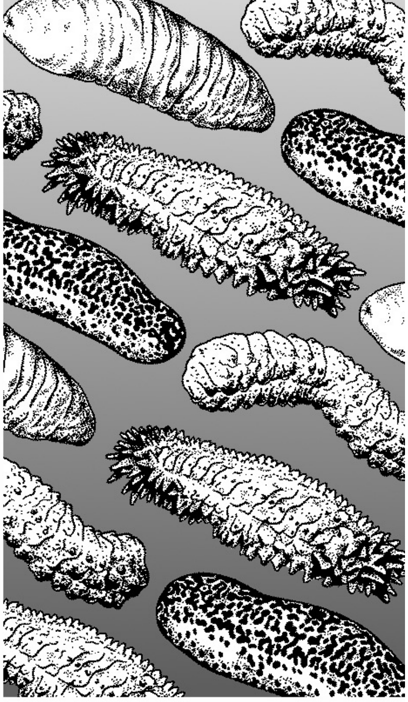

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Inside this issue

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Editorial

This 41th issue of the SPC *Beche-de-Mer Information Bulletin* includes 16 original articles and scientific observations from a wide variety of regions around the world. We first want to express our congratulations to Dr Marie Bonneel, Dr Cathy Hair and Dr Hocine Benzait who recently received their PhDs. Dr Bonneel received her PhD from the University of Mons in Belgium, and her dissertation is titled "Sea cucumbers as a source of proteins with biomimetic interest: Adhesive and connective tissue – stiffening proteins from *Holothuria forskali*". Dr Hair received her PhD from James Cook University in Australia, and the title of her dissertation is "Development of community-based mariculture of sandfish, *Holothuria scabra*, in New Ireland Province, Papua New Guinea". Dr Benzait received his PhD from the Université de Mostaganem in Algeria, and his dissertation is titled "Ecologie, dynamique de la population et reproduction d'*Echinaster sepositus*, *Ophioderma longicauda* et de *Parastichopus regalis* au niveau de la côte de Mostaganem".

The first article by Simone et al. (p. 3) recalls that at the last meeting of the Conference of the Parties to CITES in August 2019, three species of teatfish were included in CITES Appendix II. This inclusion has opened the door for potential new species listings.

The next four articles are original research contributions. Two articles are from Murphy et al. One (p. 5) provides updated conversion ratios for beche-de-mer species in Torres Strait, Australia. These values are useful for stock assessments, management and monitoring of the beche-de-mer fishery in Australia. In their second article (p. 8), the authors show the results of a field survey of eastern Torres Strait where they used a remotely operated vehicle to survey sea cucumbers. Ram et al. (p. 12) investigates the effect of salting time on the collagen content of the body wall of *Holothuria scabra*. They observed that after 72 hours of salting, collagen fibers are almost totally destroyed and disappear from the body wall of sandfish. The analysis of *Parastichopus regalis*'s digestive content, by Elakkermi et al. (p. 15), reveals that it includes mostly fine sedimentary particles and that a very small part is composed of foraminiferans, annelids, fragments of mollusc shells, sponge spicules, echinoderm ossicles, diatoms and cyanobacteria.

The next three articles concern field observations. Tanita et al. (p. 19) observed several juvenile teatfish showing intermediate ventral colour morphs and provide illustrations of these variations. Schagerström and Sundell (p. 22) and

Christophersen (p. 25) describe the biology of *Parastichopus tremulus* whose distribution is in the northeast Atlantic Ocean, mainly along the Norwegian and Swedish coasts. This species shows significant potential as a commercial product for the Chinese market. Mulochau et al. (p. 37) provide us with some extraordinary photos of a green turtle looking for and eating *Synapta maculata* in seagrass and coral blocks at Reunion Island.

Two articles follow, and relate past stories about sea cucumbers. I first describe the history of *Holothuria scabra* aquaculture in Madagascar and talk about the history behind the creation of Indian Ocean Trepang, which is becoming one of the largest sandfish aquaculture companies in the world (p. 40). Solís-Marín et al. (p. 46) then tells us an extraordinary story where sea cucumber ossicles were found in a ritual deposit of consecration, found 2 m below the monolith of the Earth goddess Tlaltecuhtli (Mexico). They have identified vestiges of 20 species of echinoderms, including five species of sea cucumbers.

Sea cucumber crimes in India and Sri Lanka are analysed by Phelps Bondaroff (p. 55). Similarly, Rodriguez-Forero (p. 66) explains the situation in Colombia, and the interest in developing a blue economy programme in that country. Mezali et al. (p. 69) show us the results of a survey in Algeria for analysing consumer behaviour to introduce sea cucumbers on the local Algerian market.

González-Wangüemert (p. 79) describes WANGUMAR, a new consultancy company linked to sea cucumber fisheries and aquaculture in the Mediterranean and northeast Atlantic regions. Lovatelli (p. 81) announces the second edition of the global guidebook for identifying commercially exploited sea cucumbers, and kindly invites people to contribute to it.

Also included in this issue are various communications (p. 79) about publications and PhD dissertations. This issue is the first where we present English and French sections. The article by Simone et al. in English, also appears in French (p. 73). Finally, Sohou et al. (p. 75) give us, for the first time, information on sea cucumber fishing in Benin (West Africa).

I deeply thank Kim Des Rochers for her editing and proofreading work on the articles in English.

Igor Eeckhaut

The listing of three sea cucumber species in CITES Appendix II enters into force

Marie Di Simone,[1] Arnaud Horellou[1] and Chantal Conand[2]

Introduction

At the last meeting of the Conference of the Parties to CITES (CoP 18) in August 2019, three species of teatfish were added to CITES Appendix II: *Holothuria nobilis*, *H. fuscogilva* and *H. whitmaei* (Di Simone et al. 2020). The international trade in these species is now regulated and controlled in accordance with the provisions of Appendix II: CITES permits and certificates will be required for international movements, attesting to the legality and sustainability of shipments. In the absence of these documents, the shipments must be seized as they are expected to be illegal trade (CITES Secretariat 2020).

Appendix II controls and regulates trade to ensure that it is based on the management (methods and volumes) of sustainable takes. Transactions will also be tracked and compiled in the Parties' annual trade reports and recorded in the CITES trade database (CITES Secretariat 2020).

An entry into force of listing: Why a delay?

This listing entered into force on 28 August 2020 after a 12-month delay in implementation agreed to by Parties at the last CoP (CITES Secretariat 2020).

This delay was intended to allow range States of these species and importers to prepare and effectively enforce the listing, including the establishment of adequate procedures for management, identification, monitoring and permitting procedures (CITES Secretariat 2020). Indeed, this amendment posed significant implementation issues that would certainly not have been resolved in the 90-day period after which a CITES Appendix listings become legally binding (CITES Secretariat 2020).

Sea cucumbers support important industries and are the basis of livelihoods for communities in remote areas with few alternatives for economic activity. It was, therefore, agreed on by the Parties that regulations should be put in place to ensure the survival of these species in the wild (CITES Secretariat 2020).

Implementation of listing: Establishment of a non-detriment findings

A listing to CITES Appendix II leads to the establishment of a non-detriment findings (NDF). The NDF is issued after a scientific risk assessment – based on an analysis of the mode of exploitation, its effects on the population, the measures and the risks – so as to determine if the removal of a species in its natural environment is detrimental or not (SPC 2010).

Thus, an NDF must include the following main information:

1. populations: levels, trends, environments, densities, locations and resilience;
2. management and harvesting: fished sites vs non-fished sites, fishing methods, conservation programmes and quotas; and
3. control measures.

This includes determining the state of a population by assessing stocks, setting catch quotas and spatial and temporal closures of fisheries, and enforcing these measures, which ensure and commit the Party to the sustainable exploitation of these three species (Shedrawi et al. 2019).

Challenges encountered in establishing an NDF

Sea cucumbers represent a novelty for CITES Parties, particularly the methods of implementation and acquisition of skills.

There remains a lack of scientific information on sea cucumber biology, ecology and population dynamics. However, this information is essential to establishing comprehensive management plans capable of ensuring sustainable harvesting and conservation of these species (CITES 2019). The data required to carry out an NDF are, therefore, difficult to assess in the absence of this information (CITES 2019).

Also, the existing data most often concerns all sea cucumber species, and individual species are rarely differentiated in trade statistics or trade reports (CITES 2019).

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Finally, the capacities of a country's management body and scientific authority are sometimes insufficient to collect the information required to assess the risk of international trade for the survival of the species in its territory (Shedrawi et al. 2019). For example, Pacific Island countries and territories are already facing difficulties in implementing effective and sustainable management measures due to economic and technical constraints (Shedrawi et al. 2019).

What next?

The listing of these three sea cucumber species in CITES has opened the door for potential new species listings (Di Simone et al. 2020). According to Purcell et al. (2012), there are 58 species of sea cucumbers of commercial interest in the world. This number can only increase: species with a high commercial value are becoming rare or even depleted, and harvesting efforts will target other species that are not yet traded (i.e. those with a low commercial value) which were not previously listed (Purcell *et al*. 2012).

For the next CoP, the European Union plans to make a proposal to list all European sea cucumber species in Appendix II.

In addition, the CITES Secretariat is finalising a study that will serve as the basis for a toolkit that Parties can use to ensure the implementation of new rules that affect the trade in these sea cucumbers. These efforts are supported by funding from the European Union (CITES Secretariat 2020).

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Updated conversion ratios for beche-de-mer species in Torres Strait, Australia

Nicole E. Murphy,[1,*] Timothy D. Skewes[1] and Éva E. Plagányi[1]

Abstract

As part of the newly endorsed Torres Strait Beche-de-mer Harvest Strategy, conversion ratios for commercial beche-de-mer species were reviewed. Accurate conversion ratios are required to determine total catches in a standard unit (e.g. wet gutted or landed weight) from data that records catch weight in several different processing stages. These values are useful for stock assessment, management and monitoring of the beche-de-mer fishery in Torres Strait, and elsewhere in Australia.

Key words: beche de mer, conversion ratios, sea cucumber, Torres Strait, fisheries

Introduction

Total allowable catch

Total allowable catch (TAC) is considered by the European Union Common Fisheries Policy to be a cornerstone conservation measure (Karagiannakos 1996). TAC represents the amount of fish of a species that can be taken from a fishery in a prescribed period. A TAC is set for a species and managed through a range of mechanisms.

Torres Strait beche-de-mer fishery

The Torres Strait beche-de-mer (BDM) fishery is a multispecies, wholly commercial, traditional inhabitant fishery (Skewes et al. 2000; Skewes et al. 2004). Twenty-three commercial sea cucumber species have been recorded in Torres Strait (Murphy et al. 2019). The fishery has undergone closures and reduced catch limits for important fishery species (Skewes et al. 2010) for a number of years. However, the implementation of recent management measures, such as revised species TACs (Plaganyi et al. 2020), along with a shift in focus from historically high-value to medium-value species, has maintained the fishery as a potentially significant source of income for local Torres Strait islander communities.

A newly endorsed multi-tier harvest strategy (Torres Strait Beche-de-mer Harvest Strategy[2]) has been implemented since January 2020 for the fishery. It incorporates modern management strategies, traditional fisheries practices, and community decision-making processes (Plaganyi et al. 2020). Precautionary evidence-based methods for reviewing and setting TAC levels for species are used. New TACs were set for species of hairy blackfish (*Actinopyga miliaris*), deepwater redfish (*A. echinites*), greenfish (*Stichopus chloronotus*) and curryfish (*S. herrmanni* and *S. vastus*). Previously, these species were grouped in a multi-species "basket", although increased fishing pressure as a result of increased market value required the species to be monitored individually (Plaganyi et al. 2020).

Conversion ratios

Catch data for the Torres Strait BDM fishery are recorded in a number of different processed states, such as live, wet gutted, salted, boiled and salted, and fully processed (dry) (Skewes et al. 2004). It is important that the relationship between the measurement of sea cucumbers in different stages of processing, from live product to dried and ready for market be determined. This allows data from different processing states to be converted by applying species-specific conversion ratios, with results used for tracking quotas for individual species.

Compulsory catch reporting was introduced to the Torres Strait BDM fishery in 2017. Fishers are required to record catch information on Torres Strait catch disposal records (TDB02) as part of the mandatory Fish Receiver System (PZJA 2017). This includes reporting the total mass of each species landed, as well as the processing method, so that conversion ratios can be used to convert all reported catch to a standard weight (i.e. wet weight gutted) for the fishery (Plaganyi et al. 2020).

As part of the Torres Strait Beche-de-mer Harvest Strategy and the inclusion of new individual TACs for some species, conversion ratios for 18 commercial BDM species in Torres Strait were reviewed and updated.

Methods

Locally relevant conversion ratios for the Torres Strait BDM fishery – which are suitable for converting weights available from abundance surveys and fishery data to the required management weight metric (wet weight gutted) – were originally compiled by Skewes et al. (2004). The study found

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[2] https://www.pzja.gov.au/the-fisheries/torres-strait-beche-de-mer-fishery

the majority of conversion ratio information available in the literature was for values for whole live weight to dry weight (Conand 1989; Preston 1990). Intermediate processing stages such as boiled or salted were found to be sparse, with many ratios estimated from oven-dried specimens (Harriot 1985), or using experimental methods that were not fully defined (Skewes et al. 2004). Processing methods, and resulting yields, were also found to be variable (Preston 1990).

A hierarchical approach was therefore used, with species conversion ratio values updated first using data from previous Torres Strait studies (Skewes et al. 2004) and raw data from Prescott et al. (2015), second from literature reviews, and third by the use of conservative proxies to fill gaps for processing state information for species (Purcell et al. 2009; Ngaluafe and Lee 2013; Prescott et al. 2015; Ram et al. 2016). Ratio decisions were based on current processing methods, average value calculations and the removal of outliers (Table 1).

Results

Conversion ratios for total whole fresh weight from wet to dry product (including values from other studies) were noted from Ngaluafe and Lee (2013; Table 1 and Table 3), with whole fresh weights also noted from Purcell et al. (2009; Table 2). Inverse values for gutted to salted and dried to gutted, were derived from Skewes et al. (2004) and Prescott et al. (2015). Empirical values were calculated for gutted to salted, gutted to dried, salted to dried, salted to gutted and dried to gutted, from Purcell et al. (2009). Calculations from raw data provided by Dr Shijie Zhou were used for live to gutted, live to dried, gutted to dry and dried to gutted (Prescott et al. 2015). Averages were taken where multiple values existed for species and processing state. Proxy values using the most conservative value for species for processing state, were used to fill in gaps for species (Table 1).

Discussion

Updated conversion ratios for BDM species are currently the best estimator for converting pooled catch data from one processed state to another, where the size frequency of the catch is not known. For example, for converting catches in gutted weight to processed weight for comparison with export data, and for tracking the TAC for individual species. These values are useful for stock assessments and are important for management and monitoring of the Torres Strait BDM fishery and other BDM fisheries in Australia.

Conversion ratios also provide an insight to the efficiency of BDM processing methodologies, and for assessing the effect of any future changes in processing techniques.

This review, and information from fishers and management agencies, shows that a critical conversion ratio information gap now occurs for curryfish species, a newly targeted species group for Torres Strait that require specialised processing upon collection due to their tendency to easily disintegrate. This involves an early boil and then salting of the animal before it can be weighed. The new curryfish processing stage will require a new conversion ratio to be determined (i.e. wet-boiled and salted) so that fishery catch data can be converted to standard (wet gutted) weight for the application of management rules.

Acknowledgments

This project was funded by the Torres Strait Regional Authority, the Australian Fisheries Management Authority, and the Commonwealth Scientific and Industrial Research Organisation. Raw data for some species were provided by Dr Shijie Zhou. Thank you to all Torres Strait traditional owners for regularly hosting us on their land and supporting this research.

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Table 1. Torres Strait beche-de-mer species and conversion ratio values for each processing state.

Common name and species	Live to gutted	Live to salted	Live to dried	Gutted to salted	Gutted to dried	Salted to dried	Salted to gutted	Dried to gutted
Deepwater redfish *Actinopyga echinites*	0.692[3]	0.652[h]	0.088[av13]	0.964[h]	0.152[f3]	0.309[h]	1.706[h]	6.579[f3]
Stonefish *Actinopyga lecanora*	0.894[c1]	0.652[c1]	0.154 [cv12*]	0.729[1]	0.158[v12*]	0.253[1]	1.372[1]	6.329[1]
Surf redfish *Actintopyga mauritiana*	0.684[2*]	0.652[h]	0.084 [av12*]	0.873[4]	0.187[v2*4]	0.286[4]	1.145[d]	5.347[egv2*4]
Hairy blackfish *Actinopyga miliaris*	0.480[4]	0.652[h]	0.067[av14]	0.964[4]	0.209[4]	0.217[4]	1.037[d]	4.785[e]
Deepwater blackfish *Actinopyga palauensis*	0.818[cv13]	0.593[cv13]	0.175[abv1]	0.728[fv13]	0.190[fv13]	0.262[fv13]	1.374[fv13]	5.263[fv13]
Burrowing blackfish *Actinopyga spinea*	0.544[3]	0.375[3]	0.073a[1]	0.689[f3]	0.135[f3]	0.195[f3]	1.449[f3]	7.424[f3]
Leopardfish *Bohadschia argus*	0.665 [cv12]	0.572[c1]	0.115 [cv12]	0.777[1]	0.171[v12]	0.233[1]	1.286[1]	5.841[gv12]
Brown sandfish *Bohadschia vitiensis*	0.735[c1]	0.612[c1]	0.116[c1]	0.834[1]	0.157[1]	0.189[1]	1.199[1]	6.337[1]
Lollyfish *Holothuria atra*	0.436[cv12*]	0.236[c1]	0.063[abcv12*]	0.586[1]	0.150[12*]	0.256[1]	1.706[1]	6.289g[12*]
Elephant trunkfish *Holothuria fuscopunctata*	0.519[4]	0.652[h]	0.133[abv14]	0.911[4]	0.242[4]	0.263[4]	1.097[d4]	4.132[e4]
White teatfish *Holothuria fuscogilva*	0.627[cv2*4]	0.593[c]	0.137[abv12*]	0.775[1]	0.237[1v2*]	0.309[1]	1.290[1]	4.219[gv12*]
Golden sandfish *Holothuria lessoni*	0.645[3]	0.526[3]	0.098[a]	0.815[f3]	0.152[f3]	0.186[f3]	1.226[f3]	6.588[f]
Sandfish *Holothuria scabra*	0.496[4]	0.355[4]	0.049 [av14]	0.758[4]	0.094[4]	0.125[4]	1.319[d]	10.638[e4]
Black teatfish *Holothuria whitmaei*	0.677[v2*34]	0.529[3]	0.108 [av12*3]	0.824[f4]	0.177[fv2*3]	0.220[f]	1.213 [f4]	5.649[fgv2*3]
Greenfish *Stichopus chloronotus*	0.894[h]	0.652[h]	0.175[h]	0.964[h]	0.242[h]	0.309[h]	1.382[h]	11.364[h]
Curryfish (common) *Stichopus herrmanni*	0.651[2]	0.652[h]	0.036[av1]	0.964[h]	0.114[2]	0.309[h]	1.706[h]	8.772[g2]
Curryfish (vastus) *Stichopus vastus*	0.894[h]	0.652[h]	0.175[h]	0.964[h]	0.242[h]	0.309[h]	1.706[h]	11.364[h]
Prickly redfish *Thelenota ananas*	0.667 [cv4]	0.481[c]	0.055[abv14]	0.736[14]	0.088[v14]	0.118[v14]	1.358[dv14]	11.364[ev14]

Superscripts denote derived value source and reference: a) Table 3 (Ngaluafe and Lee 2013), b) Table 1 (Ngaluafe and Lee 2013), c) Table 2 (Purcell et al. 2009), d) inverse gutted to salted (Skewes et al. 2004), e) inverse dried to gutted (Skewes et al. 2004), f) empirical calculation (Purcell et al. 2009), g) inverse dried to gutted (Prescott et al. 2015), h) proxy value, v) average of multiple values; References: 1) Ngaluafe and Lee 2013, 2) Prescott et al. 2015, 2* Calculation from raw data provided by S. Zhou (Prescott et al. 2015), 3) Purcell et al. 2009, 4) Skewes et al. 2004.

Successful use of a remotely operated vehicle to survey deep-reef habitats for white teatfish (*Holothuria fuscogilva*) in Torres Strait, Australia

Nicole E. Murphy,[1,*] Timothy D. Skewes,[1] Steven Edgar,[2] Kinam Salee[1] and Éva E. Plagányi[1]

Abstract

A field survey of sea cucumber species of eastern Torres Strait, Australia was recently undertaken, in order to inform stock size estimates and distribution data for the Torres Strait beche-de-mer fishery. We also surveyed deep-reef (>20 m) strata (equivalent to habitat) to investigate deep-reef sea cucumber populations of white teatfish (*Holothuria fuscogilva*) using a remotely operated vehicle. The underwater camera system proved very successful at observing sea cucumbers. Although we surveyed habitat down to 50 m, we did not observe white teatfish deeper than 37 m.

The information gathered during the survey will be used to delimit and quantify the deep-reef white teatfish population for Torres Strait.

Introduction

The Torres Strait beche-de-mer (BDM) fishery is a sea cucumber fishery on the Australian side of Torres Strait, north of Cape York. The fishery has two components: 1) the sandfish fishery that occurs on Warrior Reef and adjacent to the Papua New Guinea sandfish fishery, and 2) the eastern fishery that occurs in a 16,844 km^2 area of Torres Strait situated at its eastern extreme (Fig. 1). The eastern Torres Strait fishery contains about 1204 km^2 of shallow reef-top habitat, 185 km^2 of shallow reef edge (<20 m deep) habitat, and 600 km^2 of deep (>20 m) reef edge and deep lagoon habitat that accounts for about 64% of all the reefs in Torres Strait (Skewes et al. 2010).

A field survey of eastern Torres Strait sea cucumber species was undertaken during November 2019 and January 2020 in order to inform stock size estimates and distribution data for the fishery. Previous surveys of the Torres Strait BDM fishery have been undertaken in 2002, 2005 and 2009 (Skewes et al. 2004; Skewes et al. 2010), and were all restricted to <20 m due to diving regulations. Of interest for the recent survey was investigating the full extent of the distribution of white teatfish (*Holothuria fuscogilva*) in deeper (>20 m) habitats, in order to quantify total stock biomass and evaluate the potential for further sustainable development of this fishery.

An exploration of the deep-reef reef habitats for white teatfish was undertaken using a remotely operated vehicle (ROV). We were able to successfully survey 53 deep-reef transects for the first time for the Torres Strait BDM fishery.

Methods

A DTG3 Deep Trekker ROV unit was modified and used to complement existing sea cucumber survey methods for Torres Strait. This involved deployment from a 5.0 m inflatable Naiad vessel, as well as handling the ROV in conditions of swell, wind and inclement weather (Fig. 2).

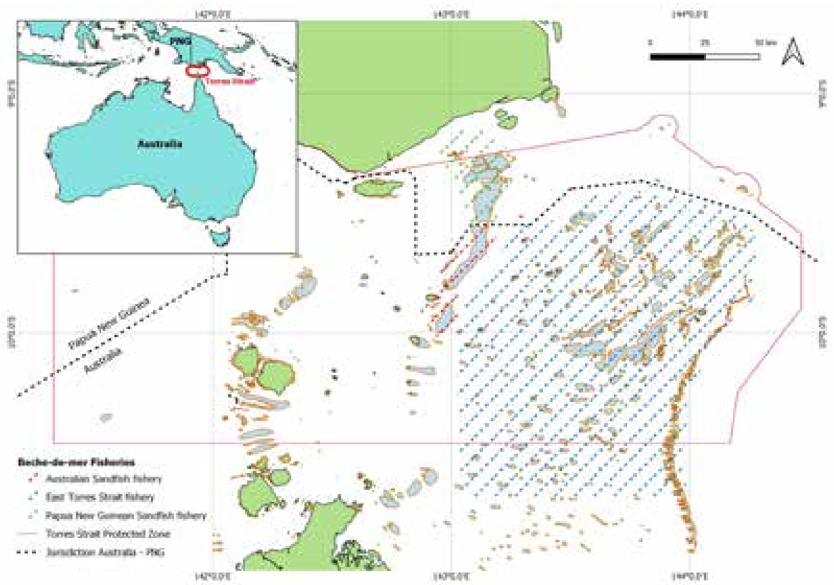

Figure 1. Approximate location of the three sea cucumber fisheries in Torres Strait, Australia.

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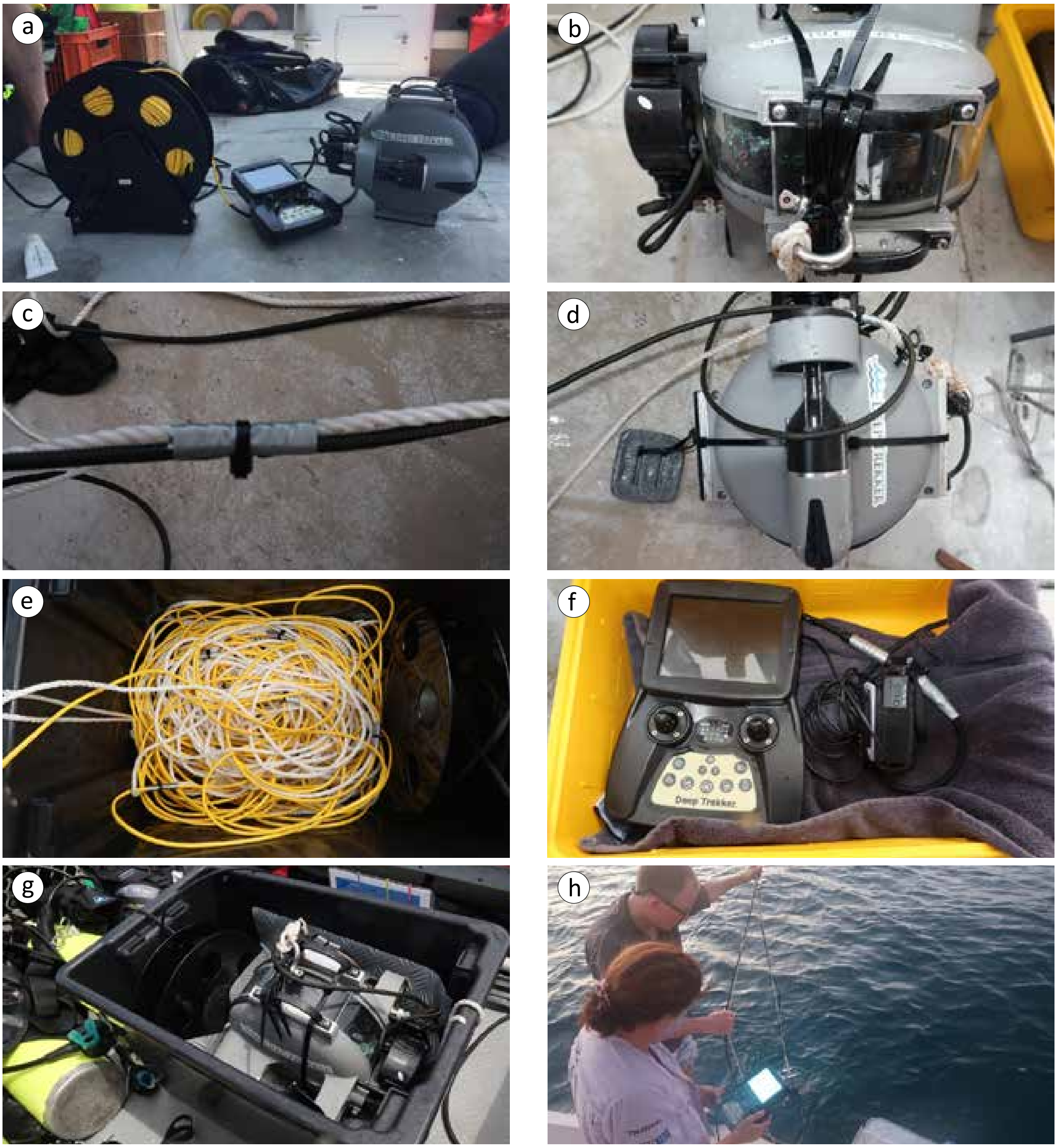

Figure 2. a) Configuration from manufacturer: Control unit connected to Deep Trekker and umbilical reel; b) Connection of cable ties (50-kg breaking strength) to the top of Deep Trekker, cables tied together then stainless steel shackle attached; c) 10 mm silver line tied and secured to shackle, then line taped and cable tied to control unit connection (black) and umbilical (yellow) every approximately 1.5 m, which takes tension off the umbilical; d) Cable ties connected around Deep Trekker circumference and 3-lb (1.4 kg) dive weight cable-tied to bottom of cabled circumference, which ensured that the unit remained upright in the water column; e) Umbilical-line loosely coiled into plastic bin to avoid kinks; f) Connections from control unit to video data recorder taped to provide protection and prevent pinching. Control-video system placed in waterproof Pelican™ case; g) The Deep Trekker was placed on a rubber mat on top of the umbilical for transport - stopped entanglement or damage from sea conditions; h) Trial deployment and video recording from control unit; i) Observing Deep Trekker underneath the Naiad vessel to determine the field of view. (images: N.E. Murphy)

Figure 3. Undertaking a survey transect from the Naiad vessel. (image: N.E. Murphy)

The Deep Trekker was used in a drop camera mode, where the ROV was negatively weighted and deployed from the vessel with a cabled tether and allowed to drift (or slowly towed) to collect data along transects undertaken from the Naiad vessel, for a set time (Fig. 3). Of note for the Deep Trekker was the controlled rotational capability and the 270-vertical-degree view that allowed for inspection of potential targets, as well as the capability to record high-quality video.

Set up

Undertaking transects

For deep-reef transects (>20 m), the unit was deployed into the water and lowered to within 1 to 2 m of the sea floor. The video was switched on to record, and 10-minute drifts were undertaken, with one person viewing the control unit, another tending to the umbilical (by raising the ROV up or down manually to follow the seabed), a third person recording information on a datasheet (including targets timestamp and depth, GPS location and distance along transect), and a fourth person controlling the Naiad vessel. Transect depths ranged from 20 to 50 m, and were 40 to 675 m long.

Observations were made in real time. The number of sea cucumbers seen and any significant habitat observed were recorded on a sampling datasheet, together with depth and time. All recorded video was reviewed to verify sea cucumber identification and total number. Habitat information was also updated on transect datasheets.

Field of view

The Deep Trekker field of view was determined by placing an object of known length on the transect and capturing it on video, with a diver in the water also taking measurements. Several images were used (after review) for comparison and assessment.

Outcomes

The white teatfish survey was exploratory and highly targeted. Deep-reef sites included sites adjacent to shallow reef edges, continuing down the reef slope, and in the deeper lagoons of the sunken northeasterly reefs of Torres Strait.

The DTG3 Deep Trekker ROV proved very successful at observing and quantifying sea cucumbers, including white teatfish. Although we surveyed habitats down to 50 m, we did not observe white teatfish deeper than 37 m. The average density of white teatfish in deep-reef habitats was the highest of any of the sampled strata (Fig. 4), at about 14 per hectare. Given the extent of the deep-reef habitat in east Torres Strait, the white teatfish in this habitat accounted for 72% of the entire white teatfish population in the area.

We are confident we have now delimited and quantified the deep-reef white teatfish population of eastern Torres Strait.

Acknowledgments

This project was funded by the Torres Strait Regional Authority (TSRA), the Australian Fisheries Management Authority, and the Commonwealth Scientific and Industrial Research Organisation. TSRA kindly offered a number of their ROV units to trial for surveying deep-reef habitats. Thank you to Ms Madeina David for her valuable assistance during the survey.

Thank you to all Torres Strait traditional owners for regularly hosting us on their land and supporting this research.

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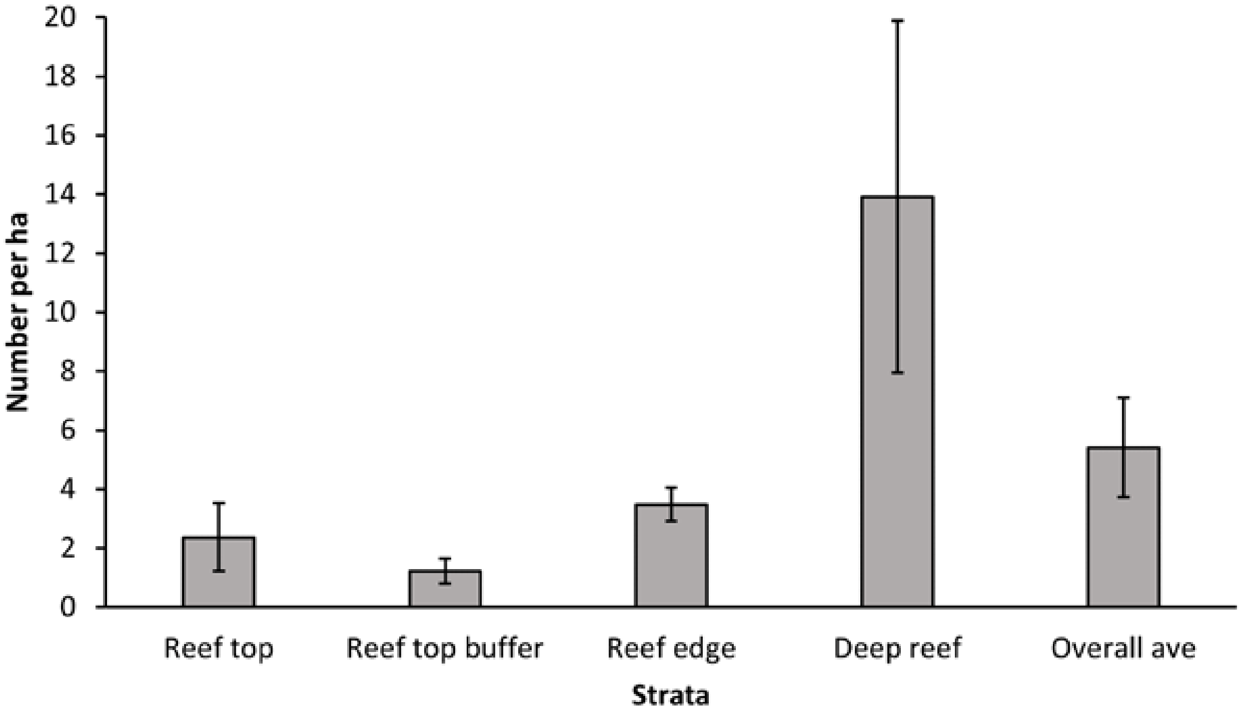

Figure 4. Density (number per hectare) of white teatfish (*Holothuria fuscogilva*) in four reef strata (habitats), and the overall stratified density for eastern Torres Strait (ave = average; error bars = one standard error).

