the same fishing trip, such as lobster (*Panulirus argus*), octopus (*Octopus maya*), and finfish (e.g., snapper [*Lutjanus campechanus*] and grouper [*Epinephelus morio, Mycteroperca bonaci*]) (2018:9).

In 2016, an investigative piece in *El Universal* (Alvarado et al. 2016), documented a number of instances of what appeared to be the clandestine stockpiling of sea cucumbers. There were a number of incidents where law enforcement found sea cucumbers being stored in warehouses and in private homes (see for example Government of Mexico 2013b; Expreso 2018). And, there were incidents involving sea cucumbers being stored in wineries, whose cellars seem well-suited to storing sea cucumbers between seasons (El Financiero 2019; Diario de Yucatán 2019; Novedades Yucatán 2019, 2021). In one particularly conspicuous incident, a fire at a winery in Merida, Yucatan led to the discovery and seizure of 3463.8 kg of sea cucumbers (see ProgresoHoy 2019a, 2019b).

Illegal trade has also affected processing activities in which women have been the primary participants. In a normal season of legal fisheries, processing camps were situated next to landing sites, and women would take an active role in processing. However, with the closure of fisheries and the rise in illegal fishing, poachers and processors take measures to obscure their processing operations, as such facilities are potentially vulnerable to identification by authorities. As a result, women are no longer as involved in sea cucumber processing as they once were. A number of incidents involved the authorities identifying processing camps in hidden remote locations.

On 12 October 2015, officers from PROFEPA and SEMAR interdicted two small fishing vessels that were actively and illegally fishing for sea cucumbers 150 km south of San Felipe in Baja California. After arresting the two fishers, authorities were then able to identify the location of their processing camp, which was located inside the the Valley of the Candles Flora and Fauna Protection Area [Área de Protección de Flora y Fauna Valle de los Cirios]. Authorities arrested four adults and two minors at the processing camp, for a total of eight arrests, and seized 137 kg of *I. fuscus* along with the fishing vessels (Milenio 2015). Another camp was found operating in this same protected area by PROFEPA, Ministry of National Defence [Secretaría de la Defensa Nacional] (SEDENA), and SEMAR officers on 15 June 2017. On this occasion, authorities seized 256 *I. fuscus* from what they described as an abandoned camp (Government of Mexico 2017a). Federal and state authorities raided and dismantled an illicit sea cucumber processing facility on the remote island of Jaina on 4 March 2016. The island, which is home to an important Maya archaeological site, is located in a poorly accessible corner of Los Petenes–Ría Celestún National Park in Campeche. The authorities disrupted processing operations, and while the perpetrators fled into the park, 144.94 kg of dried, and 191.42 kg of unprocessed, *H. floridana* were seized, along with processing equipment, vehicles and coolers (El Sol De México 2016).

Such sites are ideal for clandestine sea cucumber processing because they are away from prying eyes and offer numerous avenues of escape. Because they are set up in remote locations, poachers can use lookouts and other intelligence assets to tip them off about law enforcement activities in advance of possible raids. According to the local fishing chief in the port of Celestun, Yucatan, poachers have a hidden landing site guarded by armed men. Any person not in association with them might be at risk if approaching the site, with the exception of "gavioteras". Gavioteras (seagulls) are women who approach fishers when they land and offer to do work (such as cleaning the vessel) in exchange for fish or sea cucumbers. Gavioteras can also serve as intelligence and information assets for illicit sea cucumber operations. These women convey valuable information to poachers about the fishing activities and business operations of cooperatives and/or private fishing companies (interview with author, June 2019). On the other hand, Bennett and Basurto (2018:65) report how "a group of women from Celestún, many of whom were wives of co-op members, undertook monitoring efforts to search for temporary camps where patrons were processing sea cucumber either without a permit or outside of the legal season". After locating a camp, the women would report them to the authorities. These efforts were later disrupted by patrons paying bribes to some of the women to alert them as to when monitoring activities were planned. As a result, suspicion within groups led to their disintegration. Adequately monitoring for illegal activities in lightly populated and remote protected areas and parks will remain a challenge for Mexican law enforcement.

Sea cucumbers were typically transported by private vehicle (see for example Huard 2020), or commercial transport vehicle (see Government of Mexico 2017b; El Vigia 2014), and when they were being carried across the border, they might be concealed in a space tire, within hidden coolers or compartments, or concealed among cover products such as licit marine products (Adams 2014; Government of Mexico 2013a; Gore and Bennett 2021:7; Alvarado et al. 2016). While transport typically involved a single vehicle or multiple commercial trucks, on one occasion, smugglers appeared to be employing countermeasures to protect their shipment from the scrutiny of authorities. On 10 October 2013, Federal Police stopped a truck carrying 4014 kg of sea cucumbers in Cancun, Quintana Roo. At the same time, the police also stopped another vehicle that was apparently operating as a "blocker car". The sea cucumbers were seized and both drivers were arrested (Government of Mexico 2013c).

Corruption was a common feature of many incidents. A number of academic studies report rumours that bribes are "paid to authorities allowed transportation and commercialization of undocumented sea cucumber" (Bennett and Basurto 2018:64; and see Kaplan-Hallam et al. 2017). The payment of bribes at road stops to avoid trouble is common (Pedroza-Gutiérrez and López-Rocha 2021). For example, on 27 March 2019, a transport truck carrying 1500 kg of sea cucumbers was stopped by Federal Police in the verification area at Merida Airport in Yucatan. A newspaper story covering the incident alleged corruption on the part of local customs officials (Grillo de Yucatán 2019). This same news story noted that a previous deputy administrator for customs in Progreso in Yucatan resigned due to allegations of corruption, and that this individual was still running a protection racket relating to customs (Grillo de Yucatán 2019). Allegations of corruption extend beyond officers in the field, and high-ranking officials have been accused of corruption. In an interview with *VICE*, Mexican Senator Daniel Ávila Ruiz accused state and federal authorities of being part of the mafia (Escalante Rosado 2018).

The level of sophistication and organisation of illicit sea cucumber operations appears to be considerable, observable throughout the illicit sea cucumber supply chain. Criminals operate their own fleets of vessels, processing and drying facilities, warehousing, and transport networks, armed security for shipments, and employ bribery, corruption and false documentation to facilitate the flow of their illicit products.

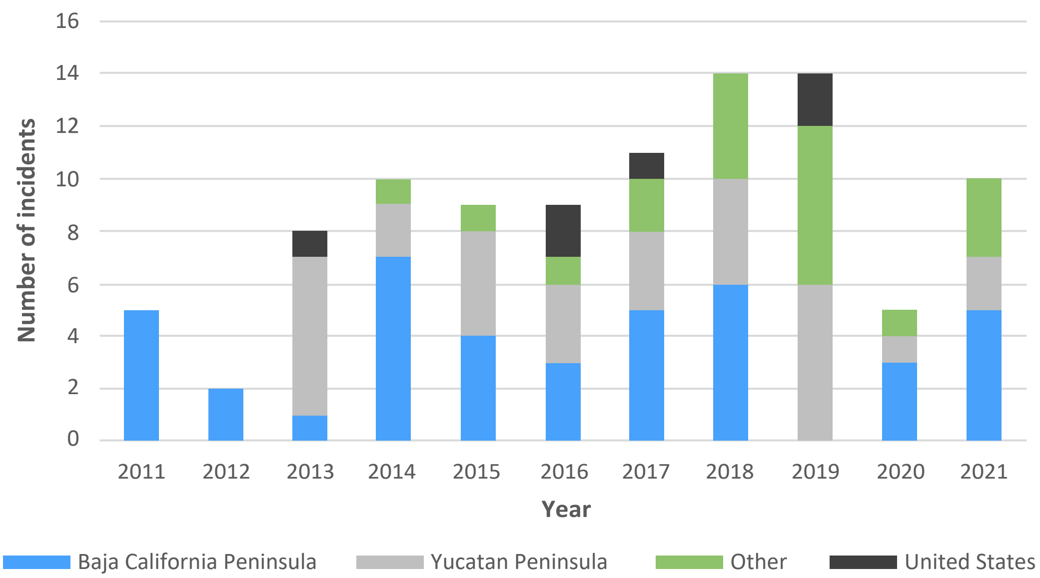


Figure 1. Number of incidents of sea cucumber crime by region, 2011–2021.

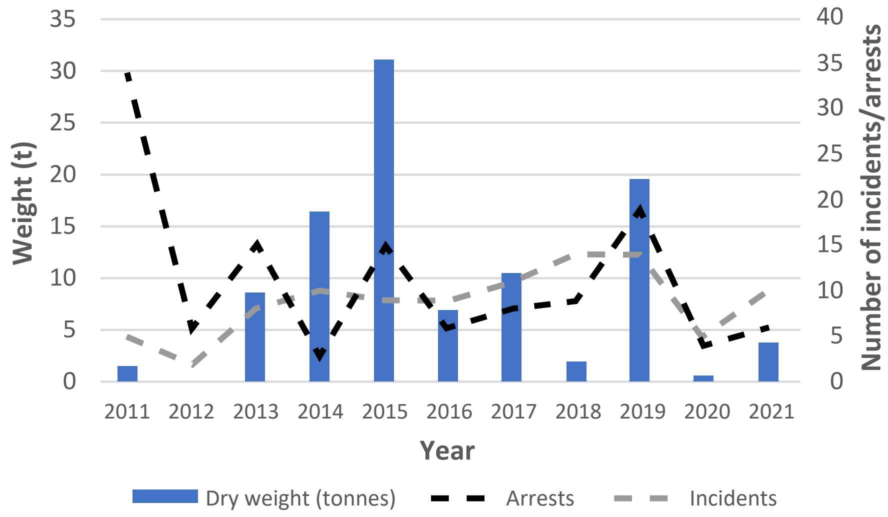


Figure 2. Weight (dry) of sea cucumbers seized, and the number of arrests and incidents, 2011–2021.

Documented arrests

The average number of people arrested per incident was 1.3 but ranged between 0 and 24, with a mode of 0. The number of incidents and arrests that occurred in the United States (4) have been excluded from Table 2. In addition to arrests, authorities seized 15 boats, along with a variety of equipment (e.g. fishing gear, dive equipment) (Table 1). The seizure of boats is significant, as boats are heavily relied on by fishers to harvest marine wildlife. Oftentimes, asset forfeiture is one punitive tool used by law enforcement. Given the number of incidents, the number of boats seized appears low, although arrests on active fishing vessels were less common, occurring on only eight occasions. It should be noted that these incidents resulted in a larger number of arrests (an average 7.6 arrests per incident).

Arrests on land were recorded in 34 out of 97 incidents, and when arrests occurred on land, an average of 1.9 people were arrested. Overall, 64 (51.2%) arrests occurred on land and 61 (48.8%) occurred on active fishing vessels. Thus, while rare, at-sea interdictions tended to result in more arrests than land-based incidents, which is consistent with the fact that it takes more personnel to operate an active fishing vessel than to transport illicit cargo in a vehicle or stockpile sea cucumbers in a warehouse. By far the largest number of arrests resulting from one incident took place on 22 September 2011, when a joint operation of PROFEPA, SEMAR and the Attorney General's Office arrested 24 fishers in seven vessels, along with 387 kg of illegally caught *I. fuscus* in the Calamajué fishing ground, off the coast of Ensenada in Baja California (El Vigia 2011) (Fig.2).

Given the number of people involved in both sea- and land-based operations, it is apparent that sea cucumber operations are coordinated, and that most would meet international definitions of organised crime (see Phelps Bondaroff et al. 2015). The United Nations Convention against Transnational Organized Crime, for example, defines an organised crime group as:

> a structured group of three or more persons, existing for a period of time and acting in concert with the aim of committing one or more serious crimes or offences established in accordance with this Convention, in order to obtain, directly or indirectly, a financial or other material benefit (United Nations General Assembly 2000:2(a)).

The number of arrests per incident is low when compared to incidents in India and Sri Lanka, where an average of four people were arrested per incident (Phelps Bondaroff 2021). This can be partially explained by the fact that many of the incidents involved the seizure of shipments at airports and from transport trucks. In these incidents, the general practice is that products are seized, but the driver(s) of the vehicle was not often arrested, likely owing to the fact that many of the truck drivers or shipping company staff were unaware of the nature of the cargo they were transporting. For example, on 28 May 2019, Federal Police seized 44 boxes of sea cucumber from the cargo hold of a commercial aeroplane at the Mexico City International Airport. The boxes contained 1,041 kg of dried sea cucumber from Merida, Yucatan (Government of Mexico 2019b).

Most incidents (45%) occurred in the region of the Baja California Peninsula sea cucumber fishery (Baja California (41%) and Baja California Sur (4%), while 34% of incidents occurred on the Yucatan Peninsula: Yucatan (25%), Quintana Roo (6%) and Campeche (3%) (Figs. 1 and 3). Mexico City was also another major location for incidents, comprising 8% of incidents (combined with "Other" category in Fig. 3). It is noteworthy that despite the Yucatan Peninsula comprising 34% of sea cucumber crime incidents, this region constituted 71% of the overall weight of sea cucumber seized; whereas the Pacific and Baja California comprised

45% of incidents constituting 12% of overall weight of sea cucumbers seized. This is likely explained by the fact that sea cucumber populations in the Baja California Peninsula were already depleted prior to the time frame studied.

The transportation and storage method was identified in 92 of 97 incidents (94.8%), with 2 incidents not fitting our categories and thus having been excluded from the following numbers. The most common mode of transportation was "vehicle", representing 31 out of 90 (34.4%) of incidents, followed by "air" (17 or 18.8%) and "shipping vessels" (3 instances or 3.3%). The number of instances where fishing vessels were interdicted (11 or 12.2%) was low by contrast. This reflects the challenges faced by law enforcement when trying to monitor large maritime areas. Rather than focusing monitoring and enforcement at sea, it appears as though Mexican law enforcement relies more heavily on land-based actions, specifically road blocks. Seizures occurred in private storage facilities (e.g. warehouses, wineries, private homes) on 20 occasions (22.2%), and these are explored in more detail below.

While many arrests were reported, there were few news stories about prosecution, conviction and sentencing. News stories and government press releases would often include mention of the maximum fines and sentences associated with the reported crimes, and a handful of incidents detailed court proceedings (see for example Adams 2014), but follow-up stories noting the actual punishments levied were rare. Actual sentences for criminals successfully prosecuted for sea cucumber-related crimes were only recorded in eight incidents. One incident was that of Alan Ren, a United States citizen and owner of two Chinese restaurants in New York. He and his girlfriend, Wei Wei Wang, a Taiwanese woman, were arrested by United States authorities at the San Ysidro Port of Entry in February 2016 with 78 kg of dried sea cucumber and 37.6 kg of frozen black abalone in a suitcase. Ren ultimately pled guilty. He was sentenced to 10 months in prison, and was required to pay a USD 7500 fine and USD 16,600 in restitution to Mexico. Wang was ultimately acquitted on four charges, including smuggling and the unlawful importation of wildlife (see Government of Mexico 2018; Davis 2018; Fox 5 2017).

In another incident from the United States, former Border Patrol Agent Cesar Daleo was given concurrent sentences of 30 and 24 months, respectively, for his role in fentanyl and sea cucumber smuggling conspiracies. The US Attorney's Office claimed that Daleo had paid someone to smuggle *I. fuscus* into the US at least 80 times between 2014 and 2016. He was also charged with conspiring to distribute 4-anilino-N-phenethyl-4-piperidine (4ANPP), a primary ingredient in fentanyl. Daleo was initially apprehended on 29 August 2017 when trying to enter the US from Mexico with a package containing what he believed to be 4ANPP. US Customs and Border Protection had previously intercepted the package sent from China at the Los Angeles International Airport, and replaced the 4ANPP with a harmless substance, before sending it back in transit, to the post office in San Ysidro, from whence Daleo recovered it. Daleo had worked as a border agent for 11 years, and was allegedly the leader of a larger network, which was under investigation and being surveilled by authorities (Alvarado 2018; Avitabile 2019). In one other incident, a federal judge in San Diego in the US, sentenced Claudia Castillo, a Mexican citizen from Tijuana, to eight months in prison and ordered her to pay USD 12,000 in restitution to the Mexican government for smuggling sea cucumbers from San Ysidro into the US in 2018 and 2019. The estimated value of the sea cucumbers Daleo smuggled exceeded USD 250,000 (Associated Press 2020; Pozzi 2021).

Despite two of the aforementioned incidents featuring women, the vast majority of people arrested for sea cucumber poaching, smuggling and related crimes in Mexico according to media coverage were men. We know women can assume a number roles in wildlife crime, and also in fisheries governance (e.g. Agu and Gore 2020), including offenders, victims, defenders and influencers. At the same time, it is well documented that women's role along the fisheries value chain is mostly concentrated in processing and transformation activities, and it is still rare to see a fisherwoman (Pedroza-Gutiérrez 2019). The lack of media coverage about the roles of women in sea cucumber crime in Mexico is noteworthy, although it is beyond the scope of our data to determine why the roles of women are not being more comprehensively profiled in the media.

Another feature of incidents where sentences were reported was the modest value of the fines levied and light prison sentences. In addition to the preceding, incidents where fines were reported included the following.

- In February 2020, a fisher from Progreso in Yucatan, was sentenced to 11 months in prison and ordered to pay a fine of MXN 14,681 (~USD 787), after he was caught with 154.1 kg of sea cucumbers in his fishing vessel (ProgresoHoy 2020).
- In January 2020, a court in Yucatan sentenced a man to one year in prison and a fine of MXN 24,260 (~USD 1287), and MXN 154,534 (~USD 8,200) after he was caught illegally transporting 572.35 kg of dried *H. floridana*, while on a suspended sentence for a previous sea cucumber smuggling offence (Diario de Yucatán 2020; Rompecabeza 2020).
- John Jaimes Torres, a Tijuana resident, was given a six-month prison sentence and ordered to pay USD 10,000 in restitution to the Mexican government for attempting to smuggle 136 kg from Mexico into the United Stataes in his truck at the Otay Mesa Port of Entry in 2019. News articles noted that the value of the sea cucumbers exceeded USD 60,000 (Huard 2020).

One feature that is apparent in all of these incidents is the discrepancy between the value of the smuggled goods and the fines and restitution levied. It is the case, as with many forms of wildlife crimes, that fines and punishments are lower than the value of the seized cargo, and low as compared with punishments handed out for smuggling other illicit goods.

Weights of seizures

Between 1 January 2011 and 1 December 2021, authorities in Mexico and the United States seized 100,611 kg of illicit sea cucumbers (Table 1). The weight of seizures ranged from 0.3 kg to 12,000 kg, with the average weight of sea cucumbers seized per incident being 1037 kg. The largest individual seizure occurred on 31 March 2019, in which SEMAR and PGR officials seized 12,000 kg of sea cucumbers from a shipping container in Manzanillo, Colima and arrested two people. The shipment, which was destined for Shanghai, China was labelled as "peanuts", when it actually contained dried *H. mexicana* and *H. floridana* (Government of Mexico 2019a; Pinto 2019). We should also note that Federal Police seized 17,000 kg of dried *I. badionotus* at Cancun International Airport on 20 May 2015, but this was treated as two separate entries because 11 t were bound for Hong Kong, while 6 t were being shipped to Florida (United States) (Government of Mexico 2015a).

The greatest weights of sea cucumbers seized during our study period were those seized in 2015 (31,009.2 kg) and 2019 (19,642.6 kg) (Table 1, Fig. 2). We were only able to identify two seizures in 2012, both of which occurred in the US. The average size of individual seizures has been decreasing over time, since a peak in 2015 (Table 1), which is consistent with declines in sea cucumber populations over time. A similar downward trend is not quite as apparent with respect to arrests and incidents (Fig. 2). This suggests that while illegal fishing has continued after the closure of overexploited fisheries, the amount of sea cucumbers being extracted is on the decline, hence smaller shipments. A decline in the size of seizures could serve as an indicator of an overexploited fishery.

The majority of sea cucumbers, by weight, were seized in the Yucatan Peninsula (71%) at Yucatan (43%), Quintana Roo (26%) and Campeche (2%), while 12% of sea cucumbers by weight were seized in Baja California. The scale of seizures in the Yucatan Peninsula peaked in 2014, and has generally declined since this time (Fig. 3).

It is interesting to note the rise of Mexico City, and specifically the Mexico City International Airport, as a major exit point for illicit sea cucumbers in 2018 and 2019, and the site of arrests. Seizures in Mexico City were typically small (seven total, averaging 259 kg), with the average being lower as a result of a number of incidents involving individuals being caught attempting to smuggle small amounts of sea cucumber out in their personal luggage. This compares to incidents in Tijuana International Airport (5), where the average size of seizures was 123 kg, with weights ranging between 3.4 kg and 281 kg. In contrast, at Cancun International Airport in Quintana Roo there were four seizures, ranging between 2100 kg and 11,000 kg, with an average of 5438 kg. Similar to Tijuana International Airport, the Tijuana border crossing saw seizures that were considerably smaller than those at Cancun International Airport. The average size of the eight seizures that involved crossing the United States/Mexico Border at Otay May Port of Entry in Tijuana was 401 kg, with seizure sizes ranging from 0.8 kg to 1794.1 kg. This disparity reflects the tendency for the Yucatan fishery to have considerably larger weights involved in seizures.

It should be noted that sea cucumbers seized in one state does not necessarily mean the sea cucumbers originated from that state. Sea cucumbers transiting through the major export points – Cancun Airport, Merida Airport, the Port of Progreso, Mexico City and Tijuana – could have originated anywhere in Mexico. That being said, we found no instances involving the seizure of *H. floridana* or *H. mexicana* in Tijuana, and it would make little sense to transport sea cucumbers from Baja California or Yucatan to Quintana Roo for export.

Value of seizures

The total estimated value of Mexican sea cucumbers seized by authorities over the time period we examined was USD 29.5 million, of which all but USD 50,000 was seized by authorities in Mexico. The value of the average seizure was USD 304,608, and the most valuable seizure was USD 3.2 million. On 20 May 2015, Federal Police at customs at Cancun International Airport seized 11 tonnes of dried *I. badionotus*, destined for Hong Kong, with an estimated value of USD 3.2 million. On the same day, the Federal Police also seized 6 tonnes of dried *I. badionotus* destined for Florida in the US, with a value of USD 1.7 million, and a combined value of USD 4.9 million (Government of Mexico 2015a).

The value of the seized sea cucumbers is considerable, especially when we consider that this does not represent all of the illegally caught sea cucumbers; there is an unknown but not insignificant number of successful smuggling efforts. The value of seizures is also large when contrasted to the size of the legal sea cucumber fishery. Estimated values of annual Mexican sea cucumbers vary. According to CONAPESCA data quoted in one news story, between 2014 and 2018, 5736 t of sea cucumbers were caught in Mexico, with an estimated value on the beach of MXN 178.86 million (USD 9.32 million, 2018 dollars) (Pradilla 2019). Another news story quoted official data saying that the annual market value of Mexico's sea cucumber exports from 2014 to 2017 amounted to USD 126 million, or more than USD 30 million a year (Terrazas 2020). While these numbers are relatively imprecise, they throw into sharp relief the value of seized sea cucumbers, which amounts to at least USD 3 million a year, or at least 10% of the value of the annual legal catch.

Species

The species of sea cucumbers was identified in 47 out of 97 incidents, and in three incidents more than one species was reported. The most commonly trafficked species was *I. fuscus* (29 incidents total), followed by *I. badionotus* (12 incidents), *H. floridana* (6 incidents), and *H. mexicana* (3 incidents). It is interesting to note that there were no recorded seizures of *H. floridana* or *H. mexicana* prior to 2015 (Table 2).

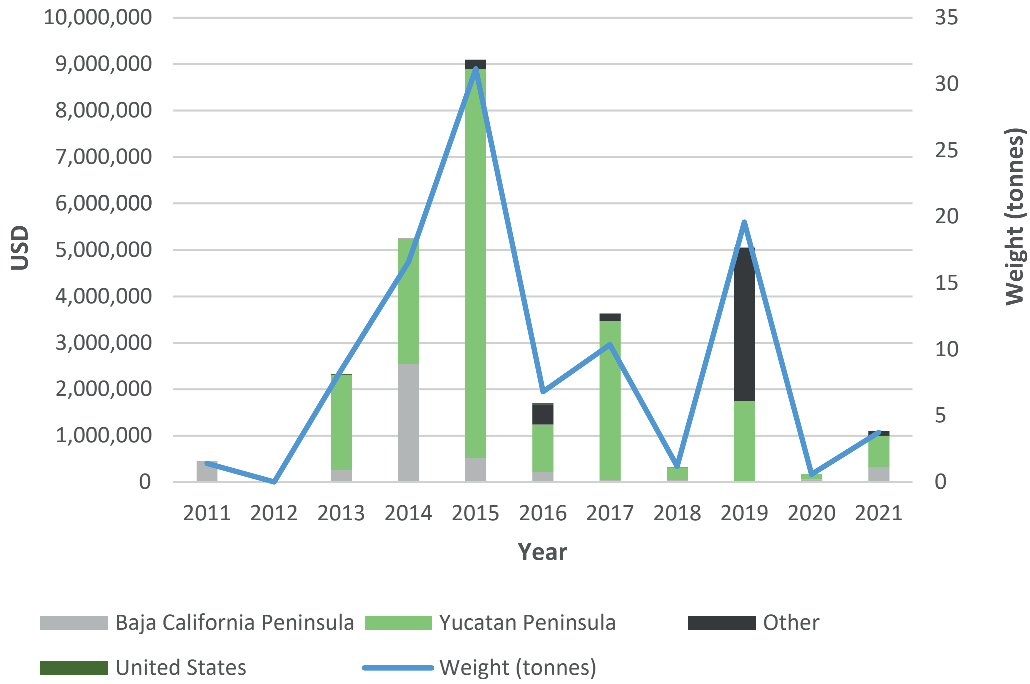


Figure 3. Value of seizures by region compared to dry weight (overall) by year, 2011–2012.

Sea cucumbers were found with other illicit commodities in 28 out of 97 incidents. The three most common categories were "marine products" (30), "live animals" (12), "drugs" (4) and "guns" (2). The most common marine species and/or products were seahorses (6), octopuses (4), totoaba (4), shark fins (4) and abalone (3). Live animals included baby crocodiles on two occasions, as well as tropical birds and other reptiles. Drugs included methamphetamines, marijuana, opioids, and precursors. In a majority of incidents (59%), when associated commodities were identified, they fell into the category of "marine products". This is consistent with the idea that clandestine networks are used to traffic a variety of products from different wildlife, as well as other illicit products. After all, many trafficked endangered species, such as abalone and totoaba, are even caught in similar locations by the same fishers, and sometimes using the same methods. It is too soon to draw any conclusions from the appearance of a number of recent incidents involving the seizure of live exotic animals such as turtles and baby alligators alongside dried marine products that have appeared in a number of more recent incidents (Novedades Yucatán 2021; Anaya 2021).

In the incidents involving drug seizures, the sea cucumbers appeared to be a minor component of the operation, and there were no instances of large amounts of sea cucumbers being found with large amounts of drugs or drug precursors. In November 2021, Michoacán Police in coordination with PGR, raided a home in Apatzingán that was being used to manufacture drugs for the United Cartel [Cárteles Unidos]. Along with 1 kg of fentanyl, authorities found a variety of precursors (e.g. acetone, caustic soda), cocaine, marijuana, and 2.5 kg of sea cucumbers (InfoBae 2021). Given the situation, it was clear that the focus of the criminal enterprise was drugs, although the presence of sea cucumbers certainly raises questions. In another incident, between 31 January and 2 February 2020, law enforcement in and around Ensenada in Baja California engaged in a series of raids. Over 72 hours, they arrested 505 people, including a significant number of individuals with outstanding warrants, and others for a variety of crimes, including burglary, theft and other property crimes, manslaughter, drug and firearms offences, and two instances of environmental crimes. At the same time, authorities seized a .22 calibre revolver, drug paraphernalia, and 18 sea cucumbers (El Vigia 2020). In this incident, the small number of sea cucumbers did not appear to be part of some broader smuggling operation. Finally, Federal Police seized 112 litres of liquid methamphetamine (labelled as paint thinner), along with 20 kg of sea cucumbers on 9 April 2018 (El Vigia 2018). Unfortunately, no additional details concerning this incident were available.

Geographic distribution

When all identified incidents are mapped, there are evident sea cucumber crime hotspots in Baja California Peninsula and the Yucatan Peninsula, which is consistent with these areas being the key sea cucumber fishing regions in Mexico. Also of note are a number of areas of concentration: in and around Merida, Yucatan and, to a lesser extent, Cancun; Tijuana, in Baja California, particularly the ground border crossings and airport; and Mexico City, specifically Mexico City International Airport (Fig. 4). Tijuana has consistently been a key point for exporting sea cucumbers, while Mexico City has only become a key exit point since 2018.

Mapping the number of incidents and weight seized by state over time revealed a number of interesting trends. The circles on the heat maps are all relatively proportional so that they represent the difference in scale of the total weight

Table 2: Species of Mexican sea cucumbers found in seizures, 2011–2021

Year	*I. badionotus*	*I. fuscus*	*H. floridana*	*H. mexicana*
2011	0	4	0	0
2012	0	0	0	0
2013	2	2	0	0
2014	2	2	0	0
2015	4	5	1	1
2016	0	4	2	1
2017	1	6	0	0
2018	2	5	1	0
2019	1	1	1	1
2020	0	0	1	0
2021	0	0	0	0
Total	**12**	**29**	**6**	**3**

Figure 4. Sea cucumber seizures across Mexico, 2011–2021.

(Fig. 4) or number of incidents (Fig. 6) of each region, over time. Due to limited number of seizures in Baja California Sur, we merged seizures from this state with Baja California, while this was not done for states on the Yucatan Peninsula because each state had a sufficient number of incidents to register on the maps. Note that each map represents two years, and that they begin with 2012, given that there were limited data for 2011.

These maps reveal how early incidents of sea cucumber crime began in Baja California, reaching their height in 2013 and 2014, after which time the majority of incidents shifted to states on the Yucatan Peninsula (Fig. 4). The number of incidents between regions is relatively similar, with the Baja fishery having 36 incidents and the Yucatan Peninsula fishery having 31 between 2012 and 2021 (Fig. 6). However, the heat maps (Figs. 5 and 6) also reveal a discrepancy between the two major sea cucumber fishing regions in Mexico, namely that while there may be a consistent number of incidents in the Baja California Peninsula, the scale of these incidents (by weight of sea cucumber seized) is considerably lower than seizures occurring on the Yucatan Peninsula. Seizures associated with the Baja California Peninsula fishery had an average weight of 316 kg (ranging between 0.3 kg and 2500 kg), and over all, authorities seized the equivalent of 11,832 kg of dry sea cucumber. On the Yucatan Peninsula in contrast, the average weight of sea all cucumbers seized per incident was considerably greater, at 2291 kg (ranging between 3.4 kg to 11,000 kg), which amounts to the equivalent of 71,015 kg of dry sea cucumber. The average weight of a seizure of sea cucumbers from the Yucatan Peninsula was 7.2 times greater than seizures from the Baja California Peninsula. This can be explained in part by the fact that sea cucumber populations in the Baja California Peninsula fishery are depleted such that it is no longer possible for poachers to extract large quantities, and by extension, large seizures are rare.

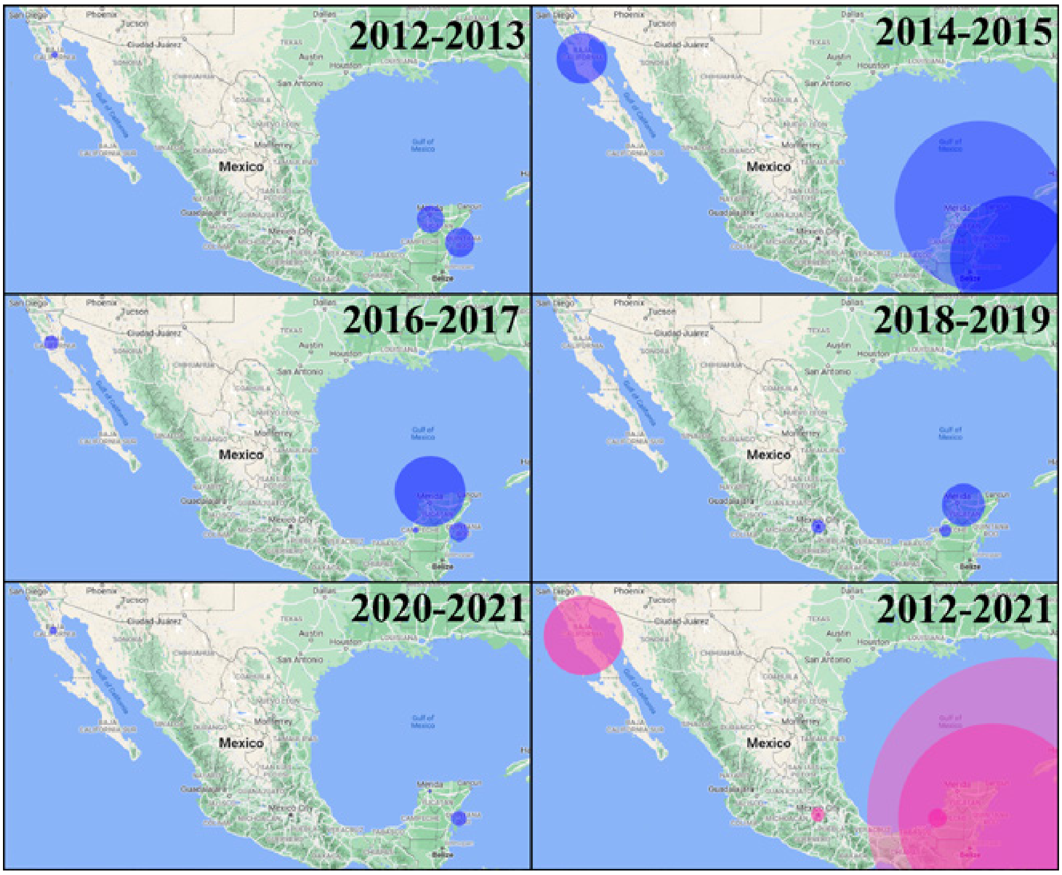


Figure 5. Heat maps of sea cucumber seizures in Mexico by weight (dry), 2012–2021.

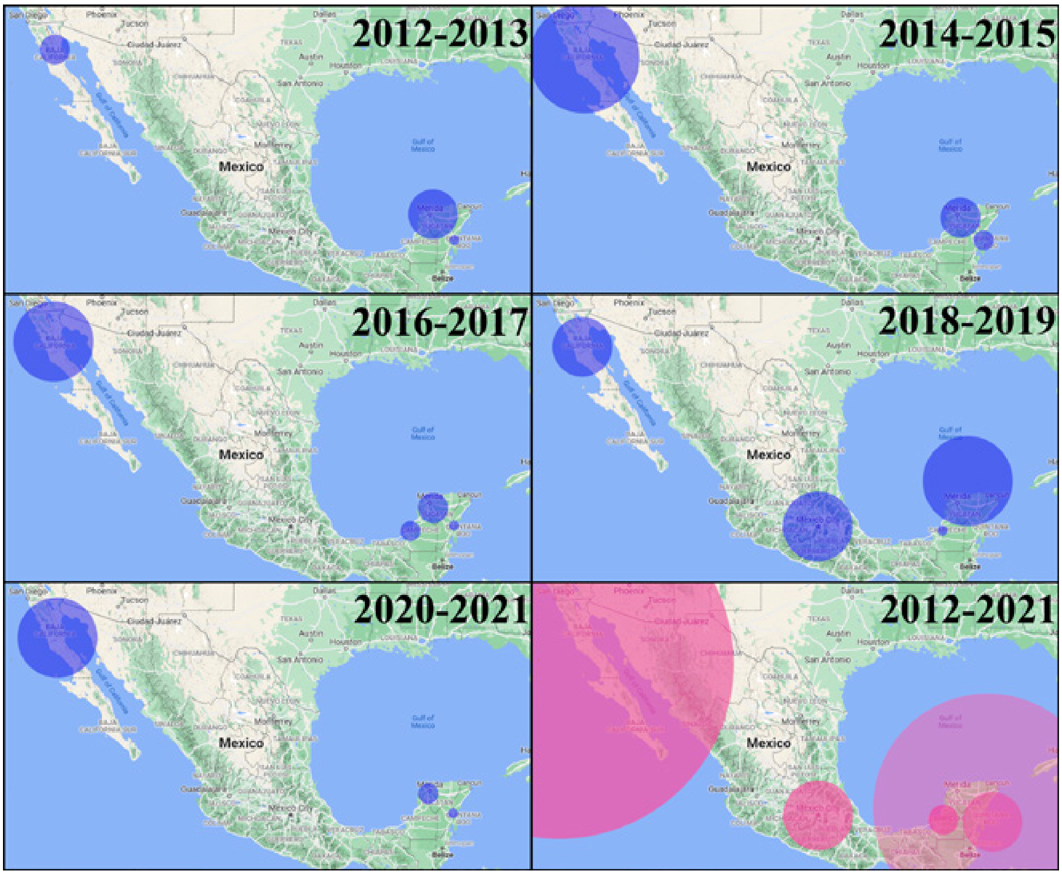


Figure 6. Heat maps of sea cucumber incidents in Mexico, 2012-2021.

Conclusion

Media coverage of sea cucumber poaching and smuggling operations in Mexico frames the crime as being organised and associated with armed violence. A brief survey of other instances of sea cucumber crime around the world over the same period yields few examples of armed violence, and yet we can see instances of violence sporadically throughout news coverage of Mexican sea cucumber fisheries. The stockpiling of illicitly caught sea cucumbers between seasons and the use of invoice manipulation and fraud to launder products is a practice that seems particularly adapted to the Mexican legal setting.

In other ways, sea cucumber crime in Mexico bears similarities to sea cucumber crime elsewhere (see for example Phelps Bondaroff 2021; Hakki and Aydin 2021): 1) we can observe clusters of seizures and incidents in and around key sea cucumber fishing areas; 2) illegal fishing constitutes a significant portion of catches, undermining management efforts and threatening the sustainability of sea cucumber populations; 3) there is a large discrepancy between the value of the smuggled goods and the fines and restitution levied; and 4) law enforcement faces challenges with monitoring and enforcement. One of the ways in which Mexican law enforcement has apparently sought to overcome monitoring and enforcement challenges is by targeting the ground transport of illicit sea cucumbers. Additional research linking seizures and/or incidents to changes in fisheries management policy and changes in law enforcement efforts and strategies would be informative, as would comparative research evaluating the efficiency and effectiveness of the approach adopted by Mexican law enforcement.

This study has relied on descriptive analysis, and additional approaches may facilitate the development of theories from these data and help us better understand sea cucumber crime. We found, for example, that the size of seizures shrank with declining sea cucumber populations and the closure of fisheries, suggesting that the declining size of seizures could serve as an indicator of declining wild populations. Ultimately, if we are to effectively combat this pernicious form of wildlife crime, more work is needed to increase our understanding of sea cucumber crime, not just in Mexico, but worldwide.

One of the secondary goals of this project was to demonstrate the effectiveness of using news media reports to study wildlife crime. The approach used in this paper has a number of strengths and drawbacks. It is particularly useful when official data are unavailable or undetailed as it helps provide insight beyond the report of raw seizure numbers, offering details as to the *modus operandi* of wildlife crime operations. In this way, this approach can help shed light on illicit and clandestine activities that might otherwise be very difficult to study. In addition to the limitations outlined, the approach ultimately relies on the issue under investigation being problematized to the extent that it receives media attention. Many forms of wildlife crime are treated as administrative issues and, as a result, do not receive extensive media coverage. Thus, it is likely that our approach did not capture those incidents of sea cucumber crime that were considered "commonplace" or "routine". Similarly, as an issue becomes increasingly problematized, such as when wild populations of sea cucumbers become depleted or when criminals employ violence, we are likely to see an increase in media attention and news stories. As such, an increase in the number of incidents recorded through our approach may not indicate an increase in wildlife crime, or even an increase in police attention to wildlife crime, but more so an increase in media coverage, and by extension public concerns over wildlife crime.

There are also limitations with respect to mapping incidents gleaned from media stories. Many of the news stories used in this study documented the point of seizure of sea cucumbers and not their point of extraction or the final destination. This approach affords us a snapshot of various stages of illicit sea cucumber supply chains but does not necessarily provide a clear picture of the entire chain. Additional qualitative research could help increase understanding of the nature of sea cucumber crime in Mexico. Our approach is a helpful tool to identify concentrations of wildlife crime and *modus operandi*, and when employed in conjunction with other approaches, such as rich qualitative interviews that add nuance and detail, could further increase our knowledge of illicit sea cucumber supply chains. It would also be informative to employ this method to investigate other forms of wildlife crime. Ultimately, better understanding and knowledge will help combat wildlife crime.

Acknowledgements

The authors would like to thank Vanessa Ultreras for her assistance with data collection, as well as Darrell Gurevitch, and Stan Phelps for his help with editing.

References

Acosta E.J., Rodríguez-Forero A., Werding B. and Kunzmann A. 2021. Ecological and reproductive characteristics of holothuroids Isostichopus badionotus and Isostichopus sp. in Colombia. PLoS One 16(2):e0247158. https://doi.org/10.1371/journal.pone.0247158

Adams A. 2014. Man admits to smuggling sea cucumbers. NBC San Diego. Retrieved from Web 25 Dec. 2021. https://www.nbcsandiego.com/news/local/man-admits-to-smuggling-sea-cucumbers/1972273/

Agu H.U. and Gore M.L. 2020. "Women in wildlife trafficking in Africa: A synthesis of literature. Global Ecology and Conservation 23:e01166. https://doi.org/10.1016/j.gecco.2020.e01166

Alvarado E., Estrata A.M. and Melgoza A. 2016. Arrasan con manjar mexicana. El Universal. Retrieved from Web 25 Dec. 2021, https://www.eluniversal.com.mx/articulo/periodismo-de-investigacion/2016/03/6/mafia-china-arrasa-con-pepino-de-mar

Alvarado Matrínez I. and Martínez E.R. 2018. Trafficking of totoaba maw. p.149–170. In: Green crime in Mexico: A collection of case studies. Arroyo-Quiroz, I., and Wyatt, T. (eds). Switzerland: Palgrave Studies in Green Criminology.

