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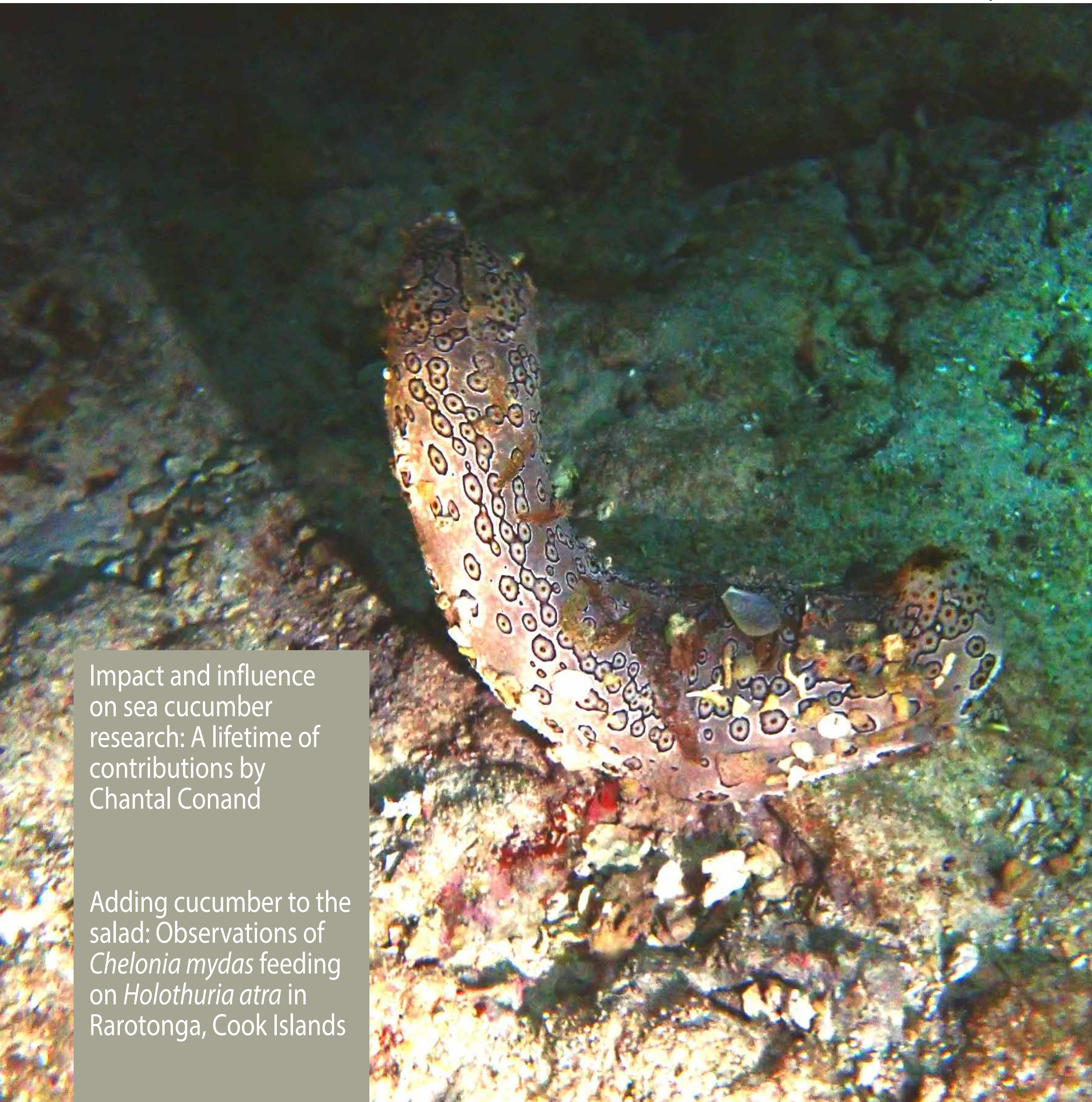

Impact and influence on sea cucumber research: A lifetime of contributions by Chantal Conand

Adding cucumber to the salad: Observations of *Chelonia mydas* feeding on *Holothuria atra* in Rarotonga, Cook Islands

Inside this issue

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Editorial

It is a pleasure for me to introduce this 45th issue of the SPC *Beche-de-mer Information Bulletin* because it is particularly dedicated to a person who is dear to us, Chantal Conand. Chantal has had an extremely prolific professional life, and we wanted to pay tribute to her by trying to summarise her extraordinary scientific production that she has had, and still has today (p. 4).

Several contributions in this issue come from the Pacific Ocean. The first comes from Leeworthy (p. 19) who describes the distribution and abundance of burrowing blackfish *Actinopyga spinea* on Gould Reef (Great Barrier Reef, Queensland), and compares his data to previous findings. The second article, by Byrne et al. (p. 31), shares observations of juvenile *Holothuria scabra* at Low Isles on the northern Great Barrier Reef. Argyle et al. (p. 35) give information about *Chelonia mydas* feeding on *Holothuria atra* in the shallow lagoon at Aroa, Rarotonga, Cook Islands. Tanita et al. (p. 38) inform us about *Bohadschia argus* spawning in the Central Province of Solomon Islands.

It is uncommon to have articles reporting on Chinese practices regarding sea cucumber aquaculture. Cong et al. (p. 40) inform us about a newly emerging farming practice in China integrating sea cucumber cultivation and photovoltaics.

In a previous issue, we learned that the sea cucumber *Cucumaria frondosa* was explored by some communities in northern Canada as a possible fishery. This issue of the bulletin includes three articles relating to the biology of this species in this location, which has rather extreme environmental conditions. Morrisson et al. (p. 44) used video surveys obtained with a remotely operated vehicle at the Belcher Islands, Hudson Bay, Nunavut to assess the distributional patterns of *C. frondosa*. Pierrat et al. (p. 56) describe an unconventional association between a marine halacarid mite (Arthropoda) and the early juveniles of this species in Nunavut. Ma et al. (p. 59) talk about unexpected biotic substrata utilised by newly settled recruits of that sea cucumber in their nursery habitat. Before leaving the Far North, Morrow et al. (p. 63) explores the historical development, regulation, and nature of wildlife crime and illegal fishing in Canadian sea cucumber fisheries.

Four articles come to us from the Indian Ocean. Keesing and Bessey report on the possible local extinction of *Holothuria lessoni* at Ashmore Reef, northwestern Australia (p. 76). Jayasekara and Dissanayake (p. 82) review the development of sandfish aquaculture in Sri Lanka. Eeckhaut et al. (p. 92) let students speak on the theoretical and practical courses they followed during their training in Madagascar on aquaculture and farming of *Holothuria scabra* (International Certificate in Artisanal Mariculture and Village Farming). Vaitilingon et al. (p. 100) detail the development of the first pilot-scale sandfish hatchery production in Mauritius.

Finally, the last three articles offered to us come from the Mediterranean. Lebouazda and Mezali (p. 109) characterise the body wall of *Holothuria sanctori* sampled in Algeria. Guetat and F. Sellem (p. 115) give us some complementary observations about *Holothuria poli* and *Cucumaria syracusana* living in Boughrara Lagoon. And finally, Zerroual and Mezali (p. 117) examine the reproductive capacity of *Holothuria poli* and *Holothuria tubulosa* sampled in the west coast of this country.

This issue ends with various information, the first being on the role of the IUCN Species Survival Commission Sea Cucumber Specialist Group by Mercier. Zang and Eeckhaut present a new Chinese-Belgian joint laboratory – Interaction and Aquaculture of Marine Economic Organisms – to learn about sea cucumber biology.

Igor Eeckhaut

Cover picture: Spawning of a male *Bohadschia argus*. Photo: Iwao Tanita

Impact and influence on sea cucumber research: A lifetime of contributions by Chantal Conand

François Conand,[1] Steven W. Purcell,[2*] Igor Eeckhaut,[3] Patrick Frouin,[4] Sven Uthicke,[5] Maria Byrne,[6] Aymeric Desurmont,[7] Alessandro Lovatelli,[8] Annie Mercier,[9] Jean-François Hamel,[9] Poh Sze Choo,[10] Kim Friedman,[11,12] and all of Chantal's friends

Abstract

This article illustrates Chantal Conand's extraordinary scientific contributions and rich professional life. Chantal has published 30 books and/or book chapters, more than 50 peer-reviewed scientific articles, and over 100 technical papers and reports. She has participated in over 30 symposia and seminars, and has co-organised several international and regional events. Her research has started, and advanced, much of what we know about tropical sea cucumber reproduction, ecology, biology, distribution, trade and conservation. She was the Managing Editor of the *Beche-de-mer Information Bulletin*, and has been a referee for many international journals, programmes, and PhD dissertations. But Chantal's legacy stretches far beyond publications, presentations and meetings. Upon her retirement, she leaves behind a stream of highly motivated scientists and researchers that will undoubtedly continue her work with the same passion that she has. And for many of us, Chantal is above all an unforgettable woman, full of energy and kindness.

Breaking new ground on sea cucumber research (by François Conand)

Chantal Kurtz was born in Poland in 1943. Her father was French-German and born in France. Her mother was from Switzerland with Polish and Russian parents. A good European melting pot albeit an impossible situation during the Second World War. In 1944 when the Russians reached Kiev, Chantal and her mother fled Poland to take refuge in Germany. The family finally landed in Marseille, France in 1947.

In 1965, I came from Grenoble in the Alps to Marseille to specialise in marine biology and met, with great interest Chantal, a young teacher of zoology practical work at the University of Marseille. In addition to our mutual interest in marine biology, several common interests brought us together: our love of skiing, Poland where I travelled and had friends, and Chantal's cousins in Grenoble that I knew a little.

At the end of 1967, I left for Senegal and worked on the island of Gorée at the marine station of the University of Dakar. A few months later, Chantal came to visit and we took part in a campaign aboard the research vessel *Charcot* and we all know how that ended! In September 1968, we got married and stayed in Senegal for eight years. I worked at ORSTOM (later to become IRD the French national Institute of Research for sustainable Development) and Chantal quickly found a position at the University of Dakar where she taught zoology (see Fig. 1), with a strong focus in marine biology. Chantal studied the reproduction of the bluefish (*Pomatomus saltatrix*) and presented a master's thesis on this subject. I studied the reproduction of sardines (*Sardinella aurita* and *S. maderensis*) as part of a regional programme of the Food and Agriculture Organization of the United Nations.

In 1977, ORSTOM asked me to change my assignment, and we left for New Caledonia where we stayed for six years. There was no university there at the time, but Chantal was able to do some research work and ORSTOM offered her a small contract to study the sea cucumber fishery. This fishery was a small activity, occasionally practiced by villagers. Her administrative position then improved and she developed an exhaustive programme on sea cucumbers in New Caledonia (Fig. 2).

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Figure 1. Chantal giving a practical course in Senegal in 1974.

In 1984, we moved to Brest, France where we stayed nine years. Chantal taught at the University of Western Brittany and analysed the observations and measurements made in New Caledonia. She published various articles that positioned her as a key person in the world of sea cucumbers and completed her PhD (Fig. 3).

After nine years in Brest, we dearly missed the tropical seas. The Indian Ocean attracted us and we went to Reunion, where Chantal became a professor at the Université of La Réunion and headed the marine ecology laboratory.

She formally retired in 2003, but is still very active 20 years later, although she has said many, many times that she has finished. The holothurians will deeply miss their "mama holothurian" but she hopes to keep close connections with all the friends that have been part of her life over the years and across the oceans.

Figure 2. Chantal falling in love with the sea cucumber *Thelenota ananas* in New Caledonia, 1983.

Ecology of New Caledonia's sea cucumbers (by Steve Purcell)

It was in New Caledonia in 2001, working with WorldFish on sea cucumber restocking, when I came to know firsthand about Chantal's studies on sea cucumbers in the territory. More than two decades prior to my stint in Noumea, she had been conducting research for her PhD dissertation at ORSTOM (now IRD) right on the coastline of the suburb of Anse Vata. I happened to acquire a hardcopy of her book, *Les Holothuries Aspidochirotes du* *lagon de Nouvelle-Calédonie: biologie, écologie et exploitation* (Conand 1989), which includes her dissertation and associated studies. That was a humbling moment – seeing how much she had achieved and the quality of her work. It stands as, arguably, the most seminal publication on sea cucumbers. Chantal's book became, and still is, a bible of everything pertaining to sea cucumbers in New Caledonia: the species, their ecology, distribution, biology, reproduction, growth, trade and fishery management. Many, though not all, of the studies in that book were published elsewhere in international and regional journals.

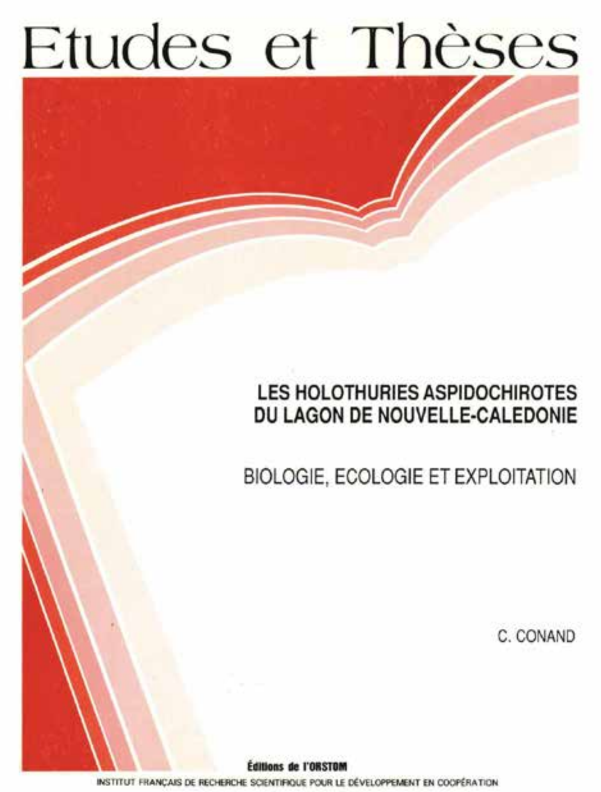

Figure 3. Chantal's PhD dissertation and studies, published in 1989.

Chantal's first published study from New Caledonia was on weight loss of sea cucumbers from postharvest processing (Conand 1979). She would later detail the processing methods in New Caledonia and their impact on product quality (Conand 1989). This work would be later incorporated into a manual on commercial species of the tropical Pacific (Conand 1994). The data were instrumental in forming equivalent minimum size limits for dried products and for calculating profits from purchases and sales.

One of Chantal's most significant contributions is her research on the reproductive biology of sea cucumbers in New Caledonia's lagoon systems (see following section). Her published works on the reproductive cycles of sea cucumbers in New Caledonia date back to the early 1980s, showing differing reproductive cycles among species (Conand 1982). Her work on size at first maturity of sea cucumbers (Conand 1989, 1990) remains one of the few published studies to underpin minimum legal size limits in fisheries throughout the Indo-Pacific.

My own research on tagging and the growth of sea cucumbers stood on the shoulders of Chantal's studies. She pioneered methods using weight-frequency distributions from sampling populations at different times to estimate growth. Her studies demonstrated the slow growth rates and long lifespans of some holothuroid species, reinforcing concerns about their susceptibility to overfishing (Conand 1988a). Her studies using external tags galvanised early reports that sea cucumbers could move within a home range and some individuals shrank in weight (Conand 1991). Her thesis and studies book provided more details of the mark and recapture studies (Conand 1989). Incredibly, she tagged 2500 wild individuals among six species! However, recapture rates were low and the studies led her to conclude that external (T-bar) tags are shed readily by most species and cause legions that could limit growth (Conand 1983). The findings later prompted the development of more reliable tagging methods, offering a reminder that research failures are also worth publishing.

Chantal's studies also helped to document the fisheries and trade of sea cucumbers in New Caledonia. She reconstructed a timeline of exports of beche-de-mer from New Caledonia (Conand 1988b). She urged for more attention to collecting catch-per-unit-effort data in fisheries (Conand 1988b) – a point still echoed by other scholars to this day. In Chantal's early publications from New Caledonia, she analysed trends in the exploitation of sea cucumbers from the territory and their trade globally (Conand and Hoffschir 1991). The study documented the fishing effort at the time, and the target species and sale prices.

Furthering her early reports about trade, Chantal also explored the socioeconomics of sea cucumber fishers in New Caledonia (Conand 1989). This was contrasted with production statistics from other parts of the Pacific Islands region. She discussed the boom in beche-de-mer exports from the territory in the early 1920s, and the pressing boom in production in the 1980s (Conand 1988a, 1988b, 1989, 1990). This presentation of trade data surely provided the signals for more vigilance in managing the fisheries, and the studies in New Caledonia that would come decades later.

Sea cucumber reproduction (by Igor Eeckhaut, Maria Byrne and Sven Uthicke)

Sea cucumber reproduction was a large part of Chantal's doctoral dissertation. She defended her PhD at the Université de Bretagne Occidentale in France on 2 July 1988 for the award of the degree of Doctor of Natural Sciences (Conand 1988a, later published as Conand 1989). It was undertaken at the ORSTOM Center in Noumea and completed at the Laboratory of Biological Oceanography of the Université de Bretagne Occidentale in Brest under the supervision of Professor Glemarec. ORSTOM allowed her to carry out her research as part of its programmes in Noumea. Her dissertation, *Les Holothuries Aspidochirotes du lagon de Nouvelle-Calédonie: biologie, écologie et exploitation,*

Figure 4. Chantal with Hampus Eriksson (left) and Steve Purcell (center) at a processing station in Zanzibar, 2012.

contains 393 pages, including 49 pages devoted to the reproduction of 9 species: *Holothuria nobilis*, *H. fuscopunctata*, *H. atra*, *H. scabra*, *H. scabra* var. *versicolor*, *Actinopyga echinites*, *A. mauritiana*, *Stichopus variegatus* and *Thelenota ananas*. Chantal was not new to the study of reproduction in marine animals. From 1970 to 1977, she studied the reproductive biology of coastal pelagic fishes from Senegal (Conand 1975, 1977).

Similar to her work on size and growth, Chantal's PhD dissertation remains a reference work in the field of sea cucumber reproduction. At that time, the main knowledge of sea cucumber reproduction came mainly from the reviews of Hyman (1955), Boolootian (1966) and Bakus (1973), and through the works of Engstrom (1980), Franklin (1980), Harriot (1982), Shelley (1981) and Ong Che and Gomez (1985) on tropical species. From monthly samplings in New Caledonia's southwest lagoon, Chantal analysed the sex ratio, gonad anatomy, sexual cycle and fecundity of nine species. In these contributions, Chantal also provided key information on the links between reproduction and ecology. This body of work from New Caledonia, especially for commercially exploited species, has been used extensively for fishery management and species conservation.

With this dissertation and her subsequent work, Chantal published 12 articles in international peer-reviewed journals (Conand 1982, 1993a, 1993b, 1996; Conand and De Ridder 1990; Tuwo and Conand 1992; Conand et al. 2002; Uthicke and Conand 2005; Gaudron et al. 2008; Kohler et al. 2009; Mezzali et al. 2014; Marquet et al. 2017) and 4 in other journals (Conand et al. 1997; Jaquemet et al. 1999 Hoareau and Conand 2001; Hoareau et al. 2008), mainly the *Beche-de-mer Information Bulletin*.

During her time in Reunion, Chantal significantly advanced our understanding of the reproductive biology of sea cucumbers in the western Indian Ocean, and other aspects of the biology and ecology of echinoderms from the region (Mangion et al. 2004; Gaudron et al. 2008; Kohler et al. 2009; Conand et al. 2016). Although most of Chantal's research was in tropical sea cucumbers, she also made important contributions on the biology of Mediterranean species (Tuwo and Conand 1992; Mezali et al. 2014).

In addition to sexual reproduction, Chantal also investigated asexual reproduction by transverse fission in several species. Her first work on asexual reproduction was on *Holothuria atra* in New Caledonia (Conand and DeRidder 1990), and this was followed by many studies on other species in other countries. For instance, asexual reproduction in *Stichopus chloronotus* was studied intensively by Chantal and her students and collaborators in Reunion (Conand et al. 1999; Hoareau et al. 2008). Chantal's team also discovered asexual reproduction in species previously not known for transverse vision in *Holothuria leucospilota* (in Conand et al. 1997) and *H. hilla* (in Hoareau et al. 2008).

My (Sven Uthicke's) first collaboration with Chantal was using genetic tools we developed on the Great Barrier Reef to assess asexual reproduction in two species of cucumbers. The three-week research trip visiting Chantal and François in Reunion was one of the most memorable travels as an early career researcher. The work we did at that stage was very productive, and genetic work confirmed the differences in the amount of asexual reproduction between locations (Uthicke and Conand 2005; Uthicke et al. 2001) and resulted in several other publications (e.g. Uthicke and Benzie 1999).

Chantal recently published a chapter in the book *The World of Sea Cucumbers – Challenges, Advances and Innovations* (Uthicke and Conand 2024) about fission as an auxiliary reproductive mode in holothuroids with a detailed look at *Holothuria atra* and *Stichopus chloronotus*.

Chantal has, through her works, established methodologies to quantify the reproduction of sea cucumbers. Her method is that a good study of the reproductive cycle includes the evolution of the different states of gonad maturity and, for that, she defined five of them through the species she has studied. These must be completed by the evolution of a gonadal index and the weight of the gonads. Chantal's approach to investigating sea cucumber reproduction has been widely adopted and remains the standard today.

My (Maria Byrne's) first publication with Chantal (Conand and Byrne 1993), was the start of a long friendship with many holidays with her and François in France and Australia. We saw Chantal and Francois several times when they visited Australia to see Gabi and family who were living in Melbourne. They also came on holidays with us and to the country with me. We always had a lot of fun.

World fisheries and trade (by Alessandro Lovatelli, Poh Sze Choo and Kim Friedman)

Chantal's expertise led her to collaborate extensively with the Food and Agriculture Organization of the United Nations (FAO). Her work with FAO, often in partnership with Sandro (Alessandro Lovatelli, a senior aquaculture officer), resulted in several landmark publications that have shaped the global understanding and sustainable management of sea cucumber fisheries (Toral-Granda et al. 2008).

Chantal has also been an assiduous user of FAO production and trade statistics, leveraging these data to provide comprehensive analyses of global fisheries and trade (Conand et al. 2024). Her regular publications have offered valuable insights into the status of fisheries, identifying trends, challenges, and opportunities for the global market. These contributions have been critical in informing stakeholders and guiding sustainable management practices worldwide.

One of Chantal's earliest contributions to FAO was co-editing the 2004 FAO Fisheries Technical Paper No. 463, *Advances in Sea Cucumber Aquaculture and Management*, which provided comprehensive guidance on fishery management strategies (Lovatelli et al. 2004). This work was particularly relevant because sea cucumber populations faced increasing pressure due to overfishing that was driven by high demand from Asian markets. Building on this work, Chantal was a key contributor to the 2008 publication *Sea Cucumbers: A Global Review of Fisheries and Trade* (FAO Fisheries Technical Paper No. 516). This pivotal report examined critical issues, such as declining populations, unsustainable harvesting practices, and trade challenges. It offered actionable recommendations to policymakers and fisheries managers for promoting sustainable harvesting and responsible trade practices.

Her collaboration with FAO continued with the 2012 publication *Commercially Important Sea Cucumbers of the World* (FAO Species Catalogue for Fishery Purposes No. 6; Purcell et al. 2012) and again for the second edition, published in 2023 (Purcell et al. 2023). This comprehensive reference work, co-authored by her, supports effective fisheries management and the trade of sea cucumbers globally (Figs 5 and 6).

Beyond these publications, Chantal's work with FAO has emphasised capacity building and the development of sustainable practices in sea cucumber fisheries. Her collaborations have frequently involved workshops and knowledge-sharing events aimed at enhancing the capabilities of local communities and fisheries managers to adopt sustainable harvesting techniques. In 1999, Chantal accepted an invitation from the organisers (Fisheries Research Institute, Penang, Malaysia and Heriot-Watt University, Orkney Campus, Scotland) of an international conference on "The Conservation of Sea Cucumbers in Malaysia: Their taxonomy, Ecology and Trade" where she presented a paper (Chantal 1999) on "World sea cucumber exploitation and the market for trepang: An overview". Chantal was introduced to the participants as "the world's foremost authority on sea cucumbers". Despite her outstanding achievements, her unassuming and friendly nature has encouraged many novice scientists to develop an interest in sea cucumber research. Since this first encounter, I (P.S. Choo) have further benefited from her generous sharing of knowledge, and we had made several visits to Langkawi Island and Sabah in Malaysia to collect information on the sea cucumber fisheries there. She was also game enough to try the raw sea cucumber (*Acaudina molpadidoides*) appetizer, which is a dish unique to Langkawi Island (Fig. 7) (Choo et al. 2016).

Recognising the shortfalls in investment of fisheries management, overexploitation and declining stocks in the western Indian Ocean region, she co-led a three-year project funded by the Western Indian Ocean Marine Science Association. This project evaluated knowledge on sea cucumbers, conducted research on their ecology, biology, and socioeconomics. These outputs ultimately influenced management practices in countries such as Kenya, Madagascar, Reunion (France), Seychelles, and Tanzania.

Her efforts in the western Indian Ocean have been instrumental in highlighting the need for improved governance structures and sustainable practices in sea cucumber fisheries, and the findings have been documented in several publications (Conand and Muthiga 2007; Conand and Muthiga

2010). The projects had increased the understanding of the status of sea cucumbers and their management, including the potential for aquaculture in the western Indian Ocean, provided key skills to management, and increased the knowledge of the impacts of the fishery on the socioeconomic status of coastal communities.

Her research has provided critical insights into the economic and ecological aspects of sea cucumber fisheries, emphasising the need for sustainable practices, but also providing the background material for the creation of global trade controls to ensure commercialisation does not threaten species in the wild. In this capacity Chantal has been a primary contributor of proposals that support the addition of sea cucumbers to CITES appendices. Working with officers of the French government, Chantal has highlighted the vulnerability of a number of trade species, resulting in submissions by the European Union for amendments to CITES appendices (market controls) in 2019 (Shedrawi et al. 2019), and likely for submissions in preparation for the 20th CITES Conference of Parties to proceed in 2025.

Complex trade networks and market dynamics drive the global sea cucumber industry. Chantal has been instrumental in identifying the socioeconomic impacts of overfishing on local communities, and has advocated for policies that balance economic benefits with ecological sustainability. Her publications have been pivotal in shaping international trade regulations and promoting responsible harvesting practices. Through her extensive analyses and broad collaborations, Chantal has helped to develop strategies that ensure the long-term viability of sea cucumber fisheries, benefiting both the environment and the livelihoods of those dependent on this valuable resource.

Biology and diversity of Indian Ocean sea cucumbers (by Patrick Frouin)

I met Chantal in September 1999 when I joined the Marine Ecology Lab, directed by Chantal, at the Université de La Réunion. She had been working there for about six years. Her focus was mainly on sea cucumber reproduction at that time. She did a huge amount of work on several major species in Reunion and always involved students in her studies (e.g. Gaudron et al. 2008 on *Holothuria leucospilota*). I can still find vials full of gonads in Bouin's solution, as they were everywhere in the lab facility. A joke in the lab is that Chantal depleted all of the sea cucumbers in Reunion with her studies! But, because we still have the world's highest densities for the three main species she targeted (*Stichopus chloronotus, H. leucospilota, H. atra*), we know this is just a lab legend. Later, we coped with more functional features, trying to understand the feeding patterns of *H. leucospilota* and *H. atra* (Taddei 2006, a PhD study Chantal and I supervised; Mangion et al 2004). That was an early focus on matter transit through holothurian individuals in tropical environments. Some work on nutrition has been done since

Figure 5. Chantal working with regional participants as she co-facilitates the Sea Cucumber Fisheries: An Ecosystem Approach to Management workshop in Zanzibar, 2012.

Figure 6. Chantal with Hampus Eriksson (left), Alesandro Lovatelli (right behind) and Steve Purcell (right, in front) at a processing facility in Zanzibar, 2011.

Figure 7. Chantal at the sea cucumber hatchery on Pulau Sayak, Malaysia, 2014.

Chantal retired, but even if not co-authoring those papers, she always had an interest in the PhD or Master's students, as soon as they worked on sea cucumbers. Students always mattered to her. She provided them with much advice and positive input, as would any sea cucumber nanny. They often kept in touch with Chantal, many years after they went their own way, showing the positive effect she could have on them.

In the late 1990s and early 2000s, Chantal spent a lot of energy strengthening a sea cucumber network in the Indian Ocean. First connected to the IH.SM (Institut Halieutique et des Sciences Marines, University of Toliara, Madagascar), through Dr Man Waï Rabenevanana, she made this collaboration important for our lab. It is still active today. WIOMSA – Western Indian Ocean Marine Science Association, which was born when Chantal arrived in Reunion – has become a powerful regional institution that helped Chantal promote sea cucumbers. Always interested in fisheries and the conservation of holothurian species, she led, with Dr Nyawira Muthiga, a large WIOMSA Marine Science for Management Regional Sea Cucumber Project, involving Kenya, Reunion, Madagascar, Seychelles and Tanzania (Conand and Muthiga 2007). I still remember Chantal in Mombasa, Kenya, working with the team to identify some local species of sea cucumbers and extract gonads (Fig.8). She was also very active on the field (Fig. 9). The work resulted in a comprehensive review of the regional knowledge of sea cucumbers, including monitoring and management guidelines.

Chantal has also contributed to improving the knowledge about sea cucumber diversity in the western Indian Ocean, especially in Reunion, Mayotte and the Scattered Islands in the Mozambique Channel. She was involved in several field studies and collaborated with many people. She produced, with colleagues, the first inventory of holothurian species from Reunion (Conand et al. 2010) – 37 species at the time – but also a general inventory of echinoderm species, from 0 to 1000 m depth (Conand et al. 2018). In the first focus on sea cucumbers, they found 10 species in the Glorioso Islands (Mulochau and Conand 2008) and 27 in Mayotte (Conand et al. 2005). Now richness is 12 species in the Glorioso Islands (Conand et al. 2016) and still the same in Mayotte.

Since her retirement in 2003 as an Emeritus Professor, Chantal has remained deeply committed to sea cucumber research. Always overbooked, always on the move. She has traveled the world to share her findings and insights on these strange creatures (from the general public's perspective, not a researcher's). When illness prevented her from working, she suffered, but the moment she could get back to her computer, reconnect to the internet, and dive into science again, she recovered. Her book of life still has many pages to be written. As a legacy to Reunion territory, beyond publications, Chantal left some persistent sea cucumber print in our lab as we are several colleagues working on these animals.

Figure 8. Chantal sharing experience about holothurian gonad extraction, Mombasa, Kenya, 2006.

Figure 9. Chantal and local experts, starting a field session in Mombasa Marine National Park and Reserve, 2006.

Sea cucumber conservation (by Annie Mercier and Jean-François Hamel)

Chantal's influence on the sea cucumber research community may have originated on the sunny islands of the Indian and Pacific oceans but it eventually spread far and wide to the cold rocky shores of the Northwest Atlantic Ocean in eastern Canada. We discovered her thesis and associated works in the 1980s when we first started exploring the biology of northern dendrochirotid sea cucumbers. There were few scientists working on this topic at the time, and knowledge sharing in the pre-internet era was painfully slow. Fortunately, Chantal responded warmly to our letters and graciously mailed us printed versions of her voluminous publications. When dialup internet emerged in the early 1990s, Chantal was among the first persons we contacted via a computer. Over the years, all her foundational contributions on the reproduction, fisheries and trade of sea cucumbers found echoes in our own investigations, and we connected despite the initial geographic and taxonomic divides. Our collaboration and friendship grew as we started working on tropical sea cucumbers in the Solomon Islands, Marshall Islands and Ecuador, and we published together for the first time (Hamel et al. 2001).

Importantly, Chantal's commitment to holothuroid echinoderms has always run much deeper than scientific curiosity. She positioned herself both as a leading researcher and as a fierce advocate of sustainable management and conservation initiatives. We first discovered this at a 2003 FAO workshop on Advances in Sea Cucumber Aquaculture and Management in Dalian (China), which had been prompted by growing worldwide interest in the resource following her seminal technical paper (Conand 1990). On the heels of this meeting, Chantal published an eye-opening overview where she described the goals and outcome of a technical workshop of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) she attended in Malaysia (Conand 2004a). Her key contributions as a Working Group Chair to that first sea cucumber conservation workshop were instrumental in helping develop future efforts (Conand 2004b, c, 2006a, b).

In 2007, another FAO workshop was convened in the Galapagos Islands (Ecuador), this one on "Managing Sea Cucumber Fisheries from an Ecosystem Approach". Chantal was among the lead participants and contributors to a technical paper aimed at helping stakeholders choose appropriate regulatory measures and management actions (Fig. 10) (Purcell 2010). Three years later, Chantal took part in the Sea Cucumber Red List Workshop hosted by the International Union for Conservation of Nature in Cartagena, Colombia to tackle the first formal assessment of the conservation status of over 360 species (Fig. 11). She spearheaded many of the resulting assessments, including those on *Actinopyga flammea*, *Bohadschia marmorata*, *Holothuria fuscogilva*, *H. moebii*, *H. nobilis*, *H. whitmaei*, *Pearsonothuria graeffei* and *Thelenota ananas* (Conand 2013a, b; Conand and Purcell 2013; Conand et al. 2013a–e) and published a summary

Figure 10. Chantal and other participants of the FAO workshop in the Galapagos.

of the meeting, which had ended with 16 sea cucumber species showcased on the IUCN Red List of Threatened Species (Conand et al. 2014).

In the following years, Chantal became a driving force behind proposals to consider listing sea cucumbers in the genera *Holothuria* (*Microthele*) and *Thelenota* inside CITES Appendix II drafted at the 30th Meeting of the Animals Committee and submitted at the 18th Conference of the Parties in 2019. The proposals relied heavily on Chantal's extensive publication record and direct feedback through personal communications. The positive result of this momentous initiative (Di Simone et al. 2021) is in no small part due to her fierce determination in convincing the CITES Scientific Authority in France. Chantal subsequently authored and co-authored several contributions on sea cucumber conservation (e.g. Byrne et al. 2022; Conand et al. 2023, 2024; Di Simone et al. 2023). It comes as no surprise that she joined the IUCN Species Survival Commission Sea Cucumber Specialist Group (see information in this issue). Her legacy also inspired a global assessment of the main threats faced by exploited sea cucumbers, which explores conservation and governance effectiveness, and outlines research perspectives in the context of climate change and booming fisheries crime (Mercier et al. 2025).

Even from this largely incomplete portrait, it is clear that Chantal has been a cornerstone of conservation efforts around holothuroids and that her leadership has resonated across the globe. She may have officially retired but never doubt that she is still fiercely guarding the sea cucumbers of this world and guiding the scientists who continue to study them.

The SPC *Beche-de-mer Information Bulletin* (by Aymeric Desurmont and Igor Eeckhaut)

In March 1988, during the Workshop on Pacific Inshore Fishery Resources, representatives of 22 Pacific Island member countries and territories urged the Pacific Community to become more active in the collection, repackaging and dissemination of information on the key fishery resources of the region. Beche-de-mer was top on the list. It was, therefore, decided to create an information bulletin to facilitate this exchange of information. To make sure the information collected and disseminated would be of high quality, and scientifically proofed, SPC looked for a specialist who would accept to take up the demanding role of the Bulletin's coordinator and scientific editor. For all those involved in the search, there was no hesitation on who should be approached first.

Our tireless Chantal kindly accepted the offer and the first issue of the SPC *Beche-de-mer Information Bulletin* (the BDM) was published in January 1990. Under her guidance, the bulletin reputation grew steadily and became more than just a simple newsletter: a very serious information journal where one can find relevant and useful information on sea cucumbers, including information about their biology, biodiversity, fisheries, trade, and their global aquaculture development. As of today, BDM remains the only scientific and technical publication fully dedicated to sea cucumbers. And, of course, Chantal didn't limit herself to her scientific editor's role, she authored or co-authored 34 articles published in this journal, once again reflecting her overflowing scientific activity.

Figure 11. Chantal and other participants of the IUCN workshop in Cartagena, Colombia in 2010.

In late 2007, following the publication of issue #26, Chantal asked me (Igor) to succeed her as scientific editor of the BDM, which I accepted with pleasure and honour, although I knew that it would be a difficult challenge to meet, given Chantal's exceptional contribution to the development of the bulletin. But as usual, Chantal helped me rise to the challenge, and thanks to her network of friends, her kindness, her passion and her unfailing help, 17 other issues have since been produced. Thanks to this network of friends and our work, the BDM now regularly reaches over 70 pages (128 p. for this issue!) of information per issue, freely available worldwide.

A big "thank you" to you, Chantal, for your shared knowledge, your good humour and your eternal youth, which we can see in the last photos of this article…

Acknowledgements

The team of co-authors is aware of the friendly relational network that Chantal has created during her professional life. It was impossible for us to invite all of Chantal's friends to contribute to this article, but we are certain that all of them associate themselves with the purpose of this article. We thank all of Chantal's friends for their understanding.

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Figure 12. Chantal travels on a quad bike with Igor (top left). She does not hesitate to dive during samplings (top right). To do this, she must stay in top form by lifting weights (bottom left). But there's also time for fun and partying (bottom right). And always with a smile…

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Solving localised depletion: Dynamics of the burrowing blackfish (*Actinopyga spinea*) population on Gould Reef, Great Barrier Reef, Australia

Grant Leeworthy[1,2]

Abstract

The prime objective of this paper is to describe the distribution and abundance of burrowing blackfish, *Actinopyga spinea*, on Gould Reef within the Great Barrier Reef of Australia, and compare these data to previous findings. The secondary objective is to present options for managing the fishery into the future.

A first survey of the Gould Reef sea cucumber population occurred in 2004, with a second survey conducted in 2006. In this paper we present a third survey, conducted in 2009, to continue the monitoring process as the burrowing blackfish fishery enters its ninth year of exploitation.

In 2004, the burrowing blackfish population on Gould Reef was in an unexploited state, with a stock biomass of 1643 t in gutted weight. Two years of harvesting followed at the conservative level of 45 t per annum before the resource was reassessed during the 2006 monitoring survey. Biomass in 2006 was estimated to be 1330 t in gutted weight. Harvesting continued at the level of approximately 45 t per annum until the 2009 survey. From the results of that survey, the estimate for the biomass of the burrowing blackfish within Gould Reef was 1489 t in gutted weight.

Different estimates of natural mortality are presented with a corresponding estimate of maximum sustainable yield. Further investigations into sustainable yields are presented in a risk-based framework. The catch-cost-risk model is applied. A cost–benefit analysis was conducted for future management and research options according to likely impacts on the total allowable catch. Further recommendations regarding the spatial distribution of diving effort are presented.

Introduction

This report details the third survey of the burrowing blackfish (*Actinopyga spinea*) population within Gould Reef, which is part of the Great Barrier Reef in Queensland, Australia. This highly productive section of the East Coast Beche De Mer Fishery (ECBDMF) has now yielded more than 290 t (blanched weight) of sea cucumber product since it was first fished. This harvesting supports a valuable export-based industry.

The ECBDMF has been managed with a global total allowable catch (TAC) and individually transferable quotas (ITQs) since 1991. A performance monitoring system (PMS) was developed by the Queensland Department of Primary Industries and Fisheries (QDPI&F) to meet the requirements of the Environment Protection and Biodiversity Conservation Act 1999. Catches of burrowing blackfish currently form a part of the "mixed species" quota although now, through the PMS, species are segregated by species-specific and spatially specific catch limits within the fishery (QDPI&F 2008). With this framework to expand catches comes a greater responsibility to demonstrate sustainability. The PMS requires that these segregated species catches are surveyed at least every three years to monitor performance. If these surveys are not completed, the catch limits are returned to their original levels, which for burrowing blackfish would be 15 t per annum. These and other management responses were developed through consultations between industry participants and fishery managers to ensure that harvesting remains sustainable and the resource is safeguarded. The 2009 survey was undertaken within three years of the previous, 2006, survey.

The formation of the Queensland Sea Cucumber Association (QSCA) has seen a large investment by the industry in the research and development required for managing the sea cucumber species that are targeted by the fishery. QSCA initiatives such as the memorandum of understanding and the rotational harvesting system have been applied as management tools aimed at preventing overharvesting of individual areas. The continued effort to monitor the burrowing blackfish sea cucumber resource has set this fishery on track to demonstrate its sustainability, if the successful application of spatial management can be achieved.

The prime objective of this paper is to describe the distribution and abundance of burrowing blackfish on Gould Reef, and compare these data to previous findings. The secondary objective is to present options for managing the fishery into the future.