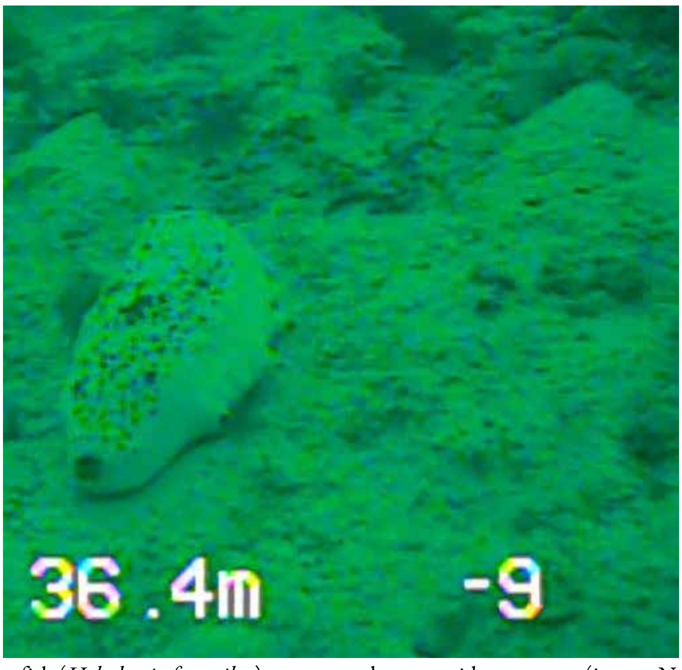

Figure 5. White teatfish (*Holothuria fuscogilva*) seen on underwater video transect. (image: N.E. Murphy)

Salting affects the collagen composition of the tropical sea cucumber *Holothuria scabra*

Ravinesh Ram,[1] Roveena Vandana Chand,[2] Sue Reilly[3] and Paul Southgate[4]

Abstract

The effect of salting time on the collagen content of the body wall of *Holothuria scabra* (sandfish) is investigated in the present work. Sandfish were harvested from Tavua Bay in Fiji, and processed using an upgraded technique. Sandfish were cooked for the first time followed by immersion in salt and then treated at different salting times of 24 hours (h), 36 h, 48 h and 72 h. The results show that after 72 h, collagen fibers were almost totally destroyed and disappeared from the body wall of sandfish. It is highly recommended that a new and better processing technique be established to prevent post-harvest nutritional losses from beche-de-mer for better value, and to ensure that salting does not exceed 48 h.

Introduction

Sea cucumbers (called beche-de-mer or trepang when dried) are regarded as an authentic cuisine for a number of Asian consumers. It is regarded as a nutritious low-fat food source that is rich in protein and essential lipids. As bottom dweller invertebrates, sea cucumbers tend to bioaccumulate essential nutritional compounds of high value. Sea cucumbers are known to have medicinal benefits such as in the treatment of cancer, arthritis and a number of other medical ailments (Bordbar et al. 2011).

Collagen is a protein that is found in all sea cucumbers, and high-quality is found in tropical sea cucumbers (Dong et al. 2011). Significantly, given the importance of body wall texture in the value of sea cucumbers, collagen has been reported to make up at least 70% of the protein content in sea cucumbers (Saito et al. 2002) and, individually, between 3.4% and 24.3% of beche-de-mer dry weight (Liu et al. 2010; Zhong et al. 2015). Collagen belongs to a family of extracellular matrix proteins that maintain the integrity of various tissues. There are approximately 27 types of collagen found, with 42 distinct types of polypeptide chains and about 20 additional proteins and collagen-like domain, and 20 other collagens modified by enzymes (Kivirikko and Prokop 1995; Myllyharju and Kivirikko 2004). Collagen molecules are composed of three α chains that are mainly stabilised by intra- and inter-chain hydrogen bonds that form the collagen triple helix (Zhang et al. 2013), which contains a repeat of the amino acids glycine, proline and hydroxyproline (Ichikawa et al. 2010). Collagen is used in leather products, biomedical products (e.g. wound dressings, implants and drug carriers), and by the food industry in the production of gelatin (Nam et al. 2008).

There is limited literature on the possible changes in collagen content during the processing of sea cucumbers, and the effects of particular processing steps and conditions (e.g. temperature) on the collagen content of sea cucumber products. Niamnuy et al. (2008) studied changes in the protein composition and the physical effects on shrimp during boiling at different salt solutions. The findings revealed that increased salt concentrations affected the protein quality and texture of the shrimp. When the boiling time and salt concentration both were increased, protein denaturation was more common and the shrimp became harder due to the decrease in myofibrillar, sarcoplasmic and stroma proteins. Niamnuy et al. (2007) reported that boiling time affected shrimp quality through protein denaturation as well as the salt, moisture and protein content of shrimp. The final product's quality can only be determined through organoleptic evaluation, and the extent of quality loss (e.g. appearance, taste, texture and colour due to boiling time and various salt concentrations), affect the overall acceptance of the final product by the customer (Tapaneyasin et al. 2005).

In Fiji, sea cucumber processing is a destructive process, with a series of cooking, salting and drying steps followed by complete dehydration of the sea cucumber for prolonged storage. In Fiji, salting sea cucumbers is done for approximately 48–72 h before further cooking and drying. It is believed that salting leaches away essential proteins and salt-soluble amino acids that make up the proteins.

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The aim of this research was to determine the effect of salting time on the collagen content of the body wall of *Holothuria scabra*.

Methodology

Holothuria scabra were harvested from Tavua Bay in Fiji and were processed using the techniques used by Ram (2017). Briefly, after harvesting, sandfish were laid on a flat surface for approximately 5 minutes (min). Fresh water was heated to a temperature of 80° C and the sandfish were immersed in the water gently and cooked for about 15–20 min, depending on their size. After the first cook, sandfish were immersed in a 3% saline solution for 24–36 h to remove the chalky spicules from the surface. The remaining spicules were gently brushed off to ensure that the surface was not damaged. The sandfish were processed with different salting treatments of 24 h, 3 h, 48 h and 72 h, using coarse "A" solar dry salt. After the salting treatments, tissue from the sandfish was cut aseptically (1 cm^2) on the ventral side, some 3–4 cm away from the anus, and transferred in a clean vial and stored in 10% formalin at room temperature for initial fixation of the tissues for histology. The samples were then delivered to the Histology Unit at James Cook University in Townsville, Australia, where the collagen composition of the sandfish tissues was analysed using the Picro Gomori staining technique standard university laboratory protocol. After embedding the paraffin, thin sections of the tissue were cut in a microtome and then stained using H&E (Hematoxylin and eosin) stain and orcein combined with either light green or one step Gomori trichrome, and orcein combined with Picro-sirius red for detection of collagen fibers. In the Picro Gomori staining technique, the collagen samples in the tissue were stained green and the tissue as pink.

Results

The results of the four salting treatments (Fig. 1) show that when the sandfish were exposed to 72 h of salting, collagen fibers were significantly lost as compared to 24 h, 36 h and 48 h exposure times.

Discussion

This study investigated the effects of different salt treatments on the body wall of *Holothuria scabra*. The results have shown that extended salting time (72 h) affects the collagen composition in the tissue. Collagen is regarded as an essential part of the protein that forms part of the connective tissue of the human body. Ram et al. (2017) showed the decrease in crude collagen composition from 103 mg/g to 99 mg/g of the dry tissue through the salting treatments at 24 h, 36 h, 48 h and 72 h of *H. scabra* exposure. Their research also showed that as the salting treatment time increased, the crude collagen

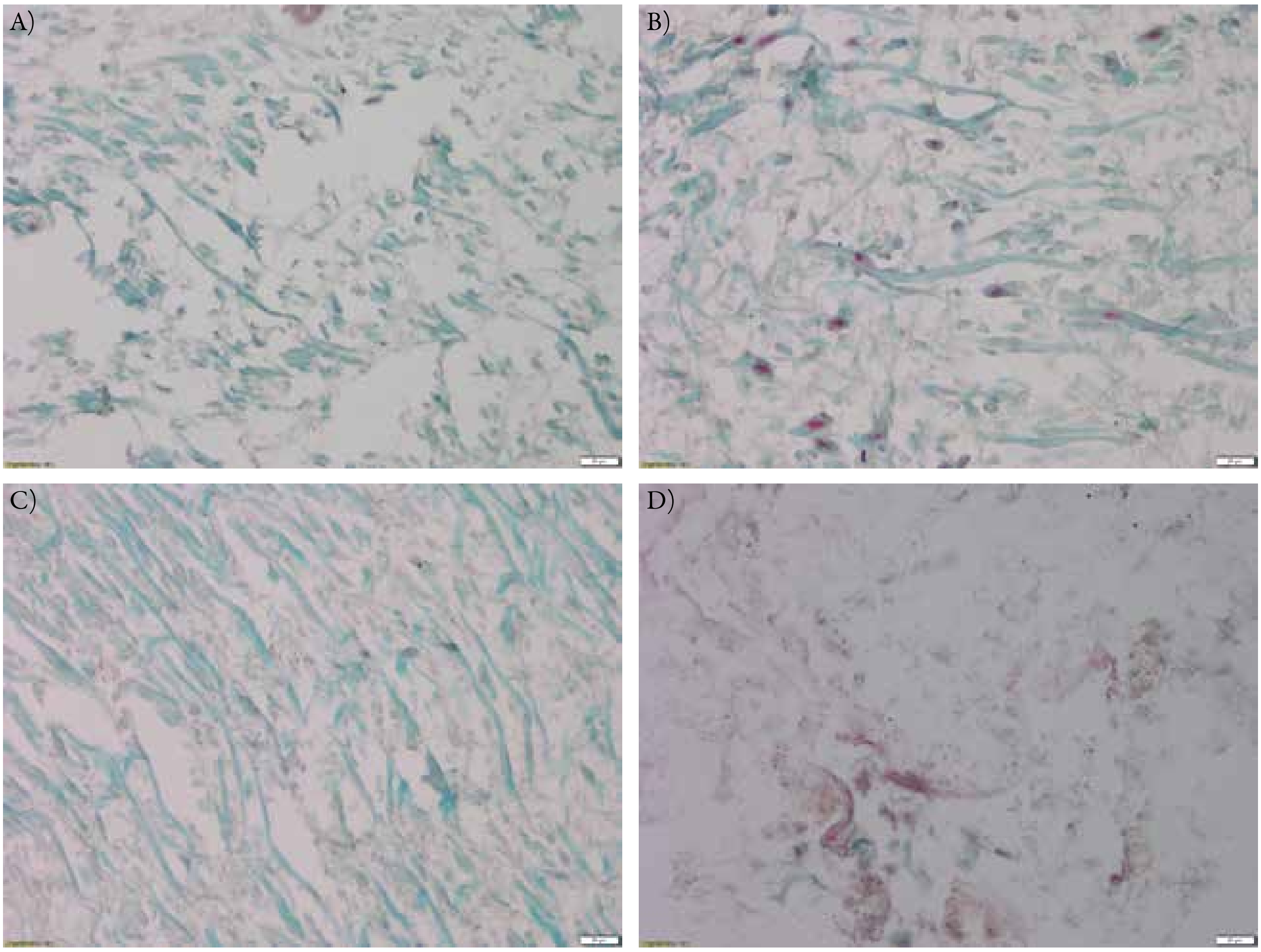

Figure 1. Picro Gomori stain of the body wall of *Holothuria scabra* treated at different salting times using the dry coarse "A" solar salt. A) 24 h; B) 36 h; C) 48 h; and D) 72 h.

concentration decreased in the holothurian body wall, indicating that the salt leached valuable collagen from the body wall of *H. scabra*. Processing sea cucumbers into beche-de-mer requires continuous attention, and the processing time plays a key role in achieving a good-quality product of high value. Exposure at 48 h was observed to be an ideal time for salting sea cucumbers during processing, and it certainly adds weight to the dried product. Twenty-four hours and 36 h of salting exposure are considered to be ideal exposure times because the body wall is still water-logged and the drying process will be problematic because of the higher chances of spoilage as compared to 48 h exposure. Processors in Fiji could have faced this issue during processing and this could have been an ongoing issue with poor-quality and poor income for the communities involved in this trade.

Conclusion

This study focused on assessing the collagen composition of the body wall of *Holothuria scabra*. The study showed that the exposure of sea cucumbers during salting affects the collagen composition and essential nutritional value of the sea cucumbers. The findings revealed that a salting time of 48 h was sufficient during processing. Exceeding 48 h extensively leaches the essential nutrition from the body wall as was reported in the present study. Better processing techniques need to be developed to prevent post-harvest nutritional losses from beche-de-mer.

Acknowledgements

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Gut content analysis of *Parastichopus regalis* (Cuvier, 1817) from the west Algerian coast

Mohammed Elakkermi, Karim Mezali,[1] Ihcene Khodja, Nor Eddine Belbachir, Hocine Benzait and Dina Lila Soualili

Abstract

Parastichopus regalis (Cuvier, 1817) is the only sea cucumber species in the family Stichopodidae that is present in the Mediterranean Sea. It is found in the upper part of the sublittoral zone of Sidi-Medjdoub (Mostaganem, Algeria). An analysis of its digestive content revealed that it is a species with a preference for very fine sediment particles that have a high organic matter content. The remaining part of its diet is composed of a faunal fraction (foraminifera, annelids, fragments of mollusc shells, sponge and echinoderm ossicles, and undetermined fauna) and a floral fraction (diatoms and cyanobacteria).

Keywords: *Parastichopus regalis***,** feeding behaviour, digestive contents, Mostaganem, Algeria

Introduction

Currently, the sea cucumber family *Stichopodidae* has 9 genera and 32 species that are distributed mainly in the Indo-Pacific region (Levin 1999; Byrne et al. 2010). *Parastichopus regalis* is the only species of this family that is present in the Mediterranean (Byrne et al. 2010). It is a benthic species that is found in a wide range of depths (5–800 m, Tortonese 1965), and which can be very abundant between 150 and 200 m depth where the sea temperature is quite constant (13°C) throughout the year (Ramon et al. 2010). It is a commercially important species for human consumption in a large area of the northwestern Mediterranean (Catalonia, Balearic Islands and Valencia), making it the only holothurian species consumed in Europe (Ramon et al. 2010). In the western Mediterranean basin, the trophic activity of *P. regalis* has been studied by Ramon et al. (2019). In Algeria, there are no data on its diet, as it was only recently reported by Benzait et al. (2020). The present work describes some qualitative aspects of its feeding behaviour.

Methodology

Study site

During May 2020, nine individuals of *Parastichopus regalis* were collected as bycatch during a fishing trip on a professional trawler in the Sidi-Medjdoub area (Mostaganem, Algeria) at a depth of 53 m (N36°0.032, E0°1.456, Fig.1).

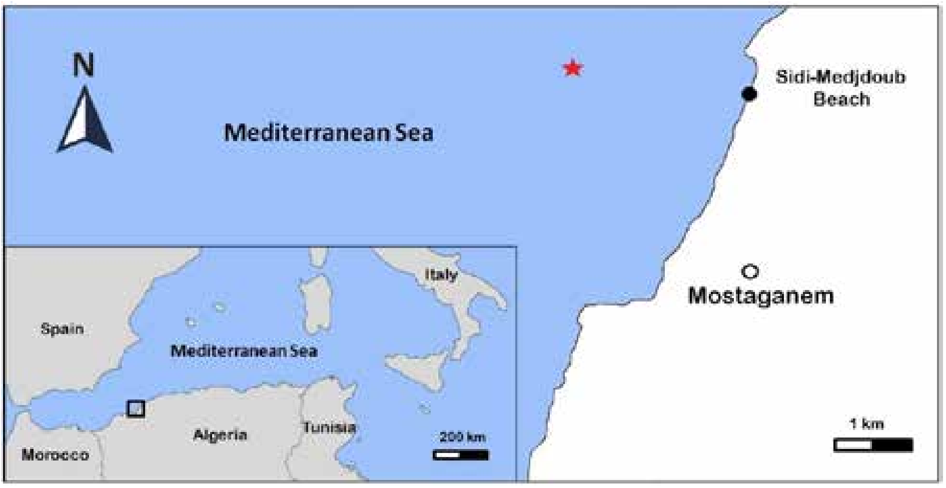

Figure 1. Location of the sampling site in the Mostaganem area (red star).

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Digestive content analysis

To prevent evisceration (due to stress), collected individuals were dissected immediately on the trawler. Among the nine collected individuals (15-cm long on average, contracted length), only four did not expel their internal organs. The gut of each individual was opened by a longitudinal incision and the digestive contents were carefully collected and placed separately in a small plastic bag containing 10% formalin-seawater, then transported quickly to the Protection, Valorization of Coastal Marine Resources and Molecular Systematic Laboratory in Algeria. The method developed by Jones (1968), and later modified by Nédélec (1982), was used to analyse the digestive content of the individuals (see Belbachir and Mezali 2018). The average contribution of each constituent (digestive contents) was calculated for all individuals.

Results

The analysis of the digestive content of *Parastichopus regalis* individuals from the Sidi-Medjdoub region shows that these sea cucumbers generally ingest the same constituents (Table 1). The digestive tract content of this species is mainly composed of a mixture of very fine particles (mud), fine particles (sand) and a small amount of large particles (gravel), all in different proportions (Table 1). An important diversity in the faunal fraction is observed, with mainly nematodes, sponge spicules, echinoderm ossicles, mollusc shell fragments, foraminifera, and an undetermined faunistic fraction. The floristic fraction is mainly represented by diatoms and cyanobacteria (Table 1).

Nearly two-thirds of the digestive contents of the four individuals of *P. regalis* consisted of very fine sedimentary fraction (61.38%) (Table 1, Fig. 2). In contrast, the rest of the sedimentary fraction was composed of fine sand particles (5.88%) and coarse sand particles (1.05%) (Table 1; Fig. 2). The latter are only observed in the digestive contents of individuals 3 and 4 (Table 1). The faunal fraction is also an important presence in the digestive content of *P. regalis*, representing a proportion of approximately 25.21% (Table 1). The presence of foraminifera in the gut was also found (7.54%), and the highest proportion is represented by undetermined foraminifera species (3.58%) (Table 1, Fig. 2). Indeed, the foraminifera of this group, in particular *Globigerina* sp. and *Textularia* sp., were observed in the guts of all individuals (Table 1). In addition, undetermined fauna (5.06%) were well represented, followed by sponge ossicles (4.98%), nematodes (3.35%), mollusc shell fragments (2.22%) and echinoderm ossicles (2.06%) (Table 1, Fig. 2). Diatoms were observed in the digestive contents of all individuals, with an average proportion of 4.04% (Table 1, Fig. 2). Finally, the cyanobacteria group is the least represented (at 2.45%) in the gut contents of *P. regalis* (Table 1, Fig. 2).

Table 1. Variation of the average contribution (in percentage) of items of the digestive contents of *Parastichopus regalis* in the region of Sidi-Medjdoub (Mostaganem).

Items	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Average
Very fines particles	66.00	63.00	56.75	59.75	61.38
Fines particles	3.75	8.25	4.17	7.35	5.88
Large particles	0.00	0.00	1.45	2.75	1.05
Nematodes	4.75	2.75	4.15	1.75	3.35
Sponge ossicles	3.25	3.24	5.18	8.25	4.98
Echinoderm ossicles	1.50	0.75	2.75	3.25	2.06
Mollusc shells fragments	3.25	4.11	1.25	0.25	2.22
Undetermined fauna	4.25	6.50	6.25	3.25	5.06
Globorotalia menardii	0.25	0.00	0.55	0.00	0.20
Globigerina sp.	1.00	0.60	0.65	0.75	0.75
Bolivina sp.	0.25	0.50	0.00	0.60	0.34
Leptohalysis scottii	3.25	1.25	2.45	0.00	1.74
Textularia sp.	0.50	0.25	1.75	1.25	0.94
Undetermined foraminifa	1.25	4.15	3.75	5.15	3.58
Total foraminifera	**6.50**	**6.75**	**9.15**	**7.75**	**7.54**
Total fauna	**23.50**	**24.10**	**28.73**	**24.50**	**25.21**
Pleurosigma sp.	0.00	1.25	0.00	0.25	0.38
Nitzschia sp.	2.00	0.40	0.60	0.75	0.94
Centric diatoms	0.25	0.00	0.00	0.00	0.06
Undetermined diatoms	3.25	2.75	3.15	1.50	2.66
Total diatoms	**5.50**	**4.40**	**3.75**	**2.50**	**4.04**
Cyanobacteria	**1.25**	**0.25**	**5.15**	**3.15**	**2.45**

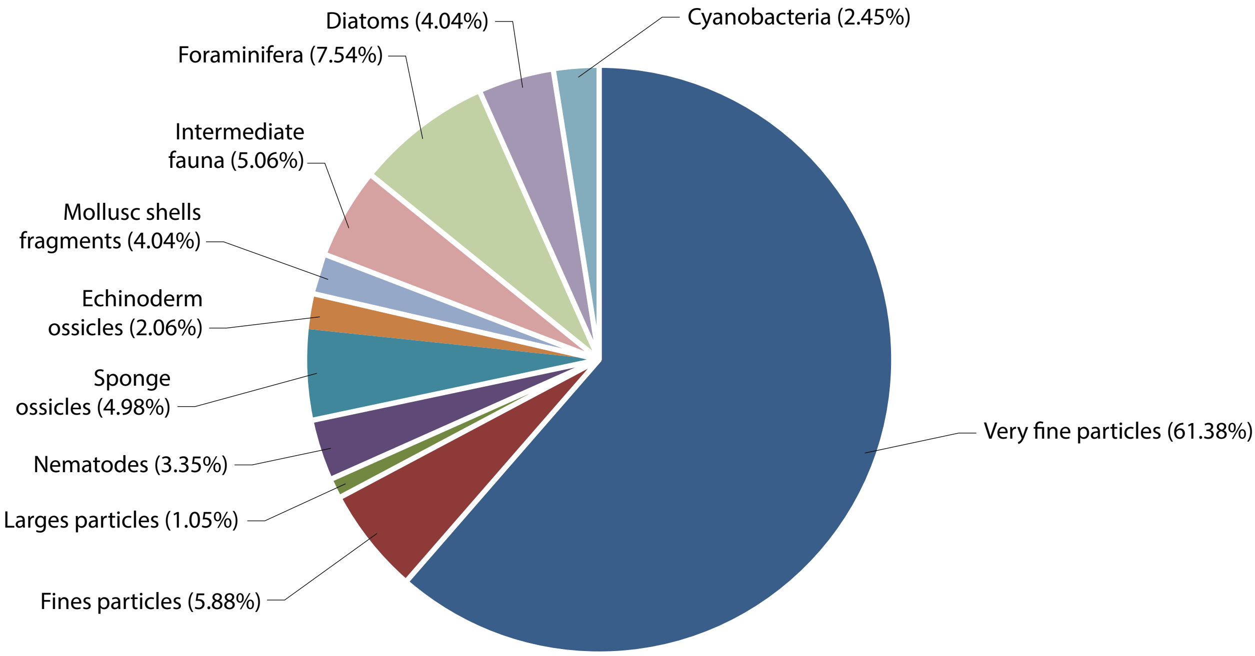

Figure 2. Main digestive tract content in *Parastichopus regalis* from the Sidi-Medjdoub area (average contributions expressed as a percentage).

Discussion

The digestive contents of *Parastichopus regalis* is divided into three components: sediments, fauna and flora – with proportions of 68.31%, 25.46% and 6.49%, respectively. The proportion of very fine particles is high at more than 61%. The presence of this fine sediment fraction in the digestive tract of *P. regalis*is due to the biotope in which this species lives. According to Ramon et al. (2019), *P. regalis* ingests these fine sand particles (between 0.103µm and 1 mm in size), which are generally high in organic matter (Hudson et al. 2005; Holmer et al. 2009). According to Belbachir et al. (2014), marine deposit feeders adapt choose foods that are easily assimilated (rapid transit in gut) and for which the release of particles requires less effort. Holothurians feed selectively and are able to discriminate between nutritionally rich and poor particles, and select the rich ones using their gustatory receivers located on their tentacles (Mezali and Soualili 2013). The shape of the tentacles is generally adapted to the size of the particles to be ingested: detritus feeders that live on fine sediment have shorter tentacles, often peltate, contractile, and have an adhesive substance on their surfaces. Species of the *Stichopodidae* family, of which *P. regalis* is a part, are mainly found on sandy and muddy bottoms (Byrne and O'Hara 2017). According to our results, low percentages of large particles were found in the digestive contents of *P. regalis*, and this could be due to their low organic matter content. Moreover, according to Dar and Ahmad (2006), the presence of large particles in the digestive system of holothurians is necessary for carrying out essential functions such as digestion. The animal (fauna) fraction occupies an important place in the digestive content of *P. regalis*, with foraminifera constituting the greatest proportion. In fact, according to Bakus (1973), foraminifera are one of the main food sources for holothurians. The low percentage of diatoms found in the digestive tract of *P. regalis* confirms that this species uses microalgae as a food source as reported by several authors (Khripounoff and Sibuet 1980; Sonnenholzner 2003; Yokoyama 2013; Xie et al. 2017). Moreover, this food source is considered to be an essential part of the diet of holothurians, especially during their early stages of development (Shi et al. 2013, 2015).

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Observation of confusing ventral colour patterns of juvenile teatfish (Holothuroidea) for species identification in Solomon Islands

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Teatfish are commercially the most valuable holothurians in tropical areas (Purcell 2014), more so than any other holothurian species (Eriksson and Byrne 2015). They have been overfished during earlier boom-and-bust cycles of the fishery (Anderson et al. 2011), which has resulted in a worldwide decrease of teatfish resources (CITES 2019; FAO 2019). In 2019, three species of teatfish – *Holothuria* (*Microthele*) *nobilis* (Selenka, 1867), *H.* (*M.*) *whitmaei* (Bell, 1887) and *H.* (*M.*) *fuscogilva* (Cherbonnier, 1980) – were listed in CITES[5] Appendix II, which was enabled by the resolution of the previous taxonomic confusion of teatfish (e.g. Cherbonnier 1980; Rowe and Gates 1995; Massin 1999) by comparing morphology and genetic sequences (Uthicke et al. 2004).

According to Uthicke et al. (2004), the above three species of teatfish are morphologically discernible b their body colours: *H. (M.) whitmaei* is entirely black on the dorsal side and dark brown on the ventral side, while *H. (M.) nobilis* has large white markings around the lateral teats. The colour of *H. (M.) fuscogilva* is white or beige on both the dorsal and ventral sides (but more yellowish on the ventral than on the dorsal side), and there is usually black or dark brown mottling on the dorsal side, which is variable in size or sometimes lacking, depending on the individual. In the case of juveniles, however, visual identification is rather difficult compared to that of adults, because the dorsal side of juvenile *H. (M.) whitmaei* can have white or yellow patches, somewhat similar to juveniles of *H. (M.) fuscogilva* (Uthicke et al. 2004; Purcell and Tekanene 2006). A clear morphological difference to distinguish juveniles of the two species has been suggested, as their respective ventral colours, which have been described as entirely dark and white or beige for *H. (M.) whitmaei* and *H. (M.) fuscogilva*, respectively (Uthicke et al. 2004).

We observed, however, several juveniles of teatfish showing intermediate ventral colour morphs, as dark brown to black in the central section of the body, and beige in the peripheral parts (Fig. 1e, f, j, k). As the peripheral white area is partly covered with ambulacra, there were undoubtedly both light and dark areas on the trivium. The series of the ventral colour morphs were continuous in ratios of light and dark areas, and also in lightness of the dark area from brown to nearly black (Fig. 1e, f, j, k). This fills the gap between the entirely white (Fig. 1d) and black (Fig. 1l) morphs, typical of *H. (M.) fuscogilva* and *H. (M.) whitmaei*, respectively (Uthicke et al. 2004). Because relatively large (≥18 cm) individuals of teatfish observed in this area exclusively show uniformly light ventral colours as Fig. 1d, most of these intermediate variants (relatively small juveniles ≤12 cm) were possibly also *H. (M.) fuscogilva*. Nevertheless, the continuous variation of ventral colour morphs makes it difficult to define a clear morphological border between juveniles of *H. (M.) fuscogilva* and *H. (M.) whitmaei*, unless testing DNA sequences. These results imply potential risks of misidentification of juvenile teatfish in visual-based data such as field surveys and also in trade records.

Time of observation: 11:00 to 16:00 on 24 January 2020

Location: Danisavo Harbour located between Danisavo and Buena Vista Islands in the Nggela (Florida) Islands, Solomon Islands. Mainly around S 8° 53′ 58", E 159° 58′ 50".

Water depth: ca. 30 cm to 1 m.

Habitat: Seagrass beds mainly comprising *Enhalus acoroides*.

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[5] CITES = the Convention on International Trade in Endangered Species of Wild Fauna and Flora

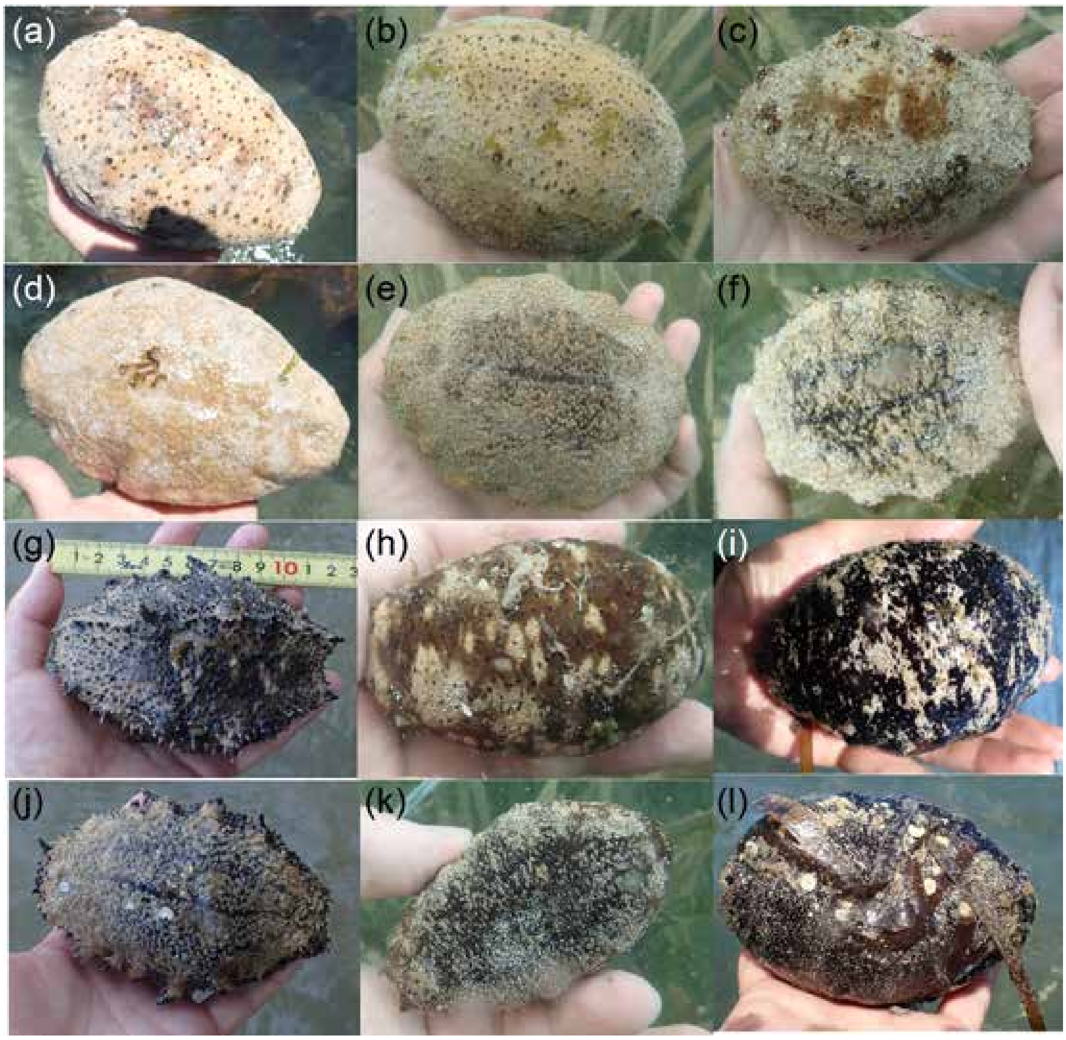

Figure 1. Teatfish juveniles in pairs, showing dorsal (a, b, c, g, h, i) and ventral (d, e, f, j, k, l) views. A white individual (a, d) showed an entirely beige-coloured ventral side (d), while a black individual with small white patches on the dorsal side (i) showed a uniformly black ventral colour (l). Other individuals showed mixed ventral colours of dark brown and beige in the central and peripheral parts, respectively (e, f, j, k). Body length: (a, d) 18 cm, (b, e) 10 cm, (c, f): 9 cm, (g, j) 12 cm, (h, k): 7 cm, (i, l): 12 cm. image: Iwao Tanita

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Parastichopus tremulus (Gunnerus, 1767) red sea cucumber, red signal sea cucumber (Sweden), rødpølse (Norway and Denmark), Aspidochirotida, Stichopodidae

Ellen Schagerström[1,*] and Kristina S. Sundell[1]

Parastichopus tremulus is found in the northeast Atlantic Ocean, mainly along the coasts of Norway and Sweden, but also Iceland, the Faroe Islands and British Isles, with recorded occurrences down to the Canary Islands. *P. tremulus* can occasionally be found from 18 m down to 4000 m but is most frequent found at 50–500 m.[2] It is often part of bycatch from commercial bottom trawling for other species in the North Sea, with the highest abundances at 150–300 m. The depth at which this species is found has limited studies of its distribution, behaviour and ecology. This is one of the larger holothurians in this depth range in the area, along with *Cucumaria frondosa* and *Psolus pantapus*, both dendrochirotid species. Fully grown specimens of *P. tremulus* from the North Sea can reach 50 cm in length, 10 cm in width and a wet weight close to 300 g, but the average size and wet weight is around 25 cm and 200 g, respectively (Kjerstad et al. 2015; Christophersen et al. 2020). *Parastichopus tremulus* is cylindrical in shape, with slightly tapered ends and a thick body wall. The dorsal side of adults is red-orange, with varying levels of saturation, and small dark spots scattered evenly along the body (Fig. 1). It is also covered with distinct papillae that are 0.5–2.0 cm in length, giving the animal a spiky look. The ventral surface is lighter coloured, often completely white, and covered by rows of tube feet. Variations occur with regard to the red markings, mottling or stripes on the ventral side (Fig. 1). There are occasionally red suckers on the locomotory podia. Wholly red or white specimens have also been documented.

Parastichopus tremulus is quite commonly found on silt-covered rocks and pebbled substrates, and according to observations from scuba divers and remotely operated vehicle-inventories, the highest abundances have been recorded on soft sediments. The species is generally described as being part of the soft bottom community (Jespersen and Lützen 1971; Hudson et al. 2004).

When placed in flow-through tanks with a muddy-sandy substrate, the animals are often found on the hard tank wall (personal observation), and when feeding, *P. tremulus* slowly moves over the substrate with the mouth ventrally directed (Hauksson 1979). Also when feeding, it uses only 10 of its 20 peltate feeding tentacles at a time to collect organic matter and inorganic particles from the surface of the sediment (Hudson et al. 2004). No mucous glands have been detected on either the tentacles or in the pharynx, suggesting that the particles are handled mechanically rather than by an adhesive substance (Jespersen and Lützen 1971). The sensory papillae surrounding the oral crown (Fig. 1) are used to "sense" the sediment prior to tentacular contact (Hudson et al. 2004). *P. tremulus* is a selective feeder, showing a preference for organic-rich material such as faecal pellets, and other sediment particles that are richer in organic material than the general surface sediments (Hauksson 1979), or silica particles (Hudson et al. 2004). Jespersen and Lützen (1971), however, suggested they were non-selective feeders at the level of actual selection of particles from the sediment, but rather at the level of organic matter in the sediment as maximum densities occur in areas where the sediment has been enriched with organic material. Feeding occurs throughout the night and day (Hudson et al. 2004), presumably due to a lack of large diurnal variation.