Alvarado I. 2018. Así fue cómo un exagente fronterizo lideró una red de tráfico de una extraña especie marina. Univision, Los Angeles. Retrieved from Web 25 Dec. 2021 https://www.univision.com/local/los-angeles-kmex/asi-fue-como-un-exagente-fronterizo-lidero-una-red-de-trafico-de-una-extrana-especie-marina

Anaya F. 2021. FGR detuvo a tres personas con animales marinos en peligro de extinción. Retrieved from Web 25 Dec. 2021, https://www.tvazteca.com/aztecanoticias/fgr-detuvo-perconas-animales-marinos-peligro-extincion-mm

Anderson S.C., Mills Flemming J., Watson R. and Lotze H.K. 2011. Serial exploitation of global sea cucumber fisheries. Fish and Fisheries 12(3):317–339. https://doi.org/10.1111/j.1467-2979.2010.00397.x

Ángeles Rivero, M.d.R. 2018. Decomisan más de una tonelada de pepino de mar en Campeche. Televisa.News. Retrieved from Web 16 Dec. 2021, https://noticieros.televisa.com/ultimas-noticias/decomisan-mas-mil-kilos-pepino-mar-campeche/

Associated Press. 2020. Woman who smuggled endangered sea cucumbers from Mexico into San Diego sentenced to 8 months in prison. KT LA. Retrieved from Web 25 Dec. 2021, https://ktla.com/news/local-news/woman-who-smuggled-endangered-sea-cucumbers-from-mexico-into-san-diego-sentenced-to-8-months-in-prison/

Avitabile R. 2019. Former BP agent sentenced for smuggling sea cucumber, fentanyl precursor. NBC, San Diego. Retrieved from Web 25 Dec. 2021, https://www.nbcsandiego.com/news/local/former-bp-agent-sentenced-for-smuggling-sea-cucumber-fentanyl-precursor/133337/

BCS Noticias. 2021. Detienen a sujeto con producto marino, sustraído de forma ilegal, en Loreto. Retrieved from Web 22 Dec. 2021, https://www.bcsnoticias.mx/detienen-a-sujeto-con-producto-marino-sustraido-de-forma-ilegal-en-loreto/

Bennett A. 2017. The influence of neoliberalization on the success and failure of fishing cooperatives in contemporary small-scale fishing communities: A case study from Yucatán, Mexico. Marine Policy 80:96–106. https://doi.org/10.1016/j.marpol.2016.06.024

Bennett A. and Basurto X. 2018. Local institutional responses to global market pressures: The sea cucumber trade in Yucatán Mexico. World Development 102:57–58. https://doi.org/10.1016/j.worlddev.2017.09.006

Borbolla D. 2021. Aseguran productos pesqueros en Tijuana y Ensenada. TV Azteca. Retrieved from Web 25 Dec. 2021, https://www.tvazteca.com/aztecanoticias/aseguran-productos-pesqueros-tijuana-ensenada-mg

Busilacchi S., Butler J.R.A., Rochester W.A. and Posu J. 2018. Drivers of illegal livelihoods in remote transboundary regions: the case of the Trans-Fly region of Papua New Guinea. Ecology and Society 23(1):46. https://doi.org/10.5751/ES-09817-230146

Cakaunivere Walesi T. 2016. Overfishing sea cucumbers: The demise of sea cucumbers in Vanua Balavu, Fiji Islands: Review from green criminological perspective and outlook on future policy measures. Thesis report. Retrieved from Web 25 Dec. 2021, https://www.researchgate.net/publication/323943731_Overfishing_Sea_Cucumbers_The_Demise_of_Sea_Cucumbers_in_Vanua_Balavu_Fiji_Islands_Review_from_Green_Criminological_Perspective_and_outlook_on_future_policy_measures

Calderon-Aguilera L.E. 2019. Illegal fishing of the sea cucumber Isostichopus fuscus is rampant in the Gulf of California, Mexico. SPC Beche-de-mer Information Bulletin 39:42–46. http://www.spc.int/DigitalLibrary/Doc/FAME/InfoBull/BDM/39/BDM39_42_Calderon.pdf

Chavarría J.L. 2018. Reportan menor cantidad de pepino de mar decomisado. Peninsular. Retrieved from Web 19 Dec. 2021, https://puntomedio.mx/reportan-menor-cantidad-de-pepino-de-mar-decomisado/

Chen J. 2003. Overview of sea cucumber farming and sea ranching practices in China. SPC Beche-de-mer Information Bulletin 18:18–23.

Chi Segovia J. 2016. Desmantelan en Campeche campamento de pepino de mar. El Solde Mexico. Retrieved from Web 16 Dec. 2021. https://www.elsoldemexico.com.mx/republica/Desmantelan-en-Campeche-campamento-de-pepino-de-mar-164426.html

Cisneros-Montemayor A.M., Cisneros-Mata M.A., Harper S. and Pauly D. 2013. Extent and implications of IUU catch in Mexico's marine fisheries. Marine Policy 39(1):283–88. https://doi.org/10.1016/j.marpol.2012.12.003

CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora). 2014. Twenty-seventh meeting of the Animals Committee, Veracruz (Mexico), 28 April – 3 May 2014. Retrieved from Web 24 Dec. 2021. https://cites.org/sites/default/files/eng/com/ac/27/E-AC27-26-05.pdf

Conand C. 2018. Recent information on worldwide illegal fisheries for sea cucumbers. SPC Beche-de-mer Information Bulletin 38:68–71.

Coomber R., Morris C. and Dunn L. 2000. How the media do drugs: quality control and the reporting of drug issues in the UK print media. International Journal of Drug Policy 11(3):217–225. https://doi.org/10.1016/S0955-3959(00)00046-3

Davis K. 2018. Restaurateur gets prison, girlfriend acquitted in sea cucumber-smuggling case. Los Angeles Times. Retrieved from Web 25 Dec. 2021. https://www.latimes.com/local/lanow/la-me-sea-cucumber-smuggling-20180215-story.html

De Jesús-Navarrete A.D., May-Poot M.N. and Medina-Quej A. 2018. Density and population parameters of sea cucumber Isostichopus badionotus (Echinodermata: Stichopodidae) at sisal, Yucatan. Latin American Journal of Aquatic Research 46(2):416–423. https://doi.org/10.3856/vol46-issue2-fulltext-17

Department of Justice. 2017. Three charged with illegal trafficking of $17 million worth of sea cucumbers. US Attorney's Office, Southern District of California. Retrieved from Web 19 Dec. 2021. https://www.justice.gov/usao-sdca/pr/three-charged-illegal-trafficking-17-million-worth-sea-cucumbers

Diario de Yucatán. 2019. Aseguran tres toneladas de pepino de mar en predios de Mérida. Retrieved from Web 2015 Dec. 2021. https://www.yucatan.com.mx/merida/aseguran-tres-toneladas-de-pepino-de-mar-en-predios-de-merida

Diario de Yucatán 2020. Condenan a tres por delitos federales en Yucatán. Retrieved from Web 25 Dec. 2021. https://www.yucatan.com.mx/merida/condenan-a-tres-por-delitos-federales-en-yucatan

DOF (Diario Oficial de la Federación). 2010. Norma Oficial Mexicana NOM-059-SEMARNAT-2010, Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo. Diario Oficial de la Federación, 30 Dec. 2010. Órgano del Gobierno Constitucional de los Estados Unidos Mexicanos. Retrieved from Web 25 Dec. 2021. https://dof.gob.mx/nota_detalle_popup.php?codigo=5173091

DOF. 2015. Acuerdo por el que se da a conocer el plan de manejo pesquero de pepino de mar café (Isostichopus badionotus) y lápiz (Holothuria floridana) en la península de Yucatán. Diario Oficial de la Federación. 12 May 2015. Órgano del Gobierno Constitucional de los Estados Unidos Mexicanos. Retrieved from Web 25 Dec. 2021. http://www.dof.gob.mx/nota_detalle.php?codigo=5391774&fecha=12/05/2015

DOF. 2019. Modificación del Anexo Normativo III, Lista de especies en riesgo de la Norma Oficial Mexicana NOM-059-SEMARNAT-2010, Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo, publicada el 30 de diciembre de 2010. Diario Oficial de la Federación, 14 Nov. 2019. Órgano del Gobierno Constitucional de los Estados Unidos Mexicanos. Retrieved from Web 25 Dec. 2021. https://www.dof.gob.mx/nota_detalle.php?codigo=5578808&fecha=14/11/2019

El Financiero. 2019. Detienen a 4 personas en Celestún por posesión de especies marítimas en veda. Retrieved from Web 25 Dec. 2021. https://www.elfinanciero.com.mx/peninsula/detienen-a-4-personas-en-celestun-por-posesion-de-especies-maritimas-en-veda/

El Sol De México. 2016. Desmantelan en Campeche campamento de pepino de mar. Retrieved from Web 25 Dec. 2021. https://www.elsoldemexico.com.mx/republica/Desmantelan-en-Campeche-campamento-de-pepino-de-mar-164426.html

El Vigia. 2011. Detienen a 24 pescadores. Retrieved from Web 22 Dec. 2021. https://www.elvigia.net/el-valle/2011/9/24/detienen-pescadores-56778.html

El Vigia. 2014. Decomisa especies protegidas. Retrieved from Web 25 Dec. 2021. https://www.elvigia.net/911/2014/12/22/decomisa-especies-protegidas-182248.html

El Vigia. 2018. Decomisan metanfetaminas y pepino de mar. Retrieved from Web 16 Dec. 2021. https://www.elvigia.net/911/2018/4/9/decomisan-metanfetaminas-pepino-300672.html

El Vigia. 2020. Agarra la Policía a 505 en tres días. Retrieved from Web 22 Dec. 2021. https://www.elvigia.net/911/2020/2/5/agarra-la-policia-505-en-tres-dias-343173.html

Escalante Rosado J. 2018. El mercado negro de pepinos de mar en Yucatán. Excelsior. Retrieved from Web 18 Dec. 2021. https://www.excelsior.com.mx/nacional/el-mercado-negro-de-pepinos-de-mar-en-yucatan/1229783

Expreso. 27 February 2018. La PGR detiene a 2 personas y aseguran 41 kilos de pepino de mar en Guaymas. Retrieved from Web 25 Dec. 2021. https://www.expreso.com.mx/seccion/seguridad/32546-agentes-de-la-pgr-detienen-a-2-personas-y-aseguran-41-kilos-de-pepino-de-mar-en-guaymas.html

Fahrenbruch M.L. 2018. 'Like scooping money out of the sea': Chinese luxury seafood consumption, roving bandits, and the book-and-bust jellyfish fishery on the Miskitu Coast of Nicaragua. Journal of Latin American Geography 17(2):209–238. http://dx.doi.org/10.1353/lag.2018.0028

Fox 5. 2017. Restaurant owner admits smuggling abalone, sea cucumber from Mexico. Retrieved from Web 25 Dec. 2021. https://fox5sandiego.com/news/restaurant-owner-admits-smuggling-abalone-sea-cucumber-from-mexico/

Gamboa-Álvarez M.Á., López-Rocha J.A., Poot-López G.R., Aguilar-Perera A. and Villegas-Hernández H. 2020. Rise and decline of the sea cucumber fishery in Campeche Bank, Mexico. Ocean and Coastal Management 184:105011. https://doi.org/10.1016/j.ocecoaman.2019.105011

Glockner-Fagetti A., Calderon-Aguilera L E. and Herrero-Perezrul M.D. 2016. Density decrease in an exploited population of brown sea cucumber Isostichopus fuscus in a biosphere reserve from the Baja California peninsula, Mexico. Ocean and Coastal Management 121:49–59. https://doi.org/10.1016/j.ocecoaman.2015.12.009

Gore M.L. and Bennett A. 2021. Importance of deepening integration of crime and conservation sciences. Conservation Biology, advance online publication, 6.

Gore M.L. and Knuth B.A. 2009. Mass media effect on the operating environment of a wildlife-related risk-communication campaign. Journal of Wildlife Management 73(8):1407–1413. https://doi.org/10.2193/2008-343

Gore M.L., Siemer W.F., Shanahan J.E., Shuefele D. and Decker D.J. 2005. Effects on risk perception of media coverage of a black bear-related human fatality. Wildlife Society Bulletin 33(2):507–516. https://doi.org/10.1080/10871200902856138

Govan H. 2019. 2018 market price update for beche-de-mer in Melanesian countries. SPC Fisheries Newsletter 158:16–20.

Government of Mexico. 2013a. Asegura Profepa millonario cargamento ilegal de pepino duro de mar, hipocampos y buche de totoaba. Retrieved from Web 21 Dec. 2021. https://www.profepa.gob.mx/innovaportal/v/5078/1/mx.wap/asegura_profepa_millonario_cargamento_ilegal_de_pepino_duro_de_mar__hipocampos_y_buche_de_totoaba.html

Government of Mexico. 2013b. Asegura Conapesca diversas cantidades de pepino de mar en Yucatán. Retrieved from Web 17 Dec. 2021. https://www.gob.mx/conapesca/prensa/asegura-conapesca-diversas-cantidades-de-pepino-de-mar-en-yucatan?idiom=es

Government of Mexico. 2013c. Policía Federal asegura más de cuatro toneladas de pepino de mar en Quintana Roo. Retrieved from Web 16 Dec. 2021. https://www.gob.mx/policiafederal/prensa/policia-federal-asegura-mas-de-cuatro-toneladas-de-pepino-de-mar-en-quintana-roo

Government of Mexico. 2014. Asegura Profepa en Baja California 10,852 piezas de pepino de mar. PROFEPA. Retrieved from Web 25 Dec. 2021. http://www.profepa.gob.mx/innovaportal/v/5895/1/mx/asegura_profepa__en_baja_california__10_852_piezas_de_pepino_de_mar.html

Government of Mexico. 2015a. Asegura Policía Federal 17 toneladas de pepino de mar en el aeropuerto de Cancún, Quintana Roo. Retrieved from Web 16 Dec. 2021. https://www.gob.mx/policiafederal/prensa/asegura-policia-federal-17-toneladas-de-pepino-de-mar-en-el-aeropuerto-de-cancun-quintana-roo

Government of Mexico. 2015b. Asegura PROFEPA dos y media toneladas de pepino de mar en Baja California. Retrieved from Web 16 Dec. 2021. http://www.profepa.gob.mx/innovaportal/v/6000/1/mx/asegura_profepa_dos_y__media_toneladas__de_pepino_de_mar_en_baja_california.html

Government of Mexico. 2015c. Autoridades federales aseguran un contenedor con 11 toneladas de pepino de mar en Yucatán. Retrieved from Web 16 Dec. 2021. https://www.gob.mx/conapesca/prensa/autoridades-federales-aseguran-un-contenedor-con-11-toneladas-de-pepino-de-mar-en-yucatan-20473

Government of Mexico. 2016a. Dicta juez federal auto de formal prisión a 1 persona por posesión ilegal de 58,115 ejemplares de pepino de mar, en Baja California. Retrieved from Web, 31 Dec. 2021. https://www.gob.mx/profepa/prensa/dicta-juez-federal-auto-de-formal-prision-a-1-persona-por-posesion-ilegal-de-58-115-ejemplares-de-pepino-de-mar-en-baja-california

Government of Mexico. 2016b. CONAPESCA y PF Aseguran tonelada y media de Pepino de Mar en el Aeropuerto de Guadalajara. Retrieved from Web 16 Dec. 2021. https://www.gob.mx/conapesca/prensa/conapesca-y-pf-aseguran-tonelada-y-media-de-pepino-de-mar-en-el-aeropuerto-de-guadalajara

Government of Mexico. 2016c. Contribuye SAGARPA en aseguramiento de pepino de mar en el aeropuerto de Mérida. Retrieved from Web 17 Dec. 2021. https://www.gob.mx/agricultura/prensa/contribuye-sagarpa-en-aseguramiento-de-pepino-de-mar-en-el-aeropuerto-de-merida

Government of Mexico. 2017a. Asegura PROFEPA, SEDENA, y SEMAR cargamento de 256 piezas de pepino de mar, en Baja California. Retrieved from Web 25 Dec. 2021. https://www.gob.mx/profepa/prensa/asegura-profepa-sedena-y-semar-cargamento-de-256-piezas-de-pepino-de-mar-en-baja-california

Government of Mexico. 2017b. Oficiales Federales de Pesca de la CONAPESCA retienen 3,000 kilogramos de Pepino de Mar en Yucatán. Retrieved from Web 25

Dec. 2021. https://www.gob.mx/conapesca/articulos/oficiales-federales-de-pesca-de-la-conapesca-retienen-3-000-kilogramos-de-pepino-de-mar-en-yucatan-139122?idiom=es

Government of Mexico. 2018. PROFEPA apoya a la corte federal de EUA en case de traficante de pepino de mar. Retrieved from Web 25 Dec. 2021. https://www.gob.mx/profepa/prensa/profepa-apoya-a-la-corte-federal-de-eua-en-caso-de-traficante-de-pepino-de-mar

Government of Mexico. 2019a. La Secretaría de Marina-Armada de México asegura 12 toneladas aproximadamente de pepino de mar en Manzanillo, Colima. Retrieved from Web 21 Dec. 2021. https://www.gob.mx/semar/prensa/la-secretaria-de-marina-armada-de-mexico-asegura-12-toneladas-aproximadamente-de-pepino-de-mar-en-manzanillo-colima

Government of Mexico. 2019b. Más de una tonelada de pepino de mar fue asegurada en el aeropuerto Internacional de la Ciudad de México. Retrieved from Web 22 Dec. 2021. https://www.gob.mx/sspc/prensa/mas-de-una-tonelada-de-pepino-de-mar-fue-asegurada-en-el-aeropuerto-internacional-de-la-ciudad-de-mexico

Grillo de Yucatán. 2019. En complicidad con la aduana, envían pepino de mar ilícito vía aérea. Retrieved from Web 22 Dec. 2021. https://grillodeyucatan.com/2019/03/28/en-complicidad-con-la-aduana-envian-pepino-de-mar-ilicito-via-aerea/

Guilford G. 2015. How China's fish bladder investment craze is wiping out species on the other side of the planet. Quartz. Retrieved from Web 21 Dec. 2021. https://qz.com/468358/how-chinas-fish-bladder-investment-craze-is-wiping-out-species-on-the-other-side-of-the-planet/

Guzmán H.M., Guevara C.A. and Hernández I.C. 2003. Reproductive cycle of two commercial species of sea cucumber (Echinodermata: Holothuroidea) from Caribbean Panama. Marine Biology 142(2):271–279. http://dx.doi.org/10.1007/s00227-002-0939-x

Hakki D. and Aydin M. 2021. Sea cucumber fishery in Turkey: Management regulations and their efficiency. Regional Studies in Marine Science 41:101551. https://doi.org/10.1016/j.rsma.2020.101551

Hair C., Foale S., Kinch J., Frijlink S., Lindsay D. and Southgate P.C. 2019. Socioeconomic impacts of a sea cucumber fishery in Papua New Guinea: Is there an opportunity for mariculture? Ocean and Coastal Management 179:104826. https://doi.org/10.1016/J.OCECOAMAN.2019.104826

Hernández-Flores A., Cuevas-Jiménez A., Poot-Salazar A., Condal A. and Espinoza-Méndez J.C. 2018. Bioeconomic modeling for a small-scale sea cucumber fishery in Yucatan, Mexico. PLoS One 13(1):e0190857. https://doi.org/10.1371/journal.pone.0190857

Herrero-Pérezul M.D. and Reyes-Bonilla H. 2008. Weight-length relationship and relative condition of the holothurian Isostichopus fuscus at Espíritu Santo Islands, Gulf of California, México. Revista de Biología Tropical/International Journal of Tropical Biology 56(supplement 3):273–280. https://doi.org/10.15517/RBT.V56I3.27143

Hickok K. 2018. Men fined $1 million for trafficking $17 million worth of squishy sea cucumbers. Live Science. Retrieved from Web 19 Dec. 2021. https://www.livescience.com/63755-smuggled-sea-cucumbers.html

Huard C. 2020. Man sentenced to six months for smuggling protected sea cucumbers across border. Retrieved from Web 25 Dec. 2021. https://timesofsandiego.com/crime/2020/12/14/man-sentenced-six-months-for-smuggling-protected-sea-cucumbers-across-border/

Hutchim-Lara O., Hernández-Flores A., Villanueva-Poot R. and Gracía E. 2018. The cost of decompression illness: The case of lobster and sea cucumber fishery in Yucatan, Mexico. Undersea and Hyperbaric Medicine: Journal of the Undersea and Hyperbaric Medical Society, Inc. 45(5):531–539. https://pubmed.ncbi.nlm.nih.gov/30428242/

InfoBae. 2021. Desmantelaron supuesto narcolaboratorio de Cárteles Unidos y detuvieron a cuatro "Viagras" en Michoacán." Retrieved from Web 22 Dec. 2021. https://www.infobae.com/america/mexico/2021/11/19/desmantelaron-supuesto-narcolaboratorio-de-carteles-unidos-y-detuvieron-a-tres-viagras-en-michoacan/

Jimémez J. 2019. Cada vez hay más gente tratando de meter pepinos de mar de contrabando en EEUU: la fiebre del 'oro negro' del Yucatán no se frena." Xataka, Mexico. Retrieved from Web 18 Dec. 2021. https://www.xataka.com/ecologia-y-naturaleza/cada-vez-hay-gente-tratando-meter-pepinos-mar-contrabando-eeuu-fiebre-oro-negro-yucatan-no-se-frena

Kaplan-Hallam M. 2016. Social shocks in social-ecological systems: The impact of sea cucumber booms for coastal communities in Mexico. Masters Thesis, University of British Columbia. UBC Open Collections. https://open.library.ubc.ca/media/stream/pdf/24/1.0339982/3

Kaplan-Hallam M., Bennett N.J. and Satterfield T. 2017. Catching sea cucumber fever in coastal communities: Conceptualizing the impacts of shocks versus trends on social-ecological systems. Global Environmental Change 45:89–98. https://doi.org/10.31230/osf.io/4k9se

Larios Gaxiola F. 2015. Asegura PGR especies en peligro de extinción en Sonora. Milenio. Retrieved from Web 16 Dec. 2021. https://www.milenio.com/estados/asegura-pgr-especies-peligro-extincion-sonora

Lizárraga K. 2020. Aseguran pepino de mar extraído de manera ilegal de la bahía de La Paz. El Sudcaliforniano. Retrieved from Web 26 Dec. 2021. https://www.elsudcaliforniano.com.mx/policiaca/aseguran-pepino-de-mar-extraido-de-manera-ilegal-de-la-bahia-de-la-paz-5294770.html

López-Rocha J.A. 2012. Distribución y abundancia del pepino de mar Isostichopus badionotus frente a la costa de Sisal, Yucatán. Proceedings of Gulf and Caribbean Fisheries Institute 64:153–160. http://hdl.handle.net/1834/36154

López-Rocha J.L. and Velázquez-Abunader I. 2019. Fast decline of the sea cucumber Isostichopus badionotus as a consequence of high exploitation in Yucatan, Mexico. Regional Studies in Marine Science 27:100547. https://doi.org/10.1016/j.rsma.2019.100547

Madrigal N. 2013. Valían 2 mdp las especies decomisadas. El Vigia. Retrieved from Web 25 Dec. 2021. https://www.elvigia.net/general/2013/5/26/valan-especies-decomisadas-115291.html

McCay B.J., Micheli F., Ponce-Díaz G., Murray G., Shester G., Ramirez-Sanchez S. and Weisman W. 2014. Cooperatives, concessions, and co-management on the Pacific coast of Mexico. Marine Policy 44:49–59. http://dx.doi.org/10.1016/j.marpol.2013.08.001

Medina E. 2021. Chocan guateros y cooperativistas de Isla Magdalena. El Sudcaliforniano. Retrieved from Web 18 Dec. 2021. https://www.elsudcaliforniano.com.mx/local/chocan-guateros-y-cooperativistas-de-isla-magdalena-7302264.html

Méndez-Medina C., Schmook B., Basurto X., Fulton S. and Espinoza-Tenorio A. 2020. Achieving coordination of decentralized fisheries governance through collaborative arrangements: A case study of the Sian Ka'an Biosphere Reserve in Mexico. Marine Policy 117:103939. https://doi.org/10.1016/j.marpol.2020.103939

Michel V.H. 2014. Campeche y Yucatán: la peor crisis por el pepino de mar. Milenio. Retrieved from Web 18 Dec. 2021. https://www.milenio.com/estados/campeche-y-yucatan-la-peor-crisis-por-el-pepino-de-mar

Milenio. 2015. Decomisan 137 kilos de pepino de mar en BC. Retrieved from Web 18 Dec. 2021. https://www.milenio.com/estados/decomisan-137-kilos-pepino-mar-bc

Murtha J. 2016. When it comes to drug busts, journalists often don't ask the right questions. Columbia Journalism Review. Retrieved from Web on 3 Jan. 2021. https://www.cjr.org/analysis/drug_bust.php

Muter B., Gore M., Gledhill K., Lamont C. and Huveneers C. 2013. Australian and U.S. news media portrayal of sharks and their conservation. Conservation Biology 27(1):187–196. https://doi.org/10.1111/j.1523-1739.2012.01952.x

Ngaluafe P. and Lee J. 2013. Change in weight of sea cucumbers during processing: Ten common commercial species in Tonga. SPC Beche-de-mer Information Bulletin 33:3–8.

Novedades Yucatán. 2019. Aseguran una tonelada de pepino de mar y pulpo. Retrieved from Web 25 Dec. 2021. https://sipse.com/novedades-yucatan/aseguramiento-pulpo-pepino-celestun-bodega-arrestos-veda-mar-326941.html

Novedades Yucatán. 2021. Decomisan tortugas y una cría de cocodrilo, así como un cargamento de mariscos en veda. Retrieved from Web 25 Dec. 2021. https://sipse.com/novedades-yucatan/decomisan-tortugas-cria-cocodrilo-cargamento-mariscos-veda-dzilam-bravo-404383.html

Pedroza C. 2013. Middlemen, informal trading and its linkages with IUU fishing activities in the port of Progreso, Mexico. Marine Policy 39:135–143. http://dx.doi.org/10.1016/j.marpol.2012.10.011

Pedroza-Gutiérrez C. 2019. Managing Mercado del Mar: A case of women's entrepreneurship in the fishing industry. Maritime Studies 18:335–346. https://doi.org/10.1007/s40152-019-00157-y

Pedroza C. and Salas S. 2011. Responses of the fishing sector to transnational constraints: From reactive to proactive change, Yucatan fisheries in Mexico. Marine Policy 35(1):41–44. https://doi.org/10.1016/J.MARPOL.2010.08.001

Pedroza-Gutiérrez C. and López-Rocha J.A. 2021. Ungovernable systems: The strength of informal institutions in the sea cucumber fishery in Yucatan, Mexico. PLoS ONE 16(3):e2049132. https://doi.org/10.1371/journal.pone.0249132

Phelps Bondaroff T. 2021. Sea cucumber crime in India and Sri Lanka during the period 2015-2020. SPC Beche-de-mer 41:55–65. https://purl.org/spc/digilib/doc/eu33f

Phelps Bondaroff T., Reitano T. and van der Werf W. 2015. The illegal fishing and organized crime nexus: Illegal fishing as transnational organized crime. The Global Initiative Against Transnational Organized Crime and the Black Fish. Retrieved from Web 1 January 2022. https://globalinitiative.net/wp-content/uploads/2015/04/the-illegal-fishing-and-organised-crime-nexus-1.pdf

Pinto C. 11 November 2019. Dos enfrentan proceso por el megadecomiso de pepino de mar en Manzanillo. Estación Pacífico. Retrieved from Web 22 Dec. 2021. https://estacionpacifico.com/2019/11/11/dos-enfrentan-proceso-por-el-megadecomiso-de-pepino-de-mar-en-manzanillo/

Pozzi S. 2021. El pepino de mar se convierte en la 'commodity' más deseada en EEUU. La Información. Retrieved from Web 25 Dec. 2021. https://www.lainformacion.com/mundo/el-pepino-de-mar-se-convierte-en-la-commodity-mas-deseada-en-eeuu/2827911/?autoref=true

Pradilla A. 2019. Conflicto por el pepino de mar golpea a la pesca en el poblado de San Felipe, Yucatán. Animal Politico. Retrieved from Web 29 Dec. 2021. https://www.animalpolitico.com/2019/09/conflicto-pepino-mar-san-felipe-yucatan/

ProgresoHoy. 2019a. Descubren bodega de pepino de mar en el Centro de Mérida gracias a un incendio. Retrieved from Web 25 Dec. 2021. https://progresohoy.com/noticias/descubren-bodega-de-pepino-de-mar-en-el-centro-de-merida-gracias-a-un-incendio-10114967/

ProgresoHoy. 2019b. Aseguran en Mérida tres bodegas clandestinas de pepino de mar. Retrieved from Web 25 Dec. 2021. https://progresohoy.com/noticias/aseguran-en-merida-tres-bodegas-clandestinas-de-pepino-de-mar-10115080/

ProgresoHoy. 2020. Dan 11 meses de cárcel a pescador de Progreso detenido con 154 kilos de pepino de mar. Retrieved from Web 25 Dec. 2021. https://progresohoy.com/noticias/dan-11-meses-de-carcel-a-pescador-de-progreso-detenido-con-154-kilos-de-pepino-de-mar-10119645/

Purcell S.W. 2014. Value, market preferences and trade of beche-de-mer from Pacific Island sea cucumbers. PLoS ONE 9(4):e95075. https://doi.org/10.1371/journal.pone.0095075

Purcell S.W., Ngaluafe P., Wang G., and Lalavanua W. 2017. Market value of flower teatfish ("pentard"): A highly exploited Indian Oceans holothuroid. SPC Beche-de-mer Information Bulletin 37:53–56.

Purcell S.W. Ngaluafe P., Lalavanua W. and Ceccarelli D.M. 2018a. Market price trends of Latin American and Caribbean sea cucumbers inform fisheries management. Regional Studies in Marine Science 17:129. http://dx.doi.org/10.1016/j.marpol.2018.02.005

Purcell S.W., Williamson D.H. and Ngaluafe P. 2018b. Chinese market prices of beche-de-mer: Implications for fisheries and aquaculture. Marine Policy 91:58. https://doi.org/10.1016/j.marpol.2018.02.005

Putnamn N. 2018. Father and son businessmen avoid jail time must repay Mexico. The Star News. Retrieved from Web 26 Oct. 2021. https://www.thestarnews.com/father-and-son-businessmen-avoid-jail-time-must-repay-mexico/

Ramos-Miranda J., del Río-Rodríguez R., Flores-Hernández D., Rojas-González R.I., Gómez-Solano M., Cu-Escamilla A.D., Gómez-Criollo F., Sosa-López A., Torres-Rojas Y.E. and Juárez-Camargo P. 2017. Reproductive cycle of the sea cucumber Holothuria floridana in the littorals of Campeche, Mexico. Fisheries Science 83:699–714. http://dx.doi.org/10.1007/s12562-017-1100-6

Reyes-Bonilla H., Calderón-Aguilera L.E., Galaviz-López J.M. and Herrero-Pérezrul M.D. 2018. Size and relative condition index of the brown sea cucumber Isostichopus fuscus in the northern Gulf of California, Mexico. Latin American Journal of Aquatic Research 46(4):831–836. http://dx.doi.org/10.3856/vol46-issue4-fulltext-21

Rohrlich J. 2019. International sea cucumber kingpin implicated in new smuggling case. Quartz. Retrieved from Web, 1 January 2022. https://qz.com/1764439/a-border-arrest-exposes-lucrative-black-market-for-sea-cucumbers/

Rivera-Téllez E. and López-Segurajáuregui G. 2021. Guía de identificación de los pepinos de mar de interés comercial en México. CONABIO. México. 47 p. Retrieved from Web 1 January 2022. https://www.biodiversidad.gob.mx/media/1/planeta/cites/files/PEPINOS_IPAD_ALTA.pdf

Rompecabeza. 2020. Vinculan a sujeto por tráfico de 'pepino de mar.' Retrieved from Web 25 Dec. 2021. https://rompecabeza.mx/index.php/merida/item/6387-vinculan-a-sujeto-por-trafico-de-pepino-de-mar

Ruido. 2019. No pueden frenar furtivismo de pepino de mar. Retrieved from Web 18 Dec. 2021. https://www.hazruido.mx/reportes/no-pueden-frenar-furtivismo-de-pepino-de-mar/

SEMARNAT (Secretaría de Medio Ambiente y Recirsos Naturales). 2020. Plan de manejo tipo para la conservación y aprovechamiento sustentable de pepino de mar (Isostichopus fuscus) en México. Secretaría de Medio Ambiente y Recirsos Naturales. Subsecretaría de Gestión para la Protección Ambiental. Dirección General de Vida Silvestre. Mexico, 48 pp. Retrieved from Web 1 January 2022. https://www.gob.mx/cms/uploads/attachment/file/574166/Plan_de_Manejo__pepino_de_mar_2020.pdf

Singh-Cabanillas J. and Vélez-Barajas A. 1996. La pesquería del pepino de mar Isostichopus fuscus en la costa oriental de Baja California Sur y propuestas de regulación. Ciencia Pesquera 12:13–18. Retrieved from Web, 1 January 2022. https://www.inapesca.gob.mx/portal/documentos/publicaciones/cienciapesquera/CP12/CP12-03.pdf

Solís-Marín F.A., Honey-Escandón M.B.I., Herrero-Perezrul M.D., Benitez-Villalobos F., Díaz-Martínez J.P., Buitrón-Sánchez B.E., Palleiro-Nayar J.S. and Durán-González A. 2013. The echinoderms of Mexico: Biodiversity, distribution and current state of knowledge. p. 11–54. In: Echinoderm Research and Diversity. Alvarado, J.J. and Solís-Marín F.A. (eds). Heidelberg Berlin: Springer-Verlag.

Solís-Marín F.A., Laguarda-Figueras A. and Honey-Escandón M. 2014. Biodiversidad de equinodermos (Echinodermata) en México. Review of Mexican Biodiversity 85 (supplemental, January). http://ref.scielo.org/wjjmwy

Terrazas R. 2020. Pepino de mar, la mina de oro de la pesca illegal. Animal Politico. Retrieved from Web 29 Dec. 2021. https://www.animalpolitico.com/atarraya/pepino-de-mar-la-mina-de-oro-de-la-pesca-ilegal/

Tierra Fértil. 2016. Captura de pepino de mar dejó derrama de 54 mdp para Yucatán. Retrieved from Web 18 Dec. 2021. https://www.tierrafertil.com.mx/captura-pepino-mar-dejo-derrama-54-mdp-yucatan/

United Nations General Assembly. 2000. United Nations Convention Against Transnational Organized Crime. A/RES/55/25.

United States Department of Justice. 2018. Illegal sea cucumber trade nets more than $1.2 million dollars in fines, forfeiture and restitution. US Attorney's Office, Southern District of California. Retrieved from 26 October 2021. https://www.justice.gov/usao-sdca/pr/illegal-sea-cucumber-trade-nets-more-12-million-dollars-fines-forfeiture-and

United States of America v. Blessings Inc., David Mayorquin, and Ramon Torres Mayorquin. S.D. Cal. Case No. 3:17-cr-01254. Retrieved from Web 17 Dec. 2021. https://storage.courtlistener.com/recap/gov.uscourts.casd.533480/gov.uscourts.casd.533480.1.0.pdf

Vidal-Hernández L., Canto-Lugo E., Carmona-Escalante A., Huerta-Quintanilla R., Garza Lagler C. and López-Rocha J. 2019. Properties, communities and robustness in the Yucatán sea cucumber trade network. Ocean and Coastal Management 168:226–237. http://dx.doi.org/10.1016/j.ocecoaman.2018.10.036

Young E. 2001. State intervention and abuse of the commons: Fisheries development in Baja California Sur, Mexico. Annals of the Association of American Geographers 91(2):283–306. https://www.jstor.org/stable/3651261

Yucatan Times. 20 May 2016. Clashes over 'sea cucumber' continue in Yucatan. Retrieved from Web 18 Dec. 2021. https://www.theyucatantimes.com/2016/05/sea-cucumber-conflict-continues-in-yucatan/

Wild sea cucumber fishery in southwestern Madagascar

Olivier Maka,[1,*] Benjamin Pascal[2] and Gildas Todinanahary[1]

Abstract

Sea cucumbers have been overexploited in southwestern Madagascar, and some measures have been established for sustainably managing them. Since these management measures have been in place, however, very few assessments of the holothurian fishery have been made. From January to December 2018, we performed an assessment of fishery activities (fishing effort, catches, processing and marketing of products), and governance analysis at three main holothurian fishing villages (Sarodrano, Ankiembe and Andrevo). The results show that 12 species of sea cucumbers are collected by fishers in the study area. Compared to previous studies (Rasolofonirina and Conand 1998; Rasolofonirina et al. 2004), catches have increased, although these mainly comprise *Holothuria notabilis* (95.4% of catches for Andrevo, 95.4% for Ankiembe and 60.2% for Sarodrano), which have a low commercial value. Three forms of holothurian commercial chains were identified involving fishermen, middlemen, fishmongers and private operators. Fishmongers and/or fishermen take care of the first part of the processing (evisceration, first cooking, salting and second cooking), and operators complete the process to obtain exportable trepang. The holothurian fishery in southwestern Madagascar is developing but some of the established measures for their management and governance are poorly applied. Thus, it is recommended to improve aspects of their governance and to reinforce and renew existing management systems.

Key words: sea cucumber fishery, management, governance, southwestern Madagascar

Introduction

In Madagascar, sea cucumber exploitation provides income-earning potential for a portion of the coastal population, particularly near coral reefs (McVean et al. 2005). Trepang production in this country has increased exponentially over the last three decades**, from** 118 tonnes in 1988 to 890 tonnes in 2011 (Andriantsoa and Randriamiarisoa 2013). There are three major trepang-producing regions in Madagascar: the north, around Nosy Be Island; the centre of the west coast, around Mahajanga city; and the southwest around Toliara city, which is the largest producer on the island (Conand 1996; Andriantsoa and Randriamiarisoa 2013).

After the overexploitation of holothurians in Madagascar between 1990 and 1994 (Rasolofonirina and Conand 1998), studies were carried out on exploitation activities and sustainable management (Rasolofonirina 1997; Mara et al. 1998; Conand et al. 1998; Rasolofonorina et al. 2004; McVean et al. 2005). Today, holothurian fishery management measures are in place, and the aquaculture of these animals has been suggested as an alternative solution to be implemented for their sustainable management (Conand 1996; Rasolofonirina et al. 2004). However, since then, holothurian farming has developed in southwestern Madagascar to an industrial scale (Robinson and Pascal 2009), and the wild exploitation of holothurians in the region, as well as the effectiveness of management measures, has not been assessed.

The aim of this study is to assess activities related to the exploitation of wild holothurians in southwestern Madagascar, assess the existing management system for these animals, and analyse the governance of this fishery.

Methodology

Study sites

This study was carried out in three fishing villages, Sarodrano, Ankiembe and Andrevo, located on the coast of southwestern Madagascar (Fig. 1).

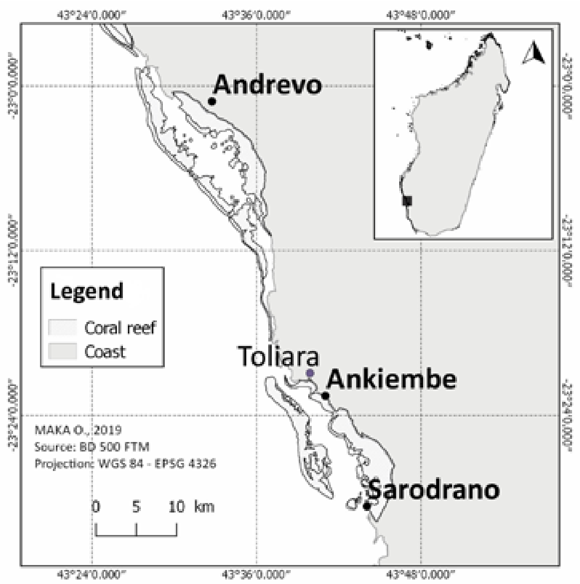


Figure 1. Location of the study villages.

[1] Institut Halieutique et des Sciences Marines, University of Toliara, BP 141, Rue Dr Rabesandratana Mahavatse II, 601-Toliara, Madagascar
[2] Indian Ocean Trepang, Enclosure of the Port - 601 Toliara, Madagascar
[*] Author for correspondence: dimaolivier@gmail.com

Surveys

Surveys were carried out with public authorities (fishery services, environment department, department of interior, and their local representatives in the villages) to collect administrative data concerning the exploitation of sea cucumbers in the region. Stakeholders (e.g. fishermen, middlemen, fishmongers and exporters) were also surveyed in order to know the organisation of this fishery, its socioeconomic aspects, its management methods and governance. These surveys were conducted by means of pre-established questions.

Individual interviews (semi-directives) were carried out with key informants from each village, followed by a focus group discussion. These forms of interviews were necessary not only to complete the information but also to explore new issues through discussions.

All of the information collected through they surveys was verified through direct observations, which allowed us to know what was happening on the ground with regard to stakeholders' activities in the sector.

Participatory monitoring of holothurian exploitation activities

Catch monitoring was carried out four days a week in each village. On each day of monitoring, a sample of 30 fishermen was randomly selected. This was done to estimate the catch composition and catch per unit effort (CPUE) at each site. Monitoring notebooks were set up to be filled out daily by fishmongers. This monitoring allowed us to observe the variation in the number of holothurian fishers who fished, and the price of fresh holothurian species. The price of semi-processed products was taken from the invoices received by the fishmongers after each sale to exporters in Toliara.

Participatory mapping

Participatory mapping was used to develop a map of the fishing sites frequented by sea cucumber fishermen. This method takes into account fishermens' knowledge and takes place in two stages: holding a community meeting, and recording the geographical coordinates of fishing sites.

A map was drawn by the fishermen with all of the information needed to make reference points on the marine and coastal environment of each village. During the community meeting, fishermen indicated on the map the location of their different fishing sites. Including both fishermen and fisherwomen in discussions was necessary in order to optimise the accuracy of these fishing sites' locations. Then, the geographical coordinates of the fishing sites on the map were taken *in situ,* with at least two fishermen who were present during the participatory mapping session.

Summary of the methodological approach

The approach of the methodology used for this research is summarised in Figure 2.

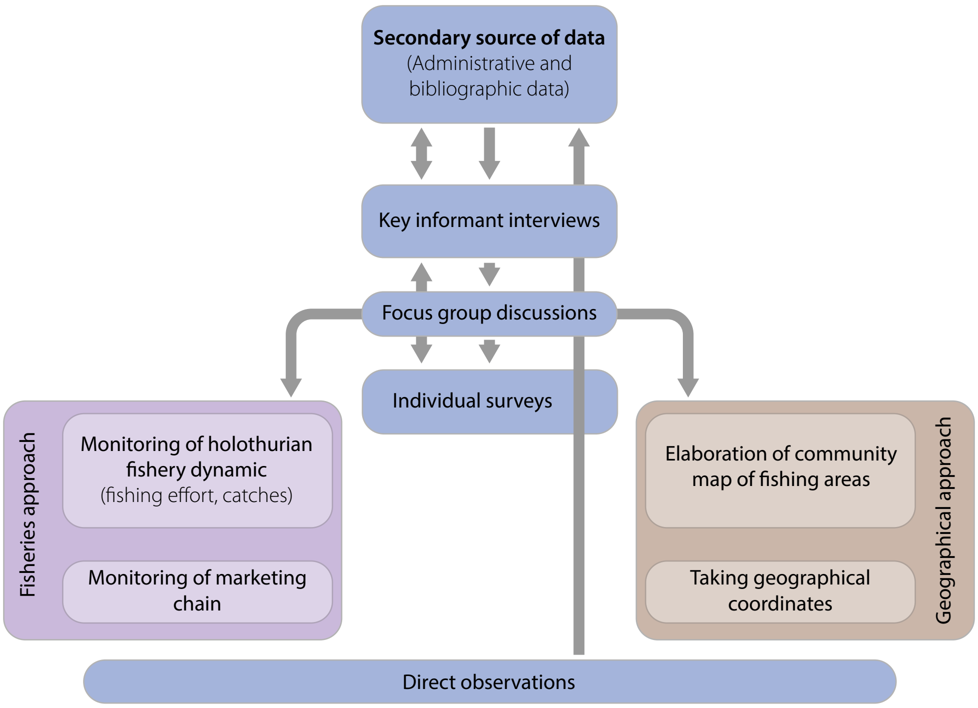


Figure 2. Summary diagram of the data collection technique used in this study.

Data treatment and statistical analysis

CPUE, expressed in kilograms per fisherman per day, is calculated using the formula:

$$CPUE = \sum_{1}^{ni} \frac{C}{ni}$$

C: daily catch of surveyed fishermen

ni: number of surveyed fishermen

The monthly production of each village was estimated by the product of CPUE and monthly fishing effort.