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Materials and methods

Samplings

The methods used to resurvey the burrowing blackfish stock followed those detailed in Leeworthy 2007a. This report should be read in conjunction with Leeworthy and Skewes (2007), which gives greater detail about the method used for underwater visual censuses. The method used for the 2009 study was adapted, with only 53 sites were sampled, and focusing on the area where core abundance was previously located. While this survey design is less spatially extensive, it covers most of the population and is adequate for monitoring purposes. Re-calibration of waypoints used for sample locations occurred during the current survey, and an abridged version of the methods is included below.

Gould Reef is an inner barrier reef atoll formation approximately 38 nm northeast of the coastal town of Bowen adjacent to the Great Barrier Reef (Fig. 1). The depth of sampling varied from 11 m to 26 m. The habitat inside the lagoon varies from coral bombies and rubble near the outer edges, to

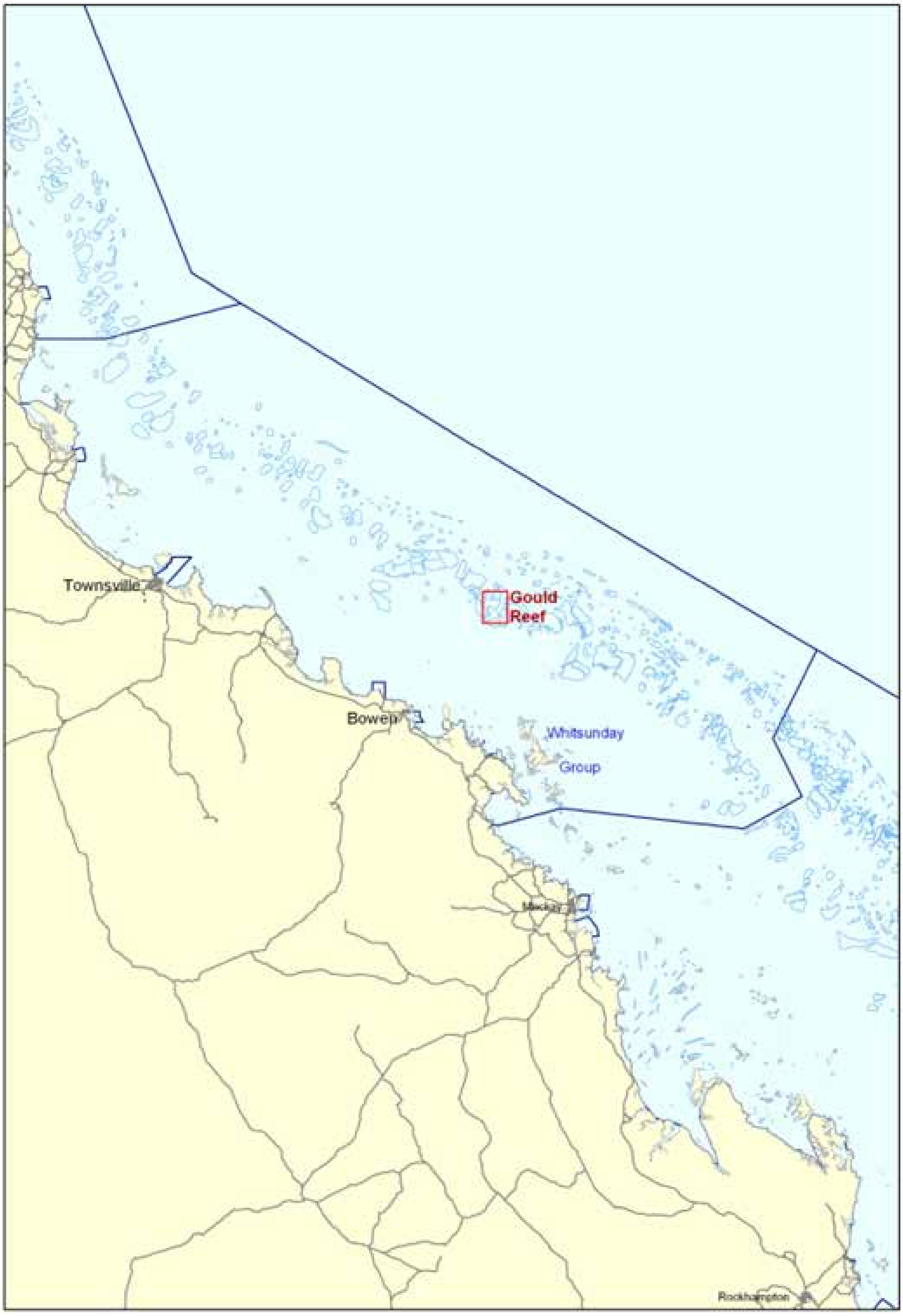

Figure 1. Gould Reef within the Great Barrier Reef.

patches of dense marine algae and open sand with filamentous algae throughout the centre and western sections.

The study was conducted from the fishing vessel *Thor* between 5 and 12 September 2009. Weather conditions for the survey were very good, with light to variable winds with a maximum strength of 10–12 kt. One 5-m dory was used as a dive tender vessel with two crew members alternating as divers. A georeferenced satellite image of Gould Reef was used to predetermine the coordinates for sampling sites. Coordinates were programmed into a Garmin® GPS and the GOTO mode was used to locate waypoints. Two divers undertook the samplings to meet the project's budget, time and depth (decompression requirement) constraints. The divers alternated, with one person diving while the other was on a surface interval, driving the dory. Diving was conducted using a hookah compressor rigged with an inline high-pressure reserve bottle on the dory as a backup. All dives were planned according to AS 2299 decompression tables, and monitored with a dive computer. Divers carried an emergency bailout bottle to allow for a safe ascent in the event of a severed or disconnected hose. A weighted rope was passed down to a diver at the end of a transect to allow for easier monitoring of ascent rate. Ascents were kept at a precautionary 3 m/minute stop at 3–5 m.

The primary objective of this study was to estimate the biomass of burrowing blackfish within the Gould Reef lagoon, and to determine if any change in abundance had occurred over the time the fishery had been operating on the reef. Hence, an estimation of abundance was required. An effective direct survey of abundance also requires accurate distribution maps for the species of interest (King 1995; Hender et al. 2001; Gunderson 1993). A distribution map of burrowing blackfish existed from previous studies of Gould Reef and this was used to determine sample locations. A systematic grid design is the most accurate method of sampling for the purpose of mapping as it keeps spatial error to a minimum (Hender et al. 2001). As previous surveys had highlighted spatial effects of fishing upon the stock, continuing with a systematic sampling design was appropriate as this would help track changes in abundance in previously sampled locations.

In the 2004 survey of Gould Reef, the lagoon area was divided by the total number of samples that were possible to achieve within the proposed three-week sampling programme. This worked out to a pattern of one 400-m^2 transect for every half-minute of latitude and longitude. This measure was chosen due to the ease of working with the half-minute of latitude and longitude coordinates on the GPS. At Gould Reef, one half minute of latitude equates to 926.6 m, and one-half minute of longitude is equivalent to 873 m. This made each transect representative of approximately 808,921 m^2 of lagoon floor. These figures, as used in biomass calculations, have been recalibrated since 2004.

In the 2009 survey, sampling focused on the areas where the highest concentration of burrowing blackfish had been previously recorded, with 53 transects being completed during this survey. Areas that had previously been recorded as having unfavourable habitats (Leeworthy 2007a) were excluded from the 2009 sampling.

A strip-transect method was used, and was conducted by having one diver swim in a single direction for a given distance, and counting the number of sea cucumbers in a given area (1 m each side) on a tally counter. The width of the transect was governed by a 2-m-wide pole. Boundary effects were dealt with by including borderline individuals on the right and end of the transect, but not on the start and left end of the transect (Andrew and Mapstone 1987). Habitat and other data were recorded on waterproof paper attached to a clipboard. Transect length was governed by a Chainman™ hip-chain device, and the direction monitored by a Suunto® underwater compass. The Chainman™ devices were modified for use in saltwater by replacing the spool mechanism with a stainless-steel bolt and drilling a hole in the body of the counter to allow for the addition of the lubricant WD40 to prevent corrosion (Tim Skewes pers. comm. 2004; Leeworthy and Skewes 2007). All sampling devices were assembled into a workstation (Figs. 2 and 3), with the addition of a triple-deck tally counter (Leeworthy 2006). The transect length was 200 m, giving a sample area of 400 m^2 (as per Leeworthy 2007a).

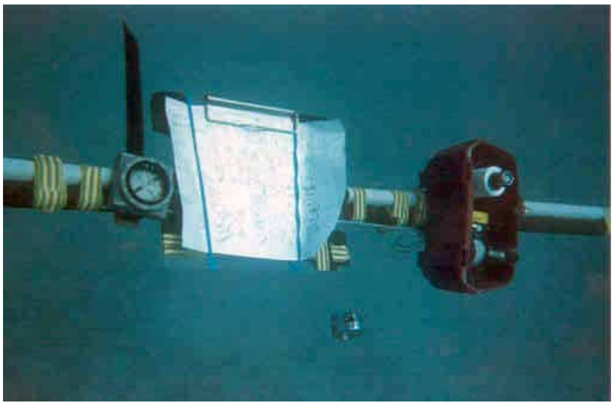

Figure 2. Detail of sampling station used to survey burrowing blackfish.

To minimise observer bias in sampling, the two divers were carefully trained in the identification of different holothurians and techniques regarding inclusions and/or exclusions for boundary effects with the sampling design (Thompson and Mapstone 1997; Purcell et al. 2009). Particular attention was focused on the differentiation between various species of sea cucumbers that have similar pigmentation to the burrowing blackfish (e.g. *Holothuria atra, H. leucospilota* and *Actinopyga palauensis*).

Population structure, spatial pattern, and potential for fishery exploitation

Biomass calculations for the 2009 survey rely on mean weight calculations derived from the larger scale (n = 93) sampling undertaken in 2006 (Leeworthy 2006). These samples were measured and weighed after gutting. The mean fresh-gutted weight was used in biomass calculations.

Measurement of spatial pattern

The two-term local quadrat variance analysis (Hill 1973) was used to determine the diameter of patches of burrowing blackfish during the 2006 survey (Leeworthy 2006; Leeworthy 2007c).

A basic biomass model, $MSY = xMB_o$, was used to give an indication of the potential fishery yields available from the burrowing blackfish resource, according to the maximum sustainable yield (MSY) (Perry et al. 1999; Skewes et al. 2004). This model was designed to give a precautionary initial estimate of MSY for sea cucumbers and other benthic invertebrates. Various estimates of natural mortality (0.5, 0.6, 0.7 and 0.8) are compared as a sensitivity analysis, and a precautionary scaling factor (x) of 0.2 is applied (see Perry et al. 1999). This approach has been used to produce MSY estimates for sea cucumber and rock lobster fisheries in Australia's Torres Strait (Pitcher et al. 1992; Skewes et al. 2004). For MSY, the lower 90% confidence limit of the survey standing stock estimate is used in this model for the biomass parameter, B, as an added precautionary approach (expressed as a fresh-gutted weight) (as per Skewes et al. 2004). This means there is a 95% chance that the true value is larger than the estimate used. A further method of analysis is used for comparing these estimates where the shortfall in estimated biomass is divided by the number of years since the last survey. Assumptions made by both methods are discussed.

Estimates of natural mortality (M) were converted to an estimated maximum age using Hoenig's equation to allow ease of interpretation regarding the assumptions made by various estimates of M (Hoenig 1983). The "catch/cost/risk" framework is applied to various estimates of MSY to determine the optimum path for future research, management and harvesting strategies (Sainsbury 2005). The effective localised exploitation rate ($ELER$) and F_{local} are described as indicators of the level of serial depletion by a given fishing method.

Results

Burrowing blackfish distribution and spatial pattern

Burrowing blackfish abundance has been observed to be highest in open, fine-sand habitats in the central area of the Gould Reef lagoon. The distribution of burrowing blackfish (abundance counts per 400-m^2 transect) observed in the Gould Reef lagoon over successive surveys conducted in 2004, 2006 and 2009 are presented in Figure 3.

The spatial pattern of the burrowing blackfish stock was first studied in 2006 as part of the second monitoring survey (Leeworthy 2006). The two-term local quadrat variance analysis (Hill 1973), as described in Leeworthy (2007c), was used to determine the diameter of patches of burrowing blackfish.

The peak variance from the three contiguous quadrat transects was approximately 155 m. A minor variance peak is discernible at around 40 m. Peak variance occurs at the radius of the patch, suggesting that patches of burrowing blackfish abundance have a diameter of between 80 m and 310 m.

The movement of *Holothuria whitmaei* has been measured to be 6.72 m/24 hr (Shiell and Knott 2010). The speed of movement for the species is relatively slow compared with other species targeted by fisheries and, therefore, the speed of emigration and population mixing is expected to be slow.

Burrowing blackfish abundance

The average abundance of burrowing blackfish within Gould Reef is 1638 individuals/ha. The distribution of the abundance of burrowing blackfish within Gould Reef is shown in Figure 3.

Using mean abundance and fresh gutted weight data, the approximate biomass of burrowing blackfish within Gould Reef was calculated. We are 95% sure that the true biomass of burrowing blackfish within Gould Reef is greater than 919 t.

A comparison of biomass estimates from 2004, 2006 and 2009 is presented in Table 1.

Potential for fishery exploitation

Using the biomass model, $MSY = xMB_o$ (Perry et al. 1999; Skewes et al. 2004) and various estimates of natural mortality, potential MSYs for the burrowing blackfish resource were estimated and compared as part of the 2004 survey. These estimates are shown in Table 2.

Perry et al. (1999) used virgin biomass (B_o), not current biomass estimate. This stochastic fishery model estimates the level of fishing pressure at which the resource should compensate for sustainability. This does not mean the resource will remain at unexploited levels, but rather assumes a certain decrease in abundance to this level where it will begin more highly productive compensatory growth. These assumptions are discussed below.

Table 1. Comparison between total biomass estimates for each survey (in fresh gutted weight).

Year of survey	LWR 90% CL estimate of biomass	Mean biomass	Precision
2004	1159 t	1643 t	29.42%
2006	612 t	1330 t	40.21%
2009	919 t	1489 t	38.26%

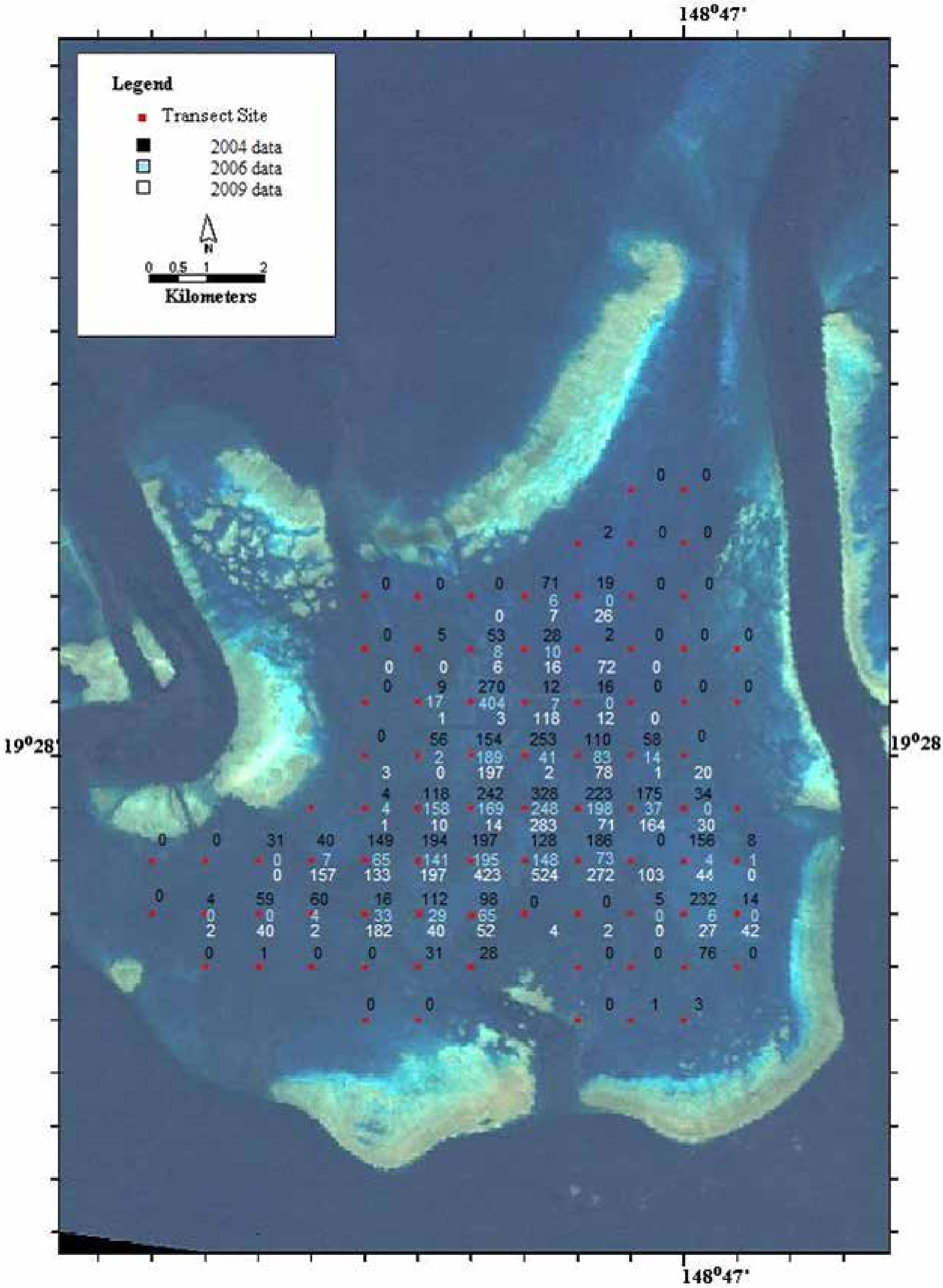

Figure 3. Location of sampling sites on Gould Reef, with raw data from abundance counts (per 400-m² transect) for surveys conducted in 2004, 2006 and 2009.

Table 2. Calculation of indicative maximum sustainable yield (MSY) and total allowable catch from Gould Reef according to various estimates of natural mortality (*M*) (Leeworthy 2007a).

M	0.5	0.6	0.7	0.8
MSY fresh gutted (t)	116	139	162	185
MSY blanched (t), assuming 70% recovery	81	97	113	129
Assumed maximum age (Hoenig 1983)	8 years	7 years	6 years	5.5 years

By applying the Perry et al. (1999) equation to the current estimate of biomass, estimates of MSY when using different estimates of *M,* based on the lower 90% confidence limit, are substantially lower. They are compared in Table 3.

An alternative analysis would be to compare the fishery catches over the last six years with the difference in mean biomass estimates between 2004 and 2009. Over this period, the burrowing blackfish has been reduced from 1643 t to 1489 t by a total of 154 t fresh gutted weight or 107.8 t blanched weight (assuming 70% recovery). From these estimates we demonstrate that the burrowing blackfish resource has rebounded by approximately 27 t per annum while being fished at 45 t per annum.

Spatial coverage of fishing effort

The area covered by divers while harvesting burrowing blackfish over the last six years may be an indicator of the impact of fishing effort on the stock. From discussions with one of the skippers operating in the fishery, it was estimated that divers complete seven, 30-minute dives at a speed of 2 kt (3704 m/hr) from the current. If divers fish effectively, it is assumed they could harvest all sea cucumbers in an area 2.5-m wide. From the average catch data (estimated to be 1500 kg/day at Gould Reef) it was estimated that a vessel covers 97,230 m^2 of sea floor each day they dive. This extrapolates to an annual spatial coverage of 2,916,900 m^2 of sea floor. When divided by the total area that was sampled during this survey (42,872,855 m^2) this equates to a spatial coverage (a) of 6.8% per annum. From these estimates, 40.8% of the lagoon's sea floor may have been dived on over the last six years (noting the need for greater testing of these parameters).

Related to this analysis of fished area is the estimation of fishing power (q) for the collecting method. Divers may swim over burrowing blackfish stocks but may not necessarily harvest every individual. The localised level of fishing power or q_{local} may give an indication of the level of impact the fishery has had on the potential productivity of the resource (after Quinn and Deriso 1952). To estimate q_{local}, the estimated average daily catch in boiled and gutted weight (U) for the reef was divided by the multiple of the estimated average density per hectare (D), the average fresh gutted weight (W) and the estimated daily coverage of the seafloor (a). The term DWa is then converted to boiled and gutted weight using two different estimates of processing recovery.

$$q_{local} = (U/DWa) \times (100/1)$$

From this analysis q_{local} has been estimated to be between 84.3% and 98.4%, depending on the estimate of processing recovery (i.e. the percentage return from fresh gutted weight to cooked gutted weight) used in the equation. While this fishing power is significant, it may reflect the high degree of selectivity in dive sites undertaken by skippers to maximise their daily catch. To test the assumed daily coverage of sea floor, I have recalculated this equation solving for U using the estimated average daily catch (1500 kg cooked and gutted weight) and an assumed processing recovery. This test shows that according to the average density and weight figures from previous surveys, the average catch per day equates to somewhere between 1524 kg/day and 1779 kg/day boiled gutted weight if divers were 100% efficient at catching all of sea cucumbers they encountered in their swept area. This suggests a high degree of agreement between the estimates of area covered by divers each day, and the true area covered each day, noting assumptions.

Due to the slow rate of mixing and the fine-scale patchiness of the stock's spatial pattern, it is likely that the hyperstability in catch per unit effort (U) analyses would make catch per unit effort a poor proxy for stock abundance for this fishery (Hilborn and Walters 1992). For this reason, further area-based methods of assessment and management are needed for this fishery.

Spatial analysis of catch

If fishing effort is spread throughout the entire reef, it may be necessary to reduce the quota to 27 t as this has been shown to be the current level of compensation per annum. If, however, there is a high degree of spatial clustering of fishing effort, then it is likely that this clustering has reduced the productivity of the reef in certain areas while underutilising other areas. MSY is set on the basis that harvests are spread over the entire reef (100% of the area). If, however, the TAC over the last six years has been taken out of just 40.8% of the reef (6.8% per annum) with little overlap, spread of effort or migration, then *ELER* may be close to 100% for that area while the remaining 59.2% of the reef remains as an unfished population (keeping the former analysis of q_{local} in mind). This fishing pattern is consistent with a serial depletion scenario for the fishery and compensation is occurring only on the perimeter of fished areas if density-dependant growth is as much of a factor in sea cucumber growth as has been suggested by data gathered during the Lizard Island survey (Leeworthy 2007b). The remaining 59.2% could then still be fished sustainably if effort was spread at the same level of compensation as was experienced in the 40.8% area (27 t/annum/59.2% of the reef). If there is a greater distribution of diving effort

Table 3. Calculation of indicative maximum sustainable yield (MSY) and total allowable catch from the 2009 survey day for Gould Reef, according to various estimates of natural mortality (*M*).

M	0.5	0.6	0.7	0.8
MSY fresh gutted (t)	91.9	110.28	128.66	147
MSY blanched (t), assuming 70% recovery	64.33	77.19	90.06	103
Assumed maximum age (Hoenig 1983)	8 years	7 years	6 years	5.5 years

each year, then the percentage of area that had a higher-than-sustainable *ELER* would be lower.

Observations of the GPS plotters from two vessels during the 2006 survey suggest that a high degree of clustering of fishing effort has occurred in the southeast corner of the reef, although the patterns of exploitation used varied from well spread drift diving (with unharvested areas left between drifts) to highly clustered depletion patterns, suggesting that the previously described serial depletion pattern of fishing is unlikely. If we estimate that the 6.8% annual area coverage has been spread over approximately 30% of the total reef area, then 27 t of productivity is coming from a suboptimally harvested area that is close to one-third the size of the reef. If this is confirmed through further spatial analysis of catch data, the true sustainable yield for the fishery may be at least 81 t/annum in the future. A precautionary approach for now would be to reduce exploitation rates in areas where clustered fishing effort has occurred in the past, and increase effort in areas that remain underexploited and ensure that *ELER* for these areas is kept at sustainable levels. A TAC set by using this approach would be approximately 54.06 t/annum until we gain data showing a full recovery of the southeast corner of the reef. Options for various TAC levels, corresponding risk analysis, and associated mitigating costs (the catch/cost/risk framework) are shown for Gould Reef in Table 4.

The cost–benefit ratio for various management options (measured in terms of departure from status quo TAC of 45 t/annum) are shown in Table 5.

Discussion

This survey has shown that the stock biomass of burrowing blackfish (*Actinopyga spinea*) remains in good condition throughout Gould Reef. While some issues of concern have been highlighted, the scale of impact of harvesting over the past six years has been within acceptable levels. Biomass has decreased 9% from virgin levels over the last six years, whereas the PMS highlights that a 15% reduction over three years would trigger a cautionary management response. This result has supported the QSCA's approach for originally setting a highly conservative TAC for Gould Reef. This has allowed adequate time for feedback from the monitoring programme to be gathered. It also has given the industry the opportunity to gain a firm understanding of the processes governing productivity of the resource, and has allowed it to apply a truly precautionary approach to adaptive fisheries management. Although the resource is in good condition, more can be done to improve the productivity of the stock through the spatial management of harvesting, which in turn, will improve growth rates and potentially, reproductive success. More also can be done to improve the precision of assessments, which will help guide management in the future.

Spatial pattern of burrowing blackfish and its impact on productivity

In the study by Leeworthy (2006), the two-term local quadrat variance analysis was used to determine the spatial pattern of the burrowing blackfish (*Actinopyga spinea*) stock.

Table 4. Catch/cost/risk framework for the Gould Reef fishery (from Sainsbury 2005).

Current risk ranking	TAC	Management requirements to enable low risk ranking	Estimated cost
Low risk	19.33 t	No change in management	Negligible
Medium risk	34.00 t	Spatial closure in highly exploited area	Negligible
Medium risk	42.80 t	Monitoring the effective localised exploitation rate (*ELER*) through diver data as well as spatial closure in highly exploited area	AUD 20,000
Medium risk	54.06 t	Monitoring *ELER* through diver data as well as spatial closure in highly exploited area	AUD 25,000
Higher risk	64.33 t	Video tow sled survey to CI ± 10% of the mean as a precision goal + monitoring of *ELER* and spatial management of harvests. Inter-annual assessment.	AUD 30,000
Higher risk	103.00 t	All the above measures plus alternating harvest rates in different areas to gain better estimates of replacement.	AUD 40,000

Table 5. Cost–benefit analysis of various management options. Note: Assuming standard processing recovery and AUD/kg profit margin.

Potential TAC	Estimated value of lost production from current TAC level	Opportunity cost of increased production	Cost–benefit ratio
19.33 t	AUD 359,380/annum	-	-
34 t	AUD 154,000/annum	-	-
42.8 t	AUD 30,000/annum	-	-
54.06 t	-	AUD 126,840/annum	5:1
64.33 t	-	AUD 270,620/annum	9:1
103 t	-	AUD 812,000/annum	20:1

This analysis determined that the aggregations of burrowing blackfish are between 80 m and 310 m in diameter. Observations of unfished aggregations suggest that the biomass and density of burrowing blackfish is highest in favourable habitats that are covered with brown filamentous algae (Leeworthy 2007a). While a lower level of abundance occurs across a wide range of habitats, sensitivity analysis (Leeworthy unpublished data) has revealed that these patches of high biomass add the most weight to the biomass estimate as a whole and, therefore, TAC is higher.

It is, therefore, important that each of these patches is preserved to ensure ongoing productivity of the fishery. Of the two vessels that were visited during the 2006 survey, one was fishing in a pattern that would result in the serial depletion of these aggregations. This was highlighted and addressed by QSCA at an industry meeting in 2007. The results from the current survey suggest a modest rebound in abundance in the previously depleted area as there has been a shift in effort away from the area.

Localised impacts on abundance in the immediate area of any fishing operation are to be expected (as gathering an abundant marine resource is the objective of all fisheries). However, some patterns of fishing effort have a detrimental effect on productivity. For this reason, QSCA has encouraged the fishing effort to be spread out to ensure that continued harvesting allows for greater productivity in the stock and shorter periods of reduced density in areas subject to fishing pressure. The two vessels visited during the 2006 survey were observed to be following different fishing patterns, thereby providing an example of how the spatial pattern of fishing effort can affect productivity.

1. The first fishing pattern observed was where a skipper fished with the anchor down (or working "live" from a dory), completely removing all sea cucumbers (other than non-marketable sizes and species) within 100 m of the vessel. Once one diver has completely fished a circular area around the vessel, the skipper then moves the vessel to another area 100 m away and successively removes all the sea cucumbers there. This continues in adjoining areas by using GPS positioning to expand the area fished using positive feedback from catches as the information to base movement direction on. This decision process is efficient for the individual skipper as movement from one area of high sea cucumber abundance to another immediately adjoining area saves time searching for new ground (i.e. areas of high abundance). This pattern, if followed methodically (i.e. with the use of GPS plotting technology), would reduce the compensation possible due to low remaining stock density in an area of acceptable habitat. This fishing pattern has, therefore, reduced technical, interannual efficiency as productive habitat is left underutilised for sea cucumber growth (estimated to be 20–30% residual stock in the localised area). From the raw data analysis, we can see an area depleted in the southeastern corner of the reef which, from the vessels' GPS plotter (see Figs 4 and 5), was the key area targeted by this fishing method.

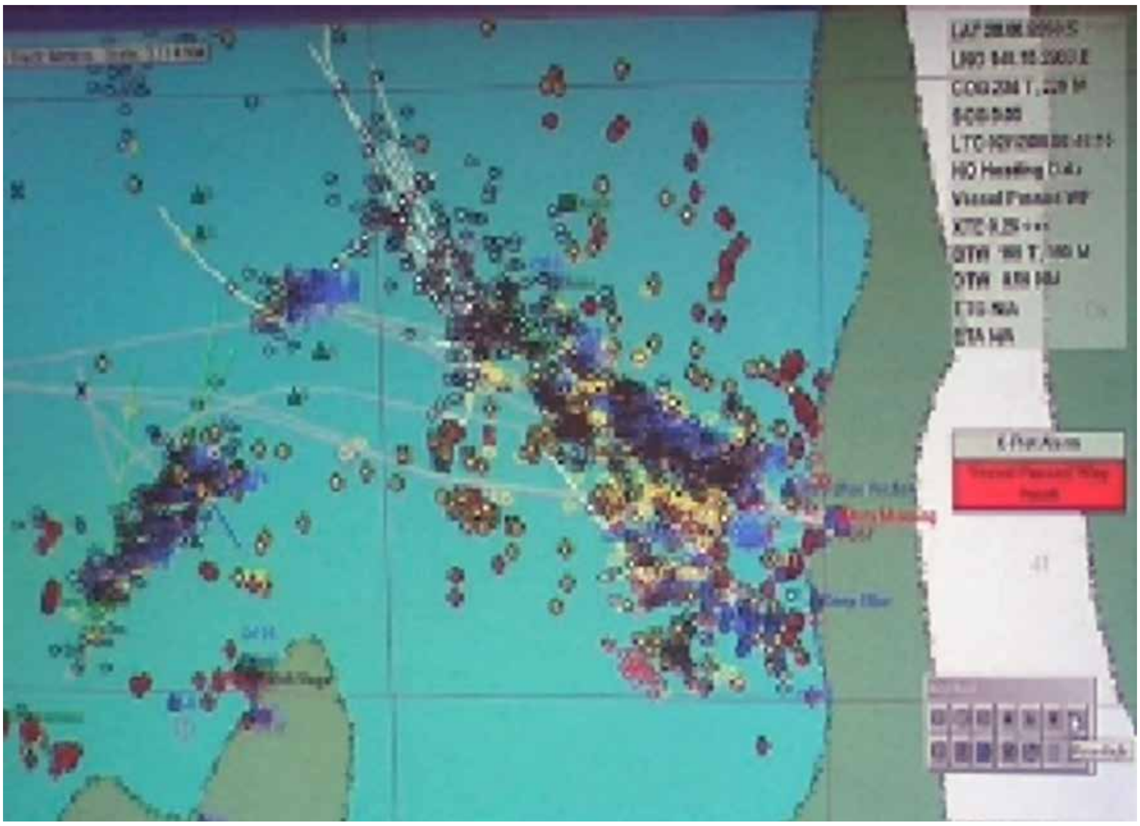

Figure 4. Detail of GPS plotter showing fishing pattern for vessel 1.

2. The second example is that of a drift diving vessel where a skipper uses a sea anchor to move the vessel slowly with the current to allow his divers to harvest in narrow strips (estimated to be 2 m x 2.5 m wide) across the acceptable habitat. This spreads depletion from fishing effort in long strips that are readily repopulated by stock from either side of the depleted area. This way, the productive habitat is reutilised by adjoining sea cucumbers that migrate into the lower abundance area within as short a time frame as 24 hours after harvesting has occurred. *Holothuria whitmaei* has been observed to move at speeds of 6.72 m/24 hr (Shiell and Knott 2010). Compensatory growth in the stock is enhanced from this spread of effort as density is reduced, thereby giving more food resources per individual (Constable 1989). The fishing pattern for drift diving is shown in Figure 5.

The anchored fishing method and the similar individual dory method of sea cucumber harvesting may be made sustainable if the skipper moves an adequate distance to allow space between fished areas. In the same manner, drift diving could overlap and create depleted areas although the diving decompression limits place a disincentive against going over areas that may have previously been fished, thus reducing catch per dive.

In both cases, the use of previously measured abundance data on a scale relevant to the fishing operation could encourage skippers to spread out fishing effort farther so they rely less on their own positive feedback loop from catches to support their decisions as to where they dive.

The $ELER$ and F_{local} equations are proposed as indicators of the level of spatial distribution of fishing effort relative to the area of the stock. The two equations are:

$$ELER = (a/\,(A_{Sp}) + (A_{TRL}))\ \text{x}\ (100/1)$$

$$F_{local} = ELER/F_{MSY}$$

Where $ELER$ is the effective localised exploitation rate, a is the area covered by divers during fishing, ASp is the area of a circle ($A = \pi r^2$) that equates to the spatial pattern of a stock, determined through a spatial pattern analysis such as the two-term local quadrat variance analysis, which estimates the radius (r) of the patch of interest.

Another spatially explicit variance analysis could also be used to estimate this area (e.g. Bailey and Gatrell 1995): A_{TRL} is two times the radius as previously determined, multiplied by the travel range length for the stock that refers to a vector that includes 95% of the displacements for a given species measured from tagging or observation data (Griffiths and Wilke 2002) but could also include distance at which 95% of fertilisation takes place. F_{local} is the localised fishing mortality and F_{MSY} is the fishing mortality equal to MSY (optimum sustainable yield or maximum economic yield could also be substituted). Where $F_{local} \leq 1$, the fishery is at or below the sustainable harvest rate and is, therefore, not subject to localised or serial depletion. Where F_{local} greatly exceeds 1, it is likely that the fishing pattern can be contributing to serial depletion.

As an example, the $ELER$ and F_{local} were estimated for both anchored fishing and drift diving. The ASp term was determined by area of a circle ($A = \pi r^2$) using the estimate of r (155 m) obtained from the two-term local quadrat variance analysis, TTLQA (A_{Sp} = 7.55 ha). For the A_{TRL} term, an estimate of sea cucumber patch movement was made by estimating the maximum annual potential linear movement

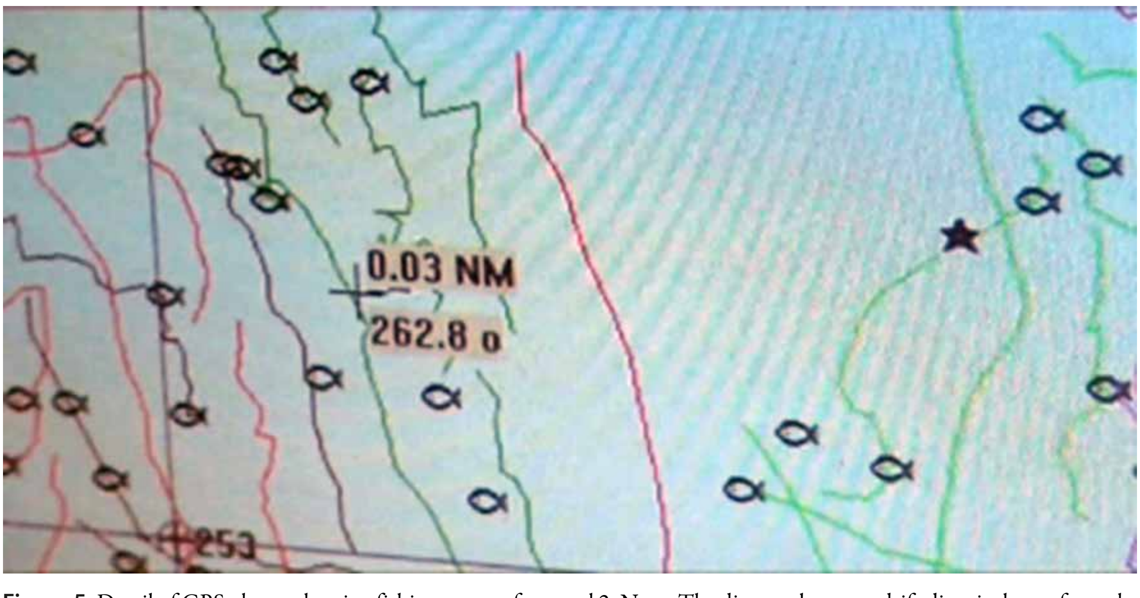

Figure 5. Detail of GPS plotter showing fishing pattern for vessel 2. Note: The distance between drift dives is shown for scale.

of a sea cucumber moving at 6.7 m/24 hr and dividing this by half to account for burial and then 6 to account for the non-linear pattern of movement observed to occur for burrowing blackfish. This estimate equated to 204 m, which was multiplied by the diameter 310 m (*2r* as determined by the TTLQVA). Thus A_{TRL} = 6.34 ha. The term ($A_{Sp} + A_{TRL}$) was then calculated to equal 13.89 ha for the larger diameter patch. Fished area was then estimated for both the anchored fishing method and then the drift diving method as the area fished within the area of the patch of sea cucumber. For the anchored method, a = 11.7 ha, assuming that a 100-m hose was used in a circular pattern around the vessel. For the drift diving method, a = 1.44 ha, assuming two divers covering 2.5 m each with each drift spread 55 m apart (as per observed GPS data). For anchored fishing *ELER* = 84.5% and F_{local} = 8.5, although for drift diving, *ELER* = 10.3% and F_{local} = 1. This basic analysis could explain the localised depletion of burrowing blackfish that occurred in the south-eastern corner of Gould Reef, and why the remainder of the resource appears to be sustainable.

Due to the rapid development of global positioning systems and geographic information systems in recent years, our capacity to conceptualise spatial parameters in fisheries management has also expanded. Concurrent to these technological advances has been a growing push for transparent monitoring and assessment processes that together, with decision rules for fisheries management, are collectively termed harvest strategies (Hilborn and Walters 1992). The requirement to develop formal harvest strategies (e.g. Australian Government 2007) and the QDPI&F performance monitoring system (2008) is not a panacea to all fisheries management problems. With the transparency and formal process conferred by the development of these harvest strategies, care must be taken to not oversimplify spatial issues. While some successful attempts have been made to incorporate spatial issues into fisheries management, there has been no coordinated recognition of the recently developed capacity to improve fisheries management through the use of these spatial tools. Babcock et al. (2005) describe the need to develop spatialised indicators for ecosystem-fisheries management. Orensanz et al. (2004) note that: "How much is allowed to be taken…is only one of the considerations to be made regarding…overfishing: where the catch is taken is likely to be at least as important". Harvest strategies or simple stochastic models (e.g. Perry et al. 1999) that use a "one size fits all" spatial mixing assumption when setting biomass reference points and levels of *F*, are not sufficient to guarantee the sustainability of spatially complex marine fisheries unless *excessive* caution is used when setting them (Gulland 1969; Hilborn 2002; Orensanz et al. 2004; Prince 2005). This is not only inefficient from a cost–benefit standpoint, but will continue to be ineffective in providing ecological sustainability (see Sugden and Williams 1978 and Sainsbury 2005). Further to this, the ineffective spatial management of fisheries reduces the productive potential of these resources, adding to the pattern of stagnation and decline in global wild capture fishery production, which is a threat to food security. To manage fisheries sustainably, an understanding of localised stock dynamics and how fishing effort relates to local stocks is necessary (de la Mare 1996; Die et al.1990; Hilborn 1985; Buckworth 2004; Prince 2005, Babcock et al. 2005; Leeworthy 2007c, Gunderson et al. 2008). The spatial dynamics of how organism abundance, foraging, growth, reproduction and fishing effort interrelate should be explicitly considered. In this context, *ELER* or F_{local} may be used as possible primary drivers for spatially resolved fisheries management that can prevent serial depletion and potentially improve fisheries productivity (Leeworthy 2007a).