There is some evidence of seasonal fasting or aestivation occurring from October to February, so it is assumed that the species ceases feeding from the end of October until the beginning of January. Intestinal regeneration is assumed to be 60–80 days, based on laboratory observations (Jespersen and Lützen 1971). It is still unknown what triggers a potential seasonal aestivation.

The starfish *Solaster endeca* (Linnaeus, 1771) has been seen praying on *P. tremulus* in aquaria. Anecdotal reports from North Sea fishermen suggest that several species of codfish and halibut are predators of this species, as they have been found in the gut content of the fish. Because sea cucumber bycatch is dumped back into the sea, *P. tremulus* may also be eaten while sinking through the water mass. It is, therefore, uncertain whether these fish actually prey upon them in their natural habitat.

Parastichopus tremulus is either male or female, without any external sexual dimorphism, and exhibits an annual reproductive cycle. The sex ratio is estimated to be 1.3:1.0 females:males. Gametogenesis initiation begins in January, and there is a successive increase in gonadal index from January until May, when the maximum gonad size was recorded in Ålesund, Norway (Christophersen et al. 2020).

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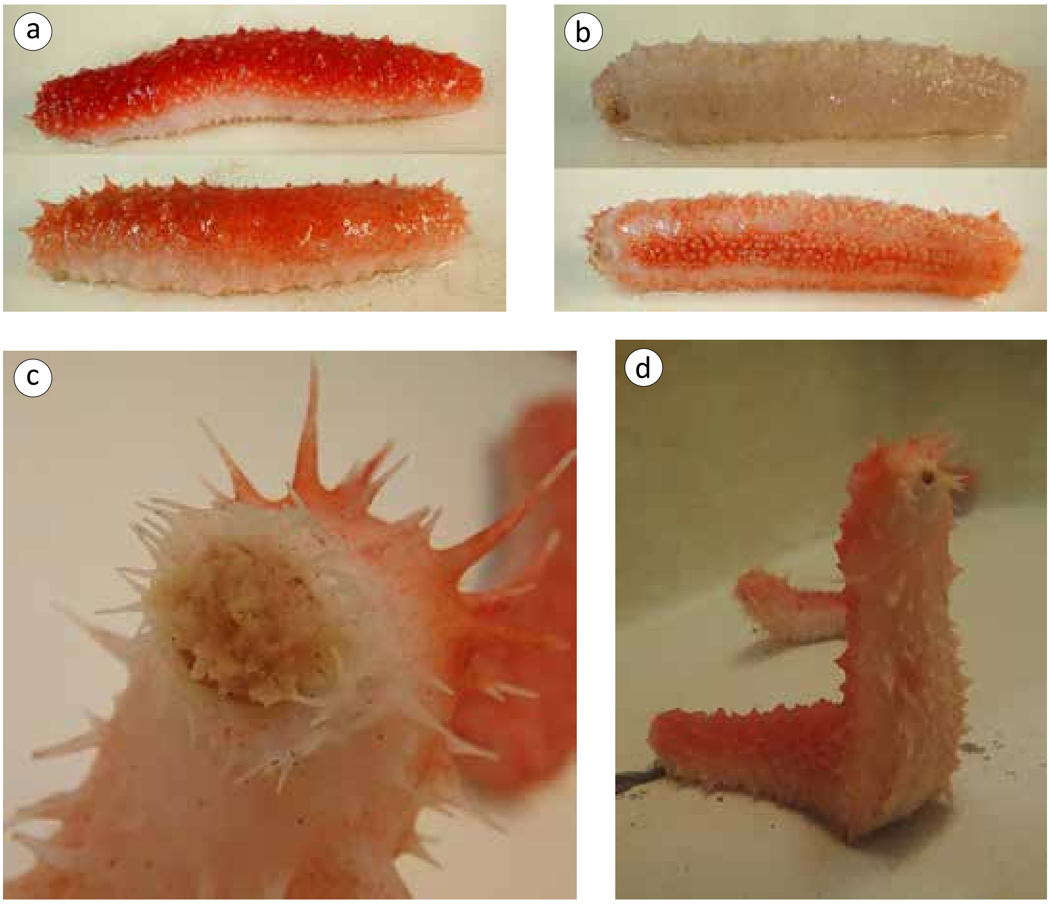

Figure 1. a) *Parastichopus tremulus* has a reddish-orange dorsal side, going from deep red (top) to a lighter hue, where the small dark spots, scattered evenly along the body, are more clearly visible (bottom); b) the ventral side is most often completely white (top), but red markings, mottling or stripes also occur (bottom); c) the 20 pelatate feeding tentacles are surrounded by sensory papillae; d) a male individual in spawning posture with the anterior body clearly raised and the mouth tightly closed. The gonopore is swollen and sperm are being released

Earlier studies state that spawning occurs slightly later, during the summer months of July and August (e.g. Rustad 1940; Lönning 1976; Holland 1981). In Sweden, successful fertilisation after induced spawning occurred between late May–July. Induced spawning has shown how first males and then females adopt the spawning posture, with the anterior part of the body more or less raised (Fig. 1d), similar to that reported for the closely related species *Parastichopus californicus* (Cameron and Fankboner 1986). Gametes are broadcasted from the gonopore into the water column, where they are fertilised. The age at which this species reaches sexual maturation is unknown, but gonads have been present in animals just 84 mm in length, although gonad viability was not checked (Christophersen et al. 2020).

No observation of any of the pelagic larval stages of *P. tremulus* have been reported from the field. Regarding newly settled juveniles, to our knowledge, there is only one observation of a juvenile < 30 mm reported by Kjerstad et al (2015) who also observed that large and small animals seem to occur at different sampling stations. Together with the observations that the size of animals differs between substrates (Jespersen and Lutzen 1971), this possibly suggests an alteration of substrate preference, so some migration is likely to occur with size or age.

In Asia, sea cucumbers are a well-known product delicacy. As of today, this species has not been formally introduced to the Asian market, but a few attempts at evaluating its potential have been made by Kjerstad et al. (2015), who reported that *P. tremulus* showed significant potential as a commercial product on the Chinese market. Their Chinese test-panel liked the properties of *P. tremulus,* such as its size, meat content, taste and nutritional content. Its red colour, although not maintained after processing, was also regarded as favourable. It was tentatively priced in the middle to lower price range.

Currently, research on spawning and artificial rearing of this species is underway in Norway and Sweden. The main aim of this novel area of research is to establish breeding and farming protocols for *P. tremulus* for use as a detritivorous component in different integrated multi-trophic aquaculture systems, for re-stocking purposes as well as for possible commercial farming. The focus of the research in Sweden is to investigate basic physiology and the physiological boundaries regarding environmental biotic and abiotic factors of *P. tremulus*. This will build the knowledge base for developing breeding, hatching and farming guidelines with a focus on animal health and welfare along with productivity for farming new sea cucumber species. The first captivity-bred juveniles of this species were successfully produced in Sweden during 2020.

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Norwegian red sea cucumber (*Parastichopus tremulus*) fishery and aquaculture north of 60°N latitude: Feasible or fictional?

Gyda Christophersen,[1] Snorre Bakke[2] and Jan Sunde[1]

Abstract

The high demand for sea cucumbers from the Asian market has led to the interest in new species from the North Atlantic. The Norwegian red sea cucumber, *Parastichopus tremulus*, is one potential species, that has yet to be exploited or cultured. The red sea cucumber is distributed along the entire Norwegian coast, and seems to be abundant north of 60°N. The population is believed to be commercially exploitable, but the lack of knowledge on its life history traits and population structure necessitates more biological investigations before this can be confirmed. Aquaculture of the species is considered, but for this to succeed knowledge about reproduction and early life stages needs to be advanced. In this paper we summarise some of the knowledge currently available for *P. tremulus*, present some recent advances from reproduction studies, and discuss prospects for utilising this species, both through a fishery and aquaculture.

Key words: Norwegian red sea cucumber, *Parastichopus tremulus*, biology, fishery, aquaculture

Introduction

There is a great demand for sea cucumbers from the Asian market and buyers are driven west and north to explore new species to replace vulnerable and depleted species from the Pacific (Purcell et al. 2014). The sea cucumbers of the Atlantic are the next to be targeted for commercial utilisation and face the threat of overexploitation unless: a) more knowledge is obtained about their life-history traits and population dynamics, and b) proper management actions are implemented (González-Wangüemert et al. 2018). Preliminary investigations have shown that the red sea cucumber *Parastichopus tremulus* (Fig. 1), which inhabits Norwegian waters, possesses many important properties favoured by Chinese customers, such as size, body shape, meat content, taste and nutritional composition (Kjerstad et al. 2015). Market introduction of this species is still in the initial phase, but there is increased interest in harvesting and exploiting this resource from the north east Atlantic. Currently, the species is only landed as bycatch in Norway, but the prospects of a lucrative trade and a desire to utilise all bycatch, encourage fishermen, entrepreneurs, and established seafood traders to fish, process and export the species. However, because no commercial fishery licenses are issued, the variable supply of bycatch complicates the development of a new value chain for this resource. Several Asian countries have, over the last decades, developed successful industrial-scale aquaculture of at least three highly appreciated species *Apostichopus japonicus*, *Holothuria scabra* and *Isostichopus fuscus* (Mercier and Hamel 2013), with China being by far the largest producer (Yang et al. 2015). Therefore, it seems likely that aquaculture production in the future will supplement, or even replace, fisheries as a more sustainable source of sea cucumbers for human consumption. There is increased interest in the aquaculture of species outside of Asia, and several European species have recently been investigated for their aquaculture potential (Santos et al. 2016; Rakaj et al. 2018, 2019; Christophersen et al. 2020; Laguerre et al. 2020). To succeed with the development of sustainable fishery and/or aquaculture, however, several biological, commercial and legislative questions need to be answered. The research institute Møreforsking started work on the utilisation of sea cucumbers in 2004, and it was concluded that there is potential for the commercial utilisation of *P. tremulus* in Norwegian coastal waters (Kjerstad et al. 2015). We report on the current status and thoughts considering the feasibility of catching and producing the Norwegian red sea cucumber *P. tremulus* above 60°N.

Observations and conditions at high latitudes

Although sea cucumbers have been studied since the early days of marine biology, limited information exists on the biology and ecology of the Norwegian red sea cucumber, *P. tremulus* (Gunnerus, 1767) in Norwegian waters. Historically, the species has been recognised under several scientific names (IUCN Red list of Threatened Species): *Stichopus tremulus* (Gunnerus); *Holothuria elegans* O.F. Müller, 1781*; Holothuria tremula* Gunnerus, 1787*; Holothuria ecalcarea* M. Sars, 1859; *Stichopus richardi* Hérouard, 1896 and *Stichopus griegi* Östergren, 1896. The

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Figure 1. An adult specimen of the Norwegian red sea cucumber, *Parastichopus tremulus*. (image: Jan Sunde, Møreforsking)

existing literature is based on observations and studies in a few limited geographical locations: the Bergen and Oslofjord areas in southern Norway (Gunnerus 1767; Nordgaard 1912; Rustad 1940; Jespersen and Lützen 1971; Lönning 1976), the Gullmarsfjord on the west coast of Sweden (Holland 1981; Hudson et al. 2005), and off the western coast of Ireland and the British Isles (Mortensen 1927; Hudson et al. 2004). There is even less documentation on the biology of *P. tremulus* from areas above 60°N (Christophersen et al. 2020; Schagerström et al. submitted) (Fig. 2).

Habitat and ecology

Parastichopus tremulus mainly lives in waters too deep to be observed by scuba divers, which is one of the reasons why biological and ecological information on the species is scarce. Modern technology, however, such as ROVs (remotely operated vehicles) and towed video rigs, has made deep-sea observations easier. For instance, the Norwegian MAREANO programme[3], financed by the Ministry of Fisheries and Coastal Affairs, the Ministry of Environment, and the Ministry of Trade and Industry since 2005, maps the occurrence of different species off the coast of Norway using both video and active sampling gear. Data on benthic organisms are collected, including depth, topography and sediment composition, have provided important information on a variety of underwater nature types and biotopes. Further, information on species occurrence from historical surveys have been digitised and made accessible through open access databases such as EMODnet[4] and the Global Biodiversity Information Facility (GBIF).[5] Recorded occurrences from these data sources show that *P. tremulus* is found in the eastern Atlantic Ocean, from the Arctic Barents Sea to the Canary Islands in the south (Fig. 2), adding new information to the distribution map shown in Madsen and Hansen (1994).

It appears that the species is especially abundant along the Norwegian coast above 60° N (Fig. 2), although it is likely that this is due to the higher survey intensity in this area, particularly through the MAREANO programme. The deepest known occurrence of *P. tremulus* is in the sea between Greenland and Svalbard at a depth of 3193 m (MNHN, Chagnoux S. 2021). This is deeper than the earlier proposed bathymetrical distributions of ca. 20–1900 m (Grieg 1921; Mortensen 1927). The majority of occurrences, however, are from 200 to 400 m depth (Fig. 3). The species has been recorded on a variety of substrates along the Norwegian coastline but appears to be most commonly observed on soft bottom sediments (Fig. 4). It should be noted that data on depth registration and substrate preference might be artefacts of geographical preference for scientific survey activity. On the other hand, the information seems to be substantiated by data from test fisheries and research cruises in Norway, which have found that the highest abundance of the species is on soft bottom habitats at depths between 100 and

[3] See https://mareano.no/en
[4] See www.emodnet.eu
[5] See www.gbif.org

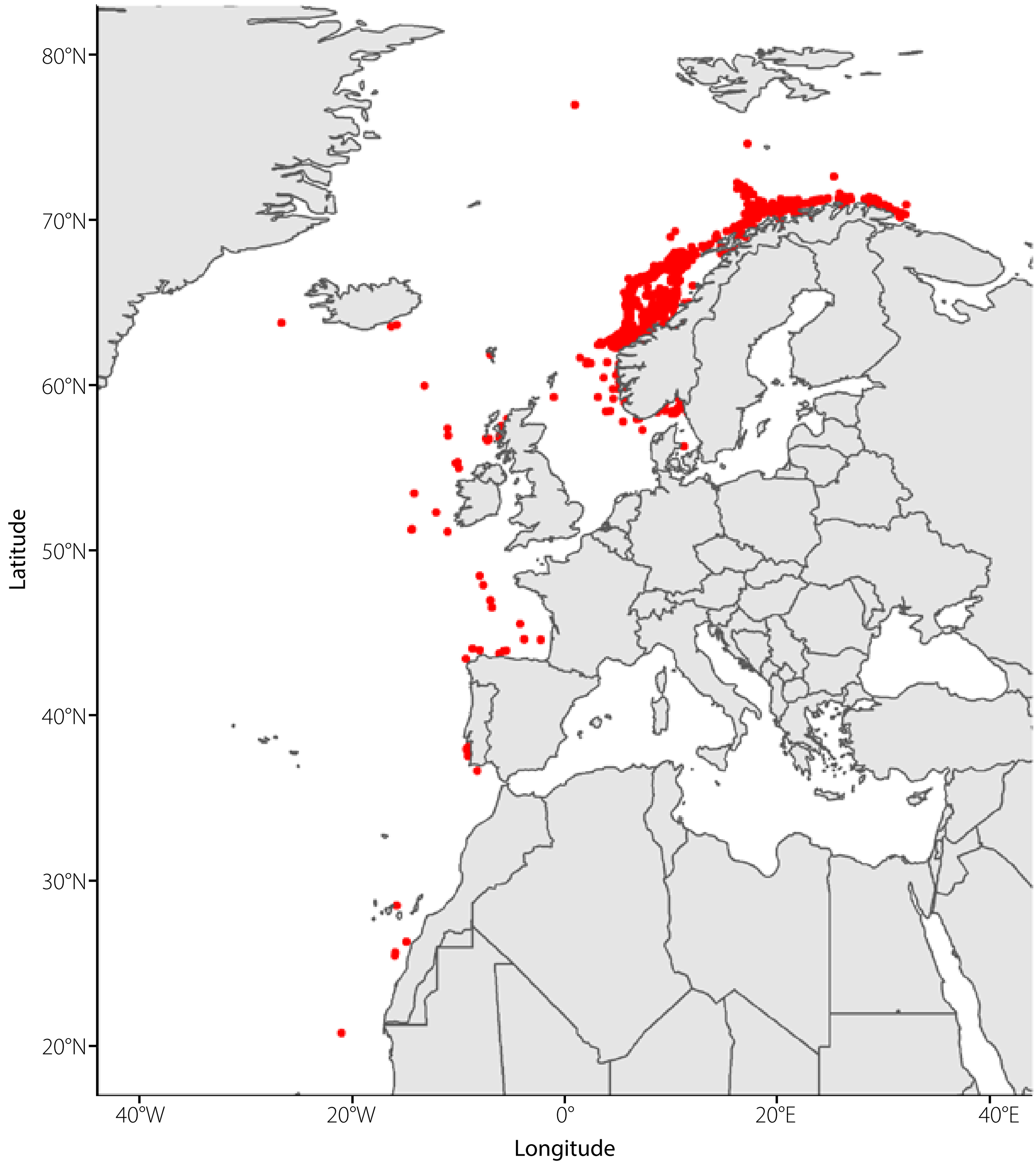

Figure 2. Recorded occurrences of *Parastichopus tremulus*. Data obtained from the MAREANO Marbunn database (www.mareano.no/marbunn), the European Marine Observation and Data Network (EMODnet Biology (2020) Full Occurrence Data and Parameters downloaded from the EMODnet Biology project (http://www.emodnet-biology.eu). Available online at http://www.emodnet-biology.eu/toolbox/en/download/selection/15f9adb20ad111, consulted on 29 October 2020), and the Global Biodiversity Information Facility (GBIF.org (2 November 2020) GBIF Occurrence Download https://doi.org/10.15468/dl.u9dvzs). (n=4319, Duplicate recordings removed from the dataset).

300 m (Kjerstad et al. 2015). Along the coast of northwestern Europe and inside the fjords of Norway, the sea temperature is between approximately 2–8° C at the depths where *P. tremulus* is most abundant (Furevik 2001; Berx and Hughes 2009; Woll et al. 2014), with the lowest temperatures found in the northern part of the species' distribution.

Parastichopus tremulus is a deposit-feeding sea cucumber and extracts nutrients from soft bottom sediments on the sea floor. Jespersen and Lützen (1971) proposed that *P. tremulus* in Norwegian waters might have a seasonal feeding pattern, and that feeding ceases between mid-October and January, at least in the Oslo fjord. Hauksson (1979) seemed to agree, based on his own observations from the Raune fjord on the west coast of Norway. It is unclear whether this observed cessation of feeding in *P. tremulus* is associated with evisceration of digestive organs (Jespersen and Lützen 1971), or if it merely is a period of aestivation as seen in other holothurioids, most notably *Apostichopus japonicus* (Ji et al. 2008; Yang et al. 2005). We believe this area deserves more research attention. Information is also lacking about feeding preferences and nutritional metabolism of *P. tremulus.*

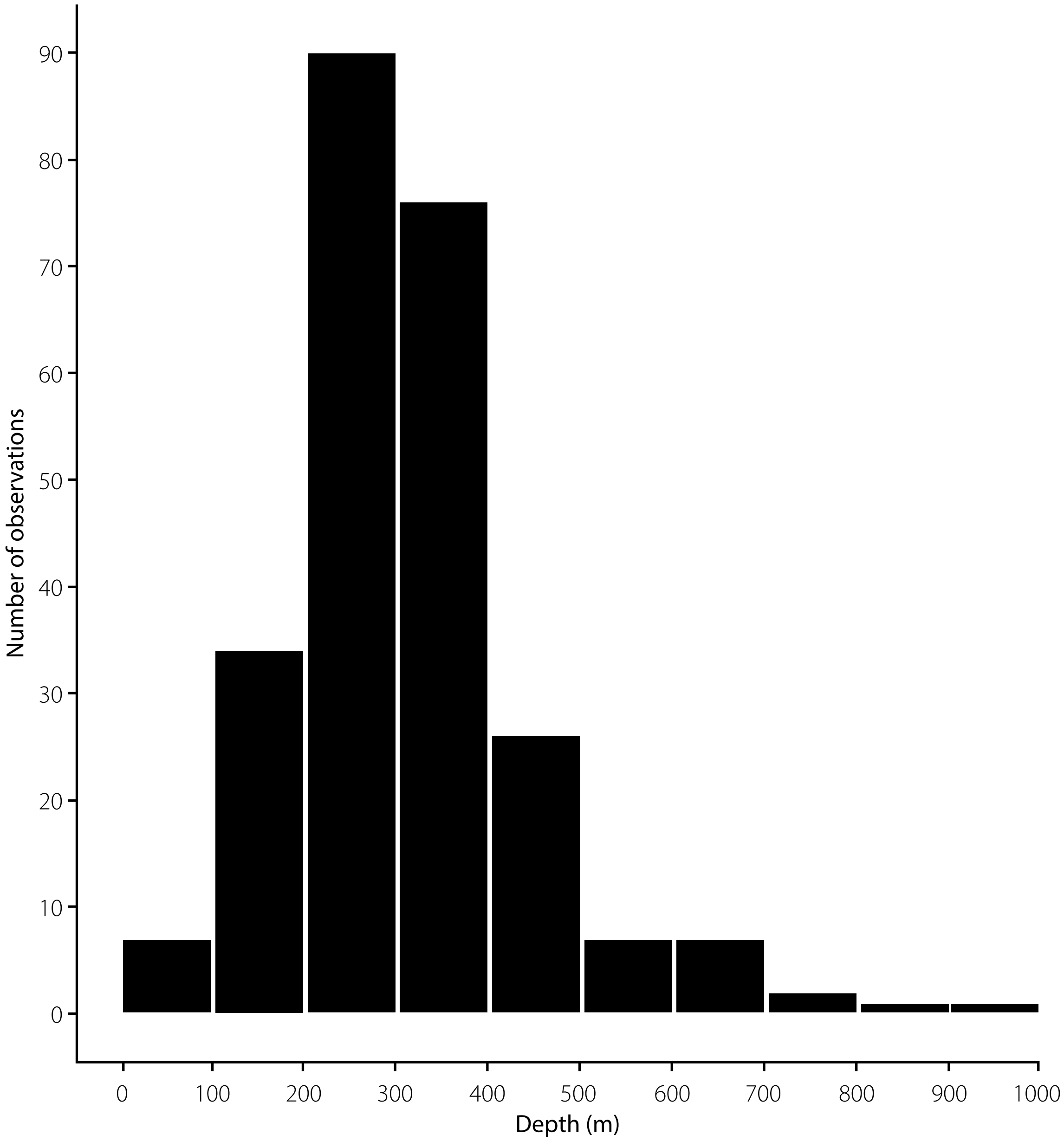

Figure 3. Recorded depth of registration of *Parastichopus tremulus*. Data obtained from the MAREANO Marbunn database (www.mareano.no/marbunn), the European Marine Observation and Data Network (EMODnet Biology (2020) Full Occurrence Data and Parameters downloaded from the EMODnet Biology project (http://www.emodnet-biology.eu). Available online at http://www.emodnet-biology.eu/toolbox/en/download/selection/15f9adb20ad111, consulted on 29 October 2020), and the Global Biodiversity Information Facility (GBIF.org; 2 November 2020) GBIF Occurrence Download https://doi.org/10.15468/dl.u9dvzs). (n=391, Duplicate recordings removed from the dataset).

A comprehensive feeding study on *P. tremulus* was conducted by Hauksson decades ago (1977, 1979), with data from both wild-caught specimens and those in controlled laboratory studies. These studies found that *P. tremulus* shows selective feeding habits with regard to both particle size and organic content, with an estimated average feeding rate of 2 g of sediment per hour. Defecation rates were estimated to be about 20 h for sea cucumbers fed a typical sediment from a Norwegian fjord. A similar defecation rate (~24 h) was also reported by Hudson et al. (2004) who studied the movement of trace particles through the intestine of *P. tremulus* held in sea cages. A higher defecation rate was reported by Jespersen and Lützen (1971) who noted that harvested sea cucumbers had emptied their intestines after about 8–10 h when held in aquaria. In the laboratory studies by Hauksson (1979), an assimilation efficiency of around 27% was estimated. This is slightly higher than reported for *Parastichopus californicus* feeding on natural sediments (Ahlgren 1998), but significantly lower than estimated assimilation efficiencies for *P. californicus* feeding on sediments high in organic content (Paltzat et al. 2008). Currently, studies are being carried out by Møreforsking that will gain more information on how efficiently *P. tremulus* extracts nutrients from more energy-dense aquaculture feeds.

There are few known predators of *P. tremulus* but it has been reported to be preyed upon by scavenging amphipods, shrimps, starfish and some species of gadoid fish (Francour 1997). Its bright red colour likely provides an efficient camouflage against visual predators in deeper waters as there is little red light to be reflected at these depths. Holothuroids

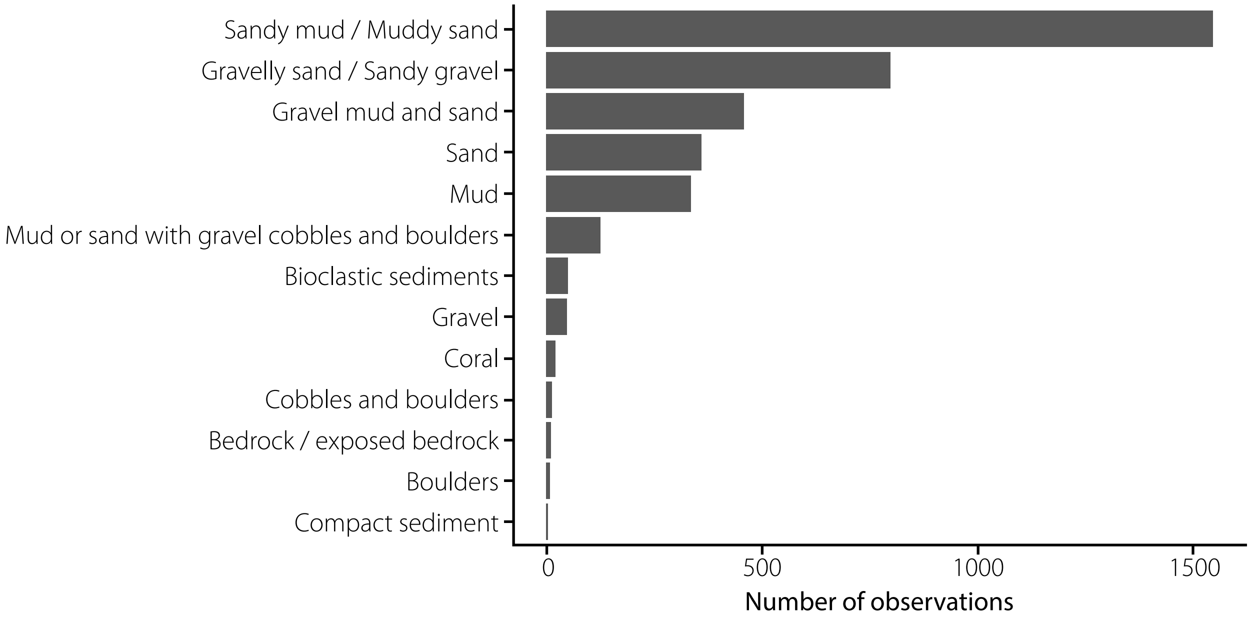

Figure 4. Substrates where *Parastichopus tremulus* have been observed in video surveys. Data from the MAREANO Marbunn database (www.mareano.no/marbunn), n=3783.

are, however, prone to parasitic infections by bacteria, protozoa and metazoa, with the main areas of infestation being the digestive system and the coelom (Eeckhaut et al. 2004). There is no single comprehensive study of the extent and diversity of parasitic infestations in *P. tremulus*, although a few have been reported (Jespersen and Lützen 1971), most notably the gastropod *Enteroxenos östergreni*, which was first described by Bonnevie (1902). Little is known about how *P. tremulus* is affected by this parasite, but a prevalence as high as 35% was reported from the Oslo fjord in Norway (Lützen 1979) and may indicate that *E. östergreni* infestation has little impact. As is the case with other holothurioids, we have frequently observed in our lab copepods on the body of the red sea cucumber, but it is likely this is a commensal, rather than parasitic, relationship (Eeckhaut et al. 2004).

Reproductive cycle

Parastichopus tremulus is a dioecious species, but individuals have no external characteristics that make the two sexes distinguishable. Several dissection studies carried out on specimens from Norwegian waters, suggest a fairly equal sex distribution, with female to male ratios of 0.98:1.00 (Jespersen and Lützen 1971), 1.33:1.00 (Hauksson 1977) and 1.3:1.0 (Christophersen et al. 2020). We have described the annual reproductive cycle of our local population (Christophersen et al. 2020), showing a seasonal pattern typical of other temperate species, with the spawning season commencing in late spring and early summer. Spawning in sea cucumbers can be triggered by light, primary production, changes in temperature and salinity, lunar phase and the presence of gametes in the water (Cameron and Fankboner 1986; Sewell and Bergquist 1990; Hamel and Mercier 1995; Mercier et al. 2007; Morgan 2009). The environmental factor that triggers spawning in *P. tremulus* is unknown. At depths where it is most abundant, the temperature is relatively low and stable (7–9° C) throughout the year (Woll et al. 2014). It is thus unlikely that any rapid seasonal changes in temperature is a direct spawning cue. At depths of 100–300 m it is more likely that gonad maturation and spawning is induced by phytodetritus, as suggested for some species of deep-water holothurians (Wigham et al. 2003). This could be confirmed in future studies by measuring the organic content in sediment samples from typical habitats during the period of expected gonad development.

Fishery opportunities and constraints

The many observations and occurrence of *P. tremulus* above 60°N could indicate a large harvest potential (Kjerstad et al. 2015). Fishing pressure on new commercial sea cucumber species can be high, and environmental conditions, genetics and fishing pressure are all factors that can affect population dynamics. The study of distribution, abundance and recruitment of indigenous species are of the utmost importance in a management perspective, although most life history traits for *P. tremulus*, such as size at maturity, fecundity, offspring sex ratio and size-specific growth rates are still unknown.

Laws and regulations

Fisheries legislation in Norway does not specifically cover echinoderms, and traditionally only harvesting of low volumes of sea urchins for gonad enhancement has been carried out. Due to increased interest in sea cucumbers, however, the Norwegian Directorate of Fisheries – as a precautionary measure – issued a general ban on targeted sea cucumber fisheries in Norwegian territorial waters and on the Norwegian continental shelf in October 2019 (Regulation J-180-2019). Exemptions to this ban can, however, be given under specific circumstances. As of January 2021, four trial fisheries permits have been issued with the purpose of testing novel fishing gear designs for a potential, future environmentally friendly sea cucumber fishing industry. These permits are limited to specific geographical areas and require a detailed description of the specific harvesting gear design used in each case. There are, however, large knowledge gaps that need to be filled before a proper legislative framework that will ensure sustainable fisheries management can be implemented.

Population dynamics and landings

The population structure of the Norwegian red sea cucumber has yet to be investigated in detail. Information about spatial and temporal distribution is key to evaluating the prospects of the species as a new fishing resource. Recordings from trial fisheries above 60°N along the Norwegian coast from Møre and Romsdal to Finnmark showed that the size of *P. tremulus* from trawl catches fell within the range of 20–250 mm in length (Kjerstad et al. 2015). In our studies from 2017 to 2019, where the purpose was to examine gonad maturation in sea cucumbers from the Møre and Romsdal region of Norway, lengths from 65 to 302 mm were recorded in animals obtained in trawl or pot fisheries in different seasons (Fig. 5a). Of these, approximately 5% were less than 100 mm in length. Round weight (total wet weight) of the same individuals ranged from 12 to 537 g, encompassing the range of 20–470 g reported by Kjerstad et al. (2015). Biometric relationships show correlations between body length and total wet weight and body wall weight, as well as between total and body wall wet weights (Fig. 5a-c). Gonad weights obtained throughout the year ranged from 0.01 to 26.3 g. A weak but significant relationship was described between body length and gonad wet weight, indicating a positive correlation between fecundity and size (Christophersen et al. 2020). Data on fecundity and reproductive parameters may show local variation between populations of the same species that are tied to latitude-specific environmental factors (Sewell 1992; Hamel and Mercier 1996; Marquet et al. 2017).

Individual measurements in our study (Christophersen et al. 2020) were not considered sufficient for detailed size distribution analyses, and thus too incomplete to obtain an indication on the structure of the local population. Juveniles rarely occur in trawl catches, but specimens as small as 3 cm (Rustad 1940; Jespersen and Lutzen 1971), and 2 cm (Kjerstad et al. 2015) have been recorded. The lack of significant data on recorded juveniles hinders estimations of year class size and recruitment in Norwegian waters. Neither have we (on basis of catch data) been able to establish size at first maturity, another measure that is important for proper management. *P. californicus*, a related species living under similar conditions, reaches first maturation at an age of approximately four years (Whitefield and Hardy 2019), but it remains to be seen if growth rates of the two species are comparable. The smallest sea cucumber we have observed with visible gonad tissue was 79 mm in length (June 2018), slightly shorter than the 84 mm previously reported by Christophersen et al. (2020).

Although the digestion rates and assimilation efficiencies reported for *P. tremulus* is comparable to other species of sea cucumbers, no studies have reported growth rates. Slow growth has been reported for other sea cucumber species living at higher latitudes, such as *Cucumaria frondosa* (Hamel and Mercier 1996; So et al. 2010) and *P. californicus* (Paltzat et al. 2008). Based on the sea temperatures in the areas where *P. tremulus* is found, it should be considered a cold-water species, which indicates that it might also have a relatively slow growth rate. However, further studies are needed to confirm this and should be prioritised as it is crucial knowledge for future management and aquaculture production.

The volume of reported landings of *P. tremulus* in Norway are mainly low and are caught as bycatch by trawl or pot fishing, both of which target other species (e.g. Nordic shrimp and Norway lobster). Such data are registered by total catch weight. Bycatch is reported to the Norwegian Directorate of Fisheries, and data from 2007–2020 are made public in electronic form.[6] In these statistics, *P. tremulus* is the only echinoderm identified to the species level, possibly due to its easily recognisable visual appearance. From 2007–2019, 10.4 tonnes of *P. tremulus* were reported as bycatch, whereas 15.6 tonnes were reported in 2020. This recent increase could be indicative of improved bycatch reporting practices but could also reflect an actual increase in catch volume due to the recently issued trial fishery permits. However, we do not think these data can be interpreted as indicative of the abundance of this species in Norwegian waters.

Aquaculture initiatives

Besides being a potentially valuable fishing resource, *P. tremulus* is an interesting candidate for land-based cultivation, sea ranching and integrated aquaculture (Landes et al. 2019). The development of a sea cucumber aquaculture industry in Norway is in its infancy. To succeed with controlled production of a new marine species, large investments in research and development are needed, although competition for funding is a bottleneck. The work related to sea cucumber aquaculture at Møreforsking was initiated through regional projects five years ago and has continued through an ongoing project called "Emerging species for sea cucumber aquaculture", which is funded by the bilateral SANOCEAN programme of the research councils in Norway and South Africa, and targets several sea cucumber species new to the market. The work covers rearing technology and growth conditions for the different stages of spat production, suitability in IMTA systems and effects of environmental pollution. Within the Nordic network HOLOSUSTAIN[7], which is coordinated by Møreforsking, North Atlantic sea cucumber species are being promoted as a novel marine resource for the Western market.