All of the statistical analyses were performed using the R software (R Core Team 2017). The Shapiro-Wilk's test was used to determine the normality of the data, and the Levene's test to calculate the homogeneity of variances. The significance (or not) of the difference in means was determined using ANOVA for normal data (followed by the Tukey Bonferroni post-hoc test to determine the source of the observed difference), and the Kruskal-Wallis test for data that did not follow the normal distribution (with the Wilcoxon comparison), at a level of 5%.

Results

The socioeconomic situation of fishermen

The population of each of the study villages is 1656 for Sarodrano, 5226 for Ankiembe and 2436 for Andrevo. Figure 3 shows the distribution of these populations according to age group. The main activity of the population of these villages is still traditional fishing: 89% of the population of Sarodrano are fishermen, 59% for Ankiembe and 83% for Andrevo (Fig. 4). Other activities in the villages are mainly agriculture, aquaculture and charcoal making.

Spatial distribution of holothurian stakeholders

Table 1 shows the number of stakeholders in the holothurian fishery, with the number of active participants in the three study villages.

None of the fishmongers in these villages are officially registered with the state. Middlemen go out to sea in a pirogue to buy sea cucumber catches from fishermen and sell them to fishmongers in the village itself.

Organisation of the fishery

Two holothurian fishing techniques were observed in the study villages: freediving and harvesting on foot. Free diving, which is practiced by men and very rarely by women (in the case of Andrevo). This fishing method is practiced every day except during bad weather (rainy periods or when the wind is blowing very strong) and requires a boat. Collecting sea cucumbers on foot is mainly done by women and children during a low spring tide. This method does not require a pirogue for travel.

Fishing sites

Sea cucumber fishing sites are located in the reef zone, and can only be accessed when the wind is moderate and blowing from the right direction because the sites that are very far from the villages are difficult to get to. In total, 15 fishing sites are frequented by fishermen in Sarodrano (Fig. 5), 20 in Ankiembe (Fig. 6) and 16 in Andrevo (Fig. 7).

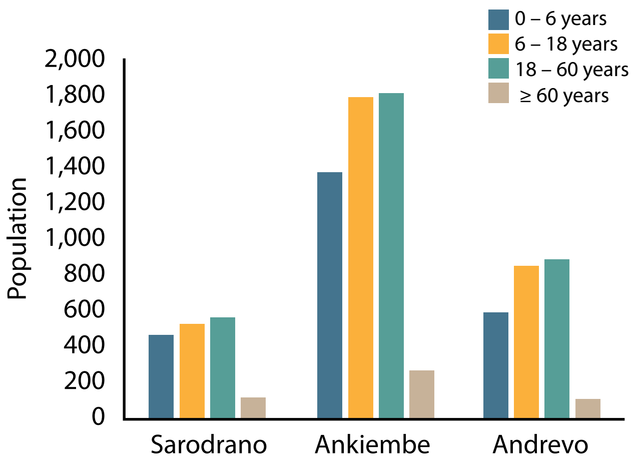


Figure 3. Population distribution at study sites by age group.

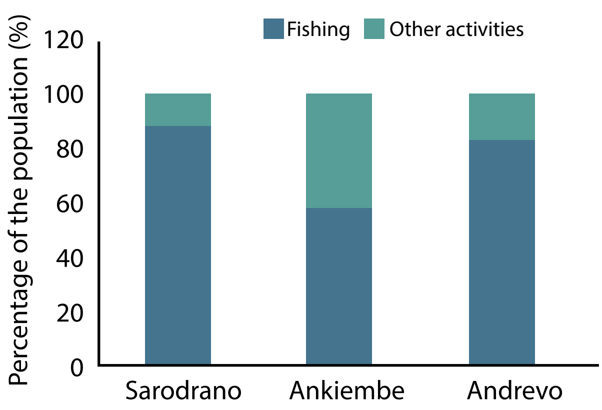


Figure 4. Population distribution at study sites according to villagers' main activities.

Table 1. List of stakeholders in the holothurian fishery in the study villages

Villages	Fishermen	Fishmongers	Middlemen
Sarodrano	216	4	0
Sarodrano	349	4	0
Andrevo	318	3	2

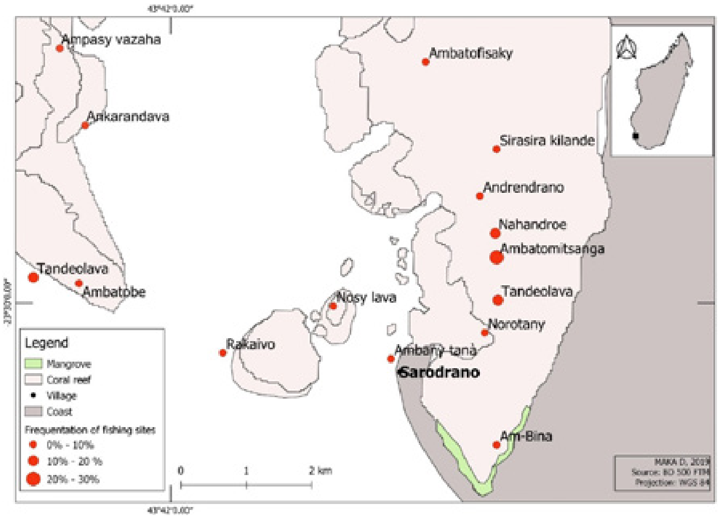


Figure 5. Fishing areas around Sarodrano and the frequency with which they are visited.

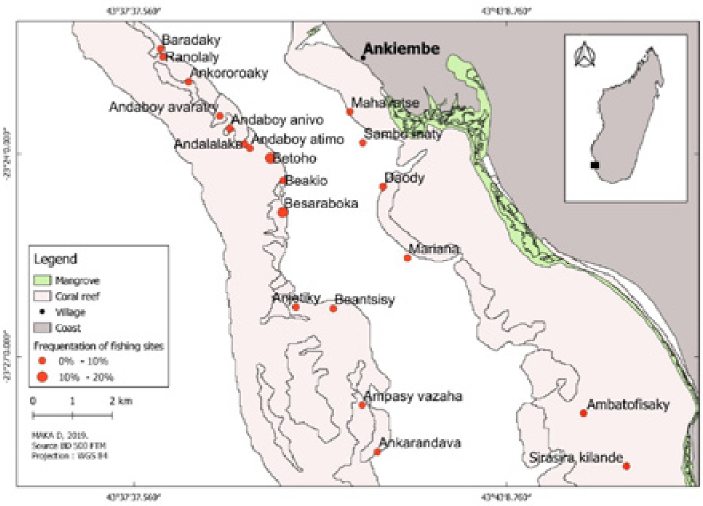


Figure 6. Fishing areas around Ankiembe and the frequency with which they are visited.

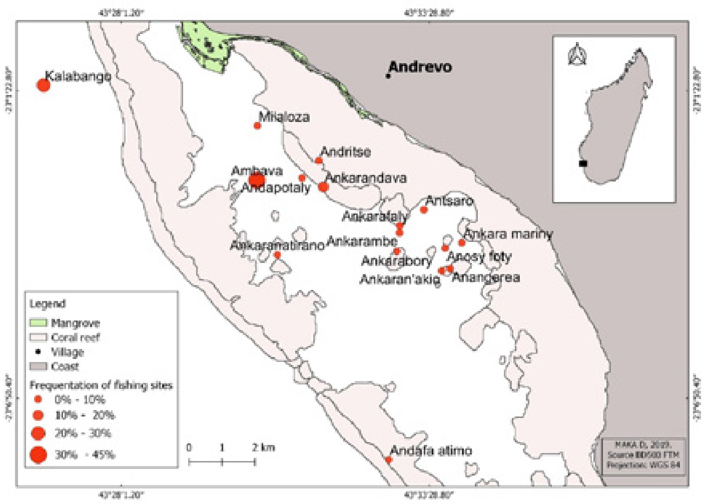


Figure 7. Fishing areas around Andrevo and the frequency with which they are visited.

Exploited species

Figure 8 shows that the accumulated number of sea cucumber species found in catches was stable from the 10th sampling for Sarodrano and Andrevo, at 11 and 10 species, respectively. For Ankiembe, the number of species found in catches was stable from the 8th sampling, with 10 species. *Holothuria cinerascens* was only found in Andrevo while *Actinopyga mauritiana* was not observed in this village. On the other hand, *Thelenota ananas* was only found in Sarodrano.

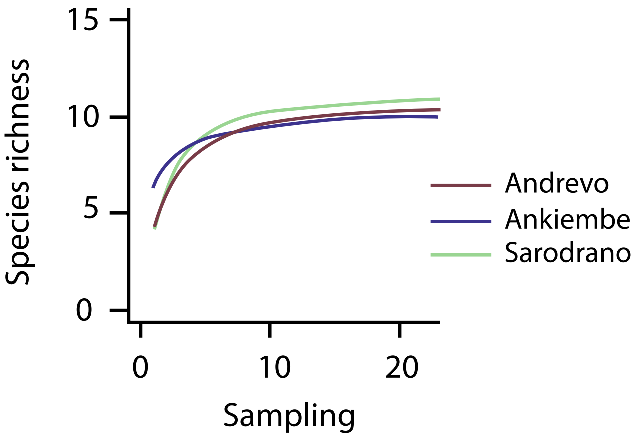


Figure 8. Trend line of sea cucumber species richness in the study villages.

The species observed in all three villages during this study are shown in Table 2. A species may have a different local name, depending on the village.

Fishing effort and catches

The average number of fishermen from Andrevo going out per month to harvest sea cucumbers is higher (804±332) than in Sarodrano (647±264) and Ankiembe (573±216) (Fig. 9), but there is no significant difference between these villages (p-value= 0.06).

The number of fishing days per month (Fig. 10) depends on weather conditions (wind and rain), sea conditions, and on events in the village (festivals or funerals).

Table 3 summarises the variation CPUE from January to December 2018 at the study sites. Andrevo's catches are significantly higher than those of Ankiembe (p-value=0.018) and Sarodrano (p-value=0.012). On the other hand, the difference between Ankiembe and Sarodrano catches is insignificant (p-value=0.99). Seasonality of catches is also observed because catches in all villages are significantly higher during the warm season than during the cold season (p-value<0.001).

Catch composition

Table 4 shows the specific composition of the catches from the study sites. Among the three villages, *Holothuria notabilis* is the most abundant species found in the catches (95.4% of the catches in Andrevo, 95.4% of those in Ankiembe and 60.2% of those in Sarodrano), followed by *Stichopus horrens* for Sarodrano and Andrevo (25.3% and 1.8%, respectively) and *Stichopus herrmanni* for Ankiembe (1.3%).

Commercial chain and holothurian processing

During this study, three sea cucumber marketing strategies were observed.

- Strategy 1: Fishermen sell freshly caught holothurians to the village fishmonger, who carrys out semi-processing before selling the product to exporters in Toliara;

Table 2. List of exploited species in the three study villages.

Scientific name	Local name (vezo)	Commercial code
Holothuria lessoni[3]	Zanga mena	ZM
Holothuria scabra	Zanga foty	ZF
Holothuria atra	Stylo	ST
Holothuria cinerascens	Folera	FL
Holothuria notabilis	Dôrlisy	DRL
Stichopus horrens	Jomely, Smurf, Crampon	CR
Stichopus herrmanni	Trakitera, Bengalo	TRK
Actynopyga echinites	Tronkena	TK
Actinopyga lecanora	Zangam-bato	ZB
Actinopyga mauritiana	Foty tsetsaky	FTSK
Thelenota ananas	Zanga borosy	BR
Bohadschia vitiensis	Kalalijaky, Falalijaky	KL

[3] *Holothuria lessoni* was previously known as *Holothuria scabra versicolor* (Purcell and al. 2012).

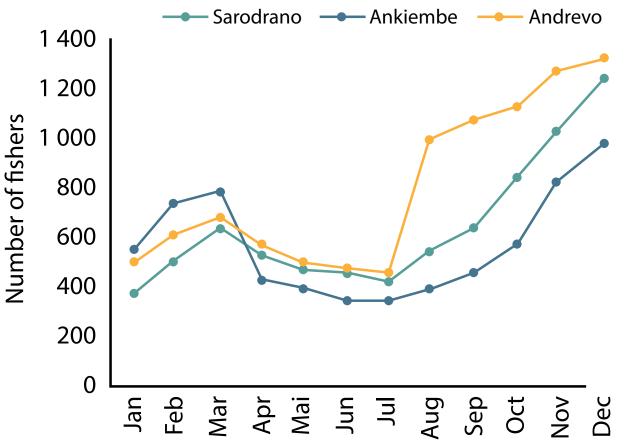


Figure 9. Monthly distribution of the number of fishermen going out to collect sea cucumbers in the villages

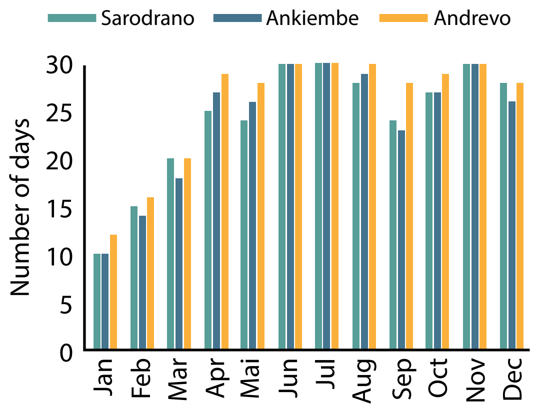


Figure 10. Number of sea cucumber fishing days per village.

Table 3. Monthly changes in catch per unit effort (CPUE) averages (in kilograms per fisherman per day) in the study villages.

CPUE	Sarodrano	Ankiembe	Andrevo
January	5.35	8.19	6.08
February	4.86	7.14	12.75
March	6.10	6.14	10.80
April	6.02	5.02	9.42
May	5.80	4.45	7.89
June	5.53	3.75	7.47
July	4.60	3.50	6.46
August	3.68	4.60	5.69
September	6.00	5.68	8.14
October	8.21	7.04	10.26
November	9.86	11.54	13.5
December	9.04	9.66	11.17
Average	**6.25**	**6.39**	**9.14**

Table 4. Composition of sea cucumber catches (in percent of total weight) from the three study villages.

Category	Species	Sarodrano	Ankiembe	Andrevo
1st	*Holothuria scabra*	2.62	0.92	0.55
	Holohuria lessoni	4.42	1.18	0.60
2nd	*Stichopus horrens*	25.31	0.24	1.84
	Stichopus herrmanni	3.23	1.27	0.63
	Actinopyga lecanora	1.16	0.003	0.002
	Actinopyga echinites	1.4	0.003	0.06
	Actinopyga mauritiana	0.41	0.030	
3rd	*Thelenota ananas*	0.02		
	Bohadschia vitiensis	0.93	0.74	0.02
	Holothuria atra	0.30	0.17	0.56
	Holothuria cinerascens			0.341
	Holothuria notabilis	60.20	95.44	95.38

- Strategy 2: Middlemen move to the fishermen's fishing areas to buy their catches and sell them, without any processing, to the fishmonger at the village, who then processes the sea cucumers in order to sell them to exporters in Toliara;

- Strategy 3: Fishermen process a part of their catch and sell directly to exporters in Toliara.

All marketing strategies of the commercial chain continue in the city of Toliara, where exporters complete the processing of products before reselling them. However, information on these exporters is very limited as they were not cooperative in this study.

Sea cucumbers are grouped into three categories according to their commercial value: high, medium and low (Table 5). Fishmongers buy fresh sea cucumbers per piece and resell them per kilogram to exporters after partial processing. The exporters complete the processing to obtain exportable trepang.

The processing of fresh holothurians is carried out by fishmongers at the villages. It generally consists of scraping, gutting, first cooking, salting, and then the second cooking, which is carried out before selling the products to exporters. But the processing steps varies depending on the species (Table 6).

For *Stichopus horrens*, the first cooking is obligatory before salting, otherwise the individual's body will deteriorate.

Management of the holothurian fishery

In 1992, the holothurian management method was based on fixing the commercial size (11 cm in fresh state and 8 cm in dry state), prohibiting the use of scuba gear, and monitoring the commercial strategy by means of compliance visas in order to collect statistical data. Since 1997, the administration's regulatory documents wanted to: 1) identify and list all of the stakeholders in the sector through fishermen's cards and registers, fishmonger's cards, collection permits, and exporter's cards; 2) require all stakeholders to provide information on their activities; and 3) require fees for col-

Table 5. The price range of species according to their commercial value (in Malagasy ariary, or MGA4).

Scientific name	Price of fresh product (ar./piece)	Price after semi processing (Ar./kg)
1st category: High		
Holothuria scabra	500–9000	20,000–30,000
Holothuria lessoni	1000–15,000	50,000–70,000
2nd category: Medium		
Stichopus herrmanni	500–4000	24,000
Stichopus horrens	500–3000	24,000
Actinopyga echinites	100–2000	15,000
Actinopyga mauritiana	500–4000	10 000
Actinopyga lecanora	500–3000	10 000
3rd category: Low		
Holothuria atra	100	1000
Holothuria cinerascens	100	4000
Bohadschia vitiensis	100	1000
Thelenota ananas	100	4000
Holothuria notabilis	20–40	4000

4 1 MGA = 0.00026 USD

Table 6. Summary of holothurian processing steps by species

	Holothuria scabra, H. lessoni	*Stychopus horrens*	Other[5]
Processing steps	Scraping		
	Gutting	Gutting	Gutting
	1st cooking	1st cooking (obligatory)	1st cooking (optional)
	Salage	Salage	Salage
	2nd cooking	2nd cooking	2nd cooking

5 "Others" refers to species other than those listed in the preceding columns (*Actinopyga echinites*, *A. lecanora*, *A. mauritiana*, *Thelenota ananas*, *Holothuria atra*, *H. cinerascens*, *H. notabilis*, *Stichopus herrmanni* and *Bohadschia vitiensis*).

lection and export, which can be used to finance actions for fisheries management. In 2016, after an overexploitation of sea cucumbers, all forms of sea cucumber fishing and trepang processing were suspended in southwestern Madagascar, except for aquaculture. This interdiction, however, was lifted three months after the publication of the regulatory text.

However, several gaps are noted in the management of the sea cucumber sector, especially with regards to applying regulatory measures.

- During this study, none of the fishmongers in the three villages were registered with the Regional Fisheries Directorate (RFD). In addition, they continue to process sea cucumbers even when the law prohibits them to do so.
- The RFD states that fishmongers and collectors do not declare their products.
- The statistical data received by the RFD via the compliance endorsements of product shipments are not the same as those in the Fisheries Ministry's records. However, the current supply chain management system is totally dependent on these data.
- Concerning exports, there is also a big difference between the data at the Fisheries Ministry and those at the Fisheries Sanitary Authority; the latter agency issues sanitary certificates only on condition that it has seen the certificate of conformity endorsed by the Fisheries Ministry.

Problems with sector governance

The sea cucumber fishery has significant governance problems, and the main one is the lack of political will. There are delays in the design and implementation of strategies in policy framework documents. Moreover, these strategies generalise all resources exploited in the region concerned. However, certain species such as holothurians deserve specific strategies. The lack of government interest in fisheries management can also be seen in the persistence of a free-access regime to resources, and the weak will to enforce regulations.

As for the RFD, it faces serious budgetary problems, lack of material resources, and has limited functional and operational links with headquarters. As a result, its functions are limited to the collection of statistical data (particularly trade data). Collection and trading permits are issued by the administration, but this is carried out without any real link to the sea cucumber management plan. Indeed, there is little scientific advice within the authorisation procedure and little consideration of regulations.

Transparency in the activities of stakeholders and their data are should be part of good governance of the sector. Unfortunately, collectors and exporters consider their activities and data to be confidential so this information is generally inaccessible to everyone. Yet, such information would facilitate research on sea cucumber exploitation.

Finally, controlling and monitoring the exploitation of sea cucumbers (as with any resource) should be the role of the Fisheries Monitoring Centre. However, this branch has difficulty in fulfilling its role because informal actors (i.e. those who carry out their activities illegally) are not arrested or fined.

Discussion and conclusion

The number of sea cucumber species exploited in southwestern Madagascar is decreasing over time. Our results show that 12 species are currently exploited in the area, whereas in 2010, Madagascar still had the highest number of species fished in the entire western Indian Ocean at 30 species (Muthiga et al. 2010). Only two species have high commercial value in this study (*Holothuria scabra* and *Holothuria lessoni*) compared to four species from 1996 (Rasolofonirina et al. 2004) to 2007 (Lavitra et al. 2008). *Holothuria fuscogilva* and *Holothuria nobilis*, which were always present in fishermens' catches in the region until 2007, are no longer observed. This is due to the depletion of these species, which have been highly targeted by fishermen because of their high commercial value.

Sea cucumber fishing has continued to intensify over time. Indeed, snorkelling, which was rarely practised during neap tides (Rasolofonirina 1997), is now practised every day to get more catches. The results show that fishing effort in the region has quadrupled in 11 years compared to Ankiembe, which averaged 143 fishermen per month in 1997. This increase could be caused by a combination of factors such as the very rapid increase in the coastal (human) population, the lack of income-generating activities, and the growing demand for sea cucumbers. In addition, catches in the study villages are high compared to those in 1997, which averaged 4.9 kg per fisherman per day for Ankiembe (Rasolofonirina 1997). However, the difference can be explained by the intense exploitation of the low commercial value species *Holothuria notabilis*, which accounts for a very large proportion of the catches. The exploitation of this species has only been observed since the 1990s (Toral-Granda et al. 2008), and its exploitation is even more intense because many fishermen devote their effort to catching this species. Targeting low-value species is a sign of stock depletion, especially of high-value species (Rasolofonirina et al. 2004), which should normally be the main targets.

The trend in CPUE is similar in the villages studied and shows seasonal variation. The decrease in catches is due to the high turbidity observed every year in the study area resulting from the increased flow of the Onilahy River from November to December (due to heavy rains). This is also the case in this study because Sarodrano and Ankiembe are subject to hyper-sedimentation from the Onilahy and Fiherena rivers (Mahafina 2011). Heavy rains and especially cyclones limit the number of fishing days for fishermen.

In the villages, holothurians are processed by fishmongers and rarely by fishermen (e.g. Ankiembe); whereas in 1996, the majority of fishermen in the region processed their products themselves (Lavitra et al. 2009). Salting is widely used in holothurian processing in the region because it limits desiccation and reduces the loss of weight and length of processed sea cucumbers (Rasolofonirina et al. 2004; Lavitra et al. 2008).

Apart from the question about the effectiveness and consistency of sea cucumber management measures, their application is also very weak. Good management of the fishery requires production models that will be combined with data on fishing activity, population dynamics, and the socioeconomic aspects of fishers (Purcell and Pomeroy 2015). It is, therefore, essential for Madagascar to first conduct a sea cucumber stock assessment in order to subsequently define total allowable catch (TAC) by species and management area based on stock biomass. Spatialised management using TACs has positive biological (on the stock) and economic (on catches) effects, according to a study in New Caledonia (Léopold et al. 2015). Subsequently, the management measures established should be strengthened and/or revised. For example, the minimum commercial size of holothurians in Madagascar should be revised as it was based on the study of a single species (*Holothuria scabra*) and then generalised to apply to all other species (Andriantsoa and Randriamiarisoa 2013). It is also necessary to encourage fishermen to process their products. This will maximise their earnings because otherwise they receive only a fraction of the potential value of their resources (Friedman et al. 2008). Then, in the face of overexploitation, it is more effective to manage trade rather than fishing by freezing licensing and imposing export ceilings (Carleton et al. 2013). Finally, in order to be able to implement these measures, a specific national management plan for holothurians must be established. Three countries in Melanesia (Papua New Guinea, Solomon Islands and Vanuatu) have carried out a study to gain political and public support for sea cucumber fisheries management interventions. They demonstrated that enforcing the commercial size limit can increase fishing income by up to 144% (Lee et al. 2018). This is an example of how to convince the government to strengthen living resource management measures.

The solutions to the problems of sea cucumber fisheries governance in Madagascar are based on the application of several principles. The priority is the transparency of all aspects of the sector (stock state, regulations, exploitation of the resource, and the economic and social performance of the sector). Another principle is that of coherence, which refers to the correctness of public action in the sector according to the sectorial fisheries objectives (Breuil 2012). As in Vanuatu, Fiji and Tonga (holothurian producing countries), their sea cucumber stocks have been overexploited and they have first opted to rebuild stocks (by closing the fishery for years) and then setting a ceiling on exports (Carleton et al. 2013). The participation of stakeholders (fishermen, economic operators, civil society) in all steps of planning ensures the quality, effectiveness and efficiency of public action (Breuil 2012). This is the case of Vanuatu and New Caledonia, which have established a shared fisheries governance regime (Léopold et al. 2015). Finally, one aspect that should not be neglected is research, as it is the basis or reference point for decisions on resource management (Lee et al. 2018). In Madagascar, holothurians are among the resources that have been most studied. However, information is still lacking on the biology and ecology of sea cucumber species that are exploited, as well as the social and economic impacts (Anonymous 2014), in contrast to other trepang-producing countries.

Acknowledgements

This study was carried out, in part, with the financial support of the Indian Ocean Trepang company. We would like to thank Gabriel Donald, Joël Arnaud Masoava (SOAVATSARADIA), Romario Tsipy and his wife, as well as the fishmongers in the study villages who helped a lot with data collection.

References

Andriantsoa M. and Randriamiarisoa. 2013. Caractérisation actuelle de la pêche maritime à Madagascar, les systèmes statistiques du MPRH et conception des activités pour le nouveau système de suivi des captures (Pêcherie Industrielle Nationale, Pêche Artisanale Nationale et Pêche Traditionnelle Nationale). Rapport du projet sur la Mise en œuvre d'une stratégie régionale de la pêche pour la région AOA-OI (IRFS) Intitulé : Renforcement des systèmes statistiques de la pêche maritime à Madagascar ; (FED/2009/021-330). 160 p.

Anonymous. 2014. Situation de référence. Lettre de politique BLEUE. 28 p.

Breuil C. 2012. Document de support à la formation sur la bonne gouvernance des pêches maritimes dans la sous-région AOA-OI, SmartFish Working Papers No 007. 34 p.

Carleton C., Hambrey J., Govan H., Medley P. and Kinch J. 2013. Effective management of sea cucumber fisheries and the beche-de-mer trade in Melanesia. SPC Fisheries Newsletter 140:24–42. https://purl.org/spc/digilib/doc/g2jdz

Conand C., 1996. Rationalisation des activités de collecte d'holothuries à Madagascar, Rapport d'intervention du COI/FED. 40 p.

Conand C., De. San M., Refeno G., Razafintseheno G., Mara E., Andriajatovo S. 1998. Sustainable management of the sea cucumber fishery sector in Madagascar. SPC Beche-de-mer Information Bulletin 10:7–9. https://purl.org/spc/digilib/doc/gaggg

Friedman K., Purcell S., Bell J. and Hair C. 2008. Sea cucumber fisheries: A manager's toolbox. ACIAR Monograph No. 135. Canberra: Australian Centre for International Agricultural Research. 32 p.

Lavitra T., Rachelle D., Rasolofonirina R., Jangoux M. and Eeckhaut I. 2008. Processing and marketing of holothurians in the Toliara region, southwestern Madagascar. SPC Beche-de-Mer Information Bulletin 28:24–33. https://purl.org/spc/digilib/doc/pmwuf

Lee S., Govan H., Wolff M. and Purcell S. 2018. Economic and other benefits of enforcing size limits in Melanesian sea cucumber fisheries. SPC Fisheries Newsletter 155:29–36.

Léopold M., Ham J., Kaku R., Gereva S., Raubani J. and Moenteapo Z. 2015. Spatial sea cucumber management in Vanuatu and New Caledonia. SPC Beche-de-mer Information Bulletin 35:3–9. https://purl.org/spc/digilib/doc/bmbw5

Mahafina J. 2011. Perception et comportement des pêcheurs pour une gestion durable de la biodiversité et de la pêcherie récifale : application au niveau des réserves marines du Sud-Ouest de Madagascar, Thèse de Doctorat, Université de la Réunion, France. Université de Toliara, Madagascar. 185 p.

Mara E., Rasolofonirina R., Rabesandratana H., RakotoarinivoW., Ravelo I. and Conand C. 1998. Étude de la pêcherie aux holothuries et propositions de mesures d'aménagement dans le Sud-ouest de Madagascar. Report IH.SM/ONE/BM, Toliara. 40 p.

McVean A.R., Hemery G., Walker R.C.J., Ralisaona B.L.R. and Fanning E. 2005. Traditional sea cucumber fisheries in southwest Madagascar: A case-study of two villages in 2002. SPC Beche-de-mer Information Bulletin 21:15–18. https://purl.org/spc/digilib/doc/sz6v2

Muthiga N., Ochiewo J. and Kawaka J. 2010. Strengthening capacity to sustainably manage sea cucumber fisheries in the western Indian Ocean. SPC Beche-de-Mer Information Bulletin 30:3–9. https://purl.org/spc/digilib/doc/376xf

Purcell S.W. and Pomeroy R.S. 2015. Driving small-scale fisheries in developing countries. Frontiers in Marine Science 2:44. doi: 10.3389/fmars.2015.00044

Rasolofonirina R. 1997. Écologie, biologie et pêche de deux holothuries aspidochirotes, *Bohadschia vitiensis* et *Holothuria scabra* var. *versicolor* dans la Région de Toliara, Madagascar. DEA, IH.SM, Université de Toliara, Madagascar. 84 p.

Rasolofonirina R. and Conand C. 1998. Sea cucumber exploitation in the Toliara region of south-west Madagascar. SPC Beche-de-mer Information Bulletin 10:10–13. https://purl.org/spc/digilib/doc/494xf

Rasolofonirina R., Mara E. and Jangoux M. 2004. Sea cucumber fishery and mariculture inMadagascar, a case study of Tuléar, south-west Madagascar. p. 133–149. In: Lovatelli A., Conand C., Purcell S., Uthicke S., Hamel J. F. and Mercier A. (eds). Advances in sea cucumber aquaculture and management. Fisheries Technical Paper No. 463. Rome: FAO. 425 p.

Robinson G. and Pascal B. 2009. From hatchery to community – Madagascar's first village-based holothurian mariculture programme. SPC Beche-de-Mer Information Bulletin 29:38–43. https://purl.org/spc/digilib/doc/roo5p

Toral-Granda V., Lovatelli A. and Vasconcellos M. 2008. Sea cucumbers. A global review of fsheries and trade. FAO Fisheries and Aquaculture Technical Paper No. 516. Rome: FAO. 317 p.

An update on sea cucumber diversity in Malaysia: Resurveying the reefs of Perhentian Island after two decades

Zaidnuddin Ilias,[1*] Md Nizam Ismail[1] and Mohamad Saupi Ismail[1]

Introduction

The importance of sea cucumbers as a lucrative marine product has made them the focus of various studies to date. Earlier studies in Malaysia focused on the presence and distribution of sea cucumbers in different habitats. The studies were conducted by various researchers and mainly took place in Sabah (see for example, Kamarudin et al. 2009).

From 1996–1999, the Heriot-Watt University in the United Kingdom and the Fisheries Research Institute of Malaysia undertook sea cucumber research as part of the Darwin Initiative for the Survival of Species (Baine and Choo 1999). One of the study sites was Pulau Perhentian Marine Park.

We resurveyed sea cucumber diversity on the coral reefs of Perhentian Island Marine Park in 2020, two decades later. Previously, 12 species of sea cucumbers were reported (Zaidnuddin and Forbes 2001), and included *Actinopyga lecanora, A. miliaris, Bohadschia argus, B. marmorata, Holothuria atra, H. edulis, Pearsonothuria graeffei, Stichopus chloronotus, S. herrmanni, S. ocellata, S. vastus and Synaptula lamperti* (Zaidnuddin and Forbes 2001).

Perhentian Island Marine Park consists of three main islands, and all were declared a marine park in early 1985. This more recent survey was conducted in order to look at the diversity of sea cucumbers found in several locations as a follow-up to the previous study.

Methodology

The survey employed belt transects (60 m length x 5 m width) and a roving diver at six sites, three each at Perhentian Kecil Island and Perhentian Besar Island (Table 1) (English et al. 1994). Transect sites were on fringing reefs paralleling the shore in depths of 5 m.

After the transect, a free-roaming dive search was made to areas beyond the laid transect (Schmitt et al. 2002). The underwater search for sea cucumbers was carried out for approximately 30 minutes. Sea cucumber species were determined using *A taxonomic key and field guide to the sea cucumbers of Malaysia* (Forbes et al. 1999; Forbes and Zainuddin 1999). Species, number and length were recorded. The sites were dominated by boulder corals (*Porites* spp.) that formed small patches of fringing reef.

Results and discussion

The eight sea cucumber species observed during the 2020 survey were *Stichopus chloronotus, S. vastus, Holothuria atra, H. edulis, Bohadschia marmorata, B. argus, Synaptula lamperti and Pearsonothuria graeffei* (Fig. 2). Other large and common sea cucumbers that had been previously reported (in 2001) – such as *Actinophyga lecanora, A. miliaris, Stichopus ocellata and S. herrmanni* – were not found in all six study sites. The Alunan Reef site had the highest number of species (6) followed by Light House (4), Pasir Petani and Pasir Tiga Ruang (3 each), Tanjung Tukas (2) and Shark Point (1) (Table 2). Sea cucumber densities were 0.21 individual/m^2 at Alunan Reef, 0.14 individuals/m^2 at Pasir Petani, 0.11 individuals/m^2 at Pasir Tiga Ruang, 0.09 individuals/m^2 at Light House, 0.03 individuals/m^2 at Shark Point and 0.1 individuals/m^2 at Tanjung Tukas.

The number sea cucumber species found during the 2020 survey was lower than the number observed in the 2001 survey (Table 3). Some large, high-value species, which could be easily found on the reefs, such as *Stichopus ocellatus* and

Table 1. Sampling locations at Perhentian Kecil and Perhentian Besar islands, northeastern Malaysian peninsula.

No	Location	GPS position	Abbreviation
	Perhentian Kecil Island		
1	Lighthouse	5°54’35.92”N 102°42’35.18”E	LH
2	Pasir Petani	5°53’42.08”N 102°43’70.24”E	PP
3	Alunan Reef	5°53’36.06”N 102°43’23.21”E	AR
	Perhentian Besar Island		
4	Pasir Tiga Ruang	5°54’47.19”N 102°45’11.07”E	PTR
5	Shark Point	5°53’03.58”N 102°44’48.03”E	SP
6	Tanjung Tukas	5°53’16.70”N 102°46’14.46”E	TT

[1] Fisheries Research Institute Batu Maung, 11960 Batu Maung, Penang, Malaysia
* Author for correspondence: zaiali71@gmail.com

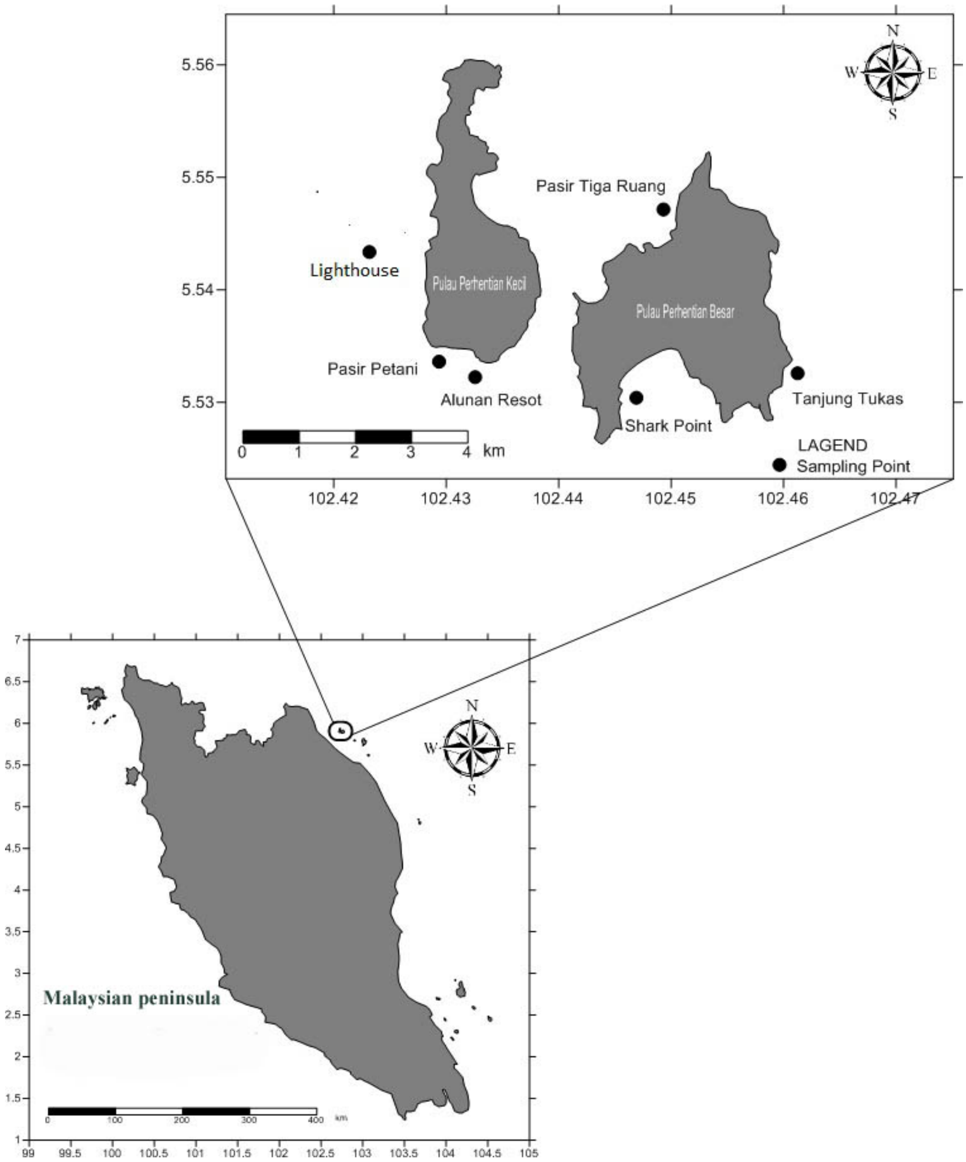


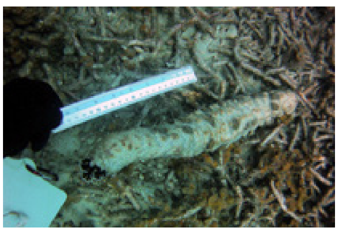
Figure 1. Perhentian Island Marine Park, Malaysia.

Bohadschia argus

B. marmorata

Holothuria atra

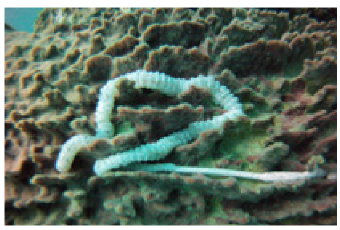
H. edulis



Pearsonothuria graeffei

Stichopus chloronotus

S. vastus



Synapta lamperti

Figure 2. The eight sea cucumber species observed during the 2020 survey.

Table 2. The number of sea cucumbers of each species encountered at each survey site.

Species	PP	AR	PTR	SP (Site*)	LH	TT	Total no/ species
Holothuria edulis	2	10	28	0	10	20	70
Holothuria atra	29	7	2	10	5	0	53
Bohadschia marmorata	0	20	0	0	0	0	20
Bohadschia argus	0	3	0	0	0	0	3
Synaptula lamperti	0	0	0	0	10	0	10
Stichopus chloronotus	12	23	3	0	0	10	48
Stichopus vastus	0	1	0	0	0	0	1
Pearsonothuria graeffei	0	0	0	0	3	0	3
No of species found at each site	**3**	**6**	**3**	**1**	**4**	**2**	

* See Table 1 for the full names of these sites.

Table 3. The presence or absence of sea cucumber species as reported in 2001 and 2020 from the northeastern Malaysian peninsula.

No	Species	2001 survey (Zaidnuddin and Forbes 2001)	2020 survey (as reported in this article)
1	*Stichopus chloronotus*	+	+
2	*Stichopus herrmanni*	+	
3	*Stichopus vastus*	+	+
4	*Actinopyga lecanora*	+	
5	*Actinopyga miliaris*	+	
6	*Bohadschia marmorata*	+	+
7	*Bohadschia argus*	+	+
8	*Pearsonothuria graeffei*	+	+
9	*Holothuria coluber*	+	
10	*Holothuria atra*	+	+
11	*Holothuria edulis*	+	+
12	*Synaptula lamperti*	+	+
	Total	**12**	**8**

S. herrmanni, were not found during the 2020 survey. The possibility that these species have been overexploited cannot be ascertained, although there was a report of an incident of intrusion and fishing in Perhentian Island Marine Park (Rubiah 2019).

Kamaruddin et al. (2009) reported 19 sea cucumber species from their reviews of sea cucumber-related research papers. Eleven of the sea cucumber species were identified while eight were unidentified. The species observed are of low value in the sea cucumber trading world. Even though the roving diver technique covers a wider search area along the transect, only a few additional species were observed outside the belt transect.

Conclusion

We observed fewer numbers of sea cucumber species during the 2020 survey. The *Stichopus* species that were not found are of concern, because these species are the most sought-after sea cucumbers for local traditional medicine. Further observations and communications with local people are needed to confirm the status of these resources.

Acknowledgements

The authors would like to thank Malaysia's Director-General of Fisheries, the Senior Director of Research, the Alunan Reef Resort, Perhentian Island, the Marine Park Division, and all those who were involved in this project but not mentioned here.

References

Baine M. and Choo P.-Z. 1999. Sea cucumber fisheries in Malaysia, towards a conservation strategy. SPC Beche-de-mer Information Bulletin 12:6–10. https://purl.org/spc/digilib/doc/mzfwi

English S., Wilkinson C.R. and Baker V.J. 1994. Survey manual for tropical marine resources. Townsville, Australia: Australian Institute of Marine Science. 368 p.

Forbes R. and Zainuddin I. 1999. The conservation of sea cucumbers in Malaysia- their taxonomy, ecology and trade. p. 49–63. In Baine M. (ed). Proceedings of an international conference. Department of Agriculture, Kuala Lumpur, Malaysia. Orkney, Scotland: Heriot-Watt University.

Forbes R., Ilias Z., Baine M., Choo P.S. and Wallbank A. 1999. A taxonomic key and field guide to the sea cucumbers of Malaysia. Orkney, Scotland: Heriot-Watt University. 61 p.

Kamarudin K.R., Rehan A.M., Lukman A.L., Ahmad H.F., Anua M.H., Nordin N.F.H., Hashim R., Hussin R. and Usup G. 2009. Coral reef sea cucumbers in Malaysia. Malaysian Journal of Science 28(2):171–186. https://doi.org/10.22452/mjs.vol28 no2.6

Rubiah O. 2019. Nelayan Vietnam curi Gamat. Sinar Harian 15 Mac 2019 (https://www.sinarharian.com.my/article/18249/EDISI/Terengganu/Nelayan-Vietnam-curi-gamat)

Schmitt E.F., Sluka R.D. and Sullivan-Sealey K.M. 2002. Evaluating the use of roving diver and transect surveys to assess the coral reef fish assemblage off southeastern Hispaniola. Coral Reefs 21(2):216–223. https://doi.org/10.1007/s00338-002-0216-y

Zaidnuddin I. and Forbes R. 2001. Inventory of sea cucumber species of Perhentian Island and Bidong Island, Terengganu. p 97–105. In: Husain M.L., F. Shahrom, A.T. Law, K. Yunus and A.R.G.Yaman. Proceeding of the National Symposium on Marine Park and Terengganu Islands. 12–13 Feb 2001. Department of Fisheries, Kuala Lumpur and KUSTEM, Kuala Terengganu. Malaysia.