The dynamic pool assumption is false for burrowing blackfish

It is important to note that the dynamic pool assumption of most stochastic fishery modelling is incorrect for this fishery. Basic models such as Perry et al. (1999) suggest a conservative MSY estimate that relies on an even spread of fishing mortality (*F*). In assuming that *F* is uniformly applied over a stock, and that compensatory effects of reducing density will also be uniformly distributed, there is potential for a significant degree of error. Most fisheries display some degree of spatial clustering or patchiness. Another consideration is that of the Allee effect of reduced fertilisation of gametes as distance between spawners increases, if a serial depletion fishing pattern is used (Babcock et al. 1994; Levitan 1991; Levitan and Petersen 1995). This effect may be a source of depensation if left unchecked. The QSCA's investment in these monitoring surveys has effectively highlighted this issue before it becomes a problem, thereby overcoming the cost of delay in fisheries management (Shertzer and Prager 2007).

Sea cucumber movement is relatively slow, measured at 6.72 m/24 hr for *Holothuria whitmaei* (Shiell and Knott 2010). It is likely that burrowing blackfish move at a greater rate than this (based on observations of both species), although this is not likely to significantly affect immigration or emigration rates. This ignores the spatial structure in the stock and the spatial pattern of fishing effort. After fishing events, recolonisation of areas depleted by divers would be a slow process if there was a high degree of connectedness of the fished areas, which is the case with anchored fishing. Where drift diving has occurred at an adequate spread, the impacts of harvesting would barely be recognisable after 24–48 hr. A circular depletion pattern has an order of magnitude less perimeter than a linear fishing pattern. As has been strongly suggested, sea cucumbers display density-dependant growth and reproduction (in a similar manner as has been measured in other echinoderms; Constable 1989), compensation would only occur where density had been reduced.

In using the model presented by Perry et al. (1999) we assume a background natural mortality, where M = 0.5 and a scaling factor of 0.2, that when multiplied by the virgin biomass (B_o), would equate to a highly conservative sustainable replacement rate for the stock. I have no doubt that these levels are highly conservative when compared to the true replacement rate of the stock, although when considering the spatial pattern of the stock compared to that of the fishing effort, there is cause for review. To optimise productivity, fishing mortality must be spread over the scale at which compensation occurs.

The initial estimation of F_{local} for the drift diving fishing method – showing a sustainable level of spread of fishing mortality together with the estimated abundance of 1489t (90% CI of ± 38.26%) after six years of harvesting the resource on Gould Reef – are positive indications that long-term sustainability is achievable for the East Coast Beche De Mer Fishery.

Recommendations

- Effort should continue to be moved away from the southeast corner of Gould Reef where it has been noted that a small area has been depleted. Note: A proposed voluntary closed area has been designed for this purpose.
- The study of recolonisation and growth within the depleted area should be a priority as this could lead to the estimation of recruitment and growth parameters.
- GPS data on diving needs to be collected from past fishing and future fishing in order to benefit all participants in the fishery.
- Within-season abundance data should be collected and monitored in real-time as fishing is underway, so that effort can be guided toward areas that have been fished at lower levels of exploitation.
- The continued harvesting of the resource should be managed for an even spread of *F*. The *effective localised exploitation rate* (*ELER*) and F_{local} should be used as performance indicators in this fishery.
- Video transects should be investigated as a means of increasing the spatial resolution of sampling and certainty of estimates.

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A nursery habitat for sandfish (*Holothuria scabra*) found at Low Isles, northern Great Barrier Reef

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Abstract

Holothuria scabra juveniles were observed emerging over time at low tide onto the surface of a sand flat at dusk at Low Isles, northern Great Barrier Reef. The juveniles were similar in size, indicating that they may represent a single cohort. The seagrass, *Halophila ovalis*, was present, which may serve as a settlement substrate for sandfish larvae. Adults were not observed but may occur in deeper habitat. The shallow, sandy habitat at Low Isles is extensive and may be an important nursery area for *H. scabra*, a species of conservation concern. Low Isles is a protected reef with minimal human disturbance and is a promising site for further investigation of sandfish population biology.

Keywords: juvenile sea cucumber, Holothuroidea, Great Barrier Reef, sand flat

Introduction

Marine invertebrate larvae often settle and metamorphose in habitats located at a distance from that of the adults (Gillanders et al. 2003; Byrne et al. 2021). These settlement sites can also serve as nursery areas for the post-larval juvenile stage. The identification of nursery habitats is critical for species' management and conservation (Gillanders et al. 2003) but are difficult to identify because of the cryptic nature and small size of the juveniles, as is the case for sea cucumbers. Juvenile sea cucumbers are rarely observed in nature (Shiell 2004; Wolfe et al. 2024). This life stage of sea cucumbers is an important gap in knowledge of sea cucumber biology and ecology (Wolfe et al. 2024), especially for commercially harvested species, many of which are of conservation concern (Hamel et al. 2022; Purcell et al. 2025).

Juvenile sea cucumbers may remain in a nursery habitat for some time before migrating to an adult habitat. Where data exist, it appears that this ontogenetic migration is most often from shallow areas where juveniles reside to deeper adult habitat (James 1975; Shiell 2004; Eriksson and Byrne 2013; Wolfe and Desbiens 2022; Wolfe et al. 2024). For sandfish, *Holothuria scabra,* the ontogenetic habitat transition involves a switch from areas of seagrass recruitment and nursery habitat of post-larvae and early juveniles, to the deeper sediment habitat of adults (Hamel et al. 2022).

Sea cucumbers that live buried in soft sediment are difficult to detect at the adult stage as well as the juvenile stage, although some species, such as sandfish, become evident as they emerge onto the surface of the substrate for feeding (Mercier et al. 2000a, b). Sandfish species tend to be nocturnal, emerging from their daytime location buried in the sand, to the sediment surface at sunset (Mercier et al. 2000a, b; Hamel et al. 2022). As reported here, while undertaking field work, we observed juvenile *H. scabra* emerging onto the surface of the reef flat at Low Isles in the northern Great Barrier Reef (Fig. 1A). This has not been reported before for the region, and was an unexpected opportunity to contribute to the biology and ecology of this endangered species (Hamel et al. 2013), which is of critical importance to coastal livelihoods as an important beche-de-mer species (Hair et al. 2019; Hamel et al. 2022; Waldie et al. 2024; Purcell et al. 2025). The Low Isles are a protected reef area with minimal human disturbance and with an extensive soft sediment reef flat (Fig. 1B).

Methodology

Our study of *Holothuria scabra* occurred at the Low Isles (16.38333 S, 145.56666 E) in the northern Great Barrier Reef, 15 km from the coast of Port Douglas, Australia (Fig. 1A-C). Juvenile *H. scabra* were detected on the surface of the reef flat on 9 and 10 June 2024 at dusk, just before sunset. The sand flat where the juveniles were observed (16.38571 S, 145.56058 E) is shown in Figure 1B. The juveniles were photographed alongside a ruler for accurate scale measurement (Fig. 1E). To estimate the population that had emerged before nightfall, three 5-m^2 quadrats were set on the surface of the sediment, and the number of juveniles were counted.

Results and discussion

Most information on wild juvenile sea cucumbers is from opportunistic observations (Wolfe et al. 2024). We observed the juvenile sandfish within a very small window of opportunity to detect them. They were observed emerging onto the surface of the sand flat just off the beach at Low

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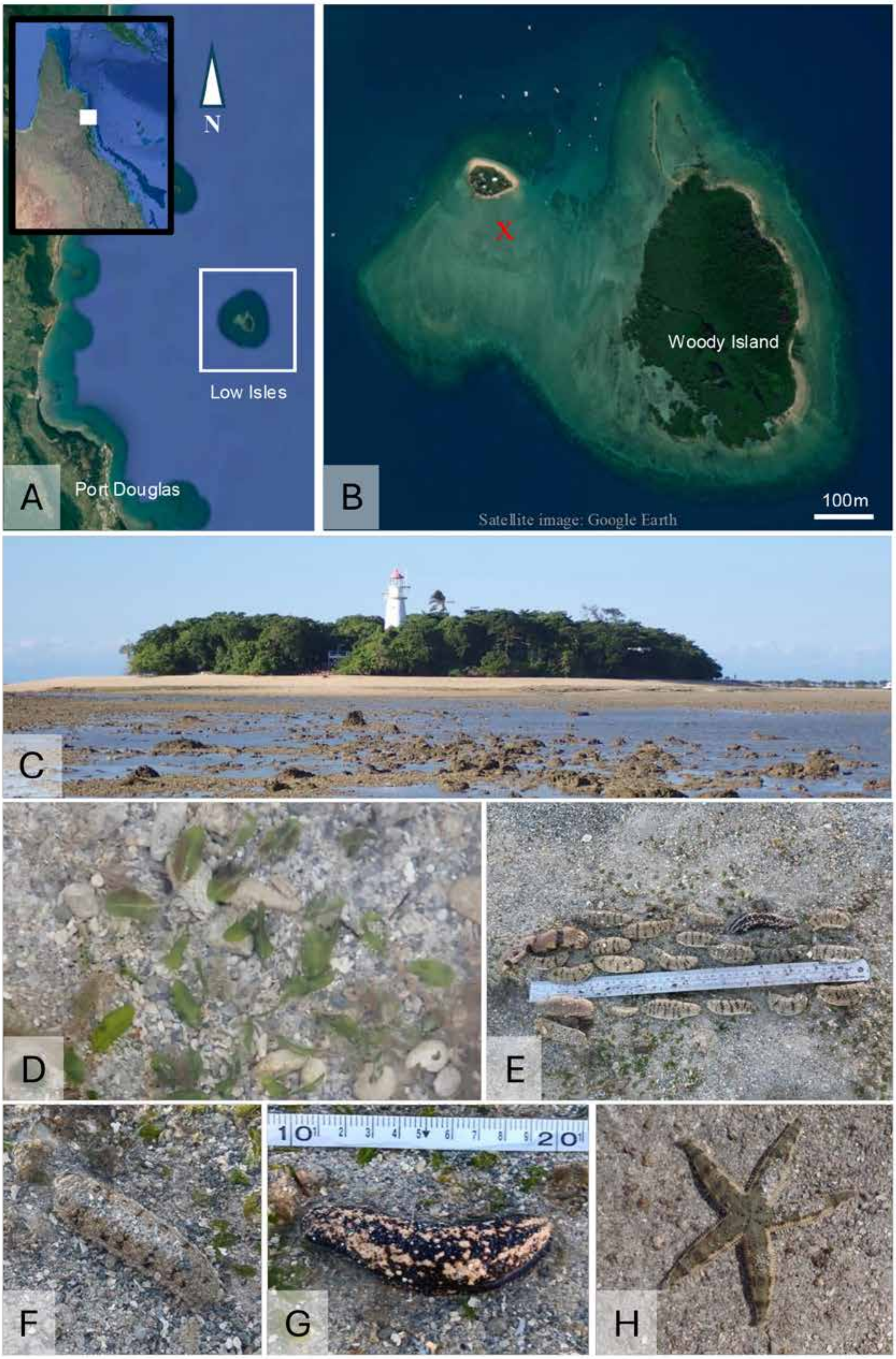

Figure 1. **A-B** Location of Low Isles in the northern Great Barrier Reef. The red "x" indicates where we found the juveniles. Note that the large sand flat is located between Low Isles, the small island on the left and Woody Island. **C.** Low Isles is a small sand cay. **D.** Sandy substrate where the juveniles were found, and the seagrass *Halophila ovalis*. **E-F.** Juvenile sandfish. **G.** Unidentified sea cucumber that also emerged at sunset. **H.** Sand star *Archaster typicus*.

Isles at dusk. It was low tide, with shallow pools of water over the substrate, so the sand was wet. The sediment was mixed with a range of grain sizes from mud to gravel sized grains, with shell fragments and small coral rubble (Fig. 1D). A population of the sand star, *Archaster typicus*, was also present (Fig. 1H). The sediment at the Low Isles sites differs from the fine sand sediment noted for juvenile sandfish habitats in a previous study (Mercier et al. 2000a).

Small plants of the seagrass *Halophila ovalis* were present in low densities across the sand flat (Fig. 1D). Virtually all reports of juvenile sandfish note the presence of seagrass in the habitat (see Wolfe et al. 2024). *Halophila ovalis* may serve as a larval settlement substrate as sandfish larvae are known to settle on seagrasses (Mercier et al. 2000a, b; Hamel et al. 2022). It seems likely that sandfish larvae settled onto seagrass leaves and, as the juveniles grew, then moved into the sediment. Thus, there are two important nursery habitats for sandfish: the seagrass habitat for the post-larvae and very early juvenile stages, and the intertidal sand flat habitat for older juveniles. Adults were not observed, but may been in nearby deeper habitat.

The juveniles were difficult to detect because their colour blended in with that of the substrate, and because the light was fading. Over 30 minutes before nightfall, we observed more individuals emerging. The juveniles had the distinct brown bands of sandfish, with some variation (Fig. 1 E and F). A second, larger unidentified sea cucumber species was also observed (Fig. 1G). The emergence of sandfish at dusk at low tide was observed on 9 and 10 June 2024, with more individuals evident on 9 June (n= 22) than on 10 June (n = 3). The mean length of the juveniles was 7.25 cm (SE = 0.246, range 4.11–9.78 cm, n = 25). The density of the juveniles on 9 July was estimated to be 12.3/m^2 (SE = 5.04, n = 3). Our survey was light-dependent, and it seemed likely that more individuals would have emerged after nightfall. We did not have torches.

As observed in Solomon Islands, the transition from the seagrass nursery to life in the sediment occurs when sandfish juveniles reached about 9 mm in length (Mercier et al. 2000a). The juveniles we observed were larger, at 7 cm. The small size range observed (Fig. 1E) indicate that they represent a single cohort.

Our observations of *Holothuria scabra* juveniles were based on an opportunistic encounter as we walked across the sand flat at low tide at dusk, and are similar to reports that juveniles burrow at sunrise and surface at sunset (James 2005; Mercier et al. 2000a). The behavioural cycle of juvenile sandfish is linked to the light cycle (Mercier et al. 1999). While the main driver of juvenile emergence is light level, we noted that emergence coincided with a falling tide when the surface of the substratum was wet. If they are to emerge at low tide, presumably the juveniles would need a falling tide to ensure the pools are wet, rather than a rising tide when drainage is complete. For the Low Isles site, the interplay between light and tide on juvenile emergence could readily be investigated using surveys that consider information from tide charts, and in a census conducted over days when the sun sets. It will also be important to search the sediment surface with torches to get a better appreciation of the extent of the population of the *H. scabra* juveniles.

The intertidal sand flat is a prominent feature of Low Isles and is likely to provide extensive suitable habitat for sandfish juveniles. This area, largely protected from human disturbance, is a promising site for further investigation of sandfish population biology, an especially important consideration for this commercially targeted species that is of conservation concern.

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Adding cucumber to the salad: Observations of *Chelonia mydas* feeding on *Holothuria atra* in Rarotonga, Cook Islands

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Introduction

The green sea turtle (*Chelonia mydas*) is an important species, both ecologically and culturally in Cook Islands. This small island state consists of 15 islands and atolls spread across a 2-million km² exclusive economic zone. *Chelonia mydas* has been observed in waters throughout the islands, and nests on at least four islands in both the Northern Group (White and Galbraith 2013; White 2014) and Southern Group (Bradshaw and Bradshaw 2012). The diet of green turtles in Cook Islands is mostly unknown, although elsewhere, they eat seagrasses and algae (e.g. Ciccione 2001; Santos et al. 2011). There is evidence of adaptation to local food sources and preferential grazing on particular plant and algae species (Bjorndal 1985; Santos et al. 2011). Originally, adult *C. mydas* were believed to only be herbivorous (Bjorndal 1985), but further observations have shown them to be omnivorous, feeding on jellyfish and other macroplankton, and sometimes even crustaceans, molluscs and polychaetes (Burkholder et al. 2011; Santos et al. 2015).

There are no seagrasses in Cook Islands, but several algae species are observed in the lagoons and on the fore reefs surrounding each island, and include *Halimedia* spp., *Turbinaria* spp., *Asparagopsis* spp., *Boodle* spp., *Padina* spp. and *Caulerpa* spp. (N'Yeurt 1999). It is likely that algae comprise at least part of the diet of *Chelonia mydas* in Cook Islands, as has been observed elsewhere (McDermid et al. 2007; Arthur et al. 2009; Carrión-Cortez et al. 2010; Nagaoka et al. 2012). *Chelonia mydas* has been observed consuming drifting *Hydroclathrus clathratus* in Rarotonga (K. Morejohn, pers. obs.), but details of general dietary preferences are unknown.

Recently, multiple records have been made of *Chelonia mydas* consuming black sea cucumbers (*Holothuria atra*) within the lagoon of Rarotonga, the most populated of the Cook Islands. *Holothuria atra* occur in high densities in Rarotonga's lagoons and reef flats, and are harvested by local subsistence and artisanal fishers (Raumea et al. 2013). Observations of sea turtle predation on sea cucumbers give insight into sea turtle feeding habits and may inform future management decisions for both species.

Observations

Chelonia mydas was observed feeding on *Holothuria atra* on 28 October 2024, 6 November 2024, and 31 December 2024, by three different observers, all in the shallow lagoon at Aroa, Rarotonga (Fig. 1).

The turtles observed were all different individuals, as determined by examining the facial scutes of each (Carpentier et al. 2016). Each turtle was observed with one specimen of *Holothuria atra* protruding from its mouth (Figs. 2–4), and were seen using their front limbs in a "wiping" motion from the back to the front of their beaks, either using this action to pull apart the sea cucumber, or to remove it from their mouths (Figs. 3–4). In the third observation, the turtle ate the viscera of the cucumber and then discarded the body cavity.

Discussion

The diet of *Chelonia mydas* in Cook Islands remains poorly documented, yet insight into their feeding habits could play a crucial role in their conservation.

In Cook Islands, the viscera of *Holothuria atra* is harvested *in situ*, with body remnants returned for the cucumbers to recover and regrow (Raumea et al. 2013). With no commercial harvest or export, *H. atra* is abundant in shallow lagoon areas across Cook Islands, and are not currently considered to be at risk of overharvesting (Raumea et al. 2013; Kora et al. 2018; Ariihee et al. 2020). If pressure on sea cucumbers increases, their management should also consider the role that sea cucumbers play in the broader ecosystem, including the diets of sea turtles.

Other observations of *Chelonia mydas* eating sea cucumbers have been made, such as in the western Indian Ocean, where it was observed consuming the holothurian *Synapta maculata* at Reunion Island, (Mulochau et al. 2021). These observations were made among seagrass (*Syringodium isoetifolium*) beds, indicating that *C. mydas* chooses this prey in addition to the regular diet of seagrasses and algae (Mulochau et al. 2021). In addition, *Synapta maculata* was specifically chosen among other sea cucumber species such as *Holothuria leucospilota* (Mulochau et al. 2021).

It is unknown if the observed behaviour of *Chelonia mydas* eating sea cucumbers is a localised phenomenon within the lagoon at Rarotongan, or if other sea cucumber species are also consumed. Further observations are necessary.

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Figure 1. Rarotonga, Cook Islands showing the location of observations at Aroa.

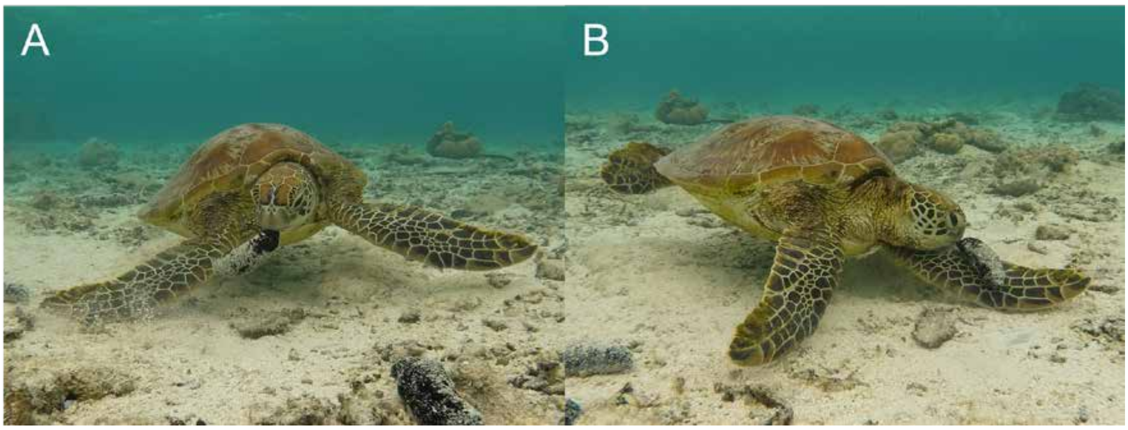

Figure 2. A) First observation of *Chelonia mydas* consuming *Holothuria atra*, and B) *C. mydas* using its flipper to pull it apart. Images: © Paul Eichler

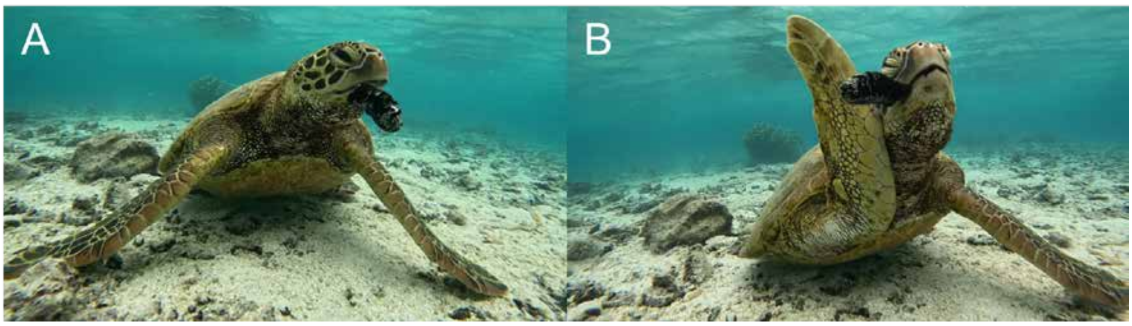

Figure 3. A) *Chelonia mydas* with a *Holothuria atra* individual in its mouth, and B) *C. mydas* using its flipper to pull it apart on 6 November 2024. Images: © Hannah Gilchrist, SPC

Figure 4. *Chelonia mydas* using its flipper to pull apart an individual of *Holothuria atra* on 31 December 2024. Image: © Phoebe Argyle

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Observed spawning of the sea cucumber *Bohadschia argus* in Central Province, Solomon Islands

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The spawning of a male sea cucumber, *Bohadschia argus* Jaeger, 1833 (common name: leopardfish, tigerfish), was observed *in situ* in the western bay of the Buena Vista area (8° 53' 11.6'' S, 159° 58' 31.9'' E) in Nggela Islands, Central Province, Solomon Islands. The spawning occurred at 20:30 local time on the night of 27 Februrary 2024, three days after the full moon. The water depth was ~3 m, and the seabed consisted of lime bedrock. The body length of this individual was 30 cm. At the time of the observation, the anterior body of the sea cucumber was standing up from the seabed and slowly shaking, continuously releasing sperm from the gonopore at the dorso-anterior end of the body (Fig. 1). During an earlier survey, *B. argus* was sparsely spotted around the site at 8.88 individuals/ha, which was estimated by the swimming transect method (Tanita et al. 2022). The distance between the spawning individual and the nearest other individual was 20.7 m, based on a GPS that was used (Garmin GPSmap 64csx). No other spawning *B. argus* individuals were found on that day (n = 12, including the spawning individual).

According to Babcock et al. (1992), the timing of *in situ* spawning of *Bohadschia argus* is the most predictable among sea cucumbers. Based on their observation in the Great Barrier Reef, *B. argus* spawns between 19:30 and 22:00 on the first, second and third nights after the full moons of October, November, December and January. The authors also described that *B. argus* males always start spawning one hour earlier than females, and that spawning lasts for up to one hour for males but only for a few bursts of eggs for females. The present observation of spawning well matches the description by Babcock et al. (1992) in terms of the time (20:30) and lunar phase (three days after the full moon), except that it was in late February. As reproductive ecology of *B. argus* is largely unknown in Solomon Islands and other Indo-Pacific areas, except for the Great Barrier Reef, the present observation may provide valuable insights for future investigations into their reproductive seasonality.

Acknowledgments

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Figure 1. Spawning of a male *Bohadschia argus*. Released sperm is indicated by an arrow. Image: © Iwao Tanita

A newly emerging type of farming in China: Integrating sea cucumber cultivation and photovoltaics

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Abstract

The integration of sea cucumber cultivation and photovoltaics is a newly emerging farming type in China that has significant development potential. Given the challenges of cultivating sea cucumbers in ponds, such as high temperatures and algal outbreaks, this report outlines the potential advantages and disadvantages of an innovative approach to sea cucumber cultivation, and proposes suggestions and prospects to address existing shortcomings, aiming to foster the "green" and sustainable development of this type of integrated farming in China.

Sea cucumbers are an important economic market in China

Sea cucumbers are an economically important species worldwide and are cultivated in many countries. As the world's largest cultivator, China produced 292,000 t (wet weight) of sea cucumbers in 2023, covering a farming area of 2890 km^2 (Agricultural and Rural Affairs 2024). Among all the cultivated sea cucumber species in China (over 20 species), *Apostichopus japonicus* is the most dominant species. It has high nutritional and medicinal values, and is in high demand by consumers (Yang et al. 2015). The cultivation methods of *A. japonicus* are diverse, with pond culture being one of the main types. Currently, the area under pond culture in China is more than 2000 km^2, accounting for about 69.2% of all farming areas. The cultivation of *A. japonicus* is rapidly developing.

Threats to cultivating sea cucumbers in ponds

There are two major threats to cultivating *Apostichopus japonicus* in aquaculture ponds. First, *A. japonicus* is sensitive to high temperatures. The frequent and extreme high summer temperatures cause pond water temperatures to rise above the tolerance limits of sea cucumbers (10–18°C), and leads to skin ulceration syndrome and death. For example, during the anomalously hot summer of 2018, the water temperature in the ponds reached 33°C (Wang et al. 2021a). As a consequence, a massive number of sea cucumbers died, resulting in a loss of 633 km^2 and 68,000 t of sea cucumbers, with a direct economic loss of CNY 6.87 billion.[2] Second, due to the low water levels (1.5–2.0m) and high light intensity in the ponds, there was an outbreak of green macroalgae (*Chaetomorpha valida*), which led to an increased incidence of sea cucumber diseases and mortality (Deng et al. 2012; Geng et al. 2023). Deng et al. (2012) found that large quantities of *C. valida* floating on the pond water's surface blocked sunlight and suppressed the growth of benthic diatoms that sea cucumbers feed on, which in turn had adverse effects on their growth.

The integration of sea cucumber cultivation and photovoltaics

The integration of sea cucumber aquaculture and photovoltaics is a newly emerging farming method in China, and can achieve dual benefits of both photovoltaic power generation and sea cucumber yield increase by installing photovoltaic panels above the cultivation ponds (Fig. 1). For photovoltaics, the aquaculture ponds provide ample space for photovoltaic panels, effectively harvesting solar energy and significantly increasing economic benefits (Pringle et al. 2017; Exley et al. 2021; Wang et al. 2021b). For sea cucumber aquaculture, this integrated approach offers new opportunities for solving the threats in sea cucumber aquaculture ponds. Typically, when culturing sea cucumbers, artificial shelters are required for them to hide in (Dong et al. 2010), but the shading effects of the photovoltaics panels provides low light intensity for sea cucumbers, which is in line with their ecological habits. Additionally, the reduced light intensity can further lead to lower pond water temperatures, ensuring the healthy growth of sea cucumbers in summer. Currently, the integration of sea cucumber cultivation and photovoltaics is booming in China, and has achieved favourable economic returns. For instance, Dongying in Shandong Province features sea cucumber cultivation ponds integrated with photovoltaics, boasting a power generation capacity of 69 MW and spanning an area of 1.3 km^2. This initiative has generated annual profits of up to USD 1.4 million. Another cultivation area in Dongying, covering 13.3 km^2, is currently under construction and is expected to have a power generation capacity of 800 MW. Meanwhile, Dalian in Liaoning Province is also initiating a 100-MW sea cucumber-photovoltaic integration cultivation base.

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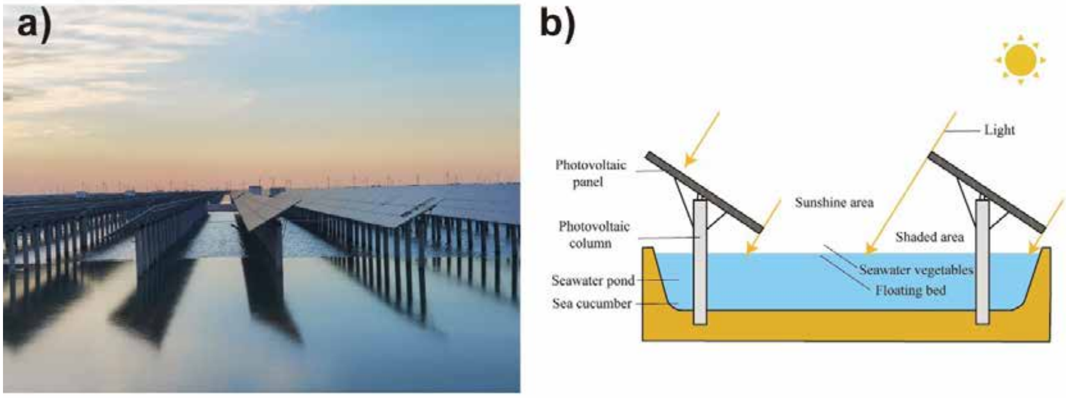

Figure 1. a) The integration of sea cucumber aquaculture and photovoltaics (Image: © Shuang Guo), and b) a schematic view of the pond and the photovoltaic panels.

A case study in Dongying of Shandong

Dongying is the primary area for sea cucumber cultivation in Shandong Province. The integration of sea cucumber cultivation with photovoltaics in this region is also advancing rapidly (Fig. 2). Therefore, we focused on a photovoltaic power plant in this area with a total installed capacity of 200 MWp, and conducted research on the annual effects of photovoltaics (occupying an area of 4.28 km^2, 40% coverage rate) on the environmental and ecological impacts, and the physiological performance of sea cucumbers in ponds (Guo 2024). Monitoring and sampling were conducted monthly from March 2023 to February 2024. To assess the environmental and ecological impacts, a luxmeter (Sigma Instruments ST9813, Germany) was used to measure light intensity. An onsite monitoring system (YSD-5400) was employed to continuously monitor water temperature, dissolved oxygen, salinity and pH. An inverted microscope and a stereoscopic microscope were used to count and identify phytoplankton and zooplankton samples. The relative abundance of Pyrrophyta, Bacillariophyta and copepods was calculated based on the formula:

relative abundance = (abundance of a specific phytoplankton/total abundance of phytoplankton) × 100%

In addition, the organic matter content of surface sediments was measured and calculated following the method outlined by Onomu et al. (2024), with minor modifications; specifically, burning for 2 hr instead of 6 hr. The density of Enteromorpha was determined by setting quadrats and weighing the biomass. For physiological performances, α-amylase activity and lipase activity were tested according to the methods described by Sun et al. (2018). The duration of aestivation for both subadult and adult stages were also calculated.

As shown in Table 1, compared with non-photovoltaic ponds (nPVPs), light intensity in photovoltaic ponds (PVPs) was significantly reduced by 7.0×10^4 lux, and thus water temperature decreased by 1.2°C. Dissolved oxygen and pH significantly increased by 0.7 mg/L and 0.2, respectively, and salinity was significantly reduced by 0.6. In PVPs, aestivation durations of subadult and adult sea cucumbers were shortened by 12 days and 1 day, respectively, and the body weight of sea cucumbers increased by 4.8 g. For phytoplankton, although the proportion of Pyrrophyta composition increased, Bacillariophyta composition decreased, although their abundance was not changed, indicating that photovoltaics did not have a significant negative impact on sea cucumber feeding. The biomass of macroalgae-enteromorpha in the pond was significantly reduced by 360 g/m^2, indicating that photovoltaics effectively inhibited the growth of macroalgae. The composition and abundance of zooplankton, the organic matter content in surface sediments and the digestive enzyme activities of sea cucumbers, remained unaffected. These findings demonstrated that photovoltaics were a highly effective solution for mitigating sea cucumber mortality caused by high temperatures or algal growth in aquaculture ponds, and significantly promoted the growth of sea cucumbers.

Perspective

The integration of sea cucumber cultivation and photovoltaics faces numerous challenges and issues in achieving sustainable development, including a severe lack of fundamental research, inefficient development mode, and the absence of specific development standards. In response to these issues, it is essential to leverage collaborative efforts among enterprises, universities, and research institutions to investigate the effects of photovoltaics on the environmental ecology and physiological performance of sea cucumbers in cultivation ponds across various latitudes. This will fill the gaps in basic research, and clarify the intricate interplay among photovoltaics, sea cucumbers, and pond environment, thereby initially establishing a theoretical system for sea cucumber–photovoltaics integrated aquaculture. Meanwhile, it is necessary to establish, innovate and improve sea cucumber–photovoltaics integrated aquaculture technology to enhance overall production efficiency and environmental adaptability. Finally, the corresponding national and sector standards need to be established to regulate the aquaculture

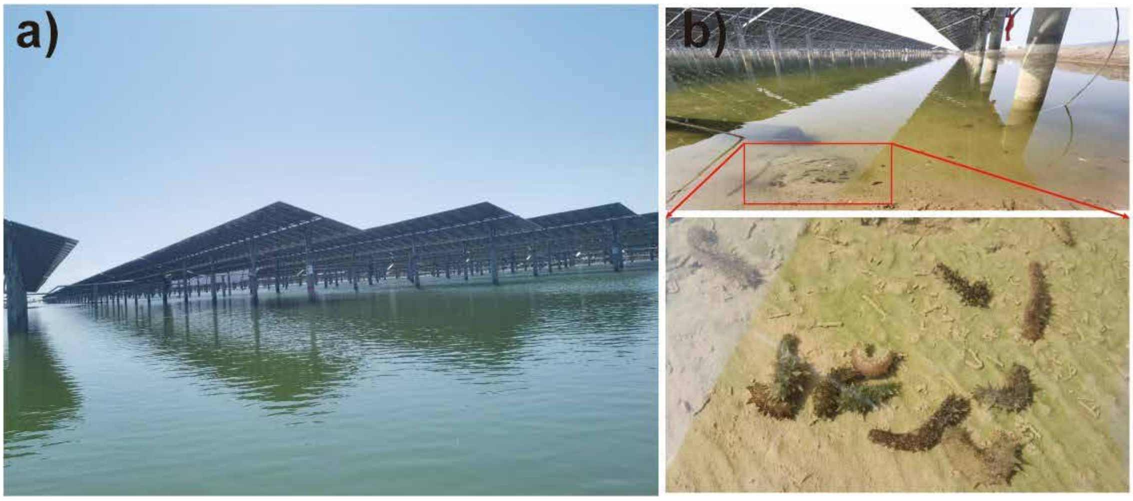

Figure 2. The integration of sea cucumber aquaculture and photovoltaics in Dongying. a) The photovoltaic arrays above the sea cucumber aquaculture ponds (Image: © Zhenglin Yu), and b) sea cucumbers in photovoltaic ponds. (Image: © Shuang Guo)

Table 1. Effects of photovoltaics on environmental and ecological impacts, as well as the physiological performance of sea cucumbers in coastal ponds of Dongying city.

Effects	Influencing factors	nPVP	PVP	Differences
Environmental and ecological impacts	Light intensity (lux)	$8.5 \times 10^4 \pm 3.3 \times 10^4$	$1.5 \times 10^4 \pm 1.0 \times 10^4$	80.5 ± 12.0%↓
	Water temperature (°C)	21.3±7.4	20.1±8.1	1.2±1.3↓
	Dissolved oxygen (mg/L)	6.6±2.3	7.3±2.6	0.7±1.7↑
	Salinity	30.5±2.6	29.9±1.9	0.6±2.1↓
	pH	8.3±0.2	8.5±0.1	0.2±0.3↑
	Pyrrophyta (%)	2.5±1.2	40.6±15.2	38.1±15.8↑
	Bacillariophyta (%)	97.3±1.3	58.9±15.4	38.5±16.0↓
	Copepods (%)	81.8±4.1	75.7±14.7	6.2±13.8↓
	Enteromorpha (g/m^2)	527.7±48.1	166.4±61.8	361.3±108.5↓
	Surface sediment organic matter content (mg/g)	61.4±1.5	58.7±1.9	2.7±10.8↓
Physiological performances	α-Amylase activity (U/mg prot)	1.1±0.5	1.0±0.6	0.1±0.7↓
	Lipase activity (U/mg prot)	0.3±0.2	0.4±0.3	0.1±0.2↑
	Subadult aestivation durations (days)	62	50	12↓
	Adult aestivation durations (days)	114	113	1↓

Note: nPVP represents the non-photovoltaic pond, PVP represents the photovoltaic pond. Data were expressed as annual mean ± SEM.

technology and management system, creating a sustainable sea cucumber–photovoltaics integrated aquaculture mode.

In conclusion, the integration of sea cucumber aquaculture and photovoltaics is promising in China. Through rational planning, technological innovation and policy support, it is possible to: 1) achieve comprehensive resource utilisation and to maximise benefits; 2) promote clean energy production and sustainable green development in China's newly emerging farming; and 3) ultimately achieve a win-win situation in terms of both ecology and economy.

Acknowledgements

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Exploring populations of the sea cucumber *Cucumaria frondosa* in Qikiqtait, Nunavut, Canada using a portable submersible

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Abstract

The expansion of harvesting efforts and the successful management of valuable echinoderm resources in new localities is heavily dependent on the ecological knowledge available. One untapped high-value species, the sea cucumber *Cucumaria frondosa*, is now being explored by some communities in northern Canada for potential fisheries. However, basic information on the species within its Arctic range is still scarce. The present study used video surveys obtained with an observation-class remotely operated vehicle at three sites within Qikiqtait (the traditional name of the Belcher Islands in Hudson Bay, Nunavut) to assess the distributional patterns of *C. frondosa*. Substratum types and depths colonised, population size structure, density and aggregation patterns, along with visual abundance of suspended particulate matter and feeding behaviour were investigated. Inter-site variations emerged following different trends. Maximum densities of *C. frondosa* reached ~1.3 ind/m^2 at the deepest (33 m) site, which is dominated by gravel and rubble, and which exhibited the greatest levels of suspended particulate matter. Sea cucumbers ranged from 3 cm to 26 cm in length, with a dominant size class of 6–10 cm found across all sites. Aggregations increased with increasing density, with a maximum of 3.0 ± 0.2 ind/aggregate. Overall, this study provides preliminary insight to the distribution and variable abundances of *C. frondosa* in relation to various habitat characteristics in the lower Arctic. These findings provide baseline ecological information that can inform the future development of small-scale commercial activities and marine protected areas in this region.

Introduction

Echinoderms are a diverse phylum, containing numerous species that are both ecologically and commercially important. In the North Atlantic, the sea cucumber *Cucumaria frondosa* is the main commercial echinoderm, and due to its market value and booming exploitation, research has focused on understanding its ecology and life history to help manage ongoing harvesting efforts (Mercier et al. 2023).

At the forefront of the knowledge required for species of commercial interest are metrics such as distribution and spatial trends in occurrence and abundance relative to various conditions (Brown 1984; Iken et al. 2010). Environmental and depth-related drivers such as temperature, salinity fluctuations, tidal amplitude, substratum types, food availability, and competitive and predatory pressures can help explain general population patterns as well as why some habitats are preferred over others (Hamel and Mercier 1996; Mercier et al. 1999, 2000; Entrambasaguas et al. 2008; Iken et al. 2010; Dissanayake and Stefansson 2012). Spatial distribution may also be modulated by biological factors such as ontogenetic development (e.g. juvenile vs adult) and reproductive activity (Hamel and Mercier 1995, 1996; Leite-Castro et al. 2016; Hamel et al. 2024).

Among echinoderms, and specifically sea cucumbers, population patterns have been explored at local to broad geographic scales as well as on various temporal scales (e.g. Hamel and Mercier 1995). For example, Mendes et al. (2006) described the distribution of the tropical sea cucumber *Holothuria grisea* in southern Brazil, and found that its density increased with an increase in the percentage of rock cover and surface rugosity. These studies, and those that consider larger spatial scales, have established that the abundance and distribution of species can be patchy or highly variable due to environmental heterogeneity over broad geographic ranges (O'Hara and Poore 2000; Tobin 2004).