Spawning in captivity

Closing the life cycle – meaning having control of spawning, fertilisation, larval development, and growth of specimens until they reach sexual maturity – is required in order to achieve sustainable aquaculture that is independent of wild

[6] See http://fiskeridirektoratet.no/Yrkesfiske/Tall-og-analyse/Fangst-og-kvoter/Fangst/Fangst-fordelt-paa-art. Accessed: 13.01.2021
[7] See https://www.holosustain.no/

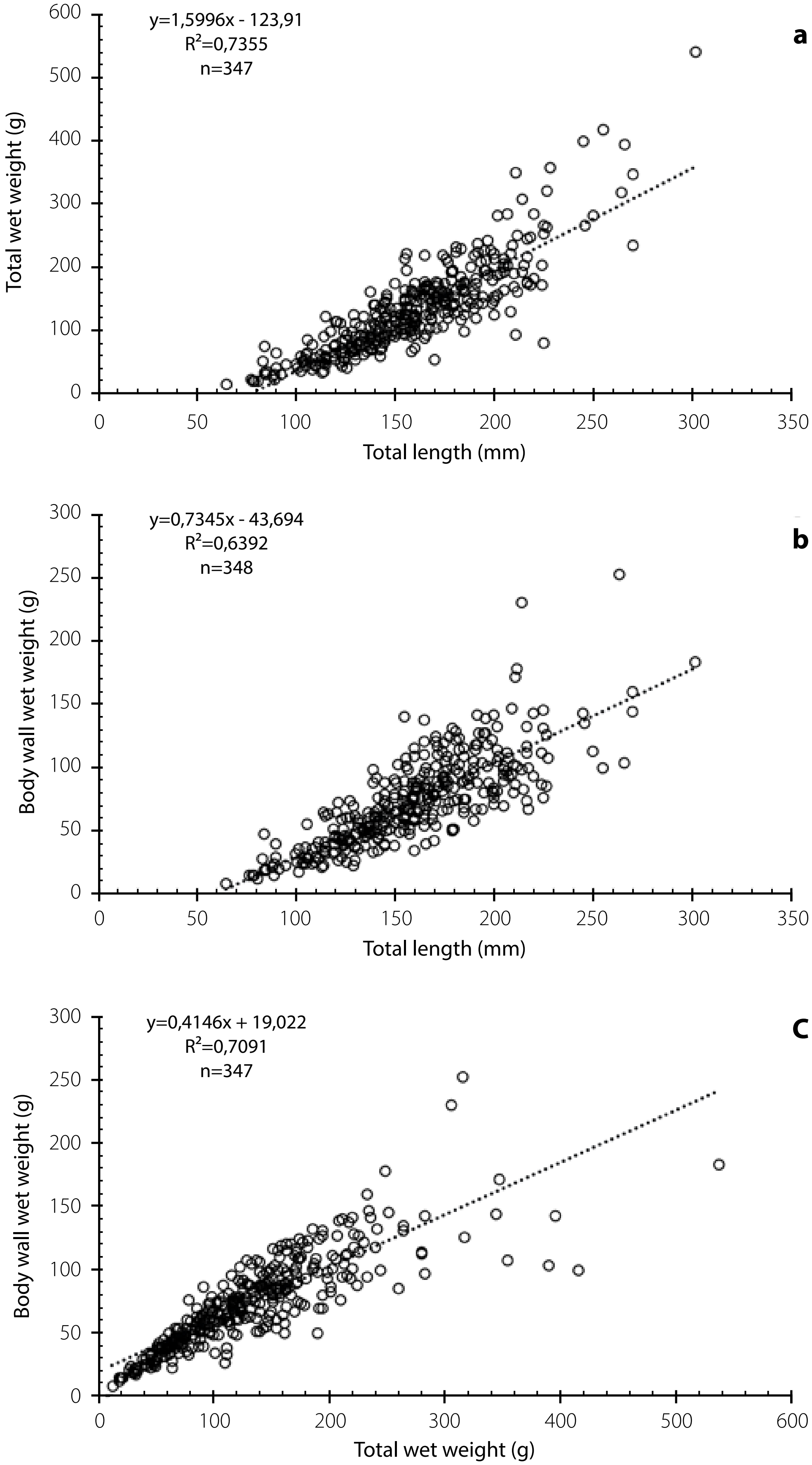

Figure 5. Biometric relationships for red sea cucumber, *Parastichopus tremulus*, caught in Møre and Romsdal, western Norway: a) length – total weight, b) length – body wall weight, c) total weight – body wall weight.

animals. We have determined the natural spawning season of our local stock of *P. tremulus* (Christophersen et al 2020), which is the starting point for mastering controlled spawning. Until now, spawning trials have relied on newly caught specimens from local fishers within the expected spawning window. Peak gonad index (GI) was observed in May (7.1 ± 5.4%, mean ± sd of body wall wet weight) for broodstock collected monthly from the wild. Sea cucumbers held in captivity for several months showed a similar gonad development pattern, but with a significantly lower GI in May and June (Christophersen et al. 2020). *P. tremulus* specimens have been kept alive in our lab for up to four years, but the build-up of gonads in captivity remains uncertain as we have chosen not to sacrifice our stock. Spawning attempts with these animals have failed, most likely due to a lack of a proper conditioning regime. Upcoming experiments will include spawning trials on animals kept in the laboratory from one year to another with year-round feeding. Synchronous spawning is a critical factor for successful hatchery production of juveniles. Thus, providing the environmental conditions that stimulate simultaneous gonad maturation in both sexes is crucial. We have not observed extensive simultaneous spawning in our tanks where groups of sea cucumbers have been kept. Spawning behaviour has been characterised by rather slow-motion events, and the asynchrony in spawning time may be due to variations in gonad status or to the lack of a correct environmental cue in captivity.

To develop aquaculture, it is necessary to develop a method that ensures a reliable production of viable gametes. To obtain sufficient spawning, a large enough group of specimens need to be collected in order to account for individual variation in spawning willingness on the part of both sexes. The equal sex ratio in this species (see above) suggests that even with a modest number of animals, it should be possible to obtain both male and female gametes. Our experience has been that the animals spawn in pulses over a period of about 1–2 h, and empty the gonads partly at each event. After a resting period of some days (less than a week), we successfully could repeat spawning with the same individuals. Previous studies reporting spawning events in *P. tremulus*, either described fecundity in purely qualitative terms as "a considerable number of eggs" (Rustad 1940), or did not report these data (Holland 1981). At different spawning events in 2019 and 2020 we obtained egg batches of between a few hundred to 165,000 per female, with fertilisation rates of between 7–100% after fertilisation *in vitro* using sperm with good motility. From the most productive females, we collected an accumulated total of between 100,000 and 200,000 eggs from two spawning events. These numbers seem low when compared to the reported fecundity of *A. japonicus* and *P. californicus* of up to 1–2 million and more eggs per female, per spawning event (Chen 2003; Whitefield and Hardy 2019). Our egg numbers most probably represent a fraction of the total number of oocytes developed in the gonad. Successful spawning was associated with typical spawning behaviour (Fig. 6a) and a visibly extruded gonopore (Fig. 6d). The maturation level varied between individuals on the same date, which was believed to be the reason for the variation observed in both egg production and fertilisation success (Sunde and Christophersen unpublished). The reproductive potential and effect of gamete quality on fertilisation success and further larval development of Norwegian red sea cucumber aquaculture is still an area that needs more research.

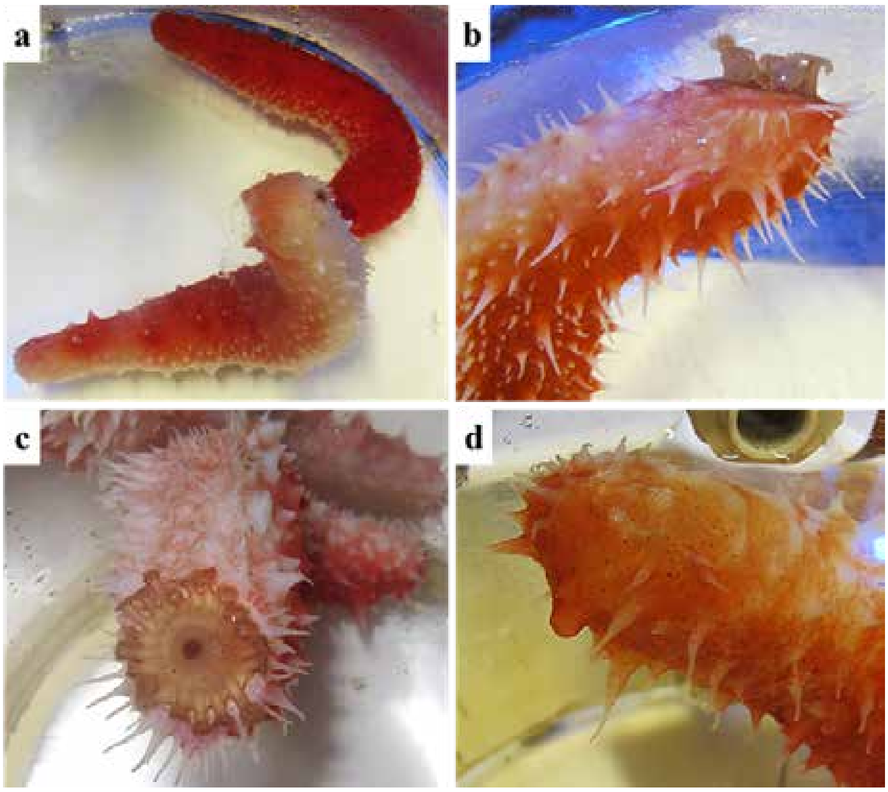

Figure 6. *Parastichopus tremulus* in containers during trials to induce spawning. The sea cucumber with half the body in erect posture is a spawning male (a), protruding mouth parts (b and c) and area (papillae) around the gonopore before spawning (d).
(images: Gyda Christophersen, Møreforsking)

Induced spawning

In 2017, we conducted a study to determine the best method to induce spawning in the laboratory. Sea cucumbers were obtained from the fjord system in the vicinity of Ålesund in western Norway (62°N–6°E). The sea cucumbers were kept in a holding tank at 9.0 ± 0.2° C (mean ± sd) until the induced spawning experiments took place. Three groups of four individuals each were either exposed to temperature shock (Δ +4–6° C in seawater), air exposure (desiccation) or salinity reduction (from 35 to 29‰), common methods for stimulating spawning in other species (Ramofafia et al. 2000; Mercier and Hamel 2002; Rakaj et al. 2018). Exposure time was 45 min. After the treatment, the sea cucumbers were transferred to transparent cylindric containers of two sizes (33.5 cm and 18.5 cm inner diameter) filled with 10 and 5 L from the inlet water, respectively. To minimise disturbance, the water was not exchanged during the observation period. From each treatment group, two individuals were placed in a large container and one in each of two small containers to observe the release of gametes (Fig. 6a-d). The same individuals were stimulated on three occasions; 5, 9 and 12 days after arrival to the laboratory, and spawning activity was observed for up to 6 h. The start time of each spawning event was recorded. The production of eggs or sperm was verified under a dissecting microscope.

Sea cucumbers of both sexes were successfully stimulated to spawn, and the overall spawning success averaged 32±3.8% (mean ± sd) for the three trials (Table 1). Spawning was observed both in the containers holding one and two individuals, and spawning events occurred for sea cucumbers given all the stimulation treatments and at the three trial dates. The percentage of sea cucumbers induced to spawn was 42%, 31% and 25% of the groups exposed to increased temperature, air exposure and decreased salinity, respectively (Table 1). In the group given thermal shock, spawning started after 45 and 245 min (date 1), 13 and 32 min (date 2) and 26 min (date 3). Sea cucumbers that were exposed to air started to spawn after 78, 86 and 92 min, respectively, and the animals exposed to lower salinity after 95, 44 and 96 min. Attempts to further stimulate spawning 4–5 h after the initial treatment were unsuccessful. From these trials we found thermal shock to be the best method to stimulate spawning within the natural spawning period June–July. Success has varied between years and between individuals but, to date, we have not observed mass simultaneous spawning events as described for other species (Olavide et al. 2011; Huertas and Byrne 2019; Marquet et al. 2018) when males and females were kept in proximity in tanks within the spawning season.

Prospects for fisheries and aquaculture

P. tremulus is a novel species considered for utilisation in Norway; a species that despite frequent observations has a secret life on the sea floor. Some advancements have been made through recent Scandinavian initiatives on the biology, fisheries and trade of this species since Hamel and Mercier (2008) reported on the status of temperate sea cucumbers in the Northern Hemisphere (Kjerstad et al. 2015; Atanassova and Kjerstad 2019; Christophersen et al. 2020; Clements et al. 2020). The documented occurrence of the species from 60°N and above has spurred Norwegian stakeholders to explore whether catching the species may be a viable option. The Asian market seems to be huge if the product can be traded legally (Atanassova and Kjerstad 2019).

Sustainable exploitation and aquaculture of sea cucumbers in Norway is discussed by Landes et al. (2019), where it is pointed that care must be taken in the interactions between wild and cultured specimens, and possible negative effects on the environment. The development of harvesting gear with negligible impact on bottom habitats must be pursued if a sea cucumber fishery is to prosper. The use of passive gear and ROVs to harvest wild sea cucumbers are being explored by Norwegian fishers but there is a need to map these resources to determine their abundance on small and large scale. Developing a fishery-based sea cucumber industry also needs a proper legal framework in case the selected fishery will be permitted in the future. The authorities of fisheries and seafood safety depend on new species-specific biological knowledge to be able to execute research-based management. For *P. tremulus*, this biological knowledge is missing, and emphasises the need for future studies on the population structure and life history of the species. The potential ecosystem impacts should also be considered. Sea cucumbers, commercial and non-commercial, have important functions within ecosystems in all oceans (Purcell et al. 2016). There is, therefore, a national responsibility to protect benthic community biodiversity in order to maintain bioturbation, cleaning and mixing of sediment layers.

Northern populations of *P. tremulus* may be vulnerable to being heavily fished as we can assume that cold and temperate water species have a slower growth rate than tropical species, thus affecting recruitment and replenishment of fishable stocks. It is, therefore, uncertain which management measures will be most effective in sustaining populations if a commercial fishery is permitted. At present, all catches in Norway originate from bycatch, and the reporting on metrics is inadequate. The use of novel genomic methods for determining

Table 1. Percentage of *Parastichopus tremulus* individuals that spawned after 45 minutes of exposure to increased temperature (+4–6° C), air exposure and decreased salinity (from 35 to 29 ‰).

Trial #	Individual #	Spawne-doverall %	Spawned heat %	Spawned air %	Spawned salinity %	Female #	Male #
1	12	33	50	25	25	1	3
2	11	36	50	33	25	2	2
3	11	27	25	33	25	1	2

population structure, origin, divergence and ecosystem function will provide useful information for the sustainable management of wild sea cucumber stocks. Knowledge on the effects of temperature on growth rates through the different life stages – egg, larvae, juvenile and adults – and tolerance to higher temperatures (>8° C) will add the necessary knowledge both for estimating yearly increases in biomass in the wild, and for establishing important aquaculture conditions to maximise growth. The experiments carried out in our lab so far have been with water temperatures varying between 6 and 14° C. It is, therefore, unknown whether *P. tremulus* could tolerate higher temperatures under aquaculture conditions, or whether this may lead to increased growth rates or cause adverse reactions due to stress, thereby affecting gonad maturation and other metabolic processes.

Landes et al. (2019) concluded that polyculture and integrated multi-trophic aquaculture, including with sea cucumbers, as well as monoculture, are conceivable prospects for Norwegian seafood production. Research efforts are, however, needed to fill knowledge gaps related to the early life stages of local sea cucumber species. A predictable supply of robust spat (juveniles) is key to developing aquaculture of the species. Hatchery production may be a viable option, but only if growth from one stage to another until commercial size lies within a time frame that is economically viable for the industry. As age determinations related to size are gaps in our knowledge about the Norwegian red sea cucumber, long-term studies in the laboratory are required to establish this knowledge. Several critical stages must be passed from fertilisation through the pelagic larval stages until metamorphosed benthic life. The development from unfertilised oocyte through the blastula stage has previously been described at 7.5° C (Holland 1981), while larval development beyond this stage has been described for two Scandinavian populations in Schagerström et al. (submitted). So far, protocols for the industrial production of *P. tremulus* juveniles are still far from being developed, and it is foreseen that large investments are needed to develop such intensive production. In addition to land-based production, flow-through or recirculating systems, sea ranching or fishery-based aquaculture may be possible cultivation methods once the technology for spat production is established. Because *P. tremulus* is a deposit feeder, it may also be suitable for reducing the particular nutrient discharges from traditional fed aquaculture, while converting it into valuable biomass. For such integrated circular systems to evolve, changes to current regulatory frameworks to facilitate the polyculture of several species for human consumption must be created.

Norway has a long tradition of harvesting and cultivating coldwater seafood species above 60°N, and decades of work has led to a comprehensive national science-based management. The seafood industry in Norway is characterised by a thriving entrepreneurial industry, that has the necessary market knowledge, and already established seafood processing infrastructure and value chains. Given the long fishery and aquaculture tradition in Norway, we believe it is likely that we will have a future industry based on the exploitation of Norwegian *P. tremulus*. The need to fill the knowledge gaps highlighted above is, however, pivotal for this development to be sustainable, and will require substantial research effort. A strategic coordinated progress plan should involve industry, research and regulatory authorities.

Acknowledgement

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Green sea turtle, *Chelonia mydas*, feeding on *Synapta maculata* (Holothuroidea: Synaptidae) on a seagrass bed (*Syringodium isoetifolium*) at Reunion Island, western Indian Ocean

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Abstract

Young green turtles, *Chelonia mydas*, frequent the *Syringodium isoetifolium* seagrass beds on Reunion's inner reef flats of fringing reefs, where they come to feed. Photographs of a green turtle looking for and eating the snake sea cucumber. *Synapta maculata*, were taken for the first time at Reunion Island. *S. maculata* is a sea cucumber species that was frequently observed on the inner reef flats and on the back-reef depression, but these abundances seem to be decreasing in recent years. Studies of *S. maculata* populations are needed to monitor changes in densities of this species, which has an important ecosystem role, as well as other observations to determine whether this case of green sea turtle predation is an isolated one or whether *S. maculata* may occasionally be part of the diet of young *C. mydas* in Reunion.

Introduction

Green sea turtles, *Chelonia mydas*, are regularly observed on the west coast of Reunion Island where they feed mainly on the red algae *Carpopeltis* sp. and *Amansia* sp. at depths of 10 to 30 m (Ciccione 2001). To a lesser extent, young individuals are observed on *Syringodium isoetifolium* seagrass beds in the inner flats where they feed (Ballorain 2010; Cuvillier 2016).

Synapta maculata is a species that is typically observed on certain areas of the back-reef depression or on inner reef flats of Reunion Island's fringing reef, particularly on sandy areas or in seagrass beds (Conand and Mangion 2002; Flammang and Conand 2004; Conand and Frouin 2007; Conand et al. 2010; Conand et al. 2016; Bourjon 2017). *Synapta maculata* feeds in particular on organic matter trapped by the epiphytic community that develop on the leaves of *Syringodium isoetifolium* (Hendriks et al. 2008). Sea cucumbers are essential organisms for the functioning of reef ecosystems and are one of the most important groups in the recycling of organic matter and bioturbation of coral reef sediments (Purcell et al. 2016).

Remains of holothurians (Holothuroidea) have previously been found in the stomach contents of some sea turtle species, such as the loggerhead turtle *Caretta caretta* (Thompson 1980; Casale et al. 2008) and cases of holothurian predation by this turtle species have been photographed on a reef in Belize (Rogers et al. 2020). To our knowledge, there has not yet been any published direct evidence showing *Chelonia mydas* feeding on a holothurian on the reef of Reunion Island.

An observation had already been made in 2010 of a *C. mydas* individual feeding on *S. maculata* on the inner reef flats south of La Saline Les Bains at Reunion Island, without, unfortunately, photographic evidence (Stéphane Ciccione, pers. comm.). Similar observations have been made in Polynesia but are not published and concern other holothurian species (A. Carpentier, Te mana o te moana, pers. comm.).

This article presents pictures of *Chelonia mydas* feeding on *Synapta maculata* in *Syringodium isoetifolium* seagrass beds and in coral heads.

Methodology

The observation was made while snorkelling on 6 January 2019 at 17:15 on a seagrass bed located on an inner reef flat of the fringing reef of La Saline Les Bains at Reunion Island (S21°05'02.5 and E55°14'17.9). This particular *Syringodium isoetifolium* seagrass bed is located at a depth of 1.0 to 1.5 m, and had an average surface area of 1100 m^2 in 2015 (Cuvillier 2016). The observation lasted 10 minutes and the photos presented were taken from several videos.

This observation was made inside the area of the Reunion Island Marine Nature Reserve in a level 2b protection zone.[4]

Results

The green sea turtle was observed eating two specimens of *Synapta maculata* during the time of the observation. The turtle first searched for this prey by swimming over the seagrass

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or coral blocks. It then pulled the holothurian out of the seagrass and coral blocks, and used its beak and fins to cut it up and eat it (Fig. 1). The observation also shows that the turtle does not seem to eat the holothurians in their entirety; some pieces were left over, but this may be due to the proximity of the divers. Furthermore, it is interesting to note that the turtle looked for and specifically chose to eat *S. maculata*, and not another species of holothurian such as *Holothuria leucospilota*, which was observed on the videos but which does not seem to be of interest to the turtle, although it is abundant in this area of the inner reef flat.

Discussion

The observation of a green sea turtle, *C. mydas*, looking for and eating *S. maculata* had never been documented at Reunion Island. Green sea turtles feed mainly on red algae on outer reef slopes (Ballorain 2010). However, young *C. mydas* visit the *Syringodium isoetifolium* seagrass beds where they are protected by the marine nature reserve[5] (Jean et al. 2010b).

The young turtle observed in these photos has been observed (Jean et al. 2010a) on this seagrass bed of the La Saline flat since September 2018, and was also seen (only once) on another seagrass bed of a reef flat 800 m to the north. All of these observations (n =14) were made while the sea turtle was feeding on *S. isoetifolium* beds, except for the one mentioned here, where it was feeding on *Synapta maculata*.

Other research suggests that immature green turtles are not strictly herbivores and adapt to local food resources (Gonzales et al. 2012).

Densities of *S. maculata* in 2014 on this seagrass bed where the observation was made were 0.3 ind. $m^{-2} \pm 0.05$, other Holothuroidea species are frequently observed there such as *Holothuria leucospilota* and *S. chloronotus* (Cuvillier 2016). Several scientists report that densities of *S. maculata* appear to be decreasing in recent years in the seagrass beds and the reef depression (pers. obs.), but there are no robust data to confirm this hypothesis. Recent observations indicate that *S. maculata* can also be found under coral blocks during the day and come out at night to feed. Studies of *S. maculata* populations in the back-reef depression and the inner reef flat of the fringing reef of Reunion Island are needed to monitor changes in densities of this species with an important ecosystem role (Purcell et al. 2016). Further observations and/or the studies of stomach contents of *C. mydas* are necessary to enable us to say whether this observation is an isolated case or whether *S. maculata* may occasionally be part of the diet of young *C. mydas* at Reunion. In this case, it might be interesting to assess the impact on *Synapta maculata* populations.

Figure 1. An individual of *Chelonia mydas* observed eating *Synapta maculata* on *Syringodium isoetifolium* seagrass beds on a coral reef at Reunion Island

[5] See https://torsooi.com/about

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From fundamental to applied research: The history of the Indian Ocean Trepang company

Igor Eeckhaut[1,2,3]

The beginnings

The "pre-history" of the Indian Ocean Trepang company begins with the fundamental research performed by the teams of Prof Jangoux, who directed marine biology laboratories at two Belgian universities – the University of Mons (UMons) and the University of Brussels (ULB). The labs in Brussels and Mons were specialised in echinoderm research, and many aspects of this animal group were (and still are) investigated. Various doctoral dissertations related to sea cucumbers emerged from these laboratories (e.g. Coulon 1994; Jans 1993; Rasolofonirina 2004; Becker 2007; Lavitra 2008; Léonet 2010; Plotieau 2012; Caulier 2016; Claereboudt PhD in progress) and, more recently, at UMons, some PhD theses on aquaculture and village farming (Todinanahary 2016; Tsiresy 2016a) (Table 1).

These two labs also had a well-established tradition of studying tropical marine invertebrates. Indeed, in the early 1970s, Prof Bouillon from the Brussels lab founded the King Léopold III Biological Station on the island of Laing in Papua New Guinea. The Laing station was founded in 1972 and directed by Prof Bouillon up until his retirement in 1993. Prof Jangoux succeeded him, and then in 1997, the station closed. This closure guided Prof Jangoux to develop a field lab elsewhere in the tropics with the aim of conducting both environmental and applied research in marine biology. The idea was to exploit the potential of two well-distributed Indo-Pacific echinoderm species that are of both ecological importance and aquacultural interest: the sea urchin *Tripneustes gratilla* and the sea cucumber *Holothuria scabra*. The other idea was to carry out the research in close collaboration with the Belgian labs where "high tech" analyses could be performed.

The research phases

Thanks to his relationship with Chantal Conand, a longtime friend, the meeting between Prof Jangoux and Prof Mara (at the time, director of the Institute of Marine Science at Toliara, University in Madagascar) was possible. Taking advantage of the good relations and common scientific interests of the two professors, a common research project was proposed to the Belgian Cooperation for Development (CUD, currently ARES-CDD). The project was accepted and started in 2000 for a four-year period (Fig. 1). The aim was to build a hatchery on the site of the Malagasy Institute where reproduction, larval development, metamorphosis and early benthic life would be studied for the selected species. Two doctoral research theses were carried out, one on the sea urchin *Tripneustes gratilla* by Devarajen Vaïtiligon (from Mauritius) and the other on the sea cucumber *Holothuria scabra* by Richard Rasolofonirina (from Madagascar). Dr Vaïtiligon continued his career in Australia, Malaysia, Papua New Guinea, and Mauritius working in sea urchin and sea cucumber aquaculture. Dr Rasolofonirina joined the team of the Malagasy Institute and still works there as a professor and scientist. The hatchery was named "Aqua-Lab". Its main section consisted of a 120 m^2 air-conditioned building containing six rooms for growing seaweed, rearing larvae, caring for genitors, and undertaking microscopic and computer analyses (Fig. 2). The room devoted to larval rearing was divided into two parts dedicated to sea urchins and sea cucumbers. The tanks of the hatchery (300 L) were connected to a saltwater pumping station where the reservoir fills up at high tide and the water is poured into a 30 m^3 settling ponds. Decanted water was filtered and sterilised by repeated applications of UV before being used in the larvae rearing tanks. Regarding *Holothuria scabra*, the hatchery was functional in 2001, and produced at that time a few thousands of 1-mm-long juveniles (<1 g ww).

Building on this success, a second project was proposed to the CUD. This time, the project, which only concerned sea cucumbers, was presented by Prof Jangoux, Dr Eeckhaut and Prof Rabenevanana (Prof Rabenevanana succeeded Prof Mara as director of the Institute) (Fig. 2). The goal was to create a pre-grow-out site made of ponds dug into the earth and a grow-out site made of enclosures at sea. However, the project also had to exceed pure research and it was proposed to study the possibility of creating a private company in which coastal fishing villagers would be involved. The project began in 2005 and ended in 2008. A doctoral grant was funded and awarded

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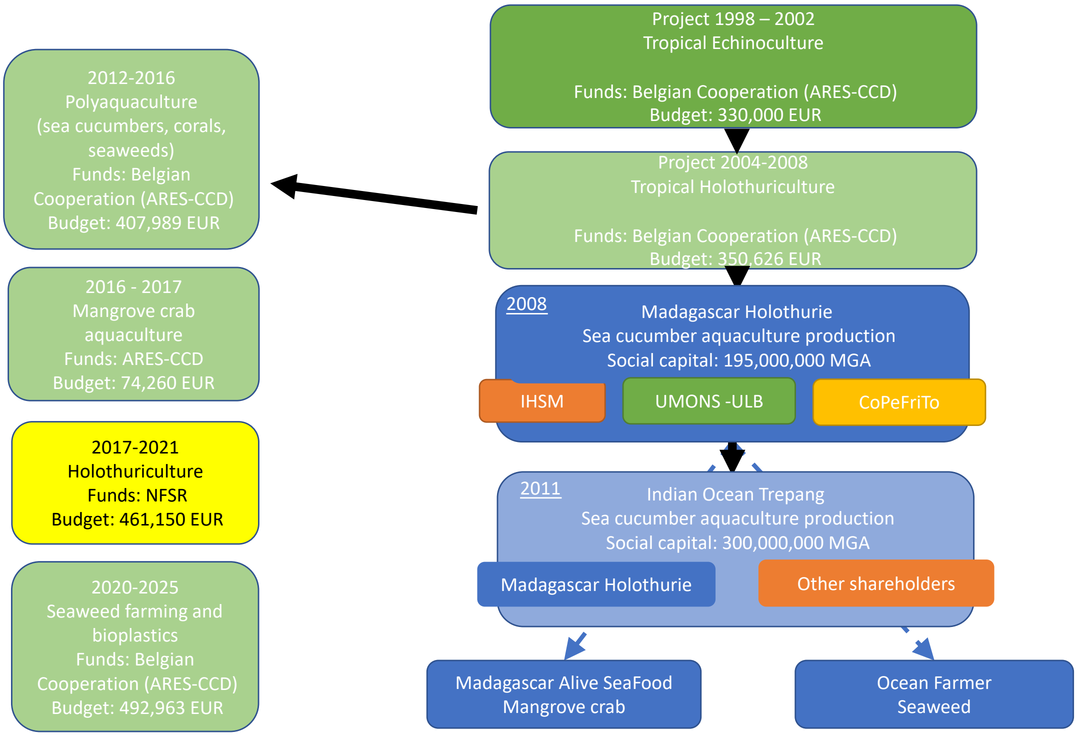

Figure 1. Representation of the different phases of the development of sea cucumber aquaculture in Madagascar and its indirect developments from the research part (top) to the industrial part (bottom). In green are represented the "oriented" research projects supporting village farming, including the development of sea cucumber farming, in yellow are the "fundamental" research projects, in blue are the companies created. Small frames inside large frames are the private and academic shareholders of companies.

to Thierry Lavitra who finished his PhD in 2008; Dr Lavitra then became part of the team at the Institute. (He became director of the Institute from 2013 to 2016, joined the Ministry of Fisheries and Fishery Resources from 2016 to 2018, and is now a professor at Toliara University and a member of the Institute's scientific staff).

This 2005–2008 project made it possible to build pre-growing ponds (nursery) on a larger site – the Belaza site – 25 km from Toliara (Fig. 2). In 2008, at the end of the project, the Belaza site was equipped with a laboratory, dormitories, a house for senior executives, 10 concrete pools of 32 m^2 each, and 600 m^2 of enclosures at sea that were designated to accommodate up to 1200 individuals of marketable size (> 20 cm long;> 300 g ww) (Fig. 2). The main problem in the production of sea cucumber juveniles was the impossibility of inducing *in vitro* the maturation of fully developed oocytes and, therefore, to fertilise them. A year before (2007), an international patent relating to the *in vitro* fertilisation of sea cucumbers was filed (Jangoux et al. 2007). This patent stems from the 2000–2004 research of Dr Rasolofonirina who discovered that ovary-extracted oocytes from *Holothuria scabra* could complete their meiosis and, therefore, be fertilised after having been incubated in an extract of *Tripneustes gratilla* (sea urchin) spawns (Léonet et al. 2009; Eeckhaut et al. 2012). Léonet et al. 2019) demonstrated that the maturation-inducing agent is a protein – thioredoxin – with a strong effect on the redox (reduction–oxidation) potential of oocytes and their environment. This was an important discovery because it made it possible to obtain fertilisable oocytes outside the reproduction period of *H. scabra* and, thus, the production of very large numbers of juveniles intended to develop in the above presented ponds. It also made it possible to have an alternative to the thermal shocks that are traditionally applied to sea cucumbers to obtain embryos. A patent of this type had definite advantages for the development of an industrial project: it had undoubtedly made it possible to create a legal framework without which large investors would certainly not have participated in the creation of the production company Indian Ocean Trepang.