Premier inventaire des holothuries (Holothuroidea) observées sur le Mont sous-marin La Pérouse – Ile de La Réunion sud-ouest de l'océan Indien – Expédition La Pérouse 2019

Thierry Mulochau,[1] Gustav Paulay,[2] Chantal Conand,[3] Florence Trentin,[4] Laurent Ballesta,[5] Thibault Rauby[5] et Patrick Durville[6]

Introduction

La zone mésophotique, située entre 50 et 150 m de profondeur, caractérisée par une baisse de la luminosité et de la température, reste peu étudiée malgré le développement des recherches au cours de la dernière décennie sur les écosystèmes coralliens mésophotiques (ECM) abritant des communautés benthiques distinctes (Hinderstein et al. 2010 ; Hoarau et al. 2021 ; Lesser et al. 2019 ; Rocha et al. 2018 ; Pinheiro et al. 2019 ; Pyle and Copus 2019). Le développement de nouvelles techniques de plongée (recycleurs et mélanges gazeux « Heliox », « Trimix »), des ROV (remotely operated vehicle) et de l'imagerie automatisée ont permis récemment d'étudier la biodiversité de quelques zones mésophotiques dans le sud-ouest de l'océan Indien, notamment à Mayotte (Mulochau et al. 2019, 2020a et 2020b) et à La Réunion (Durville et al. 2009a et b ; Hoarau et al. 2021 ; Durville et al. 2021 ; Mulochau et al. 2020c et sous presse). Les populations d'holothuries évoluant en zone mésophotique dans le sud-ouest de l'océan Indien ne sont pas ou peu connues et l'acquisition de connaissances sur ces espèces présente un intérêt pour la science, mais également pour la gestion et la conservation des stocks des espèces d'intérêt commercial très impactées en zone euphotique sur les récifs du sud-ouest de l'océan Indien (Conand 2017).

Les monts sous-marins, comme le Mont La Pérouse, sont souvent des hotspots de la biodiversité marine et des sites remarquables pour la préservation de certaines espèces commerciales (Morato et al. 2010). Le navire océanographique Marion Dufresne y a effectué une prospection en 1982 lors d'une mission autour de l'île de La Réunion (campagne MD32 du Museum National d'Histoire Naturelle https://expeditions.mnhn.fr/campaign/md32). Une cartographie du Mont La Pérouse a été réalisée et des dragages ont permis de récolter de nombreux organismes, mais à notre connaissance aucune espèce d'holothuries n'y avait été collectée. Les différentes espèces d'holothuries présentes autour de l'île de La Réunion sont connues et recensées (Conand et al. 2010 ; Conand et al. 2016 ; Conand et al. 2018).

Cette mission avait notamment pour objectif de réaliser un inventaire des holothuries du Mont La Pérouse et ainsi de compléter la liste de la diversité des espèces d'holothuries des eaux réunionnaises.

Matériel et méthodes

Le Mont La Pérouse est situé à environ 170 km au nord-ouest de La Réunion (Fig.1) et fait partie de la Zone Économique Exclusive réunionnaise qui s'étend jusqu'à 200 milles nautiques. Cet ancien volcan, au sommet plat (ancien guyot) situé entre - 57 et - 65 m de la surface, au début de la zone mésophotique, repose sur un plancher océanique à 5000 m de profondeur.

La mission s'est déroulée du 27 octobre au 5 novembre 2019 et a permis de réaliser un échantillonnage des holothuries par une équipe de 4 plongeurs équipés avec du matériel de plongée (recycleurs et mélanges gazeux) pour permettre des incursions en zone mésophotique. Au total 9 plongées ont été réalisées, entre 57 et 135 m de profondeur, avec un temps moyen de présence au fond de 38 minutes par plongeur (Tableau 1). La durée moyenne d'échantillonnage par plongée est de 115 minutes et la durée totale de l'échantillonnage sur le mont La Pérouse pendant cette mission est d'environ 17 heures. L'inventaire des holothuries a été fait à partir de photos et vidéos, de prélèvements d'échantillons de téguments afin d'étudier les spicules et l'ADN de certains spécimens. Deux holothuries ont été collectées et mises en collection au Muséum National d'Histoire Naturelle. Les spicules ont été préparés selon la méthode décrite par Samyn et al. (2006).

Les coordonnées géographiques des stations ne sont pas mentionnées pour des raisons de confidentialité liée au risque d'exploitation par la pêche des sites les plus riches en espèces commerciales recensées.

Les noms des espèces recensées dans cet inventaire sont celles référencées dans World Register of Marine Species (Worms, 2021).

Résultats

Douze espèces appartenant à la classe des Holothuroidea ont pu être inventoriées sur le Mont La Pérouse. Certaines n'ont pas pu être déterminées à l'espèce à partir des photos, et sont enregistrées au niveau de la famille ou du genre.

[1] BIORECIF, 3 ter rue de l'abatros 97434 La Saline Les Bains – biorecif@gmail.com
[2] Florida Museum of Natural History, University of Florida, Gainesville, FL, 32611, USA
[3] Professeure émérite de l'Université de La Réunion et Attaché Honoraire au MNHN Paris
[4] VIE OCEANE, 16 rue d'Aquitaine, 97427 Etang Salé les Bains
[5] ANDROMEDE OCEANOLOGIE, 7 Place Cassan, 34280 Carnon, France
[6] GALAXEA, 18 Résidence Victoria, 97434 Saline les Bains, La Réunion

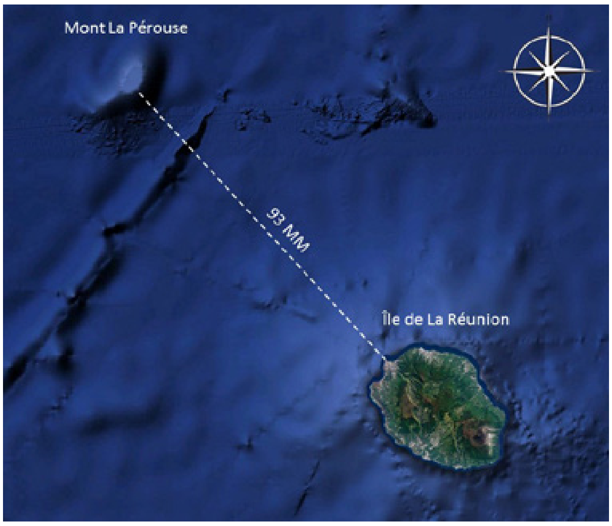


Figure 1. Localisation du Mont La Pérouse (19°42'S et 54°08'E) située à 170 km au nord-ouest de La Réunion (Google Earth, 2019)

Six d'entre elles ont pu être identifiées (Tab. 2). Plusieurs espèces ont été observées plusieurs fois sur différents sites et différentes plongées, comme *Holothuria* aff. *leucospilota* et *Thelenota ananas*.

Les plongées et la cartographie réalisées pendant la mission ont permis de décrire les habitats. Le sommet du mont, représenté par un grand plateau d'environ 50 km^2 culmine à 57 m de profondeur. Ce plateau est dominé par les zones détritiques et terrasses sédimentaires où de nombreuses macro-algues et éponges sont présentes. Les hydrozoaires sont également bien développés et les formations coralliennes y sont rarement observées. Les bords du plateau se trouvent à une profondeur de 120 m à partir de laquelle des tombants verticaux présentent des anciens karsts (Tableau 1).

Certains spécimens ont pu être déterminés à partir des photos (Fig. 2).

Holothuria sp. (type 'Pentard') (Fig. 2A) est exploitée aux Seychelles (Purcell et al. 2012) et n'avait jamais été observée dans les eaux réunionnaises, ni au-delà de 50 m.

Quatre spécimens ont été collectés pour prélever du tégument afin d'extraire les spicules et faire des analyses génétiques. Deux ont été mis en collection au MNHN et deux autres ont été remis à l'eau sur le site (Fig. 3).

Holothuria edulis (collectée à -100 m) a pu être déterminée avec les analyses génétiques et correspond à la forme grise qui, à notre connaissance, n'a jamais été observée dans le sud-ouest de l'océan Indien et dont la coloration est proche de spécimens observés au Japon (Fig. 3) (O'Loughlin et al. 2007).

Plusieurs spécimens de *Holothuria* aff. *leucospilota* ont été observés entre 112 et 120 m de profondeur sur du substrat meuble (Fig. 4). Le prélèvement de téguments sur un échantillon a permis d'analyser les spicules et de rechercher l'ADN.

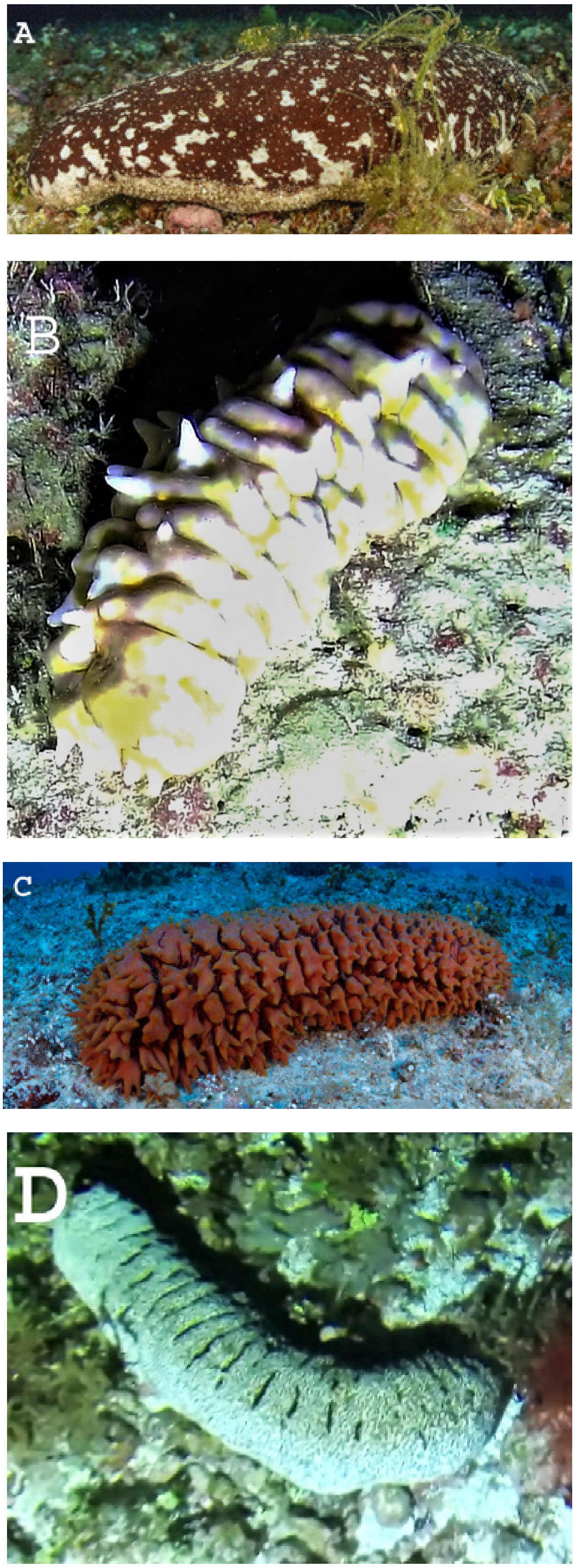


Figure 2. Photos d'holothuries observées sur le Mont La Pérouse. A. *Holothuria* sp. (type 'pentard') à - 60 m B. *Stichopus* sp observé à -135 m C. Plusieurs spécimens de *Thelenota ananas* ont été observés entre -57 et -70 m D. *Holothuria fuscopunctata* observé de nuit à -63 m

Tableau 1. Stations avec les dates d'échantillonnages, profondeurs en mètres, températures en degrés Celsius, habitats, familles, genres ou espèces échantillonnées et la durée d'échantillonnage au fond pour un plongeur en minutes

Stations	Dates	Profondeur (m)	Température (°C)	Habitats	Famille/Genres/ Espèces	Durée d'échantillonage au fond (en min)
1	27-oct-19	57 à 65	26	Zones détritiques et sédimentaires/Rhodolites/ Algues calcaires, éponges, hydraires	*Thelenota ananas* *Holothuria* sp. (type 'Pentard')	53
2	28-oct-19	60 à 65	26	Zones détrtiques et sédimentaires avec massifs coralliens/Algues calcaires, éponges, hydraires, gorgones	pas d'échantillon	58
3	29-oct-19	65 à 71	26	Zones détrtiques et sédimentaires avec massifs coralliens/Algues calcaires (Halimeda), éponges, hydraires, gorgones	*Thelenota ananas*	55
4	30-oct-19	100 à 135	25 à 26	Haut du tombant avec zone détritique, algues calcaires, éponges,… et tombant karstique peu colonisé	*Holothuria* aff. *leucospilota* ; *Holothuria edulis* ; *Stichopus* sp.	23
5	31-oct-19	120 à 133	25	Tombant karstique peu colonisé	pas d'échantillon	18
6	31-oct-19	64 (plongée de nuit)	25	Zones détritiques et sédimentaires/Rhodolites/ Algues calcaires, éponges, hydraires	*Bohadschia* sp. *Holothuria fuscopunctata* Holothuroidea sp. 1 Holothuroidea sp. 2	24
7	01-nov-19	65	25 à 26	Zones détrtiques et sédimentaires avec massifs coralliens/Algues calcaires, éponges, hydraires, gorgones	*Thelenota ananas*	59
8	04-nov-19	100 à 122	26	Haut du tombant avec zones détritiques, algues calcaires, éponges, rhodolites… et tombant karstique peu colonisé	*Holothuria fuscogilva*	26
9	05-nov-19	100 à 134	26	zones sédimentaires et détritiques et tombant ensablé	*Holothuria leucospilota* *Holothuria* sp. Holothuroidea sp. 3	27

Tableau 2. Holothuroidea recensées sur le Mont La Pérouse en octobre et novembre 2019. *Deux espèces non décrites et probablement nouvelles pour la science

Famille/genres/espèces	Statuts UICN	Profondeurs (m)	Méthodes d'échantillonnage
Bohadschia sp.	-	63	Photo
Holothuria edulis	Least Concern	100	Photos - Prélèvement – Spicules - ADN
Holothuria fuscogilva	Vulnerable	105	Photos - Prélèvement - ADN
Holothuria fuscopunctata	Least Concern	63	Photo
Holothuria sp.*	-	119	Photos - Prélèvement - Spicules - ADN
Holothuria sp. type 'Pentard'*	-	60	photo
Holothuria aff. *leucospilota*	Least Concern	112 à 120	Photos – Prélèvement – Spicules - ADN
Holothuroidea sp. 1	-	63	Photo
Holothuroidea sp. 2	-	63	Photo
Holothuroidea sp. 3	-	95	Photo
Stichopus sp.	-	135	Photo
Thelenota ananas	Endangered	57 à 70	Photo

FR

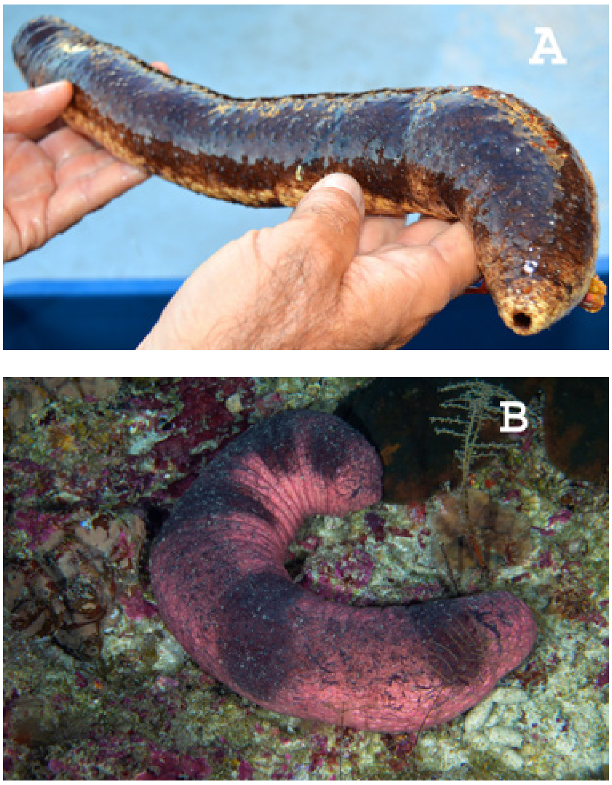


Figure 3. A) *Holothuria edulis* présentant une forme atypique grise collectée à 100 m de profondeurs sur le Mont La Pérouse ; B) un autre spécimen de *H. edulis* observé en zone mésophotique à Mayotte à -80 m présentant un morphe classiquement observé dans le sud-ouest de l'océan Indien

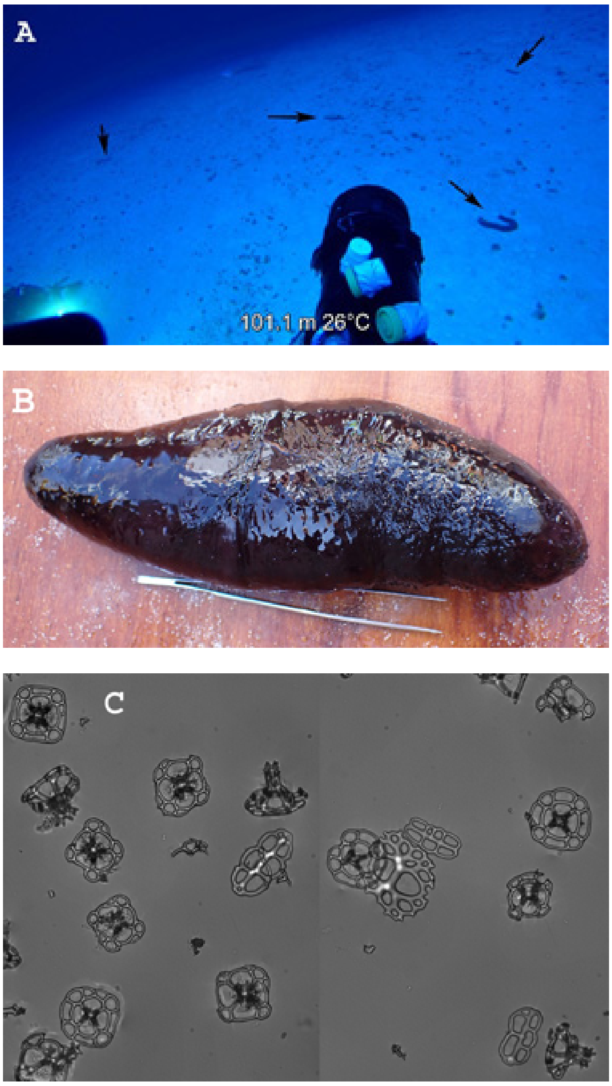


Figure 4. A) Plusieurs spécimens de *Holothuria* aff. *leucospilota* ont été observés jusqu'à 120 m de profondeur ; B) un individu a été collecté pour prélever du tégument afin (C) d'analyser les spicules et rechercher l'ADN.

Les différentes analyses ne nous ont pas permis d'identifier avec certitude cette espèce qui semble proche de *Holothuria leucospilota*. Les spicules ne correspondent pas exactement à ceux de cette espèce et des analyses génétiques complémentaires sont nécessaires pour préciser s'il s'agit bien de cette espèce ou d'une autre.

Le prélèvement d'un spécimen de *Holothuria fuscogilva* à 105 m de profondeur a permis sa détermination à partir de la morphologie et des analyses génétiques (Fig. 5).

Une autre espèce a été collectée à 119 m de profondeur, *Holothuria* sp., mais la morphologie, les analyses des spicules et de son ADN n'ont pas permis de déterminer ce spécimen. Il s'agit vraisemblablement d'une nouvelle espèce pour la science (Fig. 6). Cette espèce avait éjecté en petite quantité des tubes de Cuvier blanchâtres. Le spécimen collecté a été relâché.

Discussion

L'exploration des écosystèmes mésophotiques des récifs de l'indo-Pacifique est relativement récente. Les recherches et évaluations environnementales des récifs ont longtemps été limitées aux zones situées proches de la surface pour des raisons scientifiques, de suivis d'impacts anthropiques, mais également à cause des contraintes de la plongée subaquatique à l'air qui présente rapidement des limites aux incursions au-delà de 30 ou 40 m de profondeur. Les scientifiques trouvent un intérêt important à la connaissance de ces zones, car certains avancent l'hypothèse que les Ecosystèmes Coralliens Mésophotiques (ECM) pourraient avoir un rôle important à jouer en tant que « refuge » pour certaines espèces récifales évoluant également à faible profondeur. Plusieurs spécimens de *Thelenota ananas*, listée espèce « En Danger » et un individu de *Holothuria fuscogilva*, listée espèce « Vulnerable » (UICN, 2021) et figurant en annexe II de la convention de

FR

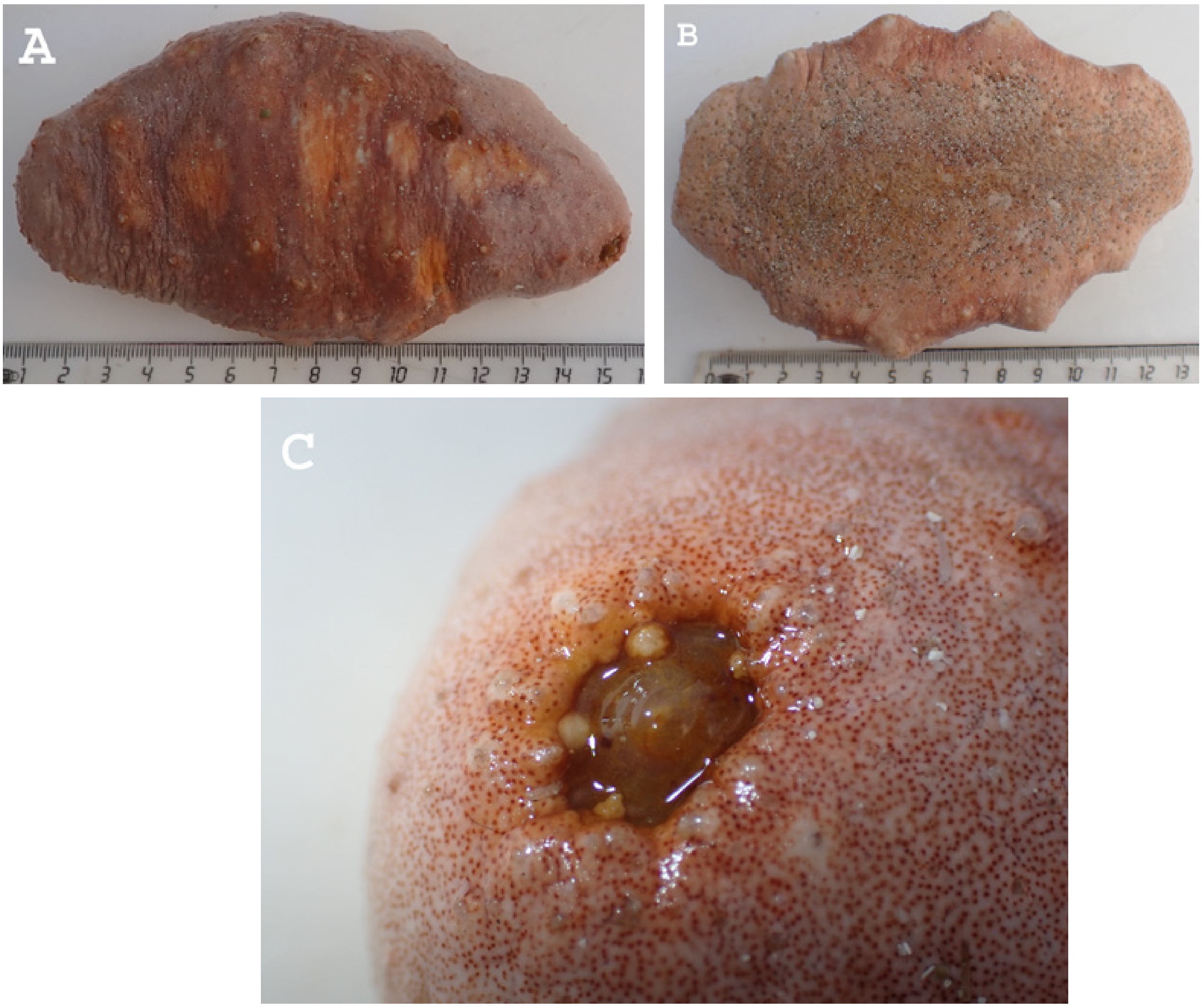


Figure 5. *Holothuria fuscogilva* collectée à 105 m de profondeur sur le Mont La Pérouse. A) face dorsale ; B) face ventrale ; et C) dents anales.

Figure 6. *Holothuria* sp. collectée à 119 m de profondeur sur le Mont La Pérouse probablement nouvelle pour la science d'une longueur de 45 cm. A. Face dorsale ; B) face ventrale ; et C) Spicules du tégument, tours et boutons.

Washington[7], ont été observées sur le Mont La Pérouse. Ces espèces ont pratiquement disparu de certains récifs coralliens de la zone du sud-ouest de l'océan Indien (Madagascar, Comores) (Conand 2017) et leurs populations pourraient être préservées de la pêche en zone mésophotique. Cependant, l'hypothèse des ECM comme zone refuge permettant à certaines espèces de « recoloniser » les zones récifales proches de la surface n'est pas encore validée et repose en partie sur des populations d'espèces communes, génétiquement identiques aux récifs euphotiques et mésophotiques (Turner *et al.* 2017). De plus, cette hypothèse de zone refuge ne concernent que certaines espèces d'holothuries, dont les stocks doivent être suffisants en zone mésophotique pour repeupler les récifs proches de la surface.

Une meilleure connaissance de la biodiversité des ECM permettra de mieux appréhender l'assemblage des espèces en zones mésophotiques et leurs interactions avec les récifs proches de la surface. Plusieurs missions scientifiques récentes dans le sud-ouest de l'océan Indien à Mayotte (programme MesoMay ; Mulochau et al. 2019 et 2020a) et à La Réunion (programme MesoRun, 2020/2021) avaient pour objectifs de recenser la biodiversité en zone mésophotique et ont ainsi permis d'améliorer nos connaissances sur les espèces d'holothuries qui pouvaient y évoluer. *Holothuria coronopertusa* a ainsi été recensée pour la première fois dans l'océan Indien sur le banc de l'Iris au nord de Mayotte à 80 m de profondeur (Mulochau et al. 2020d). *Holothuria* aff. *leucospilota* a été observé en zone mésophotique à Mayotte (Mulochau et al. 2019 et 2020a), à La Réunion (com. pers.) et sur le Mont La Pérouse, entre 80 et 120 m. Cette espèce est connue pour évoluer dans les lagons peu profonds, notamment à La Réunion (Conand et al. 2010 et 2016). Des analyses génétiques complémentaires sont en cours sur du tégument d'individus prélevés en zone mésophotique afin de vérifier s'il s'agit bien de la même espèce que celle qui évolue dans les lagons peu profonds.

Il existe trois morphotypes d'*Holothuria edulis* (O'Loughlin et al. 2007), les analyses génétiques ne différencient pas certains de ces types, cependant l'un de ces trois types a été décrit comme une espèce distincte, *H. nigralutea*, malgré une faible divergence génétique. Des nouveaux outils génétiques pourraient permettre de montrer que le type gris observé sur le Mont La Pérouse est une espèce différente de celle observée à Mayotte ou dans les îles Éparses (Glorieuses, Banc du Geyser).

L'état de santé et la stabilité des ECM, la préservation de leur biodiversité et le degré de connectivité génétique avec les récifs euphotiques pourraient contribuer à la capacité de résilience des récifs proches de la surface et à guider les futures stratégies de gestion et de conservation.

Certaines espèces d'holothuries d'intérêt commercial, impactées par la pêche sur les récifs euphotiques (< 30 m), pourraient être protégées de la collecte en plongée subaquatique en zone mésophotique. La compréhension du fonctionnement des ECM, de leur gestion et de leur protection passent nécessairement par une phase complémentaire d'acquisition de connaissance.

[7] https://cites.org/fra/app/appendices.php

Cette mission d'exploration sur le Mont La Pérouse avait pour objectif l'acquisition de connaissances sur les habitats et la biodiversité d'une zone mésophotique éloignée de certains impacts anthropiques. Dans le cadre d'une problématique de gestion et de conservation de certaines espèces commerciales, il serait intéressant à l'avenir d'évaluer les abondances des populations d'holothuries d'intérêt commercial observées sur le Mont La Pérouse, d'autant que ces données et leurs suivis dans le temps sont rares en zone mésophotique.

Remerciements

L'ensemble de l'équipage du navire La Curieuse est chaleureusement remercié pour son investissement dans cette expédition. Manon Condet, Florian Holon, Thomas Pavy, Jean-Pascal Quod et Yann Rineau sont remerciés pour leur aide et soutien dans les différentes manipulations qui ont permis la réalisation de cet inventaire. Marc Eleaume est sincèrement remercié pour son aide dans les recherches des spécimens d'holothuries mis en collection au MNHN suite à la mission MD32. Sophie Durville et Jean-Claude Martigné sont chaleureusement remerciés pour leur investissement dans le montage et l'organisation de cette expédition.

Financement

Cette « Expédition La Pérouse, 2019 » a été co-financée par l'État, au titre du contrat de convergence et de transformation 2019–2022, puis par des sponsors et mécènes : Association Vie Océane, Aquarium de La Réunion, Comité Régional d'études et de sports sous-marins de La Réunion, Inset, O Sea Bleu, Fondation du Crédit Agricole Réunion Mayotte, Fondation d'Entreprises des Mers Australes, Air France, Odyssée Créateur de voyages, Entropie, avec les partenaires d'Andromède Océanologie : Blancpain, Ocean Commitment Blancpain, RGBlue, Keldan, Topstar, Bigblue, Ap Diving, Molecular, Subspace, Nikon, Aqualung, Seacam.

Bibliographie

Conand C., Michonneau F., Paulay G. and Bruggemann H. 2010. Diversity of the holothuroid fauna (Echinodermata) in La Reunion (Western Indian Ocean). Western Indian Ocean Journal Marine Science 9(2):145–151.

Conand C., Ribes-Beaudemoulin S., Trentin F., Mulochau T. et Boissin E. 2016. Oursins, étoiles de mer & autres échinodermes. Les éditions du Cyclone. 168 p.

Conand C. 2017. Expansion of global sea cucumber fisheries buoys exports. Revista de Biología Tropical. (International Journal of Tropical Biology and Conservation ISSN-0034-7744) Vol. 65 (Suppl. 1): S1-S10.

FR

Conand C., Ribes-Beaudemoulin S., Trentin F., Mulochau T. and Boissin E. 2018. Marine biodiversity of La Reunion Island: Echinoderms. Western Indian Ocean Journal of Marine Science 17(1):111–124.

Durville P., Mulochau T., Barrère A., Quod J.P., Spitz J., Quéro J.C. et Ribes S. 2009a. Inventaire des poissons récoltés lors de l'éruption volcanique d'avril 2007 du piton de la fournaise (île de la Réunion). Annales de la Société des Sciences Naturelles de la Charente-Maritime 9(9):948–956 https://archimer.ifremer.fr/doc/00000/6604/

Durville P., Mulochau T., Alayse J-P., Barrere A., Bigot. et Roland T., 2009b. Exploration sous-marine à l'aide d'un engin de type R.O.V. sur les reliefs profonds de l'île de la Réunion expédition ABYSSEA. Revue d'écologie 64(4) :293–304. http://hdl.handle.net/2042/55792

Durville P., Mulochau T., Quod J-P. et Ballesta L. 2021. Premier inventaire ichtyologique du Mont sous-marin La Pérouse - Ile de La Réunion – Sud-Ouest océan Indien, Expédition La Pérouse, 2019. Annales de la Société des Sciences Naturelles de la Charente-Maritime 11(3):305–327.

Hinderstein L.M., Marr J.C., Martinez F.A., Dowgiallo M.J., Puglise K.A., Pyle R.L., Zawada D.G. and Appeldoorn R. 2010. Theme section on "Mesophotic coral ecosystems: Characterization, ecology and management". Coral Reefs 29:247–251. https://doi.org/10.1007/s00338-010-0614-5

Hoarau L., Rouzé H., Boissin É., Gravier-Bonnet N., Plantard P. Loisil C., Bigot L., Chabanet P., Labarrère P., Penin L., Adjeroud M. and Mulochau T., 2021. - Unexplored refugia with high cover of Scleractinian *Leptoseris* spp. and hydrocorals *Stylaster flabelliformis* at lower mesophotic depths (75–100 m) on lava flows at Reunion Island (southwestern Indian Ocean). Diversity 13: 141 https://www.mdpi.com/1424-2818/13/4/141

Lesser M.P., Slattery M., Laverick J.H., Macartney K.J. and Bridge T.C. 2019. Global community breaks at 60 m on mesophotic coral reefs. Global Ecology and Biogeography. 28:1403–1416 https://doi.org/10.1111/geb.12940

Morato T., Hoyle S.D., Allain V. and NICOL S.J. 2010. Seamounts are hotspots of pelagic biodiversity in the open ocean. Proceedings of the National Academy of Sciences 107(21):9707–11.

Mulochau T., Durville P., Barathieu G., Budet D., Delamarre C., Konieczny O., Quaglietti S., Anker A., Bidgrain P., Bigot L., Bo M., Bonnet N., Bourmaud C., Conand C., De Voogd N., Ducarme F., Faure G., Fricke R., Huet R., Mah C., Maurel L., Messing C., Philippot V., Poupin J., Sartoretto S., Schleyer M., Stöhr S., Trentin F. et Wickel J. 2019. Inventaire faunistique non exhaustif de quelques sites situés en zone récifale mésophotique à Mayotte – Rapport BIORECIF – GALAXEA - DEAL Mayotte. 30 p et annexes. https://hal.archives-ouvertes.fr/hal-03201991

Mulochau T., Durville P. et J. Mathey., 2020a. Exploration de la zone mésophotique de quelques pentes externes de Mayotte à l'aide d'un ROV – Inventaire faunistique non exhaustif - BIORECIF – Rapport MesoMay pour le compte du Parc Naturel Marin de Mayotte. 23 p et annexes https://hal.archives-ouvertes.fr/hal-03202135

Mulochau T., Durville P., Maurel L., Barathieu G., Budet D., Delamarre C., Konieczny O., Loisil C., Quaglietti S., Plantard P., Anker A., Bidgrain P., Bigot L., Bo M., Boissin E., Bonnet N., Bourmaud C., Conand C., De Voogd N., Ducarme F., Faure G., Fricke R., Huet R., Mah C., Messing C., Paulay G., Philippot V., Poupin J., Schleyer M., Stöhr S., Trentin F. et Wickel J., 2020b. Inventaire faunistique non exhaustif de quelques sites situés en zone récifale mésophotique à Mayotte. Programme MesoMay - BIORECIF – Rapport MesoMay 2 pour le compte de la Direction de l'Environnement, de l'Aménagement et du Logement de Mayotte et pour le Parc Naturel Marin de Mayotte. 47 p et annexes https://hal.archives-ouvertes.fr/hal-03202050

Mulochau T., Huet R., Trentin F., Rauby T., Holon F., Ballesta L et Durville P. 2020c. Inventaire des mollusques du Mont sous-marin La Pérouse – Ile de La Réunion, sud-ouest océan Indien. Expédition La Pérouse 2019. Folia Conchyliologica 56:3–15 http://www.cernuelle.com/download.php?lng=fr

MulochauT., Delamarre C. and Conand C., 2020d. First occurrence of the species *Holothuria coronopertusa* in Mayotte, in the Indian Ocean. SPC Beche-de-mer Information Bulletin 40 :46–48. https://coastfish.spc.int/en/publications/bulletins/beche-de-mer/512-beche-de-mer-information-bulletin-40

Mulochau T., Durville P., Fricke R., Plantard P., Loisil C., Broudic L. and Martigné J-C. in press. New observations of nine fish species from Reunion Island observed during an inventory of the fauna of mesophotic zone (70–110 m). *Cybium.*

O'Loughlin P.M., Paulay G., VandenSpiegel D. and Samyn Y. 2007. New *Holothuria* species from Australia (Echinodermata: Holothuroidea: Holothuriidae), with comments on the origin of deep and cool holothuriids. Memoirs of Museum Victoria 64:35–52.

Pinheiro H.T., Shepherd B., Castillo C., Abesamis R.A., Copus J.M., Pyle R.L., Greene B.D., Coleman R.R., Whitton R.K., Thillainath E., Bucol A.A., Birt M., Catania D., Bell M.V. and Rocha L.A. 2019. Deep reef fishes in the world's epicenter of marine biodiversity. Coral Reefs 38:985–995. https://doi.org/10.1007/s00338-019-01825-5

Purcell S.W., Samyn Y. and Conand C. 2012. Commercially important sea cucumbers of the world. FAO Species Catalogue for Fishery Purposes. No. 6. Rome, FAO. 150 p. 30 colour plates.

Pyle R.L. and Copus J.M. 2019. - Mesophotic coral ecosystems: Introduction and overview. In: Loya Y., Puglise K., Bridge T. (eds) Mesophotic coral ecosystems. Coral reefs of the world, vol 12. Springer, Cham https://doi.org/10.1007/978-3-319-92735-0_1

Rocha L.A., Pinheiro H.T., Shepherd B., Papastamatiou Y.P., Luiz O.J., Pyle R.L. and Bongaerts P. 2018. Mesophotic coral ecosystems are threatened and ecologically distinct from shallow water reefs. Science 361:281–284.

Samyn Y., VandenSpiegel D. et Massin C. 2006. Taxonomie des holothuries des Comores. Abc Taxa 1. 130 p.

Smith C.L. 1997. National Audubon Society Field Guide to Tropical Marine Fishes of the Caribbean, the Gulf of Mexico, Florida, the Bahamas, and Bermuda. 720 p. New York, NY: Alfred A. Knopf, Inc.

Turner J.A., Babcock R.C., Hovey R. and Kendrick G.A. 2017. Deep thinking: a systematic review of mesophotic coral ecosystems. ICES Journal of Marine Science, 74(9):2309–2320. https://doi.org/10.1093/icesjms/fsx085

IUCN. 2021. The IUCN Red List of Threatened Species. Version 2021-2. https://www.iucnredlist.org

World Register of Marine Species. 2021. World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. https://doi.org/10.14284/170

First trials to induce spawning and larviculture of *Holothuria scabra* in Palau

Lin Tsung Han[1] and Nan Fan Hua

Introduction

Holothuria scabra, commonly known as sandfish or molech in Palau (Fig. 1), is considered to be one of the most commercially valuable species of sea cucumber that is processed into beche-de-mer (Agudo 2006; Purcell et al. 2017). Since the turn of the century, *H. scabra* has seen a 6- to 12-fold increase in price, with studies indicating that a kilogram of extra-large, premium quality beche-de-mer can fetch up to USD 1800 in Asian markets (Purcell et al. 2018). It is without a doubt that the decline in sea cucumber populations has been driven by their high commercial value. This has led to sea cucumber species such as *H. scabra* being classified as endangered on the International Union for Conservation of Nature (IUCN) red list. A study by Anderson et al. (2011) indicated that although sea cucumbers have been exploited for centuries, only in the last 60 years have the common boom-and-bust patterns appeared, with overexploitation and a lack of fisheries management leading to a decline of 81% of global populations.

The export of *H. scabra* from Palau has been banned since 1994. A study by Pakoa et al. (2009) showed that while sandfish have a limited distribution in Palau due to their particular habitat requirements, aggregations could be found in marine protected areas of Ngatpang State. However, a further study by Pakoa et al. (2014) revealed that *H. scabra* populations in the Palau states of Ngarchelong and Ngatpang had again declined between 2007 and 2012, despite the export ban. This decline was most likely due to uncontrolled and illegal fishing activities. Another study by Kitalong (2008) in the Palauan state of Airai reported a decrease of nearly 80% in *H. scabra* stocks between 1991 and 2008.

The high value of *H. scabra* on the international seafood market, coupled with the relative ease of culturing and the low cost of implementing culture systems, make it an ideal species for aquaculture development (Ferguson et al. 2020). This study focuses on the spawning induction, larval development and nursery establishment of *H. scabra* in order to contribute to the regeneration of declining wild populations and to explore opportunities for commercial aquaculture in Palau.

Methodology

Broodstock collection

Given the local availability of wild *Holothuria scabra* in Palau, 40 individuals were collected from seagrass habitats

Figure 1. *Holothuria scabra* broodstock from Ngarchelong State, Palau. (Image: Lin Tsung Han)

[1] Palau Bureau of Fisheries, PO Box 359, Koror, Palau 96940. Email: Jack40179@yahoo.com.tw

by local fisherwomen in Ngarchelong State for each spawning induction trial. The broodstock were carefully handled and transported to the hatchery approximately one hour's drive from Koror, in 100-L plastic tanks with just enough seawater to cover the sea cucumbers. An underwater aquaculture sea pen was constructed next to the hatchery facility in a calm sandy area for holding the broodstock. This eliminated the need to maintain long-term broodstock in the hatchery tanks.

Induced spawning

In total, 10 induced spawning trials were conducted between December 2020 and June 2021 (Table 1).

For each spawning trial, 40 *H. scabra* were used, ranging between 157 and 270 g in weight. All of the broodstock were gently rinsed with seawater to remove sediment and other unwanted organisms attached to their body, before being transferred and acclimatised to the spawning tank, two days prior to spawning inductions.

The spawning induction combined three stress treatments (Table 2), as outlined by Agudo (2006). The first treatment used to induce spawning was a dry treatment. This was conducted by draining the spawning tanks and leaving the animals in just one inch of water for 1.5–3.0 hours. The tanks were then filled with water at room temperature before undergoing temperature shock in two steps. First, to induce the cold treatment, ice-filled buckets were added to the spawning tanks to gradually lower the water temperature to 20°C, which was then maintained for three hours.

Boiled seawater was then slowly added to the spawning tanks, increasing the water temperature to 33°C, which was then maintained for two hours. At the same time, spirulina powder at a concentration of 20 g/100 L was added to the tanks. Following the final treatment, water in the tanks was returned to ambient temperature through the removal of hot water and addition of ambient temperature seawater. Timing of the initial spawning behaviour from the male *H. scabra* (Fig. 2) ranged from immediately after the temperature was reduced following the final treatment, to almost one hour after the temperature was returned to ambient, with females spawning, on average, one hour later.

Throughout the treatments, gentle aeration was provided to create some water movement within the tanks, and any waste excreted was removed from the tanks to maintain water quality.

Egg collection and larviculture

Fertilisation of the eggs was checked one hour after the first female was observed spawning (Fig. 3). Egg collection then took place two hours after fertilisation by removing the aeration stones and syphoning the eggs from the bottom of the tank into a 200-mesh net[2] placed in a bucket. The eggs

Table 1. Dates and corresponding lunar phases of *Holothuria scabra* spawning trials.

Spawning date	Lunar phase
20 December 2020	9 days before full moon
11 January 2021	2 days before new moon
27 January 2021	Full moon
09 February 2021	2 days before new moon
26 February 2021	Full moon
18 March 2021	9 days before full moon
31 March 2021	5 days after full moon
26 April 2021	Full moon
11 May 2021	New moon
11 June 2021	2 days after new moon

Table 2. Timetable of spawning inducing treatment.

Time	Treatment
09:00–11:00	Dry-out treatment
11:30–14:30	Cold treatment
15:00–16:30	Hot treatment with spirulina bath (20 g/100 L seawater)
17:00–17:30	Ambient temperature/sunset
17:30–19:30	Broodstock spawning

2 https://www.kmizeolite.com/mesh-chart/

Figure 2. Male *Holothuria scabra* spawning. (Image: Tsung Han Lin)

were then rinsed with fresh sea water to remove any dirt or excess sperm, before being placed into concrete rectangular raceways (8.8 m x 1.75 m x 1 m) at a concentration of 0.5 eggs/ml.