In North America, and elsewhere across its geographic distribution, the sea cucumber *Cucumaria frondosa* has been the target of commercial harvests and research over the last few decades (Gianasi et al. 2021; Mercier et al. 2023). The geographical distribution of *C. frondosa*, however, extends beyond harvesting regions; it occurs widely in the Arctic and along the western (North America) and eastern (West Europe) sides of the northernmost regions of the North Atlantic (Gianasi et al. 2021; Hamel and Mercier 2024), with notable density variations. For instance, in the St Lawrence Estuary (eastern Canada), values ranged from 0.05 ind/m^2 (Dallaire et al. 2013) to >5 ind/m^2 (Campagna et al. 2005). Similar densities of *C. frondosa* have been documented elsewhere in Canada, the United States (Maine), Iceland and Russia (Gianasi et al. 2021). Using a combination of modelling, and laboratory and field approaches, studies have increased the knowledge on the ecology of *C. frondosa* and found that it is generally most abundant in areas with rocky substrata

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at depths of ~30–60 m and in regions with lower seawater temperatures (Hamel and Mercier 1996; Singh et al. 1998; Skjaeveland 1973; So et al. 2010; Lecomte et al. 2013).

Reduced occurrences in the bathyal zone were presumably due to limited amounts of planktonic food and hard substrata (Ross et al. 2013) on which *Cucumaria frondosa* relies (Hamel and Mercier 1998). The predominant association with rocky substrata was experimentally confirmed by Sun et al. (2020), and the infrequent occurrence of *C. frondosa* on sandy and muddy seafloors (Grant et al. 2006; So et al. 2010; Ross et al. 2013) was proposed to be a result of transitional passive dispersal (Hamel et al. 2019). Hamel and Mercier (1996) recorded smaller individuals, chiefly between 0 and 20 m in the St Lawrence Estuary, while larger sea cucumbers dominated in deeper subtidal areas. The possible occurrence of an ontogenetic vertical migration was recently brought to the forefront with the discovery of a shallow-water nursery ground in Hudson Bay, Nunavut (Hamel et al. 2023). It is hypothesised to be triggered by exogenous and endogenous factors such as food availability, salinity, light intensity, temperature and sexual maturity (Hamel and Mercier 1996; Hamel et al. 2023).

Information on the distribution patterns of *Cucumaria frondosa* outside the Atlantic Ocean is limited, including inside vast expanses of their northernmost distribution ranges at Arctic latitudes. Dredge surveys have revealed sea cucumber densities between 0.6 ind/m^2 and 0.7 ind/m^2 in Icelandic fishing zones (MFRI 2019). In the Canadian Arctic, coastal resource inventories conducted by the Government of Nunavut only report the presence of sea cucumbers (Nunavut 2010), leaving much to be discovered about their abundance and habitat preferences in this region. A recent review of the literature further highlighted that the density of sea cucumbers was variable across the Nunavut territory, emphasising the importance of determining location-specific patterns of abundance and habitat preferences (Hamel and Mercier 2024). For instance, in Qikiqtait, Hamel et al. (2023) described a clear size-class distribution of juvenile individuals (0.9–40 mm in length) of *C. frondosa*, with densities ranging between 4 ind/m^2 and 104 ind/m^2 in shallow regions. There was also a clear spatial divide between juvenile and adult sea cucumbers (Hamel et al. 2023). Overall, assessing the abundance and ecology of *C. frondosa* in its northernmost range could not only contribute to a more comprehensive ecological understanding of the species, but also help determine where further exploration is needed to quantify populations, which would help support current efforts to advance emerging harvesting and conservation developments.

The present study aimed to preliminarily assess baseline population metrics of *Cucumaria frondosa* in Hudson Bay. An observation-class, remotely operated vehicle (ROV) was used to ensure a minimal data-acquisition footprint in the context of a capacity building and community-led approach (Raoult et al. 2020; Buscher et al. 2020). Video surveys recorded at three sites in Qikiqtait (Nunavut) were used to: 1) compare abundances across depths and substrata, 2) detect aggregation patterns (clustering), and 3) explore correlations with the availability of food. The key objective was to provide foundational data to act as a starting point that can assist the local community and its partners with future research towards the development of exploratory small-scale fisheries and conservation initiatives.

Methods

Study area and surveys

Underwater videos were obtained between 5 and 7 September 2019 at three locations surrounding Sanikiluaq, Nunavut (NU) in northern Canada: site 1 = outer Kataaluk (56.623072°N, -79.103537°W), site 2 = Puttaalalik shore (56.534998°N, -79.303498°W), and site 3= Ivittuuq Island (56.499021°N, -79.534211°W; Fig. 1). Surveys were conducted using a small observation-class remotely operated vehicle (ROV; Blueye Pro Pioneer) deployed from a 6-m-long fishing vessel. The ROV was towed for 2–10 min along various transects (distance covered by the ROV varied accordingly) within each site (site 1: 6 transects, site 2: 8 transects, site 3: 10 transects). During each transect, the ROV continually logged the direction (degrees), temperature and depth of its position in the water column. The ROV weighs 9 kg, so it is highly portable and is operated via a tethered remote-control system. It is equipped with one camera (light sensitive, full HD video resolution of 1080p/30fps, image size of 1920 x 1080 pixels) that can be tilted in the vertical plane (-30° to 30°), a set of dimmable LED lights that produce up to 3300 lumens, and two lasers separated by 7.5 cm to assist with measurements in the field of view.

Video analysis

Extracted frames from each video (every 10 ± 2 s, with the highest quality frame selected within the interval) were analysed (12–60 frames per transect). For each frame, the image quality determined the degree of information that could be collected. The following metrics were determined from each frame: depth of the ROV (m), temperature (°C), and an estimate of the concentration of particulate organic material (POM) in the water. The latter was accomplished by applying a standardised grid over the frame and examining two side-by-side illuminated grid surfaces in the center of the water column (scored as absent = 0, low = <25, medium = 26–50, high = >50). An estimated percent coverage of coralline algae, macroalgae, and the proportion of each substratum type (based on a modified Wentworth scale; defined in Table 1) present in the field of view (estimated out of 100%) were also recorded. All individuals of *Cucumaria frondosa* were counted, and a subset was measured (i.e. where lasers were present, and the entirety of the individual was visible). For this, the length (mouth to anus distance) of sea cucumbers was recorded to the nearest centimeter. Given that the ROV camera angle was variable and never perpendicular to the benthos (facing down at 90°), the measurements used

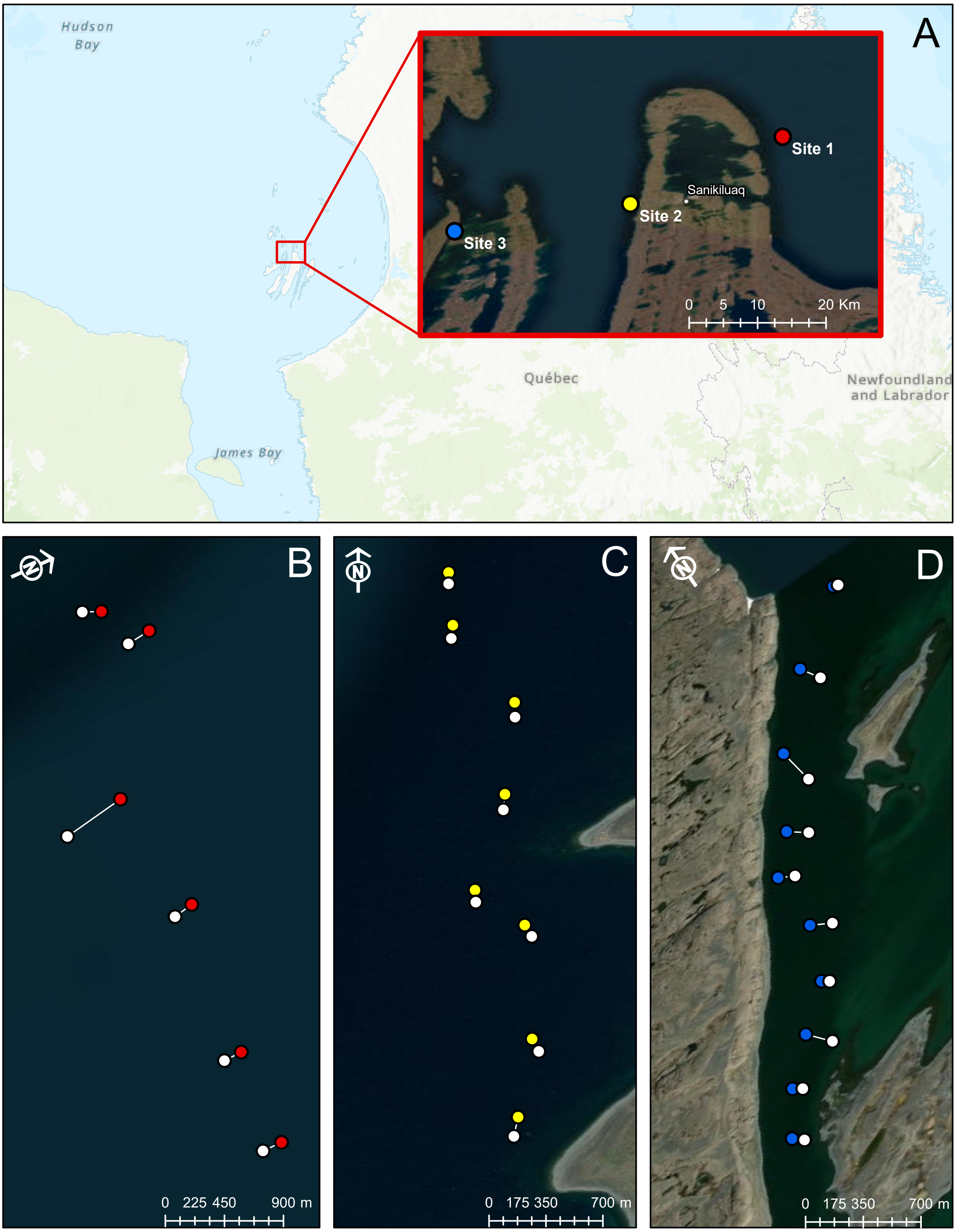

Figure 1. Sites where remotely operated vehicle (ROV) surveys were completed between 5 and 7 September 2019 in Sanikiluaq, Nunavut (NU). A) General location in northern Canada, with inset displaying the three field sites (B, C and D) that were analysed: red = site 1, Kataaluk (56.623072° N -79.103537° W); yellow = site 2, Puttaalalik shore (56.534998° N, -79.303498° W); blue = site 3, Ivittuuq Island (56.499021° N, -79.534211° W). In B), C) and D) the start of each transect completed in sites 1, 2 and 3 are represented in the corresponding colour. White dots represent the end of each transect. Note the variable north-pointing arrows and scale bars in B), C) and D).

the distance between the lasers within the same horizontal plane as the focal individual (see Fig. A1 for further explanation). The proportion of sea cucumbers with feeding tentacles extended was also recorded. Finally, images were examined for the formation of aggregations at two levels, either pairs or clusters of more than two individuals. Aggregations were determined based on individuals that were within one to two body lengths of each other.

To estimate the density of *Cucumaria frondosa*, a subset of the extracted video frames was selected from each transect across the three sites based on when lasers were clearly visible. These frames were then used to approximate the consistent area (m^2) of the field of view (FOV) that was unobstructed and in focus (central portion where the previously mentioned metrics could be accurately obtained). The average clear FOV surface area from all the extracted frames was then used as a standard to get an estimate of the density of both species.

Statistical analysis

Data were first analysed at the global level (all sites combined) to determine general trends and relationships influencing sea cucumber distribution. To do so, Spearman correlation tests were used as well as regressions, where possible (with variables such as: depth, substrata composition, POM level, coralline algae coverage). Then, density and size data were compared among the three sites to determine inter-site variability, which helped to identify the driving factors of density and size distribution. For this, each dataset was first tested for normality and equal variance using the Shapiro-Wilk test and Brown-Forsythe test, respectively. Assumptions were not met, therefore a non-parametric one-way ANOVA (Kruskal-Wallis test) on ranks was performed, followed by Dunn's test for pairwise comparisons. In addition, chi-square tests were performed to assess whether density was dependent on within-site variables. Statistical analysis was performed using SigmaPlot V15.0 software (Systat Software Inc) using $\alpha = 0.05$. In addition, substratum composition was analysed to assess the percentage of dissimilarity between the different sites using a SIMPER analysis, and a principal coordinate analysis (PCO) in the PRIMER V7 software (PRIMER-e). Data reported in the text are provided as mean ± standard error (SE).

Results

General characteristics of study sites

Overall, sea temperature was consistent across the three sites at 5.3 ± 0.01°C. The mean depth across all three sites combined was 26 ± 0.3 m. Site 1 was the deepest overall, with an average depth of 33 ± 0.5 m (min: 19 m, max: 41 m), being 36% deeper than site 2 (mean: 23 ± 0.5 m, min: 8 m, max: 30 m) and 3 (mean: 23 ± 0.5 m, min: 6 m, max: 43 m). According to a SIMPER analysis of the substratum compositions of each site, sites 1 and 3 had an average dissimilarity of 64% from site 2, while sites 1 and 3 had an average dissimilarity of 58%. Further descriptions of the substratum types, as well as the POM levels, are included below as they were analysed as explanatory variables of abundance. Figure 1 shows the location of the three sites.

Sea cucumber demographics

The density of Cucumaria frondosa across all three sites combined was 0.5 ± 0.04 ind/m^2, while densities showed clear inter-site variability ($H_{2,712} = 119.9$, $p < 0.001$). Specifically, site 1 had the highest sea cucumber density (1.3 ± 0.1 ind/m^2), which was about three times greater than the density at site 2 (0.4 ± 0.06 ind/m^2; $Q = 5.4$, $p < 0.001$) and 13 times greater than the density at site 3 (0.1 ± 0.02 ind/m^2; $Q = 8.9$, $p < 0.001$; Fig. 2 A). Overall, there was a positive correlation between density and increasing depth when all three sites were combined ($\rho = 0.08$, $p = 0.03$; Fig. 2 A, C, D). In terms of size, the longest sea cucumbers were seen at site 1 (17 ± 1.4 cm), which were significantly larger than those at sites 2 (11 ± 0.5 cm; $Q = 3.3$, $p = 0.002$) and 3 (10 ± 1.7 cm; $Q = 2.9$, $p = 0.01$; Fig. 3), by about 43% and 52%, respectively.

The size distribution across all three sites showed that 39% of the sea cucumbers were in the 6–10 cm size class,

Table 1. Modified Wentworth classification scale used to identify the various substrata present at the three sites analysed in the study, with the addition of the general "fine substrata" and shell debris categories, which were not distinguished by size.

Substratum	Size range (cm)
Fine (sand, silt, mud or mix thereof)	Not defined – beyond measuring ability
Gravel	1–8
Rubble	9–30
Small boulders	31–60
Large boulders	≥ 61
Shell debris	N/A

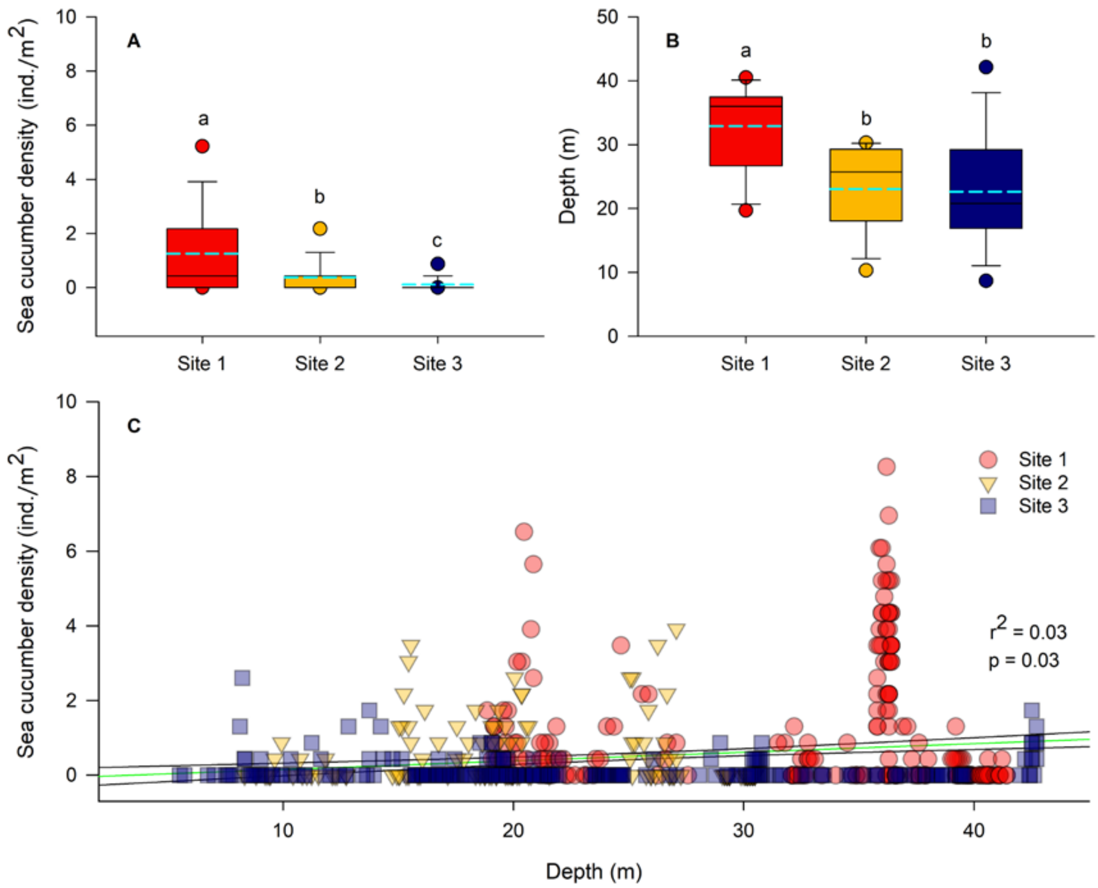

Figure 2. A) Density of the sea cucumber *Cucumaria frondosa* (ind/m²) at the three sites. B) Depth at each of the three sites. Data presented in A and B are the median (horizontal line), mean (blue dashed line), data range (edges of box), standard error (whiskers) and 5th/95th precentile (dots), while differing letters above each indicate significant differences between sites (one-way ANOVA on ranks and Dunn's test). C) The relationship between depth and the density of sea cucumbers present across the three sites. The green solid line is the regression of the relationship, with p and r^2 value displayed. The two black lines are the confidence intervals of the regression. Note the variable y-axis scales.

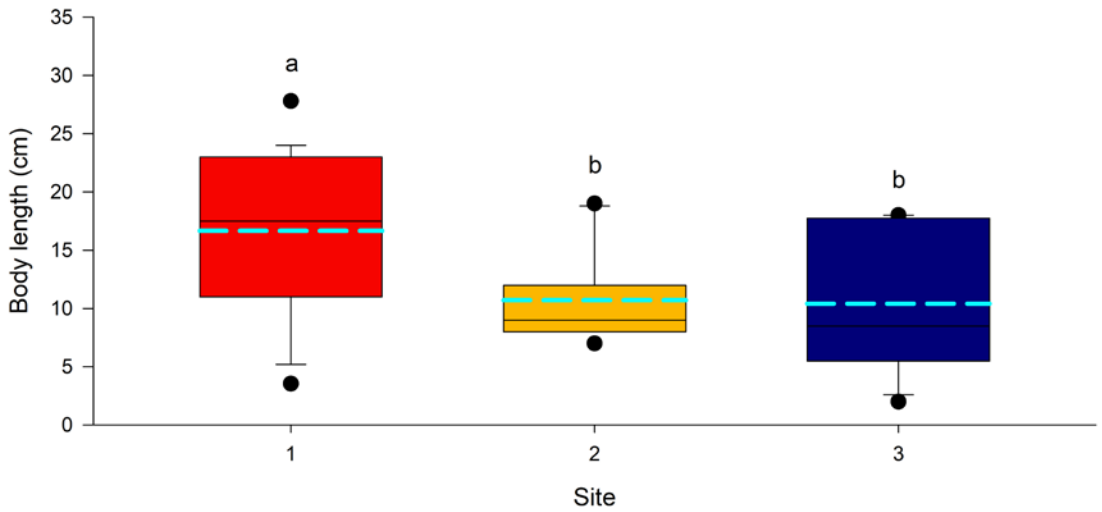

Figure 3. Length of *Cucumaria frondosa* at each site. Data presented are the median (horizontal line), mean (blue dashed line), data range (edges of box), standard error (whiskers) and 5th/95th precentile (dots), while differing letters above each indicate significant differences between sites (one-way ANOVA on ranks and Dunn's test).

followed by 16% in the 11–15 cm class and 17% in the 16–20 cm class. Within site 1, all size classes were represented, but the 21–25 cm size class was the most prevalent at 40% of sea cucumbers, while 27% and 13% fell under the 11–15 cm and 6–10 cm size classes, respectively (Fig. 4). Sites 2 and 3 both had truncated size distributions, with the main size class being in the 6–10 cm range (representing 71% and 33% of sea cucumbers, respectively; Fig. 4). However, site 2 had 14% of sea cucumbers in the 11–15 cm and 16–20 cm size ranges, while site 3 had 33% in the 16–20 cm range and 25% in the 0–5 cm range (Fig. 4).

When comparing the overall substratum occupancy across the three sites (Fig. 5), sea cucumbers predominantly occurred on gravel (35% of individuals), rubble (29%) and small boulders (16%); the remaining occupied fine

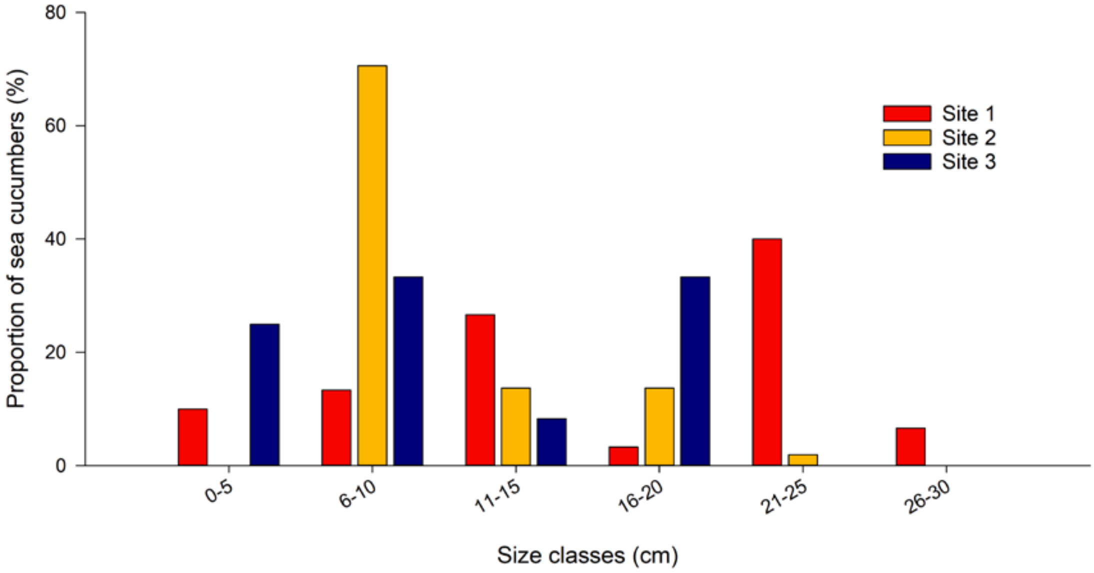

Figure 4. Proportion of individuals of *Cucumaria frondosa* within each size class range. The total number (n) of sea cucumbers measured for each site are: site 1 (n = 30), site 2 (n = 51), and site 3 (n = 12).

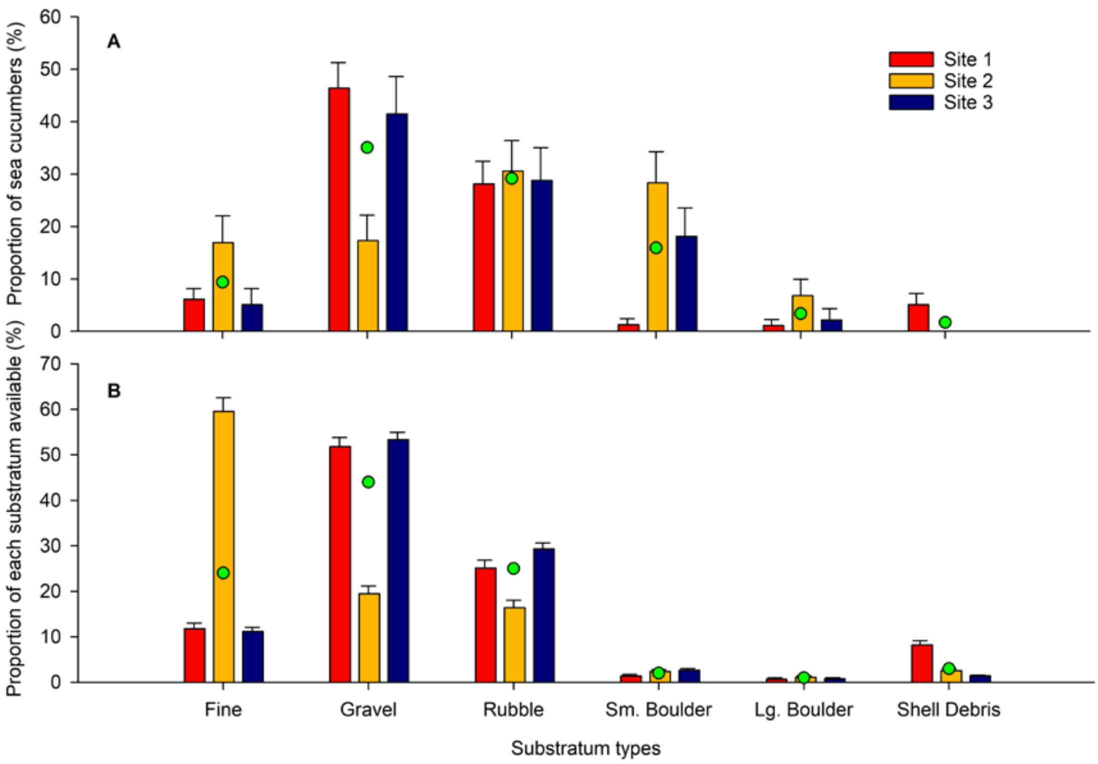

Figure 5. A) Proportion of individuals of *Cucumaria frondosa* (n = 69–264; % of total individuals observed) on each substratum (fine substrata, gravel, rubble, small boulder, large boulder, shell debris). B) Proportion of substrata (% of all defined) present at each site. Data presented as mean ± SE. Green circles represent the global means for all sites combined. Note the variable y-axis scales.

substrata (9%), large boulders (3%) and shell debris (2%). However, inter-site disparities in substratum composition were noted (see "General characteristics of study sites"). The distribution of *Cucumaria frondosa* on the various substrata was directly related to the substratum composition at each site (χ^2_{12} = 159.2, p < 0.001). The majority of sea cucumbers at site 2 were recorded on rubble (30%) and small boulders (28%), even though each of these substrata only made up 16 ± 1.6% and 2 ± 0.4% of the composition, respectively (Table 2; Fig. 5 A, B). In terms of rubble, site 2 had significantly less rubble than site 1 (25± 1.7%; Q = 4.6, p < 0.001) and 3 (29 ± 1.3%; Q = 7.6, p < 0.001; Table 2; Fig. 5 B), yet the occupancy of this substratum by sea cucumbers was similar across all sites ($H_{2,712}$ = 0.7, p = 0.7; Fig. 5). In fine substrata, sea cucumber occupancy was greatest at site 2 (17%; Fig. 5 A), which was dominated by fine substrata (60 ± 3.0%) in a proportion that was ~5 times greater than at site 1 (12 ± 1.2%; Q = 2.5, p = 0.04) and site 3 (11 ± 1.0%; Q = 2.8, p = 0.01; Table 2; Fig. 5 B). Occupancy on sand was lower at site 1 (6%) and site 3 (5%). The presence of small and large boulders was also greatest at site 2, particularly with respect to site 1, even though the availability of these substrata was similar among sites (Table 2; Fig. 5 A, B). Sea cucumbers were only observed on shell debris at site 1 (5% of all individuals), which had 3–5 times more sea cucumbers than sites 2 and 3 (Q = 6.5–8.5, p < 0.001; Table 2). When considering colonisation of surfaces other than the predefined substrata, sea cucumbers were observed on top of live scallops, especially at site 1. Finally, the density of *C. frondosa* was weakly negatively correlated with an increasing presence of coralline algae on rocky substrata (ρ = -0.1, p = 0.002).

The concentration of POM in the water column was not a good predictor of sea cucumber density (ρ = 0.007, p = 0.9). However, the proportion of sea cucumbers with their tentacles deployed across all three sites showed a positive correlation with increasing POM levels (ρ = 0.2, p = 0.01). When looking across the three sites, site 3 had the greatest proportion of sea cucumbers with their tentacles deployed (90 ± 3.6%), and 84% of POM observations at that site were categorised as "high", while at site 1, high levels of POM made up 100% of the observations and 88 ± 2.5% of sea cucumbers had their tentacles deployed. Site 2 had both the lowest proportion of POM observations recorded as "high" (77%), and the lowest proportion of sea cucumbers with their tentacles deployed (64 ± 5.8%). Analyses supported that POM levels increased with depth (ρ = 0.5, p < 0.001) and were site dependent (χ^2_4 = 48.6, p < 0.001).

Across all three sites, 76 ± 6% of sea cucumbers occurred as single individuals, 14 ± 3% as pairs, and 10 ± 4% as larger clusters. Site 3 had the greatest proportion of single individuals (85%), followed by site 2 (77%) and site 1 (65%) (Fig. 6 B). The proportion of sea cucumbers found as pairs was greatest at site 1 (19%), followed by site 3 (13%) and site 2 (9%). The proportion found in clusters of >2 individuals was greatest at site 1 (16%) followed by site 2 (13%) and site 3 (1%). The distribution of aggregation types was, thus, clearly dependent on the site (χ2 = 15, p = 0.004). Moreover, the proportion of paired and clustered individuals showed a positive correlation with density (ρ = 0.3, p < 0.001; ρ = 0.7, p < 0.001; respectively). Accordingly, site 1 had the greatest density of sea cucumbers (see above) and the greatest average aggregation size (3.0 ± 0.2 ind/aggregate), while site 2 had an average of 2.7 ± 0.3 ind/aggregate, and site 1 had 2.1 ± 0.2 ind/aggregate (Fig. 6 A), although no clear statistical differences emerged ($H_{2,588}$ = 6.0, p = 0.051).

Discussion

Despite their limitations (discussed later), video transects conducted with an observation-class portable ROV across the three different sites within Qikiqtait in Hudson Bay, proved useful for reconnaissance demographic surveys and gathering baseline information on benthic assemblages of interest. The image analysis revealed that densities and average body sizes of *Cucumaria frondosa* were highest at site 1 (Kataaluk). This species showed an overall preference for gravel and rubble substrata, and displayed increased tentacle deployment in areas with higher levels of POM. Aggregation size and types differed among sites but were tied to the density present in each. Such differences in density and

Table 2. Proportion (%) of each substratum present in the three sites analysed in Sanikiluaq, Nunavut (NU), as well as for all three sites combined. Data are provided as mean ± standard error for site 1 (number of frames = 223), site 2 (n = 176), site 3 (n = 316) and for combined sites (n = 715). Different superscript letters indicate statistically significant differences between the substrata proportions among the sites. Ranked one-way ANOVAs were used to compare proportions between sites.

Substrata	Percentage			
	Site 1	Site 2	Site 3	Combined
Fine substrata	12 ± 1.2^a	60 ± 3.0^b	11 ± 1.0^a	24 ± 1.3
Gravel	52 ± 2.0^a	19 ± 1.7^b	53 ± 1.6^a	44 ± 1.2
Rubble	25 ± 1.7^a	16 ± 1.6^b	29 ± 1.3^a	25 ± 0.9
Small boulders	1.4 ± 0.4^a	2 ± 0.4^a	3 ± 0.4^a	2 ± 0.2
Large boulders	0.7 ± 0.3^a	1 ± 0.3^a	0.8 ± 0.3^a	1 ± 0.2
Shell debris	8 ± 0.9^a	3 ± 0.4^b	1 ± 0.2^b	3 ± 0.3

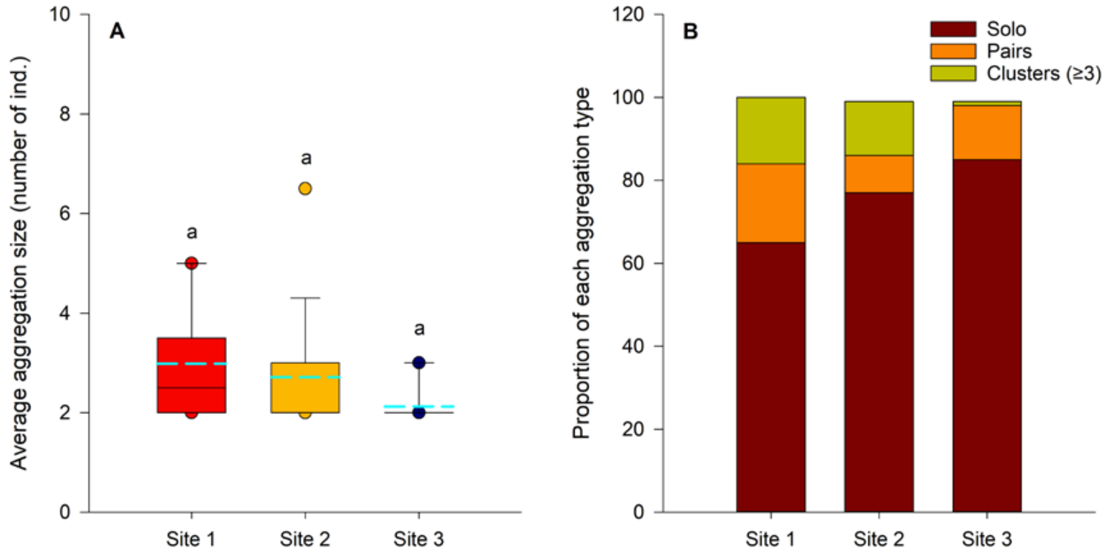

Figure 6. A) Aggregation size (individuals/aggregate) of *Cucumaria frondosa*. Data presented are the median (horizontal line), mean (blue dashed line), data range (edges of box), standard error (whiskers) and 5th/95th precentile (dots), while differing letters above each indicate significant differences between sites (one-way ANOVA on ranks and Dunn's test). B) Proportion of total sea cucumbers found in the different aggregation types (solo, pairs, or clusters of three or more individuals) at each site.

distribution patterns are likely modulated by the environmental conditions found within each site.

Across the three sites investigated in Qikiqtait, densities of *C. frondosa* ranged between 0.1 ind/m^2 and 1.3 ind/m^2, in line with the various values reported in the literature for other locations in its distribution range (i.e. 0.05 to >5 ind/m^2; Campagna et al. 2005; Dallaire et al. 2005; Hamel and Mercier 1996). However, those values were lower than the maximum reported for the same geographic area by Hamel and Mercier (2024), with densities up to 30–50 ind/m^2 for both small and large sized sea cucumbers on rocky substrata, especially in channels with high tidal currents. As shown by Sun et al. (2018), currents around 40 cm/s are preferred by adults of *C. frondosa*, and they appear to create ideal conditions for young recruits (Hamel et al. 2023) through increased food capture and oxygenation. Currents were not recorded in the present study, but were likely weaker than that optimum value as the sites were not located inside channels. When considering other potential environmental drivers, site 1 was the deepest, and was dominated by rocky substrata such as gravel and rubble. Site 1 also exhibited the highest levels of suspended POM, which represent three factors of interest.

The density of sea cucumbers globally increased with increasing depth in the present study. Hamel and Mercier (1996) suggested possible vertical migrations with age, after detecting increasing sizes and densities of *Cucumaria frondosa* with depth in a population from the St Lawrence Estuary (eastern Canada), which aligns with the present study in Qikiqtait. The preferred depth range, based on the recorded abundances of adults of *C. frondosa*, is between 30 m and 60 m (Klugh 1923; Hamel and Mercier 1996), whereas recruits and small juveniles (0.9–40 mm) occur at much shallower depths between 1.8 m and 2.5 m (Hamel et al. 2023). While all three study sites are roughly in line with the lower end of the preferred depth range of adults, only site 1 falls directly into that optimal range (33 m), further supporting both the increased occurrence and greater proportion of large sea cucumbers (20–25 cm) at that site. This finding also lends support to the hypothesis of an ontogenetic vertical migration in *C. frondosa*.

The size distributions recorded here, however, may not be solely due to depth. It was hypothesised that differences in other environmental conditions, such as available substrata, may also play a role by fulfilling the unique requirements of the different size classes (Hamel et al. 2023). In the present study, sites 2 and 3 were at the same depth, yet each site had very distinct seafloor characteristics, with site 2 being dominated by fine substrata (i.e. sand). Although average sea cucumber lengths were roughly the same, 70% of the sea cucumbers at site 2 fell in the intermediate size class (6–10 cm), while at site 3 only 33% fell within that class and more sea cucumbers were larger. So et al. (2010) studied the substrata preferences of *Cucumaria frondosa* in relation to body size in laboratory settings and found that larger sea cucumbers chiefly associated with coarse rocky substrata such as gravel and rubble, while smaller sea cucumbers were associated with fine substrata. These findings help validate the role of substratum in the population size structures recorded at sites 2 and 3. Moreover, sea cucumbers were found to preferentially occur on rocky, rather than fine, substrata in the video frames that were analysed, especially site 2 where the former was limited. This further exemplifies the importance of considering substrata, in combination with depth, when assessing or wanting to predict the distribution of *C. frondosa*.

In addition to physical benthic characteristics, food availability is another key variable. Levels of POM, which was shown to be part of the diet of *Cucumaria frondosa* (Hamel and Mercier 1998), increased with depth along with sea cucumber densities, although this was not significantly correlated. Site 1, where more and larger sea cucumbers were found, displayed the highest levels of suspended POM, while the lowest proportion of sea cucumbers with deployed tentacles occurred at site 2, which had the lowest levels of POM and greatest intra-site variation in POM levels. Finally, the proportion of actively feeding sea cucumbers increased with increasing levels of POM, as observed in the video clips. This behavioural response to food availability has been described in experimental studies, whereby high particle concentrations resulted in increased feeding activity in *C. frondosa* (Singh et al. 1998, 1999). The present study aligns with these findings to suggest that areas with consistently high POM levels support the greatest feeding activity, thereby enhancing growth and the presence of larger sea cucumbers, and this is an important consideration from both harvesting and conservation perspectives.

At a finer scale, the incidence of both pairs and larger clusters increased with increasing sea cucumber density. According to the literature, aggregating behaviours in echinoderms are associated with various factors such as improved food acquisition, protection against predators, and increased reproductive success via chemical signalling (Ormond et al. 1973; Broom 1975; Levitan et al. 1992; Mercier et al. 2000). Claereboudt et al. (2023) used combined field observations and experimental methods to confirm the non-random distribution of both juveniles and adults of the tropical sea cucumber species *Holothuria scabra*. Individuals moved toward a stimulus (a saponin extract) when placed in a Y-maze experiment. In addition, the study found that increasing the stocking density of juveniles resulted in higher aggregation behaviours even though space was not a limiting factor (Claereboudt et al. 2023). Like *H. scabra*, and despite its different feeding strategy, *Cucumaria frondosa* was found to display aggregations outside the reproductive season, possibly in response to small-scale variability in planktonic food supplies and conspecific interactions. Further investigation will be needed because aggregating behaviours in *C. frondosa* are not fully understood and a multitude of other environmental or social factors may be involved that have yet to be considered.