Madagascar Holothurie and Indian Ocean Trepang

With the research carried out and the patent in place, a spin-off company was born (Eeckhaut et al. 2008). It was probably this phase of moving from applied research to building a company that was the most complicated. Only the pugnacity of the researchers and the choice of competent and motivated

[4] MGA 195,000,000 = ~EUR 42,530 or ~USD 51,577 as of 30 January 2021

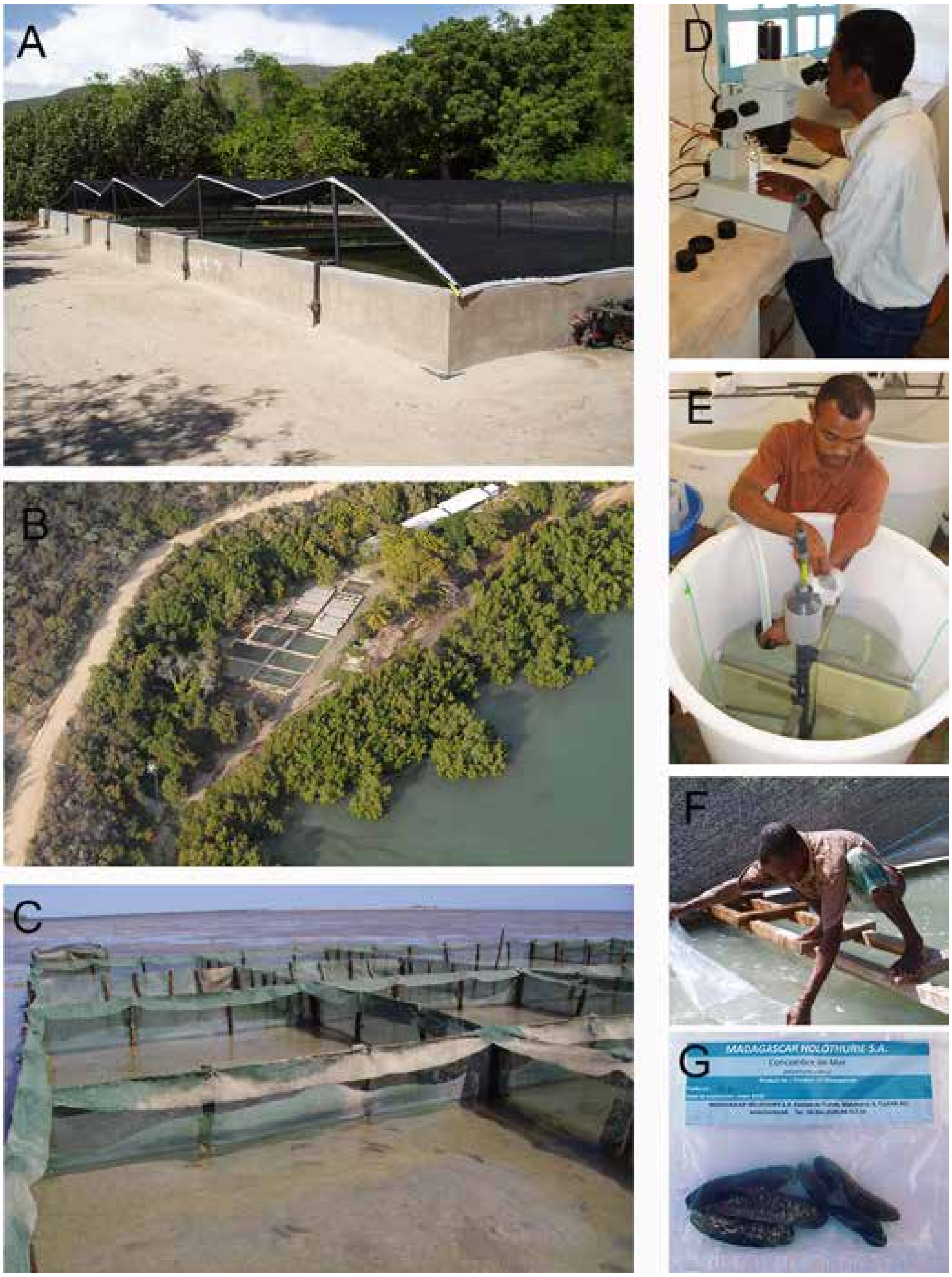

Figure 2. The research phase and the pilot-scale company Magasacar Holothurie. A) Concrete ponds on the site of Belaza used for testing the pre-growing of *Holothuria scabra* during the research phase; B) aerial view of the site of Belaza during the pilot-scale phase (several ponds were added to the concrete ponds to reach 1000 m^2 of surface area in total; C) the first sea pens located in front of Belaza; D) Dr Richard Rasolofonirina during his PhD in the hatchery "Aqua-Lab"; E) the technician Pascal preparing tanks in the Aqua-Lab hatchery; F) the technician John transferring *H. scabra* juveniles in the ponds of Belaza; G) First samples of *H. scabra* delivered to potential buyers in Asia.

private partners enabled this phase to be completed. On 22 April 2008, "Madagascar Holothurie" was created with a capital of MGA 195 million[4] in which the private company Copefrito and three universities (UMons, ULB and the Institut Halieutique et des Sciences Marines) were shareholders (Fig. 1). The exclusivity (first international then in Madagascar) of the use of the patent was purchased by Madagascar Holothurie. One of the company's objectives was to demonstrate the feasibility after three years of obtaining an annual production of around one hundred thousand juveniles with the existing hatchery and to estimate the average annual productivity of the hatchery and nursery phases and grow-out at sea. The capacities of the hatchery and nursery have been increased for this. The Belaza site nursery was then equipped with 1000 m^2 of ponds and the surface area of the at-sea enclosures reached a few hectares in area (Fig. 2). With the support of Madagascar Holothurie, the non-governmental organisation partners TransMad and Blue Venture both obtained ReCoMAP (Regional Program for the Sustainable Management of the Coastal Zones of the Countries of the Indian Ocean) funding from the Indian Ocean Commission to test and develop for three years, the village farming of *H. scabra* in southwestern

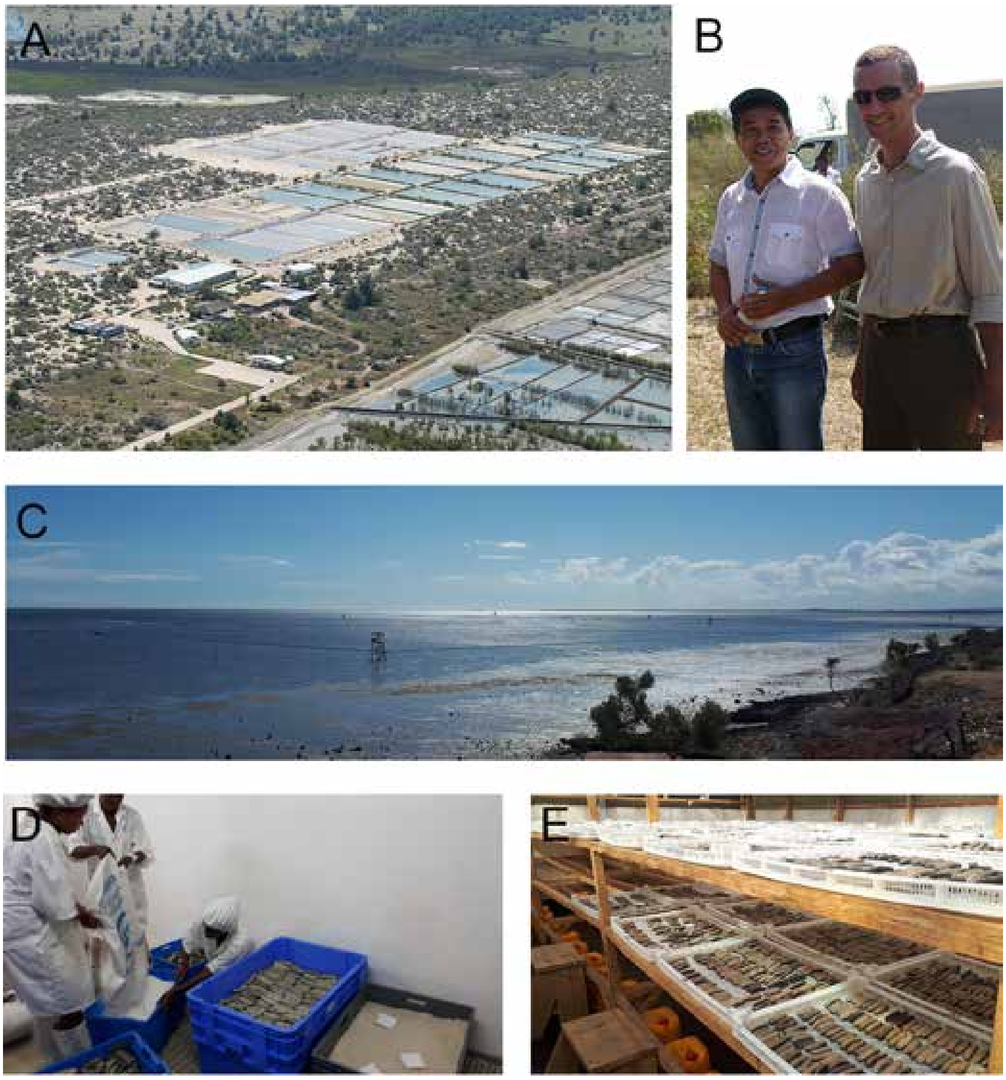

Figure 3. Indian Ocean Trepang, the industrial phase. A) Aerial view of Indian Ocean Trepang (IOT), showing the hatchery building and ponds of 1000 m² each; B) two of the actors of the success story, Olivier Avalle (right) who was the first Director of IOT, and Man Wai Rabenevanana (left) one of the promotors of the research phase; C) the Mangrove site, a 100 ha site of *Holothuria scabra* growing sea pens; D and E) the factory where *H. scabra* are processed into trepang.

Madagascar over an area over 300 km long. Madagascar Holothurie was, and still is, the supplier of *H. scabra* in the grow-out produced by coastal villagers.

With the first trials of Madagascar Holothurie, the Indian Ocean Trepang (IOT) company was created on 8 October 2011 with Madagascar Holothurie, Copefrito and Madagascar Sea Food as the main shareholders (Fig. 1). The acceptance of a PSI project (private sector investment) from the Dutch Ministry of Foreign Affairs, and a French investment fund (Investors and Partners) made it possible to provide the necessary funding for the project, totaling an initial investment of EUR 1.25 million. A production of 33 tons (dw) was expected in the business plan from 2013. A new hatchery of 500 m² was built on a new site, Ankaloha, 10 km south of Tulear (Fig. 3). Adjoining the hatchery, a nursery was created now equipped with around 50 ponds of 100 m² (for juveniles coming out of the hatchery), and 50 other ponds of 1000 m² (for the largest juveniles) (Fig. 3). Much of Ankaloha runs on solar energy. In addition, the bay of Sarodrano acts as a grow-out site. Named the "Mangrove" site, it currently includes 101 ha of enclosures (Fig. 3). A second site, Andamilamy, north of Tulear, was created in 2018 and currently includes 96 ha of growing area. A trepang factory and the offices of the IOT company are located in the free zone in the port of Tulear. IOT currently employs 227 people, including 143 permanent staff who are divided into the following departments: hatchery, nursery, seapens, factory, logistic, security, maintenance and administration and direction. The big jobs in terms of personnel are seapen maintenance (38.7% of personnel) and security (23.3% of personnel). Security includes 40% of the company's full-time people.

The fattening of *Holothuria scabra* in enclosures is, therefore, done partially according to the "company farm" model (company employees paid for the grow-out work) but also according to the "village farming" model (assisted villagers paid for production). Currently, village farming includes 37 ha of enclosures at sea. This area of enclosures represents 226 farms: 145 of 2000 m² each with one household, and 81 of 900 m^2 each with two households. In all, village farming currently affects 307 households, a household roughly corresponding to a family of fishing villagers. Currently, village farming is very beneficial in terms of publicity for IOT but much less beneficial in terms of financial profitability. Without counting export costs, an *H. scabra* costs the company USD 2.02 each, broken down as follows: purchasing adults = USD 1.04; factory and logistics costs = USD 0.26; cost of juvenile production = USD 0.72. These combined costs all greatly decrease profitability.

Problems, solutions and interests for private and public partners

The start of IOT was not easy, with investors wanting a return on their investment within five years. Founded in 2011, the company only managed to export 3.4 tons (dw) of trepang in 2017, reaching 7 tons (dw) in 2020 when, for the first year, it reached an adequate financial break-even point. The problems encountered were various, among them, high salary costs, overestimation of profitability of the three phases (hatchery, nursery and grow-out), and a completely unknown up-scaling effect at the start. One of the mistakes was to transpose the profitability of the three phases at the start to the new, much larger economic model. For example, the profitability of the magnification obtained during the first studies in enclosures where the enclosures were of the order of 100 m^2 were transposed to the enclosures of 10,000 m^2. As a result, the profitability obtained by IOT enclosures at the start was 22% instead of the expected 50%. This poor performance over the years has been analysed and improved on. It is now known that this low performance was due to six main causes: 1) too small of a size of transferred juveniles, 2) predation (mainly by crabs), 3) diseases (mainly skin ulceration diseases), 4) too high of a growing density, 5) temperature stress (mainly cold), and 6) thefts. Thefts constituted the most obvious negative impact of the development of sea cucumber aquaculture in Madagascar and, in particular, the lack of security that near the grow-out sites. Dahalo, or "zebu thieves" from the interior of the country, with the help of some bad intentioned coastal locals, have repeatedly stolen sea cucumbers from the enclosures. It happened that Dahalo bands of more than 50 people looted the enclosures, and community members asked the IOT company to call the Malagasy gendarmerie to solve this problem, which resulted in scuffles involving weapons and arrests.

Alongside the direct benefits obtained by private partners, we can also observe beneficial developments obtained by these partners which, without their departure into the world of sea cucumber aquaculture, would not have existed (Fig. 1). Copefrito was, from the start, the central private partner in the development of sea cucumber aquaculture in Madagascar. This company exports seafood, mainly fish and cephalopods (squid, octopus), which are collected by villagers around Tulear. The entry into sea cucumber aquaculture strengthened the conviction of the private partner in the positive development of village aquacultures. Thus, in 2017, Ocean Farmers became a company outside Copefrito (Fig. 1). This company cultivates the red algae *Kappaphycus alvarezii* and, through village farming, it now produces and exports some 1000 tons of dried algae. It works closely with village communities (algae farmers) where 1700 households (around 3500 villagers) are now involved in growing seaweeds in several dozen villages. In 2015, Madagascar Alive Sea Food – a spin-off company of Copefrito – began cultivating mangrove crabs (*Scylla serrata*) (Fig. 1). This company is still in the development phase.

Contrary to what one might think, the direct financial impact of the patent on universities (ULB, UMons and Institut Halieutique et des Sciences Marines being the legal holders of the patent), laboratories and inventors has been very low. As an example, from the EUR 60,000 provided by a license established initially between the universities and the license applicant to have the exclusivity of the patent, only EUR 10,000 were paid, which is mainly due to the successive revisions concerning this license following the difficulties the company had in breaking even. Of these EUR 10,000, the rule established in Belgian universities stipulated that they take back 40% for the costs of the constitution of the patent (the patent cost the universities more than EUR 50,000, mainly in notarial fees and translation costs). The remaining 60% are divided into three equal sums for the three universities, which remunerate then their laboratories and their researchers according to internal rules. At UMons, the "three-thirds" rule is in force, whereby the budget is divided into three – between university, laboratory and researchers-inventors. Out of these EUR 10,000, the researchers-inventors have each received some EUR 300 to date.

For university laboratories and researchers, the indirect benefits represent the main benefits generated by the history of sea cucumbers in Madagascar (Fig. 1). Thanks to the success of Indian Ocean Trepang, funds for scientific research and for sustainable development have been raised. In 2012, the Belgian Development Cooperation (ARES-CCD) funded a five-year project supporting the development of village polyaquaculture (sea cucumbers, seaweeds, corals). In 2016, ARES-CCD financed a two-year project supporting the development of mangrove crab aquaculture, and in 2019 a five-year project supporting the production of degradable algae-sourced bioplastics. The Belgian National Fund for Scientific Research financed many fundamental researches on reef ecology and, in 2017, a five-year project on the biology of *Holothuria scabra*.

The three pillars of university actions are the development of fundamental, focused and applied researches for the reasoned development of our society, the provision of high-quality education by integrating this research into the courses given to students and researchers, and concrete effects (direct and indirect) of research results in civil society. The history of sea cucumber aquaculture in Madagascar is a fine example of academic research and the establishment of direct application in civil society.

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Table 1. PhD theses and resulting scientific articles relating to aquaculture research on *Holothuria scabra* in Madagascar, and PhD theses on related topics

Doctor of Biological Sciences	PhD theses	Scientific articles related to sea cucumbers (or organisms that could be coupled with sea cucumber farming) resulting from a PhD thesis
Richard Rasolofonirina (2004); ULB Funds: ARES-CCD	Reproduction et développement de Tholothurie comestible *Holothuria scabra* (Jaëger, 1833) (Holothuroidea: Echinodermata).	Rasolofonirina R. and Jangoux M. 2005a; Rasolofonirina R., Vaïtilingon D., Eeckhaut I. and Jangoux M. 2005
Pierre Becker (2007); UMons Funds: FRIA - NSFR	Biologie des symbioses en milieu marin : caractérisation et éthiologie des lésions tégumentaires chez deux espèces d'échinodermes d'intérêt économique.	Becker P., Gillan D.C., Jangoux M., Rasolofonirina R., Lanterbecq D., Rakotovao J. and Eeckhaut I. 2004
Thierry Lavitra (2008a); UMons Funds: ARES-CCD	Caractérisation, contrôle et optimalisation des processus impliqués dans le développement postmétamorphique de *Holothuria scabra* (Jaeger, 1833) (Holothuroidea : Echinodermata)	Lavitra T., Rachelle D., Rasolofonirina R., Jangoux M. and Eeckhaut I. 2008; Lavitra T., Rasolofonirina R., Jangoux M. and Eeckhaut I. 2009a; Lavitra T., Rasolofonirina R., Grosjean P., Jangoux M. and Eeckhaut I. 2009b; Lavitra T., Fohy N., Gestin P.-G., Rasolofonirina R. and Eeckhaut I. 2010a; Lavitra T., Rasolofonirina R. and Eeckhaut I. 2010b
Aline Léonet (2010); UMons Funds: FRIA - NSFR	Caractérisation d'un agent induisant la maturation ovocytaire chez *Holothuria scabra* (Holothuroidea), espèce à haute valeur commerciale.	Léonet A., Rasolofonirina R., Wattiez R., Jangoux M. and Eeckhaut I. 2009; Léonet A., Delroisse J., Schuddinck C., Wattiez R., Jangoux M. and Eeckhaut I. 2019
Thomas Plotieau (2012); UMons Funds: FRIA - NSFR	Caractérisation et rôle de la microflore bactérienne intradigestive chez *Holothuria scabra* (Jaeger, 1833) (Holothuroidea), macrodétritivore majeur des milieux intertidaux récifaux.	Plotieau T., Baele J.M., Vaucher R., Hasler C.A., Koudad D. and Eeckhaut I. 2013a; Plotieau T., Lavitra T., Gillan D. and Eeckhaut I. 2013b; Plotieau T., Lepoint G., Baele J.M., Tsiresy G., Rasolofonirina R., Lavitra T. and Eeckhaut I. 2014a; Plotieau T., Lepoint G., Lavitra T. and Eeckhaut I. 2014b
PhD theses on related topics: Fundamental research on sea cucumbers		
Guillaume Caulier (2016); UMons Funds: FRIA - NSFR	Chemical Communication in Marine Symbioses: Characterization of the kairomones in two crustacean-echinoderm association models.	Caulier G., Flammang P., Gerbaux P., Eeckhaut I. 2013; Caulier G., Lepoint G., Van Nedervelde F. and Eeckhaut I. 2014
Emily Claereboudt (PhD thesis in progress); UMons/ULiège Funds: FRIA - NSFR	Saponins and their role as pheromones in the communication of holothuroids	Claereboudt E., Eeckhaut I., Lins L. and Deleu M. 2018; Claereboudt E., Caulier G., Decroo C., Colson E., Gerbaux P., Claereboudt M., Schaller H., Flammang P., Deleu M. and Eeckhaut I. 2019
PhD theses on related topics: Applied research on aquacultures and farming coupled with sea cucumber aquaculture		
Gildas Todinanahary (2016); UMons Funds: ARES-CCD	Evaluation du potentiel biologique, économique et social de la coralliculture dans le sud-ouest de Madagascar.	Todinanahary G., Lavitra T., Puccini N., Grosjean P. and Eeckhaut I. 2017.
Gaëtan Tsiresy (2016a); UMons/Uliège Funds: ARES-CCD	Analyses l'incorporation de l'azote et du carbone, phénologie et phylogénie) des algues épiphytes responsables de l'EFAD ("Epiphytic Filamentous Algal Disease") dans les champs de *Kappaphycus alvarezii* Doty à Madagascar.	Tsiresy G., Preux J., Lavitra T., Dubois P., Lepoint G. and Eeckhaut I. 2016b.

Sea cucumbers – mysterious offerings to Mexica gods

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Abstract

Tenochtitlan offerings (AD 1325–1521) were buried by the Mexica priests inside religious buildings and under the plaza floors in order to consecrate the enlargements of their temples, to commemorate special festivities, or to appease their gods. Each one of these offerings contained all kinds of gifts, including raw minerals, plants, animals, human remains and artifacts. In the last 10 years, and thanks to the careful recovery and analysis of all kinds of materials found at the bottom of the offerings, we have identified vestiges of 20 species of echinoderms: 6 species of starfish, 1 species of brittle star, 8 species of sea urchins and 5 species of sea cucumbers (*Neothyone gibbosa*, *N. gibber*, *Pachythyone lugubris*, *Neopentamera anexigua* and *Isostichopus fuscus*). The latter species were identified from dermal ossicles found at the lowest level of ritual deposit of consecration (offering 126), found 2 m below the monolith of the Earth goddess Tlaltecuhtli. Spatial analysis of the offering made it clear that the Mexica priests distributed the gifts in a patterned way to create a cosmogram; that is, a miniature model of a large section of the universe according to the prevailing religious conceptions.

Key words. Zooarchaeology, Tenochtitlan, Mexico City, ossicles, faunal remains, religious ceremonies

Like many Mesoamerican cultures, the Mexicas used to bury rich offerings in their main places of religious worship. In general, they did so on the occasion of significant events for the State, such as the construction and remodelling of religious buildings, the opening of sculptural monuments, the end of time cycles, the rites of passage of the sovereigns, war victories and natural catastrophes. Animal remains are a common feature of archaeological discoveries from around the world and are present in different cultures and periods of time. Archaeozoology is defined as the study of faunal remains left behind when an animal dies on an archaeological site, and includes bones, shells, hair, scales, proteins, and sometimes DNA (Kalof 2012).

Tenochtitlan offerings (AD 1325–1521) were buried by the Mexica priests inside religious buildings and under plaza floors. Each of these offerings contained all kinds of gifts, including raw minerals, plants, animals, human remains and artifacts (López Luján 2005). In terms of animals, archaeologists and biologists have identified the remains of more than 500 species associated with Tenochtitlan's Templo Mayor, corresponding to six different phyla: Porifera, Cnidaria, Echinodermata, Arthropoda, Mollusca and Chordata, the latter with six classes (Chondrichthyes, Osteichthyes, Amphibia, Reptilia, Aves and Mammalia). There is a clear predominance of species endemic to regions quite far away from the Basin of Mexico, where Tenochtitlan is located. These were imported by the Mexicas from practically all corners of the empire and beyond, and from contrasting ecosystems such as tropical forests, temperate zones, marine environments, estuaries, coastal lagoons and mangrove swamps. The scarcity of edible species reveals the clear interest on the part of priests in those animals that were attributed with profound religious or cosmological significance (López Luján et al. 2014). In the last 10 years, and thanks to the careful recovery and analysis of all kinds of materials found at the bottom of the offerings, we have identified vestiges of 20 species of echinoderms (Table 1).

In 2010, a group of researchers from the Institute of Marine Sciences and Limnology (ICML) at the Universidad Nacional Autónoma de México (UNAM), and the Templo Mayor Project (PTM), Instituto Nacional de Antropología e Historia, began a fruitful collaboration to study marine organisms, and specifically echinoderms, that had been recovered during archaeological excavations carried out at the base of the main pyramid of Tenochtitlan. These materials, of incalculable scientific value, come from the ritual deposits buried by the Mexicas in the 15th and 16th centuries inside religious

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Table 1. Species of echinoderms found in the offerings of the Templo Mayor, Tenochtitlan (modern Mexico City).

Class Asteroidea
Astropecten regalis Gray, 1840
Astropecten duplicatus Gray, 1840
Luidia superba A.H. Clark, 1917
Phataria unifascialis (Gray, 1840)
Nidorellia armata (Gray, 1840)
Pentaceraster cumingi (Gray, 1840)
Class Ophiuroidea
Ophiothrix rudis Lyman, 1874
Class Holothuroidea
Neopentamera anexigua Deichmann, 1941
Neothyone gibbosa Deichmann, 1941
Neothyone gibber (Selenka, 1867)
Pachythyone lugubris (Deichmann, 1939)
Isostichopus fuscus Ludwig, 1874
Class Echinoidea
Eucidaris thouarsii (L. Agassiz & Desor, 1846)
Toxopneustes roseus (A. Agassiz, 1863)
Echinometra vanbrunti A. Agassiz, 1863
Clypeaster speciosus Verrill, 1870
Encope laevis H.L. Clark, 1948
Mellita notabilis H.L. Clark, 1947
M. quinquiesperforata (Leske, 1778)
Meoma ventricosa grandis Gray, 1851

buildings and under the plaza floors of their sacred precinct. It is still possible to detect them because they were protected inside ashlar boxes covered with slabs, or in cavities dug in the construction fill and then sealed with slabs or stucco floors.

In the first phase, our team – comprising biologists, restorers and archaeologists – focused our efforts on the analysis of the remains of starfish (class Asteroidea) and brittle stars (class Ophiuroidea), which are observed in the excavation as concentrations of disarticulated calcareous plates. After a long learning process and multiple comparative examinations, we were able to identify six species of starfish, of which five came from the northeastern Pacific (*Luidia superba*, *Astropecten regalis*, *Phataria unifascialis*, *Nidorellia armata*, *Pentaceraster cumingi*) and one from the Atlantic (*A. duplicatus*), together with a brittle star from the Pacific (*Ophiothrix rudis*) (Martín-Cao-Romero et al. 2017; López Luján et al. 2018; Zúñiga-Arellano et al. 2019). The surprising results of this work were soon made known through conferences for the general public, presentations at specialist meetings, museographic and photographic exhibitions, as well as in a series of popular and scientific publications. For the second phase, we focused on the remains of echinoderms, mainly on those belonging to the class Echinoidea. In this case, we were able to identify eight species (*Echinometra vanbrunti*, *Eucidaris thouarsii, Toxopneustes roseus*, *Clypeaster speciosus*, *Encope laevis*, *Mellita notabilis, M. quinquiesperforata* and *Meoma ventricosa grandis*). All but one (*M. quinquiesperforata*) have a northeastern Pacific distribution (Zúñiga-Arellano et al. 2019). The third and most recent phase of research is still in process but has already yielded important results. This phase is focused on sea cucumbers (class Holothuroidea). So far, we have identified five species that we will report for the first time in this work.

Methodology

Sea cucumber ossicles were found at the lowest level of offering 126, an ashlar box found 2 m below the monolith of the Earth goddess Tlaltecuhtli (AD 1486–1502) (Figs. 1–3). After being described in their original contexts, all of these microscopic holothurian remains were collected using Eppendorf tubes, labelled, and recorded in a database. Later, they were carefully isolated, cleaned and dried in the laboratory, then placed in a scanning electron microscope (SEM) sample holder, sputter coated with gold 2.5 kV in the ionizer Polaron E3000 for 3 min, and photographed using a Hitachi S–2460N SEM. The examined material is deposited in the Museo del Templo Mayor in Mexico City. They were then separated according to their differential morphology. We distinguished various shapes (buttons, tables, and rods) of the ossicles, which enabled us to begin the genus and species identifications using taxonomic keys such as those of Deichmann (1941, 1958). We compared our archaeological remains to those found in modern specimens collected in Mexican waters and stored in the National Echinoderm Collection (NEC) ICML, UNAM.

Results

Systematics

Five species of sea cucumber were found in offering 126 at the Templo Mayor of Tenochtitlan (modern Mexico City):

Phylum Echinodermata Bruguière, 1791

Class Holothuroidea

Order Dendrochirotida Grube, 1840

Family Sclerodactylidae Panning, 1949

Genus *Neothyone* Deichmann, 1941

Neothyone gibbosa Deichmann, 1941

Neothyone gibber (Selenka, 1867)

Genus *Pachythyone* Deichmann, 1941

Pachythyone lugubris (Deichmann, 1939)

Genus *Neopentamera* Deichmann, 1941

Neopentamera anexigua Deichmann, 1941

Order Aspidochirotida Grube, 1840

Family Stichopodidae Haeckel, 1896

Genus *Isostichopus* Deichmann, 1958

Isostichopus fuscus Ludwig, 1874

Neothyone gibbosa Deichmann, 1941

Figure 1. Earth goddess monolith on offering 126, located at the old Mayorazgo de Nava Chavez urban ground, Mexico City. (Scan 3D by Saburo Sugiyama, courtesy of the Templo Mayor Project)

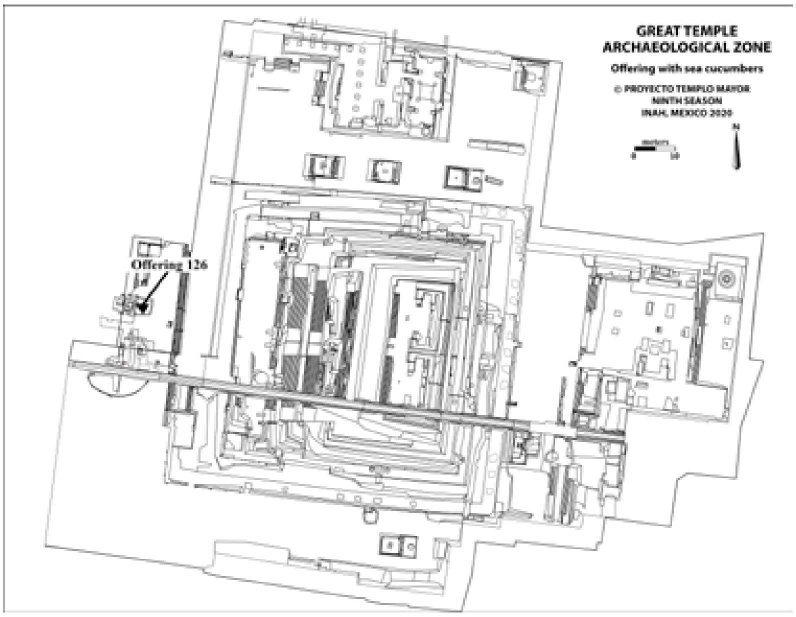

Figure 2. Map of offering 126 at the archaeological zone in the Templo Mayor.

Figure 3 Offering 126 was the ritual deposit for the consecration of the monolith of Tlaltecuhtli. (Courtesy of Templo Mayor Project)

Fig. 4A, 1–4.

Description. When adult, body size varies from 2 to 5 cm. U-shaped body, with the posterior end smaller than the anterior. Thin and rough skin due to the presence of a large number of spicules, tube-like feet covering the entire body. Dark grey to reddish, with darker tentacles.

Description of the archaeological elements. Eroded knobbed buttons from the body wall (Fig. 4A, 1, 2, 4), supporting table from a tube foot (Fig. 4A, 3).

Geographic and bathymetric distribution. From Baja California Sur, Sonora, Sinaloa, Guerrero, Mexico (Fig. 5); El Salvador; Costa Rica; Ecuador to Peru. From 0 to 50 m depth.

Habitat. This species is usually found in cavities or crevices within hard substrates such as large rocks, associated with pieces of dead coral and under large stones that move very little. This species practically never moves and lives aggregated in small populations.

Neothyone gibber (Selenka, 1867)

Fig. 4B, 1-5.

Description. When adult, body size varies from 4.5 to 8.0 cm. U-shaped body, with rounded ends, thick and rough skin due to the large number of spicules present, tube feet more abundant in the terminal areas of the body. Yellowish to white skin, with brown stripes along the body. Front end and tentacles are brown or slightly purple.

Description of the archaeological elements. Eroded supporting tables from tube feet (Fig. 4B, 1, 2, 4), body wall knobbed buttons (Fig. 4B, 3, 5).

Geographic and bathymetric distribution. From Baja California Sur through Guerrero and Oaxaca, Mexico (Fig. 5), to Isla de Lobos de Afuera, Peru. From 0 to 50 m depth.

Habitat. Usually found in hollows of hard substrates such as rocks, associated with pieces of dead corals and in some areas with little a sand. They hide under stones of different sizes.

Pachythyone lugubris (Deichmann, 1939)

Fig. 4C, 1–2.

Description. Adults reach a total length of from 2 to 5 cm. U-shaped body, thin skin, with numerous tube feet covering the entire body, those on the ventral surface larger than those on the dorsal area. With yellow to brown colourations.

Description of the archaeological elements. Eroded supporting table from a tube foot (Fig. 4C, 1) and knobbed button from the body wall (Fig. 4C, 2).

Geographic and bathymetric distribution. From Bahia Magdalena and "Isla Cerros", Baja California, through Baja California Sur, to Oaxaca, Mexico (Fig. 5). From 18 to 73 m depth.

Habitat. The species inhabits crevices within hard substrates such as large rocks and under large stones. The species is practically sessile. As they grow, they tend to erode the substrate to increase the size of the void.

Neopentamera anexigua Deichmann, 1941

Fig. 4D, 1–2.

Description. Body size from 0.5 to 2.0 cm. Body slightly curved, anterior region with the tentacles smaller than the posterior region, thin and flexible skin, abundant tube feet on the ventral surface. Dark skin and white tube feet. The tentacle area is orange or light brown. **Description of the archaeological elements**. Eroded knobbed button from the body wall (Fig. 4D, 1) and smooth supporting table from a tube foot (Fig. 4D, 2).

Geographic and bathymetric distribution. From Baja California, through Baja California Sur, Jalisco to Guerrero, Mexico (Fig. 5). From 8 to 12 m depth.

Habitat. This species is usually found in hollows of hard substrates such as rocks, associated with pieces of dead corals and in some areas with a little sand. They hide under stones of different sizes.

Isostichopus fuscus Ludwig, 1874

Fig. 4E, 1–3.

Description. Adults reach a size of 20 to 28 cm total length. Flat shape ventral side with convex dorsal surface, very robust body with thick edges, mouth directed to the substrate, soft and hard skin, feet on the dorsal surface with the appearance of thick warts, feet on the ventral surface soft and thin. Colour from dark to light brown and greenish in some specimens. Dorsal podia may have lighter shades.

Description of the archaeological elements. Eroded ossicles of the body with C-shaped body (Fig. 4E, 1), table (Fig. 4E, 2) and perforated plate from the body wall (Fig. 4E, 3).

Geographic and bathymetric distribution. From Baja California Sur to Oaxaca, Mexico, through the Revillagigedo Archipelago (Fig. 5), and Central America to the Galapagos Islands, Ecuador. From 0 to 37 m depth.

Habitat. This species is usually found on hard substrates such as large rocks covered by algae and other organisms associated with coral reef systems. In some cases, it hides under stones during the day.

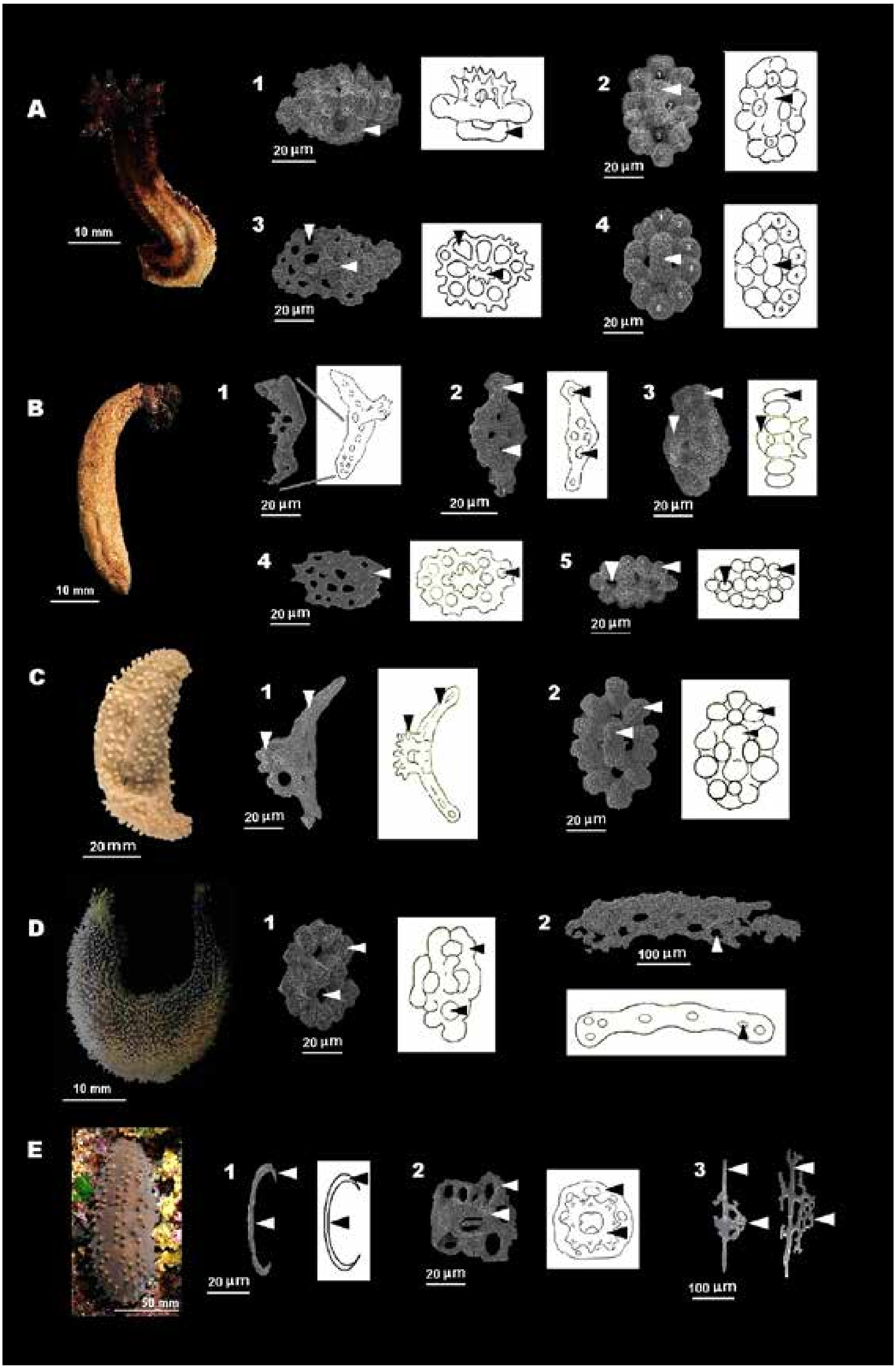

Figure 4. A) *Neothyone gibbosa* Deichmann, 1941. 1. Lateral view of a knobbed button showing the inner handle. 2. Knobbed button. 3. Table. 4. Knobbed button. B) *Neothyone gibber* (Selenka, 1867). 1. Fragment of a supporting table from a tube foot. 2. Supporting table from a tube foot. 3. Knobbed button. 4. Table. 5. Knobbed button. C) *Pachythyone lugubris* (Deichmann, 1939). 1. Lateral view of a supporting table from a tube foot. 2. Knobbed button from body wall. D) *Neopentamera anexigua* Deichmann, 1941. 1. Knobbed button from the body wall. 2. Smooth supporting plate from a tube foot. E) *Isostichopus fuscus* Ludwig, 1874. 1. "C" shaped body. 2. Table. 3. Perforated plate from the body wall. Archaeological elements are represented by SEM photographs, linear drawings were taken from Deichmann (1941, 1958) for comparison.