Prior to the addition of eggs, the raceways were filled with 1µm-filtered and UV-filtered seawater. Because the raceways are located outside and under cover, no heaters were required to maintain the temperature, which ranged between 28.0 and 29.5°C, with a salinity of 33–35 ppt. This also meant that lighting followed natural day and night cycles and there was no need for artificial lighting. Aeration was distributed evenly throughout the tank to provide gentle water circulation. No water changes or filtration of the tank water were conducted until day 15, when the flow-through system was opened and 1µm-filtered, and UV-filtered seawater was added at a rate of 1 L/min.

On day 2 when the first larvae were observed at the early auricularia stage (Fig. 3), live *Tetraselmis* sp. were used as feed. This was supplemented with 0.5 g of *Spirulina* and *Chlorella* powder daily per raceway, until day 15 when the majority of doliolaria larvae were observed disappearing from the water column, metamorphosing into the benthic pentactula stage (Table 3). At this point, naturally conditioned settlement plates covered with diatoms were deployed into the tanks to provide a greater surface area for settlement.

Table 3. Timetable of the life stages of *Holothuria scabra* from trials conducted, including size ranges.

Stage	Time after fertilisation (days)	Size (µm)
Fertilised eggs	0	177–191
Blastula	1	149–170
Gastrula	2	284–330
Early auricularia	2–3	469–501
Mid auricularia	4–5	708–719
Late auricularia	6–9	718–1131
Doliolaria	10–14	478–632
Pentactula	15–23	362–433
Early juveniles	24	>500

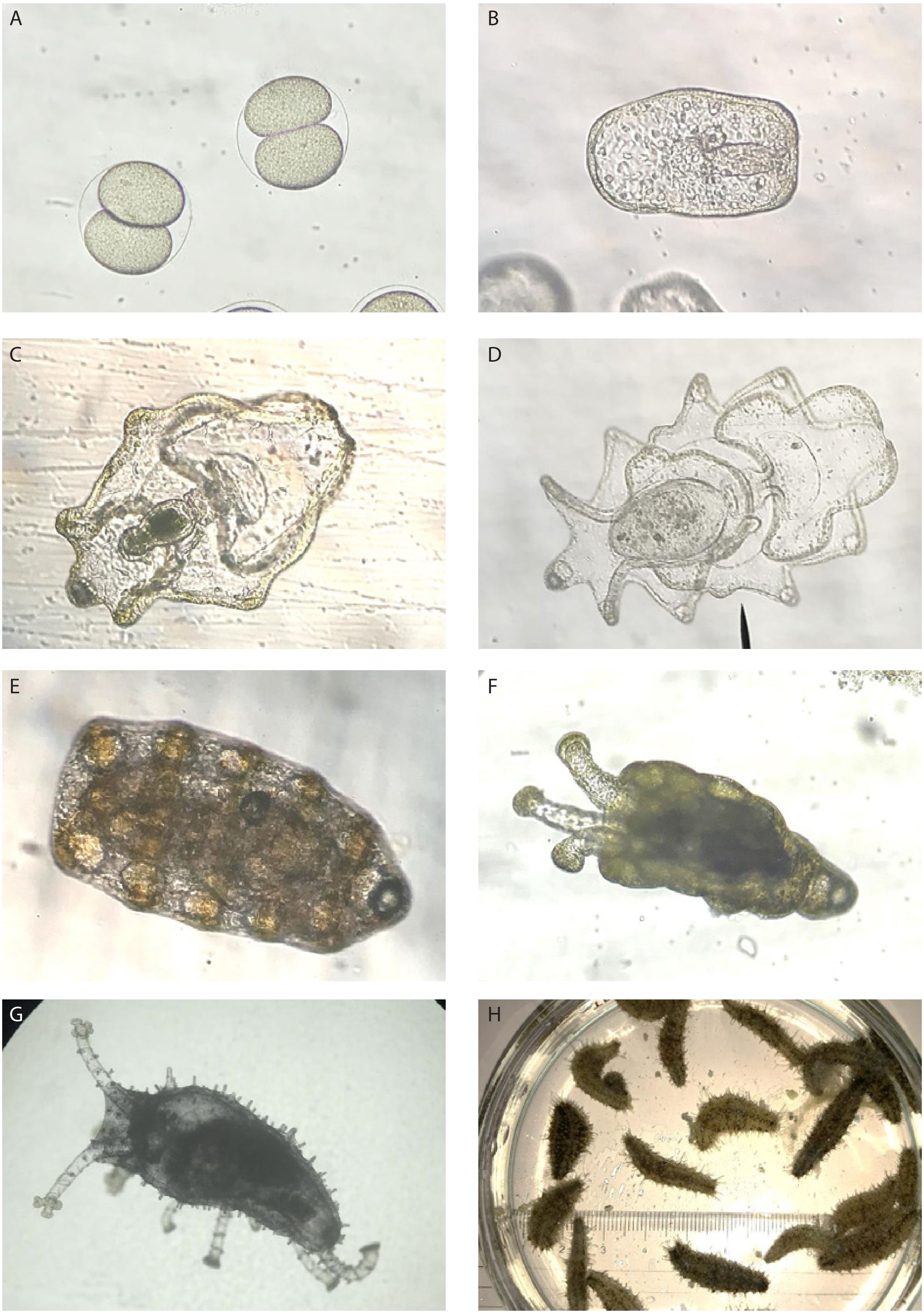


Figure 3. Larval development of *Holothuria scabra*: A) fertilised eggs; B) gastrula; C) early auricularia; D) late auricularia; E) doliolaria; F) pentactula; G) and H) juveniles. (Image: Lin Tsung Han)

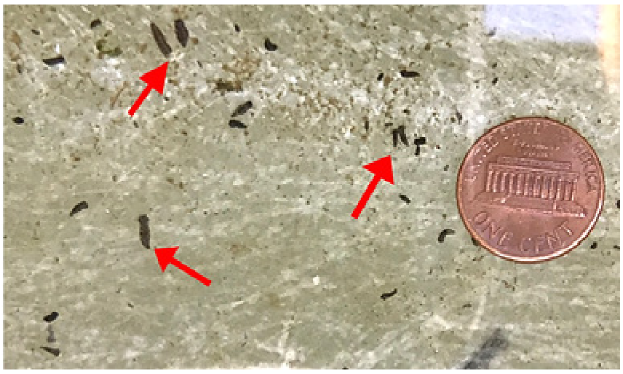


Figure 4. Thirty-day-old *Holothuria scabra* juveniles on settlement plates. (Image: Tsung Han, Lin)

Figure 5. A) Captive-bred *Holothuria scabra* juveniles, 60–90-days old (2–4 g); B) and C) *H. scabra* juveniles being reseeded by community members in seagrass beds of Ngarchelong State, Palau. (Images: Tsung-Han Lin)

Nursery stage

Juveniles of 1-mm length were visible on the settlement plates 24 days after fertilisation (Fig. 4). When they reached 1 mm in size, the juveniles were transferred into new raceways prepared with a thin sandy substrate layer. According to Schagerström (2003), juveniles grow faster on a thin sandy substrate layer than when reared in tanks without sediments. We used a sand layer of approximately 2-mm thickness, and juveniles were stocked at a density of 200–300 individuals/m².

Water was changed daily using a water flow through the raceway at a rate of 1 L every 20 seconds, thereby reducing unwanted algal growth and copepod outbreaks that can severely affect survival rates. No supplemental food was added to the tanks during this period because natural sunlight and water conditions provided an environment for sufficient diatom and algal growth, which the young *H. scabra* can consume. Under this regimen, juveniles reached a weight of 3 g (approx. 4–5 mm in length) between 60 and 90 days after fertilisation, at which stage they were of sufficient size to distribute to local coastal communities, with the aim of restocking wild populations previously depleted from overfishing (Fig. 5) (Purcell and Simutoga 2008).

Results and discussion

After this first successful attempt at inducing spawning and rearing of *Holothuria scabra* in Palau, it is clear that there is potential for the development of sea cucumber rearing and restocking of depleted wild populations. However, it is also apparent that our current methods need refining in order to optimise larval culture and juvenile rearing in Palau.

The combination of the three treatments to induce spawning was effective, with a 100% success rate, indicating that protocols developed with *H. scabra* populations in other countries work in Palau as well. Comparing growth rates of the larval stages experienced in these trials appeared to be on par with existing literature (Agudo 2006; Dabbagh and Sedaghat 2012) with pentactula larvae appearing, on average, between 15 and 23 days after fertilisation (Table 3).

However, differing growth rates were observed with some batches during these trials, with late auricularia larvae taking up to seven weeks to progress to the doliolaria stage. Our overall survival rate from fertilisation to early juvenile stage was lower (<1 %) than the 1–2% survival rate reported by Agudo (2006) and Militz et al. (2018). There may be several reasons for these results, such as our limited sources of live algal cultures for feeding, while most publications recommend the use of varying concentrations of live and dry feed (James 2004; Agudo 2006). Furthermore, the concentration of live algae feeds was not measured, which may have resulted in over or underfeeding. High algal concentrations (>40,000 cells/ml) are known to inhibit larval growth during the auricularia stage (Agudo 2006). It must also be noted that we did not conduct any water changes during the first 15 days of larval rearing, which may have resulted in poor water quality, resulting in suboptimal conditions for larval development (Agudo 2006; Ivy and Giraspy 2006; Ito 2015). Despite these setbacks, our trials did reveal that whilst many *H. scabra* populations have spawning peaks in specific seasons, which also follow lunar cycles (James 2004; Dabbagh and Sedaghat 2012; Penina 2017), it was possible to induce spawning irrespective of the lunar cycle or season in Palau (Table 1).

Following the successful spawning and rearing effort conducted at the hatchery of the Bureau of Fisheries, juvenile *H. scabra* were released into a few selected areas in collaboration with the Ebiil Society. The sites chosen were located inside marine protected areas in order to minimise the possible impact of fishing activities on the survival of the released juvenile *H. scabra*. The releasing methodology and timings were based upon those outlined in existing literature. Purcell and Simutoga (2008) indicate that *H. scabra* juveniles between 3 and 10 g are of sufficient size to be released with a 7–20% survival rate to market size. Purcell (2004) also indicates that releasing juvenile *H. scabra* at this size is the most cost effective.

In total 11,000 juveniles were released between February 2021 and July 2021, with these events also being used as educational opportunities for the local community and school children to further the understanding of sea cucumbers within the marine environment.

In the future, our goal is to refine our techniques, including quantifying survival rates, monitoring water quality, and expanding and diversifying our live feed production, to achieve higher yields. It would allow to accelerate the restocking of wild populations, and a possible distribution of juveniles to local aquaculture farms for commercial rearing. It is also hoped this will provide the basis for larviculture of other domestic sea cucumber species, such as *Actinopyga miliaris* and *Actinopyga* sp., which also play important roles in Palau's sea cucumber fisheries.

Acknowledgements

I would like to thank the Bureau of Fisheries (BOF) Director Ms Adelle Lukes Isechal, Aquaculture Division Chief Mr Percy Rechelluul, and all BOF colleagues, in addition to Executive Director of Ebiil Society Inc. Mrs Ann Singeo for their support during the project and providing materials to carry out this experiment. Thanks also to Mr Alex Ferrier-Loh for giving instructions on the sandfish spawning technique and article editions.

References

Agudo N. 2006. Sandfish hatchery techniques. Noumea: Australian Centre for International Agricultural Research, Secretariat of the Pacific Community and the WorldFish Center. 44 p. https://purl.org/spc/digilib/doc/ze7r8

Anderson S.C., Flemming J., Watson R. and Lotze H.K. 2011. Serial exploitation of sea cucumber fisheries. Fish and Fisheries 12(3):317–339.

Dabbagh A.-R. and Sedaghat M.R. 2012. Breeding and rearing of the sea cucumber *Holothuria scabra* in Iran. SPC Beche-de-mer Information Bulletin 32:49–52. https://purl.org/spc/digilib/doc/sobh3

Ferguson C., Singeo A. and Ferrier-Loh A. 2020. Bridging fishers' and Western scientific knowledges to farm sea cucumbers in a community setting in Palau. SPC Women in Fisheries Information Bulletin 31:47–49. https://purl.org/spc/digilib/doc/z8wqn

Ito M. 2015. A hatchery operations manual for rearing sandfish, *Holothuria scabra*, in Tarawa, Republic of Kiribati. Noumea, New Caledonia: Pacific Community. 54 p. https://purl.org/spc/digilib/doc/gnwyg

Ivy G. and Giraspy D.A.B. 2006. Development of large-scale hatchery production techniques for the commercially important sea cucumber *Holothuria scabra* var. *versicolor* (Conand, 1986) in Queensland, Australia. SPC Beche-de-mer Information Bulletin 24:28–34. https://purl.org/spc/digilib/doc/y6soz

James D.B. 2004. Captive breeding of the sea cucumber, *Holothuria scabra*, from India. FAO Fisheries Technical Papers 463. Rome: FAO.

Kitalong A.H. 2008. Invertebrates, communities, and reef health in Airai, the Republic of Palau. Proceeding of the 11th International Coral Reef Symposium. Florida, USA.

Militz T.A., Leini E., Dinh Quang Duy N. and Southgate P.C. 2018. Successful large-scale hatchery culture of sandfish (*Holothuria scabra*) using micro-algae concentrates as a larval food source. Aquaculture Reports 9:25–30.

Pakoa K., Lasi F., Tardy E. and Friedman K.J. 2009. The status of sea cucumbers exploited by Palau's subsistence fishery. Noumea, New Caledonia: Secretariat of the Pacific Community. 36 p. https://purl.org/spc/digilib/doc/cacy6

Pakoa K., Simpson R., Demei L., Olsudong D., Salong C., Rechelluul P. and Fisk D. 2014. The status of sea cucumber fisheries resources and management for Palau. Noumea, New Caledonia: Secretariat of the Pacific Community. 48 p. https://purl.org/spc/digilib/doc/cjzn9

Penina Tua Rahantoknam S. 2017. Maturity gonad sea cucumber *Holothuria scabra* under the month cycle. IOP Conference Series: Earth and Environmental Sciences 89, 12015.

Purcell S.W. 2004. Criteria for release strategies and evaluating the restocking of sea cucumbers. Session II- Resources Management. FAO Fish. Tech. Pap. (463):181–191. Noumea, New Caledonia: WorldFish Centre.

Purcell S.W. and Simutoga M. 2008. Spatio-temporal and size-dependent variation in the success of releasing cultured sea cucumbers in the wild. Review in Fisheries Science 16(1–3):204–214.

Purcell S.W. and Wu M. 2017. Large-scale sandfish (*Holothuria scabra*) aquaculture in multitrophic polyculture ponds in southern China. SPC Beche-de-mer Information Bulletin 37:51–52. https://purl.org/spc/digilib/doc/to53q

Purcell S.W., Williamson D.H. and Ngaluafe P. 2018. Chinese market prices of beche-de-mer: Implications for fisheries and aquaculture. Marine Policy 91:58–65. https://www.sciencedirect.com/science/article/pii/S0308597X17308035

Schagerström E. 2003. A study of juvenile *Holothuria scabra* (Jaeger) (Echinodermata) on different types of sediment at Bolinao, Pangasinan, Philippines. Degree project work, University of Kalmar, Kalmar, Sweden.

The challenge of economically viable aquaculture of the cold-water sea cucumber *Parastichopus tremulus* in Norway

Gyda Christophersen[1*] and Jan Sunde

Abstract

The cold-water sea cucumber *Parastichopus tremulus* has been identified as a potential aquaculture candidate for sea ranching and integrated aquaculture, mainly due to its high market value. Success, however, depends on whether economically viable growth and survival rates can be achieved during the different life stages. Results from preliminary studies on this species' behaviour in captivity related to feeding and physiology are used to evaluate a probable production time to commercial size and the species' suitability in integrated aquaculture systems.

Keywords: Norwegian red sea cucumber, *Parastichopus tremulus,* biology, growth, aquaculture, IMTA

Introduction

Cold temperatures and slow growth are challenges to cultivating marine species at high latitudes. Seasonal variations in particular influence which species and which life stages can be grown extensively or semi-intensively in the sea or in land-based systems supplied with natural seawater. Low trophic species such as bivalves and macroalgae are typically grown in sea-based systems, utilising only the food produced by nature itself. Even though Norway has a long tradition of cultivating cold-water fish species, the aquaculture of invertebrate species is less developed and characterised by boom-and-bust cycles, depending partly on varying growth conditions, but also due to immature farming practises and obstacles in business development. It is a long-term goal of the Norwegian government to diversify the species that are cultured, and the red sea cucumber, *Parastichopus tremulus,* is among the species listed as a new marine species with the potential for aquaculture in Norway (Akvaplan-niva 2019). A recent review of North Atlantic sea cucumber aquaculture prospects by Landes et al. (2019) concluded that monoculture, polyculture and integrated multi-trophic aquaculture (IMTA), including with *P. tremulus*, could be strategies for diversifying Norwegian aquaculture production. However, biological and technical constraints related to life in captivity still hinder the next step forward in developing a sea cucumber industry based on this species (Christophersen and Sunde 2021). Further substantial research efforts are required to fill the knowledge gaps related to the reproduction, growth and development stages, nutritional requirements, water quality and environmental conditions, all of which are crucial for building a sustainable industry.

Parastichopus tremulus – a suitable deposit-feeding species in integrated aquaculture systems?

The ability of deposit-feeding sea cucumbers to feed on particulate organic waste produced by, for example, mussel farming (Zamora and Jeffs 2011) has led to interest in research on the potential of combining sea cucumber culture with the aquaculture of other species, either in polyculture or more tightly integrated IMTA systems (Zamora et al. 2018). The inclusion of deposit-feeding organisms in mathematical IMTA models opens possibilities for optimising production in integrated aquaculture systems (Cubillo et al. 2016). In Norway, the aquaculture industry is dominated by the aquaculture of salmonids (Atlantic salmon, rainbow trout and trout), which in 2020 reached an output of 1.48 million tonnes (Norwegian Directorate of Fisheries 2021). In comparison, the aquaculture of molluscs, crustaceans and echinoderms is marginal, with a total annual production of only 2071 tonnes (Norwegian Directorate of Fisheries 2021). There has been an increased interest in recent years in integrating the farming of seaweed and other low trophic species with existing salmonid farms to create IMTA systems.

Atlantic salmon and rainbow trout production in Norway takes advantage of the geographical features of Norway's long sheltered coast and uses open cage systems located in areas of good water quality. Feed waste from open cage-based fish farms is continuously being reduced due to technological innovations, but fish farms still release substantial amounts of dissolved nutrients and particulate matter annually. In addition, land-based aquaculture systems face the problem of accumulation of particulate waste (sludge). This waste represents a potential feed resource for suspension-feeding species as well as deposit-feeding lower trophic species. Research on other species as "add-ons" to salmonid aquaculture in Norway has, to a large extent, focused on macroalgae, blue mussels, polychaetes and ascidians, whereas comparatively little has been carried out on sea cucumbers. The inclusion of sea cucumbers in IMTA systems has the potential to decrease the sediment and nutrient loads to the environment, thus contributing to healthy waters and added production value.

[1] Møreforsking AS, PO Box 5075, N-6021 Ålesund, Norway
[*] Author for correspondence: gyda.christophersen@moreforsking.no

The red sea cucumber *Parastichopus tremulus* has been identified as a potential aquaculture candidate for sea ranching and integrated aquaculture, mainly due to its high market value (Landes et al. 2019; Schagerström et al. 2021). However, its suitability in such systems, and the possibility of establishing a viable aquaculture industry will, among other factors, depend on whether economically viable growth and survival rates can be achieved. Their potential for North American sea cucumber species to be part of an IMTA system has been demonstrated (Nelson et al 2012; Hannah et al. 2013). The first steps in assessing the suitability of *P. tremulus* will, therefore, be to document its capacity for consuming waste from other aquaculture organisms (fish, shellfish, seaweed/kelp) as well as evaluating its performance and growth in open-water systems versus under controlled environmental conditions. We have several ongoing projects in our lab investigating the potential for growth and nutrient recycling of *P. tremulus* in integrated aquaculture systems, including studies on the uptake of nutrients from different feed sources, the effect of water quality, and the development of larval and broodstock rearing practices.

In our lab, initial feeding trials have documented that *P. tremulus* will feed on a mixture of sand and dried sludge obtained from a local fish farm (J. Sunde and G. Christophersen, unpublished). Analyses are ongoing, comparing nutrient uptake from sludge and a standard feed mix of sand and dried *Sargassum* spp. In the same project, we also explore growth and survival of *P. tremulus* by placing sea cucumbers in cages underneath salmon fish farms. Similar studies have been performed on other cold-water sea cucumber species, with varying results. For instance, Sun et al. (2020) found that the suspension-feeding sea cucumber *Cucumaria frondose*, cultured in the effluent from a land-based salmon farm, assimilated nutrients from the fish waste but decreased in size during a long-term experimental period, and had smaller organ indices compared to wild controls. Hannah et al. (2013) found seasonal growth patterns of small and large *Parastichopus californicus* when it was co-cultured with sablefish. Fortune (2018) also found seasonal variation in growth rates of juvenile *P. californicus* placed underneath a Pacific oyster farm, and registered negative growth rates during the autumn and winter seasons. At present, growth rates of the different stages of *P. tremulus* as well as seasonal variations in nature are unknown and therefore we lack the baseline knowledge for comparing to what extent modified environmental conditions are beneficial in terms of biomass production.

Initial growth studies on small individuals

In our lab, experimental animals originated from the nearby fjords of Ålesund in Møre og Romsdal County (62°N and 6°E) in western Norway (Fig. 1). The sea cucumbers were obtained from bycatch in commercial coastal trawl and pot fisheries, and primarily intended as broodstock for inducing spawning in captivity. The majority (76%) of *P. tremulus* individuals that we received during the period 2017–2021 had a body length between 10 and 20 cm, corresponding to a total wet weight of 28–297 grams, while 6% measured ≤ 8 cm in length (Fig. 2). The potentially smallest mature specimens we have observed in our lab, based on the presence of gonad tissue, were approximately 8 cm in length (Christophersen et al. 2021). We cannot conclude this is the size at first maturity based on so few observations, although it does indicate that *P. tremulus* reached adulthood by this size. Nevertheless, juvenile sizes of different sea cucumber species in the field have been reported as ranging between 0.3 and 21 cm in length (Shiell 2004), with the smallest registered specimen of *P. tremulus* measuring 2 cm (Kjerstad et al. 2015). The maximum juvenile length of another temperate sea cucumber, *Australostichopus mollis*, is reported to be <7 cm (Slater et al. 2010), and Fortune (2018) included specimens from 1 to 10 cm contracted length in juvenile studies of *P. californicus* in Canada.

With the exception of growth rates during larval rearing (Schagerström et al. 2021), no published results on the growth of *P. tremulus* exists. Due to a lack of reared juveniles, we selected the smallest individuals from sea cucumbers that had been kept under lab conditions for one to two years prior to the experiment in order to perform a baseline growth study of the "next stage" (Fig. 3). Because of their age, these individuals were most probably beyond the stage of being termed juveniles. Their initial size varied from 42 to 92 mm in length and from 5 to 25 g total wet weight. They were held in flow-through tanks supplied with unfiltered seawater from 40 m depth and without extra bottom substrate. The animals were occasionally fed but were allowed to empty their intestines a couple of weeks prior to the experiment. Twenty-four individuals were distributed in three experimental (fed) groups and one control group, respectively, each consisting of six individuals with a total biomass of 79.1 ± 6.1 g (mean ± sd, n = 4). The average start weight of individuals was 13.2 ± 6.4 g (mean ± sd, n = 24). The control group was supplied only with unfiltered seawater, with no supplementary feed other than the organic matter present in the incoming water. The fed groups were provided additional feed at a 50:50 (vol:vol) mix of *Sargassum* sp. (dried powder) and sand (particle size 0.6–1.0 mm) in excess during the whole growth period (approx. 30% dried weight *Sargassum* per animal wet weight every 14 days). Growth was calculated monthly, based on individual length and weight measurements, as a specific daily growth rate (SGR)(%/day) using the equation

$$SGR = \frac{\ln S2 - \ln S1}{t} \times 100$$

where S = mean size (length or weight) at final (S2) and previous (S1) sampling time, and t = length of growth interval (days).

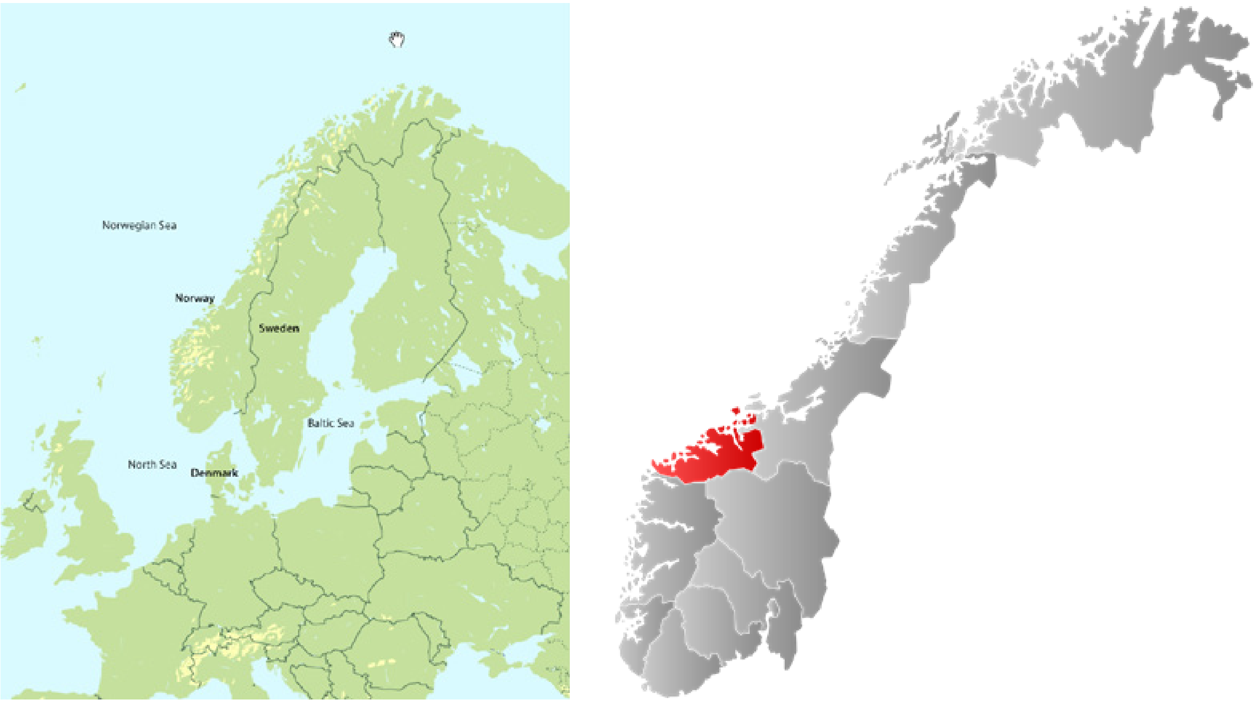


Figure 1. Norway showing the location of Møre og Romsdal County, in red. (Images: https://www.visitnorway.com/maps [left] and Wikimedia Commons, CC-BY-SA-3.0 [right])

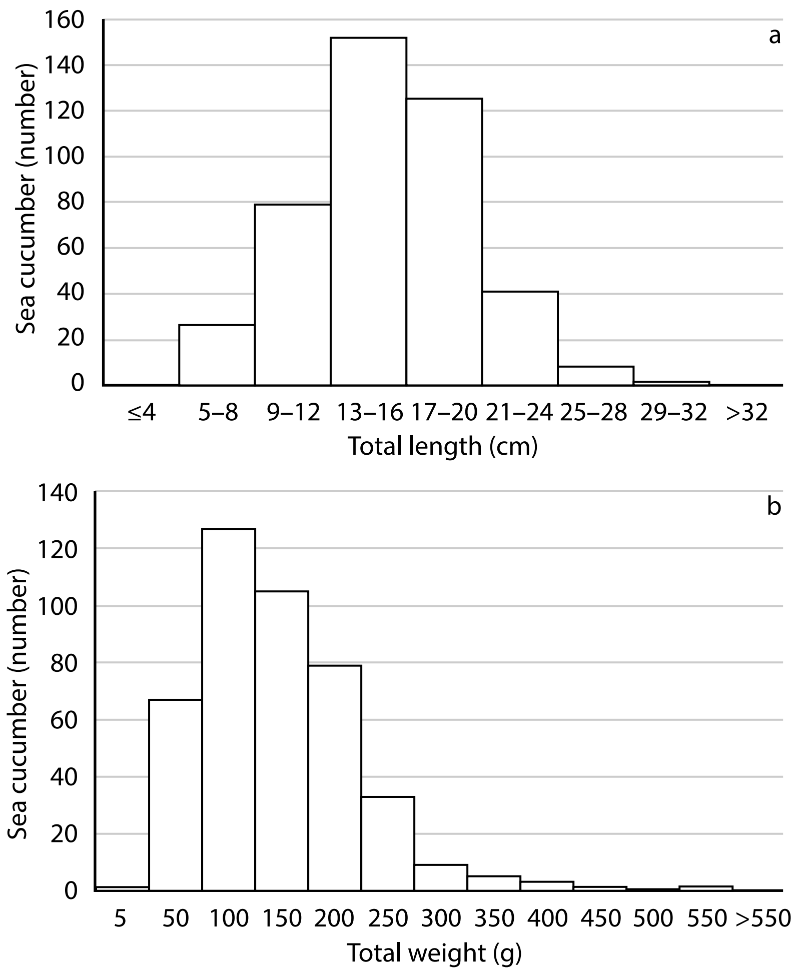


Figure 2. Frequency distribution of sea cucumbers according to their length (2a) and weight (2b) during the period 2017–2021 (n = 432).

Figure 3. Experimental group of *Parastichopus tremulus* kept under lab conditions.

The temperature and salinity of the incoming water in our lab varies with the season. Salinity varies between 31 and 34 ppt. During the experimental period, the temperature fluctuated from 8.2 to 12.7°C, with a mean temperature 9.4 ± 0.8 (SD) (Fig. 4). Temperature was measured every 15 minutes using waterproof temperature loggers (Hobo TidbiT v2). At the depths at which the sea cucumbers are caught (100–200 m) the temperature is 7–9°C throughout the year, whereas 6–14°C is normal at depths of <50 m.

The control group grew less than the fed groups during the period May to October. The average length of the studied animals varied between months (Fig. 5a), and SGR over the total period was 0.02/day in the control group and 0.08%/day in the fed groups. The biomass growth showed diverging growth in wet weight between the unfed and fed sea cucumbers from May to July (Fig. 5b). Thereafter, growth slowed down and negative growth rates were observed from July to October in the fed groups, whereas the control group seemed to level out in size (Fig. 5, Table 1). Across the growth period, the control group showed negative growth based on weight (-0.09%/day) and the fed groups positive growth (0.03%/day). The highest interval growth rate in length was 0.21%/day, and for weight 0.28%/day (Table 1).

Reflections on the potential of cultivating *Parastichopus tremulus*

Successful aquaculture relies on the ability to close and maintain the complete life cycle of the target species in captivity, and predictably provide spat (juveniles) to farming operations. More research and investment are needed to be able to understand the biology of the different *P. tremulus* life stages and achieve viable production. The different life stages (larvae, juveniles, adults) require conditions that suit their physiology and feeding habits. We assume that the metabolism (oxygen consumption) of cold-water sea cucumber species is lower than that of warmer water species when in their natural habitat, and that *P. tremulus* will, therefore, grow more slowly than tropical species. In aquaculture,

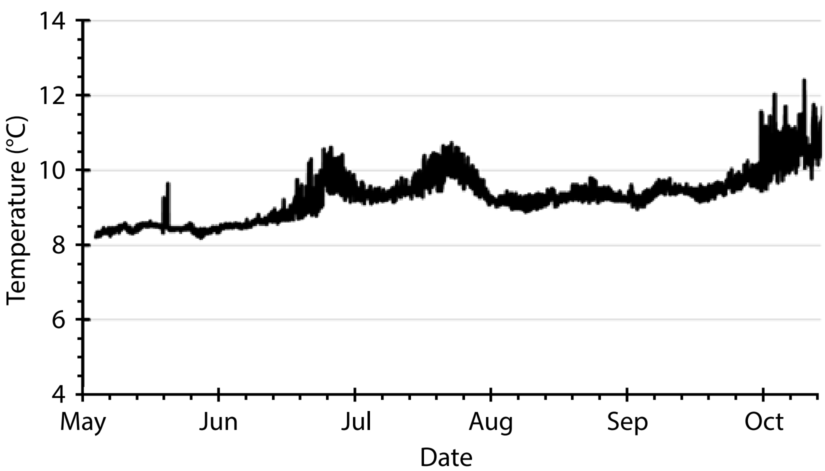


Figure 4. Temperature during the experimental period from May to October 2021.

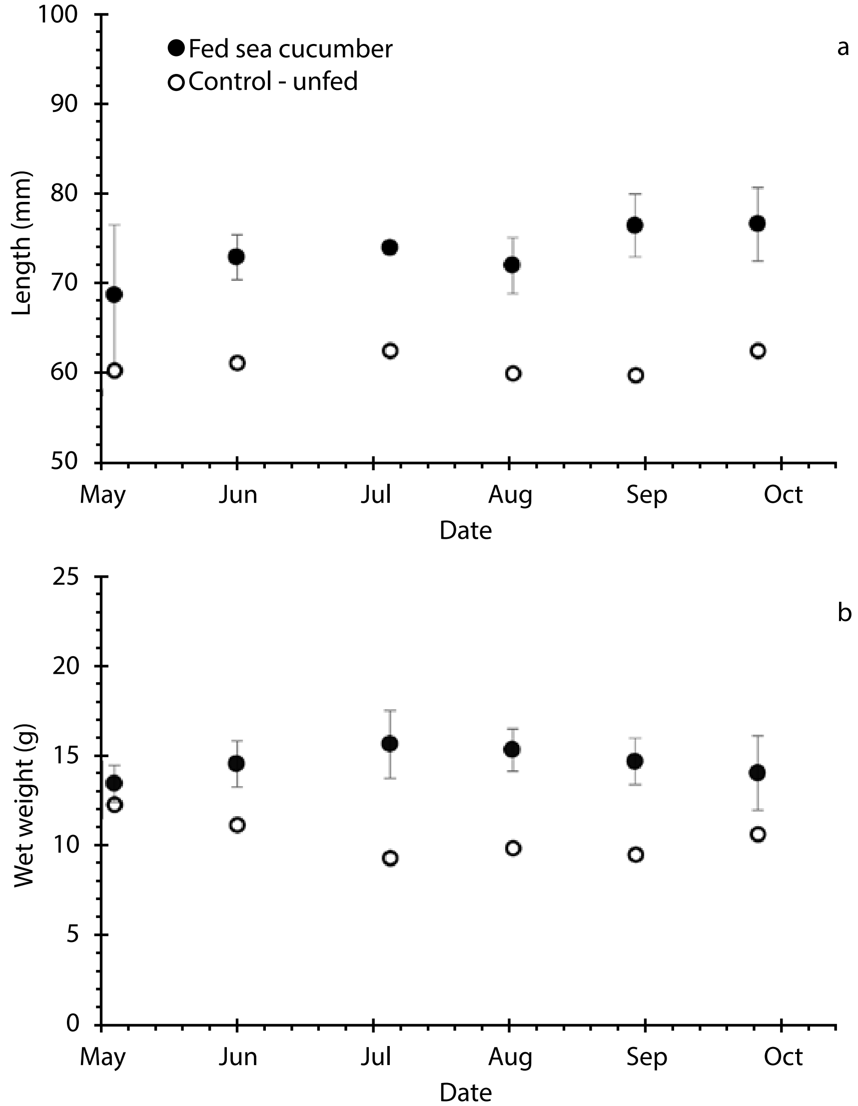


Figure 5. Length a) and weight b) of *Parastichopus tremulus* from May to October. Control animals were only supplied with unfiltered seawater. Black circles show the average ± SD growth of sea cucumber groups (n = 3) provided with additional feed.

Table 1. Monthly specific growth rate (SGR%/day) of *Parastichopus tremulus* total length and total weight. Control animals were supplied unfiltered seawater only. The "Fed" columns shows the average growth of sea cucumber groups (n = 3) provided additional feed.

SGR	Length (%/day)		Weight (%/day)	
Period	Control	Fed	Control	Fed
May–Jun	0.05	0.21	-0.34	0.28
Jun–Jul	0.06	0.04	-0.52	0.20
Jul–Aug	-0.15	-0.10	0.20	-0.07
Aug–Sep	-0.01	0.21*	-0.13	-0.15*
Sep–Oct	0.16	0.01	0.40	-0.16

*One sea cucumber died during the time interval.

temperature and feed conditions can be optimised to facilitate growth. The combined effects of temperature and food concentration have been studied for *P. tremulus* larvae, showing the possibility of growing pelagic larvae at temperatures above what we assume would normally be experienced in nature (Schagerström et al. 2021). Specific growth rates of larvae in our lab were between 18% and 20%/day during the first week, and 1–4%/day until day 20. Larvae were reared at an approximate mean temperature of 15°C (Christophersen and Sunde 2021). Whether adequate growth rates can be achieved during later stages remains to be seen.

Our study is very preliminary and includes many biases, given the low number of individuals per test group (n = 6), and the uncertainty related to the age and variation in size, which is related to the age of the individuals used.

In this study, the supplied seawater was not temperature controlled, but followed the natural seasonal fluctuation. The incoming water was supplied from a shallower depth (40 m) than from where the sea cucumbers originally were caught (100–200 m). We offered what is currently our standard feed (*Sargassum* spp. and sand mix), a mix often provided as the main feed component in *Apostichopus japonicus* aquaculture (Shi et al. 2015). Our preliminary results suggest that *P. tremulus* achieves low growth rates in culture under these conditions. Weight-specific growth rates were lower (<0.5 SGR %/day) in late spring-summer than the >1 SGR %/day found for *P. californicus* (Hannah et al. 2012), but similar to this study, we also measured negative growth rates. Our study is still ongoing and will follow the growth development for 12 months under present conditions, before replacing the feed type and/or feed distribution method. Currently, it is difficult to evaluate if the negative growth response is due to suboptimal environmental conditions or nutrition, or to a seasonal feeding and growth pattern where feeding ceases during autumn and winter, as postulated by other authors (Jespersen and Lützen 1971). Manipulation with temperature and feed quality is likely to improve growth compared to the results we have obtained so far.

We do not know the size-at-age of *Parastichopus tremulus*, but the results indicate that the species is slow growing, similar to other sea cucumber species living at higher latitudes such as *Cucumaria frondosa* (Hamel and Mercier 1996; So et al. 2010) and *P. californicus* (Cameron and Fankboner 1989; Paltzat et al. 2008; Fortune 2018). The low growth rates measured in our preliminary studies are in line with previous oxygen consumption measurements of *P. tremulus* performed in our lab. We found that the average oxygen consumption rate (OCR) was 0.29 mg O_2/hour/individual (11.5 ± 1.5 cm, 60 ± 15 g) at 14°C, corresponding to 1.98 µg O_2/hour/g body weight (A. Landes unpublished). This is in accordance with Fox (1936), who measured individuals weighing 130 g and found the OCR at a temperature of 6°C to be between 0.70 and 2.30 µg O_2/hour/g body weight, with an average of 1.80 µg O_2/hour/g body weight. In comparison, faster growing species living at higher temperatures, such as the tropical *Holothuria scabra* show OCR orders of magnitude higher (12–60 µg O_2/hour/g at 27°C) and a decrease in OCR with increasing body weight (Kodama et al. 2015; Kühnhold et al. 2019). Juveniles of the temperate species *Actinopyga japonicus* that weighed <5 g and grown at 15°C and 18°C also showed OCRs within a similar range (Dong and Dong 2006).

To what extent the growth of *P. tremulus* can be modulated in culture by manipulating environmental conditions and optimising feed composition remains to be seen. There are indications, however, that even under optimal conditions, this species might be much slower growing than temperate and tropical species that are already cultured in large volumes. There is also the question of whether the animals go through seasonal feeding behaviours, cessation in feeding or intestine atrophy during the winter months (Jespersen and Lützen 1971; Fankboner and Cameron 1985; Hannah et al 2013; Fortune 2018), a matter that further complicates the development of aquaculture management practices. Based on our average size measurements and two of the higher positive SGRs (0.20 and 0.05) we attempted to predict an approximate time to rear the larvae to commercial size, which is 15 cm in length, according to whole traders. Based on length–growth measurements, the estimated time needed to reach a length of 15 cm from a start length of 7 cm will be between one and four years under our laboratory conditions. Based on the corresponding weight growth measurements and the equivalent weights (115 g from a start weight of 15 g), estimates of time to commercial size will be between 3 and 11 years. Assuming that the experimental animals of approximately 7 cm are a minimum of two to three years old, and that an additional growth period of a minimum of one to two years is needed, these estimates suggest that commercial size (length) could be reached within four to five years.

Our results indicate that *P. tremulus* is a slow-growing species. Under the conditions used in this first experiment, economically viable aquaculture production seems unlikely at this stage. However, a production cycle of four to six years is not unusual for marine species in cold-water areas. More knowledge is needed to explore the possibilities of reducing the production time during the different stages within the biological limits of *P. tremulus*. It is to be expected that growth can be increased through development of suitable feeds and improved culture technology, and that profitable production of *P. tremulus* may be possible in the future. However, substantial research efforts are still needed to establish the nutritional requirements and optimal rearing conditions for this species.

Acknowledgements

The work has been funded by the Research Council of Norway – SANOCEAN (project no. 288536), and the Møre og Romsdal County Municipality – marint miljø og verdiskapingsfond (grant no. 2018-0150).

References

Akvaplan-niva A.S. 2019. Kunnskapsgrunnlag for nye arter i oppdrett (in Norwegian). APN-report 60679. https://www.regjeringen.no/no/dokumenter/kunnskapsgrunnlag-for-nye-arter-i-oppdrett/id2685473/

Cameron J.L. and Fankboner P.V. 1989. Reproductive biology of the commercial sea cucumber *Parastichopus californicus* (Stimpson) (Echinodermata: Holothuroidea). II. Observations on the ecology of development, recruitment, and the juvenile life stage. Journal of Experimental Marine Biology and Ecology 127:43–67.

Christophersen G. and Sunde J. 2021. Norwegian red sea cucumber (*Parastichopus tremulus*). Steps towards life in captivity – a viable option? Poster at Aquaculture Europe 2020, April 2021. doi: 10.13140/RG.2.2.31943.83366

Christophersen G., Bakke S. and Sunde J. 2021. Norwegian red sea cucumber (*Parastichopus tremulus*) fishery and aquaculture north of 60°N latitude: Feasible or fictional? SPC Beche-de-mer Information Bulletin 41:15–36. https://purl.org/spc/digilib/doc/fvfxj

Cubillo A.M., Ferreira J.G., Robinson S.M.C., Pearce C.M., Corner R.A. and Johansen J. 2016. Role of deposit feeders in integrated multi-tropic aquaculture – A model analysis. Aquaculture 453:54–66.

Dong Y. and Dong S. 2006. Growth and oxygen consumption of the juvenile sea cucumber *Apostichopus japonicus* (Selenka) at constant and fluctuating water temperatures. Aquaculture Research 37(13):1327–1333.

Fankboner P.V. and Cameron J.L. 1985. Seasonal atrophy of the visceral organs in a sea cucumber. Canadian Journal of Zoology 63:2888–2892.