Overall, valuable sea cucumber demographics were obtained, but interpretations must remain cautious. While the use of portable ROVs is gaining popularity in community-based marine surveys (Raoult et al. 2020; Buscher et al. 2020), it comes with a number of limitations that should be acknowledged, even though the technology is evolving rapidly. A common limitation is the unaccounted variability in the positioning (depth and camera angle) of the ROV relative to the benthos, which is contrary to work-class ROVs that may offer downward-facing cameras and more position control for quantitative spatial analyses. However, the latter are very costly and difficult to operate, typically being deployed from large boats by qualified pilots, and thus are often not suited for shore-based field research. In addition, they cannot be launched through ice. Drop cameras and trawls are alternatives offering a more standardised approach, although they also require the support of a boat, are unsuitable for ice-based studies, and have their own limitations (de Mendonça and Metaxas 2021). In line with community-based work targeting capacity building in remote regions, the present study took a mixed qualitative and semi-quantitative approach, providing baseline information about sea cucumbers in the Arctic. Many metrics were reported as proportions to reduce any bias related to differences in the number of transects per site and the length of each survey. Additionally, size distributions and density measurements relied on calibration with lasers on a subset of suitable images. Overall, this study may be considered a reconnaissance survey, providing baseline information that adds to the currently limited knowledge of sea cucumber populations in the focal region, on which future work can build. In terms of community-led work, a key consideration is to balance the resources available (e.g. boat) and approach (e.g. non-destructive) with the cost, capabilities and user-friendliness of the survey method chosen to gain the best possible results given the constraints.

Integrating key elements of the complex ecology of *Cucumaria frondosa* will be a crucial next step in informing the development of management and conservation initiatives around Arctic marine ecosystems. The present study emphasises the careful consideration of synergistic effects of different physical and biological parameters on the distribution patterns of *C. frondosa*, as some factors that have yet to be considered (e.g. predation, ice scouring) may additionally constrain the spatial ecology of this species. Our findings suggest that portable ROVs may be helpful tools for gathering in situ information about benthic species while also being a non-disruptive method of sampling that can be used by local communities to conduct baseline appraisals. To enhance our understanding, future studies using portable ROVs should not only seek to cover a broader range of depths and locations, but also consider other critical aspects, such as interactions among benthic fauna. Finally, the potential benefits of more quantitative, yet potentially more costly and/or invasive surveying methods might be explored. Efforts are concurrently ongoing to expand the use of observation-class ROVs for stock assessments, such as developing standardised virtual quadrats to increase their quantitative power (Gover 2024; Ma et al. in prep.). Ultimately, the present (pioneering) study offers crucial insights into the ecology of sea cucumbers in Hudson Bay, establishing a baseline for future reference, which is especially important due to rapidly changing conditions in the face of climate change and expanding human activities.

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Association between a marine halacarid mite (Halacaroidea: Arthropoda) and early juveniles of the northern sea cucumber *Cucumaria frondosa* in Nunavut

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Abstract

Juvenile and adult sea cucumbers are integral to marine food webs across the globe. The northern species *Cucumaria frondosa* is part of the diet of sea stars, crabs, fishes, birds and mammals, including seals and walruses, across its wide geographic distribution in the North Atlantic and Arctic Oceans. However, the trophic ecology of early juveniles is far less understood. In Qikiqtait (southern Nunavut, northern Canada), a nursery comprising newly settled and early juveniles <1 year of age (<1 mm in length) was recently identified. One juvenile sampled from this nursery was fortuitously discovered to host a transparent halacarid mite (~150 µm in length). The colour of the mite's digestive tract mirrored the colour of the sea cucumber's tissues, which are rich in red pigmented cells. Accordingly, the mite was cryptic, almost invisible when seen from above, and was presumed to feed on the tissues of juveniles. This represents the first observation of a direct interaction between juvenile sea cucumbers and a mite, providing novel insight on halacarid–echinoderm associations and adding an element to our understanding of northern sea cucumber populations.

Introduction

Juveniles and adults of the sea cucumber *Cucumaria frondosa* are known to be part of the diet of numerous cold-water and Arctic species. Among its major predators are sea stars, crabs, fishes, eider ducks, walruses, bearded seals and humans (Gianasi et al. 2021; Mercier et al. 2023). However, similar to all sea cucumbers, the ecology of early juveniles (<1 year) of *C. frondosa* in their natural environment is poorly studied, including their potential competitors and predators, as they are difficult to find. The recent discovery of a nursery of *C. frondosa* in Qikiqtait (Nunavut, Canada; Hamel et al. 2023Nunavut, Canada) has unlocked exciting research perspectives on the ecology of early juvenile sea cucumbers.

Marine halacarid mites

The Halacaridae family (Arthropoda: Arachnida) consists of more than 1100 non-swimming species of mites that are distributed worldwide, from the intertidal zone down to abyssal depths (Bartsch 2009). Halacarids are mostly benthic marine species, but some have adapted to freshwater. They are found on a variety of substrata, including macroalgae, muddy and sandy bottoms, sponges, hydrozoans, bryozoans, barnacles, mussels and polychaetes (Bartsch 2006). Twenty halacarid species, belonging to 10 genera, have been described living in the same environments or in association with all five extant classes of echinoderms (Chatterjee 2021). However, the exact nature of the relationship between halacarid mites and echinoderms is poorly understood because live observations are rare (Chatterjee 2020). For instance, one species of halacarid was described as a parasite in the gut of a sea urchin in Indonesia (Viets 1938) and another was observed crawling on a brittle star in Australia (Bartsch 1993). Four more halacarid species were reported to be associated with sea cucumbers in the Adriatic Sea (Viets 1940), without providing any details, and another six species were found in sediments where *Cucumaria* sp. co-occurred in Norway (Viets 1928). Because they have never been directly seen together *in situ*, the relationship between halacarid mites and sea cucumbers remains an enigma.

In this study, recently settled juveniles of *Cucumaria frondosa* (~3 months old) were collected in the subtidal zone (~1-4 m depth) of the Kataaluk channel north of Renouf Island (Qikiqtait, Nunavut, Canada; 56.603611, -79.142500). Stones of different sizes from 1 cm to 36 cm in diameter were collected with a long pole net, brought to the boat and examined for juvenile sea cucumbers. Several hundred juvenile sea cucumbers (≤10 mm long) were collected from the surfaces or crevices of stones. They were stored in Eppendorf tubes with seawater and transported to the laboratory for further study and processing.

While sorting live juveniles (which are orange-reddish) under the microscope, one was found to harbour a transparent halacarid mite on the surface of its body. The mite (~150 µm in length) was seen walking on the juvenile (~900 µm) for five minutes, exploring the external body wall with its palps and inserting chelicerae into it (Fig. 1A, B). The body and digestive tract of the mite clearly showed the pale reddish colour of the tissues of the juvenile sea cucumber, suggesting that it ingested them. The mite most probably consumes the fluids containing red pigmented cells, chiefly coelomocytes or their aggregates, as described in Caulier et

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al. (2020). This would be achieved by piercing the body-wall epithelium to reach the hydrovascular system of the juvenile sea cucumber. In support of this assumption, some mites have been described sucking the fluid from their prey using specialised piercing mouthparts (Dabert 2005). Considering the size of the mites, they may solely target early juveniles of *C. frondosa* that possess a thin body wall. The possibility that they can also pierce the thicker epithelia of adults, including that of the podia, would need to be investigated as mites were found in the same habitat as adults of the species in Norway (Viets 1928).

Given that mites are small relative to juvenile sea cucumbers (ratio of 1:6 in the current study; down to 1:66 for juveniles up to 10 mm), it is unlikely that they represent a major burden, although intense or repetitive predation, especially on smaller individuals (≤2 mm), may impede their growth rate. While the collection method was not well adapted to the preservation of free-living epibionts (see discussion below), the density of mites seems to be low in comparison to the density of small juvenile sea cucumbers (up to 104 ind/m^2, Hamel et al. 2023), further spreading the potential burden they represent. Video observations clearly showed the rapid displacement of the mite on the surface of juvenile sea cucumbers, supporting its capacity to quickly move from one host or prey to another. However, further investigations will be required to determine the abundance of halacarid mites and their potential impacts on early juvenile sea cucumbers inside the nursery, as most of them may have been lost during the sampling. The long pole net scraped the bottom and brought the rocks to the surface, during which time the mites could have detached and fallen off. Moreover, the early juvenile sea cucumbers were collected from the rocks using tweezers and the mites may have been accidentally crushed. Finally, the mites are small and well camouflaged, and nearly invisible to the naked eye. During this field expedition in Qikiqtait, a second mite was fortuitously observed crawling on another juvenile sea cucumber sampled in the intertidal zone near the hamlet of Sanikiluaq, while a third one was found under a rock (in a sea cucumber habitat), suggesting that more mites might be discovered with further and more careful sampling.

Interestingly, the color of the mite matched almost perfectly the color of the sea cucumber host, making it almost invisible when viewed from above (Fig. 1C). This suggests a mimetic adaptation, likely to prevent detection by predators, and supports the possibility that the mite concentrates on juvenile sea cucumbers as a food source. The observation of mimesis and evidence of feeding on juvenile sea cucumbers suggest a parasitic relationship between the two species, to the advantage of the mite.

This contribution represents a first direct observation of a mite crawling and feeding on a juvenile sea cucumber, possibly the first association between living Halacaridae and Holothuroidea as a whole. The observation also, quite possibly, represents a newly described, non-lethal predator of *C. frondosa*. As fishing pressure on *C. frondosa* continues to increase across its distribution range, and with potential

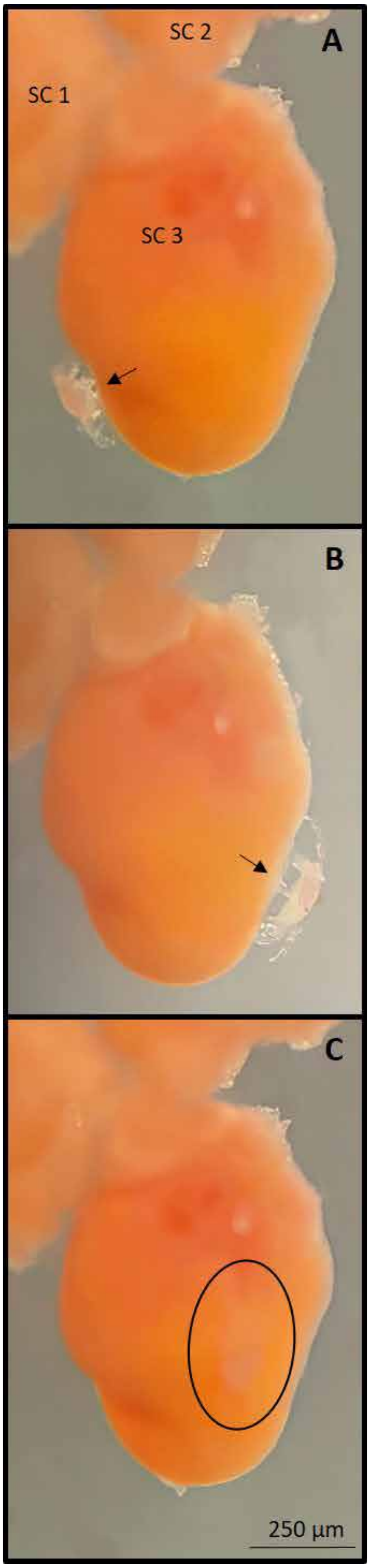

Figure 1. Still frames extracted from video footage showing the mite (arrow pointing at it) actively moving over the juvenile *Cucumaria frondosa*. The reddish colour of the digestive tract of the mite rendered it nearly invisible from certain angles (circle), which is in line with the ingestion of sea cucumber tissues. SC: sea cucumber.

expansion of small-scale fisheries into the Canadian Arctic in the near future, close monitoring of nursery habitats and of the trophic position of early life stages in food webs should be undertaken to ensure sustainable activities.

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Unexpected biotic substrata utilised by newly settled recruits of the sea cucumber *Cucumaria frondosa* in their nursery habitat

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Abstract

Recently, the occurrence of newly settled recruits and early juveniles of the sea cucumber *Cucumaria frondosa* was described in shallow waters (depth <2.5 m) of Qikiqtait, Nunavut (northern Canada) on shells of live and dead mussels, and on the bare surfaces of stones, forming a nursery habitat. It was assumed that most young individuals (i.e. <2 y) occurred on these substrata. However, since the initial publication by Hamel et al. (2023), new biotic substrata have been identified to host newly recruited juveniles in their nursery habitat, including the holdfast and blade of seaweeds, sea urchin spines, encrusting bryozoans, barnacles, coralline algae, and bivalves other than mussels, suggesting that the recruitment of *C. frondosa* may be more complex and opportunistic than originally suspected. As *C. frondosa* is currently the most heavily fished sea cucumber in the world, with fishing initiatives emerging in the Arctic, knowledge of where its recruits and juveniles are distributed is of major importance to protecting this potentially vulnerable resource.

Background

Despite the growing number of field reports that mentioned sightings of juveniles from various species of sea cucumbers (Wolfe et al. 2024), few studies have effectively detected new recruits (i.e. recently settled individuals) and identified nursery habitats (Mercier et al. 1999; Shiell 2004; Rogers et al. 2021; Hamel et al. 2023). Nevertheless, based on field observations, some sea cucumbers have been shown to have specific settlement and recruitment requirements (Mercier et al. 1999; Rogers et al. 2021; Hamel et al. 2023; Wolfe et al. 2024).

The dendrochirotid sea cucumber *Cucumaria frondosa* broadly distributed in the North Atlantic and Arctic oceans, and is commercially exploited in North America and Europe (Gianasi et al. 2021; Mercier et al. 2023). Small juveniles, 15–30 mm long, were documented on gravel and boulders, in shallow-water environments (<10 m deep) in the St Lawrence River Estuary (Hamel and Mercier 1996). However, recruits (i.e. <1–2 mm, and presumed to be <2 y old), have so far only been reported in Qikiqtait (Nunavut, northern Canada) on bare surfaces (i.e. visible absence of any macro-organisms) of stones and on shells of live and dead mussels (also on their byssus; *Mytilus* sp.) in waters between 1 m and 2.5 m deep (Hamel et al. 2023).

The present contribution summarises all other substrata on which annual recruits and early juveniles of *C. frondosa* were observed during additional sampling campaigns conducted over a two-year period in Qikiqtait. Specifically, sampling occurred in Kataaluk (56.603300°N, 79.150200°W) at a depth of ~1.0–3.5 m; Kataapik (56.629238°N, 79.269109°W) at a depth of ~1–3 m depth; Katak (56.537183°N, 79.132764°W) at a depth of ~2–3 m; and east of the hamlet of Sanikiluaq (56.548755°N, 79.205297°W) in tide pools at low tide. Subtidal and intertidal collections of various substrata between 2023 and 2024 were analysed opportunistically. For each recruit and juvenile observed in the field (~1400 individuals examined), the substratum on which they were attached was recorded, with a focus on novel substrata.

Although new recruits of *C. frondosa* can reach densities upwards of 100 individuals/m^2 (Hamel et al. 2023), these levels were recorded almost exclusively on blue mussels (shell and byssus) and bare stones (generally on undersurfaces and in crevices). The present report documents a few exceptions to these substratum preferences by new recruits of the current year (i.e. estimated to be ≤2 mm in length). At least 30 recruits were found on the elongated blade of *Chorda* cf. *borealis* (~50 blades examined), themselves attached to a large stone (36 cm in diameter) at ~1 m depth (Table 1 and Fig. 1A, B). On the holdfast and blade of *Fucus distichus*, six recruits were found in tide pools and four at ~1 m depth (Table 1 and Fig. 1A, C). Three recruits were found attached to coralline algae (probably belonging to the genus *Lithothamnion*) at a depth of ~1–3 m (Table 1 and Fig. 1D). Additionally, a few dozen recruits were found settled on, or at, the margin of colonies of encrusting bryozoans at a depth of ~1–3 m (Table 1 and Fig. 1E). Moreover, at depths of ~2–3 m, two recruits were observed on live shells of the bivalve *Hiatella arctica* (Table 1 and Fig. 1F), a third recruit was found on the shell plate of a barnacle (*Balanus* cf. *balanus*; Table 1 and Fig. 1G). Finally, a fourth recruit was observed on a sea urchin spine (*Strongylocentrotus droebachiensis*; not illustrated). In Kataapik and Katak sites, recruits and juveniles were only observed on the typical

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Table 1. Summary of novel and typical substrata utilised by newly settled recruits and early juveniles of *Cucumaria frondosa* in Qikiqtait, Nunavut, northern Canada.

Substratum	Number of recruits	Body length (mm)	Depth (m)	Date	Site
Novel substratum					
Chorda cf. *borealis*	~30	1	1	5 October 2024	Kataaluk
Fucus distichus	6	1–2	Tide pools	2 October 2024	Sanikiluaq
Fucus distichus	4	1–1.5	1	5 October 2024	Kataaluk
Coralline alga	3	1–2	1–3	5 October 2024	Kataaluk
Encrusting bryozoan	A few dozen	1–2	1–3	5 October 2024	Kataaluk
Hiatella arctica	2	1	2–3	25 May 2023	Kataaluk
Balanus cf. *balanus*	1	1	2–3	25 May 2023	Kataaluk
Strongylocentrotus droebachiensis	1	1.5	2–3	25 May 2023	Kataaluk
Typical and previously known substratum					
Mytilus sp.	340	1–24	2–3	29 April 2024	Kataapik
Mytilus sp.	30	1.5–19	2–3	23 May 2023	Katak
Mytilus sp.	12	1–2.5	2–3	25 May 2023	Kataaluk
Bare rock	~800	0.5–16.5	1–3	5 October 2024	Kataaluk
Bare rock	120	0.5–9.5	2–3	25 May 2023	Kataaluk
Bare rock	49	1–9	2–3	3 October 2024	Kataaluk
Bare rock	10	1–4	2–3	23 May 2023	Katak
Bare rock	9	1–2	Tide pools	15 November 2023	Sanikiluaq

nursery substrata of mussel shells and bare stones, down to depths of ~3 m (Table 1).

On rare occasions, recruits and early juveniles occur outside crevices and on exposed surfaces – for instance, on the blade or holdfast of seaweeds and on the plate of barnacles – which contradicts the majority of observations that were made initially (Hamel et al. 2023) and the known settlement preferences of new recruits previously described under laboratory conditions by Hamel and Mercier (1996). Further, early juveniles, aged 12 months or older (~3.6 mm or longer), preferred coralline algae (*Lithothamnion glaciale*) under experimental conditions (Gianasi et al. 2018). Presumably, a dense canopy of seaweeds provides sufficient shelter (e.g. shade) to stimulate the onset of settlement of pentactulae and to entice early juveniles to stay put instead of moving to find refuge, as is normally observed in *C. frondosa* (Hamel and Mercier 1996). Because the newly described nursery substrata (this contribution) represented only a small fraction of the available substrata, it is likely that these settlements were accidental. They may also be the result of the so called "desperate larva" theory, whereby the pentactulae might have run out of time and resources to search for more optimal or suitable microhabitat onto which to settle and recruit, as suggested for the sea cucumber *Isostichopus fuscus* (Hamel and Mercier 2022).

Although they represent only a small proportion of the new recruits or small juveniles found along the coast of Qikiqtait, the newly described nursery substrata used by *C. frondosa* suggest that the settlement phase may be less selective than previously thought. Moreover, the use of diversified settlement substrata (especially seaweeds) by *C. frondosa* suggests that the annual recruitment pulse could be higher than previously established in the inshore subtidal waters of Qikiqtait (Hamel et al. 2023), reinforcing the notion that this area of northern Canada represents the largest known nursery of sea cucumbers on the globe.

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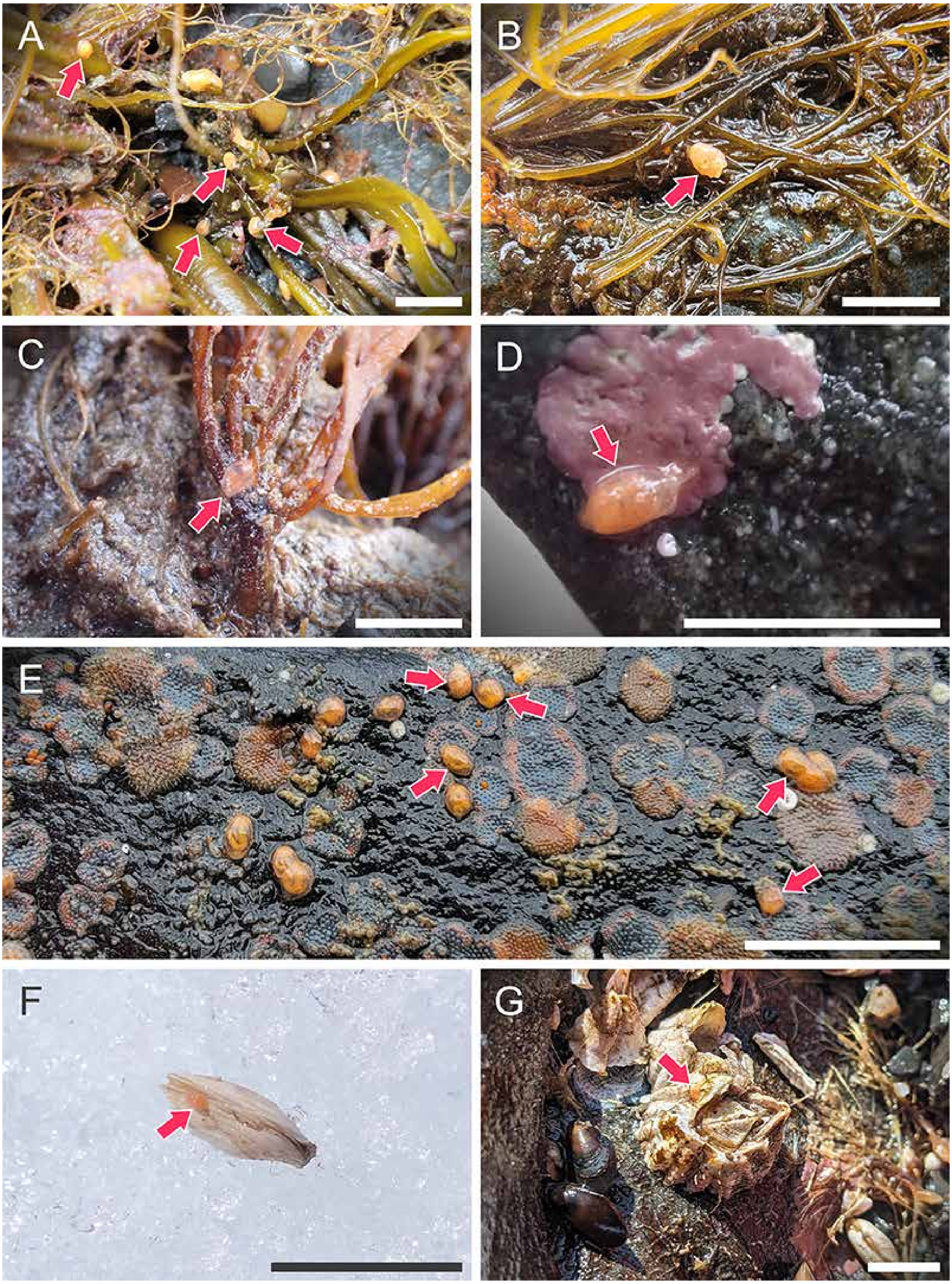

Figure 1. Newly settled recruits of the sea cucumber *Cucumaria frondosa* on A) the blades of *Chorda* cf. *borealis* and *Fucus distichus*, B) the blade of C. cf. *borealis*, C) the holdfast of *F. distichus*, D) a coralline alga, E) colonies of encrusting bryozoan, F) *Hiatella arctica*, and G) a barnacle *Balanus* cf. *balanus*. Arrows indicate juveniles on living biotic substrata. Scale bar = ~5 mm in panels A–D and ~10 mm in panels E–G. Photo credits: J.-F. Hamel (A–D); K.C.K. Ma (panels E–G).

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Characterising Canadian sea cucumber fisheries: History, regulation and compliance

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Abstract

This paper explores the historical development, regulation, and nature and scale of wildlife crime and illegal fishing in Canadian sea cucumber fisheries. Cases of illicit activities within Canadian sea cucumber fisheries were identified through a rigorous search of media stories (1 instance), legal cases (1 instance), and law enforcement records (22 instances) from 2015 to 2022. When compared to case studies in other jurisdictions, crime in the Canadian sea cucumber fishery is of a lower scale and severity, and receives less media attention. The paucity of news stories is explained by the largely administrative nature of most offenses, an absence of transnational cases, and the fact that issues relating to sea cucumbers have not been problematised in Canada. Efforts to triangulate between the three data sources yielded no overlap, suggesting that those analysing open-source information to better understand wildlife crime would do well to explore multiple sources.

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

Introduction

Wildlife crime refers to environmental crime that targets non-human animals, with a devastating effect on ecosystems. Wildlife crime is seen to be a highly profitable criminal endeavour, as evidenced by its prevalence among multinational criminal organisations, after drugs, counterfeiting, and human trafficking (Alden and Harvey 2021; Lohmuller 2015; Nellemann et al. 2016; Gluszek et al. 2021). Given the typically covert nature of this criminal activity, it can be difficult to estimate the scale of wildlife crime. Global estimates suggest that annual proceeds of the products of the illegal wildlife trade, which involves the sale of live and dead specimens for medicinal, decorative or cultural reasons, are between USD 7 and USD 23 billion (Nellemann et al. 2016), USD 19 billion (Lohmuller 2015; Illegal Wildlife Trade n.d.), and even USD 40 billion (Alden and Harvey 2021). A vast variety of animals are targeted, ranging from well-known charismatic species such as elephants, rhinoceroses and tigers, to less-well-known species, such as caterpillars, the Tibetan antelope, and Brazilian blue tarantula. Crime targeting sea cucumbers falls into this latter category (Phelps Bondaroff and Morrow 2024).

Sea cucumbers are a valuable commodity. Dried tropical commercial species such as *Holothuria whitmaei* (black teatfish), *H. fuscogilva* (white teatfish) and *H. scabra* (sandfish) can sell for around USD 300/kg, and prices for dried *Apostichopus japonicus* (Japanese spiky sea cucumber) can reach as high as USD 5000/kg (Akamine 2024; Purcell et al. 2018). The high value of the commodity is a major driver of illegal activities targeting sea cucumbers. Sea cucumber poaching is seen to be a low-risk, high-reward trade bolstered by a lack of government scrutiny and driven by greed and desperation (Phelps Bondaroff and Morrow 2024). As a result, crime can often be found in sea cucumber fisheries.

Crime has been identified in sea cucumber fisheries around the world (Conand 2018; Phelps Bondaroff and Morrow 2024), and there is a limited, although growing, body of literature exploring this phenomenon. While the covert nature of illicit activities presents challenges to studying and quantifying crime in these fisheries, we know from macro-level indicators that it is extensive. For example, in 2006, Hong Kong recorded a volume of imports that was 130% of the total global export reported that year, and the exports were found to be less than half of reported global imports (Anderson et al. 2010).

A recent review by Phelps Bondaroff and Morrow (2024) sheds light on crime at every stage of the sea cucumber fisheries supply chain, and details the *modus operandi* and impacts of this form of wildlife crime. Several studies and reports have attempted to quantify sea cucumber crime in countries and regions, with many relying on open-source information, including news stories, press releases from law enforcement agencies and government, and other online sources. Studies of sea cucumber crime relying on one or a combination of these sources have examined crime in Malaysia and Singapore (Ong and Chi 2022), India and Sri Lanka (Phelps Bondaroff 2021), Mexico (Phelps Bondaroff et al. 2022) and Turkey (Dereli and Aydin 2022).

Crime is often mentioned in broader explorations of sea cucumber fisheries, including ethnographies of fisheries in

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the Gulf of Mannar (Muralidharan and Rai 2020), gender-based violence in fisheries in Madagascar (Baker-Medard and Kroger 2023), and the history of Japanese and Russian sea cucumber fisheries (Kalashnikov 2024). Ferguson et al. (2022) note how crime can undermine conservation and management efforts in the South Pacific, and Aceves-Bueno et al. (2021) explore a similar issue in Mexico, as do Gore and Bennett (2022). Further, Alden and Harvey (2021) explore the challenges in addressing transnational wildlife crime networks originating in Tanzania, where legal sea cucumbers exports are associated with, and sometimes used as cover for, the export of illegal ivory.

To our knowledge, no studies have examined crime within the Canadian sea cucumber fisheries. This paper seeks to fill this gap and endeavours to answer the question: What is the nature and scale of crime in the Canadian sea cucumber fisheries? In answering this question, we also explore a history of Canadian sea cucumber fisheries and their regulation.

Sea cucumber fisheries in Canada

Sea cucumber harvesting in Canada goes back to time immemorial. Indigenous people of the Northwest Coast have historically consumed sea cucumbers as a traditional part of their diet (Mueller et al. 2024). Similarly, in the north, the Inuit have been consuming sea cucumbers for centuries (Hamel and Mercier 2024). Commercial sea cucumber fishing has emerged more recently, with two species of sea cucumber commercially exploited in Canada. In British Columbia (BC), *Apostichopus californicus*, commonly referred to as the giant red sea cucumber, is commercially targeted (Lochead et al. 2024; Sutherland 1996). *Apostichopus californicus* can be up to 60 cm in length, weigh upwards of 1 kg, and is the largest of the 45 species of sea cucumber found in BC (Fisheries and Oceans Canada 2022b). In the Atlantic provinces of Newfoundland and Labrador (NL), Nova Scotia (NS), and New Brunswick (NB), *Cucumaria frondosa*, commonly referred to as the orange-footed sea cucumber, is commercially targeted (Hamel and Mercier 2008). *Cucumaria frondosa*, depending on depth, grows to upwards of 50 cm in length with a weight of 5 kg (Feindel et al. 2011).

In this article we briefly outline the history and status of Canada's Pacific and Atlantic sea cucumber fisheries. It is noteworthy that there is no commercial fishery in the Canadian Arctic (Hamel and Mercier 2024). Maritime fisheries in Canada are regulated by the federal government, principally through the *Fisheries Act* (Government of Canada 1985).

British Columbia

Commercial sea cucumber fishing on the North American west coast (Washington State) began in 1971, and in BC and California in the early 1980s. By the late 1980s, overexploitation, poor management, and price instability resulted in Canada and the United States implementing management measures. By 1988, two governments had implemented a fishing season, an individual quota system, and geographic limitations on where fishing could occur (Fisheries and Oceans Canada 2022b). In BC, commercial licenses were implemented in 1983 with no limit on the number of licenses available. Additionally, in that same year, early management procedures were implemented, with specifically mandated record keeping in logbooks and the recording of sale information. In 1986, a precautionary total allowable catch (TAC) was imposed in the BC sea cucumber fishery, although this did little to curb increased fishing effort. In 1987, a rapid increase in fishing effort led to conservation concerns, and as a result, quotas specifically tied to regions and a fishing season were implemented.

In 1989, an "official consultative body" was formed – the Sea Cucumber Sectoral Committee (SCSC) (Lochead et al.2024). SCSC included various stakeholders, including sea cucumber harvesters, potential license holders, First Nations members, sea cucumber processors, and Fisheries and Oceans Canada (DFO) fishery managers and scientists (Lochead et al. 2024). SCSC still meets today, and has been central in the creation of sea cucumber management plans. Later, in 1991, a cap on the number of licenses was implemented, reducing the number of licenses from 215 to 85 (Toral-Granda et al. 2008; Fisheries and Oceans Canada 2024). Allocation of the 85 total licenses issues were allocated an equal 1/85th of the TAC. In 1992, the Pacific Sea Cucumber Harvesters Association (PSCHA) was formed, with the goal of representing the interests of license eligibility holders. PSCHA funds marketing, catch reporting initiatives, and scientific assessments (Lochead et al. 2024).

One source noted that there were still deficiencies with these measures, particularly area quotas, and that TACs were often exceeded. Furthermore, as the season was short lived, some harvesters were found to hoard sea cucumbers underwater just before the fishery opened to harvest them as soon as possible after the opening of the season. Concerns were also raised regarding the rate of fishing (Sporer n.d.). This led to the development of a precautionary management approach, which was implemented over the course of three stages.

Prior to the three stages, an earlier phase began in 1995 and entailed a review of research regarding *Apostichopus californicus*, with the aim of collecting known information and identifying knowledge gaps. This phase ultimately resulted in the recommendation that independent stock surveys, experimental fishing areas, and regional closures be implemented. In 1997, the fishery entered Stage 1, collecting new information, which occurred alongside the implementation of an adaptive management plan. During this stage, commercial and experimental fishing zones were designated, each comprising 25% of BC's coastline. The data collected through Stage 1 helped develop estimates of sea cucumber population densities and modelled the impact of three theoretical exploitation rates. Based on these data, TAC was periodically increased. While Stage 1 concluded in 2007, knowledge gaps persisted (Lochead et al. 2024; Fisheries and Oceans Canada 2022b). In

2022, DFO noted that there was a dearth of information regarding population sizes, distribution, lifespan, maturity rate, and recruitment rates (Fisheries and Oceans Canada 2022b). Stage 2 began in 2008 and continues to the present. This stage involves the reopening of regions that had previously been closed to fishing during Stage 1. The net result of re-openings has been the proportion of the British Columbian coastline open to commercial sea cucumber fishing increasing from 25% to 52%.

Currently, the TAC for BC sea cucumber fisheries is 614 t, which has been fished consistently between 2011 and 2022 (Lochead et al. 2024). This TAC saw a modest increase to 617 t in 2023 (Fisheries and Oceans Canada 2023b). At present, the commercial fishery includes an estimated 30 small vessels (12 m or less) and is open for eight weeks, starting in early October. During this season, sea cucumbers possess thicker skins as a result of having reabsorbed their internal organs, qualities that facilitate further processing and improve product quality. Sea cucumbers are gathered by hand in large mesh bags by scuba divers (Lochead et al. 2024).

The value of the BC sea cucumber fishery has increased in recent years from CAD 8.6 million in 2021, to CAD 15.4 million in 2022 (26%) (Fisheries and Oceans Canada 2024). This increase has been driven, in large part, by the increased demand from China and, to a much lesser extent, the US. The vast majority of Canadian sea cucumber exports (99%) are sent to China and Hong Kong (Fisheries and Oceans Canada 2024; Lochead et al. 2024). In BC, recreational harvesters are permitted a daily limit of 12 sea cucumbers, with a possession limit of 24, and are required to only hand collect (Fisheries and Oceans Canada 2024). There are no fishing limits for First Nations peoples, if sea cucumber harvesting is for the sole purpose of food and/or social and ceremonial purposes (Fisheries and Oceans Canada 2024).

From a conservation perspective, *A. californicus* has been assessed as a species of least concern and determined to have a stable population by the International Union for Conservation of Nature (Mercier et al. 2010). More research is needed on the biology and behaviour of *A. californicus*, which would provide insight that could prevent localised overfishing. This could also help evaluate the impacts of the climate crisis and rising sea temperatures, which may lead to increased disease outbreaks in sea cucumber populations (Fisheries and Oceans Canada 2023b). While sea cucumber fishery management measures in BC appear to be ecologically successful, the fishery does have substantial issues relating to economic equity. The use of individual transferable quotas – a market-based management regime – has resulted in the price of fishing rights ballooning, making entrance into the fishery (as an independent owner-operator) highly capital intensive. As a result, ownership of fishing rights is concentrated in the hands of investors and processors, not harvesters (Lochead et al. 2024).

The harsh economic realities of the fishery for harvesters can be seen in the 2023 testimony of Tasha Sutcliffe, of Ecotrust Canada, to the Standing Committee on Fisheries and Oceans. In her testimony, Sutcliffe reported that in the sea cucumber fishery,

> …licences are going for $1.5 million. That's doubled since 2015. Most skippers lease and only get $2.25 a pound, but if you are an owner-operator, you get $9.25. If we go with that number, after expenses, the average skipper would make about $40,000 of a boat share. That means it would take them, even if they had all the capital and didn't have any cost of borrowing, at least 36 years to pay off that licence. Chances are that they would never be able to pay it off. I don't know anyone who's going to give a fisherman $1.5 million with no cost of financing. (Parliament of Canada 2023)

These issues are not unique to sea cucumber fisheries in BC. Ecotrust Canada has found that quotas in BC are owned by a small number of larger firms. In the case of groundfish trawlers, 50% of the value to quotas are owned by 1.2% (four) operators in the fishery (Parliament of Canada 2019). The alternative for harvesters trying to operate within BC fisheries is leasing quotas from owners, which is a practice used in BC sea cucumber fisheries (Lochead et al. 2024). Quota leasing enables quota owners to offset production costs and much of the financial risk onto harvesters who are often in debt to the person or company from whom they are leasing the quotas. Furthermore, quota leasing contracts have been found to often set the prices at which a catch is sold, and restrict to whom it can be sold, among other conditions, such that they favour the interests of quota-owners (Sutcliffe et al. 2018; Morrow and Casavant 2023).

Atlantic Canada

Sea cucumber fisheries are also present on the Atlantic side of Canada in NL, NS and NB. These fisheries occur in waters that fall under the purview of the North American Fisheries Organization (NAFO), a regional fisheries management organisation. These are all commercial fisheries and recreational sea cucumber harvesting is not permitted, nor is there an Indigenous Food, Social and Ceremonial fishery for sea cucumber in the region (Fisheries and Oceans Canada 2019, 2022a; Department of Fisheries and Oceans n.d.).

Compared to BC, commercial sea cucumber fisheries on the east coast of Canada are much more recent. In the early 1990s, mismanagement led to the collapse of several important fish populations, and their associated fisheries were closed. To explore new fishing opportunities, the federal government implemented the New Emerging Fisheries Policy, which lays out prerequisites for the creation of a new fishery that is centered around a scientifically based approach to the assessment of fishing pressures (Hamel and Mercier 2008).

In the early 2000s, efforts to diversify Atlantic fisheries through the Fisheries Diversification Programme, identified

Cucumaria frondosa as a species that could sustain a fishery (Hamel and Mercier 2008). This fishery has largely been developed as a high-volume, low-value model, much like the groundfish and shrimp fisheries (Mercier et al. 2023). DFO granted permission for the use of drag gear for harvesting sea cucumbers (Purcell 2010), gear that was originally developed for the scallop fishery. This method is known to be highly destructive, and in addition to damaging benthic habitats, it also leads to the capture of several non-target species as bycatch, including other echinoderms, molluscs, fishes and crabs (Hamel and Mercier 2008). Studies have suggested that although bycatch is not significantly high in volume, the full extent of the consequences of drag net fishing on the marine environment and its inhabitants are not fully known (Seafood Watch 2017). Other conservation concerns relating to the *C. frondosa* fishery include the species reproductive strategy. Unlike most commercially exploited species that can be found in shallow tropical or temperate waters and which broadcast millions of oocytes multiple times a year, *C. frondosa* live in cold, subtidal waters and spawn once annually. It is a slow-growing and late maturing species that produces yolky eggs (Mercier et al. 2023). This presents multiple conservation and fisheries management challenges.

In NL, an exploratory *Cucumaria frondosa* fishery was launched in the early 2000s, and a five-year resource survey was used to gather data to estimate biomass, better understand the distribution of sea cucumbers on the St. Pierre Bank, and ultimately explore the possibility of establishing a commercial fishery. As part of this exploratory stage, eight inshore licenses were issued (Fisheries and Oceans Canada 2019). In 2012, the fishery transitioned from "emerging" to "commercial". In 2023, the TAC for this fishery was 6959 t (Fisheries and Oceans Canada 2023a). Permit holders can harvest 118 t per year, and use drag gear. The season runs from 1 June 1 to 31 December, and harvesters must maintain and submit their logbooks to authorities. All landings must be dockside monitored via a vessel monitoring system (Fisheries and Oceans Canada 2019). The fishery has a rough value of CAD 10 million (CBC News 2021).

The sea cucumber fishery in NS developed through fits and starts, with several exploratory fishing permits being granted for various areas throughout the 1990s and early 2000s (Fisheries and Oceans Canada 1997). TACs are distributed across inshore, midshore, and offshore portions of these divisions, and amounted to 2300 t in 2022/2023, with fishing occurring between 1 May 1 and 31 March. The value of this fishery has been increasing alongside the growing cost of sea cucumbers. In 2012, Nova Scotian sea cucumber exports amounted to CAD 3.6 million, while in 2015, they amounted to CAD 5.3 million (Hansen 2016).

The sea cucumber fishery in southwest NB was launched in 1999. Two inshore experimental licenses fished a portion of the NAFO Division 4X between 1999 and 2006, with most (80–90%) of the fishing effort being concentrated in a single zone, known as "The Passage" (Fisheries and Oceans Canada 2009). The Tongue Shoal area in St Andrews Harbor was closed to commercial sea cucumber fishing in 2006, existing as a reserve (Fisheries and Oceans Canada 2021). This same year, a TAC of 1370 t, distributed across four fishing zones, was implemented. The two exploratory licenses were converted to limited entry licenses in 2011, and both changed hands in 2012. The TAC was adjusted over the years, and in 2019 was reduced to 500 t due to declining catch rates (Fisheries and Oceans Canada 2021). The value of the sea cucumber fishery has declined in recent years, according to one news story citing NB's 2020 seafood export report. Sea cucumber exports from there have fallen from over CAD 2 million in 2018 to CAD 780,000 in 2020, a small increase from the 2019 value of CAD 580,000 (Province of New Brunswick 2021).