Discussion

Spatial analysis of the offering made it clear that the Mexica priests distributed the gifts in a patterned way to create a cosmogram, that is, a miniature model of a large section of the universe according to prevailing religious concepts. In the bottom of the box, they first deposited thousands of disarticulated bones and defleshed anatomical segments belonging to mammals, birds and reptiles, according to the detailed study of the bioarchaeologist Ximena Chávez. They then completely covered that first level, which could be described as "skeletal", with a second level of "aquatic" symbolism, made up of very numerous and varied marine animals. They immediately formed a third level with flint knives strung on copal bases. According to the archaeologist Alejandra Aguirre, these represent – through masks, attire and ornaments – a contingent of dead warriors, one a god of rain and another of wind. Finally, in the fourth and uppermost of the levels, the priests represented the Earth's surface with a sawfish rostrum (symbol of the primeval telluric monster) and with seven basalt images of the god of fire, marking with them the three stones of the hearth in the navel of the world and the four cardinal directions. At the same level they arranged gifts of copal, as well as a bowl and a ceramic pot painted blue, the latter full of seeds.

One of the things that amazes us the most about offering 126 is its unusual biodiversity. At the bottom of the box, according to the identification by Ximena Chávez and the mastozoologist Montserrat Morales, there were bones belonging to seven taxa of mammals (28 wolves, 19 lynxes, 15 pumas, 3 jaguars, 1 ocelot, 1 Florida rabbit, 1 deer mouse), birds (5 golden eagles, 4 American owls, 2 red falcons, 1 red-tailed hawk, 1 chicken hawk, 2 quails) and one reptile (1 rattlesnake). At the intermediate levels, all sorts of marine organisms were concentrated. According to the ichthyologist Ana Fabiola Guzman, six Osteichthyes taxa were present there (two needlefish, two globe fish, two shoemaker fish, one cabrilla, one remora, one hunchback). Chondrichthiologists Oscar Uriel Mendoza and Nataly Bolaño concluded that there was only one taxon of cartilaginous fish (two sawfish). Regarding molluscs, the malacologist Belem Zúñiga reported 65 clam taxa (624 individuals), 60 snail taxa (833 individuals) and one polyplacophoran (96 individuals). For his part, marine biologist Pedro Medina recognised four taxa of cnidarians (four gorgonians, three brain corals, one deer horn coral, one elkhorn coral). Finally, with regard to echinoderms, we counted six taxa of starfish (13 individuals), one of regular sea urchin (seven individuals), two of non-regular sea urchins (four individuals), one of brittle star (one individual) and five of sea cucumbers (five individuals). We also detected remains of at least one Porifera taxon (one marine sponge).

The total numbers of the fauna recovered in offering 126 are overwhelming: a minimum of 1688 individuals belonging to no less than 167 taxa, 90.4% of which are of marine origin. Offering 126 possess a truly exhaustive list or complete inventory of the organisms that inhabit that "aquatic world" of absolute fertility that, in the Mexica worldview, is located just below and around the crust of the primeval telluric monster.

Incredible as it may seem, the discovery was made by analysing a sediment sample as small as 1 g under the stereomicroscope and the scanning electron microscope. There, dozens of spicules from the body walls of sea cucumbers appeared. These fragile calcium carbonate structures managed to survive to this day, although highly degraded, thanks to a combination of various environmental factors. During the excavation of offering 126, a flooded context was recorded, where the groundwater had not undergone seasonal level fluctuations that would have triggered leaching processes. The pH of the water was practically neutral (6.8–7.0) and temperature stable (17–19º C), to which we must add that there was a minimum amount of dissolved oxygen, and total darkness.

At present, specimens of these five species of sea cucumber are easy to collect near the beach, free diving no deeper than 20 m deep on the Mexican Pacific (Fig. 5). At the end of the 15th century, it is possible that sea cucumbers were moved to the imperial capital, particularly with ceremonial interest, such is the case of the large brown sea cucumber *Isostichopus fuscus*, which may have been transported live. This implies a minimum distance of 290 km from the coasts of the current Mexican state of Guerrero, which could have been covered by a carrier in 10 to 12 days, according to estimates by archaeologist Kenneth Hirth. The sea cucumbers could have been kept for a long time in the saltwater ponds that existed in the Moctezuma vivarium in Tenochtitlan, awaiting the arrival of the festivity in which they would be buried as an offering in the sacred enclosure. On the other hand, unlike the brown sea cucumber that lives on rocks on the shallow coast, the rest of the species were found buried alive between sand, corals or rocks. There is the possibility that these species were extracted indirectly as an accompanying fauna as they were associated with *Spondylus* shells or large coral heads, organisms that were also found in offering 126.

We obviously expect more discoveries in the near future. For now, it remains for us a lesson of this research phase that, during the process of archaeological exploration of the offerings, we must always recover all the sediments and store them as true treasures for our awaiting analysis.

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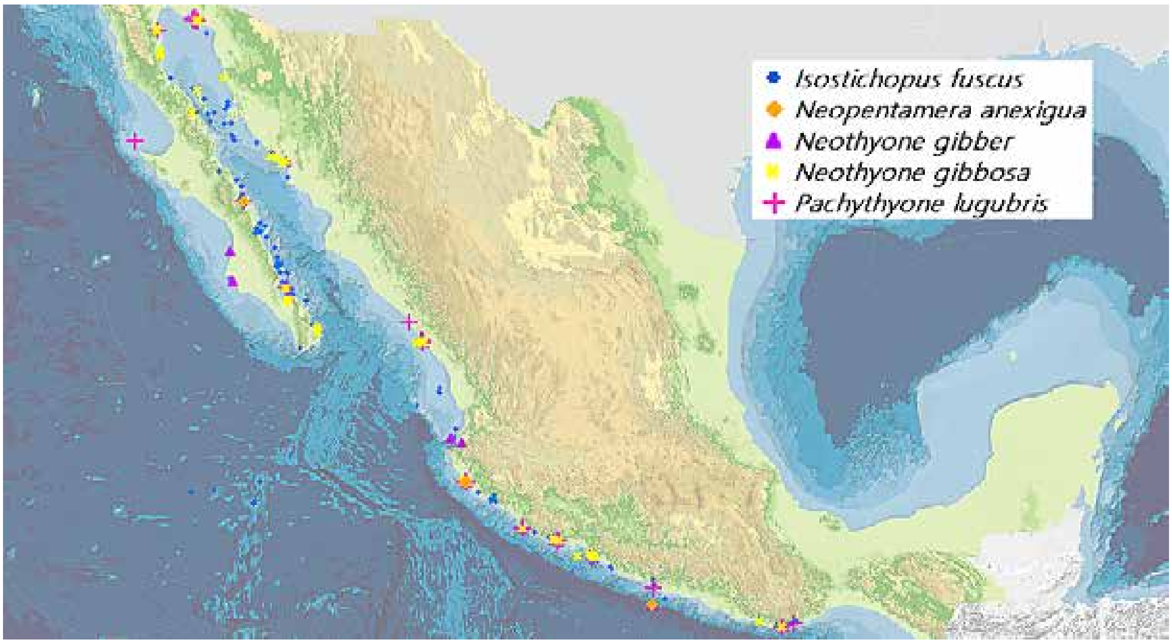

Figure 5. Distribution map of the sea cucumber species exhumed at offering 126 of the Templo Mayor. *Isostichopus fuscus*: blue rhombuses; *Neopentamera anexigua*: orange rhombuses; *Neothyone gibber*: purple triangles; *Neothyone gibbosa*: yellow circles; *Pachythyone lugubris*: purple crosses.

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Sea cucumber crime in India and Sri Lanka during the period 2015–2020

Teale Phelps Bondaroff[1]

Abstract

Sea cucumber poaching and smuggling has been on the rise in Sri Lanka and the south of India. This study analyses incidents of sea cucumber crime in India and Sri Lanka between 2015 and 2020, compiled from news media reports and government press releases. The 120 incidents analysed reveal 502 arrests, with an average of 4 arrests per incident and 544 kg of sea cucumbers seized. Over 64.7 tons of sea cucumbers – representing 104,531 individual animals – were seized by Sri Lankan and Indian authorities, worth an estimated USD 2.84 million. Sea cucumber poaching and smuggling operations are highly organised and incidences sharply increase in 2019 and 2020. Sea cucumber crime appears to be spreading from a core area in the Gulf of Mannar from Palk Bay to Lakshadweep. This paper concludes that sea cucumber crime should be treated as a form of transnational organised crime, that monitoring and enforcement efforts be expanded, and that intergovernmental and interagency cooperation be increased.

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

Introduction

Poaching and smuggling occurs within sea cucumber fisheries globally (Conand 2018), with the waters of southern India and Sri Lanka having emerged as a global hot spot for sea cucumber poaching and smuggling. For a number of years, authorities have been fighting a protracted battle to combat this form of wildlife crime, and the number of arrests and seizures appears to be on the rise. For the past several years, the majority of identified sea cucumber-related crimes have taken place in the waters and coastal areas of the Gulf of Mannar and Palk Bay – the waters between Sri Lanka and India. In 2020, however, a number of cases were reported in Lakshadweep, a group of islands 200 km off the southwest coast of India.

For the past two years, the OceansAsia research team has been monitoring these crimes. Using news media reports and government press releases, a database documenting 120 incidents of sea cucumber crime in India and Sri Lanka between 2015 and 2020 has been compiled. By analysing these data, this study seeks to better understand the nature, scale and increase of sea cucumber crime in the region.

The history of sea cucumber fishing in southern India and Sri Lanka is long, dating back a thousand years, when Arab and Chinese merchants set up supply chains (Hornell 1917 in Asha et al. 2017; Terney Pradeep Kumara et al. 2005). There is almost no domestic demand for sea cucumbers in India or Sri Lanka, which are principally exported to Hong Kong, Singapore and Chinese markets (Asha et al. 2017).

The Gulf of Mannar and Palk Bay is the principal region for sea cucumber fisheries. This region is bordered by both India and Sri Lanka, and as such, it is worth considering the region as a whole. Differences in sea cucumber harvesting and export regulations in India and Sri Lanka, coupled with the short distance between these two countries, has resulted in extensive smuggling, with organised criminal operations able to launder illicit sea cucumbers caught in India by smuggling them into Sri Lanka. Understanding this legal context is important to understanding the rise of sea cucumber crime in the region.

Of the more than 1700 species of sea cucumbers described globally, some 200 can be found in Indian waters, and of these, roughly 20 are considered commercially important (Kashyap et al. 2020; James 2001). The majority of these are found in the Andaman and Nicobar islands, followed by the Lakshadweep Islands, Gulf of Mannar, Palk Bay and Gulf of Kutch (James 2001; Asha et al. 2017). Of these regions, the Gulf of Mannar and Palk Bay, home to roughly 39 species of sea cucumber, is the principal centre of historic sea cucumber production in India. Although it is a multi-species fishery, harvesting focuses chiefly on *Holothuria scabra*, *H. spinifera*, and *H. nobilis*, when it can be found (Sastry 1998). In the illicit sea cucumber fishery that has emerged in Lakshadweep in recent years, *Holothuria fuscogilva*, *H. nobilis*, and *Thelenota ananas* the are high-value species that are exploited (Asha et al. 2017).

High demand and excessive harvesting resulted in serious population declines; as a result, in 1982, the Indian Ministry of Environment, Forests and Climate Change implemented

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size regulations on exported beche-de-mer. This regulation proved ineffective and populations continued to decline. In 2001, a blanket ban was implemented, and all species of holothurians were listed under Schedule I of the Indian Wildlife (Protection) Act of 1972. This had the effect of prohibiting all sea cucumber fishing and exports in India (Asha et al. 2017). In the face of the ban, illegal sea cucumber fishing has expanded, along with the growth of clandestine organised criminal networks that help smuggle sea cucumber products out of the country.

Roughly 24 species of sea cucumbers can be found in Sri Lankan waters, of which 20 have commercial value (Dissanayake and Stefansson 2012). A multi-species fishery operates year round, and is focused on the northern arc of the country (north, northwest and northeast regions), after unsustainable extraction caused the collapse of sea cucumber populations in the south (Terney Pradeep Kumara et al. 2005; Prasada 2020). The sustainability of the current fishery is in question: Dissanayake and Stefansson (2012) found that "the total abundance of all the species declined between 2008 and 2009," with 11 species being exploited and a higher presence of immature and smaller animals in catches (Dissanayake and Stefansson 2012). A recent study by Nishanthan et al. (2019) recorded only nine species in commercial catches.

In contrast to India's complete ban, Sri Lanka permits fishing for sea cucumbers, but requires licenses for fishing, diving and transportation. As populations decline, the government has reduced the number of sea cucumber harvesting licenses it issues, reducing the number by 25% in 2016 (Daily News 2016).

Because it is still legal to export sea cucumbers from Sri Lanka, and due this country's proximity to India, significant numbers of sea cucumbers that are caught illegally in India are smuggled into Sri Lanka where they are laundered and then re-exported to Southeast Asian markets through licit supply chains. Sri Lankan fishers will also venture into Indian waters to poach sea cucumbers (Daiji World 2015), and Indian fishers will fish illegally in Sri Lankan waters (New Indian Express 2018; News First 2020).

Methodology

In order to better understand the nature, scale and increase of sea cucumber crime in the region, we have built a database of illegal incidents involving sea cucumbers from 1 January 2015 to 31 December 2020 in India and Sri Lanka. A detailed study of English-language news media stories, and the Sri Lankan Navy's archive of press releases and reports was conducted (Sri Lanka Navy n.d.). When an incident was identified, where possible, triangulation was used to confirm the details of the case. Google Alerts were set up for key terms – "sea cucumber", "sea cucumber + smuggling", and "sea cucumber + illegal", and monitored daily from March 2018.

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. For example, on 22 October 2019, 10 people were arrested at Nallur beach in Trincomalee, and three dinghies, three outboard motors, 300 kg of sea cucumber, and other illegally caught fish were seized. The same day, a suspicious three-wheeler was stopped at a roadblock in Vankalai, and a search revealed 40 kg of sea cucumbers. Because the driver did not have a permit for the sea cucumbers, he was arrested, and the three-wheeler and sea cucumbers were seized. These two incidents were reported together by the Sri Lanka Navy but separated into two entries in the database (Sri Lanka Navy 2019).

We identified 120 incidents over the time period under examination (50 in India, 70 in Sri Lanka), but were required to exclude portions of one of these entries from our analysis due to a lack of specificity. The report in question, from 26 August 2020, detailed the results of a week-long Sri Lanka Navy operation across the country that culminated in the arrests of 48 people for illegal fishing and "other unlawful activities", including harvesting sea cucumbers without a license. Because we were unable to determine how many individual arrests were linked to sea cucumber crime, we have included the total number of sea cucumbers seized through this operation (370 kg) in our analysis, but excluded it from some of the analysis (Sri Lanka Navy 2020b).

For each entry, we recorded the date, location, weight and/or number of sea cucumbers seized, the state of the sea cucumber (live, wet, dry), the value of the seizure (estimated by the authorities), any other seizures (boats, fishing gear, vehicles, diving equipment), the number of suspects arrested, and any details regarding the suspects (age, place of origin, name) and the authorities who made the arrest (agency and names), when this information was available.

Not all of this information was available for each entry. We found that either the weight or number of sea cucumbers seized was reported, but seldom both, and that there was often evidence of rounding numbers. The state of the sea cucumbers seized varied from case to case, and it was often unclear whether the sea cucumbers seized were live, wet, semi-processed, or processed (dry), a factor that influences estimates regarding the weight and commercial value of the seizure. This could not necessarily be inferred from the context in which the seizure took place. For example, on two occasions Indian authorities seized both live and processed sea cucumbers from fishing vessels intercepted in Lakshadweep (Chatterjee 2020a; 2020b). In both of these cases the live sea cucumbers were released.

The species of sea cucumbers involved was rarely reported, and the images that accompanied news stories were often stock photos and could not be relied on for species identification. Sri Lanka Navy press releases often included photos of individuals arrested and items and sea cucumbers seized (Sri Lanka Navy 2020a). While it was often difficult to identify the species involved from these photos, what was indicated was that sea cucumbers of different sizes and species were typically seized, reflecting the multi-species nature of this fishery.

Finally, the value of the sea cucumbers seized was rarely reported, and when it was, it was unclear how the value was calculated. Most stories failed to provide details as to the species and whether retail, wholesale or price paid to the fisher was used in the calculation. For example, where values were given, the rate per kilogram ranged from USD 17.76/kg from a seizure of 800 kg by Indian customs officials in the Gulf of Mannar on 22 August 2019 (ANI News 2019), to USD 1353.32/kg from a seizure of 155.5 kg (220 sea cucumbers) made by Lakshadweep Forest Department officials on 10 October 2020 at a jetty in the Agatti Islands (Chatterjee 2020f). This reflects the range of prices paid for sea cucumbers, with fishers often paid a pittance, while expensive specimens of *Holothuria scabra* can retail for as much as USD 1800/kg, or H. fuscogilva selling for as much as USD 401/ kg (Purcell et al. 2018). However, given that dollar values in crime reporting are notoriously unreliable (Murtha 2016; Coomber et al. 2000), and that factors such as species, length, weight and quality of processing can affect the price, ultimately these numbers were not used (see Purcell 2014; Purcell et al. 2018; Purcell et al. 2017; Govan 2019).

Given the desired goal of tracking changes in sea cucumber crime over time, it was necessary to estimate weights, numbers and values for sea cucumber catch seizures where this information was lacking. The price of sea cucumbers can vary considerably, on an individual specimen level, at various stages of the supply chain, and even between market places. Prasada (2020) for example notes that Sri Lankan fishers may be paid ~ USD 7.00 for a fresh individual of *H. scabra*, ~USD 2.00 for a fresh individual of *H. spinifera*, *B. marmorata* and *T. anax*, and ~USD 0.50 for fresh specimens of low-value species (Prasada 2020). For simplicity, an average price was calculated using the November 2016 Hong Kong retail prices for *H. fuscogilva* and *H. scabra*, and the retail price for these species and the *T. ananas* from Guangzhou from the same date (see Govan 2019; Purcell et al. 2018), resulting in an average 2016 price of USD 200.40/kg.

The price of beche-de-mer has been steadily increasing. Chen (2003) observed that the price of a kilogram of this product in China has increased from the equivalent of ~USD 3.0 in the 1960s, to ~USD 60.0 in the 1980s, ~USD 120.0 in the 1990s, and ~USD 370 in the 2000s (Chen 2003). Purcell et al. (2018) calculated that the average price of beche-de-mer has been increasing 2.4% annually; this number was used to generate an average price used in this analysis.

Weights were drawn from the literature. For the live and/or wet weight, the average weights at capture of *H. fuscogilva*, *H. scabra* and *T. ananas* were drawn from a number of sources, and an average was calculated (Ngaluafe and Lee 2013; Koike 2017; Skewes et al. 2004). This resulted in an average weight of 2.45 kg per live and/or wet sea cucumber seized. To calculate the dry weight of the average seized sea cucumber, an average market weight for *H. fuscogilva*, *H. scabra* and *T. ananas* – as reported by Purcell et al. (2018) (for Hong Kong and Guangzhou markets) – yielded a weight of 0.15 kg. Where the state of the sea cucumber was unknown, we used the wet weight (2.45 kg) to determine the number of sea cucumbers seized, given that 72.6% of seizures (53 out of 73) where the state was identified, the sea cucumbers were recorded as being live and/or wet. It is recognised that this approach introduces a possible source of error that would underestimate the number of sea cucumbers seized, and that these weights, and the numbers derived from them are rough estimates, however this approach produces consistent values that allows for trends to be tracked.

Dry weight was used for the purposes of calculating values, and all wet weights were converted into dry weight using the conversion ratio of 6.0 – the average of the Secretariat of the Pacific Community (SPC) recommended conversion ratios of *H. fuscogilva* (8.0), *H. scabra* (5.0) and *T. ananas* (5.0) (Ngaluafe and Lee 2013).

Further limitations must be noted. This study relied on English-language media and reports, and as a result, cases reported in non-English language sources may have been missed. Cases that did not receive media attention or that were not reported by the Sri Lanka Navy would also have been overlooked. Given that some cases involving very small seizures were still reported in the press, it is unlikely that smaller cases were not reported. For example, several news outlets reported on the 5 October 2020 Forest Department seizure of 20 dry sea cucumbers from an abandoned building in Lakshadweep (Kedia 2020; Chatterjee 2020e). We can be more confident that fewer incidents were missed through the analysis of reports of the Sri Lanka Navy because it is a government agency. Finally, we noted inconsistent reporting in a number of news stories, particularly with regards to dates and locations of incidents. Triangulation was used to mitigate this potential source of error.

Results

From 1 January 2015 to 31 December 2020, there were 120 incidents involving sea cucumber crime in Sri Lanka and India, with the number of incidents increasing substantially in the past two years (Fig. 1). These incidents resulted in 502 arrests, which have also increased in the past two years (Fig. 2). On average, an incident resulted in four arrests, but ranged between zero and 29, with a mode of one. Reports and new stories often included details about those arrested, typically age and place of origin. Of those arrested, all were men, ranging from 15 to 63 years of age (see The Hindu 2020; Arockiaraj 2020).

In addition to the seizure of sea cucumbers (see below) and arrests, authorities often seized fishing and diving gear, oxygen cylinders and other equipment, as well as 105 vessels (8 from India and 97 from Sri Lanka), a considerable number of outboard motors, and land vehicles, including a number of lorries (2), three wheelers (4) and an SUV. While the vast majority of vessels were dinghies, a variety of vessels were seized, including country boats, fiberglass dinghies, and fishing trawlers (Table 1) (see News First 2020). During any given incident, an average of 0.88 vessels were seized.

When these incidents are mapped, a distinct cluster emerges in the Gulf of Mannar and Palk Bay region (Map 1). This is consistent with this area being a key sea cucumber fishing area (historically in the case of India). Magnifying this area (Map 2) identifies a key sea cucumber crime area in and around Adam's Bridge (Rama's Bridge/Rama Setu), the shallow portion of sandbanks and shoals between Mannar Island in Sri Lanka, and Rameswaram (Pamban) Island in India separating the Gulf of Mannar and Palk Bay. Also of note is the cluster of incidences occurring in Lakshadweep in 2020, particularly on and around Agatti Island (Map 3).

The total combined calculated weight (wet and dry) of sea cucumbers seized over the period studied was 64,733 kg (64.7 t), with 40,433 kg seized by Indian authorities, and the remaining 24,300 kg seized by Sri Lankan authorities (Table 2).

The overall average size of a seizure was 543.98 kg per incident, though this amount fluctuated considerably over the years and was particularly influenced by individual large seizures (Fig. 3), such as the 26 October 2015 Indian Coast Guard interdiction of two Sri Lankan fishing vessels with 9300 kg of poached sea cucumbers at Cherbaniani, about 35 km off Lakshadweep (Daiji World 2015), and the 1 June 2019 seizure of 2410 kg of processed sea cucumbers at Nagapattinam by Indian authorities (New Indian Express 2019). The majority of seizures in both jurisdictions involved wet and/or live sea cucumbers (Fig. 4). Of the incidents where the state of the sea cucumber seized was known (73 incidents), 27.4% were identified as dry and/or processed sea cucumber, representing 14.0% of the total weight seized.

During the period under examination, it is estimated that 104,531 sea cucumbers were seized by Sri Lankan and Indian authorities (wet and dry), with an average of 871 sea cucumbers seized per incident (Table 3).

Table 1. Number of sea cucumber crime incidents, arrests and seizure in Sri Lanka and India, 2015–2020.

Year	Number of incidents		Number of arrests		Vessels seized		Other vehicles seized	
	Sri Lanka	India	Sri Lanka	India	Sri Lanka	India	Sri Lanka	India
2015	4	4	15	34	3	2	2 lorries	-
	8		49		5		2 three wheelers	
2016	1	5	5	9	0	0	-	-
	6		14		0			
2017	1	6	3	4	1	1	-	-
	7		7		2			
2018	6	3	51	0	11	1	-	-
	10		51		12			
2019	19	13	93	30	26	3	1 three wheeler	1 - SUV
	32		123		29			
2020	40	18	225	33	56	1	1 three wheeler	
	58		258		57			
Total	72	48	421	81	99	6		
	120		**502**		**105**			

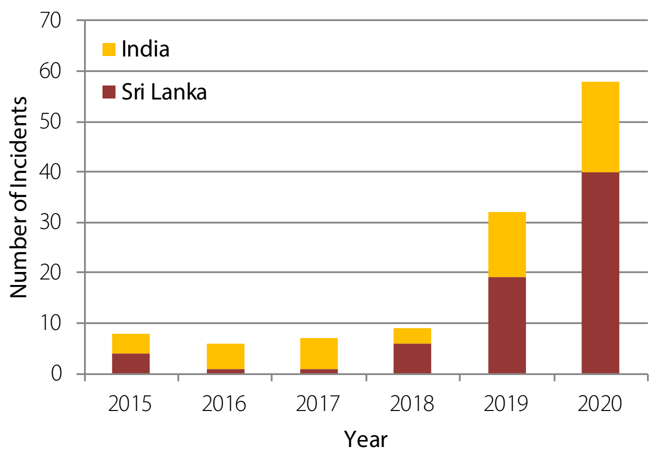


Figure 1. Number of sea cucumber crime incidents in Sri Lanka and India, 2015–2020.

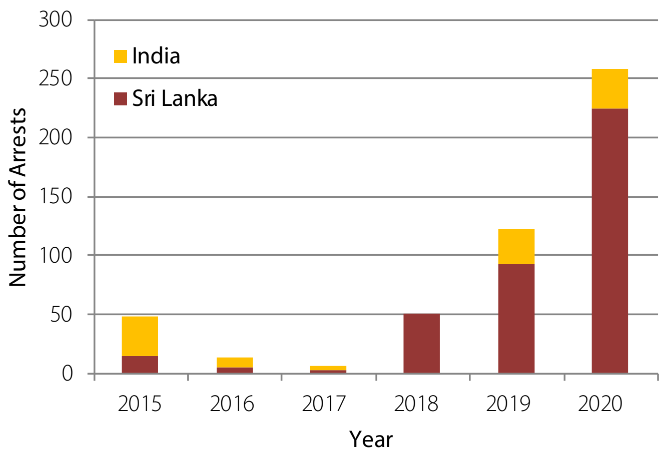
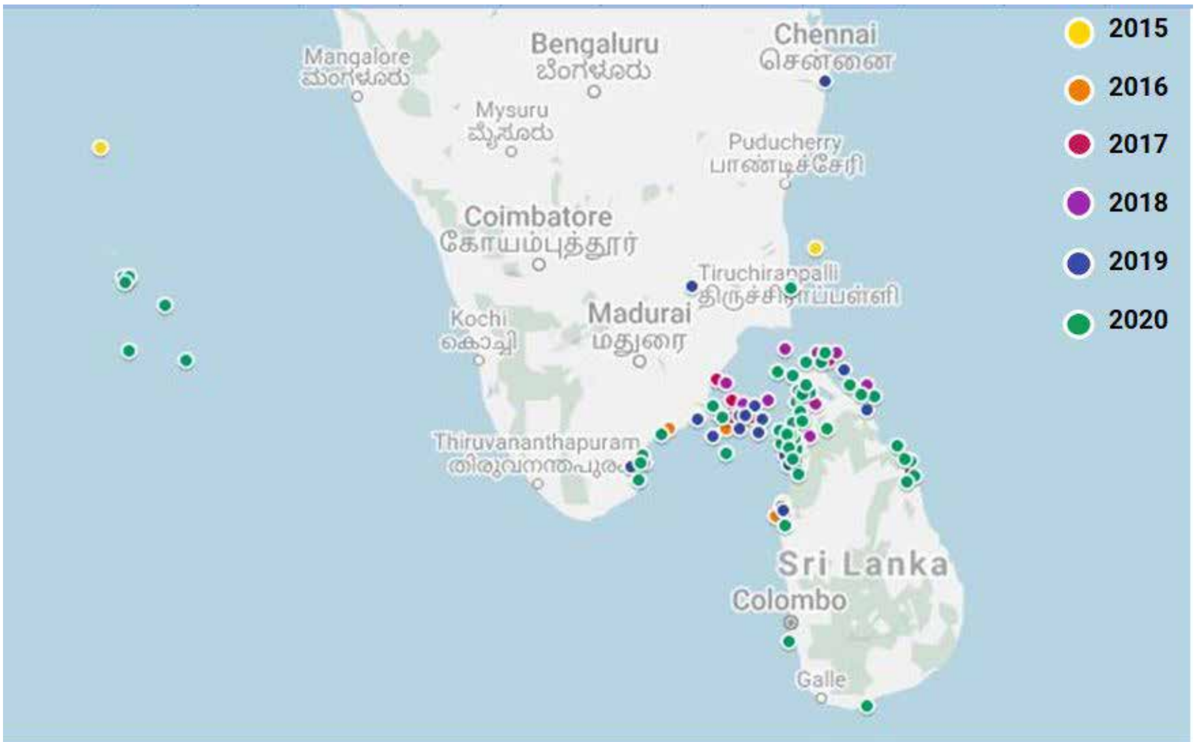
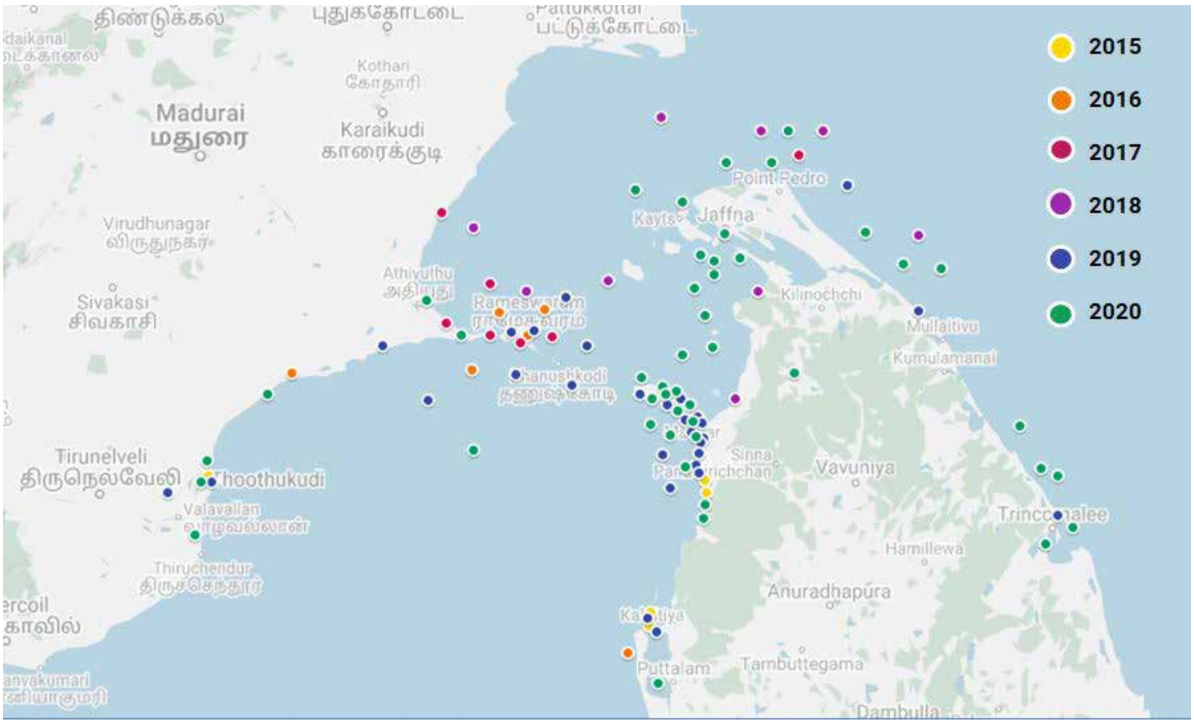


Figure 2. Number of sea cucumber crime-related arrests in Sri Lanka and India, 2015–2020.



Map 1. Sea cucumber crime in Sri Lanka and the south of India, 2015–2010.[2]



Map 2. Sea cucumber crime in the Gulf of Mannar and Palk Bay, 2015–2020.

[2] Note, the map does not include an incident that occurred on 7 November 2020, 14 nautical miles west of Rutland Island in the Andaman and Nicobar Islands, where Indian Coast Guard officials detained 12 fishers and a vessel of Myanmarese origin (Mangal 2020; The Economic Times 2020). The points on the map approximate the locations of incidents, as reports were seldom clear on the exact location.

Map 3. Sea cucumber crime incidents in Lakshadweep, India, 2015–2020.

When all weights and numbers were converted into dry weights for cost calculation purposes, the overall estimated dry weight was 13,480.81 kg, which, using the estimated price of USD 200.40/kg modified by 2.4% to accommodate annual increases, equated to USD 2,837,928 (Table 4). Tracking the overall number of incidents, the value of seized sea cucumbers was greater in 2015, and then after three years of relatively low values, increased significantly in 2019 and 2020 (Fig. 6).

The average (mean) value of a seizure was USD 23,848.14, and the median value was USD 4,469.68, although values ranged from USD 26.44 to USD 518,583.80.

Discussion

There has been a marked increase in sea cucumber crime in Sri Lanka and the south of India in recent years, particularly in 2019 and 2020. Over the period under study (2015 to 2020), 120 incidents resulted in 502 arrests and the seizure of an estimated 64.7 t of sea cucumbers (104,531 individual animals) by Sri Lankan and Indian authorities. The value of these seizures was over USD 2.84 million (INR 20.7 or LKR 528.3 billion). This illegal catch robs legal fishers, in the case of Sri Lanka, and denies local environments of the ecosystem services of these important animals (see Chary et al. 2020; Purcell et al. 2016).