Fortune A.C. 2018. Integrated multi-trophic aquaculture with the California sea cucumber (*Parastichopus californicus*): Investigating grow-out cage design for juvenile sea cucumbers co-cultured with Pacific oysters (*Crassostrea gigas*). M.S. thesis, Simon Fraser University, British Columbia, Canada.

Fox H.M. 1936. The activity and metabolism of poikilothermal animals in different latitudes. I. Proceedings of the Zoological Society of London 106(4):945–955.

Hamel J.F. and Mercier A. 1996. Early development, settlement, growth, and spatial distribution of the sea cucumber *Cucumaria frondosa* (Echinodermata: Holothuroidea). Canadian Journal of Fisheries and Aquatic Sciences 53(2): 253–271.

Hannah L., Duprey N., Blackburn J., Hand C.M. and Pearce C.M. 2012. Growth rate of the California sea cucumber *Parastichopus californicus*: Measurement accuracy and relationships between size and weight metrics. North American Journal of Fisheries Management 32:167–176.

Hannah L., Pearce C.M. and Cross S.F. 2013. Growth and survival of California sea cucumbers (*Parastichopus californicus*) cultivated with sablefish (*Anoplopoma fimbria*) at an integrated multi-trophic aquaculture site. Aquaculture 406:34–42.

Jespersen A. and Lützen J. 1971. On the ecology of the aspidochirote sea cucumber *Stichopus tremulus* (Gunnerus). Norwegian Journal of Zoology 19:117–132.

Kjerstad M., Ringvold H., Søvik G., Knott E.K. and Thangstad T.H. 2015. Preliminary study on the utilisation of Norwegian red sea cucumber, *Parastichopus tremulus* (Gunnerus, 1767) (Holothuroidea, Echinodermata), from Norwegian waters: Resource, biology and market. p. 109–132. In: Gundersen A.C. and Velle L.G. (eds). Blue Bio-resources. Orkana Akademisk, Norway.

Kodama M., Sumbing J.G., Lebata-Ramos M.J.H. and Watanabe S. 2015. Metabolic rate characteristics and sediment cleaning potential of the tropical sea cucumber *Holothuria scabra*. Japan Agricultural Research Quarterly 49(1):79–84.

Kühnhold H., Steinmann N., Huang Y.H., Indriana L., Meyer A. and Kunzmann A. 2019. Temperature-induced aerobic scope and Hsp70 expression in the sea cucumber *Holothuria scabra*. Plos one 14(3):e0214373.

Landes A.M., Sunde J. and Christophersen G. 2019. Atlantic Sea cucumber species in the spotlight – Prospects for Norwegian aquaculture. p. 19–49. In: Akslen-Hoel L. K. and Egilsson B. (eds). International perspectives on regional research projects and practice. Orkana Akademisk, Norway.

Nelson E.J., MacDonald B.A. and Robinson S.M.C. 2012. A review of the northern sea cucumber *Cucumaria frondosa* (Gunnerus, 1767) as a potential aquaculture species. Reviews in Fisheries Science 20(4):212–219.

Norwegian Directorate of Fisheries 2021. https://www.fiskeridir.no/Akvakultur/Tall-og-analyse/Akvakulturstatistikk-tidsserier

Paltzat D.L., Pearce C.M., Barnes P.A. and McKinley R.S. 2008. Growth and production of California sea cucumbers (*Parastichopus californicus* Stimpson) co-cultured with suspended Pacific oysters (*Crassostrea gigas* Thunberg). Aquaculture 275(1–4):124–137.

Schagerström E., Christophersen G., Sunde J., Bakke S., Matusse N.R., Dupont S. and Sundell K.S. 2021. Controlled spawning and rearing of the sea cucumber, *Parastichopus tremulus*. Journal of the World Aquaculture Society. DOI: 10.1111/jwas.12816

Shi C., Dong S., Wang F., Gao Q. and Tian X. 2015. Effects of the sizes of mud or sand particles in feed on growth and energy budgets of young sea cucumber (*Apostichopus japonicus*). Aquaculture 440:6–11.

Shiell G. 2004. Field observations of juvenile sea cucumbers. SPC Beche-de-mer Information Bulletin 20:6–11.

Slater M.J., Carton A.G. and Jeffs A.G. 2010. Highly localised distribution patterns of juvenile sea cucumber *Australostichopus mollis*. New Zealand Journal of Marine and Freshwater Research 44(4):201–216.

So J.J., Hamel J.F. and Mercier A. 2010. Habitat utilisation, growth and predation of *Cucumaria frondosa*: implications for an emerging sea cucumber fishery. Fisheries Management and Ecology 17(6):473–484.

Sun J., Hamel J.F., Gianasi B.L., Graham M. and Mercier A. 2020. Growth, health and biochemical composition of the sea cucumber *Cucumaria frondosa* after multi-year holding in effluent waters of land-based salmon culture. Aquaculture Environment Interactions 12:139–151.

Zamora L.N. and Jeffs A.G. 2011. Feeding, selection, digestion and absorption of the organic matter from mussel waste by juveniles of the deposit-feeding sea cucumber, *Australostichopus mollis*. Aquaculture 317(1–4):223–228.

Zamora L.N., Yuan X., Carton A.G. and Slater M.J. 2018. Role of deposit-feeding sea cucumbers in integrated multitrophic aquaculture: progress, problems, potential and future challenges. Reviews in Aquaculture 10(1):57–74. https://doi.org/10.1111/raq.12147

Culinary valorisation of sea cucumbers from the Algerian west coast

Nour-el-Houda Belkacem[1] and Karim Mezali[1]*

Abstract

In Algeria, sea cucumbers are not available through sales outlets and are less appreciated by Algerian consumers. The present work aimed to introduce sea cucumbers into the national cuisine. For that, 70 sea cucumbers – comprising the two species *Holothuria tubulosa* and *H. arguinensis* – were collected from the western coastal region of Mostaganem in Algeria. Once the sea cucumbers were dried, we prepared four dishes imitating the recipes of dishes commonly consumed in Algerian cuisine. A tasting session was carried out on a sample of the population of the Mostaganem region in order to have an idea of the quality of each prepared dish.

Keywords: sea cucumber-based dishes, tasting, nutritional value, Mostaganem

Introduction

Nowadays, sea cucumbers are considered to be excellent food and nutritional products. Indeed, they are rich in essential amino acids, have a high protein content (5–12% of fresh body weight) and are considered to be a source of omega-3, omega-6 and other fatty acids (Zhong et al. 2007; Mecheta et al. 2020). They are rarely consumed in the Mediterranean region, and all catches are exported to Asian countries (Aydin 2018; Mezali and Slimane-Tamacha 2020) where they are sold in shops at very high prices. The Chinese consume sea cucumbers on special occasions such as during festive meals (Purcell 2017). The body wall, longitudinal muscles and viscera are the most consumed parts of the sea cucumbers (Conand and Byrne 1993). The most important Mediterranean species are *Holothuria poli, H. tubulosa* and *H. arguinensis.* Since 2008, the collection of sea cucumber species in Algeria is allowed but not for commercial purposes (Mezali et al. 2021). The use of sea cucumbers as a food source, however, began in China 1000 years ago (Purcell et al. 2012).

In 2020, a survey conducted by Mezali and Slimane-Tamacha indicated that sea cucumbers are not available through traditional sales outlets and are not really appreciated by Algerian consumers. A survey conducted by Mezali et al. (2021) showed that the most consumed seafood in Algeria are round sardines, sardinella and anchovies (due to their accessibility and affordability), and shrimps, lobsters and mussels when budgets allow. This survey also showed that although sea cucumbers are little known by Algerian consumers, the majority of respondents were willing to introduce them in their culinary dishes. For the present study, we prepared different sea cucumber dishes for a tasting session to assess whether they can be enjoyed by the western Algerian community.

Methodology

Seventy sea cucumber individuals comprising the two most abundant species – *Holothuria tubulosa* and *H. arguinensis* – were sampled during October 2021 at "Petit-port" station in the municipality of Sidi-Lakhdar, Mostaganem, on the west coast of Algeria (36°12'25.8"N, 0°22'29.9"E). The sampled individuals were processed into the dry product beche-de-mer (Purcell 2017). Four culinary dishes were prepared using the dry product, similar to the most popular recipes in Algeria. A tasting session was held at the Faculty of Natural and Life Sciences at the University of Mostaganem, Algeria. A questionnaire, prepared in two languages (French and Arabic), was distributed to 42 people of different sexes and ages in order to gain their opinions on the quality of each sea cucumber dish according to its similarity with other dishes commonly consumed by the Algerian community (see Box 1).

Processing fresh product into beche-de-mer

The transformation of freshly harvested sea cucumbers into beche-de-mer is based on the simple traditional methods described by Purcell (2017): cleaning, salting, cooking and sun drying. Each individual is dissected and emptied of its digestive tract and viscera (Fig. 1A). The integument is rinsed with tap water and washed of all traces of sediment, then drained and wrapped in absorbent paper (Mezali 1998) and placed in a box filled with coarse salt (1 kg per 3 kg of sea cucumbers) for 2–5 days (Fig. 1B). After that, the animals are placed in a saucepan filled with hot water and boiled until the water reaches 70–90°C, stirring every 5 minutes to avoid damage to the integuments (Fig. 1C). For the first cooking, the integuments are boiled for 10–30 minutes until they have a soft consistency. After that, they are drained into a strainer (Fig. 1D), spread on a cotton towel, and then dried in the open air in a place exposed to

[1] Protection, Valorization of Coastal Marine Resources and Molecular Systematic Laboratory, Department of Marine Science and Aquaculture, Faculty of Natural Sciences and Life, University of Mostaganem Abdelhamid Ibn Badis, PO Box 227, 27000, Mostaganem, Algeria.
* Author for corespondence: karim.mezali@univ-mosta.dz

the sun for 4–5 days (Fig. 1E). The drying time depends on how cloudy the sky is. The product obtained after drying has a very hard consistency (Fig. 1F).

In order to improve product quality and to give the sea cucumber a straight shape, a second cooking is carried out after 2–3 days of sun drying (Purcell 2017). In order to rid the integuments of their calcareous deposits, each integument is placed for 24 h in water mixed with white vinegar (one part vinegar to three parts water). After that, each integument is scrubbed using a stiff brush. This operation removes all of the calcareous deposits from the integument. At this stage, the product is ready to be used in various dishes.

Preparation of sea cucumber-based dishes

Four dishes were prepared for the tasting survey (Fig. 2).

Sea cucumber with white sauce (Fig. 2A)

To prepare the white sauce, in a pan, 3 tablespoons of vegetable oil are mixed with well-fried green onion, garlic, mushrooms, spices and afterward fresh cream. Cut the sea cucumber into small pieces, add to the sauce, and cook and stir over a low heat for 5 minutes until softened.

Marinated sea cucumber salad (Fig. 2B)

Cut sea cucumber into very small pieces and add a half a teaspoon of salt, and a dash of black pepper to 45 ml of lemon juice, 3 tablespoons of vegetable oil, finely chopped parsley, small diced carrots, mustard, mushrooms, olives (cut into small pieces), leafy thyme, two cloves of miinced garlic and red pepper. After mixing everything, store the marinated sea cucumber salad in the refrigerator (at 5°C).

Sea cucumber bourek (Fig. 2C)

Bourek is a delicious Algerian festive meal starter served during the holy fasting month (Ramadhan) to accompany traditional chorba (soup). The name is Turkish and this starter is the signature dish in Algiers. It is usually prepared from the leaves of "dioule" or "brick" (very fine paste composed of wheat flour, cornstarch, water and salt) filled with minced meat, tuna, eggs, chicken or cheese. Our bourek replaced minced meat with chopped sea cucumber. A grated onion is cooked over low heat with a little vegetable oil. Once cooked, an egg with grated cheese is added. In the meantime, the integuments of sea cucumbers are cut into small pieces (3–4 cm), and then chopped using an electric chopper, adding spices (half a teaspoon of salt and black pepper, cumin, paprika and finely chopped parsley). After mixing

Figure 1. Steps to transform fresh sea cucumbers into dried product. A) cutting and cleaning; B) salting; C) cooking; D) integuments drained in a strainer; E) sun drying; F) final dried product beche-de-mer.

Figure 2. The dishes presented for the tasting survey: A) sea cucumber with white sauce and mushrooms; B) sea cucumber bourek; C) marinated sea cucumber salad; D) minced sea cucumber meatballs; and E) tasting plate of the four sea cucumber dishes and the questionnaire.

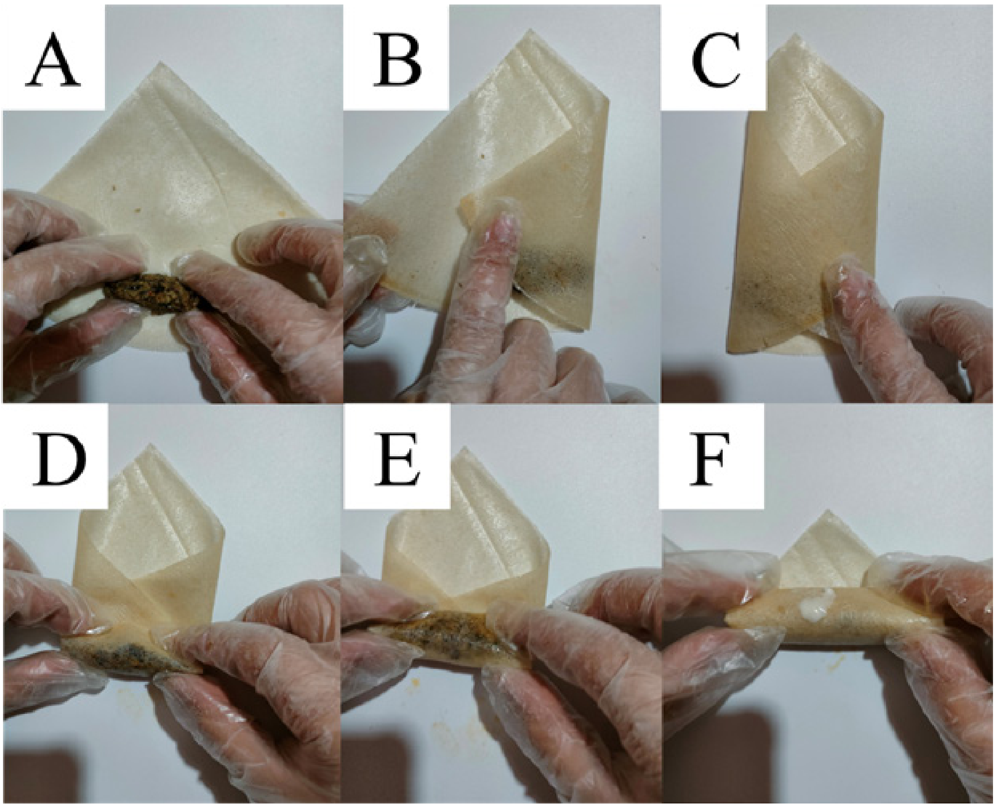


Figure 3. Preparation of sea cucumber bourek. A) Placing the stuffing on a leaf of dioule; B) closing the first side; C) closing the second side; D) rolling up the bourek; E) squeezing the bourek tightly; F) adding a small dip of cheese to glue the leaf of dioule.

the chopped sea cucumbers with the other ingredients, the stuffing was put inside the leaves of dioule (Fig. 3A) by squeezing well on both sides of the bourek (Fig. 3B and C) wound or into any desired shape (triangle, rolled) (Fig. 3D, E and F).

Minced sea cucumber meatballs (Fig. 2D)

Cut a sea cucumber into small pieces (about 3–4 cm), then chop finer using an electric chopper. A teaspoon of salt, black pepper, cumin, paprika and finely chopped parsley are added. The "meatballs" are then made in the palm of the hand. To prepare the tomato sauce, pour 3 tablespoons of vegetable oil in a pan and add a well-fried green onion. To this, add 2 cloves of pressed garlic and concentrated tomato paste with a grated tomato. The sauce is then stirred over low heat until thickened.

Tasting survey

The tasting session was accompanied by a questionnaire that included: 1) information about the people who participated in the survey (e.g. their gender, age, origin, preferred seafood and whether they suffer from chronic diseases); 2) a visual assessment of the meal presented (i.e. appearance and similarity to other commonly consumed dishes, such as red or white meat or fish meals); 3) an assessment of each dish's smell; and 4) an assessment of each dish's taste and texture.

Another questionnaire was distributed, which included information about the four sea cucumber dishes, and the nutritional benefits of sea cucumbers in general. This questionnaire included: 1) a description of the four dishes; 2) a question about participants' willingness to introduce sea cucumber dishes into their eating habits); and 3) the type of product they would like to find in outlets (fresh animals or dried beche-de-mer).

Results and discussion

Our survey was conducted on 42 people from three age groups under 18 years (5%), 18–35 years (62%) and over 35 years (33%) (Fig. 4A). A high percentage of respondents were women (74%) (Fig. 4A). The predominance of women is explained by the fact that they have the curiosity to discover, prepare and test new food products. Some 69% of respondents came from coastal municipalities, while the others (31%) came from inland areas (Fig. 4A). See Box 1 for the list of questions that were asked of participants.

Algerian gastronomy is very rich thanks to the different culinary cultures of its regions. Like pasta or rice, which are staple foods for Italians or Chinese, couscous is a symbol of food identity for the peoples of the Maghreb countries and especially for the Algerians who prepare it according to different recipes, depending on the region (Chemache et al. 2018). Our results show that most respondents like seafood (93%) (Fig. 4A), but each person had their own particular preferences. Depending on their financial means, some people prefer mussels, others prefer cephalopods, shellfish and even fresh sea urchin gonads. Regarding the visual test, the prepared dishes looked very good to most (88%), 5% were uncertain and 7% said that the dish was not pleasant, especially for the first dish, which is soft in consistency (Fig. 4B and Fig. 2A). The smell of the dishes was considered to be quite pleasant by 69% of respondents but only moderately pleasant by others (31%) (Fig. 4B). The preferred dish was the sea cucumber bourek (32% of respondents; Fig. 2B), closely followed by the minced sea cucumber meatballs with tomato sauce (31% of respondents; Fig. 2D). People who chose those dishes were attracted by their presentation, which was comparable to dishes prepared with chicken or other minced meat. Other respondents thought it was a seafood blend. Generally, the sea cucumber bourek and the minced sea cucumber meatballs with tomato sauce were appetizing and easy to eat (39%), with a smooth texture (19%) (Fig. 4C).

The marinated sea cucumber salad was preferred by only 20% of respondents (Fig. 2C), while the sea cucumber with white sauce and mushrooms dish was even less popular at 17% (Fig. 2A) because they had a grainy (15%) or elastic (22%) texture, or were considered difficult to chew (4%) (Fig. 4C). About 93% of respondents found sea cucumbers easy to eat (chew), according to the results of the tasting. In addition, 43% of people recognised the ingredients of our four dishes but guessed that the seafood was crab, mollusc or squid. Indeed, according to an Italian chef, Mauro Colagreco[2], the taste of sea cucumbers is close to that of squid (Goullet de Rugy 2020). Most respondents (69%) said they would likely buy beche-de-mer if it was sold at the market (Fig. 4C). Perhaps because of the information provided about the health benefits of eating sea cucumbers, 83% of respondents reported being interested in our prepared meals (Fig. 4C).

Conclusion

The majority of people who attended the tasting survey liked seafood and claimed that our four sea cucumber-based dishes were very good (in appearance, smell and taste). The favourite dishes were the sea cucumber bourek and the minced sea cucumber meatballs with tomato sauce. Sea cucumbers in our dishes had a texture comparable to this of squid. The majority said they would be willing to buy beche-de-mer and include it in their meals.

[2] In 2019, Mauro Colagreco's restaurant Mirazur was elected "best restaurant in the world" by the World's 50 Best Restaurants (https://www.theworlds-50best.com/).

BOX 1. Tasting questionnaire

1. Are you: A man? A woman?
2. How old are you?
3. Where do you live?
4. Do you like seafood and seafood products?
5. What products do you usually eat?
6. Do you have a chronic disease? If yes which one(s)
7. Does this dish look good to you? (Visual test)
8. Do you recognise the ingredients?
9. What do you think it looks like?
10. Is the smell of the dish pleasant? (Olfactory test)
11. Did you find this dish convenient to eat?
12. Which is your favorite dish?
13. What do you think about the texture?
14. Did you recognise the ingredients?
15. Can you name them?
16. What do you like or dislike about these dishes?
17. Does this dish require the addition or removal of any ingredients?
18. If you found the product in the market; would you be willing to buy it?
19. Did you know that these dishes were sea cucumber dishes?
20. Would you be interested to know more about these sea cucumber recipes?
21. Would you be interested in another workshop?

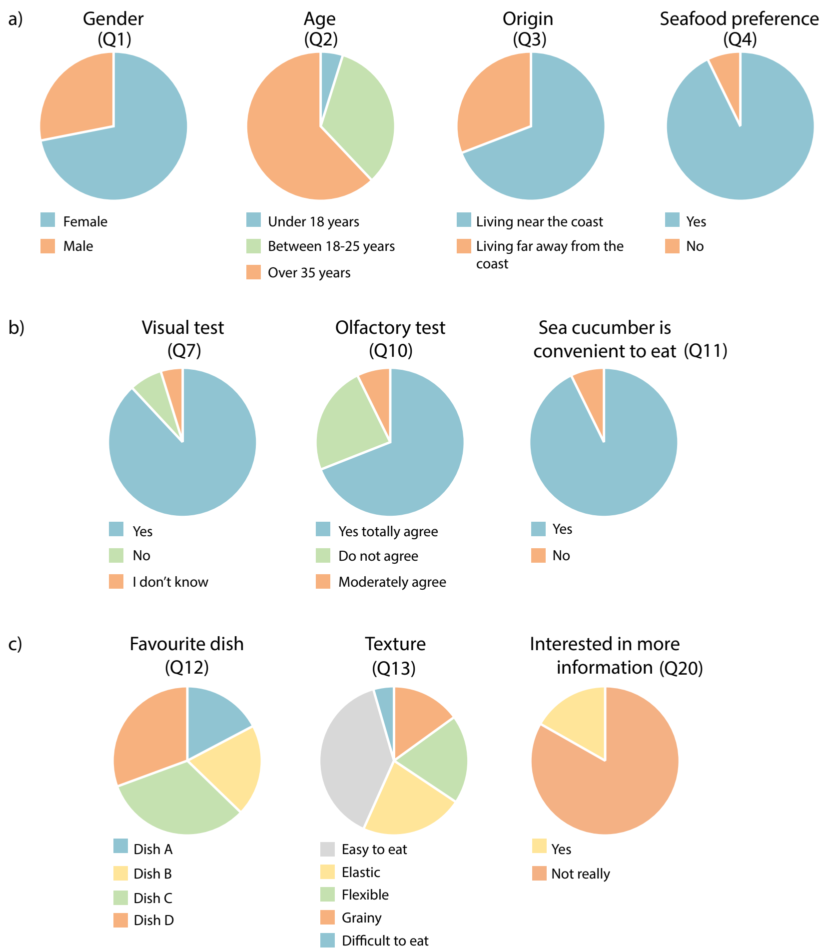


Figure 4. Results of the tasting session questionnaire.

References

Aydin M. 2018. Biometry, density and the biomass of the commercial sea cucumber population of the Aegean Sea. Turkish Journal of Fisheries and Aquatic Sciences 19(6):463–474.

Chemache L., Kehal F., Namoune H., Chaalala M. and Gagaoua M. 2018. Couscous: Ethnic making and consumption patterns in the Northeast of Algeria. Journal of Ethnic Foods 5: 211–219.

Conand C. and Byrne M. 1993. A review of recent developments in the world sea cucumbers fisheries. Marine Fisheries Review 55:1–13.

Goullet de Rugy A. 2020. Le marché de l'holothurie en France : état des lieux et pistes de développement. Science du vivant [q-bio]. 72 p. https://dumas.ccsd.cnrs.fr/dumas-02969147

Mecheta A., Hanachi A., Jeandel C., Arab-tehrany E., Bianchi A., Velot E., Mezali K. and Linder M. 2020. Physicochemical properties and liposomal formulations of hydrolysate fractions of four sea cucumbers (Holothuroidea: Echinodermata) from the Northwestern Algerian Coast. Molecules 25(13):2972.

Mezali K. 1998. Contribution à la systématique, la biologie, l'écologie et à la dynamique des populations de cinq espèces d'holothuries aspidochirotes (*Holoturia tubulosa*, *Holothuria poli*, *Holothuria stellati*, *Holothuria forskali* et *Holothuria sanctori*) de l'herbier à Posidonia oceanica (L.) Delile de la presqu'ile de Sidi-Fredj- Algérie. Thèse de Magister. Ecole National des Sciences de la Mer et de l'Aménagement du Littoral (Ex ISMAL), Alger, Algérie. 192 p.

Mezali K. and Slimane-Tamacha F. 2020. The status of Algeria's sea cucumbers and their illegal trade. SPC Beche-de-mer Information Bulletin 40:23–31. https://purl.org/spc/digilib/doc/2uwhi

Mezali K., Khodja I., Lebouazda Z. and Belkacem N. 2021. Knowledge of sea cucumbers by the Algerian community and an attempt to introduce them into the national gastronomy. SPC Beche-de-mer Information Bulletin 41:69–72. https://purl.org/spc/digilib/doc/4qg2e

Purcell S.W. 2017. La transformation des holothuries en bêches-de-mer : manuel à l'usage des pêcheurs océaniens. Lismore, Australie : Southern Cross University et Nouméa, Nouvelle-Calédonie: Communauté du Pacifique. 44 p. https://purl.org/spc/digilib/doc/uzqky

Purcell S., Samyn Y. and Conand C. 2012. Commercially important sea cucumbers of the world. In: FAO Species Catalogue for Fishery Purposes No. 6 (Issue 6). Rome: FAO. 150 p.

Zhong Y., Khan M.A. and Shahidi F. 2007. Compositional characteristics and antioxidant properties of fresh and processed sea cucumber (*Cucumaria frondosa*). Journal of Agricultural and Food Chemistry 55(4):1188–1192.

Proximate composition and *in vivo* digestibility of the integument of *Parastichopus regalis* (Cuvier, 1817) collected from the Mostaganem area in the western Mediterranean Sea

Ihcene Khodja[1] and Karim Mezali[1]*

Abstract

The exploitation of sea cucumbers in Algeria began a few years ago but only targets species of the genus *Holothuria*. Another species belonging to the order Synallactida (*Parastichopus regalis*) with important nutritional and economic value is also present along the Algerian coast. This species is caught in depths of over 50 m by professional fishers as bycatch but it is not consumed or sold. Studies devoted to this species are few. The aim of this study was to evaluate the quality of this species' tegument through the evaluation of moisture, lipid and ash contents as well as its digestibility by the gastric enzyme pepsin. Forty-two individuals of *P. regalis* were collected in four stations of the Mostaganem region. The integument of *P. regalis* individuals were freeze-dried to determine the water content, lipid content, ash content and its *in vitro* digestibility by pepsin. The results obtained showed a high-water content (90.98 ± 0.71 %), a low lipid content (1.40 ± 0.57%), an ash content of 40.45 ± 0.54% and a good digestibility by pepsin (46.96 ± 3.08%). These results were compared and discussed with those found in the literature.

Keywords: Sea cucumber, integument, approximate composition pepsin, occidental Algerian basin

Introduction

The depletion of sea cucumbers of the genus *Holothuria* has led to the exploration of new areas in several regions of the world, including Algeria (Mezali and Slimane-Tamacha 2020). But this exploitation has not yet considered species belonging to other genera such as *Parastichopus regalis,* which is the only representative of the order Synallactida recently found along the Algerian coast (Benzait et al. 2020; Khodja et al. 2021). This is probably due to its inaccessibility as this species lives in depths of 50 m or more. Indeed, *P. regalis* is caught incidentally by small-scale fisheries and trawlers that consider it as worthless bycatch (Benzait et al. 2020). On the other hand, in Spain, *P. regalis* is highly valued for its five muscle bands and represents the most expensive seafood product in Catalan markets, reaching a price of EUR 130/kg (Ramón et al. 2010). Several other representatives of this family are exploited worldwide, including *Parastichopus tremulus* and species of the genera *Thelenota* and *Stichopus* (Dissanayake and Stefansson 2010). Sea cucumbers also have important nutritional values and have long been used in traditional medicine in Asian countries (Khotimchenko 2015) because they contain bioactive compounds that reduce the risk of certain chronic diseases, and they improve health by meeting some basic nutritional needs (Pangestuti and Arifin 2018). These bioactive compounds include polyunsaturated fatty acids and triterpene glycosides (saponins) (Caulier et al. 2016; Mecheta et al. 2020). In the Mediterranean, several studies have detailed the composition of holothurian species of the genus *Holothuria* (Wen et al. 2010; Aydin et al. 2011; Roggatz et al. 2015; Gonzalez-Wangümert et al. 2018; Mecheta and Mezali 2019; Mecheta et al. 2020). However, few studies have been done on species of the genus *Parastichopus*. As far as we know, the chemical composition of *P. regalis* has been studied only by Santos et al. (2015) in Portugal and by Roggatz et al. (2018) in Spain. Hence, the interest of this study whose purpose is to evaluate the quality of *P. regalis* integument through the study of its moisture, lipid and ash contents as well as its digestibility by the gastric enzyme pepsin.

Methodology

This study was carried out on 42 individuals of *Parastichopus regalis* from four stations in the region of Mostaganem on the western Algerian coast (36°02'36.66"N and 00°01'49.38"W; 36°05'4.62" N and 00°00'29.40"E; 35°59'6.54" N and 00°01'5.34"E; 36°27' 58.68"N and 00°38'25.86"E). Sampling was carried out in June 2020 by small-scale fisheries in the area. In the laboratory, measurements were carried out the contracted body length (CBL) of the individuals (± 0.10 mm), wet weight of the integument (TWW) (± 0.001 g) and thickness of the integument (TT) (± 0.01 mm). After these measurements were recorded, the integument was frozen for biochemical analysis.

Five frozen integuments were selected for biochemical analysis. These integuments were freeze-dried (Christ Alpha 2-4 LD plus) to remove all water without altering their chemical composition by high temperatures, then weighed

[1] Protection and Development of Marine and Coastal Resources and Molecular Systematics Laboratory. Department of Marine Sciences and Aquaculture, Faculty of Natural and Life Sciences, Abedelhamid Ibn Badis University, Mostaganem 27000, PO Box 227, Algeria
* Author for correspondence: karim.mezali@univ-mosta.dz

dry (DTW) to determine the moisture content according to the following formula and the wet/dry weight ratio:

$$\text{Moisture content (\%)} = \frac{\text{Wet weight - Dry weight}}{\text{Wet weight}} \text{ X } 100$$

The *in vitro* digestibility of the integument of *P. regalis* individuals was performed using a digestive enzyme (pepsin 1:10,000). This step was performed in three replicates on three different individuals following the protocol of Escudero et al. (2010) and modified by Wen et al. (2015). For this study, 0.5 g of dry integument was homogenised twice in 2 ml of distilled water for 1 min at 6000 rpm/min. The whole was centrifuged twice for 1 min at 6000 rpm/min, then the pH was adjusted to 2 with HCL (1 M) before adding pepsin 1:10,000 with an amount of 5% based on the dry weight of the integument. The mixture was kept at 37°C for 2 h, then the pH was adjusted to 7 with NaOH (1 M) to inactivate the pepsin. The undigested integument was dried at 60°C for 72 h and then weighed. The digestibility of the integument by pepsin was calculated according to the following formula:

$$\text{DT (\%)} = \left(\frac{\text{Wt - Wi}}{\text{Wt}} \right) \text{ X } 100$$

Where DT = digestibility of the integument by pepsin, Wt = dry weight of the integument before pepsin digestion, and Wi = dry weight of the integument not digested by pepsin.

The extraction of lipids from the integument of *P. regalis* was performed according to the method of Folch et al. (1957) and later modified by Low and Ng (1987) on two individuals. A total of 1 g of freeze-dried integument samples was dissolved in 120 ml of 2:1 (v/v) chloroform/methanol mixture. The mixture was homogenised for 2 h and then filtered through Whatman No 1 filter paper, and 30 ml (v/4) of 0.73% NaCl was added. The solution was left to decant for 2 h then the chloroform was filtered over sodium sulphate and recovered in a previously weighed flask. The methanol was washed with 40 ml of chloroform and 10 ml of 0.58% NaCl and left to decant for 30 min. The chloroform containing the lipids was also filtered over sodium sulphate, recovered and then removed at 53°C. The lipid content was deduced by weight difference.

To determine the ash content of *P. regalis* integument, approximately 1 g of sample was incinerated completely at 600°C for 6 h. The ash content expressed as a percentage is the difference between the weight of the samples before and after incineration. This step was performed on two individuals.

Results and discussion

The contracted length of the 40 *P. regalis* individuals varied between 80 and 230 mm (mean 140.55 ± 45.27 mm). The integument thickness had a mean value of 3.67 ± 1.40 mm and the wet integument weight ranged from 7.22 to 133.86 g (mean 56.25 ± 28.48 g). Dried individuals had an average weight of 6.07 ± 1.35 g.

The ratio between the wet (TWW) and dry (TDW) weights of the integument was 9.27. This value is very close to the standard value (10:1) established for holothurians by Newell and Courtney (1965). This ratio was calculated in other species of the genus *Holothuria* in the central and western Algerian region by Mezali (1998) and Mecheta and Mezali (2019). The ratio obtained for *P. regalis* was higher than that of *Holothuria poli* (6.44 and 7.02 obtained by Mezali 1998) and Mecheta and Mezali (2019), respectively, *H. tubulosa* (6.44 and 8.69 obtained by Mezali 1998) and Mecheta and Mezali (2019), respectively, and *H. forskali* (8.98 obtained by Mezali 1998), close to that of *H. sanctori* (9.39 obtained by Mezali 1998) and lower than that of *H. arguinensis*, which possesses the highest ratio of 15.78 (Mecheta and Mezali 2019). According to Mezali (1998, 2001), the variation in this ratio between species may be related to their physiology and the chemical composition of their integument. In fact, the percentage of water content and the percentage of ossicles in the integument that differ between species can influence dry weights and create considerable variation. Habitat may also play a role in the variation of this ratio. In fact, unlike species of the genus *Holothuria* that inhabit coastal areas and have a rigid integument, *P. regalis* is found on muddy substrates (Elakkermi et al. 2021) and its integument is soft. When this ratio is accurately calculated for commercial species, it can be used to estimate the weight of fresh sea cucumbers from previously processed ones (Ngaluafe and Lee 2013).

Approximate composition

The moisture content (Table1) in the integument of *P. regalis* was 90.98 ± 0.71%, this value is close to that observed in the same species in Spain (Roggatz et al. 2018). According to Chang-Lee et al. (1989), the moisture content in holothurians is between 82.0 and 92.6%, and is high compared to that of fish and molluscs, although higher or lower values have been observed in some species (Table 1). Such is the case for *Holothuria tubulosa*, *H. poli* and *Stichopus variegatus*, with moisture contents of 81.09 ± 1.97%, 93.53 ± 1.95% and 93.36 ± 0.02%, respectively (Mecheta and Mezali 2019; Ridhowati et al. 2018). The value observed in the species studied remains within the range of rates reported in the literature. Within the same species, fluctuations in the moisture content can be observed depending on the sampling period, such as the case of the species *Isostichopus* sp., where the moisture content varies but not significantly by 3% between the months of January and July (Vergara and Rodríguez 2016). This monthly variation has also been observed in the species *Holothuria scabra* (Özer et al. 2004). In the case of our comparison, all individuals were collected in summer except in the case of *P. regalis* from the Spanish coast and *S. variegatus*, which were collected from fall-winter and winter-summer, respectively (Roggatz et al. 2018; Ridhowati et al. 2018). Thus, the observed interspecific water content variations are simply due to species and genus differences.

Table 1. Approximate composition of the integument of *Parastichopus regalis* compared to other sea cucumber species.

Species	Moisture content (%)	Lipid content (%)	Ash content (%)	References
Parastichopus regalis	90.98 ± 0.71	1.40 ± 0.57	40.45 ± 0.54	Present study
P. regalis	-	3.63 ± 0.11	-	Santos et al. (2015)
P. regalis	91.40	1.27	36.80	Roggatz et al. (2018)
Holothuria arguinensis	88.13 ± 4.16*	2.57 ± 0.28	47.31 ± 0.08	Mecheta et al. (2020)
H. poli	93.53 ± 1.95*	5.53 ± 0.59	41.78 ± 1.82	Mecheta et al. (2020)
H. sanctori	-	3.07 ± 0.50	31.58 ± 0.10	Mecheta et al. (2020)
H. scabra	84.91	-	-	Özer et al. (2004)
H. tubulosa	81.09 ± 1.97*	3.81 ± 0.25	40.77 ± 0.60	Mecheta et al. (2020)
Stichopus herrmanni	-	0.80 ± 0.02	37.90 ± 0.33	Wen et al. (2010)
S. variegatus	93.36 ± 0.02	-	-	Ridhowati et al. (2018)
Thelenota ananas	-	1.90 ± 0.01	25.10 ± 0.30	Wen et al. (2010)

*Mecheta and Mezali (2019)

The lipid level (Table 1) obtained from *P. regalis* was 1.40 ± 0.57%. This value is more or less close to that of *Stichopus hermanni* and *Thelenota ananas* (0.80 ± 0.02% and 1.9 ± 0.01%, respectively) (Wen et al. 2010). The chemical composition of marine organisms in general can be influenced by several factors such as physiological characteristics, habitat, life cycleand environmental conditions, as well as biological factors such as diet and reproductive cycle (Taboada et al. 2003; Diniz et al. 2012). According to Khotimchenko (2015), the organic and non-organic compositions of fresh holothurians vary with species, season, habitat and probably stage of ontogeny.

Two studies approached the lipid level in the integument of *P. regalis* in the Mediterranean. The level obtained in individuals from Portugal is higher (3.63 ± 0.11%) (Santos et al. 2015) than those obtained in Spain by Roggatz et al. 2018 (1.27%), and those obtained in this study. This variation in lipid levels observed within the same species is explained by several factors but particularly by temperature and availability of food resources due to the selective behaviour of holothurians (Tabaoda et al. 2003; Neto et al. 2006). Indeed, the three values obtained correspond to samples from different regions and different periods, with the highest lipid level observed in September 2012 (Santos et al. 2015) and the lowest between fall and winter 2011 (Roggatz et al. 2018). The intermediate value was obtained in our study in summer 2020.

The ash content (Table 1) obtained in the integument of *P. regalis* is 40.45 ± 0.54%, which is slightly higher than that obtained by Roggatz et al. (2018) for the same species in Spain (36.80%) as well as those of the other two species of the same family, *Stichopus herrmanni* and *Thelenota ananas* with contents of 37.9 ± 0.33 % and 25.10 ± 0.30%, respectively (Wen et al. 2010). Compared to other species of the genus *Holothuria* from the Algerian west coast, only *H. arguinensis* has a higher ash content than the species studied (47.31 ± 0.08%), *H. tubulosa* and *H. poli* both have almost similar levels (40.77 ± 0.60% and 41.78 ± 1.82%, respectively) and *H. sanctori* has lower values (Mecheta et al. 2020). The results of the ash content should be taken with caution because the number of ossicles could influence this value.

In general, sea cucumbers are high in protein, low in lipids and contain several minerals and vitamins (Çakli et al. 2004; Mecheta et al. 2020). This chemical composition is influenced by the nutrition of these organisms, their geographical location, the handling procedure of these organisms after they are harvested, and the method by which they are processed into beche-de-mer (Chang-Lee et al. 1989; Özer et al. 2004; Aydin et al. 2011).

In vitro digestibility of the P. regalis *integument by pepsin*

An assessment of the quality of a protein source is usually based on the amino acid composition and digestibility of the protein in the digestive tract (Santé-Lhoutellier et al. 2017). The *in vitro* pepsin digestibility of *P. regalis* integument of 46.96 ± 3.08% is the same as that observed in fish (Wen et al. 2010) and close to that of chicken and beef (44.67% and 42.75%, respectively) (Table 2). Compared to other holothurian species from the Algerian west coast, the integment of *P. regalis* is more digested by pepsin than that of *H. poli* or *H. tubulosa* (34.68 ± 8.66% and 25.96 ± 2.04%, respectively) (Mecheta and Mezali 2019). Despite the fact that *P. regalis* has a low protein content (14.7% according to Roggatz et al. 2018) compared to *H. arguinensis* (66.41% according to Mecheta et al. 2020), their integuments are almost equally digested by pepsin. This digestion may not be related to the protein level but instead to its composition. Indeed, pepsin cleavage is more influenced by the amino acid residue in the P1 position, and when the amino acids His, Lys, Arg or Pro are in this position they prohibit this cleavage (Hamuro et al. 2018). These amino acids represent approximately 19.6%–26.4% of the protein in *H. arguinensis*, *H. tubulosa*, *H. poli* and *P. regalis*, and have low lysine/arginine levels (Roggatz et al. 2015; Gonzalez-Wangümert et al. 2018; Roggatz et al. 2018).

Table 2. Digestibility of *P. regalis* integument by pepsin compared to other sea cucumber species and to commonly consumed meats.

Species	Digestibility (%)	References
Parastichopus regalis	46.96 ± 3.08	Present study
Holothuria arguinensis	53.56 ± 3.41	Mecheta and Mezali (2019)
H. poli	34.68 ± 8.66	Mecheta and Mezali (2019)
H. tubulosa	25.96 ± 2.04	Mecheta and Mezali (2019)
Pork	47.22	Wen et al. (2015)
Fish	46.98	Wen et al. (2015)
Chicken	44.67	Wen et al. (2015)
Beef	42.75	Wen et al. (2015)

Conclusion

The sea cucumber *Parastichopus regalis* has a high-water content, low lipid content and good digestibility by pepsin. Thus, *P. regalis* from the Algerian coast could constitute a new nutritional and economic source to be exploited. Before that, however, studies on its reproduction must be carried out in order to establish management measures that guarantee the sustainability of the stocks such as the determination of fishing closure periods and minimum commercial sizes, which are not available for any species exploited in Algeria.

References

Aydin M., Sevgili H., Tufan B., Emre Y. and Köse S. 2011. Proximate composition and fatty acid profile of three different fresh and dried commercial sea cucumbers from Turkey. International Journal of Food Science and Technology 46(3):500–508. https://doi.org/10.1111/j.1365-2621.2010.02512.x

Benzait H., Khodja I., Soualili D.L. and Mezali K. 2020. Note on *Parastichopus regalis* (Cuvier, 1817) from the Sidi-Medjdoub area of Mostaganem, Algeria. SPC Beche-de-mer Information Bulletin 40:43–45. https://purl.org/spc/digilib/doc/gkcza

Çakli S., Cadun A. and Kisla D. 2004. Determination of quality characteristics of *Holothuria tubulosa* (Gmelin, 1788) in Turkish Sea (Aegean Region) depending on sun drying process step used in Turkey. Journal of Aquatic Food Product Technology 13(3):69–78. https://doi.org/10.1300/J030v13n03

Caulier G., Mezali K., Soualili D.L., Decroo C., Demeyer M., Eeckhaut I., Gerbaux P. and Flammang P. 2016. Chemical characterization of saponins contained in the body wall and the Cuvierian tubules of the sea cucumber *Holothuria* (*Platyperona*) *sanctori* (Delle Chiaje, 1823). Biochemical Systematics and Ecology 68:119–127. https://doi.org/10.1016/j.bse.2016.06.005

Chang–Lee M. V., Price R. J. and Lampila L. E. 1989. Effect of processing on proximate composition and mineral content of sea cucumbers (*Parastichopus* spp.). Journal of Food Science 54(3):567–568. https://doi.org/10.1111/j.1365-2621.1989.tb04653.x

Diniz G.S.D., Barbarino E. and Lourenço S.O.L. 2012. On the chemical profile of marine organisms from coastal subtropical environments: Gross composition and nitrogen-to-protein conversion factors. p. 297–320. In: Marcelli, M. (ed). Oceanography. InTechOpen. https://doi.org/10.5772/29294

Dissanayake D.C.T. and Stefansson G. 2010. Abundance and distribution of commercial sea cucumber species in the coastal waters of Sri Lanka. Journal of the Marine Biological Association of the UK 23:303–313. https://doi.org/10.1017/S0025315411001019

Elakkermi M., Mezali K., Khodja I., Belbachir N.E., Benzait H. and Lila Soualili D. 2021. Gut content analysis of *Parastichopus regalis* (Cuvier, 1817) from the west Algerian coast. SPC Beche-de-mer Information Bulletin 41:15–18. https://purl.org/spc/digilib/doc/jozdz

Escudero E., Sentandreu M. Á. and Toldrá F. 2010. Characterization of peptides released by in vitro digestion of pork meat. Journal of Agricultural and Food Chemistry 58(8):5160–5165. https://doi.org/10.1021/jf904535m

Folch J., Lees M. and Sloane Stanley G.H. 1957. A simple method for the isolation and purification of total lipides from animal tissues. Journal of Biological Chemistry 226:497–509.