Collecting data of illegal incidents

We initially sought to create a dataset of illegal incidents involving sea cucumbers using news media stories, government and law enforcement press releases, and other open-source information. This has been done elsewhere to explore this phenomenon, such as Sri Lanka and India (Phelps Bondaroff 2021), and Mexico (Phelps Bondaroff et al. 2022). When we replicated the method used by Phelps Bondaroff et al. (2022) in Canada in August 2023, it failed to uncover any news stories concerning illegal activities involving sea cucumbers.

In early 2022, we submitted a request to Fisheries and Oceans Canada, through the *Access to Information Act* (A-2021-013191/CBL). We initially set out to cross-reference news stories with reports from law enforcement, but given the absence of news media reports, we found this information made up the core of our dataset. The request asked for any and all records pertaining to violations (administrative or criminal) of laws and regulations pertaining to sea cucumbers and sea cucumber fisheries in Canada from 2015 to the present (at the time, 2 February2022). The request also asked for a break down of individual cases, including (when known):

- The date.
- Location of incident (with as much precision as possible).
- Number of people involved and their nationalities.
- The species and number/weight of sea cucumbers involved, and whether or not they were seized as a result of the incident.
- The state of the sea cucumber (live, fresh, processed, etc.).
- The value of the sea cucumbers seized.
- The authorities/agency responsible for the seizure/incident (local police, RCMP, Fisheries Officer, etc.).

- The destination and source of the sea cucumbers.
- Details about any punishments/sanctions that resulting [sic].
- Any associated commodities found with the sea cucumbers (i.e. found with illicit shark fins, found alongside halibut, smuggled with illicit drugs, etc.).

The results of this request produced a collection of data that included violation, occurrence, and exhibit reports from DFO enforcement officers, copies of court filings and case records, associated documents, hand-written inspection reports, field notes and officer notes, fisheries monitoring documents (catch reports), tickets and warnings, and some internal office email communications relating to incidents.

We then constructed a database of cases extracted from these data, which included, where possible, the date and location of an offense, the specific sections of laws and/or regulations that were violated, the number of individuals arrested, punishments, and the weight and estimated value of illicit catches, and additional qualitative information relating to how violation and enforcement occurred. While most of this information was available for individual cases, we found that the weight and estimated value of illicit catches was only included in a single case. Additionally, information regarding arrests was also sparse, and this is likely a result of the cases primarily constituting minor administrative violations, rather than, major incidents of illegal fishing.

While the information gleaned from the Access to Information request shed light on the nature of offenses, it provided little information regarding the outcome of any court cases. As such, we sought to supplement and cross-reference our Access to Information request with the outcomes of any legal cases resulting from incidents. To this end, the term "sea cucumber" was entered into the Canadian Legal Information Institute's (CanLII) online search engine for Canada-wide results, and an open search was conducted.

The CanLII database contains "court judgments from all Canadian courts, including the Supreme Court of Canada, federal courts, and the courts in all Canada's provinces and territories. CanLII.org also contains decisions from many federal and provincial administrative tribunals" (What is CanLII n.d.). This database was established in 2001, and notes that "for most Canadian courts and tribunals, our collection is generally complete for cases decided after 2001" (What is CanLII n.d.). The database also includes a number of significant pre-2001 cases, which have been added as a result of several historical projects. These cases were reviewed for relevance. Given our focus on wildlife crime, we were specifically interested in cases that included violations of laws and regulations relating to the sea cucumber harvesting, fisheries or aquaculture, as well as associated crimes facilitating any illicit activity involving sea cucumbers.

Results

News media stories

Multiple rounds of searches of Canadian media resulted in only one positive result. This story was published on 10 June 2020, and featured a case where, in the previous month, a man was apprehended in Sechelt Inlet, BC, with a catch of oysters, whelks and sea cucumbers that were all over the legal limit (Eckford 2020). On 1 May, Mr Z.Y.L., the harvester in question, received tickets for three counts of catching and retaining more than the daily quota. He later agreed to pay the CAD 3000 in fines prior to a court date set for 14 May. The news story then went on to list other recent fishing incidents, all of them involving the overfishing of rockfish and unspecified species.

Another news story was published in May 2022, but was not captured by our initial search as it fell outside the time range of this search. This article, from *Macleans Magazine*, tells the story of Mr S.S., a BC harvester notorious for violating fisheries laws, and which the magazine described as "the most prolific poacher on the West Coast" (Markusoff 2022). The article reported that Mr S.S. had been found fishing illegally for a wide range of species, including crabs, halibut, ling cod and prawns, for which he had received fines, had his gear confiscated, had been prohibited for fishing for a protracted period of time, and had received jail time. The in-depth article provides a lengthy history of this poacher, which includes a mention of charges he received in 2019 for illegally harvesting sea cucumbers (Markusoff 2022). The only details about the case that are mentioned in the article, state that apart from receiving a "raft of charges," he was also charged with immigration offense. Mr S.S. had allegedly hired Mexican nationals who lacked work permits (Markusoff 2022). The article noted that these counts were still before the courts.

Since conducting our initial media survey, we subsequently identified more recent stories, including: coverage of court proceedings relating to Mr S.S. (Hoekstra 2021; Markusoff 2022), a group of harvesters caught overfishing near Powell River, BC (Galinski 2022), and another involving a bankruptcy and insolvency court case involving the company Atlantic Sea Cucumber Ltd in NS (Cameron and Wong 2023).

Access to information, DFO

From our Access to Information request, we were able to extract 22 cases from between 5 October 2015 and 26 November 2020. From these cases, two broad categories of infraction emerged – administrative violations and illegal fishing. For analytical purposes, overruns[5] were separated from other types of administrative violations, given their prevalence and primary method of identification. Specifically, dockside and on-the-water inspections identified the bulk of administrative violations recorded, whereas,

[5] An overrun is an instance of a harvester being found to have exceeded their fishing quota.

overruns were found through administrative review of records submitted by harvesters. Additionally, there was a single instance of obstructing an investigation, which coincided with a case of illegal fishing. In terms of geographic distribution, BC had the most cases (13), followed by NL with 8, and NB with 1. Most cases occurred in 2017, which accounted for 11 of our 22 total cases. Other years ranged between one and four cases.

The increase in cases in 2017 is explained by five cases of quota overruns. These were not "found committing offenses" – which is when a law enforcement officer did not actively identify someone actively fishing over their quotas – rather these resulted from an administrative enforcement review of fishing records submitted by harvesters. That is, an administrator from the DFO enforcement programme reviewed records submitted by harvesters at a later date in order to identify inconsistencies in reporting. Whether it was the result of a complaint or an internal enforcement audit (regular or *ad hoc*), it is unclear what prompted this review.

Administrative violations (BC)

Administrative infractions in BC, which accounted for 10 out of 22 identified cases, consistently related to fishing licenses. The most common infraction in this category (seven cases) was harvesters forgetting their license, resulting in a violation of Section 11 of the Fisheries General Regulations (FGR), which requires anyone engaged in fishing to show their license to fisheries officers when asked. The penalty for such violations is a CAN 35[6] fine, and this has remained consistent throughout the period studied. In all cases, the harvester had a valid license, but they did not have it on their person, as required by the FGR.

The largest administrative violation, in terms of punishment, occurred in 2018 and was related to falsifying records and unsafely storing seafood products. In this case, the offender was found in possession with mislabelled boxes of salmon and sea cucumbers. Information regarding how the salmon and sea cucumbers were obtained was repeatedly not provided by the suspect. The suspect was issued six tickets relating to not complying with storage facility requirements, failing to make reports and keep records, and providing false information and keeping false records. Each of the six fines issued were for CAD 403, totalling CAD 2418.

In 2018, a more serious administrative violation relating to a fishing license was recorded. In this case, a harvester was asked by a fisheries officer to produce their license and logbooks. The harvester failed to produce a license but claimed that they had purchased one. It was later determined that, at the time of the incident, they did not yet possess a fishing license. This was a violation of Section 25 of the Pacific Fisheries Regulations (PFR), and a guilty plea on the part of the accused resulted in a CAD 300 fine. Section 25 of the PFR requires that anyone commercially fishing have a license. In a further administrative violation, in 2017, a vessel was intercepted and, upon inspection of provided paperwork, the skipper was found to be missing licenses and license conditions. Eventually, licenses were produced alongside logbooks. The lack of license conditions made the produced licenses invalid placing the harvesters in violation of Section 26(1) of the PFR, which requires that fishing cannot occur except under the auspices of a license.

Administrative violations (East Coast)

Two administrative violations were recorded. Of these, one occurred in NB and one in NL. In NL, the sole administrative violation occurred in 2017 and related to a vessel that was identified as lacking a visible registration number. This placed them in violation of Section 26(1)(A) of the FGR, which requires that fishing vessels must have a visible, painted on, registration number. This infraction resulted in a written warning.

In NB, the identified administrative violation occurred in 2017 and involved a harvester failing to record mandatory information in their logbook. Specifically, the harvester had not recorded an estimated weight of catch prior to landing a catch at a port. This placed the harvester in violation

Table 1. Access to information cases by year, province, and category of offense

Province	Year	2015	2016	2017	2018	2019	2020	Total
BC	Administrative	1	1	4	2	1	1	10
	Overrun	0	0	0	0	0	0	0
	Illegal fishing	1	0	0	1	1	0	3
NB	Administrative	0	0	1	0	0	0	1
	Overrun	0	0	0	0	0	0	0
	Illegal fishing	0	0	0	0	0	0	0
NL	Administrative	0	0	1	0	0	0	1
	Overrun	0	0	5	0	0	0	5
	Illegal fishing	0	0	0	1	0	1	2
Overall	Administrative	1	1	6	2	1	1	12
	Overrun	0	0	5	0	0	0	5
	Illegal fishing	1	0	0	2	1	1	5
	Total	*2*	*1*	*11*	*4*	*2*	*2*	22

[6] CAD 1.00 = USD 0.70, as of 25 February 2025

of Section 14 of sea cucumber license rules (SCLR) that require harvesters to keep accurate records. Violating section 14 of the SCLR placed the harvester in violation of section 22(7) of the FGR, which requires harvesters to follow the rules imposed by their license(s). The officer involved recommended that a written warning be issued.

Overruns (East Coast)

Overruns represented 5 of the 22 violations identified. The remediation for such cases is an equivalent reduction in their quota the following year. These cases lacked detail regarding the size of the overrun, which was only provided in one case. Unlike other types of violations, no legal or regulatory violations were included in documents provided to us in our Access to Information request.

Illegal fishing (BC)

In BC, three cases of illegal fishing were identified. The first incident occurred in 2015, near Sidney. When fisheries officers boarded the vessel, they found three harvesters had exceeded their recreational fishing quota. This quota amounts to 12 sea cucumbers per day, and in this case, the harvesters had collected 527 sea cucumbers, of which 90% were estimated to be eviscerated. As a result, the three suspects were found to be in violation of Section 35(1) of the BC Sports Fishing Regulations, which prohibits exceeding daily fishing limits. Additionally, based on their investigation, fisheries officers suspected the three harvesters of diving in a fishing area that had been closed due to unsafe biotoxin levels. This resulted in a violation of section 3(2) of the Management of Contaminated Fisheries Regulations, which require harvesters to obey closures. The individual who had been diving pled guilty to three counts and received CAD 5000 in fines. They were banned from fishing or being in the presence of someone fishing and had their diving gear seized and auctioned. The two suspects who had not been found diving pled guilty and were fined CAD 1,000 each.

Another form of illegal fishing that occurred twice in the time period studied was fishing with prohibited gear, specifically the use of hooks and lines, with one occurring in 2018 and the other in 2020. In both instances, the harvester was found to be in violation of Section 38 of the BC Sports Fishing Regulations, which prohibits the use of certain fishing gear to be used with particular species. In each case, this violation resulted in a CAD 150 fine. Additionally, in the 2020 case, the harvester was found to have retained the sea cucumbers they had caught with the offending fish gear, resulting in a guilty plea and a further CAD 5000 fine.

Illegal fishing (Newfoundland and Labrador – NL)

Two substantial cases of illegal sea cucumber fishing were identified in NL. The first case occurred in 2018, where fisheries officers waved down a vessel that had illicitly caught scallops. The scallops were thrown overboard by the suspects who attempted to evade capture, fleeing in their vessel. After they were apprehended, the harvesters were determined to have been illegally harvesting both sea cucumbers and scallops, placing the suspects in violation of section 22(7) of the FGR. Their attempted flight and disposal of evidence resulted in a further violation of section 62 of the Fisheries Act for obstructing an investigation of a fishery officer. No data on the quantity of the illicit catch or the penalty were included in the available records.

The second incident occurred in 2020 and involved five harvesters with a catch of 30,220 kg of sea cucumbers. In this case, fisheries officers inspected a fishing vessel and its catch at dockside, and a number of violations were found. These included inaccurate keeping of logbook records, non-compliance with SCLR regarding dockside inspections, and fishing in prohibited areas. Their logbooks were found to include inaccurate weight estimates, specifically, the harvesters had reported a catch of 28,573 kg of sea cucumbers, whereas their holds contained 30,220 kg, a discrepancy of 1647 kg. DFO estimated the value of the sea cucumbers at CAD 19,488, which we calculated to be CAD 0.64/kg. Using 2020 rates set by the Standing Fish Price-Setting Panel (CAD 0.60/lb), the value of this catch to harvesters was likely CAD 39,975 (Government of Newfoundland and Labrador Department of Fisheries and Aquaculture 2021). The harvesters were also found to have violated multiple provisions of their license, placing them in violation of section 22(7) of the FGR. Specifically, they were cited for fishing for harvesting sea cucumbers in non-designated zones, retaining incidental catch, not calling ahead to book a dockside inspection, and providing inaccurate weights to dockside inspectors. Their fishing in a non-sea cucumber zone resulted in a violation of section 14(1)(b) of the Atlantic Fishing Regulations (AFR), which prohibit fishing for a particular species without authorisation. When it came to prosecution, a previous logbook violation from 2017 was also taken into consideration. In this previous case, the same suspects had been found to have inaccurately filled in their logbooks. In 2016, 97% of coordinates recorded in their logbooks were found to be incorrect. The harvesters held quotas for 685 t, but the wrong fishing zones were recorded. This resulted in the misallocation of sea cucumber quotas by DFO across the region. All five onboard the vessel were charged but, ultimately, charges were dropped against four of the suspects and one suspect pled guilty and was fined CAD 2000.

Canadian Legal Information Institute database

Our search of the CanLII database produced an initial 42 results (1967–2023) of legal cases across Canada that included the term "sea cucumber". Of these cases, the overwhelming majority did not address wildlife crime, illegal fishing, or associated non-compliances, and were, therefore, excluded from further comparative analysis. The one case that related directly to sea cucumber harvesting violations was the 2019 case of *R. v. Z.*, a prolific fisheries offender who pled guilty by joint submission to various offenses in BC, with the court noting:

> [3] On Information 66282, he [Mr Z.] pled guilty that, on the July 21, 2018 he was fishing for sea cucumber other than by hand-picking or diving, in contravention of s. 38 of the B.C. Sport Fishing Regulations.
>
> [4] The circumstances of the offences are that, on June 17, 2017 Mr. Z. was working as a recreational fishing guide. He was operating a boat, the Luna Sea, which belonged to a friend of his but which he had permission to use for those purposes.
>
> [5] He had a number of people onboard the boat on June 17 and was observed pulling up traps from the area of the glass sponge reef in Howe Sound. There were four traps on the line and a piece of one of the glass sponges was attached to one of the traps. A further inspection found four of eight crabs which had been caught were undersized. He was in possession of two undersized lingcod. He did not have his current licence. He had the licence from the year before and had not recorded the lingcod on that licence.
>
> [16] The aggravating circumstances are that he impacted the glass sponge reef. He has had a history of ongoing offences and now this recent spate of offences. His motive for fishing contrary to the regulations, was profit. He did plead guilty, although on the trial date. Nevertheless, he is entitled to some mitigation in that regard (*R. v. Z.* 2019).

Exploring the details of this case, it appears as though the court both expressed some sympathy towards Mr Z. while simultaneously admonishing him for his history of non-compliance, and even his style of parenting:

> [20] Mr Z. I consider the penalties that your counsel and the Crown have agreed to be very lenient, in all the circumstances. I find your behaviour quite egregious and careless. You appear to put your own interests above that of the environment, and that is why I find that you have such a high moral culpability.
>
> [21] You have children, Mr Z.
>
> [22] THE ACCUSED: Yes.
>
> [23] THE COURT: I do not know what kind of model you think you are being for your children. Do you not want them to have the benefit of a healthy ocean when they grow up? We depend on our oceans and all of the species in them. People who ignore the need for conservation and care in fishing are causing long-term damage, and it has to stop (*R. v. Z* 2019).

The judges' remarks underscore the importance of sea cucumbers to the overall ecological well-being of our oceans, and indicate that overfishing was not merely an administrative faux pas, but rather an action that has broad reaching conservation implications. A CAD 5000 penalty was levied on the matter of overfishing sea cucumbers. An additional CAD 25,000 in fines were also imposed by the court for several other fishing offenses, to which the accused pled guilty. Apart from this case, no others were identified.

Discussion

We set to better understand the nature and scale of crime in Canadian sea cucumber fisheries. To accomplish this, we searched for media stories, legal cases, and submitted an Access to Information request. The results were limited. Our media review identified one news story, as did our review of legal cases on CanLII. While the results of the Access to Information request were comparatively more plentiful, only a small number of cases were identified (22), with the vast majority of these relating to minor administrative issues.

Overall, our approach allowed us to identify seven non-administrative cases, the result of which was the levying of fines, amounting to CAD 21,300. The fines levied for administrative cases amounted to CAD 2858. To our knowledge, no jail time was issued for any incidents involving sea cucumbers, and it is unclear if any gear or sea cucumbers were seized. It is noteworthy that the punishment for those who were caught fishing over their quotas was an equivalent reduction in their quota the following year.

For comparison, when similar media studies were used to examine sea cucumber crime in India and Sri Lanka (from 2015 to 2020), 50 cases were identified in India and 70 in Sri Lanka, and 502 arrests and the seizure of 64.7 t of sea cucumbers were recorded (Phelps Bondaroff 2021). A similar study of crime in Mexican sea cucumber fisheries (from 2011 to 2021) identified 97 incidents, and documented 125 arrests and 100.6 t in seizures (Phelps Bondaroff et al. 2022). Additionally, a case study of Turkey (2015 to 2020) identified 541 total infractions that resulted in the confiscation of 80 t of illegally caught sea cucumbers (Dereli and Aydin 2022). In this context, our findings show that illegal sea cucumber fishing and associated crime is comparatively smaller in scale, severity, and volume in Canada.

Based on our findings, it is difficult to properly assess the scale or nature of sea cucumber crime in Canada. What we can say, is that there are very few cases, that the vast majority of cases are minor administrative issues, and that even more serious criminal matters receive relatively low fines. Without more data, it is not possible to determine such factors as the percentage of license holders who may be fishing over their quotas, or the extent to which quotas are being exceeded.

When assessing records of wildlife crime, or more accurately the absence of records, it is very difficult to determine whether the scarcity of cases indicates that compliance levels in the fishery are high, or whether crime is simply going undetected. If it is the case that incidents are going undetected, it is equally difficult to determine whether this is on account of a lack of monitoring and enforcement, political interest or will, or broader challenges related to factors such as geographic scale and resourcing.

While the number and severity of cases identified may be small, these findings provide some insight into Canadian sea cucumber fisheries, as well as other issues, such as the effectiveness of the research method used and the treatment of sea cucumbers by the media and legal systems.

Our approach sought to triangulate cases reported in the press, with police and court records. It is noteworthy that while each of these searches yielded at least one case, there was no overlap between the cases. The covert nature of wildlife crime presents many challenges when it comes to better understanding this phenomenon, and our findings reinforce the importance of research carried out on the ground. In the face of challenges with conducting this type of research, and absent such studies, analysing open-source information remains a pragmatic approach to better understanding wildlife crime (Challenger et al. 2022). Our findings suggest that those seeking to better understand wildlife crime through the analysis of open-source information would do well to cast as wide a net as possible and pursue multiple avenues of information, to ensure important cases are not missed.

When we replicated the method used by Phelps Bondaroff et al. (2022) to identify news media stories concerning sea cucumber crime, the approach only produced one relevant news story. This single case is noteworthy for several reasons. First, the story itself shows a lack of general media interest in crimes relating to sea cucumbers. While the initial incident occurred on 1 May 2020, the story was not published until 20 June 2020, nearly two months after the initial incident (Eckford 2020). While the featured case was one involving sea cucumbers and other species, the case was only reported by the mainstream media after a number of other cases involving overfishing and other fisheries crimes involving other species had occurred and could be included in the story. Furthermore, rather than reporting on the individual case, the story was instead framed around prosecutors asking for larger fines and vessel forfeitures for those engaged in fisheries crime. The one case that emerged after we conducted the initial search, that of Mr S.S. the repeat fisheries crime offender, similarly included his illegal harvesting of sea cucumbers and immigration issues with his employees as just a fraction of his litany of crimes.

While media coverage of sea cucumber crime was sparse, given that our other searches resulted in the identification of other cases, the absence of reporting on these cases speaks to the media's treatment of legal issues relating to sea cucumbers. Simply put, there seems to be little media interest in sea cucumber crime-related stories in Canada. While there are several factors that contribute to lower media attention, not least of which is the largely administrative nature of most of the cases, it speaks to an overall lack of interest in holothurians by the press.

For comparison, a cursory search for fisheries infractions in Canada reveals relatively substantial news coverage typically relating to cases of illegal fishing. For example, the press has reported on tampering with lobster traps (Withers 2023a), under-reporting catches (CBC New 2021), and increases in fines for violations at processing plants (Withers 2023b). Similarly, in other jurisdictions, minor incidents involving sea cucumbers have received media attention. For example, in media coverage relating to Mexican sea cucumber fisheries, minor cases involving as little as 1.13 kg of sea cucumbers, being carried in a bag over the US border received coverage (International News Pacific 2019).

Unpacking why sea cucumber crime is neglected by Canadian media, while successfully captured in media in other jurisdictions, is the subject of further research. However, there are likely several mechanisms at play here, including the largely administrative nature of the crimes that were detected, and that transnational smuggling incidents, even minor ones, seem to attract more attention as compared to workaday administrative crime. Additionally, the fact that crime in sea cucumber fisheries has not been framed as an issue of importance in Canada likely contributes. Put another way, crime in sea cucumber fisheries in Canada has not been problematised.

In other case studies, illicit sea cucumber fishing and associated crimes are perceived as social problems. In India, for example, the government worked to address overfishing in sea cucumber fisheries in the early 1980s, and when these efforts failed, it closed the fishery (2001). In Sri Lanka, unsustainable extraction led to the collapse of sea cucumber fisheries in the south of the country, and a fishery only began to develop in the north after the conclusion of the civil war (Terney Pradeep Kumara et al. 2005; Prasada 2020; Phelps Bondaroff 2021). The close proximity of one country with a closed fishery and the other with a legal fishery has led to poaching, smuggling, and laundering operations. As a result of this history, the issue has been framed as a problem, and an increasingly serious one. In Mexico, long-standing issues relating to overfishing, fisheries closures, and illegal fishing similarly helped to problematise the issue, furthered still by associations with violence and organised crime (Phelps Bondaroff et al. 2022).

Pre-existing and long-standing issues relating to sea cucumber conservation and crime contributed to the framing of these issues as ones that are worthy of media attention, even those minor incidents involving a small number of sea cucumbers. The existence of researchers and advocates working on sea cucumber conservation issues also likely contributed to the elevation and problematisation of the issue. To our knowledge, there are no advocacy organizations or researchers working on issues relating to crime in Canadian sea cucumber fisheries.

Examining legal cases relating to sea cucumber crime, or the lack thereof, we find a similar lack of interest. Except for the case of *R v Z.*, we found an overall lack of relevant prosecutions over many decades relating to sea cucumbers and sea cucumber fisheries. Further, where charges do arise for violations, such as in the case of *R v Z.*, these charges stem as ancillary to other primary fishing offenses best positioned as the "true" reason for fisheries enforcement observation and patrol. In other words, the enforcement and prosecution of sea cucumber crime first requires the presence of other primary fishing violations that are of greater interest to fisheries officers.

In this case, Mr Z. was being monitored because he was a prolific offender and was apprehended while pulling traps in an area of Howe Sound, where there is a protected glass sponge reef. The case mentioned the word "sea cucumber" only three times, but "glass sponge" is mentioned ten times (*R. v Z.* 2019). Impetus for his apprehension was that Mr. Z. was being monitored and because of conservation concerns regarding glass sponge reefs, rather than concerns for sea cucumbers.

As a standalone critical species, the case law data presented here do not support a view that sea cucumber crime is taken as a serious enforcement issue, unless it is ancillary to other offenses already being investigated. While laws exist to protect sea cucumbers, enforcement actions specific to the species seem rare, and where relevant laws are enforced, they are ancillary to other offenses. Put another way, sea cucumbers do not rate.

It should be noted that the search method that was used to identify legal cases was a high level one. We relied on the CanLII database, and did not engage in an extensive or detailed province by province and court by court physical law library archival research for further detailed analysis on unreported cases and older cases not available on CanLII. Such an approach was deemed out of scope for this project. As a pioneering paper into the protection of Canada's sea cucumbers, it is enough for the purposes of this paper to broadly highlight that readily available (on CanLII) and reported legal cases involving sea cucumbers are scant and largely not related to the physical breach of conservation and/or overfishing regulations – thereby raising questions about the enforcement appetite and legal community commitment to the protection of vulnerable sea cucumbers.

Conclusion

Across other regions, illegal sea cucumber fishing is typically associated with broader social issues – organised crime and violence, conservation concerns, or geopolitics. In Canada, not only is the volume of illicit activities smaller, but there are substantively different social realities surrounding criminal activities and the framing of crime within sea cucumber fisheries. As a result, it is unsurprising that there is an absence of broader appreciation of environmental issues facing sea cucumbers in Canada because when these issues do arise, they do not correspond to broader, and more visible, social issues.

There is a terrestrial bias when it comes to perceptions of wildlife crime, yet marine species are heavily targeted and exploited by criminals. Wildlife crime targeting marine species, is often referred to as illegal fishing, or illegal, unreported, and unregulated fishing, although we prefer the term "fisheries crime" as this term better captures the widespread nature of crime throughout fisheries' supply chains (Phelps Bondaroff and Morrow 2024). The scale of fisheries crime is considerable. In one recent study, Sumaila et al. (2020) suggested that "between 8 and 14 million metric tons of unreported catches" are estimated to be traded illegally per year, resulting in gross revenues valued from USD 9 billion to USD 17 billion. Beyond the value of the illicit catch itself, fisheries crime deprives legal fisheries and fishing activity of revenue to the tune of USD 26 to USD 50 billion, and results in a tax revenue deficit estimated to be between USD 2 and USD 4 billion (Sumaila et al. 2020).

Despite its scale and impact on the environment, fisheries crime often receives considerably less attention than other forms of wildlife crime, and is often treated as an administrative crime (Sumaila et al. 2020; Aceves-Bueno et al. 2021). Although there are indications that increased attention is being paid to wildlife crime in general, and fisheries crime specifically, the focus is on charismatic and well-known species (Hutchinson et al. 2022). Given this, crime targeting less-well-known marine species such as sea cucumbers is often neglected.

Our efforts to identify media cases covering sea cucumber crime indicate that this phenomenon remains a very low-profile activity in Canada, which could reflect the low occurrence rate of violations. Similarly, our review of legal cases relating to sea cucumber crime reveals a paucity of incidents. While it is unclear whether this reflects a lack of incidents, or a lack of monitoring or enforcement, what is clear is that when incidents are identified by authorities, appropriate legal action is taken. Methodologically speaking our efforts to triangulate between the three data sources (media stories, legal cases and law enforcement records) yielded no overlap. This suggests that those seeking a better understanding of wildlife crime through the analysis of open-source information would do well to explore as many sources as possible.

Sea cucumbers play important roles in marine ecosystems. Rules put in place to ensure that harvesting of these animals is sustainable are important, as is compliance with these rules. As the conservation adage goes, people protect what they know, and when it comes to sea cucumbers in Canada, it is evident that these species are poorly known.

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Local extinction of golden sandfish at Ashmore Reef, northwestern Australia

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Abstract

Once common and heavily exploited at Ashmore Reef Marine Park off northwestern Australia, the golden sandfish *Holothuria lessoni* has not been observed there since 1987, despite 13 surveys of sea cucumber populations since then up until 2023, covering more than 107 ha of total search area. Based on the extensive nature of these surveys, and with no observations of *H. lessoni* at Ashmore Reef in over three decades, we argue that it meets the definition of extirpation or local extinction. We discuss overfishing as the mostly likely cause of this extinction and why it is unlikely the species will reestablish in this area. We also clarify the status of *Holothuria scabra* at Ashmore Reef, which while also absent in recent and most historical surveys, was probably never common there. There has been only two verified individual sightings of *H. scabra* at Ashmore Reef (1978 and 2013) and there have been none since.

Key words: extirpation, extinction, sea cucumber, *Holothuria lessoni, Holothuria scabra*

Introduction

Golden sandfish, *Holothuria lessoni* Massin, Uthicke, Purcell, Rowe and Samyn, 2009, is polyonymous in the literature, having been referred to as *Holothuria scabra* var. *versicolor*, *H. timana, H. timama* and *H. aculeata. Holothuria timama* Lesson, 1830 and *H. scabra* var. *versicolor* Conand, 1986 were found to be either invalid or synonyms of *Holothuria lessoni* by Massin et al. (2009) who also determined that *H. aculeata* Semper, 1867 was a separate valid species. *Holothuria timana* is a spelling mistake dating back to 1931 (see Massin et al. 2009) and has been widely repeated since.

Holothuria lessoni is widely distributed in the tropical Indian and western Pacific oceans between Africa and Tonga, and is fished in multiple places over that geographic range, including Australia and Indonesia (Purcell et al. 2023). Aspects of its biology, contrasted with that of *Holothuria scabra*, were reported by Conand (1986). It was recorded from Ashmore Reef (situated between Australia and Indonesia) in 1986 (Marsh et al. 1993) and in 1987 (Russell and Vail 1988).

Ashmore Reef, which is part of the Australian Territory of Ashmore and Cartier Islands, is 25 km long and 217 km^2 in area. It is 340 km from the nearest point of the Australian mainland but just 140 km from the Indonesian island of Rote. Indonesian fishermen are known to have visited Ashmore Reef from at least the mid-18th century to collect fish, shark fins, clams, sea cucumbers, turtles and trochus (Fox 2009). Ashmore Reef was annexed by Britain in 1878 and the territory was ceded to Australia in 1933 (Fox 2009). Indonesian fishermen continued to access resources at the reef and a memorandum of understanding, reached in 1974 between Australia and Indonesia, provided continued but limited access by Indonesian fishers to an area referred to as the MOU74 Box of Australia's exclusive economic zone, which includes Ashmore Reef. The arrangement precluded the taking of turtles but allowed continued fishing of clams and sea cucumbers. Ashmore Reef was gazetted as a nature reserve in 1983, and there was growing concern over the levels of fishing. Very heavy rates of exploitation of holothurians and clams were reported in 1986 and 1987 (Berry 1993; Marsh et al. 1993; Russell and Vail 1988). Berry (1993) records an observation of 15 fishers from two vessels harvesting an estimated 1300 giant clams in a single, low tide event. As a result of these concerns, bilateral arrangements were reviewed in 1988 (Fox 2009). The taking of giant clams and sea cucumbers was prohibited, and access to Ashmore Reef was greatly restricted to just a small area (within the current Recreational Use Zone), comprising mostly the safe anchorage in the deep lagoon near West Island (Commonwealth of Australia 2002).

Despite these formal conservation measures, pressure from (what was by then) illegal fishing continued. Field et al. (2009) point to a significant rise in reports and detection of illegal fishing in late 2005 and 2006. The reported increase in illegal fishing at Ashmore Reef prompted the surveys conducted by Ceccarelli et al. (2007, 2011), and to which those authors attributed significant declines in trochus abundance at Ashmore Reef between 2005 and 2006. Another dramatic increase in illegal fishing off northwestern Australia in 2021 (Keesing et al. 2025) prompted further surveys of sea cucumbers at Ashmore Reef and other Australian marine parks in 2022 (Keesing et al. 2023).

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Since 2008, an almost continuous surveillance presence has been maintained at Ashmore Reef by Australian Customs and Naval vessels. (Speed et al. 2018). While this has been done to principally deter illegal immigration, it has also kept illegal fishing at Ashmore Reef at low levels. Prior to this, there has also been an intermittent enforcement and surveillance presence at Ashmore Reef since 1985 (Guinea 2020) and especially between 2000 and 2002 (Commonwealth of Australia 2002). Lapses in surveillance and enforcement in 2005 and 2006 may have contributed to high levels of illegal fishing (Field et al. 2009; Ceccarelli et al. 2007; Vince et al. 2021). Although the level of illegal fishing and the effectiveness of enforcement between 1989 and 2008 is debated (Guinea 2020; Meekan et al. 2020) there have clearly been steps taken to enforce the regulations in place at Ashmore Reef since 1988 when fishing for sea cucumbers was completely prohibited.

Despite the formal conservation, surveillance and enforcement measures applied at Ashmore Reef Marine Park, a comprehensive survey in 1998 (Skewes et al. 1999, 2005) failed to find any specimens of *Holothuria lessoni*. The purpose of this study was to determine the status of *H. lessoni* and another economically valuable sea cucumber, *H. scabra*, at Ashmore Reef based on a review of all surveys to date, and including two comprehensive surveys of sea cucumbers at Ashmore Reef in 2019 and 2022.

Methodology

We conducted extensive surveys for sea cucumbers and other invertebrates (mainly corals, giant clams, other large molluscs and echinoderms) at Ashmore reef in 2019 (Keesing et al. 2021) and 2022 (Keesing et al. 2023). The survey design was the same statistically rigorous, reef-wide generalized random tessellation stratified (GRTS) base survey proposed by Hosack and Lawrence (2013) and used by Ceccarelli et al. (2013). This design provided balanced sampling across all the five benthic habitat facies at Ashmore Reef, established in the first comprehensive survey of Ashmore Reef by Skewes et al (1999, 2005) in 1998. These facies were shallow, intertidal reef flat; shallow, intertidal sand flat; shallow, subtidal lagoon; deep lagoon; and reef slope sites on the windward and leeward sides of the reef. While Ceccarelli et al. (2013) surveyed 95 sites (each 80 m^2) in 2013, our surveys were much more extensive with 224 sites surveyed in 2019 and 128 sites surveyed in 2022, with an area of 200 m^2 searched at each site. The survey method was the standard and widely used method established by Reef Life Survey (Edgar et al. 2017). Briefly, in our surveys, two scuba divers descended the anchor line at each site, each running out a 50-m tape and then counting and identifying all sea cucumbers to a width of 1 m on each side of the tape. Each diver surveyed 100 m^2 and at each site had a total area of 200 m^2 searched.

Using our survey data from 2019 and 2022, and a review of data from all previous and subsequent surveys that we could locate, we sought to draw conclusions about the status of *Holothuria lessoni* and *H. scabra* at Ashmore Reef.

Results and discussion

Ashmore Reef is regarded as having a diverse population of echinoderms (Marsh et al. 1993) and this is in part attributed to a wide variety of habitat types, as well as the closeness of the Indonesian archipelago and connections to the Australian and Papuan continental shelves. This is in contrast to the more isolated Scott Reef and Rowley Shoals, located approximately 230 km and 680 km southwest of Ashmore Reef, respectively, which have less diverse fauna (Marsh et al. 1993). The first survey of Ashmore Reef, which included sea cucumbers, was conducted by the Soviets in 1978 (reported in Marsh et al. 1993). This was followed with surveys by the Northern Territory Museum and the Western Australian Museum between 1986 and 1987 (Berry 1993; Marsh et al. 1993). Marsh et al. (1993) recorded 178 species of echinoderms and compared these to the lower numbers found at Scott and Seringapatam Reefs (119) and Rowley Shoals (90). Of the 178 echinoderm species recorded at Ashmore Reef by Marsh et al. (1993), 47 were holothurians. Berry (1993) and Marsh et al. (1993) commented on the intensity of fishing at Ashmore Reef and the rarity of the highly valued *Microthele* spp. (now *Holothuria whitmaei* and *H. fuscogilva*) and *Thelenota ananas* in 1986 compared with Rowley Shoals.

With the exception of additional biodiversity-focused museum expeditions to Ashmore Reef (e.g. Keesing et al. 2024), subsequent marine surveys at Ashmore Reef Marine Park have been much more quantitative and have concentrated on exploited species of holothurians, giant clams and trochus. Many of these surveys were prompted by concerns about overexploitation of giant clams and sea cucumbers. Including our surveys in 2019 and 2022, there have been 14 surveys between 1987 and 2023 using a variety of survey methods (Table 1), but all have made detailed quantitative records of the sea cucumbers present. A summary of the level of search effort from each of these studies indicates more than 107 ha were searched at 968 sites (Table 1). The only survey to record *H. lessoni* was that of Russell and Vail (1988). All but two of the surveys recorded between 11 and 19 species of sea cucumbers. This is much less than the species list of 47 by Marsh et al. (1993), although that survey used different methods that included a search for small and cryptic species under coral rubble. These species would not be encountered by the large-scale quantitative surveys summarised in Table 1.

Holothuria lessoni was common at Ashmore Reef during, and prior to, the last time it was observed in 1987 as evidenced with photographic documentation and by catch composition (Figs. 1 and 2). Russell and Vail (1988) found 110 *H. lessoni* (17% of catch) among the catches of holothurians on five Indonesian *prahus* (small sail boats) and another 94 (11% of catch) taken by seven Indonesian fishermen in dugout canoes.

Figure 1. Indonesian fisherman processing a large catch of *Holothuria lessoni* on one of the islands at Ashmore Reef in 1987. Plate 12 reproduced from Russell and Vail (1988) with permission. Image: Lyle Vail.

Figure 2. Indonesian fishermen with a catch of sea cucumbers laid out for drying on a sand cay at Ashmore Reef in 1987. The catch shown is mainly *Actinopyga* spp. and *Holothuria lessoni*. Plate 12A reproduced from Russell and Vail (1988) with permission. Image: Lyle Vail.

At least the latter was known to be from a single day of fishing. Russell and Vail (1988), however, recorded very few individuals of *H. lessoni* in their own surveys. The Indonesian fishers interviewed by Russell and Vail (1988) stated that *H. lessoni* was the most valuable of all holothurian species they harvested from Ashmore Reef. Its absence in the extensive surveys undertaken between 1998 and 2023 indicate that *H. lessoni* is locally extinct at Ashmore Reef, and is most likely the result of overfishing. The consequence of depletion from overfishing leads to an absence of reproductive effectiveness from an anthropogenically induced Allee effect (Purcell et al. 2014), whereby the distance between remaining individuals is so great that dilution of gametes exceeds the threshold necessary for egg fertilisation.

Holothuria scabra was recorded by the Soviet survey of Ashmore Reef in 1978 (Marsh et al. 1993) and again in 2013 (Keesing et al. 2024) but has not been observed in any of the quantitative surveys undertaken between 1998 and 2023 (Table 1). *Holothuria scabra* is perhaps one of the most heavily exploited species of holothurian throughout the Indo-Pacific (Kinch et al. 2008; Friedman et al. 2011). Both *H. scabra* and *H. lessoni* were regarded as being locally extinct by 1998 (Skewes et al. 1999; Smith et al. 2001) although there is no evidence *H. scabra* was ever common at Ashmore Reef.

Russell and Vail (1988) included photographs of both *H. scabra* and *H. rubrofusca* in their report as part of a set used to aid interviews with Indonesian fisherman, but these species were not observed at Ashmore Reef (Lyle Vail, pers. comm.). Smith et al. (2001, 2005) stated that *H. scabra* was not found during the 2000 survey, but it is listed in a table in both reports. We were unable to resolve this inconsistency and so have treated this report of *H. scabra* as being unverified. The record of *H. scabra* at Ashmore Reef by Marsh et al. (1993) is verified by a specimen (registration number 58776) in the Western Australian Museum (WAM), collected in 1978. The specimen from 2013 recorded by Keesing et al. (2024) is also in the WAM (registration number 68148). Both preserved specimens are very small (less than 6 cm long), and are probably juveniles.

Holothuria scabra is a widespread Indo-Pacific species but is predominantly an inshore species inhabiting generally more muddy or silty habitats (Hamel et al. 2022) than those that occur at Ashmore Reef. It is likely that *H. scabra* was never common at Ashmore Reef and that its possible absence now cannot be primarily attributed to overfishing.