With respect to types of sea cucumber crime in the region, the two major types appear to be illegal fishing (poaching) and smuggling. Sea cucumbers are illegally fished in both India and Sri Lanka, in operations that vary in size from individuals opportunistically gleaning along shorelines, to highly organised criminal enterprises. The average number of individuals arrested per incident was four, and 544 kg of sea cucumbers were seized on average. The vast majority of cases (0.88) involved vessels, ranging from small dinghies to fishing trawlers. Given arrest records, it is clear that fishers from both countries regularly cross into the waters of the other country to harvest sea cucumbers illegally.

Smuggling operations also appear to be highly organised. Sea cucumbers are often cached in hidden sites to be retrieved later. This can include being buried in remote locations (The Times of India 2020), stored in godowns (warehouses) (The Hindu 2020), or hidden in private homes (Sri Lanka Navy 2020c). Large consignments are then transported by teams, including lookouts and getaway drivers operating trucks, three wheelers and motorcycles on land, and by a variety of watercraft at sea. For example, in one case, over the course of eight months, a perpetrator collected 2410 kg of sea cucumbers that he kept in cold storage near Nagapattinam. He and a driver were arrested on 11 January 2020 while the sea cucumbers were being loaded onto vehicles (The New Indian Express 2019). In another case, Indian marine police, acting on a tip, recovered 600 kg of sea cucumber that was hidden in a sack buried off a beach near Thiruvadanai (The Hindu 2017).

This approach appears to be common. In an interview with the press concerning a case where 51.5 kg of sea cucumbers were found buried near Agatti Airport, Lakshadweep's chief wildlife warden, A.T. Damodhar, described a *modus operandi* whereby "at selected locations in the southern Indian Ocean, large consignments [6 to 10 tons] are packed together in a watertight material and dropped in international waters." He went on to describe how these packages are then tracked using global positioning system (GPS) and how "divers from large ships collect these shipments from these locations, and funds are simultaneously transferred through illegal web networks" (Chatterjee 2020d).

When sea cucumber crimes are mapped, they clearly reveal smuggling routes connecting India to Sri Lanka, whereby illegally caught sea cucumbers are smuggled into Sri Lanka in order to be laundered and then re-exported to Southeast Asian markets. The waters around Adam's/Rama's Bridge is one such route, but there are likely others. For example, in one case, Indian authorities intercepted a consignment of sea cucumbers that were destined for Kuala Lumpur (Malaysia) at Trichy Airport (Times of India 2019).

Mapping sea cucumber crimes also reveals a worrying trend. While the vast majority of crime was documented in the Gulf of Mannar and Palk Bay area, there were eight incidents in Lakshadweep in 2020. This region previously had only one incident, on 26 October 2015, where the Indian Coast Guard arrested 29 Sri Lankan fishers in two vessels with 9300 kg of sea cucumbers (Daiji World 2015). The concern is that sea cucumber crime could be expanding to Lakshadweep in the face of high demand, or that roving bandits could be shifting their operations from the Gulf of Mannar and Palk Bay due to increased monitoring and enforcement in this area (see Swedish FAO Committee 2009). This pattern of serial

Table 2. Total annual sea cucumber seizures (combined wet and dry weights) in Sri Lanka and India, 2015–2020.

	Weight seized (wet and dry) (kg)			
	Sri Lanka	India	Total	Average
2015	2 802	10 280	13 082	540,29
2016	950	1 025	1 975	329,17
2017	578	1 680	2 258	322,57
2018	1 171	1 900	3 071	341,27
2019	5 711	11 196	16 907	528,36
2020	13 088	14 352	27 440	481,4
Total	33 600	31 133	64 733	543,98

Table 3. Number of individual sea cucumbers seized by Indian and Sri Lankan authorities, 2015–2020.

	Total number seized	Average # per seizure
2015	22 818	2852
2016	2 022	337
2017	2 596	371
2018	2 625	292
2019	40 823	1 276
2020	33 647	580
Total	104 531	871

Table 4. Annual value of sea cucumber seizures in Sri Lanka and India, 2015–2020.

	Sri Lanka	India	Total
2015	$453 108	$268 970	$722 078
2016	$15 230	$53 306	$68 537
2017	$9 489	$27 580	$37 069
2018	$19 692	$31 940	$51 632
2019	$442 562	$785 827	$1 228 389
2020	$391 772	$338 451	$730 223
Total	$1 331 854	$1 506 075	$2 837 929

exploitation is unfortunately all too common with sea cucumber fisheries, both licit and illicit (see Anderson et al. 2011).

Another location that may see an increase in sea cucumber crime in the future is the Andaman and Nicobar islands, an archipelago of 572 islands 150 km north of Aceh, Indonesia. On 7 November 2020, the Indian Coast Guard apprehended a Myanmarese boat with 12 fishers and 60 kg of sea cucumbers on board near Rutland Island (Mangal 2020; Economic Times 2020). This represents only one case, and as such it is too soon to tell whether roving bandits will target this region for sea cucumbers, but authorities must remain vigilant. Both Lakshadweep and the Andaman and Nicobar islands are dispersed archipelagoes that included many remote and often uninhabited islands, characteristics that challenge monitoring and enforcement activities, and thereby make them particularly vulnerable to illegal fishing.

Conclusion

Sea cucumber crime in Sri Lanka and the south of India is on the rise. One of the reasons why this growing problem has come to light is an increase in monitoring and enforcement on the part of Indian and Sri Lankan authorities. The dramatic increase in arrests and seizures in 2019 and 2020 attests to this increased vigilance. Other actions have also been taken. India formed the Lakshadweep Sea Cucumber Protection Task Force (Pandey 2020). In August 2020, the Union Ministry of Environment, Forest and Climate Change announced the formation of a number of "anti-poaching camps" to increase monitoring capacity on the uninhabited islands of Suheli, Thinnakara and Veliyapani in Lakshadweep (Shaji 2020b). India also created the world's first conservation area for sea cucumbers in February 2020 – the Dr K.K. Mohammed Koya Sea Cucumber Conservation Reserve, a 239 km^2 area near Cheriyapani, Laksadweep (Chatterjee 2020c).

As this study demonstrates, sea cucumber poaching and smuggling is highly organised and transnational in nature. Groups of fishers illicitly remove hundreds of kilograms of sea cucumbers that are then smuggled though highly coordinated networks. Given these characteristics, sea cucumber crime must be considered a form of transnational organised crime (Phelps Bondaroff et al. 2015).

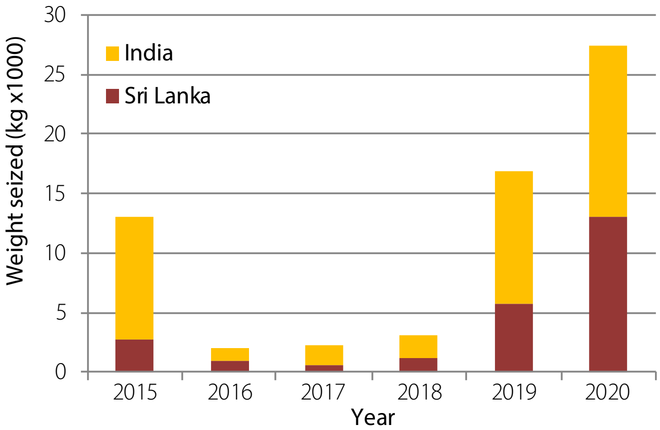


Figure 3. Total annual sea cucumber seizures (combined wet and dry weights) in Sri Lanka and India, 2015–2020.

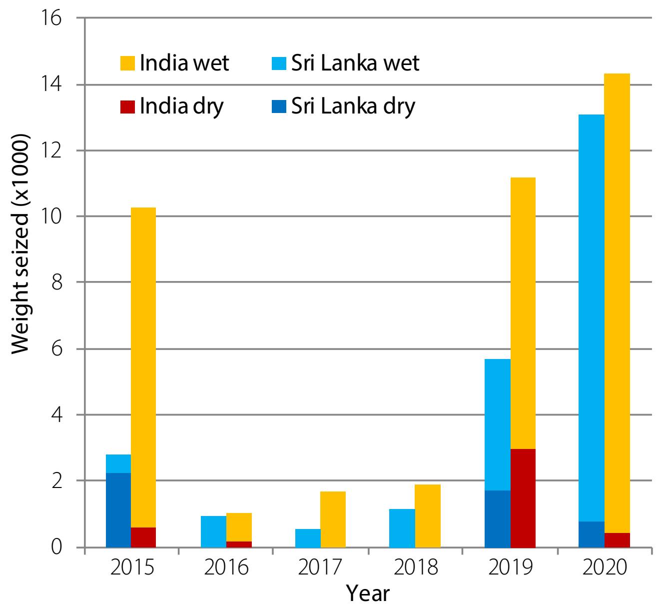


Figure 4. Sea cucumber seizure by state (wet/live or dry/processed) in Sri Lanka and India, 2015– 2020.

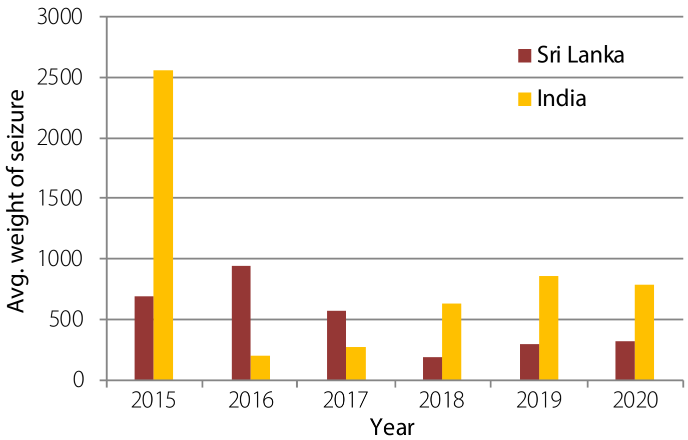


Figure 5. Average weight of sea cucumber seizures (combined wet and dry weights) in Sri Lanka and India, 2015–2020.

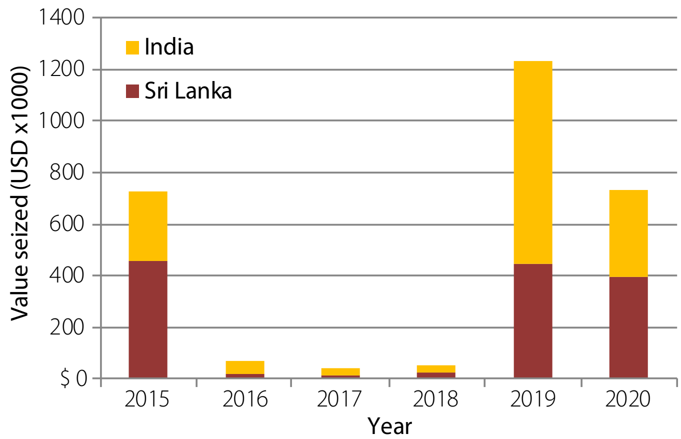


Figure 6. Value (USD) of seized sea cucumbers by year in Sri Lanka and India, 2015–2020.

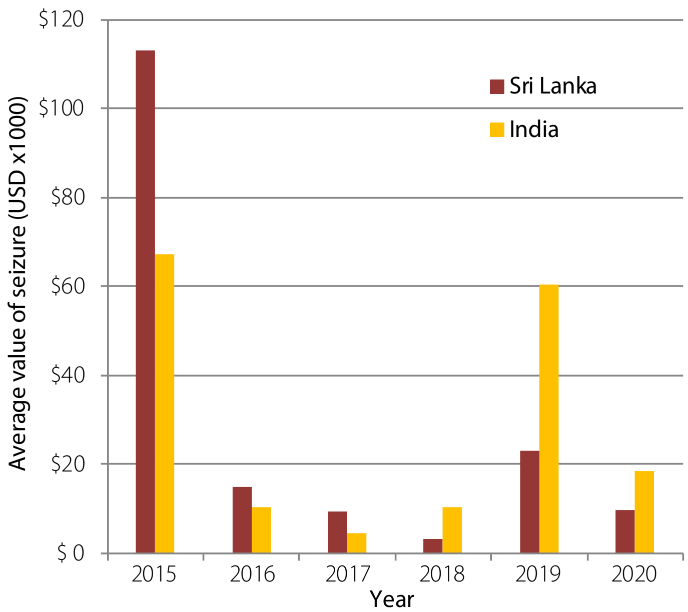


Figure 7. Average annual value of sea cucumber seizures by Sri Lankan and Indian authorities, 2015–2020.

It is promising to observe that increasingly this appears to be how Indian and Sri Lankan authorities are treating the issue. In India, a number of cases have been referred to the Central Bureau of Investigation (CBI) (see Pandey 2020; Shaji 2020a), an agency whose jurisdiction covers law enforceable by the Indian Government, multi-state organised crime, multi-agency, and international cases (CBI n.d.). Another case involving the seizure of over 2 t of sea cucumbers in the Nagapattinam and Ramanathapuram districts on 9 March 2020 was handled by the Organised Crime Intelligence Unit of the Tamil Nadu State Police (Arockiaraj 2020). In Sri Lanka, the navy regularly conducts patrols for illegal, unreported, and unregulated (IUU) fishing, and follows up on reports and tips from the public, thus netting an increasing number of sea cucumber poachers and smugglers. Investigations in cooperation with terrestrial law enforcement are also common (Sri Lanka Navy 2020c; 2020d). These existing efforts need to continue, with monitoring and enforcement agencies properly trained and resourced to intensify efforts.

Cooperation is key to effectively combating transnational organised sea cucumber crime. Increased coordination and cooperation between Indian and Sri Lankan authorities is required (intergovernmental and interagency cooperation). Furthermore, these same authorities must look to strengthen cooperation with other states, particularly market states, in order to disrupt other stages of illicit sea cucumber value chains. States should ensure that penalties and sanctions serve as an effective deterrent and that they are promptly imposed.

Sea cucumber crime should continue to be monitored in order to track potential shifts by roving bandits as enforcement and monitoring efforts increase in the Gulf of Mannar and Palk Bay area. Additional research is also needed. Analysis of the characteristics and demographics of those involved in sea cucumber crime should also be conducted in order to identify push and pull factors so that these can be addressed. While Sri Lanka is a key gateway for those seeking to smuggle sea cucumbers out of India, it is clear that other routes are also being employed. Additional work is required to identify these routes.

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The sea cucumber and its role in the blue economy in Colombia

Adriana Rodríguez-Forero[1]

In Colombia there is an illegal sea cucumber market that exploits native species and involves artisanal fishermen, indigenous people and poor communities in the Caribbean region (Toral 2008; Agudelo Vergara et al. 2017). Recently, several arrests have been made that show how sea cucumber species have been fished illegally from different regions of the country in various quantities. Records of illegal catches in Colombia have increased in the last three years. Twelve plastic bags with 400 kg were seized in La Guajira (Riohacha city). In San Onofre city (Sucre), 5554 dehydrated sea cucumbers were seized near the international airport; the airport police seized 540 sea cucumbers that were intended to be exported from Bogotá to Hong Kong. In contrast, sea cucumber aquaculture has become viable in in Latin America countries such as Mexico and Colombia; in the case of Colombia, research activities are mainly carried out by the Research and Technological Development Group in Aquaculture, in Santa Marta, Magdalena (Agudelo Vergara et al. 2017).

Artisanal fishermen of the Colombian Caribbean are very poor due to social inequalities, but also because of the decrease in their catches, which is emphasised by the lack of technology in their fishing gear and the lack of other sources of income. Some families are deeply impoverished. The average annual income level in this region was reported (in 2018) to be around USD 1900 for fishers who are involved in small-scale fishing cooperatives (Lavalle and Pretel 2019), with five fishermen, on average, in charge of one boat. These figures indicate that a fisherman earns around USD 5 to 6 daily, depending on whether or not he is part of a cooperative, and that this is his main source of income to support his family. Meanwhile, women barely earn half of what mean earn, clearly showing gender inequality (Viloria-Maestre et al. 2016; Lavalle and Pretel 2019).

In turn, there are no conditions for natural resources to become an opportunity for sustainable local development, with marked overexploitation of fisheries and inadequate resource management (Beltrán and Villaneda 2000). Global warming is an additional factor increasing the region's problems (Lavalle and Pretel 2019; DANE 2020).

A blue economy is based on the principles of the Code of Conduct for Responsible Fisheries (Pauli 2010). It recognises the importance of seas and oceans as engines of the economy because of their potential for innovation and growth. A blue economy attempts to prioritise the balance of sustainable and socioeconomic management of natural aquatic resources, emphasising the efficient use of resources from fisheries and aquaculture, ecosystem services, trade and food systems (Pauli 2010; FAO 2015). Its aim is to reconcile economic growth with better livelihoods and social equity, and to strengthen transparent, reliable and safer food systems. A blue economy also places greater responsibility on national and regional policies for the protection of living aquatic resources, and aims to create an enabling environment whereby fisheries and aquaculture stakeholders are not only resource users, but are also active role in protecting and safeguarding them, for the benefit of future generations (Campbell et al. 2021). In general, developing countries have begun to adopt blue economy strategies, also called blue growth, to promote food security and increase quality of life, and to minimise or mitigate the impacts of these economic sectors on living aquatic resources, biodiversity and ecosystem services (FAO 2015).

Sea cucumber species such as *Isostichopus badionotus*, *Isostichopus* sp. and *Holothuria mexicana* – all of which are grown in aquaculture facilities in Colombia – are included in the blue economy because these species feed on microalgae (e.g. *Isochrysis galbana*, *Chaetoceros calcitrans*, *Nannochloropsis oculata*), sand and organic matter, which do not harm the environment (Agudelo and Rodríguez 2017; Acosta et al. 2020). In outdoor aquaculture facilities, juveniles and adults feed on sand and lime, as well as microorganisms such as bacteria, diatoms and detritus. These foods do not have a significant impact on production costs (which account for anything between 56% and 83%) as compared with foods used in tilapia culture, which is the most popular aquaculture species and is farmed in over 120 countries in the world (Scorvo-Filho et al. 2006; Sabbag et al. 2007; Osamaki et al. 2017). When reared in controlled facilities, sea cucumbers do not need artificial foods, one of the most expensive components of aquaculture activity, and their production incurs low operating costs. The infrastructure investment is also lower than for many other types of aquaculture, such as shrimp or finfish (Osamaki et al. 2017; Barroso et al. 2019). In addition, Caribbean Sea cucumbers have an acceptable nutritional content with a protein content of 6.6% and fat content of 0.35% (Arias et al. 2016; Vergara and Rodríguez 2016).

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The implementation of a blue economy in Colombia can be an option for the legal production of laboratory-reared sea cucumbers and other marine ornamental products, such as fish, crustaceans, mussels and other invertebrates, under controlled conditions. Rearing sea cucumbers will help reduce, for example, the pressure on extractive fisheries. The possibilities of increasing the socioeconomic conditions of fishermen can be carried out by incorporating family aquaculture models that involve sea cucumbers. Ecological benefits should be created, as sea cucumbers are bioremediators that help purify the marine environment through bioturbation (Uthicke 1999; Wolfe and Byrne 2017; Hamel et al. 2001; Uthicke 2001). Sea cucumbers are also organisms that can be cultivated in polyculture, with low operating costs and low infrastructure investments (Inui et al. 1991; Wu 1995; Slater and Carton 2007). This could help reduce pressure on extractive fishing and create additional possibilities for clinical, pharmaceutical and cosmetic applications. Because sea cucumbers have a high collagen content, they are ideal for the manufacture of skin care products (Liu et al. 2002; Li et al. 2020). Colombia, however, has poor environmental legislation, and is facing overexploitation of resources, climate change and environmental pollution among others, so the role of aquaculture in recovering resources has even more pitfalls to be solved. Blue aquaculture could generate tangible work and benefits to change the economies of vulnerable populations like those that inhabit our coastlines.

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Knowledge of sea cucumbers by the Algerian community and an attempt to introduce them into the national gastronomy

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Abstract

In order to introduce sea cucumbers to the local Algerian market, a survey of 453 people was carried out in different region of the Algerian territory in order to analyse consumer interest in and their behaviour regarding sea cucumber food habits. Our results show that most people are able to spend between DZD 500 (USD 3.78) and DZD 2000 (USD 15.11) to buy seafood. Sea cucumbers are not well known by Algerians, but about 72% of the surveyed people would be able to afford them. These results provide basic data for the establishment of a marketing strategy for sea cucumbers in Algeria.

Key words: Sea cucumbers, seafood, Algeria

Introduction

Due to the high demand for sea cucumbers in recent decades (Conand 2018), new fisheries have rapidly developed since the 1990s in countries of the northeast Atlantic and the Mediterranean Sea, including Italy, Spain, Greece, Portugal and, particularly, Turkey, which monopolises the sea cucumbers export market (Conand 2006; Marquet et al. 2017). Sea cucumbers are rarely consumed in the Mediterranean region, and the entire sea cucumber catch is exported to Asian countries (Aydin 2018; Neghli and Mezali 2019). Since 2008, the collection of sea cucumbers in Algeria has been allowed but not for commercial purposes (Mezali and Slimane-Tamacha 2020). The exploitation of sea cucumbers is limited to their use as artisanal fishing bait. However, it is illegally traded to foreign countries (Neghli and Mezali 2019; Mezali and Slimane-Tamacha 2020). The fresh product – or its derivatives – have never existed on the local market and have never been introduced into the Algerian gastronomy. The present work aims to analyse the acceptance of sea cucumber by Algerian consumers and the possibility of integrating the sea cucumbers into their culinary habits as a way to establish consumption, fishing and production patterns in Algeria, taking into account the sociodemographic, economic and gustatory characteristics of Algerian consumers.

Methodology

The survey was carried out using an online questionnaire in two languages (French and Arabic) and shared on social network. The survey targeted a sample of 453 Algerian citizens from the 14 coastal wilayas (administratives divisions) of Taref, Annaba, Skikda, Jijel, Béjaia, Tizi-Ouzou, Boumerdes, Alger, Tipasa, Chélif, Mostaganem, Oran, Ain-Témouchent and Telemcen, and from different interior wilayas such as Sétif, Blida, Ghardaïa, Tiaret, Adrar and M'sila, during summer 2020 (Fig. 1).

The sample of the surveyed population is composed of twice as many women (66%) as men (34%). This high ratio of women to men is due to the fact that the majority of women are housewives and they are interested in gastronomy, and are the ones who are primarily responsible for preparing food. Interviewees from coastal wilayas represent 74% while those from inland wilayas represent 26% of the sample. The age of respondents was divided into four categories, with a predominance of respondents in the age group 18–25 (41%), followed by the age group 25–35 (39%). Those aged less than 18, and those over age 35 represented a relatively low rate (20%). Thus, the sample is mainly composed of young citizens between the ages of 18 and 35 who are mostly students (43%) and employees (40%). The dominance of young people in the sample is explained by the fact that they are more present on social networks than other age groups.

The survey covers three main parts:

1) The personal information of the interviewees: sex, age, wilaya of origin and socioprofessional situation.

2) Food habits of the consumers with regard to seafood products: involvement in food purchases (fully, partly or not at all); frequency of consumption of seafood (once a week, once a month, occasionally or never); species consumed (grouped into five categories: small pelagic fish, white fish, molluscs, crustaceans and sea urchins or mussels); budget devoted to the purchase of these products (< DZD 500 or USD 3.78,

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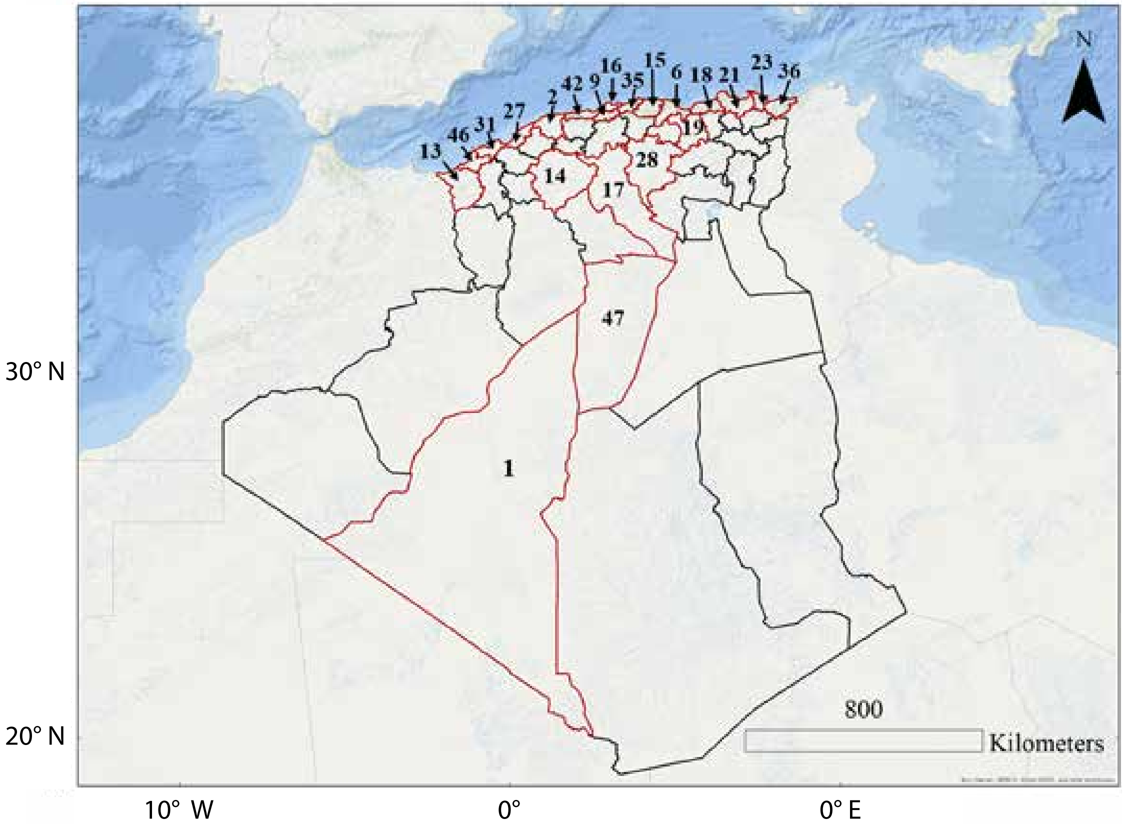

Figure 1. Residential location of Algerian citizens who participated in the questionnaire survey. Numbers indicate the numerical code of each wilaya. 1: Adrar; 2: Chelif; 6: Béjaia; 9: Blida; 13: Tlemcen; 14: Tiaret; 15: Tizi-Ouzou; 16: Algiers; 17: Djelfa; 18: Jijel; 19: Setif; 21: Skikda; 23: Annaba; 27: Mostaganem; 28: M'sila; 31: Oran; 35: Boumerdes; 36: El Taref; 42: Tipasa; 46: Aïn-Temouchent; 47: Ghardaïa.

DZD 500–1000 or USD 3.78–7.56, DZD 1000–2000 or USD 7.65–15.11 and > DZD 2000 or USD 15.11) and the purpose of their consumption (just for taste or for their nutritional or health benefits).

3) State of knowledge of sea cucumbers by Algerian consumers (through its field of study, work, documentaries or through an intermediary): their ability to introduce it into their foods habits knowing its nutritional benefits; types of dish they will be tempted by (longitudinal muscles of *Parastichopus regalis*, raw sea cucumber cut into slices, cooked cut into small pieces and cooked entirely) and finally the type of product they would like to find on the market (fresh to prepare at home or already prepared).

Results and discussion

Differences between women and men in food purchases

Our results show that 48% of people are partially involved in food purchases, 22% are fully involved and 30% are not involved at all. It turns out that men are the most involved in purchasing food (Fig. 2A) and a large number of women are not. Generally, in Algerian society, men have more contact with the outside world and take care of outside household tasks, including food purchases, while women take care of inside household tasks such as food preparation.

Preferences with regard to seafood

The results show that 50% of interviewees consume fish occasionally, 26% consume fish once a week and 23% once a month. In addition, 40% choose fish for its good protein intake, 40% opt for seafood for its good taste while 20% consume it for both reasons. The most consumed seafood products in Algeria (Fig. 2B) are sardines, round sardinellas allache and anchovies (40.3%) because of their accessibility and their affordable price (between DZD 500 or USD 3.78, and DZD 800 or USD 6.04) by most interviewees, followed by white and redfish (red sea bream, sea bream, tuna and swordfish), with a percentage at 21.9%. The prices of these fish are within the margins of the average budget spent on fish which varies between DZD 500 (USD 3.78) and DZD 2000 (USD 15.11) (73%) (Fig. 2B). The more the budget for purchasing seafood increases, the more these products are of high commercial value, such as shrimps, lobsters and mussels. Indeed, the more the price of these products increases, the more their demand by consumers decreases and this is explained by the low purchasing power of the Algerian citizen.

The budget devoted to the purchase of seafood is closely related to the frequency of their consumption. Frequency increases when the consumer's budget is relatively high (Fig. 2C). The consumption of seafood is therefore conditioned by the purchasing power of consumers; people with high monthly income can afford to consume seafood regularly and spend more money for its purchase, unlike middle- and low-income families.

Figure 2. a) Responsibility for food purchases by gender; b) Type of seafood purchased according to the budget spent; c) Purchase frequency of seafood products according to the budget spent; d) Knowledge of sea cucumber by interviewees according to their work (in or out the sea sector); e) Ability of the respondents to introduce sea cucumbers into their food habits according to their knowledge of this product.

Sea cucumbers and the Algerian consumer

More than half of the interviewees (51%) do not know what sea cucumbers are, and 96% work outside the sea sector. However, of the 49% who are not familiar with sea cucumbers, more than half do not work in the sea sector (Fig. 2D). The means that allowed them to know about sea cucumbers are different, but is mostly by their field of study and from other people (59%). Others know about sea cucumbers through science documentaries and through their profession (divers or fisherman). By bringing to the attention of interviewees the benefits of sea cucumbers, 78% are ready to introduce these animals into their diet and 63% are tempted by the dishes proposed. According to our results, those who did not know about sea cucumbers are more able to introduce them into their food habit than those who do (Fig. 2E).

Among the four dishes proposed in the survey, 48.5% of interviewees chose the one made from small pieces of sea cucumbers (probably because it looks similar to chicken or some other meat), 27.4% chose the dish presented by the longitudinal muscles of the royal sea cucumber *Parastichopus regalis* (Cuvier, 1817), while dishes made of raw sea cucumbers – sliced or cooked – are not attractive to many people (12.5% and 11.6% of those surveyed, respectively).

If sea cucumbers were available in Algerian markets, 48.3% of those surveyed reported that they would tend to buy the fresh product and prepare it at home, while 24.3% reported that they would buy it already prepared in restaurants, and 27.4% would not buy it at all. The reasons given by those who refuse to include sea cucumbers in their diet fall into four categories: 1) those who feel sea cucumbers are "disgusting", "strange" or "frightening" in appearance, and find their texture and shape disagreeable; 2) those who fear they are toxic and might cause allergies; 3) those who believe they are important for their and its ecological role; and 4) those who are undecided because they are not part of Algeria's traditional cuisine and prefer to taste it first and then possibly learn how to cook it so as to introduce it into their culinary habits.

Conclusion

The sample of the Algerian population on which this work is carried out is composed mainly of young people coming mostly from coastal wilayas. The consumption of seafood by Algerians is occasional and not very diversified. The majority of Algerians prefer small pelagic fish species (e.g. sardines, round sardillas and anchovies) and devote a budget of DZD 500 (USD 3.78) to DZD 1000 (USD 7.56) on these. Sea cucumbers are not well known to Algerian consumers, but the majority of respondents affirms their ability to introduce this seafood into their dishes. Hence, the importance of organising tasting sessions to present this seafood product to the Algerian community (in dry or raw form), organise workshops to show how it is cooked and especially to make people aware of its culinary importance as a source of omega-3, omega-6 and other fatty acids and proteins that can decrease the risk of certain diseases (Mecheta et al. 2020), its role in the marine environment and the need to exploit in a rational way these marine species while avoiding the collapse of their natural stocks.

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L'inscription de trois espèces d'Holothuries à l'Annexe II de la CITES entre en vigueur

Marie Di Simone,[1] Arnaud Horellou[1] et Chantal Conand[2]

Introduction

Lors de la dernière Conférence des Parties à la CITES (CoP 18 CITES) en août 2019, l'inscription à l'Annexe II de la CITES de 3 espèces d'Holothuries à mamelles (Teatfish) : *Holothuria nobilis, H. fuscogilva et H. whitmaei a été acceptée* (Di Simone *et al.* 2020). Désormais, le commerce international de ces espèces est réglementé et contrôlé conformément aux dispositions de l'Annexe II : des permis et certificats CITES seront nécessaires pour les mouvements internationaux, attestant de la légalité et de la durabilité des envois. En l'absence de ces documents, les envois doivent être saisis car ils sont considérés comme du commerce illégal (CITES Secretariat 2020).

L'Annexe II vise la surveillance et régulation du commerce afin de s'assurer que celui-ci s'appuie sur la gestion (méthodes et volumes) de prélèvements soutenables. Les transactions seront également suivies et compilées dans les rapports annuels sur le commerce des Parties et enregistrées dans la base de données sur le commerce CITES (CITES Secretariat 2020).

Entrée en vigueur de l'inscription : pourquoi un délai ?

Cette inscription est entrée en vigueur le 28 août 2020 après un délai de mise en œuvre de 12 mois convenu par les Parties lors de la dernière CoP (CITES Secretariat 2020).

Ce délai visait à permettre aux États de l'aire de répartition de ces espèces et aux importateurs de se préparer et appliquer efficacement l'inscription, notamment la mise en place de procédures adéquates de gestion, d'identification, de suivi et de délivrance de permis (CITES Secretariat 2020). En effet, cet amendement posait d'importants problèmes de mise en œuvre qui n'auraient sûrement pas été réglés dans la période de 90 jours après laquelle une inscription aux Annexes de la CITES devient juridiquement contraignante (CITES Secretariat 2020).

Les holothuries soutiennent d'importantes industries et sont les bases des moyens de subsistance des communautés présentes dans des régions éloignées avec peu d'alternatives pour l'activité économique. Il a donc été convenu par les Parties que des réglementations devraient être mises en place pour assurer la survie de ces espèces dans la nature (CITES Secretariat 2020)

Mise en place de l'inscription : élaboration d'un Avis de Commerce non Préjudiciable

Une inscription en Annexe II de la CITES entraine préalablement l'établissement d'un Avis de commerce non préjudiciable (ACNP, NDF pour *Non Detriment Findings* en anglais). L'ACNP est remis à l'issue d'une évaluation scientifique des risques, axée sur une analyse du mode d'exploitation, de ses effets sur la population considérée, des mesures et des risques, de sorte à déterminer la nature préjudiciable ou non préjudiciable du prélèvement d'une espèce dans son milieu naturel (SPC 2010).

Ainsi, un ACNP doit comporter les principales informations suivantes :

1. à propos des populations : les niveaux, tendances, milieux, densités, localisations, résilience
2. la gestion et les prélèvements : les sites de pêches vs sites non pêchés, modes de pêches, programmes de conservation, quotas
3. les mesures de contrôle

Il s'agit notamment de déterminer l'état d'une population par l'évaluation des stocks, de fixer des quotas de prises et des

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fermetures spatiales et temporelles des pêcheries, et de faire respecter ces mesures qui assurent et engagent l'Etat Partie dans une exploitation soutenable de ces 3 espèces (Shedrawi *et al*. 2019).