González-Wangüemert M., Roggatz C.C., Rodrigues M.J., Barreira L., da Silva M.M. and Custódio L. 2018. A new insight into the influence of habitat on the biochemical properties of three commercial sea cucumber species. International Aquatic Research 10(4):361–373. https://doi.org/10.1007/s40071-018-0210-9

Hamuro Y., Coales S.J., Molnar K.S., Tuske S.J. and Morrow J.A. 2008. Specificity of immobilized porcine pepsin in H/D exchange compatible conditions. Rapid Communications in Mass Spectrometry 22:1041–1046. https://doi.org/10.1002/rcm

Khodja I., Mezali K. and Thandar A.S. 2021. Multiple records and polymorphism of *Parastichopus regalis* (Cuvier, 1817) (Echinodermata: Holothuroidea: Stichopodidae) along the Algerian coast. Zootaxa 5032(4):549–562. https://doi.org/10.11646/zootaxa.5032.4.5

Khotimchenko Y.S. 2015. The nutritional value of holothurians. Russian Journal of Marine Biology 41(6):409–423. https://doi.org/10.1134/S1063074015060061

Low L.K. and Ng C.S. 1987. Analysis of oils: Extraction of lipids (modified Folch's Method). p. 1–2. In Hasegawa H. (eds). Laboratory Manual on Analytical Methods and Procedures for Fish and Fish Products. Bangkok: Marine Fisheries Research Department, Southeast Asian Fisheries Development Center.

Mecheta A. and Mezali K. 2019. A biometric study to determine the economic and nutritional value of sea cucumbers (Holothuroidea: Echinodermata) collected from Algeria's shallow water areas. SPC Beche-de-mer Information Bulletin 39:65–70. https://purl.org/spc/digilib/doc/z4m7w

Mecheta A., Hanachi A., Jeandel C., Arab-Tehrany E., Bianchi A., Velot E., Mezali K. and Linder M. 2020. Physicochemical properties and liposomal formulations of hydrolysate fractions of four sea cucumbers (Holothuroidea: Echinodermata) from the northwestern Algerian coast. Molecules 25(2972):1–24. https://doi.org/10.3390/molecules25132972

Mezali K. 1998. Contribution à la systématique, la biologie, l'écologie et la dynamique de cinq espèces d'holothuries aspidochirotes [*Holothuria* (*H.*) *tubulosa*, *H.* (*L.*) *polii*, *H.* (*H.*) *stellati*, *H.* (*P.*) *forskali* et *H.* (*P.*) *sanctori*] de l'herbier à *Posidonia oceanica* (L.) Delille de la Prèsqu'île de Sidi-Fredj. Thèse de Magister. Ecole National des Sciences de la Mer et de l'Aménagement du Littoral (Ex- ISMAL), Alger, Algérie. 192 p.

Mezali K. 2001. Biométrie des holothuries aspidochirotes (Holothuroidea: Echinodermata) de la presqu'île de Sidi-Fredj (Algérie). Communication poster, 36ème Congrès de la CIESM, Monaco, 24–28 septembre 2001.

Mezali K. and Slimane-Tamacha F. 2020. The status of Algeria's sea cucumbers and their illegal trade. SPC Beche-de-mer Information Bulletin 40:23–31. https://purl.org/spc/digilib/doc/2uwhi

Neto R.R., Wolff G.A., Billett D.S.M., Mackenzie K.L. and Thompson A. 2006. The influence of changing food supply on the lipid biochemistry of deep-sea holothurians. Deep-Sea Research Part I 53(3):516–527. https://doi.org/10.1016/j.dsr.2005.12.001

Newell R. C. and Courtney W.A.M. 1965. Respiratory Movements in *Holothuria forskali* Delle Chiaje. Journal of Experimental Biology 42(1):45–57. https://doi.org/10.1242/jeb.42.1.45

Ngaluafe P. and Lee J. 2013. Change in weight of sea cucumbers during processing: Ten common commercial species in Tonga. SPC Beche-de-mer Information Bulletin 33:3–8. https://purl.org/spc/digilib/doc/ezf5w

Özer N.P., Mol S. and Varlık C. 2004. Effect of the handling procedures on the chemical composition of sea cucumber. Turkish Journal of Fisheries and Aquatic Sciences 4:71–74.

Pangestuti R. and Arifin Z. 2018. Medicinal and health benefit effects of functional sea cucumbers. Journal of Traditional and Complementary Medicine 8:341–351.

Ramón M., Lleonart J. and Massutí E. 2010. Royal cucumber (*Stichopus regalis*) in the northwestern Mediterranean: Distribution pattern and fishery. Fisheries Research 105:21–27. https://doi.org/10.1016/j.fishres.2010.02.006

Ridhowati S., Chasanah E., Syah D. and Zakaria F.R. 2018. Evaluation of the safe consumption of aqueous extract of flour from *Stichopus variegatus*. Biomedical Research and Therapy 6(11):3452–3459. https://doi.org/10.15419/bmrat.v6i11.574

Roggatz C.C., González-Wangüemert M., Pereira H., Rodrigues M.J., Da Silva M.M., Barreira L., Varela J. and Custódio L. 2015. First report of the nutritional profile and antioxidant potential of *Holothuria arguinensis*, a new resource for aquaculture in Europe. Natural Product Research 1–7. https://doi.org/10.1080/14786419.2015.1107555

Roggatz C.C., González-Wangüemert M., Pereira H., Vizetto-Duarte C., Rodrigues M.J., Barreira L., Da Silva M.M., Varela J. and Custódio L. 2018. A first glance into the nutritional properties of the sea cucumber *Parastichopus regalis* from the Mediterranean Sea (SE Spain). Natural Product Research 32(1):116–120.

Santé-Lhoutellier V., Astruc T., Daudin J.D., Kondjoyan A., Scislowski V., Duchène H., Gaudichon C. and Rémond D. 2017. Digestion des protéines des viandes en fonction de la cuisson. Viandes & Produits Carnés 33:1–10.

Santos R., Dias S., Pinteus S., Silva J., Alves C., Tecelão C., Pombo A. and Pedrosa R. 2015. The biotechnological and seafood potential of *Stichopus regalis*. Advances in Bioscience and Biotechnology 6:194–204. https://doi.org/10.4236/abb.2015.63019

Taboada M. C., Gonzalez M. and Rodriguez E. 2003. Value and effects on digestive enzymes and serum lipids of the marine invertebrate *Holothuria forskali*. Nutrition Research 23:1661–1670. https://doi.org/10.1016/S0271-5317(03)00175-1

Vergara, W. and Rodríguez A. 2016. Nutritional composition of sea cucumber *Isostichopus* sp. Natural Resources 7:130–137. https://doi.org/10.4236/nr.2016.73013

Wen J., Hu C. and Fan S. 2010. Chemical composition and nutritional quality of sea cucumbers. Journal of the Science of Food and Agriculture 90:2469–2474. https://doi.org/10.1002/jsfa.4108

Wen S., Zhou G., Song S., Xu X., Voglmeir J., Liu L., Zhao F., Li M., Li L., Yu X., Bai Y. and Li C. 2015. Discrimination of *in vitro* and *in vivo* digestion products of meat proteins from pork, beef, chicken, and fish. Proteomics 15(21):3688–3698. https://doi.org/10.1002/pmic.201500179

First spawning observations in sandfish farmed in sea pens, and evidence of wild juveniles growing

Loïc Gaumez[1]* and Igor Eeckhaut[1,2,3]

Introduction

Numerous observations of *Holothuria s*cabra spawning in the wild have been made throughout the distribution area of this species (Conand 1993; Mercier et al. 2000; Rahantoknam 2017; Lee et al. 2018; Shelley 1981; James and James 1993; Hamel et al. submitted for review). Observations of natural spawning in farmed sea pens, however, has not yet been reported in the literature.

We report here, for the first time, on the natural spawning of sandfish in farmed sea pens and give evidence that the larvae settled and grew in the sea pens. This occurred in farmed sea pens of Indian Ocean Trepang (IOT), a company in southwestern Madagascar that specialises in the aquaculture of *Holothuria scabra* (Eeckhaut et al. 2008; Eeckhaut 2021). IOT carries out the entire rearing cycle and utilises two grow-out models: the "company farm" model where salaried workers take care of the fattening of sea cucumbers in sea pens, and the "village farming" model where villagers take care of the fattening and are paid according to the total weight of sea cucumbers produced at the end of the rearing process (Eeckhaut 2021).

Observations of Holothuria scabra *spawning*

Spawning of *H. scabra* was observed during a monthly observation of stock in the IOT rearing pens. The sea ranching site is located south of Tulear lagoon (23°29'S and 43°45'E) in southwestern Madagascar in an area protected by the Great Reef of Tulear. The spawning observation was made on 25 March 2020. The tide had a coefficient of 86 and the high tide was at 18:23.

Spawning was observed in a single pen that was 10 ha in size. Individuals in that sea pen were five months old when they were transferred from the nursery on 12 December 2019. They spawned at around 9.5 months after their birth (fertilisation time). The average weight of the animals in mid-February 2020 was 263.85 g. The water temperature on 25 March 2020 was 26°C. We observed the spawning of about 50 individuals in an estimated area of 100 m^2 about one hour before high tide. Figure 1 shows one individual in breeding position, and three individuals that are not spawning. In the 100 m^2 area, there were either isolated individuals in the spawning position, or several gregarious individuals were close together (less than 1 m^2 apart). Aggregation prior to spawning has been reported from Solomon Islands, where spawning is correlated with the lunar cycle (Hamel et al. submitted; Mercier et al. 2000). The aggregation behaviour of *H. scabra* suggests that chemical communication may occur during period. Their position, with the anterior end bent upright, allows them to expel their gametes over the leaves of the phanerogams (seed-producing plants) that cover the floor of the sea pens. This position favours the dispersal of gametes towards other partners and prevents gametes from falling on the sediments (Hartley et al. 2020). Contrary to the observations of Moosleitner (2006) and Hartley et al. (2020), there were no fish in the spawning area.

In nature, *H. scabra* exhibits two main reproductive patterns: seasonally predictable spawning at high latitudes, and aseasonal spawning at low latitudes (Hamel et al. submitted). In Tulear, an annual reproduction cycle occurs, with most individuals becoming fully mature between November and April. Spawning is thus considered to occur in this period, between November and April (Rasolofonirina et al. 2005). Observations regarding the influence of the moon on the spawning period of *H. scabra* vary significantly from author to author (see Hamel et al submitted). Spawning, when forced, can be obtained at any time of the lunar cycle (see Hamel et al submitted, Lin and Nan in this issue). Here, spawning was observed one day after the new moon.

Observations of natural juveniles in farmed sea pens

Part of IOT sea ranching is done by village farmers. In southern Tulear Bay, there is one village enclosure site where 40 farmers work. The farmers started finding juveniles of *H. scabra* around 100 g or less in their sea pens in July 2020. These juveniles obviously come from natural reproduction because no juveniles of this size were introduced into those sea pens since the seeding in December 2019. In order to avoid disrupting the monitoring of production in sea pens, IOT decided to create a special enclosure dedicated to these juveniles and to carry out a monthly count of these juveniles.

In total, 1717 juveniles were collected in the farmed sea pens by village farmers. The smallest harvest was in August with 205 individuals and the largest harvest was in September with 848 individuals. Figure 2 shows the monthly number of juveniles that were <100 g and harvested by village farmers. Since the end of the 20th century, natural stocks of *H.*

1 Madagascar Holothurie (R&D of Indian Ocean Trepang), Toliara, Route du Port Mahavatse II, PO Box 141, 601 Toliara, Madagascar
2 Biology of Marine Organisms and Biomimetics, Research Institute for Biosciences, University of Mons – UMons, Place du Parc, 6, 7000, Mons, Belgium. Email: igor.eeckhaut@umons.ac.be
3 Marine Station of Belaza, Institut Halieutique et des Sciences Marines (IH.SM), University of Toliara, 601 Toliara, Madagascar
* Author for correspondence: loic.gaumez@iotrepang.com

Figure 1. Spawning *Holothuria scabra*.

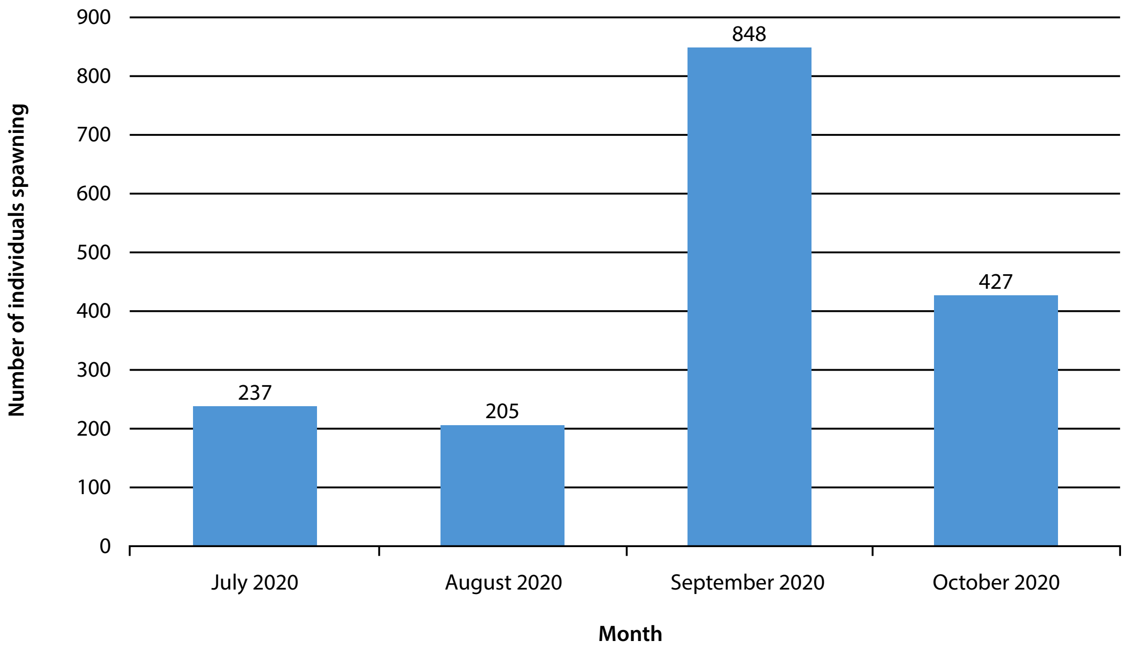


Figure 2. Number of *Holothuria scabra* individuals of 100 g or less sampled in farmed sea pens in Tulear lagoon from July to October 2020.

scabra have been drastically reduced in Madagascar (Conand and Byrne 1993) to the point that none can be found in Tulear lagoon. This allows us to correlate the observation of spawning in March 2020 with the fact that villagers found animals weighing around 100 g in the sea pens. With a modelled projection, a growth curve suggests that a weight of 100 g requires 100 days of growth for *H. scabra*, or about three months (see Hamel et al. submitted). In addition, in the present work, spawning was observed on 25 March and the juveniles that were observed between July and October would be between four to seven months old if they came from this spawning event.

References

Conand C. 1993. Reproductive biology of the holothurians from the major communities of the New Caledonian Lagoon. Marine Biology 116(3):439–450.

Conand C. and Byrne M. 1993. A review of recent developments in the world sea cucumber fisheries. Marine Fisheries Review 55(4):1–13.

Eeckhaut I. 2021. From fundamental to applied research: The history of the Indian Ocean Trepang company. SPC Beche-de-mer Information Bulletin 41:40–47. https://purl.org/spc/digilib/doc/zmk8h

Eeckhaut I., Lavitra T., Rasoforinina R., Rabenevanana M.W., Gildas P. and Jangoux M. 2008. Madagascar Holothurie SA: The first trade company based on sea cucumber aquaculture in Madagascar. SPC Beche-de-Mer Information Bulletin 28:22–23. https://purl.org/spc/digilib/doc/8crw5

Hamel J.F., Eeckhaut I., Conand C., Sun J., Caulier G. and Mercier A. (submitted). Global knowledge on the commercial sea cucumber *Holothuria scabra*. Advances in Marine Biology.

Hartley S.L., Purcell S.W. and Rowe F.W.E. 2020. Spawning of *Australostichopus mollis* at its northernmost subtropical locality. SPC Beche-de-mer Information Bulletin 40:56–58. https://purl.org/spc/digilib/doc/86sfd

James P.S.B.R. and James D.B. 1993. Ecology, breeding, seed production and prospects for farming of sea cucumbers from the seas around India. Fishing Chimes 13(3):24–34.

Lee S., Ford A., Mangubhai S., Wild C. and Ferse S. 2018. Length-weight relationship, movement rates, and in situ spawning observations of *Holothuria scabra* (sandfish) in Fiji. SPC Beche-de-Mer Information Bulletin 38:11–14. https://purl.org/spc/digilib/doc/zjivr

Lin T.H. and Nan F.H. 2022. First trials in inducing spawning and larviculture of *Holothuria scabra* in Palau. SPC Beche-de-mer Information Bulletin 42:58–64.

Mercier A., Battaglene S.C. and Hamel J.-F. 2000. Periodic movement, recruitment and size-related distribution of the sea cucumber *Holothuria scabra* in Solomon Islands. Hydrobiologia 440:81–100.

Moosleitner H. 2006. Observation of natural spawning of *Holothuria tubulosa*. SPC Beche-de-mer Information Bulletin 24:53. https://purl.org/spc/digilib/doc/q8sb4

Rahantoknam S.P.T. 2017. Maturity gonad sea cucumber *Holothuria scabra* under the month cycle. In: IOP Conference Series: Earth and Environmental Science Vol. 89. IOP Publishing, p. 012015.

Rasolofonirina R., Vaïtilingon D., Eeckhaut I. and Jangoux M. 2005. Reproductive cycle of edible echinoderms from the southwestern Indian Ocean. II The sandfish *Holothuria scabra* (Jaeger, 1833). Western Indian Ocean Journal of Marine Science 4:61–75.

Shelley C.C. 1981. Aspects of the distribution, reproduction, growth and fishery potential of holothurians (beche de mer) in the Papuan costal lagoon. University of Papua New Guinea (Papua New Guinea). Ocean and Coastal Management 51(8–9):589–593.

Natural spawning of *Holothuria leucospilota* (Brandt, 1835) in an urbanised bay in the southwestern lagoon of New Caledonia

Philippe Borsa[1]

Location

Baie des Citrons in Noumea, New Caledonia (22.301S and 166.435E), at 8-meter depth on grey sandy bottom with a moderately sparse seagrass bed, about 100 meters off the drop off of the fringing reef located south of the bay under the ledge road that leads to Vata Cove.

Date and time

The spawning event was observed on 25 December 2002 at around 09:00 local time (UTC+11). The full moon was on December 19; spawning therefore took place six days after the full moon, that is, two days before the last quarter.

Notes

The mean surface water temperature in December 2002, taken at Anse Vata 1400 meters from the observation site was 25.7°C or 25.9°C, depending on the measurement method (Varillon et al. 2018). Surface temperature on 25 December was 27.2°C, that is, 1°C warmer than the week before. Several other *H. leucospilota* were seen in erected position in the surrounding area of the bay. A small, indeterminate Monacanthid fish (Laboute and Grandperrin 2000: 461) hid behind the upright part of the sea cucumber (Fig. 1). This fish may take advantage of its mimicry with *H. leucospilota* as it was of the same black colour and had hair-like extrusions reminiscent of the integument texture and of the podia of this sea cucumber.

Egg-laying in *H. leucospilota* has been documented at Kimbe Bay in Papua New Guinea, three days after the full moon[2] (20 May 2011). A photograph of a partially erected individual of *H. leucospilota* in the lagoon of Rodrigues Island in Mauritius has been published by Bédier et al. (2013) but no spawning was observed. The date indicated was 12 January 2013, a day after the new moon. Spawning in *H. leucospilota* from Daya Bay, Shenzhen in China (22.561N and 114.513E) has been induced in aquaculture ponds using either transportation of mature individuals, or cold shock, or temporary exposure to air; the latter method has been considered the most efficient (Huang et al. 2018). Highest (>13%) spawning rates in such conditions were on 23 September 2016 (four days after the full moon), 11 June 2017 (two days after the full moon), 26 June 2017 (two days after the new moon), 14 August 2017 (seven days after the full moon), and 1 September 2017 (five days before the full moon). From the foregoing, it appears that the factors triggering spawning in *H. leucospilota* are likely complex and not just linked to lunar phase.

References

Bédier A., Bourmaud C. and Conand C. 2013. Natural spawning observations on Rodrigues Island, Indian Ocean. SPC Beche-de-mer Information Bulletin 33:53–55. https://purl.org/spc/digilib/doc/entuj

Huang W., Huo D., Yu Z., Ren C., Jiang X., Luo P., Chen T. and Hu C. 2018. Spawning, larval development and juvenile growth of the tropical sea cucumber *Holothuria leucospilota*. Aquaculture 488:22–29.

Laboute P. and Grandperrin R. 2000. Poissons de Nouvelle-Calédonie. Nouméa, Nouvelle-Calédonie: Editions Catherine Ledru. 520 p.

Varillon D., Fiat S., Magron F., Allenbach M., Hoibian T., De Ramon N'Yeurt A., Ganachaud A., Aucan J., Pelletier B. and Hocdé R. 2018. ReefTEMPS: The Pacific Island coastal ocean observation network. SEANOE. http://doi.org/10.17882/55128

Figure 1. *Holothuria leucospilota*. Semen is visible as subtle white swirls in the central part of the picture. The caudal fin of an unidentified Monacanthid fish is visible behind the upright part of the animal. Image: IRD/Philippe Borsa

[1] Institut de recherche pour le développement, Noumea, New Caledonia. Email: philippe.borsa@ird.fr

[2] https://www.alamy.com/sea-cucumber-spawning-ist-eggs-holothuria-leucospilota- kimbe-bay-new-britain-papua-new-guinea-image278747824.html

Observation de ponte naturelle chez *Holothuria leucospilota* (Brandt, 1835) dans une baie urbanisée du lagon sud-ouest de la Nouvelle-Calédonie

Philippe Borsa[1]

Lieu de l'observation

Baie des Citrons à Nouméa, Nouvelle-Calédonie (–22.301, 166.435). A 8 mètres de profondeur sur fond de sable gris avec herbier modérément clairsemé, à 100 mètres environ au large du tombant du récif frangeant situé au sud de la baie sous la route de corniche qui mène à l'anse Vata.

Date et heure de l'observation

25 décembre 2002 vers 09:00 heure locale (TU+11). La pleine lune était le 19 décembre ; la ponte a donc eu lieu six jours après la pleine lune, soit deux jours avant le dernier quart de lune.

Remarques

La température moyenne de l'eau de surface en décembre 2002, prise à l'Anse Vata à 1400 mètres du site de l'observation était 25.7°C ou 25.9°C, selon la méthode de mesure (Varillon et al. 2018). La température de surface le 25 décembre était 27.2°C, soit 1°C de plus que lors de la semaine qui précédait. Plusieurs autres *H. leucospilota* ont été aperçues dressées de même dans la zone alentour. Un petit poisson Monacanthidae indéterminé (Laboute & Grandperrin 2000 : 461) se tenait caché derrière la partie dressée de l'holothurie (figure 1). Ce poisson tire peut-être parti de son mimétisme avec *H. leucospilota* puisqu'il est de la même couleur noire et possède des excroissances piliformes évoquant la texture du tégument et les podia de cette holothurie.

La ponte de *H. leucospilota* a été également documentée à Kimbe Bay en Papouasie Nouvelle-Guinée, trois jours après la pleine lune[2]. Une photographie d'un individu dressé de *H. leucospilota* dans le lagon de l'île Rodrigues a été présentée par Bédier et al. (2013) mais aucune ponte n'a été observée par ces auteurs. La date indiquée était le 12 janvier 2013, un lendemain de nouvelle lune. La ponte de *H. leucospilota* à Daya Bay, Shenzhen (22.561, 114.513) a été induite dans des bassins d'aquaculture en procédant soit au transport d'individus matures, soit à un choc froid, soit à une exposition temporaire à l'air ; cette dernière méthode a été considérée comme la plus efficace (Huang et al.2018). D'après ces auteurs, les taux de ponte les plus élevés (> 13%) dans de telles conditions étaient celles provoquées le 23 septembre 2016 (quatre jours après la pleine lune), le 11 juin 2017 (deux jours après la pleine lune), le 26 juin 2017 (deux jours après la nouvelle lune), le 14 août 2017 (sept jours après pleine lune) et le 1er septembre 2017 (cinq jours avant la pleine lune). D'après ce qui précède, il apparaît que les facteurs déclenchant la ponte de *H. leucospilota* sont probablement complexes et pas simplement liés au calendrier lunaire.

Bibliographie

Bédier A., Bourmaud C., Conand C. 2013. Observations de pontes en milieu naturel sur l'île Rodrigues (océan Indien). La Bêche-de-mer, Bulletin d'information de la CPS 33:53-55.

Huang W., Huo D., Yu Z., Ren C., Jiang X., Luo P., Chen T., Hu C. 2018. Spawning, larval development and juvenile growth of the tropical sea cucumber *Holothuria leucospilota*. Aquaculture 488:22-29.

Laboute P., Grandperrin R. 2000. Poissons de Nouvelle-Calédonie. Catherine Ledru, Nouméa, 520 p.

Varillon D., Fiat S., Magron F., Allenbach M., Hoibian T., De Ramon N'Yeurt A., Ganachaud A., Aucan J., Pelletier B. and Hocdé R. 2018. ReefTEMPS: The Pacific Island coastal ocean observation network. SEANOE. http://doi.org/10.17882/55128

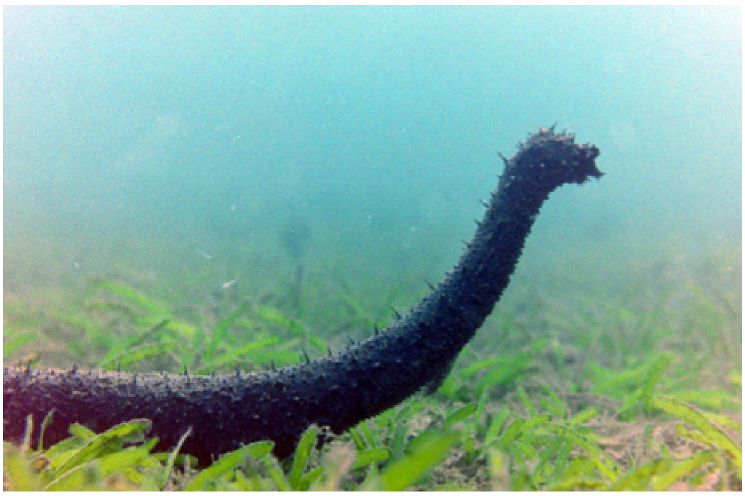


Figure 1. *Holothuria leucospilota*. La semence de l'animal est visible sous la forme de subtiles volutes de couleur blanche vers le centre de l'image. La nageoire caudale d'un poisson Monacanthidae non identifié est visible derrière la partie dressée de l'animal. Photo : IRD / P. Borsa.

[1] Institut de recherche pour le développement, Nouméa, New Caledonia, Courriel : philippe.borsa@ird.fr

[2] https://www.alamy.com/sea-cucumber-spawning-ist-eggs-holothuria-leucospilota-kimbe-bay-new-britain-papua-new-guinea-image278747824.html

FR

Spawning observations of the sea cucumbers *Stichopus chloronotus* and *Holothuria isuga* from One Tree Reef lagoon, southern Great Barrier Reef

Maria Byrne[1]

Introduction

Despite the important ecological roles of tropical aspidochirotid holothuroids in coral reef ecosystems and their commercial value, for many species we have a limited understanding of their reproductive biology. Spawning observations of aspidochirotids in nature have been reported in the *Beche-de-mer Information Bulletin* over the years, and address gaps in knowledge of their reproduction and spawning behaviour. In this contribution, spawning observations of *Stichopus chloronotus* and *Holothuria isuga* in the lagoon at One Tree Island (23°30'S and 152°05'E) in the southern Great Barrier Reef are reported. While reproduction of *S. chloronotus*, an abundant epifaunal and shallow water species, has been well studied (Tan and Zulfigar 2001; Conand et al. 2002), this appears to be the first observation of the reproductive biology of *H. isuga*. *Holothuria isuga* is common in the lagoon at One Tree Island and is usually located just below the sediment surface. It is a large species, up to half a meter in length in the non-contracted state.

A recent study of reproduction and spawning of *Stichopus herrmanni* from One Tree lagoon and elsewhere, indicated a breeding season that spans the summer months, and that aggregated-coordinated spawning coincides with the new moon and continues 1–2 days following it (Balogh et al. 2019). This indicates that gamete release is influenced by the lunar cycle. Male *S. herrmanni* spawn first.

Spawning observations

Stichopus chloronotus

Date: 26 October 2018

Time: 16:00–17:00

Lunar phase: Full moon + 2 days

Spawning in *S. chloronotus* was observed in a location called The Gutter where water enters and exits the lagoon. The tide was low, and the lagoon was ponded. The lagoon at One Tree Reef is completely surrounded by reef and so at low tide the water does not flow out resulting in a ponded (no exchange) state. The animals were in 0.5 m of water. In total, 12 animals were observed spawning in an area approximately 100 m x 50 m. All of these were males. They remained on the surface of the substrate (Fig. 1A–C). Some individuals elevated their anterior end slightly (Fig. 1A). Sperm was released from the gonopore as a blob that remained concentrated until it was gently dispersed by water movement (Fig. 1B and C). There was no evidence of spawning on the following day at the same location, time and tide conditions.

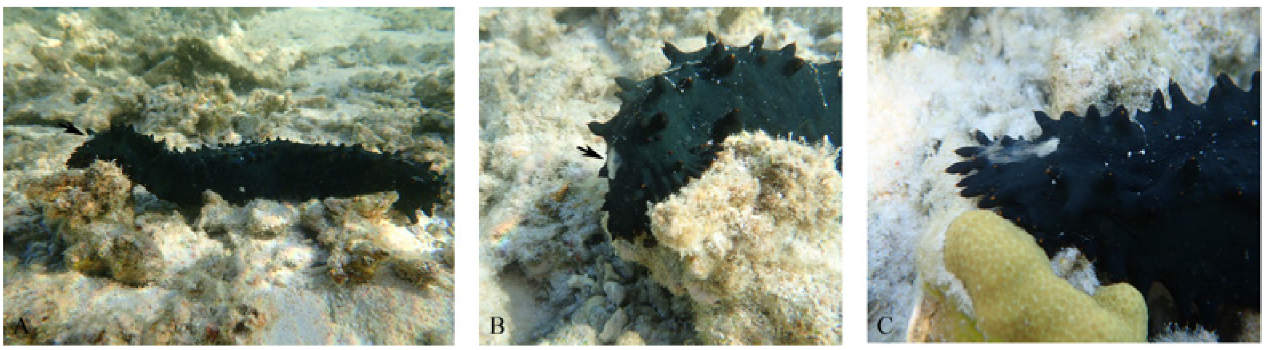


Figure 1. *Stichopus chloronotus* spawning. A) and B): Male with anterior end slightly elevated and with a blob of sperm released from the gonopore (arrows). C): A different male with the sperm being slowly dispersed by water movement. (Images: ©Maria Byrne)

[1] School of Life and Environmental Sciences, University of Sydney, NSW 2006, Australia. Email: maria.byrne@sydney.edu.au

Holothuria isuga

Date: 23 January 2019

Time: 16:00

Lunar phase: Full moon + 2 days

Spawning in *H. isuga* was observed in the lagoon at a location called Shark Alley where this species is common in sediment (Fig. 2A–C). The tide was low, and the lagoon was ponded. The animals were in 2 m of water. In total, five animals were observed on top of the sediment in an erect spawning posture along approximately 200 m of Shark Alley. These were all males, and the sperm was released from the anterior end and dispersed by water movement (Fig. 2 C). In this location *H. isuga* are dispersed in the sediment and are generally 3–5 m apart during reproduction (M. Byrne pers. obs.). Coincident with these observations, the nearby population of *Acanthaster* sp. (crown-of-thorns sea star) was also releasing gametes, with both males and females were spawning.

Discussion

The spawning of *S. chloronotus* in late October may be at the start of the spawning season as this species is reported to spawn in the southern Great Barrier Reef in November and February (Franklin 1980). *S. chloronotus* may spawn other times of the year, as seen elsewhere (e.g. Tan and Zulfigar 2001).

This is the first report of *H. isuga* spawning and was seen in January (summer), as is also the case for a suite of co-occurring species (e.g. *Stichopus herrmanni* and *Holothuria atra*) (Harriott 1982; Balogh et al. 2019). To determine the reproductive season of *S. chloronotus* and *H. isuga,* more extensive observations and details of gonad development are needed.

Similar to the pattern observed for other aspidochirotids (Babcock et al. 1992; Balogh et al. 2019), male *S. chloronotus* and *H. isuga* spawned first. At One Tree lagoon this is often seen late in the afternoon (M. Byrne, pers. obs.). The presence of sperm in the water, especially when the lagoon is ponded, may serve as a pheromonal cue for females, which appear to wait to release their eggs until after dusk. This may be a mechanism to prevent predation on the eggs by diurnal fishes. Spawning in *S. chloronotus* and *H. isuga* may be triggered by the lunar cycle as it occurrs around the full moon.

For *Stichopus herrmanni*, spawning has been observed over many years and is known to occur around the new moon (Balogh et al. 2019). It will be interesting to continue documenting spawning in sea cucumbers and the timing of these events with respect to lunar phases.

Acknowledgements

Thanks to Dione Deaker for the images of *Holothuria isuga* and Matt Clements for assistance with figures.

References

Babcock R., Mundy C., Keesing J. and Oliver J. 1992. Predictable and unpredictable spawning events: *in situ* behavioural data from free-spawning coral reef invertebrates. Invertebrate Reproduction and Development 22:213–228.

Balogh R., Wolfe K. and M. Byrne. 2019. Gonad development and spawning of the vulnerable commercial sea cucumber, *Stichopus herrmanni*, in the southern Great Barrier Reef. Journal of the Marine Biological Association of the United Kingdom 99:487–495.

Conand C., Uthicke S. and T. Hoareau. 2002. Sexual and asexual reproduction of the holothurian *Stichopus chloronotus* (Echinodermata): a comparison between La Réunion (Indian Ocean) and east Australia (Pacific Ocean). Invertebrate Reproduction Development 41:235–242.

Franklin S. 1980. The reproductive biology and aspects of the population ecology of *Holothuria leucospilota* (Brandt) and *Stichopus chloronotus* (Brandt). PhD dissertation, University of Sydney.

Harriott V. 1982. Sexual and asexual reproduction of *Holothuria atra* (Jaeger) at Heron Island Reef, Great Barrier Reef. Australian Museum Memoir 16:53–66.

Tan S.H. and Z. Zulfigar. 2001. Reproductive cycle of *Stichopus chloronotus* (Brandt, 1835) in the Straits of Malacca. p. 389–394. In: Barker M. (ed). Echinoderms 2000. Lisse, the Netherlands: A.A. Balkema.

Figure 2. *Holothuria isuga* spawning. A) and B): Spawning males elevated above the floor of the lagoon. C): Anterior end showing sperm being released and dispersed by water movement. (Images: ©Dione Deaker, University of Sydney)

Stichopus herrmanni spawning observation

Observer/photographer: Aaron Chai
Species: *Stichopus herrmanni*
Location: Heron Island, Great Barrier Reef, Australia (23.4423° S, 151.9148° E)
Date and time: 15 January 2021 (summer) at 18:30
Moon phase: Two days after new moon
Notes: This observation matches the trends documented in Balogh et al. (2019) and previous spawning observations (SPC Beche-de-mer Information Bulletin #38)[1] for *S. herrmanni*. Spawning typically occurs within 1–2 days after new moon in warm summer months.

Stichopus herrmanni spawning. (Image: Aaron Chai)

Reference

Balogh R., Wolfe K. and Byrne M. 2019. Gonad development and spawning of the vulnerable commercial sea cucumber, *Stichopus herrmanni*, in the southern Great Barrier Reef. Journal of the Marine Biological Association of the United Kingdom 99:487–495.

[1] https://purl.org/spc/digilib/doc/v5wgt

Observations of juvenile *Stichopus herrmanni* and confirmation of "pie crust" nursery grounds

Kennedy Wolfe[1]* and Amelia Desbiens[1]

Some of the smallest *Stichopus herrmanni* found in the wild are documented from the outer reef crest of Heron Island, Great Barrier Reef, Australia (Fig. 1A) (Palazzo et al. 2016; Wolfe and Byrne 2017). Juveniles as small as 10 cm in length were found in April 2015 and 2016. The size distribution of *S. herrmanni* across Heron Reef during this period indicated a pattern of ontogenetic migration lagoonward, wherein smaller individuals dominated the outer shallow reef matrix. As such, this habitat – commonly termed "pie crust" (Fig. 1A,B) – was suggested to be an important recruitment and juvenile nursery site for *S. herrmanni* (Wolfe and Byrne 2017).

The same location at Heron Reef was revisited in March 2021 to investigate the possibility for this spatio-demographic structure to be maintained through time. In a ~1 h reef walk at around 14:00, we found eight *S. herrmanni* below 15 cm, including individuals of 8, 9, 9.5, 10.5, 12, 13, 14, 14.5 cm in length (Fig. 1C–E). These individuals were found in almost the exact same location as previous observations in the shallow water (0–0.5 m) pie crust matrix (Fig. 1B). This confirms previous suggestions that this habitat type provides a nursery ground for juvenile *S. herrmanni* on Heron Reef (Palazzo et al. 2016, Wolfe and Byrne 2017), as indicated elsewhere (Bourjon and Morcel 2016).

Larger adult *S. herrmanni* were found nearby, generally lagoonward in slightly deeper and sandier patches (Fig. 1A). Newly settled juveniles have not been found in this location, but this would likely require more intensive surveys in the dead reef, rubble matrix, as noted for some of the smallest *Stichopus* sp. found in nature elsewhere (Bourjon and Conand 2015; Desbiens and Wolfe 2020).

We also observed high densities of *Stichopus chloronotus* in this shallow reef area, with individuals as small as 5–10 cm in length (Fig. 1F). Aggregations of juvenile *S. chloronotus* have been noted previously, including their tendency to aggregate on hard-reef substrate (Eriksson et al. 2012). This behaviour is supported by our observations at Heron Reef.

Additionally, two small holothuroids were found under plate-like rubble in the shallow pie crust matrix (Fig. 1G). These may belong to the Apodida but remain unidentified and are not necessarily juveniles. One individual eviscerated when it was spotted in the rubble (Fig. 1G).

References

Bourjon P. and Conand C. 2015. Juvenile holothurian observed at La Réunion (Indian Ocean). SPC Beche-de-mer Information Bulletin 35:64–65. https://purl.org/spc/digilib/doc/vj9zh

Bourjon P. and Morcel E. 2016. New observations of holothurian juveniles on Réunion reefs. SPC Beche-de-mer Information Bulletin 36:41–44. https://purl.org/spc/digilib/doc/qttxq

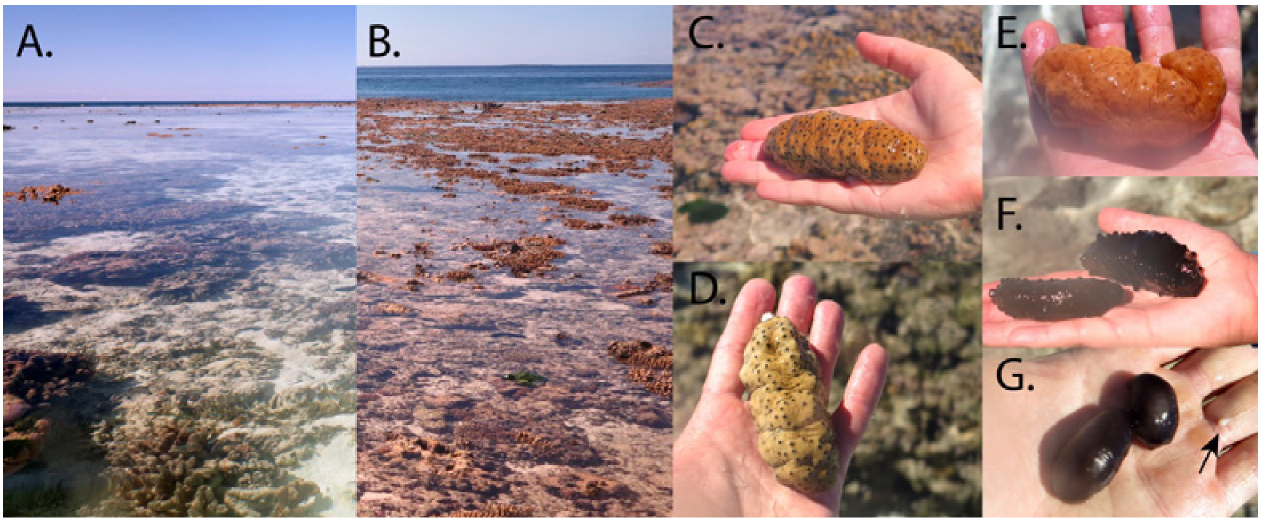


Figure 1. Photographs of the shallow (A) sandy reef and (B) pie crust at Heron Island, Australia, as well as of juvenile (C–E) *Stichopus herrmanni*, (F) *S. chloronotus* and (G) two unidentified holothuroids with black arrow indicating evisceration.

[1] Marine Spatial Ecology Lab, School of Biological Sciences and ARC Centre of Excellence for Coral Reef Studies, University of Queensland, St. Lucia 4072, Australia

* Author for correspondence: k.wolfe@uq.edu.au

Desbiens A. and Wolfe K. 2020. Observations of juvenile *Stichopus* sp. on a coral reef in Palau. SPC Beche-de-mer Information Bulletin 40:53–55. https://purl.org/spc/digilib/doc/zsz3o

Eriksson H., Jamon A. and Wickel J. 2012. Observations on habitat utilization by the sea cucumber *Stichopus chloronotus*. SPC Beche-de-mer Information Bulletin 32:39–42. https://purl.org/spc/digilib/doc/cofeq

Palazzo L., Wolfe K. and Byrne M. 2016. Discovery and description of *Stichopus herrmanni* juvenile nursery sites on Heron Reef, Great Barrier Reef. SPC Beche-de-mer Information Bulletin 36:36–40. https://purl.org/spc/digilib/doc/cv2zh

Wolfe K. and Byrne M. 2017. Population biology and recruitment of a vulnerable sea cucumber, *Stichopus herrmanni*, on a protected reef. Marine Ecology 38:e12397.