Table 1. Summary of all quantitative surveys for sea cucumbers at Ashmore Reef from 1987 to 2023.

Survey	Years	No. of sites	Transect size	Transect replication	Area surveyed (m^2)	Area surveyed (ha)	No. of species
Russell and Vail (1988)	1987[a]	5	20 m x 50 m	10-24	134000	13.40	17
Skewes et al. (1999, 2005)	1998	240	4 m x 20-100 m[b]		25140	2.51	13[c]
Smith et al. (2001, 2005)	2000	96	various[d]		106000	10.60	19[d]
Rees et al. (2003)	2003	38	5 m x 500 m	3	285000	28.50	17[e]
Kospartov et al. (2006)	2005	45	5 m x 500 m	3[f]	172500	17.25	16
Ceccarelli et al (2007, 2011)	2006	55	5 m x 500 m	3[f]	217500	21.75	18
Richards et al. (2009)	2009	8	10 m x 100 m	10[g]	80000	8.00	11
Ceccarelli et al. (2013)	2013	95	2 m x 40 m		7600	0.76	11[c]
Edgar et al. (2017)	2013	12	2 m x 50 m	1-2[i]	2400	0.24	2
Edgar et al. (2020)[h]	2018	20	2 m x 50 m	1-2[i]	4000	0.40	10
Keesing et al. (2021)	2019	224	2 m x 50 m	2	44800	4.48	18
Reef Life Survey[h]	2021	16	2 m x 50 m	1-2[i]	3200	0.32	10
Keesing et al. (2023)	2022	128	2 m x 50 m	2	25600	2.56	17
Reef Life Survey[h]	2023	12	2 m x 50 m	1-2[i]	2400	0.24	4
Total		968				107.01	

[a] Russell and Vail (1988) surveyed the same sites in both April and September 1987. Photographs of both *H. scabra* and *H. rubrofusca* are shown in the report as part of a set used to aid interviews with Indonesian fisherman, but these species were not observed at Ashmore Reef (Lyle Vail, pers. comm.).

[b] Transect length varied with habitat type.

[c] Skewes et al. (1999) and Ceccarelli et al. (2013) identified 13 and 11 taxa respectively but grouped *Actinopyga spp*. as one taxa.

[d] Smith et al. (2001, 2005) used three methods and transect sizes (4 m x 500 m reef walks [n=10], 2 m x 500 m manta tow [n=59], 4 x 250 m scuba or snorkel swims [=27]), they found 19 species but only record the names of 15 species and one unidentified *Holothuria species.* The text of both these references indicates that *H. scabra* was not found on the 2000 survey, but it is listed in Tables in both references. This inconsistency has not been able to be resolved so *H. scabra* is not included in the right-hand column total. This has been clarified with the senior author Luke Smith who confirmed that *H. scabra* was not found at Ashmore Reef in 2000.

[e] Rees et al. (2003) identified 17 taxa but grouped *Actinopyga* spp. other than *A. lecanora* and *A. mauritiana* as one taxa.

[f] Kospartov et al. (2006) and Ceccarelli (2007) used three replicate transects totalling 7500m^2 at some sites, while others had a single 2500 m^2 transect.

[g] transects per site, replicated at 2 depths.

[h] RLS data downloaded from https://portal.aodn.org.au/search on 10 January 2025, note 2018 includes sites surveyed early new year of 2019.

[i] Total area calculation assumes 2 replicates per site, which was almost always the case, only occasionally 1.

In the absence of adult immigration, which for an isolated reef such as Ashmore Reef can be ruled out for *H. lessoni* and other shallow water holothurians, any future recruitment to Ashmore Reef will rely on larval supply from distant reefs. The absence of *H. lessoni* at Ashmore Reef since at least 1998 suggests that this has not occurred and, therefore, unlikely to change. The species is one of several sea cucumbers threatened by overexploitation (Purcell et el. 2014) and its extirpation at Ashmore Reef suggests that it may be vulnerable to local extinction elsewhere across its range.

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Sea cucumber aquaculture in Sri Lanka: A journey from past challenges to future opportunities

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Abstract

Sandfish (*Holothuria scabra*), a high-value sea cucumber species widely distributed across tropical oceans, is considered an excellent candidate for aquaculture. Sri Lanka, a small tropical island southeast of the Indian subcontinent, has a long history of sea cucumber fishing and has been a key exporter of beche-de-mer to China and other East Asian markets. However, the growing demand led to intense fishing pressure, causing the collapse of the sandfish fishery in the 1980s, severely impacting the livelihoods of thousands of fishing families. Artificial breeding and aquaculture practices are increasingly being proposed to relieve the pressure on wild sea cucumber populations and improve the livelihoods of coastal fishing communities. This study reviews the development of sandfish aquaculture in Sri Lanka using field data collected from March 2023 to December 2024, and publicly available information. With technical breakthroughs in the breeding of sandfish, the National Aquatic Resources Research and Development Agency reported the first-ever successful breeding programme in 2011. Today, both government and private hatcheries (n = 3) operate at a commercial scale, contributing to the expansion of the industry. Pen culture (n = 700) remains the most common grow-out method, primarily practiced in the shallow coastal waters of northern and northwestern Sri Lanka. Sandfish culture production exceeded 580 tonnes (wet weight) in 2021, and is expected to continue growing in the coming years. A significant advancement in the industry was the introduction of *in vitro* fertilisation (IVF), a technique that enhances hatchery efficiency by enabling embryo production under controlled laboratory conditions. Despite existing challenges, such as inadequate seed supply and nursery facilities, poaching, environmental perturbation and research gaps, the continued development of sustainable culture practices has the potential to generate vital foreign revenue for the country while safeguarding the livelihoods of coastal communities.

Introduction

The sea cucumber fishery was introduced to Sri Lanka by the Chinese, and beche-de-mer has been a major commodity exported to China for centuries. Currently, sea cucumber fishing is successfully conducted along the coasts of Sri Lanka: northern (around the Jaffna Peninsula), eastern (Trincomalee, Pothuwil and Kalmunai), northeastern (Mullaitivu), and northwestern (from Kalpitiya to the Gulf of Mannar) (Nishanthan et al. 2019; Veronika et al. 2017). This fishery is highly seasonal due to the influence of monsoon winds. Although 10–12 sea cucumber species are commercially harvested in Sri Lanka's coastal waters, they are not traditionally consumed locally. As a result, the entire production is processed into beche-de-mer (dried sea cucumber) and primarily exported to Singapore, Taiwan (Province of China), and China (Kumara et al. 2015; Dissanayake and Stefansson 2010). In 2021, 336 t of beche-de-mer, worth USD 8.5 million, were exported.[2]

This industry has been a vital source of income for more than 10,000 artisanal fishing families in the country's northwestern, northern, and northeastern regions, and a significant contributor to the nation's foreign revenue (Nishanthan et al. 2019). According to Hamel et al. (2022), Sri Lanka ranked first in sea cucumber catches in the eastern Indian Ocean. However, heavy and unregulated fishing pressure – mainly through gleaning, snorkeling, and scuba gear in deeper waters – has led to the severe depletion of this valuable resource across the country (Dissanayake and Stefansson 2010; Kumara et al. 2013; Nishanthan et al. 2019). The ease of collecting these slow-moving, bottom-dwelling organisms and limited fishery regulations has further exacerbated this situation. Proving this further, the entry of previously untargeted, low-value species into the fishery has also been reported (Dissanayake and Stefansson 2010).

The sandfish (*Holothuria scabra*) is one of the most valuable sea cucumber species exploited in tropical regions (Purcell 2010; Purcell et al. 2012). Sandfish are highly abundant and widely distributed in shallow, seagrass-rich coastal seas and lagoons with soft bottom habitats, particularly in the northwest and northern regions of Sri Lanka (Nishanthan et al. 2019; Hamel et al. 2022). A lucrative fishery for sandfish was evident in Puttalam Lagoon during the early 1970s. It collapsed, however, in the mid-1980s due to overexploitation and inadequate management measures. Similarly, the depletion of sandfish populations in northern Sri Lanka has severely impacted the livelihoods of thousands of fishing families (Nishanthan et al. 2019; Prasada 2020).

The depletion of sandfish has driven increased research into aquaculture opportunities for this valuable species. In the early 1980s, researchers in India developed aquaculture

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techniques for sandfish, followed by hatchery advancements in various parts of the world. Artificial breeding and aquaculture practices have been increasingly promoted to reduce pressure on wild populations, support stock restoration, enhance commercial production and improve the sustainable livelihoods of coastal communities (Purcell et al. 2012; Kumara and Dissanayake 2017).

This article reviews the development of sandfish aquaculture in Sri Lanka over the past 30 years. Recent data on farming and hatchery production were collected from March 2023 to December 2024 through field visits, questionnaire surveys, and direct interviews with farmers in northern Sri Lanka, covering Mannar, Kilinochchi, and Jaffna fisheries districts. Additional information was sourced from existing literature, the National Aquaculture Development Authority (NAQDA), the National Aquatic Resources Research and Development Agency (NARA) of Sri Lanka, and publicly available online sources. The study also incorporates insights from Madagascar (October–December 2024) on sea pen construction, comparing these practices with those in Sri Lanka.

Early developments (1990–2020s)

The aquaculture of wild-collected sandfish juveniles to a larger size (~500 g), known as fattening, has been practiced in northern Sri Lanka since the 1990s using sea or lagoon pen culture systems. This practice provided a vital source of livelihood for fishers affected by the civil war, 1983–2009 (Fig. 1).

Studies have shown that fattening is an effective method for restoring depleted sea cucumber stocks (Purcell et al. 2012). In Sri Lanka, NAQDA promoted this practice in 2009, having a demonstration farm in the Pallimunei area in Mannar. It quickly gained popularity in Kalpitiya, Mannar and Jaffna, with around 30–40 pens operating successfully. However, in 2011, the fattening of wild-collected sea cucumbers was banned due to conflicts among resource users (Kumara and Dissanayake 2017).

Scientific research on hatchery production and grow-out techniques for sandfish juveniles has advanced significantly worldwide in recent years. Sri Lanka initiated a sea cucumber aquaculture programme over a decade ago, achieving the first successful artificial breeding of sandfish in 2011 at Nara's sea cucumber hatchery in Kalpitiya. Accordingly, eight breeding trials were conducted during 2011–2012 producing an average, of 1.16 million eggs per trial (Kumara and Dissanayake 2017). Spawning was induced using three different methods: thermal stimulation, a powerful jet of water, and dry treatment. Among these, thermal stimulation (ambient temperature ±3–5°C) was identified as the most effective. Additionally, researchers found that combining both cold and heat shocks was more successful than using either method alone. The juvenile survival rate after 30 days of the hatchery phase averaged to 2.7%, which is comparable to rates reported in other regions (Kumara and Dissanayake 2017; Agudo 2006; Purcell et al. 2012; Militz et al. 2018; Han and Hua 2022; see Hamel et al. 2022).

Although no commercial production has been reported by NARA, a sale of 500 individuals to a farming facility was documented in 2012. NARA has conducted various field experiments to determine optimal grow-out conditions (Kumara and Dissanayake 2017; Medagedara et al. 2019), explore co-culture possibilities (Kumara et al. 2012), and evaluate suitable larval and grow-out feeds (Thilakshi et al. 2017) using hatchery-produced sandfish juveniles. A preliminary study by Kumara and Dissanayake (2017) suggested that lagoon pens are more suitable for rearing hatchery-produced sandfish juveniles than mud ponds or tanks.

According to NAQDA's 2013 annual report, Sri Lanka and Vietnam established a bilateral cooperation initiative to facilitate technology transfer in sea cucumber breeding and farming. As part of this initiative, Vietnamese experts provided training to NAQDA officials and local farmers on sandfish breeding and grow-out techniques. Simultaneously, several key aquaculture projects were launched, including the establishment of a sea cucumber hatchery in Ambakadawila,

Figure 1. Pen constructed in the Waleipadu area of northern Sri Lanka, for fattening wild-collected sandfish juveniles in the 1990s.

Chilaw, a pond farming system in Pulinchikulam, and a pen culture system in Kiranchi. Additionally, expertise was provided to support sea cucumber breeding in a private hatchery. This effort had resulted in the successful production of 239,000 sea cucumber juveniles in 2015 (NAQDA 2015).

In December 2013, NARA organised a two-day residential training workshop on artificial breeding and larval rearing of sandfish at its Regional Research Center in Kalpitiya. This workshop provided hands-on training to a diverse group of participants, including private sector stakeholders such as hatchery owners and managers, and officers from government agencies and non-governmental organisations. The initiative aimed to enhance technical expertise and promote sustainable sandfish aquaculture practices (Kumara 2014).

In 2015, Sri Lanka launched a pilot study on sandfish aquaculture, introducing a community-based farming model. This initiative recognised sandfish aquaculture as a viable alternative livelihood for both sea cucumber fishers and other coastal fishing communities (Kumara et al. 2015). The artificial breeding of sandfish and larval rearing practices were actively supported by NARA and NAQDA, reinforcing Sri Lanka's commitment to sustainable aquaculture and marine resource management. During this period, two to three privately owned hatcheries were in operation, primarily following a trial-and-error approach.

SL Aquatech International Company, the very first commercial sea cucumber hatchery established in Sri Lanka, began sandfish breeding in 2015, with nursery rearing conducted in pond systems under the supervision of NAQDA. In 2021, NAQDA expanded its efforts by establishing a sea cucumber hatchery at Oleithuduwai in the Mannar region. This facility aims to produce 1 million juveniles annually, with plans for gradual production intensification.

As a result of all these initiatives, sea cucumber aquaculture production has grown steadily since 2017, reaching a peak production of 580 t (wet weight) in 2021, providing livelihood opportunities for 700–800 families (Fig. 2).

Currently, two private sea cucumber hatcheries and one state-owned hatchery operated by NAQDA are in operation. Although their exact production figures are not publicly available, each hatchery targets an average annual production of 0.5–1.0 million juveniles. Approximately 700 grow-out pens, covering 486 ha, are actively operated across northern Sri Lanka, while some are obtaining licenses. The size of these pens varies, based on investment levels. For example, livelihood-level pens cover up to 0.4 ha (4000 m^2), small- and medium-scale investment pens, which cover 0.4–2.0 ha, and large-scale investment pens that cover 2.0–4.0 ha. Large-scale farms are owned by private companies engaged in processing and exporting sandfish, while the majority of farms (86%) are community-owned. This widespread community ownership underscores the vital role of aquaculture in creating sustainable livelihoods for coastal families, and transforming local economies while preserving marine resources (Fig. 3).

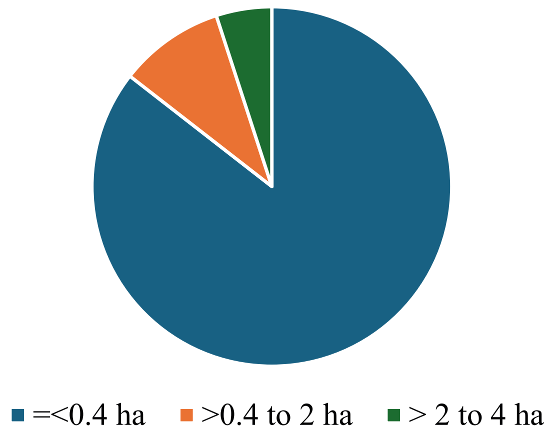

Figure 2. Trends in cultured sandfish production (wet weight; Mt). Source: NAQDA 2013, 2015

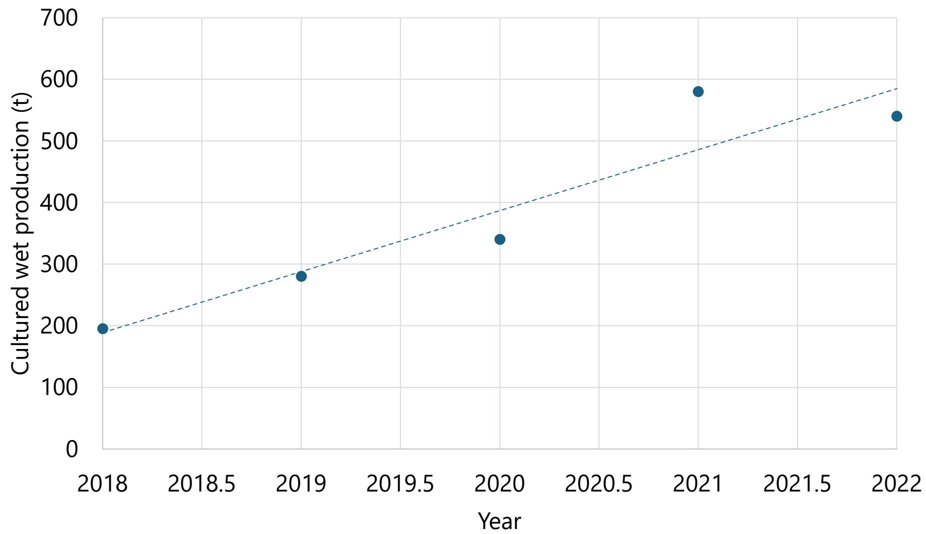

Figure 3. Size distribution of pen culture systems in northern Sri Lanka, including licensed and license-awaiting grow-out pens.

Sandfish aquaculture in Sri Lanka is primarily practiced in lagoons and shallow coastal waters, using the pen culture system. In rare cases, culture practices are carried out in mud ponds (Fig. 4). Pen culture systems facilitate natural seawater exchange, ensuring that sea cucumbers have access to sediments, seagrass, organic matter and detritus, all of which are essential for their growth and survival (Purcell et al. 2012; Hamel et al. 2022). Therefore, this system not only supports sustainable aquaculture production but also mimics the natural habitat of sandfish, thereby promoting healthier and more resilient stock.

A typical sandfish farm consists of a pen enclosure which is constructed with wooden poles and mesh nets (high density polyethylene/HDPE nets) surrounding the demarcated area (Fig. 4). Most pen culture systems have two netting walls an inner and outer layer to provide extra protection for the crop. Additional farm components include a security hut, lighting system, solar panels, closed-circuit television (CCTV), sometimes hapa nets for juvenile rearing, and a boat to access the farm. The farms are monitored 24 hours a day, mainly to protect the facility from poachers. Pens are usually separated by a buffer zone of approximately 50–100 m, ensuring accessibility and ease of movement. However, pens owned by the same individual or family may share adjoining walls, thereby optimising space and resource use (Fig. 4).

Hatchery-reared juveniles (~10 g) and wild-collected sub-adults (50–150 g) are stocked into these pens, typically at an average stocking density of 1–2 ind/m². However, stocking densities may vary, depending on juvenile availability and the farmer's preference. Stocked individuals are reared for 8–12 months before harvesting. In large-scale farms, culture

Figure 4. Grow-out culture system and its components. a) Pens separated by buffer zones (Jaffna); b) lighting systems with solar panel; c) security hut; d) mud pond culture system at Manna; and e) farmer with sandfish.

duration can extend up to 18 months, with continuous stocking and partial harvesting of market-sized individuals throughout the grow-out period. Culture duration varies according to site and region, and is influenced by weather conditions, seed availability, growth rate and market price. Harvests from cultured sandfish range between 350 g and 800 g, (averaging around 500 g) and the value is determined according to the weight, ranging from USD 2–7 per individual, respectively. The lifespan of a grow-out pen is typically two to three years, after which a fallow period is observed. Regular maintenance, including monthly cleaning and repairing of pens and mesh nets, is essential for ensuring optimum water flow into the farm and for securing the crop.

Several small- and large-scale processing plants operate in northern Sri Lanka. Normally the harvest is purchased by local processing centers, which then supply the sea cucumbers to large-scale processing companies after partial or complete processing (Fig. 5). Fresh sandfish from large-scale farms are often purchased directly by large-scale processing plants.

A legal framework is in place for investors seeking farm licenses. The licensing process requires investers to submit a proposal of the farm to NAQDA, where a pre-feasibility study will be carried out to assess the site's suitability. After approval from the relevant authorities, the license is granted. Priority is given to individuals transitioning from destructive or unregulated fishing.

Recognising the economic potential of sandfish aquaculture, the Sri Lankan government has introduced several initiatives to expand the industry. One proposal involves cluster-based sea cucumber farming under the "sea cucumber village" concept. Additionally, a large-scale commercial farming project spanning 2023 ha across the Jaffna, Mannar and Kilinochchi districts has been proposed.

Constraints and challenges

Sandfish aquaculture has proven to be a promising source of income. However, several critical areas require attention, including technical expertise, infrastructure development for all production phases, innovative processing techniques, enhanced value-adding along the supply chain, and research and development. The following key constraints were identified during the study.

Lack of supplies of juvenile sea cucumbers

Despite the establishment of the sea cucumber aquaculture sector, several technical challenges must be overcome to ensure its long-term sustainability. One major challenge is the refinement of hatchery production techniques, which are still in development. Upscaling juvenile production to meet the current requirement of 4 million juveniles is essential for the growth and sustainability of the industry. It is essential to achieve 100% sandfish seed requirements for aquaculture through hatchery production to ensure the long-term sustainability and economic viability of the aquaculture sector. The ongoing collection of wild sandfish juveniles and subadults for stocking farming facilities poses a significant threat to traditional sea cucumber fishing practices and the sustainability of natural sandfish stocks Furthermore, purchasing wild subadults significantly reduces farmers' profits, as their cost is five to six times higher than that of hatchery-produced juveniles. This leads to high operational expenses, which can be challenging and may discourage potential investors from entering the sandfish farming industry. Several private hatcheries have now been established to meet the growing demand.

Weaknesses in nursery and grow-out culture phases

The industry also faces challenges due to limited infrastructure, facilities, and technical knowledge related to nursery techniques. Currently, the nursery phase is mainly conducted in hapa systems and a few outdoor ponds. Since hatchery-produced juveniles (1–2 g) are not ready for direct stocking in farms, they must be reared in outdoor nursery facilities for at least one to two months until they reach the optimal stocking size (~10–15 g). The lack of adequate nursery facilities and technical expertise remains a major obstacle for hatchery practitioners in transferring juveniles

Figure 5. Unloading a harvest (left), and processing (right) the sandfish at a medium-scale local processing center.

to farmers. Training programmes can play a crucial role in addressing this gap by equipping farmers with knowledge and hands-on training to develop and maintain their nursery infrastructure.

Farmers tend to prefer wild-collected sandfish juveniles over hatchery-bred ones, driven by the common belief that wild juveniles exhibit higher growth and survival rates. However, no comprehensive studies have been conducted to compare the growth and survival rates of sandfish juveniles in these facilities. Such research, however, is essential to assess success rates and improve nursery-rearing practices.

Reduced growth rates, high mortality, and inadequate control over and predation in grow-out facilities significantly hinder the production efficiency of sea cucumber aquaculture. Stocking size and stocking density are important factors related to the growth and survival of the sandfish in the grow-out. The recommended carrying capacity of a site may range from 225–500 g/m^2 for sea pens, unless specified for a particular site (Klückow 2020). Therefore, inappropriate stocking densities leading to overstocking or understocking must be minimized to increase the performance of the farm. Stocking smaller sized juveniles (particularly <6 cm) in the sea makes them vulnerable to predation (example: by crabs) and are less resilient for the natural conditions leading to low survival. Additionally, the lack of comprehensive statistical data on key aspects such as hatchery production, beche-de-mer yield, and export trends poses a major challenge, potentially impacting decision-making and future projections for the sandfish aquaculture sector.

Ensuring sustainability

Responsible and sustainable farming practices are important to achieve the expected environmental, social and economic growth. Poaching remains the most significant challenge for sea cucumber farmers in Sri Lanka. While this issue is prevalent worldwide, it is particularly common in low-income countries (Purcell et al. 2012). Appropriate and adequate legal actions are required to control poaching.

Conflicts among different resource users, particularly between sea cucumber farmers and fishers, are another major constraint to the sustainability of sandfish aquaculture. Demarcation of farming areas and implementation of marine spatial planning are key strategies to overcome this problem.

The lifespan of sea cucumber pens depends on the construction materials. Long-term investment in farm construction may ensure both profitability and environmental sustainability. In Sri Lanka, typically, pens are constructed with wooden poles, which require replacement after a few culture cycles. In contrast, countries such as Madagascar use galvanised metal poles that can be reused for over a decade, thereby significantly reducing environmental impacts (Fig. 6). Using wooden poles may pose a threat to sustainable aquaculture by impacting local ecosystems. Therefore, adopting sustainable construction practices is essential to strengthening the foundation of sandfish aquaculture in Sri Lanka.

Maximising the sale price of sea cucumber products is crucial for farmers and processors to enhance their income. However, limited technical knowledge and inadequate training in producing premium-quality beche-de-mer remain significant challenges in the industry. This knowledge gap directly affects product quality, ultimately reducing the economic returns of sea cucumber aquaculture.

Sandfish production cycle involves gender participation at various stages. While men predominantly engage in farming activities, women play a key role in the processing practices. In Madagascar, women also contribute to sea cucumber aquaculture by participating in sea pen maintenance and sandfish harvesting. Implementing similar practices in Sri Lanka, alongside targeted awareness programmes, can be a valuable strategy for promoting women's empowerment in the industry.

Environmental and economic challenges

Changing weather conditions, such as heavy rainfall leading to freshwater influx, flooding and cyclones pose significant challenges to sandfish aquaculture. A recent heavy rainfall event in November–December 2024 resulted in high mortality rates and skin damage in many sandfish cultured in the Jaffna region due to a sharp drop in seawater salinity (<15 ppt). Proper site selection is important for minimising such risks, while continuous weather monitoring and forecasting can help farmers make informed decisions, including timely harvesting.

Fluctuations in foreign exchange rates can also impact sandfish farmers, potentially forcing adjustments to the harvesting period even when the sea cucumbers have reached marketable size. This delay increases vulnerability to environmental risks such as monsoon rains. Accurate forecasting will help farmers to maximise their profits by optimising harvest timing.

Research gaps

Selecting the right broodstock for induced breeding in hatcheries is a key factor in determining breeding success. For artificial breeding methods such as thermal shocks, understanding the reproductive season and size at first maturity of the target stock is important for achieving optimal results. However, scientific knowledge of the biology of sandfish in Sri Lanka remains significantly limited, particularly regarding reproduction, recruitment, growth and mortality. Therefore, further research is essential to bridge these knowledge gaps and refine the biology and culture conditions necessary to optimise sandfish aquaculture.

Recent developments

The Food and Agriculture Organization (FAO) of the United Nations, in collaboration with NAQDA, has taken significant initiatives to address some of the challenges of sandfish aquaculture in Sri Lanka. One of the most impactful efforts was the introduction of *in-vitro* fertilization

(IVF) as an induced breeding technique for sandfish. Originally developed in Madagascar in 2007, IVF is an innovative method designed to ensure the consistent production of sandfish juveniles year-round, regardless of their reproductive seasons. This technique involves fertilising the eggs and sperm of sandfish under controlled conditions, after the maturation of eggs using an egg maturation inducer. The gonads of sandfish, which are typically discarded during the processing of beche-de-mer, can be repurposed for juvenile production using this technique (Eeckhaut et al. 2024).

To disseminate knowledge about IVF, training sessions were conducted for public and private hatchery technicians in 2023 (Fig. 7). In addition, FAO further supported the sea cucumber industry by providing technical assistance in grow-out preparation and processing through specialised workshops held in Jaffna and Mannar (Fig. 7). The hatchery manual "New methods and strategies to improve the performance of *Holothuria scabra* hatcheries" (Eeckhaut et al. 2024), developed based on activities conducted in Madagascar and Sri Lanka, was translated into local languages (Sinhala and Tamil) and distributed among stakeholders.[3]

FAO, in collaboration with NARA, launched a sea ranching programme in northern Sri Lanka to replenish the depleted sandfish population there. According to NARA, 10,000 juveniles obtained from NAQDA's sea cucumber hatchery

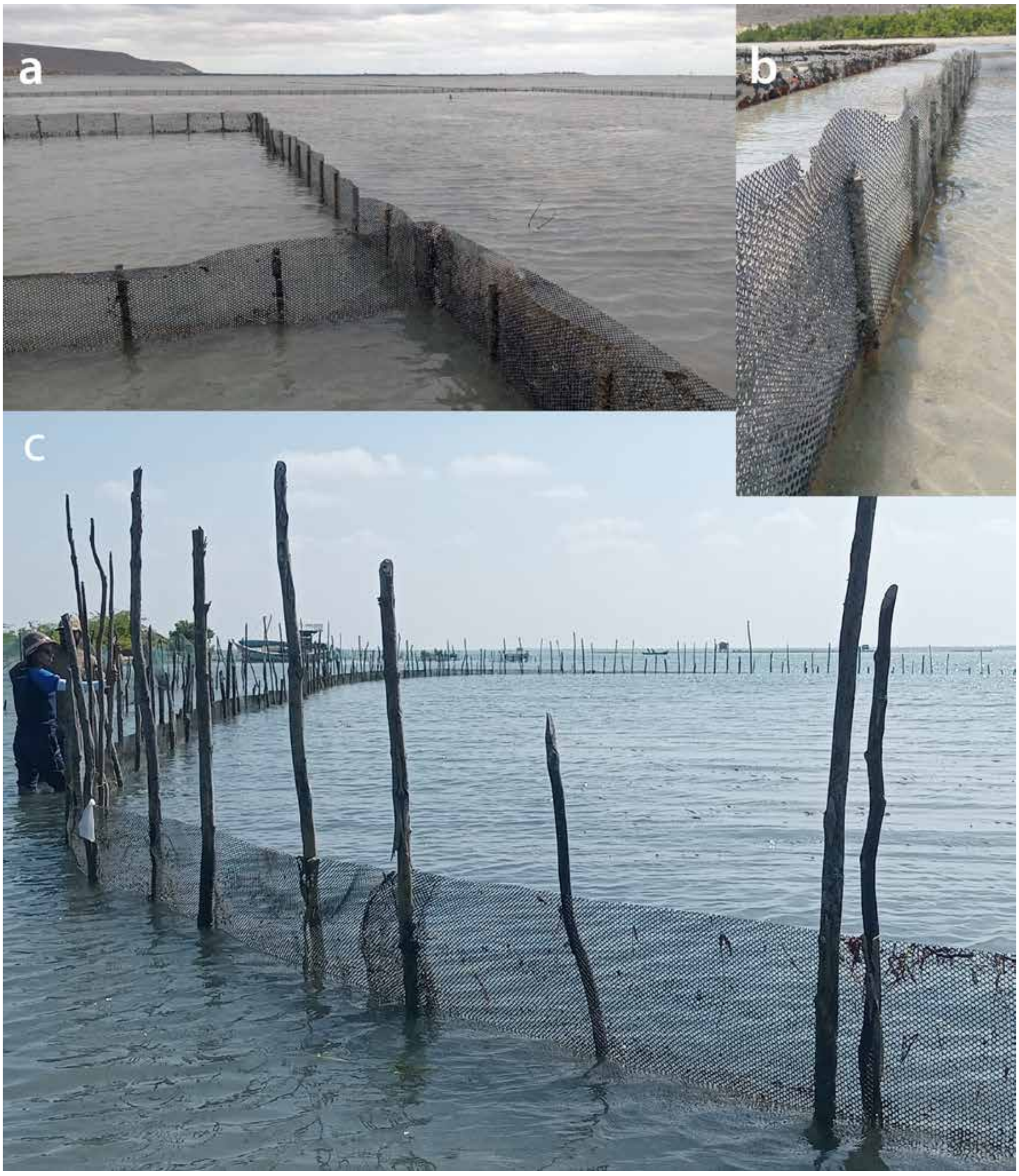

Figure 6. a) and b) Pen enclosures in Madagascar made of metal poles. c) Pen constructed in Sri Lanka.

[3] See https://openknowledge.fao.org/server/api/core/bitstreams/6fef167f-12e1-48c4-a2ef-bf0228d2785e/content

were released into designated areas in 2024, and monitoring is ongoing with community support.

A PhD candidate attached to the University of Sri Jayewardenepura in Sri Lanka received a scholarship under ARES-CCD funding from Belgium, to participate in a three-month programme titled "Science of artisanal maricultures and village farming" held at the Fisheries and Marine Sciences Institute at the University of Tuléar, Madagascar from October to December 2024. Participants in the "breeding and aquaculture of holothuroids" component of the programme were able to get hands-on experience related to artificial breeding (including *in vitro* fertilisation), farming, processing and hatchery management practices of sandfish (Fig. 7). This was a great opportunity for many participants from countries such as Sri Lanka, where sandfish aquaculture has a significant potential for further development.

Future opportunities

The sandfish export market has significant potential to positively impact the economy of Sri Lanka. Because Sri Lanka is facing a huge economic crisis after the COVID-19 pandemic, sandfish aquaculture would be a major source of foreign revenue for the country. The proposed large-scale, community-based sandfish farming projects in Mannar, Kilinochchi and Jaffna regions, however, will provide livelihood alternatives for coastal communities, which will further strengthen sandfish aquaculture practices in northern Sri Lanka.

Beyond the traditional markets for processed sea cucumber, there is significant potential to expand the industry by producing value-added products, such as processed food items, supplements and cosmetics. By strengthening research and development in this area, based on sea cucumber extracts, oils or even medicinal formulations, the aquaculture industry can diversify its revenue streams. This would increase the economic viability of sea cucumber farming and provide new opportunities for local businesses to thrive in local and international markets.

A circular economic approach can be applied to sea cucumber farming by using waste materials. Waste from sea cucumber processing, such as viscera and other byproducts, are valuable sources of nutrients and bio-active compounds. Reusing waste generated from processing also enhances sustainability by turning low-value materials into profitable products. Integrating these practices could improve environmental and economic outcomes for the industry.

In addition to *Holothuria scabra*, the potential of breeding other high-value species of sea cucumbers that may be better suited to local environmental conditions, or have more desirable market characteristics, can be evaluated. Research and development in breeding programmes could expand the diversity of commercially viable species, thereby reducing pressure on wild populations and ensuring the industry's long-term sustainability.

Sandfish aquaculture is a fast-developing industry in Sri Lanka's blue economy and addresses many of the United Nations Sustainable Development Goals, including "No Poverty, Zero Hunger, Gender Equality, Decent Work and Economic Growth, Industry Innovation and Infrastructure, Responsible Consumption and Production, and Life Below Water". With scientifically sound, right initiatives and practices, Sri Lanka is expecting to reach its maximum potential in sandfish farming, and beche-de-mer production.

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Figure 7. Workshops and training programmes conducted by FAO in collaboration with NAQDA to develop sandfish aquaculture at a) at Jaffna (Suganth International (Pvt) Ltd) and b) at Oleithuduwai, Mannar sea cucumber hatchery. c) Breeding and aquaculture of holothuroids programme by ARES-CCD, Belgium in Madagascar.

providing the necessary facilities to carry out this study successfully. The Prof Sena S. de Silva memorial scholarship is greatly acknowledged for financial contribution. Special thanks to the ARES-CCD (funding from Belgium) for the scholarship programme, which enabled sharing technical knowledge and experience in sea cucumber breeding and farming between countries and with the most experienced experts in the field. Special thanks to Mr Ajith Kumara (NARA) for the continuous support. We are highly thankful for all the farmers who engaged in interviews and who helped with technical challenges (e.g. communications, translations). The reviewers are thanked for their useful comments.

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Sea cucumber aquaculture training for the International Certification in Sciences of Artisanal Maricultures and Village Farming

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Introduction

The first class of the International Certification in Sciences of Artisanal Mariculture and Village Farming (see Eeckhaut 2024) began in September 2024 in Toliara (Madagascar), with the module on aquaculture and farming of *Holothuria scabra*. Some students joined the long course for one year, during which four modules on aquaculture – sea cucumbers, algae, *Spirulina* and corals – were (and still are) taught. Others joined the short course to learn about *H. scabra* aquaculture for three months, with this module ending in December 2024. Students came from Sri Lanka, Morocco, Tanzania, Comoros, Seychelles and Madagascar (Fig. 1A and B). This article, which is written by the students, provides information on the theoretical and practical courses they followed during these three months (Fig. 2). Students who pass their exam will receive an international university certificate accredited by Belgium (universities of Mons and Liège) and Madagascar (Univeristy of Toliara). The second course on sea cucumbers will begin in September 2025.

Theorical courses

The theorical courses are based on Hamel et al (2022). Each week, students took online courses taught by an expert. Eight courses were given via interactive videos posted on a website, on the following topics: Biology of aquacultured organisms; Mariculture overview; Management and entrepreneurship related to artisanal mariculture; Diseases of organisms in the marine environment; Sociology of village farming; Gender in artisanal mariculture; Legislation relating to village farming; and Sea cucumber aquaculture and farming. Students could access these courses in different ways, including via QR codes for their smartphones. Figure 2 shows a QR code that gives students access to the course on sea cucumber anatomy.

Practical courses

The practical courses were based on Eeckhaut et al. (2024a), and took place every day, from Monday to Friday. The following subjects were covered: Anatomy of sea cucumbers; Broodstock collection; Thermal shocks; *In vitro* fertilisation; Embryo collection; Stocking and larval rearing; Feeding with freeze-dried microalgae powder; Feeding with *Sargassum* extract; Nursery management; Sea pen management; Statistical analysis; and Trepang processing.

Anatomy of sea cucumbers

The anatomy of some sea cucumbers – *Bohadschia* sp., *Holothuria notabilis* and *H. scabra* – were studied. The internal organs and other anatomical structures were identified, including the digestive system, gonads, respiratory trees, calcareous ring, parts of the ambulacral system, and immune cells (Fig. 3). The biological parameters of sea cucumbers were studied and recorded, including their length, weight, diameter, sex, development stage for gonads (to calculate the sex ratio), and gonadosomatic index.

Broodstock collection

Students collected sandfish broodstock (each individual >350 g) from the Indian Ocean Trepang Company (IOT) in Toliara, Madagascar (Eeckhaut 2021), and transported them to the Aqua-Lab for spawning trials. Spawning trials involved thermal shocks (along with biological shock) as well as *in vitro* fertilisation (Table 1).

Thermal shocks

Two trials were conducted during the course (for theory see Eeckhaut et al. 2024b, for practice see Eeckhaut et al. 2024a). For the first trial, three conditioning tanks were prepared using sandy-silty sediments collected from the sea, around 30 m in front of the mangroves. Broodstock was conditioned for two days in the laboratory, and frequent visits were made to ensure there was no evisceration or mortality. The optimum water quality parameters (pH, salinity, temperature, dissolved oxygen) were maintained and a complete water exchange was carried out each day. Brooders were gently cleaned with filtered sea water to remove sediments and unwanted organisms attached to their bodies. Next, they were moved six hours before the spawning induction to a holding tank with no sediment

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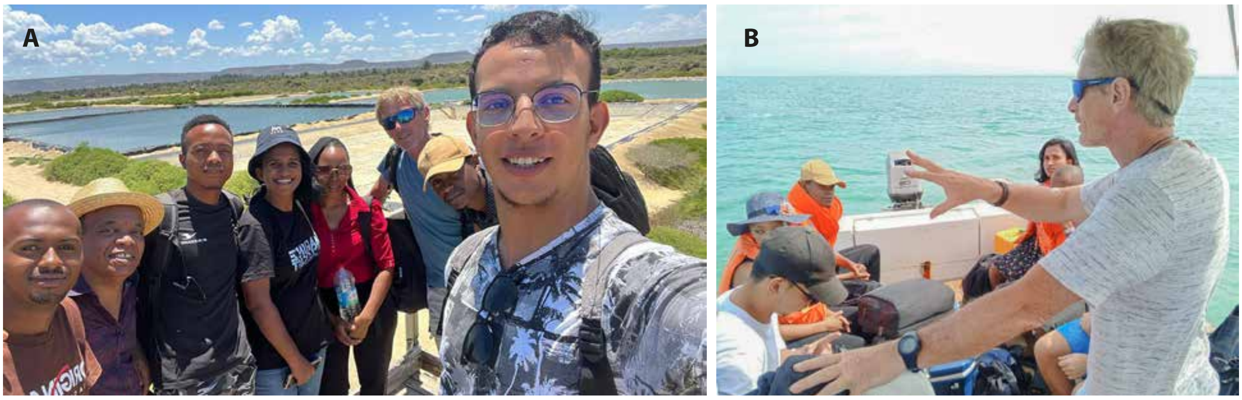

Figure 1. A) The first group of students in the course with professors Igor and Richard (man with hat on the left). B) A practical course where students snorkel to see sea cucumbers *in situ*.

to ensure no defecation occurred during spawning. Two 1000-L spawning tanks were prepared for the thermal shock spawning induction, one with ambient water temperature and the other with cold water (ambient temperature minus 5°C, equaling 25°C) (Fig. 4 A and B). A cold water shock was selected rather than a hot water shock because the ambient water temperature was 29°C. The same water quality parameters were maintained, and gentle aeration was provided. One male brooder was sacrificed to collect its spermatozoa, which were added to the spawning tank to provide a biological shock. Sperm were introduced into the spawning tank with an ambient water temperature (Fig. 2).