Les difficultés d'élaboration d'un ACNP

La thématique holothurie représente une nouveauté pour les Etats Parties CITES, particulièrement les méthodes de mise en œuvre et d'acquisition des compétences.

Il subsiste un manque d'informations scientifiques sur les holothuries, sur leur biologie, écologie et dynamique des populations. Or ces informations sont indispensables pour établir des plans de gestion complets, susceptibles d'assurer un prélèvement durable et la conservation de ces espèces. (CITES 2019). Les données requises pour réaliser un ACNP sont ainsi donc difficilement évaluables en l'absence de ces informations (CITES 2019).

Aussi, les données existantes concernent le plus souvent l'ensemble des espèces d'holothuries, les espèces individuelles sont rarement différenciées dans les statistiques du commerce et les bilans commerciaux (CITES 2019).

De plus, les capacités de l'organe de gestion[3] et de l'autorité scientifique[4] d'un pays sont parfois insuffisantes pour recueillir les informations nécessaires pour évaluer le risque du commerce international pour la survie de l'espèce sur son territoire (Shedrawi *et al*. 2019). Par exemple, les pays insulaires océaniens rencontrent déjà des difficultés dans la mise en œuvre d'une gestion efficace et durable dû à des contraintes économiques et techniques (Shedrawi *et al*. 2019).

Perspectives

L'inscription de ces trois espèces d'holothuries à la CITES a ouvert les portes pour de potentielles nouvelles inscriptions d'espèces (Di Simone *et al*. 2020). D'après Purcell *et al.* (2012), 58 espèces d'holothuries sont commercialisées dans le monde. Ce nombre ne peut être qu'en augmentation : les espèces avec une forte valeur commerciale étant rares voir épuisées, la pêche cible d'autres espèces pas encore commercialisées (ou avec faible valeur commerciale) qui n'étaient pas répertoriés avant (Purcell *et al*. 2012).

Pour la prochaine CoP, l'Union européenne a pour projet de faire une proposition pour une inscription en Annexe II de toutes les espèces d'holothuries européennes.

Aussi, le Secrétariat CITES est en train de finaliser une étude qui servira de base à un guide dont les Parties pourront se servir pour assurer la mise en œuvre des nouvelles règles qui affectent le commerce de ces holothuries. Ces efforts sont soutenus par un financement de l'Union européenne (CITES Secretariat 2020).

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Présentation de la pêche aux holothuries au Bénin

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Résumé

L'objectif de ce travail est de présenter la pêche des holothuries au Bénin. Cette filière a commencé à se développer avec l'arrivée des chinois qui ont pris la licence de pêche. Quelques espèces ont été recensées sans détermination exacte, ce qui est préoccupant. Les premières données montrent que les mois de juin à septembre sont considérés comme la mauvaise saison. Il s'avère nécessaire de suivre l'exploitation toute l'année. Les différentes espèces seront déterminées. Avec le développement de cette activité au Bénin, il vient d'être mis en place une licence spéciale pour leur exploitation. Un suivi strict de la filière reste nécessaire en raison de l'importance des holothuries dans la chaine trophique.

Mots clés Holothuries, Exploitation, Bénin

Abstract

The objective of this work is to present the sea cucumber fishery in Benin. This sector began to develop with the arrival of the Chinese who took up the fishing license in Benin. A few species have been recorded without exact determination, which is of concern. Until now, sea cucumbers had not even been reported in many reports. The first data show that the months of June to September are considered as bad season. It is necessary to monitor the operation all year round. The different species will be determined. With the development of this activity in Benin, a special license has just been set up for their operation. Strict monitoring of the sector remains necessary due to the importance of sea cucumbers in the trophic chain.

Keywords : Holothurian ; Exploitation; Benin

Introduction

La pêche commerciale des holothuries, ou bêche-de-mer est très ancienne dans plusieurs pays de l'Asie et les espèces ciblées appartiennent la plupart à l'ordre des Aspidochirotida. Leur exploitation a pris de l'ampleur ces 25 dernières années et alimente des marchés internationaux en pleine expansion (Purcell et al. 2013 ; Tanzer et al. 2015). Pendant longtemps ces espèces n'ont eu aucune valeur commerciale au Bénin. Ces 'pains de mer' comme, on les appelle au Bénin sont jetés simplement sur les plages ou dans des poubelles. L'exploitation a commencé timidement à partir de l'année 2018 à bord des bateaux chinois qui ont commencé à les pêcher pour l'exportation. Il faut noter qu'en Afrique de l'Ouest, il y a peu de travaux sur les holothuries. Néanmoins une nouvelle espèce a été répertoriée au Ghana par Thandar et Sifiso en 2014. Lors des campagnes océanographiques de pêche organisées par l'UEMOA en 2015, la diversité biologique des holothuries a été étudiée. Selon Thandar et Sifiso (2014), au total, six espèces ont été signalées : *Holothuria (Holothuria) dakarensis* Panning, 1939; *H. (Semperothuria) imitans* Ludwig, 1875; *H. (Vaneyothuria) lentiginosa lentiginosa* (von Marenzeller, 1893); *Stereoderma congoana* (Heding, 1935); *Ocnus cruciformis Thandar n. sp.* et *Leptopentacta cabindaensis* (Cherbonnier, 1949) transféré ici à un nouveau genre *Cherbocnus Thandar* érigé à cet effet. Une autre espèce d'Afrique de l'Ouest, *Cladodactyla monodi Cherbonnier*, 1950 est appelée *Stereoderma*.

La population béninoise ne trouvait aucun intérêt pour l'exploitation des concombres de mer. Les chinois, après la capture font un traitement sur place et les font sécher, avant de les exporter en Chine. Au Bénin, les holothuries sont exploitées par les navires chinois qui battent pavillon béninois. Elles sont pêchées durant des périodes favorables, en dehors desquelles ils retournent vers la pêche aux poissons.

Ces espèces sont anciennement signalées dans la littérature (Cherbonnier, 1965, Zaouali, 1993) ainsi que dans des travaux portant sur leurs activités biologiques et leur apport nutritionnel (Louiz et al, 2003, Ben Ismail, 2010, Telahigue et al, 2014).

Matériels et méthodes

L'exploitation se fait à, bord de navires de pêche de 14 à 19 mètres, utilisant des chaluts de fond et muni de tangons pour le chalutage. Les chaluts sont construits avec des

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bourrelets lestés par des chaines autour desquelles sont enroulés des cordages pour amortir les chocs du fond marin.

La pêche se fait essentiellement à des profondeurs variant de 25 à 28 mètres.

La durée de chalutage (trait) est de 4 heures comme pour les poissons avec une vitesse de chalutage de 1,8 nœuds tandis qu'avec la capture des poissons, elle est de 2,5 nœuds.

Résultats et discussion

Les holothuries sont pêchées avec une vitesse minimale de chalutage. La pêche se fait surtout dans la nuit entre 18 heures et 5 heures du matin. Lorsqu'elles sont pêchées, il y a très peu de poissons car à cette vitesse, les poissons s'échappent du chalut utilisé (à peine 10 kg de poissons) pour une sortie de 72 heures, avec au plus 12 sacs de 20 kg par jour de pêche. Les holothuries se rencontrent dans les zones sableuses et sablo-détritiques.

Selon les données, la période de bonne pêche va d'octobre à avril avec un pic en janvier. Les mois de juin à septembre sont considérés comme « mauvaise saison » (figure 1). Durant la période janvier - février 2019, l'inactivité des navires se justifie par les réparations ; les capitaines/mécaniciens des bateaux et les pêcheurs à bord témoignent de l'usure du bateau et de l'engin pour cette pêche.

La photo 3 présente l'espèce pêchée au Bénin. Il s'agit probablement de *Holothuria (Rowethuria) sp.* Chez cette espèce, la région dorsale est de couleur marron avec quatre à cinq bandes transversales des points, comme des tubercules blancs et marrons. La face ventrale a une couleur beige rosé à grisâtre avec des tubercules, de couleur beige.

Ces deux spécimens collectés auprès des pêcheurs sont conservés dans du formol à 10%, ce qui rend difficile l'identification de l'espèce par les spicules.

La poursuite des travaux pourra permettre de mieux affiner la détermination de l'espèce.

La figure 1 présente l'évolution mensuelle des captures. On remarque que le mois de janvier est le mois le plus productif avec 2811 kg (poids humide), tandis que le mois de mai n'a que 36 kg (poids humide ; c'est alors que les navires ont cessé leurs activités. Les poids sont relevés sur des individus entiers.

La figure 2 montre la relation entre le poids et la taille des concombres. La valeur du coefficient « b » est égale à 0,94. Il est à noter que la corrélation entre les paramètres (taille -poids) est significative avec un coefficient de corrélation de 0,86.

Les informations sur les holothuries ne sont pas très détaillées dans la sous-région car elles ne constituent pas des espèces cibles pour les populations locales. Il est à noter que les pêcheurs, tant artisans qu'industriels les pêchaient souvent lors de leurs sorties en mer.

Photo 1. Navire de pêche au quai de débarquement à Cotonou

Photo 2. Chalut de fond pour la capture des concombres sur l'aire de débarquement à la crié

Photo 3. l'espèce pêchée au Bénin, a) vue ventrale, b) vue dorsale

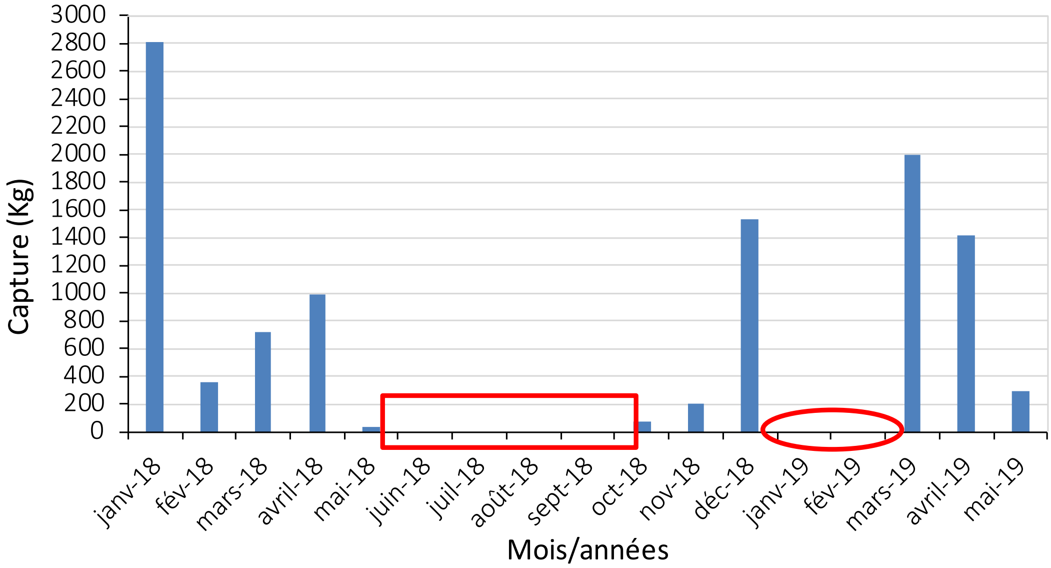

Figure 1. Évolution mensuelle des captures moyennes (poids humide total) des holothuries de janvier 2018 à mai 2019

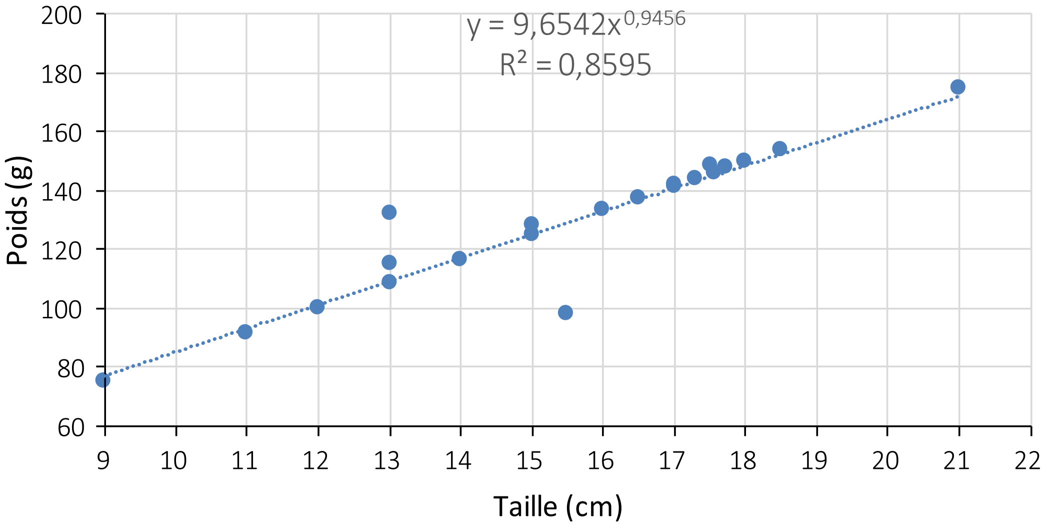

Figure 2. Relation entre la longueur et le poids des holothuries

Conclusion

Dès lors que les concombres de mer deviennent des cibles de pêche à forte valeur commerciale, il est nécessaire de poursuivre les travaux de recherche afin de pouvoir déterminer avec plus de précision les espèces présentes sur le plateau continental béninois.

Au début de la pêche par les chinois, l'administration des pêches ignorait l'importance de ces espèces qui ne sont pas répertoriées dans les statistiques alors que les chinois les pêchent en grande quantité. C'est la constance dans la production qui a attiré l'attention de l'administration qui a commencé à collecter systématiquement les données au débarquement. Aujourd'hui une licence a été instituée pour leur pêche afin de contribuer au budget national. Ainsi cette filière devra être bien organisée.

Remerciements

Sincères remerciements au Professeur Gustav Paulay de Florida Museum of Natural History, USA, qui a déterminé le genre des holothuries et qui continue de travailler à la détermination des espèces.

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COMMUNICATIONS

WANGUMAR: A new company focused on advice and consultancy in sea cucumber aquaculture and fisheries management from the Mediterranean and northeast Atlantic regions

Mercedes González-Wangüemert[1]

In the last few years, there has been an increase in demand for sea cucumbers from Asian countries. Sea cucumbers are being exported mainly from Asian countries, such as Japan, China and Hong Kong (González-Wangüemert et al. 2018), although Mediterranean countries – such as Turkey, Greece, Spain and France – are also exporting sea cucumbers. As an example, Turkey reached a total production of 1292 t in 2019 (Dereli and Aydin 2021). The main importing countries are Hong Kong, the United States and China, although Spain (2152 t), France (363 t), and Belgium (236 t) are also importing sea cucumbers, probably to later re-export them to other countries, considering the low consumption of these species in Europe (González-Wangüemert et al. 2018).

Overexploitation is driving the risk of extinction of the most commercially valuable sea cucumber species, with 16 species now classified as "vulnerable" or "endangered" on the International Union for Conservation of Nature Red List (Conand et al. 2014). As consequence, Asian markets are looking for new target species, mainly from the Mediterranean Sea and northeast Atlantic Ocean (Gonzalez-Wangüemert et al. 2014; 2015; 2016; 2018). The most important species are *Holothuria polii* and *H. tubulosa* from the Mediterranean Sea; *Holothuria mammata*, *H. sanctori*, *H. forskali*, and *Parastichopus regalis*, inhabiting both the Mediterranean Sea and northeast Atlantic Ocean; and *Holothuria arguinensis*, with a very restricted geographical distribution, including the Portuguese coast from Berlengas to Castro Marim, South Atlantic Spanish coast, Canary Islands and northwestern African coast. In the recent years though, this species is colonising the Mediterranean Sea (González-Wangüemert and Borrero-Perez 2012).

Increasing fishing pressure on these species during the last few years and some symptoms of overexploitation of their stocks have been recorded (González-Wangüemert et al. 2015; 2018). Also, many illegal catches are being registered in different European countries due to non-existent or insufficient regulations (Fig. 1). Considering the complexity of developing a proper management plan for the European sea cucumber fishery, based on experience with tropical species, aquaculture could be a sustainable way to expand sea cucumber production, thereby decreasing fishing pressure on wild stocks. Aquaculture could be an essential tool for restocking wild populations, if necessary (Fig. 2a, Fig. 2b and Fig. 3).

Figure 1. *Holothuria arguinensis* individuals caught in southwestern Spain.

Despite the ecological and economical importance of this resource, very few experts are working on these new target species in the Mediterranean and northeast Atlantic regions. These experts are essential to carrying out consultancy actions on stock assessments, accurate species identification, regulations and rules for fishery management, and the development of aquaculture production.

WANGUMAR (Wangüemert Fisheries Management and Aquaculture SLU; www.wangumar.com) fills an empty niche with regard to marine consultancy linked to sea cucumber fishery and aquaculture in the Mediterranean and northeast Atlantic regions. This company is intending to promote the

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Figure 2. Thermal induction for reproduction of *Holothuria arguinensis* (left) and *Holothuria mammata* (right) breeders.

Figure 3. Aquaculture production of *Holothuria arguinensis* juveniles.

Figure 4. Polyculture system, including *Holothuria arguinensis* and *Ulva* spp.

sustainable exploitation of new marine resources and their use for aquaculture (for food production), and to increase economic returns from polyculture through impact mitigation with integrated multitrophic aquaculture systems, Fig. 4), and to produce bioactives for medical and pharmaceutical applications), thereby diversifying the target species, and offering new opportunities for investment in this sector. This company is based on Dr Wangüemert's 18 years of experience, working in sea cucumber fisheries and aquaculture, mainly with Mediterranean and northeast Atlantic species. This experience has been acquired through several job postings with international research centres and universities, collaborations with private companies and public organisations from different continents, leading the first European sea cucumber aquaculture company (Guatizamar S.L.), travelling, and using a wide network of contacts from different sectors and institutions.

WANGUMAR has carried out different projects on sea cucumbers (fishery, aquaculture, research and training actions)[2] To highlight the FARM project (Asociación de Empresas de Acuicultura de la Región de Murcia), which is currently being developed to assess sea cucumber stocks along the Murcia coast (southeast Spain) (Fig. 5). This project arises from GALPEMUR (Grupo de Acción Local de Pesca y Acuicultura de la Región de Murcia), a local association of fishermen and fish-farmers. This organisation has shown interest in looking for new fishery resources and new potential species for aquaculture, and is getting funding from the European Maritime and Fisheries Fund (www.wangumar.com/portfolio-items/farm-murcia/).

Initiatives like this could: improve the management of sea cucumber resources in the Mediterranean and northeast Atlantic regions, protect their stocks, and allow for better and faster development of their aquaculture production.

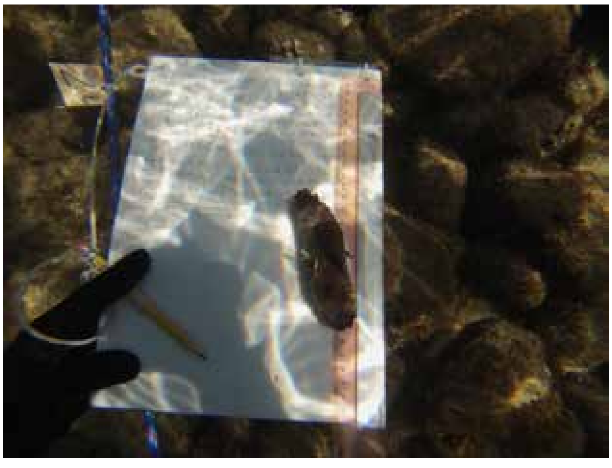

Figure 5. Sea cucumber sampling along transects under the FARM (Asociación de Empresas de Acuicultura de la Región de Murcia) project.

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Sea cucumbers are now harvested in more than 80 countries

Alessandro Lovatelli

Sea cucumbers are now harvested in more than 80 countries. These high-value export commodities are often subject to illegal, unreported and unregulated fishing; therefore, identification tools for fishery and trade workers (including fisheries and customs inspectors) are required to enable proper resource management and reporting. In 2012, the Food and Agriculture Organization of the United Nations (FAO) published the first global guidebook for the identification of commercially exploited sea cucumbers, but species from some ocean regions were not included (the guide is available here: http://www.fao.org/docrep/017/i1918e/i1918e.pdf).

FAO has recently launched the collection of new and updated information that will be included in a second edition of this guide. The new edition may include information on as many as 30–40 additional species that are now fished and traded, including those from the Mediterranean Sea, western Africa and Latin America and the Caribbean. The revised edition will also update information on fisheries, market prices and the distribution of previously reported species.

With the kind financial support from the Muséum national d'Histoire naturelle (Paris –www.mnhn.fr/en), the collection of information has begun for all traded species in the Mediterranean and northeast Atlantic and western Africa, led by Dr Mercedes Wanguemert (mercedes@wangumar.com; wangumemar@gmail.com) and Dr Ed Butler (ed.butler.fish@gmail.com), respectively. FAO is funding the work in Latin America and the Caribbean through the collaboration of Dr Francisco Solís (fasolis@cmarl.unam.mx).

Collecting the information needed will be a challenge because little is actually published or easily available and, therefore, public and private sector people engaged somewhere along the sea cucumber value chains in the Mediterranean and northeast Atlantic, west Africa, Latin America and the Caribbean are kindly invited to contribute by contacting Drs Wanguemert, Butler or Solís directly within the next few months. The work has started so the earlier the better! Thank you. The overall coordination of this FAO project is under the supervision of Mr Alessandro Lovatelli (alessandro.lovatelli@fao.org) with assistance from the FishFinder Programme lead, Dr Kim Friedman (Kim.Friedman@fao.org).

PhD theses

Development of community-based mariculture of sandfish, Holothuria scabra*, in New Ireland Province, Papua New Guinea*

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Abstract

Sea cucumber, processed into its dried form of bêche-de-mer (BDM), is one of the oldest commercial marine commodities in the Pacific Islands region. High prices, low tech harvest and processing methods, strong demand in Asian markets, and well-developed supply chains make it an important economic livelihood for coastal communities in Papua New Guinea (PNG). Sea cucumber fisheries in the Pacific have historically followed boom and bust cycles and are very difficult to manage effectively to maintain sustainable yields. Depletion of sea cucumber stocks led the PNG National Fisheries Authority (NFA) to declare a nation-wide moratorium on the harvest of sea cucumber and sale of BDM from 2009 until 2017. The Tigak and Tsoi Islands in New Ireland Province, PNG, were the site of a commercial fishery for the high-value sea cucumber, sandfish (*Holothuria scabra* Jaeger), for a short period in the late 1980s before it was overfished. Despite no history of mariculture in the study area, sandfish represents a promising aquaculture candidate due to well-established hatchery production and ocean grow-out techniques. Sandfish sea ranching was proposed as a mariculture livelihood activity for Tigak and Tsoi communities; this involves releasing cultured juvenile sandfish (> 3 g) into unfenced areas of suitable habitat under community management, where they would be protected from fishing until they reach commercial size. The initial objective of this study was to assess the potential of sandfish sea ranching as a livelihood activity for Tigak and Tsoi Islands fishing communities. However, lifting of the moratorium during the study provided unexpected opportunities to assess the reopened fishery and the potential for sandfish mariculture alongside it. The focus of this study shifted as a result, to include assessment of social aspects of the sea cucumber fishery and the technical and social factors that may influence uptake of sandfish mariculture as a potential livelihood activity. Research was conducted in three collaborating partner communities; Limanak and Enuk in the Tigak Islands, and Ungakum in the Tsoi Islands.

The first two chapters draw on understandings of local culture and political economy, together with the results from the historic (pre-moratorium; 1988 to 2009), and the contemporary (post-moratorium; 2017) wild sea cucumber fishery, to examine how a livelihood based on sandfish culture could coexist with the wild fishery to increase benefits to coastal communities in PNG. Data presented in Chapter 1 confirmed that sandfish was the main target species in the early wild sea cucumber fishery but had been overfished. A history of disregard for fisheries regulations and poor-quality BDM processing was revealed. Chapter 2 presents socio-economic data on income-earning activities, household income, expenditure, BDM quality, processing, gender roles, diet and attitude toward the fishery from Enuk, Limanak and Ungakum before, during and after the sea cucumber fishery re-opening in 2017. Fishing for sea cucumber and processing BDM replaced most other livelihoods and significantly increased mean weekly household income, which was spent on store-bought foods and assets. Sandfish remained a target species but the season lasted for less than two months before the NFA BDM quota was reached and the fishery closed. These two chapters indicated there was excellent potential for cultural compatibility of sandfish sea ranching due to its value, familiarity and preference among fishers, but raised concerns regarding unsustainable practices.

Research into technical aspects of sea ranching was conducted concurrently with the social research. Results from sea pen grow-out experiments are presented in Chapter 3. Cultured juvenile sandfish (≥ 3-g mean weight) were released into 100-m^2 sea pens, located within suitable seagrass habitat at four sites near the study communities. Newly-released juveniles were provided with nil, one or seven days' cage protection to investigate if short-term predator exclusion increased survival. Cage protection did not significantly affect survival at any site but there were significant differences in overall survival and mean sandfish weight between three sites where juveniles survived. Sandfish growth and sea pen biophysical parameters were monitored at regular intervals for up to 24 months after release. Multivariate analysis of biophysical factors clearly differentiated the sea pen habitats.

One outstanding site, Limanak-1, had high survival and growth of sandfish and its habitat was characterised by higher coarse-grain fraction, seagrass epiphytes and chlorophyll-a sediment content, and low fine-grain fraction. Ungakum, a site with total mortality, had more predators and higher fine-grain fraction. Valuable qualitative data were obtained on the relationship between sandfish and habitat at the four sites. Chapter 4 presents a preliminary assessment of how geographic information systems (GIS) and remote sensing can assist in describing and predicting suitable sandfish mariculture sites. GIS is a valuable tool for aquaculture site selection but underutilised in sea cucumber mariculture. Spectral analyses of WorldView satellite imagery showed promise but were inadequate as stand-alone pre-assessment methods. However, based on these findings and the literature a three-stage GIS approach was proposed: (1) spatial multi-criteria evaluation based on parameters that influence sandfish survival and growth; (2) field data collection and liaison with stakeholders at promising sites; and (3) pilot trials with cultured juveniles at selected suitable sites, to gauge the risk of high predation and other unanticipated factors.

The success of mariculture activities involving the release of cultured marine invertebrates into the ocean is contingent on high survival and appropriate growth rates. However, physical, physiological or behavioural characteristics that differ from those of wild conspecifics, and may compromise the 'fitness' of cultured animals. These may be acquired through hatchery rearing, or as a result of stress induced by the release process. Chapter 5 investigated the influence of such factors on sandfish by comparing survival, growth and behaviour of release-size cultured juveniles to those of like-size wild conspecifics. After 85 days there was no significant difference in weight between cultured and wild sandfish juveniles. Burying behaviour of cultured and wild sandfish juveniles was observed over a 48-h period in natural habitat with or without seagrass. Cultured juveniles were found to be slower to bury in the substrate after release, less likely to be buried at most times, and more likely to be buried in substrate where seagrass was present; however, they became better synchronised with their wild counterparts after 30 h. Survival of cultured and wild sandfish was high in experiments (> 85%), but reduced burying by cultured individuals may increase the potential for predation because diel burying is the main predator avoidance strategy of sandfish juveniles. When combined with the results of Chapter 3, the findings indicate that protection of newly-released juveniles might only be advantageous where predation risk exists, and that seven days of protection may be inadequate. Minimising transportation stress and adhering to best practice release methods are key to successful ocean mariculture.

The quality of BDM from ocean-cultured (hatchery bred) sandfish was compared with that of like-size wild sandfish by processing both groups with identical methods in Chapter 6. The ratio of fresh whole to dried weight, and fresh body wall width, were significantly greater for wild individuals than cultured individuals. However, key determinants of BDM quality, including fresh gutted to dried weight ratio, dried to fresh length ratio, dried body wall width and BDM collagen content, were similar in both groups, indicating that BDM produced from ocean-cultured sandfish has similar recovery rate and quality as that from wild.

Development of mariculture livelihood activities also requires careful attention to the human dimension. Chapter 7 reports on a community trial sea ranch, in which a 5-hectare area was stocked with 5,000 cultured juvenile sandfish in order to: (1) generate data on their survival, growth and movement; and (2) to explore social aspects of community-based management and distribution of economic benefits. In 2018, during the sea cucumber fishing season, sandfish from the trial sea ranch were poached, terminating research at the site. Community attitudes and responses to the 2018 season, mariculture research and the failure of the trial sea ranch were investigated. Widesprea d community approval of the trial sea ranch and respect for the fishing prohibition were reported. However, minor poaching within the ranch escalated because community-based management proved inadequate to sanction the poachers. The trial sea ranch failed due to internal factors (i.e., weak local leadership, community disunity), exacerbated by external pressures (i.e., increased buying pressure, higher prices, limited project oversight). Poor BDM quality and ineffective fisheries management remained concerning. Results of Chapters 2 and 7 are concerning, given that sea ranching success is predicated on adoption of sustainable harvest practices, improved BDM processing and strong community-based management.

This thesis presents the first evaluation of a range of social and technical factors affecting the development of a community-based sandfish mariculture livelihood in New Ireland Province, PNG. The broad and comprehensive approach generated sound baseline data and indicated priority areas for future research. Although no data were obtained from the community-scale sea ranch experiment, other technical investigations into survival, growth, optimal habitat, BDM value and the fitness of cultured sandfish all demonstrated significant potential. These results, and ongoing research in other countries, indicate that technical bottlenecks are unlikely to constrain community sandfish sea ranching success. Unfortunately, there were social barriers to community-based sea cucumber mariculture in New Ireland Province. It was concluded that further development of this livelihood and associated socio-economic benefits will be stymied until there is effective local control of the wild sea cucumber fishery. The findings presented in this thesis contribute to further development of sandfish mariculture in New Ireland Province should the requisite socio-economic conditions be met in the future. This research will also be of value to the development of sea cucumber mariculture elsewhere in the broader Indo-Pacific region.

*Écologie, dynamique de la population et reproduction d'*Echinaster sepositus,Ophioderma longicauda *et de* Parastichopus regalis *au niveau de la côte de Mostaganem*

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Résumé

Notre étude a été réalisée le long de la région littorale de Mostaganem, située à l'Ouest de la côte algérienne, sur les traits de vie de quelques espèces d'échinodermes prélevées par plongée en scaphandre autonome ainsi que par la collecte des prises accessoires des petits métiers à savoir : l'astérie *Echinaster sepositus* (Retzius, 1805) du port de la Salamandre, l'ophiure *Ophioderma longicauda* (Retzius, 1789) de la plage de Stidia, et l'holothurie royale *Parastichopus regalis* (Cuvier, 1817), provenant des eaux profondes de la région de Sidi-Medjdoub et du petit port de Sidi-Lakhdar. Un échantillonnage mensuel a été réalisé pour les deux espèces *Echinaster sepositus* et *Ophioderma longicauda*. Pour l'espèce *Parastichopus regalis*, les échantillons ont été récoltés au niveau des débarquements des petits métiers des ports de Sidi-Medjdoub et de Sidi-Lakhdar.

L'étude des traits de vie de la population d'*Echinaster sepositus* a montré sur un total de 403 individus, un taux de 1.44 % d'hermaphrodisme et un taux de régénération des bras de 2.60%. Par ailleurs, l'analyse des paramètres de reproduction [suivi microscopique des stades de maturités sexuelles et des indices physiologiques (indice gonadique et indice du caeca pylorique)] a montré un cycle de reproduction annuel, caractérisé par une activité gamétogénetique des individus durant toute la période Printemps–Eté marquée par une ponte qui débute au printemps, devient massive durant l'été et s'étale jusqu'en début d'automne. La structure démographique, présente une distribution bimodale et un recrutement continu pendant toute l'année, particulièrement durant les saisons de printemps et de l'automne. La mortalité naturelle chez les femelles est de 1.113, la valeur de Z est de 1.483 et Z/K de 0.259. En revanche, chez les mâles la mortalité naturelle est de 0.935, Z de 1.883 et Z/K=0.707. Ces résultats ont montré une augmentation de la population d'*Echinaster sepositus* dans le port la Salamandre. Aussi, on a pu déterminer une croissance différente entre les mâles (avec $L\infty$ de 98.28mm) et les femelles (avec $L\infty$ de 88.20mm), ainsi qu'une croissance isométrique entre la longueur des bras et le poids du corps chez cette espèce.

Sur un total de 125 individus d'*Ophioderma longicauda* de la plage de Stidia, le suivi mensuel du rapport des variations morphométriques du disque, a permis de cibler les périodes de la pleine maturité sexuelle localisées aux mois d'Avril et d'Aout. Aussi, l'analyse des gonades a permis de déterminer que cette espèce est à larves planctoniques. La distribution de taille est de forme bimodale, avec un recrutement annuel continu. La mortalité naturelle est de 2.29, et le rapport Z/K de 0.329 ; Ce qui explique la fluctuation du nombre d'individus de la population de cette espèce dans la plage de Stidia. La relation diamètre du disque-poids du corps a montré une croissance isométrique entre ces deux paramètres. Par ailleurs, la relation Longueur de bras - Poids du corps d'*O. longicauda*, a montré une allométrie minorante confirmée par le test t de Student avec $P<0.05$).

L'analyse des prises accessoires des filets de pêche de la région de Sidi-Lakhdar et Sidi- Medjdoub, a révélé la présence d'une espèce d'holothurie de l'ordre des Synallactida L'analyse morphologique, endosqueletique et anatomique de cette espèce indiquent qu'il s'agit de l'holothurie royale *Parastichopus regalis* qui a été signalée pour la première fois dans les eaux de l'Ouest algérien. La population échantillonnée de cette espèce est caractérisée par une distribution bimodale et une relation allométrique minorante entre la taille du corps relaxé et le poids du corps. Par ailleurs, chez *Parastichopus regalis*, on a observé un commensalisme fréquent avec le poisson perle Carapide Carapus acus.

Publications related to holothurians, published in 2020.

By Chantal Conand

A Google Alert, using the word "holothurian", was set up for the period from January to December 2019. The same method had first been used in 2015 to produce the article "Bibliography on holothurians: Access to modern tools to follow new publications", which was published in the SPC.

Table 1. Number of documents related to holothurians published in 2020, from January 1st to December 31

	Category					
Month	General, ecology, biology	Biochemistry, microbiology	Genetics	Aquaculture	Fishery, socioeconomics	Total/month
January	9	9	1		2	21
February	9	6	4	3	4	26
March	20	7	1	2	4	34
April	5	12	1	3	2	23
May	5	7	1		2	15
June	10	11	4		4	29
July	8	9	1		2	20
August	9	12		1	3	25
September		9	3	2	3	17
October	5	8			2	15
November	6	5		2	3	16
December (partial)	2	1		2	2	7
Total	88	96	16	15	33	248
%	35	39	6	6	13	100

NOAA Central Library

Sea Cucumbers 2013-2020

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Jamie Roberts, Librarian, NOAA Central Library
Erin Cheever, Librarian, NOAA Central Library

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June 2020

New species from Brazil: *Chantalia conandae*

The latest issue of *Marine Biology Research* contains a paper by Luciana Martins and Camilla Souto (2020), "Taxonomy of the Brazilian Apodida (Holothuroidea), with the description of new genera in the family Chiridotidae." The authors describe a new genus and new species of a small holothurian. This genus is named in honour of Dr Chantal Conand, in recognition for her contributions to research on Holothuroidea.

This small species lives in the sediment of Ubatuba and São Sebastião, Brazil

Chantalia conandae Martins and Souto, 2020

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