Observation of predation by the titan triggerfish on a holothurian at Reunion Island

Peggy Richard[1]

On 3 February 2021, in the lagoon of La Saline, Reunion Island, I to observed a titan triggerfish (*Balistoides viridescens*) for a half an hour, from 17:35 to 18:05.

This one was of good size (about 80 cm), was less than 15 m from the beach, in a depth of about 1 m and was feeding. At first, it was rather interested in corals, putting itself vertically to lift them.

Then, from 17:50, it started to attack a sea cucumber *Holothuria leucospilota*. At first, it sucked the sea cucumber with its mouth, certainly biting it with his teeth, and then spit it out. It repeated this several times. After less than 5 minutes, the holothurian expelled its Cuvieran tubules and probably part of its internal organs, which were pinkish. The titan triggerfish first ate the internal organs, then it started to crunch the black flesh of the holothurian until it was cut into two. It then devoured the entire black flesh.

The sea cucumber was completely gone in less than 15 minutes.

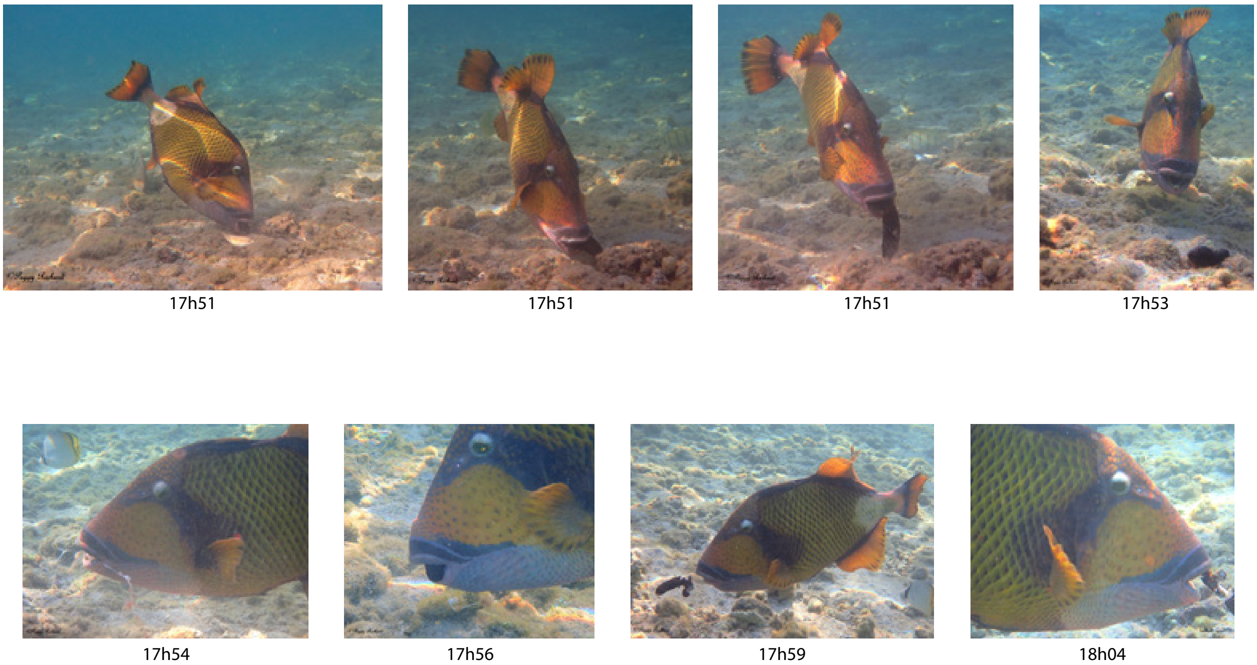


Figure 1. Sequence of predation on *Holothuria leucospilota* by a titan triggerfish. (Images: Peggy Richard)

[1] Email: peggyrichard34@yahoo.fr

Observation de prédation par le baliste titan sur une holothurie, à La Réunion

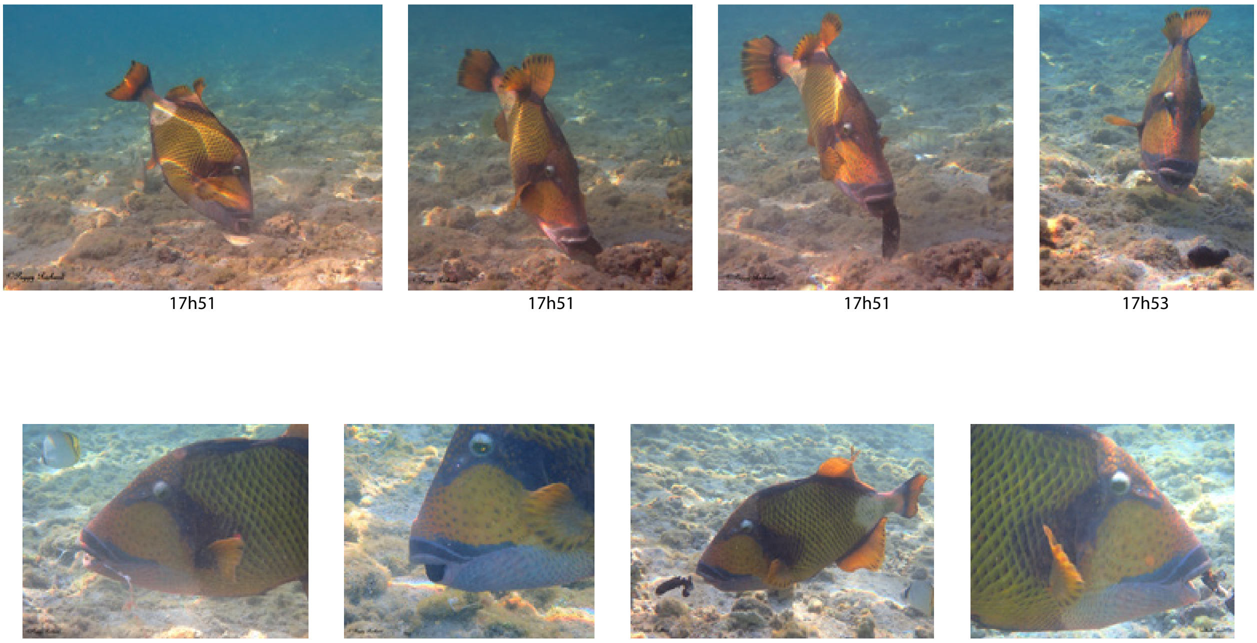
Peggy Richard[1]

Le 3 février 2021, dans le lagon de la Saline, Ile de la Réunion, j'ai eu la chance de pouvoir observer un baliste titan (*Balistoides viridescens*) durant une demi-heure, de 17h35 à 18h05.

Celui-ci était de bonne taille (environ 80 cm), se trouvait à moins de 15 m de la plage, à une profondeur d'environ 1m et était en train de se nourrir. Dans un premier temps, il s'est plutôt intéressé à des coraux, se mettant à la verticale pour les soulever.

Puis, à partir de 17h50, il a commencé à s'attaquer à une holothurie *Holothuria leucospilota.* Au début, il l'aspirait avec sa bouche, certainement en donnant des coups de dents, puis la recrachait. Il a réitéré cette opération plusieurs fois. Au bout de moins de 5 minutes, l'holothurie a expulsé ses tubes de Cuvier et probablement une partie de ses organes internes qui étaient de couleur rosée. Le baliste titan a tout d'abord mangé les organes internes, puis il a recommencé à croquer la chair noire de l'holothurie jusqu'à la couper en deux. Il a ensuite dévoré l'intégralité de la chair noire.

L'holothurie avait totalement disparu en moins de 15 minutes.



17h51 17h51 17h51 17h53

17h54 17h56 17h59 18h04

Figure 1. Séquence de la prédation sur *H. leucospilota* par le baliste titan. Images: Peggy Richard

The trepangs of Leschenault

Michel Jangoux[1]

Théodore Leschenault de la Tour (1773–1826) was a French naturalist and traveller. He was one of the scientists who took part in the discovery voyage to the Southern Lands of Captain Nicolas Baudin onboard the vessel *Le Géographe* (1800–1804). For health reasons Leschenault was landed in Timor in May 1803 with the mission of going, once cured, to Batavia and, from there, to Île de France (today Mauritius) where *Le Géographe* was supposed to stop on the way back to France. In the impossibility of finding a passage neither for Île de France or for Europe, Leschenault accepted the offer of Nicolas Engelhard, the Dutch governor of East Java, to welcome him and provide for his needs by putting his talents to work as a naturalist. Leschenault explored Java for nearly three years in the service of the governor. He returned to France via the United States in July 1807. During these years on Java, Leschenault regularly kept a botanical journal and a zoological journal. Two of the latter's 195 items concern sea cucumbers.

Item N°176. Sea cucumbers. Trepang. There are five species of trepang which are in considerable trade for China. The Chinese eat them like the nests of swiftlet. Trepangs are found abundantly on all the coasts of the archipelago: Buru, Bali, etc., and on the north coast of New Holland [today Australia] where boats from Macassar go fishing. The preparation of this mollusc consists only of drying them. We empty them first and then we boil them for a while in fresh water where there is a little alum, then it is dried over a low heat.

1°. **Tripan pouti** [*Holothuria scabra*; Putih]. This species of sea cucumber is the size of the wrist and about 1 foot[2] long when it is extended. It is not cylindrical but a little compressed looking like a very big slug. (Although the most usual state is the form I indicate, yet the animal can flatten a lot. After it is harvested, its substance sags and deforms. This is what happened to the individual kept in the arack.) The back is greyish, and the belly is dirty white. The whole body, except the back, is covered by small tubercles from which emerge as many small papillae half à line in length somewhat resembling the horns of slugs. The animal can remove them and extend them out at will. These tubercles are much more abundant on the belly. The anterior part of the back is leathery in consistency[3] as if covered with a cartilaginous test. The posterior part and the belly are soft. The mouth is located at the end of the anterior part under the cartilaginous test. It consists of a large number of suckers[4] whose shape I cannot describe because I have not seen them extended. When the suckers are not extended, they form a bead around the mouth. The anus is located at the end of the posterior part. It is round, surrounded by a bead.

By lightly squeezing one of these animals, its intestine came out of the anus almost effortlessly as by their own weight. It completely emptied himself. In my observation of it, I saw a long gut about 1½ foot in length about the size of a little finger, filled with mud. To the anterior part of this gut was attached a red gelatinous mass which I thought were the animal's gills.[5]

This animal that I observed alive has very slow movements. It lengthens, shortens, folds in various directions. I did not see it change places, but I think that the numerous papillae that are under the belly help it in this operation. Its whole body is covered with a slimy, mucus-like mantle. It lives in shallow waters, near shores where there is sand mixed with mud. This species is the least of all and it only sells for around 6 or 7 piastres[6] for 1 picole[7] (125 pounds) in Batavia. When it is dried out, its size shrinks a lot.

2°. **Tripan koro** [*Holothuria (Microthele) nobilis*; Koro]. This species is the best of all. It is bigger than the tripan pouti. Its colour is greyish black. It lives in sandy and rocky places at considerable depths. Tripan koro sells almost 70 piastres in Batavia.

3° **Tripan itam** or **Tripan bator** [*Holothuria atra*; Hitam]. We designed under these two names a species of tripan that differs from tripan koro because he is very dark and only lives in rocky places. It is of the same quality as the tripan koro.

4°. **Tripan kouiette** [*? Holothuria (Microthele) fuscopunctata*; Kunyit]. This species is the same size as the tripan koro. It is blackish with a yellow strip on each side of the body. It is of lower quality than the two preceding species. It only sells for 25 to 30 piastres a picole. It lives in the same place as the two preceding species.

5°. **Tripan nanas** [*Thelonota ananas*]. This species is the largest of all. This animal is reddish with large tubercles which made it name ananas[8] by the kind of resemblance it has to this fruit. It is about the same quality and the same price as tripan kouiette, which is a little more expensive. It lives in the same places.

1 Marine Biology Department, Université Libre de Bruxelles, 1050 Brussels, Belgium

2 A foot is 30.5 cm.

3 Consistency linked to the occurrence of a periesophageal calcareous crown.

4 These are the peri buccal tentacles.

5 This is the dense haemal network associated with the middle part of the digestive tract.

6 General name then given to different currencies, in the present case to the Batavia florin which was worth, in 1820, 2.14 French francs, or a little less than 5 euros.

7 The picole or quintal of Asia is worth about 50 kg.

There is one more species of black sea cucumber which is very common on the shores covered with molluscs and coral. I have found it abundantly on Bali Island. This sea cucumber species, named 'bouton mati' by Malaysians, has, after his death, a strong smell of rotten fish.There is one more species of black sea cucumber which is very common on the shores covered with molluscs and coral. I have found it abundantly on Bali Island. This sea cucumber species, named 'bouton mati' by Malaysians, has, after his death, a strong smell of rotten fish.

Item N°195. **Tro** [*Phyllophorus* sp.] is a species of almost globular sea cucumber, the size of a large truffle which is fished near Gresik[9] and that the Javanese, after having emptied it, fry in coconut oil to eat it. This sea cucumber lives in sandy places mixes with sand [sic]. When it comes out of the water, all its tentacles being withdrawn inside the body, it is globular and, because of the mud which blackened it and its shape, it looks like a big truffle.

References

Jangoux M. 2004. Les zoologistes et botanistes qui accompagnèrent le capitaine Baudin aux Terres australes. Australian Journal of French Studies 41(2):55–78.

Leschenault T. 1807. Carnet zoologique de Java. Archives du Muséum national d'Histoire naturelle (Paris).

Setyastuti A. and Purwati P. 2015. Species list of Indonesian *trepang*. SPC Beche-de-mer Information Bulletin 35:19–25. https://purl.org/spc/digilib/doc/mpzv3

[8] Ananas means pineapple in French.
[9] A city of Java Island, northwest to Surabaya.

Les trepangs de Leschenault

Michel Jangoux[1]

Théodore Leschenault de la Tour (1773–1826) était un voyageur naturaliste français. Il était l'un des scientifiques qui participa, à bord du vaisseau *Le Géographe*, au voyage de découvertes aux Terres australes du commandant Nicolas Baudin (1800–1804). Pour des raisons de santé Leschenault fut débarqué à Timor en mai 1803 avec pour mission de se rendre, une fois guéri, à Batavia et, de là, rejoindre l'Île de France (actuellement île Maurice) là où le *Géographe* devait relâcher sur le chemin du retour en France. Dans l'impossibilité de trouver un passage tant pour l'Île de France que pour l'Europe, Leschenault accepta l'offre de Nicolas Engelhard, le gouverneur hollandais de la région orientale de l'île de Java, de l'accueillir et de pourvoir à ses besoins en mettant à son service ses talents de naturaliste. Leschenault explora Java pendant près de trois ans au service du gouverneur Engelhard. Il regagna la France via les États-Unis en juillet 1807. Pendant ces années javanaises, Leschenault tint régulièrement un journal botanique et un journal zoologique. Deux des 195 items de ce dernier concernent des holothuries.

Item 176. Holothuries. Tripan. Il y a 5 espèces de tripans qui sont d'un commerce considérable pour la Chine. Les Chinois les mangent comme les nids de la salangane[2]. Les tripans se trouvent abondamment en toutes les côtes de l'archipel au sud de l'île de Java, Buru, Bali, etc., et sur la côte nord de la Nouvelle-Hollande (actuellement Australie) où des bateaux de Macassar les vont pêcher. La préparation de ce mollusque ne consiste qu'**à** les faire sécher. On les vide d'abord puis on les fait bouillir quelque temps dans de l'eau douce où il y a un peu d'alun puis on le fait sécher à petit feu.

1°. **Tripan pouti** [*Holothuria scabra* **;** Putih[3]]. Cette espèce d'holothurie est de la grosseur du poignet et d'environ 1 pied[4] de long lorsqu'elle est étendue. Elle n'est point tout à fait cylindrique, mais un peu comprimée ressemblant à une très grosse limace. (Quoique l'état le plus habituel soit la forme que j'indique, cependant l'animal peu s'aplatir beaucoup. Après la récolte de l'animal, sa substance s'affaisse et se déforme. C'est ce qui est arrivé à l'individu conservé dans l'arack.) Le dos est grisâtre et le ventre d'un blanc sale. Tout le corps, à l'exception du dos, est couvert de petits tubercules desquels sortent autant de petites papilles d'une demi-ligne de longueur ressemblant un peu aux cornes de limaces. L'animal peut les retirer et les faire sortir à volonté. Ces tubercules sont beaucoup plus abondants sur le ventre. La partie antérieure du dos est d'une consistance coriace comme recouverte d'un test cartilagineux[5]. La partie postérieure et le ventre sont mous. La bouche est située au bout de la partie antérieure sous le test cartilagineux. Elle est composée d'un grand nombre de suçoirs[6] dont je ne peux décrire la forme parce que je ne les ai pas vus étendus. Lorsque les suçoirs ne sont point étendus, ils forment autour de la bouche un bourrelet. L'anus est situé au bout de la partie postérieure. Il est rond, entouré d'un bourrelet. En pressant légèrement un de ces animaux, ses intestins sont sortis par l'anus presque sans effort, comme par leur propre poids. Il s'est entièrement vidé. J'ai vu, dans l'observation que j'en ai faite, un long boyau d'environ 1 pied ½ de longueur de la grosseur d'un petit doigt, rempli de vase. À la partie antérieure de ce boyau était attaché une masse gélatineuse rousse que j'ai cru être les branchies de l'animal[7].

Cet animal que j'ai observé vivant a les mouvements fort lents. Il s'allonge, se raccourcit, se replie en divers sens. Je ne l'ai pas vu changer de place, mais je pense que les papilles nombreuses qui sont sous le ventre l'aident dans cette opération. Tout son corps est recouvert d'un manteau visqueux et glaireux. Il habite les endroits de la mer peu profonds, près des rivages où se trouve du sable mélangé de vase. Cette espèce est la moindre de toutes et [elle] ne se vend qu'environ 6 ou 7 piastres le picole[8] (125 livres) à Batavia. Lorsqu'elle est desséchée, sa grosseur se réduit beaucoup.

2°. **Tripan koro** [*Holothuria (Microthele) nobilis* **; Koro].** Cette espèce est la meilleure de toutes. L'animal est plus gros que le tripan pouti. Sa couleur est noir grisâtre. Il habite les lieux sablonneux et rocheux à des profondeurs considérables. Le tripan koro se vend presque 70 piastres à Batavia.

3°. **Tripan itam** ou **tripan bator** [*Holothuria atra* **;** Hitam]. On désigne sous ces deux noms une espèce de tripan qui diffère du tripan koro en ceci qu'il est très noir et habite seulement les endroits rocheux. Il est de même qualité que le tripan koro.

4°. **Tripan kouiette** [*? Holothuria (Microthele) fuscopunctata* **;** Kunyit]. Cette espèce est de la même grosseur que le tripan koro. Elle est noirâtre avec une bande jaune de chaque côté du corps. Elle est de moindre qualité que les 2 espèces précédentes. Elle ne se vend que de 25 à 30 piastres le picole. Il habite les mêmes lieux que les deux espèces précédentes.

5°. **Tripan nanas** [*Thelonota ananas* ; Nanas]. Cette espèce est la plus grosse de toutes. L'animal est rougeâtre avec de

1 Laboratoire de Biologie Marine CP 160/15, Université Libre de Bruxelles, Belgique.
2 Nom vernaculaire des oiseaux de la famille des Apodidae, parmi lesquels les martinets.
3 Nom indonésien de l'espèce (Setyastuti et Purwati 2015)
4 Le pied vaut 30 cm.
5 Consistance liée à la présence d'une couronne calcaire périoesophagienne.
6 Ce sont les tentacules péribuccaux.
7 Il s'agit du réseau hémal dense (réseau admirable) associé à la partie médiane de tube digestif.
8 Le picole ou quintal d'Asie vaut environ 50 kg.

FR

gros tubercules ce qui l'a fait nommer ananas par l'espèce de ressemblance qu'il a avec ce fruit. Il est à peu près de la même qualité et du même prix que le tripan kouiette qui est un peu plus cher. Il habite les mêmes lieux.

Il y a encore une espèce d'holothurie noire qui est très commune sur les rivages couverts de mollusques et de madrépores. Je l'ai abondamment trouvée sur l'île Bali. Cette espèce d'holothurie, que les Malais nomment 'bouton mati', a, après sa mort, une forte odeur de poisson pourri. On n'emploie pas cette espèce.

Item 195. **Tro** [*Phyllophorus* sp] est une espèce d'holothurie blanche presque globuleuse de la grosseur d'une grosse truffe qui se pêche près de Gresik[9] et que les Javanais, après l'avoir vidée, font frire dans l'huile de coco pour la manger. Cette holothurie se plaît dans les lieux sablonneux mélangés de sable [sic]. Lorsqu'elle sort de l'eau, tous ses tentacules étant retirés dans l'intérieur du corps, elle est globuleuse et ressemble à une grosse truffe.

Bibliographie

Jangoux M. 2004. Les zoologistes et botanistes qui accompagnèrent le capitaine Baudin aux Terres australes. Australian Journal of French Studies, 41[2]:55–78.

Leschenault T. 1807. Carnet zoologique de Java. Archives du Muséum national d'Histoire naturelle (Paris).

Setyastuti A. et Purwati P. Recensement des espèces d'holothuries pêchées et transformées en Indonésie. La Bêche-de-mer, Bulletin d'information de la CPS 35:19–25. https://purl.org/spc/digilib/doc/g3n5

[9] Ville de l'île de Java au nord-ouest de Surabaya.

COMMUNICATIONS

Communications prepared by Chantal Conand

New books/works on holothurians

Mohsen M. and Yang H. 2021. Sea cucumbers: Aquaculture, biology and ecology. First edition. Academic Press.

Sea cucumbers: Aquaculture, biology and ecology is a reference book that gathers practical and biological knowledge necessary to promote the aquaculture of sea cucumbers, aiming to share experience across regions and facilitate learning so that mistakes are not repeated. The book pays particular attention to sea cucumber research in the Middle East, where sea cucumber experience is limited but of potential value.

The book starts with the basic biology and ecology of sea cucumbers, drawing a general idea of the sea cucumbers morphology, internal biological processes and interaction with the surrounding environment. The second part of this book aims to shed light on the lesser mentioned sea cucumber resources in the Middle East. This part summarised the available knowledge on sea cucumbers in the Mediterranean Sea, the Red Sea and the Persian Gulf, particularly the variety of sea cucumber species, aquaculture development and utilisation research of sea cucumbers. The last part of this book is about sea cucumbers from production to consumption. This part summarises the standard culture techniques for six newly introduced sea cucumber species: *Holothuria tubulosa*, *H. poli*, *H. arguinensis*, *H. leucospilota, H. mammata* and *Stichopus horrens*. It then reviews the modern processing and cooking methods of sea cucumbers. Finally, the book discusses the steps needed to promote sea cucumber aquaculture and stock enhancement in the Middle East.

For more information: m.mohsen@azhar.edu.eg

Global knowledge on the commercial sea cucumber Holothuria scabra

By Jean-François Hamel, Igor Eeckhaut, Chantal Conand, Jiamin Sun, Guillaume Caulier and Annie Mercier

This article will be published in *Advances in Marine Biology* in 2022.

One of the most intensively studied holothuroids, *Holothuria scabra* has been discussed in the literature since 1833. The species is important for several reasons: 1) it is abundant and widely distributed in several shallow soft-bottom habitats throughout the Indo-Pacific; 2) it has a high commercial value on the Asian markets, where it is mainly sold as beche-de-mer; and 3) it is the only tropical holothuroid species that can currently be mass-produced in hatcheries. Over 20 years elapsed since the last comprehensive review on *H. scabra* was published in 2001. Research on *H. scabra* has continued to increase, fuelled by intense commercial exploitation and further declines in wild stocks over the entire distribution range. This review compiles data from over 900 publications pertaining to the biology, ecology, physiology, biochemical composition, aquaculture, fishery and trade of *H. scabra*. Although several references are likely to have been missed by our investigation, we present the most complete reference list to date, including material published by local institutions and/or in foreign languages. The main goal of this project was to summarise and critically discuss the abundant literature on this species, making it more readily accessible to all stakeholders wishing to conduct fundamental research, aquaculture and stock enhancement, and management programmes on *H. scabra* across its geographic range.

For more information: Jean-François Hamel, jfhamel.seve@gmail.com and Annie Mercier, amercier@mun.ca

Research on echinoderms in Latin America V is now available from the webpage of the Journal of Tropical Biology[1]

This special issue included several papers presented at the Fourth Latin American Conference of Echinoderms, held from 10–15 November 2019 in La Paz, Baja California Sur, Mexico. It is dedicated to our dear Dr Blanca Estela Buitrón Sánchez, and was published in memory of Dr Jonh Pearse. In the first pages you can read the dedications that Francisco Solís and Renato Ventura kindly wrote.

[1] https://revistas.ucr.ac.cr/index.php/rbt/issue/view/3030

The contributions on holothurians are:

Feeding habits of *Holothuria* (*Stauropora*) *fuscocinerea* (Echinodermata: Holothuroidea) in a Mexican Pacific reef
By Brenda Maya-Alvarado, Laura-Georgina Calva-Benítez, Rebeca Granja-Fernández, Jessica Pérez-López, Andrés López-Pérez

First record of the genus *Leptopentacta* (Cucumariidae: Colochirinae) for the Nicaraguan Caribbean.
By Francisco-Alonso Solís-Marín, Osmar-Benito Sandino, Carlos-Andrés Conejeros-Vargas, Andrea-Alejandra Caballero-Ochoa

Reproductive cycle of the sea cucumber *Holothuria forskali* (Holothuriida: Holothuriidae) in the Ría de Vigo (NW of Spain)
By Tania Ballesteros, Ana Tubío, Rosana Rodríguez, Alba Hernández, Damián Costas, Jesús Troncoso

Expansion of the genus *Massinium* (Holothuroidea: Thyonidae) to the American continent and description of a new species
By Francisco-A. Solís-Marín, Alfredo Laguarda-Figueras, Carlos-A. Conejeros-Vargas, Andrea-A. Caballero-Ochoa, Alicia Durán-González

New records of the family Cucumariidae (Holothuroidea: Dendrochirotida) for the Mexican Pacific
By Daniel-M. Sánchez-Alonzo, Francisco-A. Solís-Marín, Carlos-A. Conejeros-Vargas

Translation of two articles by J.M. Lawrence

Catalogue Raisonné of the Families, Genera and Species of the Class of Echinoderms

Agassiz L. and Desor E. 2020. Catalogue Raisonné of the families, genera and species of the class of echinoderms: A translation of Agassiz L. and Desor E. 1846. Catalogue raisonné des familles des genres et des espèces de la Classe de Echinodermes. Annales des sciences naturelles, volume 6, series 3, p. 305–374. (translated by J.M. Lawrence). https://doi.org/10.5038/bin.books.1024

Memoir on the Synapte of Duvernoy (Synapta Duvernæa A. de. Q.)

de Quatrefages A. 2021. Memoir on the Synapte of Duvernoy (Synapta Duvernæa A. de. Q.): A translation of de Quatrefages A. 1842. Mémoire sur la Synapte de Duvernoy (Synapta Duvernæa A. de Q.). Annales des sciences naturelles. Zoology. Series 2, volume 17, p. 19–93. (translated by J.M. Lawrence). https://doi.org/10.5038/bin.books.1031

Statistics on publications published in 2021 related to holothurians

by Chantal Conand

A Google Alert, using the word "holothurian", was set up for the period January to December 2020. The same method had first been used in 2016 to produce the article "Bibliography on holothurians: Access to modern tools to follow new publications", which was published in the SPC Beche-de-Mer Information Bulletin #36.[2]

Table 1. Number of documents related to holothurians published in 2021, from 1 January to 31 December.

Months	General biology, ecology	Biochemistry, microbiology	Genetics	Aquaculture	Fishery, socioeconomics	Total/month
January	10	5	2	3	2	22
February	10	6	3	2	2	23
March	11	3	0	4	4	22
April	11	7	1	0	6	25
May	6	10	2	2	1	21
June	7	9	1	1	1	19
July	8	5	3	8	3	27
August	12	4	4	4	1	25
September	6	8	5	5	3	27
October	3	2	1	2	4	12
November	9	6	2	0	2	19
December	6	3	0	0	5	14
Total	**99**	**68**	**24**	**31**	**34**	**256**
Ratio %	39%	27%	9%	12%	13%	

[2] https://purl.org/spc/digilib/doc/gbcbb

Information collected on the Internet

Crocodiles kill two divers hunting for sea cucumbers in Solomon Islands after ban lifted[3]

by Tahlea Aualiitia

Two men have been killed in separate crocodile attacks in Solomon Islands while diving for sea cucumbers at night.

Key points:

- A sea cucumber catch can earn Pacific divers hundreds of dollars.
- The lifting of a sea cucumber ban has sparked a harvesting craze.
- Crocodile population are booming in the Solomon Islands

The deaths last week of a 36-year-old man and another man in his 20s came less than a month after the country lifted a ban on harvesting the marine animal called beche-de-mer, in order to boost the economy after COVID-19.

Royal Solomon Islands Police Force Provincial Assistant Commissioner Joseph Maneluga said he was concerned about the attacks, which occurred just a day apart.

"I think the people are going crazy because of the reopening of the beche-de-mer," he said.

"And the population of crocodiles is really increasing, and so that is the threat that we have."

Sea cucumber crime is a thing, and this is where it's happening[4]

by Frank Jacobs

A "seafood mafia" is plying the waters between India and Sri Lanka to satisfy China's appetite for an increasingly rare delicacy.

Sri Lanka's legal market for sea cucumbers next to India's illegal one is proving too tempting a proposition for poachers.

Long a delicacy in China and East Asia, sea cucumbers are now also becoming a rarity worldwide.

India has outlawed the trade, inaugurated a marine reserve, and put together a law enforcement task force.

But the trade remains legal in Sri Lanka, which has become the hub for widespread "seafood laundering".

Sea cucumbers pinch out "5 Eiffel Towers' worth" of poop per reef, per year[5]

by Nicoletta Lanese

Sea cucumbers – those chubby tubes of flesh that scooch around the ocean floor – have a very special talent: The tubular creatures are elite poopers, collectively expelling more than 64,000 tonnes of sandy poop out of their bottoms each year.

That's not an estimate for the entire globe; that's how much sea cucumbers poop on a single coral reef, per year. And even that tremendous number may be an underestimate, according to a new study, published Feb. 2 in the journal Coral Reefs.[6]

Williamson J.E., Duce S., Joyce K.E. et al. 2021. Putting sea cucumbers on the map: Projected holothurian bioturbation rates on a coral reef scale. Coral Reefs 40:559–569

Les nouvelles formes de pêche à Saint-Pierre-et-Miquelon (New forms of fishing in St. Pierre and Miquelon (A short video on sea cucumber fishing in St. Pierre and Miquelon.)[7]

Une courte video sur la pêche aux concombres de mer à Saint-Pierre et Miquelon. (A short video on sea cucumber fishing in St. Pierre and Miquelon.)

[3] https://www.abc.net.au/news/2021-10-10/divers-killed-by-crocodiles-hunting-sea-cucumber-beche-de-mer/100515588
[4] https://bigthink.com/strange-maps/sea-cucumber-crime/
[5] https://www.livescience.com/sea-cucumber-poop-reef.html
[6] https://link.springer.com/article/10.1007/s00338-021-02057-2

Illegal trade in Africa's high-value marine products escalating[8]

by Shem Oirere

Only six of the 30 African countries with sea cucumber resources have reported their export totals over the past decade, despite an escalating trend of underreporting and illegal trade of it and other high-value marine species in the region.

According to a report by TRAFFIC,[9] an international non-governmental organization that campaigns against illegal trade in wild animals and plants, the current illegal trade in high-value marine products between Africa and Asia – especially of species like seahorse, sea cucumber, and fish maw – is flourishing. That illegal trade is decimating the species' populations and denying several coastal communities means to a livelihood, the report found.

TRAFFIC based the report on findings of a study compiled in September 2020 showing "population declines, inadequate regulation, stretched law enforcement, and local communities impacted by illegal and unsustainable catch and trade."

"As the trade in fish maws, sea cucumbers, and seahorses from Africa to Asia increases in volume, we simultaneously see significant discrepancies in the reported imports and exports of products linked to these taxa," TRAFFIC Project Support Officer Simone Louw said. Louw also served as lead author of the reports.

The report said smuggling networks are taking advantage of existing legal shortcomings in some African countries to divert illegally harvested high-value marine products to international supply chains. Shark fins, abalone, sea cucumber, and fish maws are some of the most at-risk marine species in the illegal trade due to being "highly-prized luxury seafood products consumed as symbols of status of wealth," the report found.

The report's findings are consistent with previous observations with from the Food and Agriculture Organization of the United Nations (FAO), indicating in 12 of 30 countries in Africa and the Indian Ocean region the sea cucumber resource "appears to be overexploited or fully exploited."

The region, which FAO estimates to be producing at least one-third of the world's dried sea cucumber products, has also attempted various measures to address the overexploitation of the marine species, such as the imposition of total bans that "seem to be insufficient for a sustainable use of the resources."

The international trade in high-value marine products, the FAO said, is characterized by "by exports from the producer countries, imports in 'intermediates' such as Yemen and Dubai, and final markets, where the key role of China/Hong Kong/Southeast Asia is most apparent."

The FAO estimated sea cucumber species *H. scabra,* found in various marine regions off Africa's coast, fetches up to USD 369 (EUR 305) per kilogram, making it one of the continent's highest-value marine products.

Kenya, Tanzania, Madagascar, and South Africa are some of the African countries where the underreported and illegal marine products trade or harvest is more pronounced, according to the report.

In Tanzania, a country formed after the 1964 union of Tanganyika (mainland) and the island of Zanzibar, a powerful smuggling cartel has taken advantage of legislative inconsistencies between the two territories to overexploit the sea cucumber. In mainland Tanzania, trade in sea cucumber is banned, but in Zanzibar it is legal to trade in the marine species, creating a loophole for the cartels to smuggle out sea cucumber and other high-value seafood, the report said.

"High demand, especially from East Asia, has resulted in an expanding marine product 'gold rush,' with more than 80 percent of African coastal states now exporting fish maw to Hong Kong Special Administrative Region alone," the report said.

In an effort to reverse this flourishing illegal trade in prized marine species, two sea cucumber species that mostly occur in the Western Indian Ocean – *Holothuria fuscogilva* and *H. nobilis* – have been listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

[7] https://www.facebook.com/france3/videos/515592209480496
[8] https://www.seafoodsource.com/news/environment-sustainability/illegal-trade-in-africa-s-high-value-marine-products-escalating
[9] https://www.traffic.org/publications/reports/sea-cucumber-trade-from-africa-to-asia/

The commercially exploited aquatic species were listed on CITES1 Appendix II in 2019, placing an obligation on customs officials across Eastern and Southern Africa "to identify these species from other non-listed species and grant export permits to adequately regulate international trade."

The report calls for urgent and immediate action in the short term to reverse the trend including increased regulation and closer scrutiny of trade through efforts like creating specific HS codes and investigating "discrepancies between African and Asian countries/territories."

Additionally, African governments, it said, should urgently probe the findings in the report "as it indicates significant levels of unsustainable and illegal harvest and trade, which is having a detrimental impact on target marine populations, and the local fishing communities that rely on them."

Shem Oirere is a Kenyan journalist who previously worked for daily newspapers as a general news correspondent, business reporter and sub-editor before turning to full-time freelancing. For the more than 20 years, he has covered various sectors of Africa's economy including agriculture, food processing, and maritime industries. A graduate of the University of South Africa, he has traveled within and outside Africa covering various industry events that have a bearing on the continent's economy on behalf of different international consumer and trade publications. He currently lives in Nairobi, Kenya.

COVID-19 fears driving medicinal interest, demand for sea cucumbers in China[10]

by Mark Godfrey

New Zealand Wild Catch Limited has reached an agreement with leading Chinese traditional medicine retailer Beijing Tongrentang for exclusive sales of dried and instant sea cucumber in New Zealand. One of the largest global retailers of traditional Chinese medicine, Beijing Tongrentang has eight stores in Auckland, New Zealand.

Chinese buyers are using sea cucumber as a home remedy to prevent infection from COVID-19, New Zealand Wild Catch Limited Co-Founder and CEO James Parfitt told SeafoodSource. The firm sells the gold tip sea cucumber (*Stichopus mollis*), which is native to New Zealand waters, under the Gold Tip brand.

"After a brief stop in sales in March, April 2020 Gold Tip sales have been very strong since the COVID outbreak, given the immune benefits of regular consumption of sea cucumber," Parfitt said. "But there is still room to grow by increasing harvest and processing in New Zealand and distribution capacity in China."

Parfitt said his brand has thrived during the pandemic due to Chinese customers' trust in the company's wild products and the company's policy of not using additives. Additionally, a study performed by researchers at Auckland University showed the company's products' bioactives compared favorably with farmed Chinese sea cucumber, Parfitt aid.

"Trade ... is going well into formal offline channels in China," Parfitt said. "The New Zealand government has been very supportive and engaging since the COVID outbreak, meaning airfreight disruptions have been minimized."

Parfitt said his firm is still looking for one or two retail distributors in China "who fit with our channel strategy." He's also hoping to secure support from Beijing Tongrentang's affiliates in Southeast Asia "once travel opens up and we can meet face-to-face." The company has plans to expand sales in Japan and Singapore as well.

But Parfitt said he's encountering efforts to counterfeit his brand in many of his markets."There are still fake gold tip sea cucumber from Indonesia claiming to be New Zealand gold tip, as well as cheaper shallow-water black tip sea eggplant in New Zealand," he said. "But the encouraging thing for us is that consumers are starting to realize that irregular shape of gold tip is a good way to tell wild from farmed sea cucumber. We are seeing in the COVID climate repeat customers placing more value in function and health benefits rather than form and uniformity."

Sea cucumber prices in China rose year-on-year in 2020 and have remained strong, according to Djames Lim, CEO of the Lim Shrimp Organisation, which has been building a large indoor sea cucumber farming facility in northern China. "We plan to restart remaining construction after the winter season," he told SeafoodSource. COVID is restricting produce from being imported smoothly into China, complicating his company's business, Lim said.

[10] https://www.seafoodsource.com/news/supply-trade/covid-19-fears-driving-medicinal-interest-demand-for-sea-cucumbers-in-china

600 kg sea cucumber worth Rs 3 crore seized by Indian Coast Guard[11]

by Sidharth MP

New Delhi: An Indian Coast Guard team in Tamil Nadu seized 600 kg of sea cucumber from a small boat that was involved in smuggling. Based on a tip-off, the ICG team at Mandapam, Ramanathapuram district, tracked the suspected vessel and laid a cordon to block its escape.

Subsequently, the boat was found to be anchored off Uchhipalli, Ramanathapuram on Tuesday (October 19, 2021) afternoon.

Coast Guard nabs two for attempted smuggling of 1.2 tonnes of sea cucumber[12]

by Sidharth MP

Chennai: The Indian Coast Guard in a joint operation with the Forest Department seized 1200 kg of sea cucumber being smuggled off the coast of Mandapam, Ramanathapuram district in Tamil Nadu on Tuesday (July 6).

They arrested two persons who were trying to ship the consignment abroad illegally.

The joint patrol was initiated after intelligence was received regarding the illegal trans-shipment of sea cucumber in the late intervening hours of Monday and Tuesday. Operating in the dark of the night, the officials monitored the movement of a suspicious vessel and intercepted it.

"Boarding the vessel in the morning hours of Tuesday, officials recovered 100 gunny bags of sea cucumber weighing 1.2 tonnes and brought the two-crewed vessel to Mandapam North Fishing Harbour. Investigation revealed that the bags of Sea cucumber were meant to be shipped across the International Maritime Boundary Line (KMBL) under the cover of the night," the ICG said in a statement.

Sea cucumbers are an important constituent of the coral ecosystem and are categorised as an 'endangered species' with their harvest being banned under the Wildlife Protection Act of 2001. They play an important role in maintaining the health of marine ecosystems.

Much of the sea cucumbers smuggled out of Tamil Nadu go to Sri Lanka and other South-East Asian countries, where they are consumed as food and used to prepare medicines.

Indian Coast Guard seize two tonnes of endangered sea cucumber worth Rs 80 million[13]

by Sidharth MP

The boat along with seized sea cucumbers was brought to Mandapam and handed over to forest officials.

Chennai: Based on a tip-off, the Indian Coast Guard team at Mandapam, Ramanathapuram, Tamil Nadu seized a 2-ton shipment of marine species Sea Cucumber, that was being smuggled via Indian waters. Early on Sunday, Coast Guard teams in the Gulf of Mannar and Palk Bay areas tracked the boat and laid a cordon to block the suspect vessel at sea.

Sea cucumbers are an important constituent of the marine ecosystem as they play an important role in maintaining the health of the ecosystem. In India, Sea cucumber is treated as an endangered species listed under schedule 1 of the Wildlife Protection Act of 1972.

The boat which was found anchored 15 km off the Vedalai South locality in Mandapam was boarded and searched by an ICG team. The boarding team of ICG Hovercraft H-183 recovered 200 gunny bags of sea cucumber weighing 2000kg or 2 tons. The boat along with seized sea cucumbers was brought to Mandapam and handed over to forest officials. The value of seized sea cucumbers is said to be around Rs.8 crores.

[11] https://zeenews.india.com/india/600-kg-sea-cucumber-worth-rs-3-crore-seized-by-indian-coast-guard-2404074.htmlcrore
[12] https://zeenews.india.com/india/coast-guard-nabs-two-for-attempted-smuggling-of-1-2-tonnes-of-sea-cucumber-2374439.html
[13] https://www.wionews.com/india-news/indian-coast-guard-seizes-two-tonnes-of-endangered-sea-cucumber-worth-rs-80-million-414256

According to the Coast Guard, an investigation revealed that the consignment was planned for transshipment across the International Maritime Boundary Line during dark hours. Sea cucumbers are in high demand in China and Southeast Asia, where it is consumed as food and used in medicine. This endangered species is primarily smuggled from Tamil Nadu to Sri Lanka in fishing vessels from Ramanathapuram and Tuticorin districts.

By excreting inorganic nitrogen and phosphorus, they enhance the productivity of benthic animals - those living on the ocean floor. One of the by-products of the sea cucumber's digestion of sand is calcium carbonate, a key component of coral reef. To survive, coral reefs must accumulate calcium carbonate, and thus sea cucumbers play a vital role in their preservation. Sea cucumbers also maintain the transparency of seawater by eating sewage. Feeding and excretion by sea cucumbers also increase alkalinity, which counteracts ocean acidification. Illegal harvesting and overexploitation of these animals leads to poorer sediment health, reduces nutrient recycling and impacts biodiversity.

2022 meetings

The Second International Conference on Biodiversity, Ecology and Conservation of Marine Ecosystems

More information at: https://www.become2022.com/

Workshop on sea cucumber aquaculture and diseases

A workshop with European researchers working on these topics in Europe and abroad, in collaboration with researchers from Thailand and Madagascar, will take place in October 2022 at "Station marine de Concarneau" (France)

For more information: Prof. Nadia Améziane: ameziane@mnhn.fr

Original text: English and French

Pacific Community, Fisheries Information Section, BP D5, 98848 Noumea Cedex, New Caledonia
Telephone: +687 262000; Fax: +687 263818; cfpinfo@spc.int; http://www.spc.int/coastfish