Brooders were introduced into the spawning tanks, starting with the cold-water tank, and consecutively introducing them to the ambient water tank. Each of the two sessions lasted one hour. The shock started in the evening (17:00) so that spawning was synchronised with natural spawning. The initial spawning behaviour from the male *Holothuria scabra* was observed during the first cold shock. To continue the spawning, brooders were left overnight in the ambient water temperature tank as the final treatment.

The water samples from the spawning tanks were checked under a microscope the next morning to confirm the occurrence of fertilisation, and the embryos were then collected. The number of embryos obtained was 1.04 million (Table 1).

The second trial was designed to compare the effect of using two different treatments of drying and a *Spirulina* bath (biological shock) with thermal shock (see Eeckhaut et al. 2024b). For that, two experiments were designed. In treatment 1, the broodstock was cleaned with filtered seawater, dried, and placed under a *Spirulina* bath following a cold-water shock and water with ambient temperature (Table 2). Treatment 2, recorded as the control, was similar to treatment 1. The number of embryos obtained from treatment 1 was 2.8 million (Table 1), but almost no embryos were obtained from treatment 2.

Figure 2. This QR code can be scanned with a smartphone to gain access to an example of the theorical course on sea cucumber anatomy.

In vitro fertilisation

In the *in vitro* fertilisation part of the course, students first studied the oocyte maturation inducer (OMI) (for theory see Eeckhaut et al. 2024a; Jangoux et al. 2007; Léonet et al. 2009; Léonet et al 2019, Delroisse et al. 2021; for practice see Eeckhaut et al. 2024b). During natural spawning, oocyte

Table 1. Summary of induced spawning trials carried out during the training period.

Trial	Date	Induction type	No. of brooders	Lunar phase	No. of embryos obtained
1	28 October 2024	Thermal shock	20	Close to third quarter	1,040,000
2	14 November 2024	Thermal shock	16	One day before full moon	2,795,000
3	30 October 2024	*In vitro* fertilisation	14	Close to third quarter	1,200,000

Figure 3. Practical training on sea cucumber anatomy. A) Dissection, B) digestive system, C) ampullae of tentacles, and D) brown bodies in ampullae.

Figure 4. A) Preparing the tanks for thermal shock. B) Spawning by a male *Holothuria scabra*.

Table 2. Summary of treatments carried out to induce spawning (treatment 1: with *Spirulina* incorporated thermal shock, and treatment 2 with normal thermal shock).

Treatment 1	Water temp (°C)	Duration (min)	Treatment 2	Water temp (°C)	Duration (min)
Drying		20	Cold water bath	25	60
Ambient water bath	29	40	Ambient water bath	29	60
Spirulina bath		30	Cold water bath	25	60
Cold-water bath	25	40	Ambient water bath	29	until morning
Ambient water bath	29	until morning			

maturation occurs naturally just before spawning. However, during *in vitro* fertilisation, oocytes are not fully mature for fertilisation. An OMI powder is used to induce complete maturation of sandfish oocytes, and to make them ready for fertilisation. For that, sea urchin ovaries are extracted and freeze-dried. Then, an OMI solution is prepared (2 g of OMI per liter of filtered seawater) and added to the extracted sandfish oocytes. The incubated oocytes are kept for 1–3 hr in the OMI solution to complete maturation. The sperm are added later, and fertilised embryos are collected after fertilisation.

Managing larvae in the hatchery

Embryo collection is conducted by filtering water from a spawning tank or fertilisation unit using a 50-µm mesh net. The stocking density was determined according to the embryonic count. Embryos were then transferred into rearing tanks (300 L) with a stocking density of 0.5 embryos/ml. A complete water exchange was conducted every day for the first two days, and then once every two days after the appearance of early auricularia.

With the appearance of auricularia (approximately on days 2–3), larval feeding commenced with two types of freeze-dried microalgae powder: *Phaeodactylum* sp. and *Isocrysis* sp. For that, 0.1 g of each species was placed in 1 L/day, and 500 ml of this mixture were added to each tank in the morning and afternoon. Feeding continued until auricularia were present in the culture tanks even after the appearance of doliolaria and pentactula.

Fresh *Sargassum* (combined weight of approximately 750 g) collected from the seashore was cleaned first with fresh water to remove dirt and unwanted organisms, and then with 1µm of filtered seawater. The leaves were cut separately and grounded to extract the juice. The grounded content was transferred to a small basin where about 1 L of filtered seawater was added and mixed thoroughly by hand to remove any large particles. Then, the solution was first filtered through a 250-µm mesh net and then through a 50-µm mesh net to completely remove unwanted particles. The extract was finally placed in 4 L of filtered seawater and kept overnight in a refrigerator so the *Sargassum* extract could settle. The next day, the *Sargassum* precipitate was collected and used over the next four days to feed the pentactula and early juveniles. Feeding aerators were removed and tank cleaning was halted to facilitate the settlement of larvae.

Managing juveniles in the nursery

After the hatchery phase, when juveniles reached 1–2 cm (three months after fertilisation), they were transferred to small ponds with sediment in a nursery system (pre-growing system) before their final transfer after two or three months to open sea pens (growing system). For the nursery training, from IOT sent the students around 1280 juveniles of *Holothuria scabra*, each with an average weight of 4.2 ±0.7 g and average length of 3.7±0.3 cm. An experiment was conducted that aimed at testing the effect of replacing marine sediments with terrestrial sediments from quarries, the latter being of ancient marine origin. This approach attempted to reduce the depletion of marine sand and limit the degradation of coastal habitats. The main goal of this experiment was to evaluate the impact of this intervention on the survival, growth and health of the juveniles.

Four, 32-m^2 ponds at the Belaza marine station in Toliara, Madagascar, were each divided into two 16-m^2 compartments (Fig. 5A), so that each pond had two compartments, one containing marine sediment and the other terrestrial sediment.

Storage and acclimatisation of all juveniles were carried out for three days in a non-sediment pond at a stable temperature of 27 ± 1°C (Fig. 5B). This period enabled juveniles to eliminate all the contents of their intestines and digestive system. At the same time, the ponds were prepared as follows: after cleaning and removing old sediments, new marine sediments were deposited and spread out in four 16-m^2 compartments, at a height of around 5 cm. The same operation was repeated for terrestrial sediments in the other four compartments (Fig. 5C). Finally, all ponds were filled with water pumped directly from the sea.

Once the tanks were prepared, 160 individuals of *Holothuria scabra* were weighed and their length measured. They were then transferred to a 16-m^2 compartment (Fig. 5E). The ponds were later covered with shade cloth to avoid the water temperature in the tanks from increasing, and the water was changed twice a week (Fig. 5F). Each week, the weight and length of 50 juveniles were randomly measured in each 16-m^2 compartment. All data were saved to an Excel file, and a one-way analysis of variance (ANOVA), with a significance level fixed at $\alpha = 0.05$, was performed to compare the significant differences in the initial average weight and length, as well as the final average weight and length of sea cucumbers reared on the two sediment types. This analysis was carried out using the R program (version 4.4.1).

At the start of the experiment, no significant difference was observed in the initial average weight of juveniles in

Figure 5. Steps of experimental design preparation: A) storage and acclimation of juveniles; B) dividing the tanks into two compartments; C) transferring the sediments; D) randomly collecting juveniles; E) counting, weighing and measuring juveniles; F) ponds covered with shade cloth.

either the terrestrial or marine sediments, with values of 3.77 ± 0,80 g and 4.62 ± 0,43 g, respectively ($P = 0.11 > 0.05$) (Table 3; Fig. 6). After four weeks, the average final weight of juveniles in the terrestrial sediment was higher than in the marine sediment, at 28.15 ± 14.24 g vs16.73 ± 1,52 g, respectively, but statistical analysis did not show any significant difference between the two groups ($P = 0.162 > 0.05$) (Table 3; Fig. 6).

Similarly, for average initial length, no significant difference was observed between the two groups ($P = 0.725 > 0.05$), with juveniles measuring an average of 3.76 ± 0.14 cm in marine sediment, and 3.68 ± 0.65 cm in terrestrial sediment (Table 3; Fig. 7). At the end of the experiment, juveniles in terrestrial sediment reached an average length of 8.62 ± 1.68 cm, whereas juveniles in marine sediment reached an average of 6.46 ± 0.77 cm. However, this difference was not statistically significant ($P = 0.058 > 0.05$) (Table 3; Fig. 7).

The conclusion of this experiments showed that replacing marine sediments with terrestrial sediments in nursery systems for the pre-growth of *Holothuria scabra* juveniles is a sustainable alternative. No significant differences were observed between the two sediment types for weight and length growth ($P > 0.05$), although juveniles in terrestrial sediments showed slightly higher values at the end of the experiment. These results suggested that the use of terrestrial sediments could reduce pressure on marine and coastal ecosystems while maintaining comparable growth performance.

Table 3. Initial and final average weight and length of juvenile *Holothuria scabra* by sediment type, WI: weight initial, WF: weight Final, LI: length initial, LF: length final. The presence of the same letter in both types for the same parameter indicates the absence of a significant difference, according to the one-factor ANOVA test, with a significance level set at $\alpha = 0.05$.

Sediment type	WI	WF	LI	LF
Marine	4.62[a]	16.74[a]	3.76[a]	6.46[a]
Terrestrial	3.77[a]	28.16[a]	3.68[a]	8.62[a]

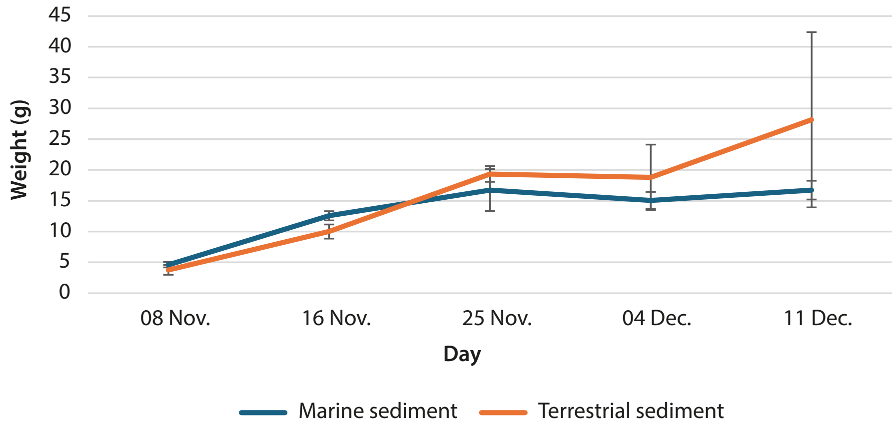

Figure 6. Weight growth curves of juvenile *Holothuria scabra* reared on marine and terrestrial sediments.

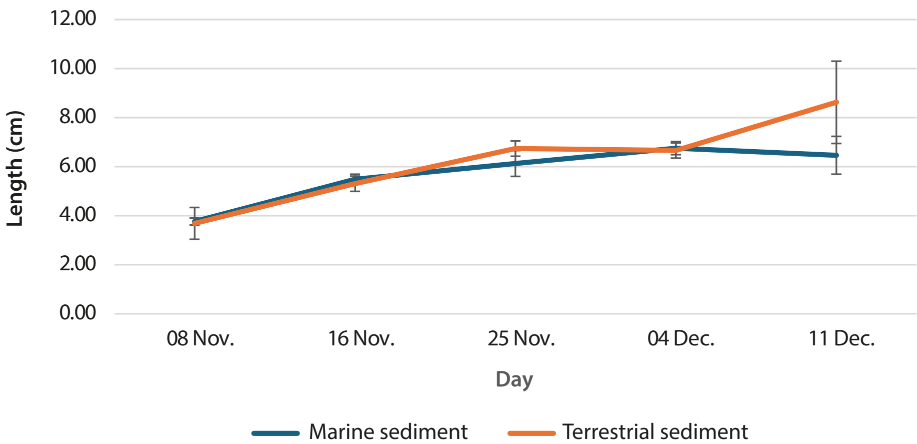

Figure 7. Length growth curve of juvenile *Holothuria scabra* reared on marine and terrestrial sediments.

Sea pen management

When the juveniles reached a size of 7–8 cm in the nursery systems, they become less vulnerable to predators, such as crabs, which could no longer attack them. At this stage, the juveniles were transferred to open sea pens (growing system). In parallel with the work in the nursery, the construction, transfer of juveniles, and monitoring and maintenance of the enclosures, were carried out.

Holothuria scabra enclosures were built in the open sea in front of the Marine Belaza Station. The site was carefully chosen, and considered several criteria to ensure optimal conditions for the growth of holothurians. The main criteria included the presence of seagrass beds and sediment type, mainly muddy sand, accessibility of the site at low tide, and the absence of predators, such as crabs that could attack juveniles.

After site selection, the 100-m^2 enclosures were constructed, taking into account wind direction and ocean currents (Fig. 8A). The weight and size of *Holothuria scabra* juveniles in the nursery system were then measured before their transfer to pens at a density of 2 ind/m^2 (Fig. 8B). Regular cleaning of the enclosure nets (Fig. 8C) was carried out to optimise water exchange for juveniles' health, and to prevent disease. This cleaning also helped prevent the destruction of the pens by sea currents. Nets were also repaired periodically to prevent leaks (Fig. 8D), and juvenile weights were checked from time to time.

Trepang processing

The processing technique that the students learned involved removing calcareous ossicle from individuals, gutting (evisceration), cleaning, boiling, and drying under the sun for five days (Fig. 9). Three techniques of trepang processing were used. In the first, the calcareous layer was brushed out. Then the specimen was gutted, cleaned, boiled for 15 minutes, then dried under direct sunlight for five days. The second technique involved gutting, boiling for 15 minutes, rubbing in ground papaya leaves for 15 minutes, brushing out the calcareous layer, cleaning, boiling for another 10 minutes, and drying under direct sunlight for five days.

Figure 8. A) Construction of new enclosures; B) measuring the weight and size of juveniles; C) cleaning the old pens; D) repairing nets.

Figure 9. Different stages of trepang processing learned during the training.

The third technique involved gutting, cleaning, 15 minutes of boiling, 12 hours of being buried in sand, calcareous layer brushing, cleaning, 15 minutes of boiling, and drying under direct sunlight for five days. Weight and length parameters were recorded prior to each technique, after boiling and after five days of drying.

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Sea cucumber seed production in Mauritius: First pilot-scale production of juvenile sandfish (*Holothuria scabra*)

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Abstract

This study details the outcomes from a fruitful collaboration between two private entities to develop the first pilot-scale seed production of sea cucumbers in Mauritius. The project was initiated following records of the overexploitation of sea cucumbers around Mauritius during the opening of the commercial sea cucumber fishery from 2005 to 2009. A four-year fishery coupled with improper fishery management measures has led to the depletion of wild stocks and, in some extreme cases, the localised extinction of certain high-value species such as the sandfish. The study was conducted over a 19-month period, which included the harvesting and conditioning of broodstock, spawning trials, fertilisation, larval, postlarval and early juvenile rearing. The study mainly focused on the feasibility of producing of sandfish seeds from the hatchery. Production output was very promising, with potentials for scaling up to a commercial level, although the grow-out phase poses certain challenges that are discussed further.

Keywords: Mauritius, echinoderm, sandfish, aquaculture

Introduction

The farming of sea cucumbers (called *barbara* in Mauritian creole) has been a top priority for the Mauritian government for the past 10 years, following the depletion of the wild stock due to the improperly managed commercial fishery from 2005 to 2009. Prior to 2005, sea cucumbers in Mauritius were only harvested traditionally by the local Chinese community and during specific events such as the spring festival. Commercial exploitation started in 2005 when the government issued export permits to two local companies and under a six-month trial basis. Following this period, 12 other export licenses were issued together with some management measures in place such as a strict quota system, size limits, and later a three-month closed season from January to March (Conand et al. 2022). Production data (in dry weight) from 2006, 2007, 2008 and 2009 were 94 t, 50 t, 21 t and 5 t, respectively. Following the four years of commercial sea cucumber fishing in Mauritius and the outer islands, sea cucumber populations suffered a net loss in diversity with some species, such as the sandfish (*Holothuria scabra*) becoming locally extinct. The lack of knowledge in the biology and ecology of sea cucumbers, and data on the standing stock prior to opening of the commercial fishery, were the main reasons behind the inability to properly manage the fishery and, subsequently, its sudden overexploitation. Quotas were allocated based on non-scientific data, and management measures were most often not enforced. After four years, a moratorium was implemented in October 2009 to ban the sea cucumber fishery in Mauritian waters (including outer islands) until populations had recovered. Local stakeholders, motivated by the lucrative business initiated the fishery, but no consideration was given to the sustainability of the resource. To date, the fishery is still banned and in some places around the island sea cucumber populations never recovered; and where they did recover, a net decrease in diversity was observed (Conand et al. 2022).

In view of replenishing some of the loss of sea cucumber stocks, particularly the sandfish and to diversify local aquaculture products, the authority sought expertise from overseas to help develop a sea cucumber breeding programme in Mauritius. A first initiative was carried out in 2005, focusing on two sea cucumber species namely *Bohadschia marmorata* and *Holothuria atra* (Laxminarayana 2005). Although the study was successful in producing individuals up to the pentactula stage (newly settled postlarvae), the species choice did not spark interest from the private sector due to their low market value. After some failed attempts to develop sandfish breeding technology, an international expert was finally hired in 2019, although due to a lack of commitment by the authority in providing the proper infrastructure at the Albion Fisheries Research Centre for the breeding programme, the project failed at the government level. The private sector has showed interest in sea cucumber breeding since 2015, when Mauricoast Ltd approached the government to seek the operation of the Grand Barachois of Poudre d'Or for sandfish breeding. Later in 2020, the company seized the opportunity of having access to expertise in sandfish breeding locally, and developed a fruitful collaboration with the expert to develop the first sandfish breeding programme in Mauritius.

This article presents detailed results obtained from this continuous collaboration, and describes the infrastructure set up, methodology and outcome of the different sandfish breeding trials from October 2020 to May 2022. The study mainly focused on the output of the hatchery unit and the ability to replicate production at different times of the year.

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Hatchery location and rearing facilities

Mauricoast Ltd is an aquaculture company based in north-eastern Mauritius and operates the Grand Barachois of Poudre d'Or. A *barachois* is a protected bay, partly enclosed naturally and partly by humanmade rocky walls. These bays were established a couple of centuries ago by the first settlers to entrap fish, and for passive mariculture. Nowadays, the *barachois* are being used to promote small-scale aquaculture on the island. The Grand Barachois is about 52 ha, with 6 ha of land and 46 ha of shallow lagoon (see Fig.1A and 1B).

The sea cucumber hatchery is located indoors within a multipurpose building of about 66 m² used for sea cucumber seed production and oyster depuration. The building can accommodate 12 x 500 L cone-bottom fiberglass tanks, where a minimum of 6 x 500 L is dedicated to sea cucumber larval production (Fig. 1C). The building is covered but not

Figure 1. Hatchery location and infrastructure. A and B: Google Earth maps showing location of the hatchery in northeastern Mauritius and the Grand Barachois of Poudre d'Or. Arrow in B points to the hatchery; C: Indoor larval culture tanks; D: Outdoor nursery raceways; E and F: Phytoplankton production in 10 L (E) and 50 L (F) plastic bags.

temperature controlled, and has a certain level of biosecurity. The building is supplied with seawater pumped from the *barachois* via a pumping and filtration station located onsite. It delivers coarse (30 µm) and fine-filtered seawater (up to 1 µm) to the building. The seawater used for larval culturing is sterilised using an 80 W ultraviolet (UV) sterilisation system. Seawater salinity is fairly stable at around 30–32 ppt, with pH averaging 8.0 all year. The seawater temperature varies from as low as, 23°C in winter, to as high as 30°C in summer. A centralised compressor supplies the hatchery with compressed air.

The outdoor set up for the nursery is composed of five raceways for a total surface area of 350 m^2, and is made with wooden frames and HDPE lining, and covered with shade cloths (Fig. 1D). Sea cucumber larvae are fed with coarsely filtered seawater from the pumping station and compressed air. All raceways operate on a flow-through principle.

The phytoplankton room (feed production unit) is annexed to the hatchery and is equipped for the production of three phytoplankton species – *Nannochloropsis gaditana* and diatoms *Phaeodactylum tricornutum* and *Chaetoceros calcitrans* – the latter two are used for sea cucumber larval and early juvenile feeding. Production capacity is approximately 200 L in small 10-L plastic bags and 400 L in larger 50-L plastic bags (Fig. 1E and 1F) for all three species.

Broodstock management and spawning trials

Sandfish stocks (Fig. 2A) used for the spawning trials were harvested in the *barachois* and Poudre d'Or lagoon from October to December 2020. In total, 102 individuals were collected over the course of two months with an average weight of 750 g/ind. After each harvest, sandfish individuals were kept in a pen within the *barachois* (Fig. 2B), located next to a mangrove patch and surrounded by seaweed such as *Gracillaria salicornia*. The sediment within the pen is rich with organic matter from the surrounding seaweed and mangrove ecosystem. Every month, bunches of *G. salicornia* were harvested from the surrounding area and placed in each compartment of the pen. At the same time, sandfish individuals were counted and checked for any sign of external skin diseases or predation marks by crabs.

The pen was divided into six compartments so that after each spawning trial, male, female and unspawned individuals could be separated from the rest of the stock. A record system was used so that each batch of sandfish previously spawned could be traced back and followed over time. From December 2020 to December 2024, only six sandfish individuals were missing, which could have either escaped from the pen or died.

Spawning was induced using the thermal stimulation technique. For each spawning trial, a batch of 15–20 individuals were taken from the pen, cleaned, and allowed to rest for 1 hour in a 500-L tank in the hatchery. They were then separated and placed into two or three 40-L glass aquaria prefilled with filtered and UV sterilised seawater. The temperature of the seawater in each aquarium was then raised by 3–5°C. Once spawning was triggered, mature males always spawned first, which then triggered mature females to spawn (Fig. 2C and 2D) usually within 30 minutess to 1 hour after the first male spawned. The number of eggs collected varied with the size of the female but ranged from 0.8 to 3.6 million eggs per female.

From October 2020 to May 2022, 12 spawning trials were conducted, with one trial every month except during the first two months when two trials were carried out. The spawning success rate obtained is shown in Figure 3. On average, our recorded spawning success rate was about 50%, with 30% of males and 20% of females spawning. The highest rate observed was 72% recorded in January 2021. The drop observed in November and December 2020 is probably explained by the change in environment from the wild to pens.

Larval, postlarval and juvenile rearing

Following the successful spawning of males, the amount of sperm collected in each aquarium was monitored closely to prevent polyspermy, and males were removed once a sufficient amount of sperm was released. If excess sperm was obtained, a partial water change was performed before any females displayed their spawning behaviour. Females were then allowed to spawn, and fertilisation occurred within the aquaria. They were then immediately removed from the aquaria and placed back in the 500-L tank. Spawned males and females were kept separated for several hours before being transferred back to the pen in their respective compartments. Two hours after the release of gametes, water samples were taken from each aquarium to quantify the number of eggs released and the success of fertilisation. Only those cultures with a >90% fertilisation rate were kept and transferred into the larval culture tanks prefilled with fine filtered and sterilised seawater. The fertilised eggs were transferred to each tank at a rate of 500–600 eggs/L. All tanks were supplied with air via a diffuser attached around the central standpipe, and there were at least 6–12 tanks operating at any one time, depending on the number of eggs collected. The parameters of seawater within the larval cultures were monitored daily using a handheld multiprobe seawater quality meter. Seawater temperature was the only parameter that varied depending on the season. During cold winters, when seawater dropped below 25°C, aquarium heaters were used to increase the temperature to around 27°C.

Two days after fertilisation, at the onset of larval feeding, a larval density count was made and the morphology of the larvae was monitored under binoculars. Only those cultures with fully formed auricularia (larval stage) were kept and fed with a mixture of two live diatoms (*Phaeodactylum tricornutum* and *Chaetoceros calcitrans* at bloom stage) at a ratio of 1:2 L of mixed live phytoplankton per larval culture tank per day. Daily monitoring of larval development, culture density, and seawater parameters were performed

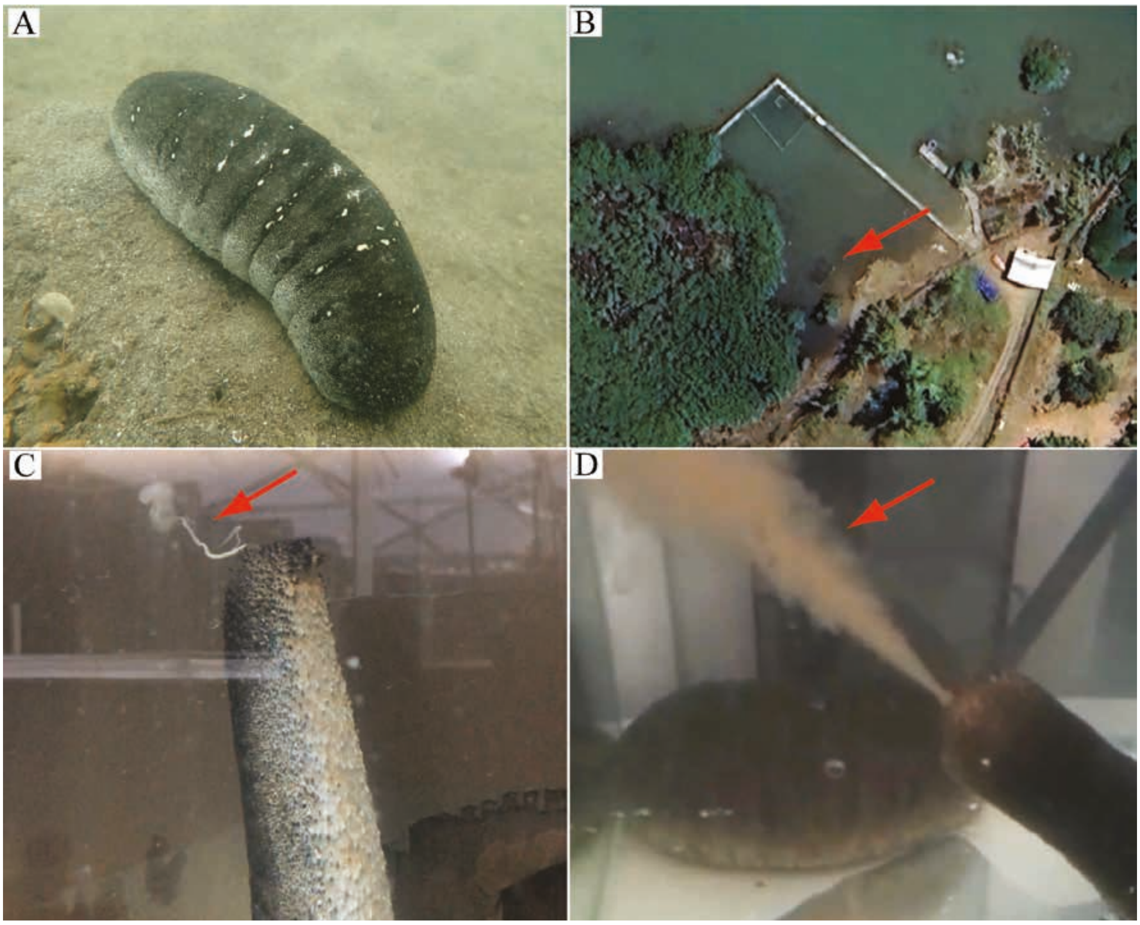

Figure 2. *Holothuria scabra*. Broodstock management and spawning. A) Sandfish *in situ* from the *barachois*. B) Google Earth map showing the broodstock pen (arrow) housing up to 102 sandfish individuals for use in spawning induction. C) Male sandfish spawning (arrow showing sperm release after thermal induction). D) Female sandfish spawning (arrow showing eggs).

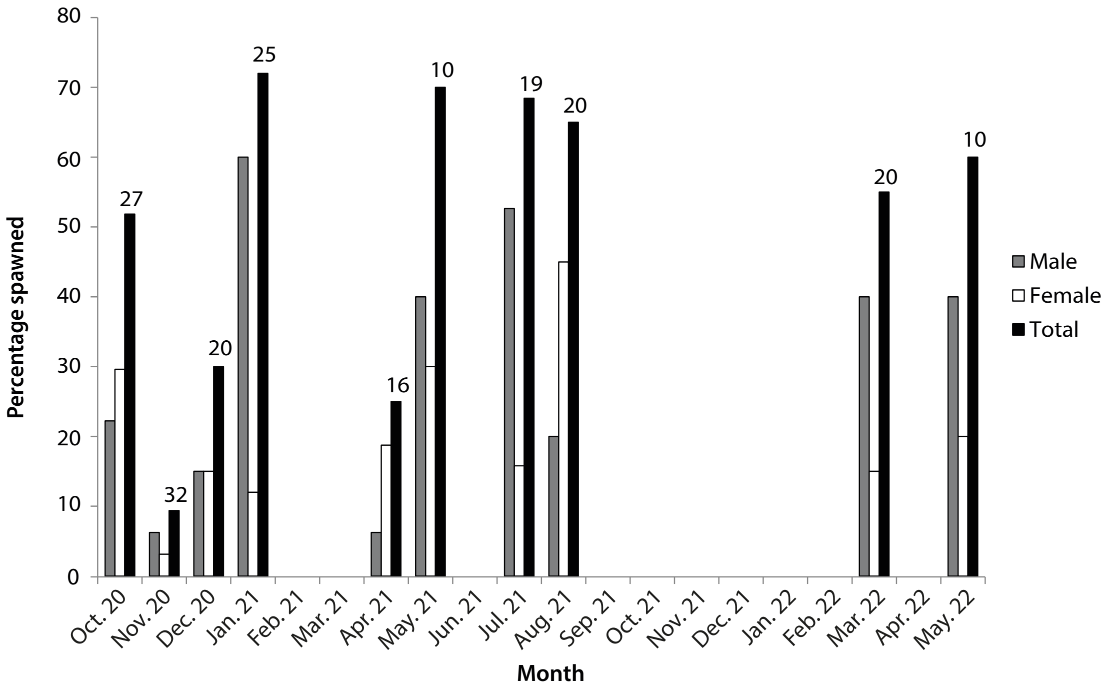

Figure 3. Spawning success rate observed from twelve trials made from October 2020 to May 2022. Note that in both October and November 2020, two trials were carried out per month, and data shown here are pooled data. For the rest, only one trial was conducted per month. Total number of individuals induced to spawn for each trial is indicated above the bars.

throughout the duration of the larval culture stage. Partial water changes were made at least once during the larval culture period. The different larval culture stages are shown in Figure 4, showing the transition from early (Fig. 4A) to late (Fig. 4B) auricularia, metamorphosis to doliolaria (Fig 4C and D), and to pentactula (Fig. 4E), and finally to the early juvenile stage (Fig. 4F). The larval phase was completed within 13–18 days post-fertilisation, depending on the cultures. As soon as the late auricularia stage appeared, settlement plates, preconditioned with spirulina paste, were introduced in each larval culture tank to induce metamorphosis of doliolariae into pentactulae. The resulting pentactulae were allowed to grow in the same larval culture tank until they reached about 2–3 cm long, about 2 to 2.5 months post-settlement (see Fig. 5). During this period, partial seawater exchanges were performed in each tank and the resulting early juveniles were fed with the same mixture of phytoplankton. Towards the end of the hatchery phase, early juveniles were also fed with some finely crushed *Gracillaria salicornia*. Once the juveniles were about 2–3 cm long and could easily be manipulated without harming them, they were transferred to the outdoor nursery raceways.

Table 1 shows some a summary of the output data recorded from the hatchery production trials from October 2020 to May 2022. The average larval survival rate obtained two days prior to settlement was about 26%, and the maximum survival rate of 2-cm-long early juveniles recorded in any culture tank prior to transfer to the nursery raceways was about 1%. Thus, for every 1 million fertilised eggs obtained from spawning, about 10,000 early juveniles will leave the hatchery and transferred to the nursery.

The nursery raceways were filled with coarsely filtered seawater and operated under a flow-through principle. A thin layer of fine sand was also added to the raceways before introducing the early juveniles, which were reared at an average density of 150 individuals/m^2 for another two months and were fed with mix of crushed *Gracillaria salicornia* and *Sargassum* sp. (both collected from the *barachois*). Once they reached at least 6 cm long, they were moved to the *barachois* for grow-out.

The stages after the hatchery and nursery production were not quantified simply because our focus at that time was on evaluating the hatchery potential, using broodstock from the wild, and after conditioning them in the pen. The company was not yet equipped for grow-out pens in the *barachois* at the time these studies were conducted.

Discussion

The results obtained over the 19 months of sandfish breeding in Mauritius are very promising for the establishment of a commercial sandfish hatchery. The successful hatchery production of sandfish seeds is dependent on four main stages: 1) broodstock availability and conditioning; 2) spawning and fertilisation; 3) larval rearing and settlement; and 4) postlarval rearing (Hamel et al. 2022).

The commercial sea cucumber fishery in Mauritius from 2005 to 2009 severely impacted the population of sea cucumbers in the lagoons around the island, particularly among high-value species such as the sandfish. Looking at observed surveys made prior to the commercial fishery (Luchmun et al. 2001) and after 2009, the sandfish populations were almost wiped out. A survey conducted at 23 sites in the lagoon around Mauritius in 2013 revealed only one sandfish individual out of 7488 sea cucumbers recorded (Lampe-Ramdoo et al. 2014). The search for wild stock to constitute our broodstock was challenging and took us several trips over two months to harvest 102 individuals. The conditions in our sea pen were, however, optimum for survival of the sandfish because after four years in the pen, we lost only six individuals, that is, around 6%. The fact that spawning was successful most of the year and the quantity of oocytes released was quite high (> 1.5 million except on one occasion where it was less than 1 million), indicated that conditioning in the pen was optimal even after individuals spent 19 months. The broodstock management process was also very efficient. Separating males and females in the pen optimised the spawning procedures and protocol, and also allowed for a better follow up on recovery post spawning. During the 12 spawning runs over the 19-month period, the average number of spawned males and females used during the fertilisation process were six and four, respectively. The gametes from the males were mixed together to fertilise the oocytes released from the females. This practice ensures a good genetic diversity of the resulting larvae, postlarvae and juveniles (Hamel et al. 2022).

The larval, postlarval and juvenile rearing procedures used were the same as previously established rearing protocols that have proven to be efficient (Vaitilingon et al. 2016). The seawater used was always fine filtered and UV sterilised to prevent the proliferation of undesired organisms such as copepods. Water exchanges during the larval culture phase were kept to a minimum so as not to disturb and damage larvae. The key aspect that was monitored to evaluate the performance of the larvae was the development of the hyaline spheres and their homogeneity among the larvae. In our cultures they first appeared at days 5–8 and fully developed by day 12 post-fertilisation. The function of these spheres has been linked to nutrient storage and more specifically lipid storage that is used later during the metamorphosis into doliolaria and pentactula stage (Peters-Didier and Sewell 2019). The hyaline spheres, therefore, gave us a good visual indication on how the larval cultures were performing and if the feed mixture and ration used were optimal or not.

A good hatchery production is determined by how homogenous the larval cultures are within and among the different tanks of the same batch. In our larval cultures, larval development was homogenous within the tanks but not necessarily among the tanks, and this was mainly due to rearing conditions as the building was not temperature controlled. This issue was mainly observed during cold winters and during very hot summers. During winters, the change in seawater temperature in our rearing tanks during day and night was significant enough to affect larval development. The use

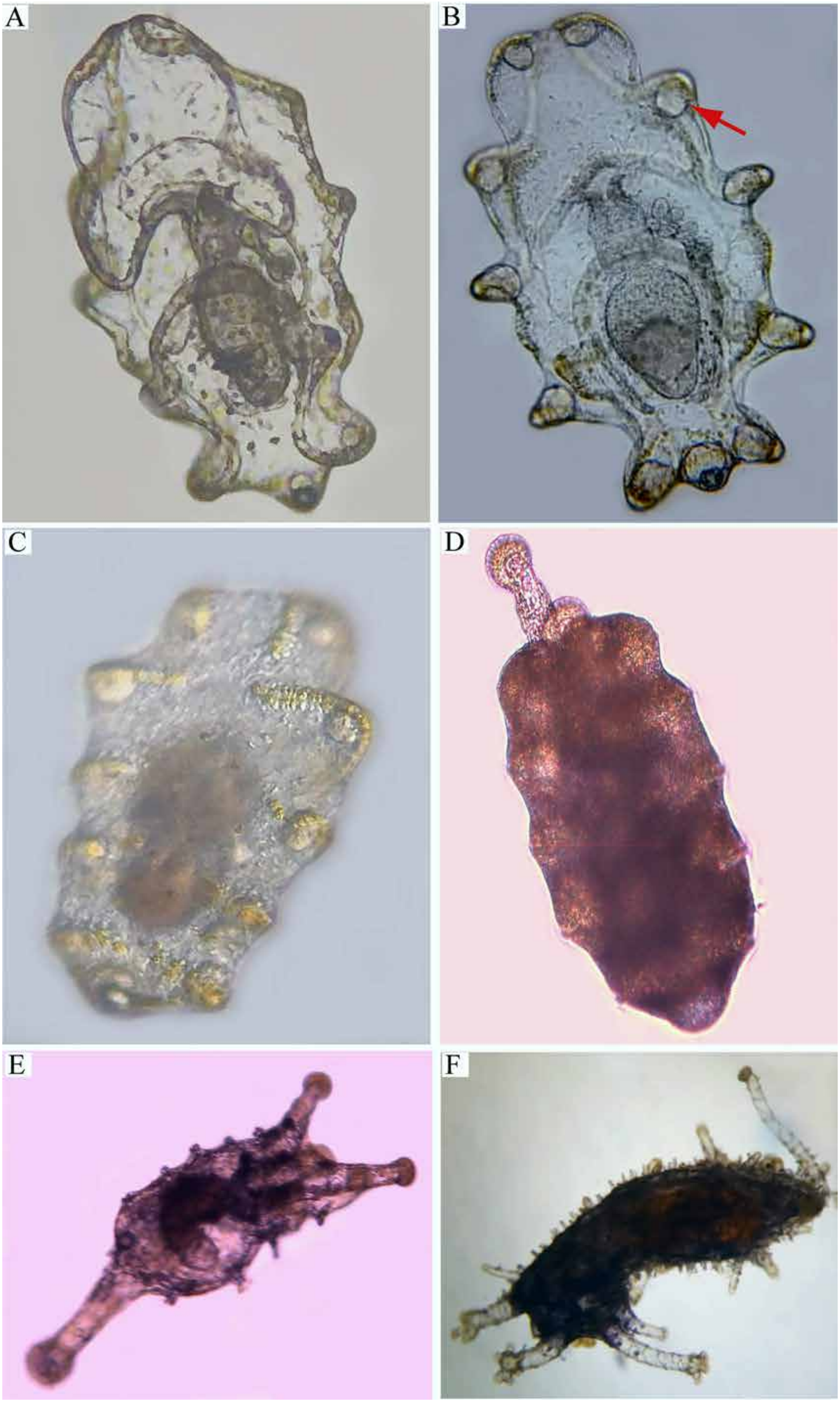

Figure 4. *Holothuria scabra*. Larvae, postlarvae and early juveniles. A) 8-day-old auricularia; B) 12-day-old auricularia (arrow pointing to the hyaline sphere); C) 15-day-old doliolaria; D: 16-day-old doliolaria. E) Pentactula, 5 days post-settlement. F). Early juvenile, 24 days post-settlement.

Table 1. Summary of data recorded during the hatchery production trials.

Spawning trial #	Date	Spawning success (%)	Average number of eggs per female	Time to settlement (days after fertilisation)	Average larval survival rate (%)	Maximum survival rate (%) at early juvenile stage (2 cm)
1	Oct-20	52	2,450,000	15 to 17	20	1.2
2	Nov-20	9	1,880,000	15 to 18	22	0.6
3	Dec-20	30	3,150,000	14 to 16	28	1.5
4	Jan-21	72	1,640,000	15 to 16	30	1.7
5	Apr-21	25	1,750,000	14 to 17	23	0.7
6	May-21	70	3,600,000	15 to 16	25	1.5
7	Jul-21	68	1,866,667	13 to 15	27	0.6
8	Aug-21	65	2,200,000	15 to 17	31	1.5
9	Mar-22	55	875,556	14 to 15	25	1.5
10	May-22	60	2,740,000	15 to 16	29	1.0

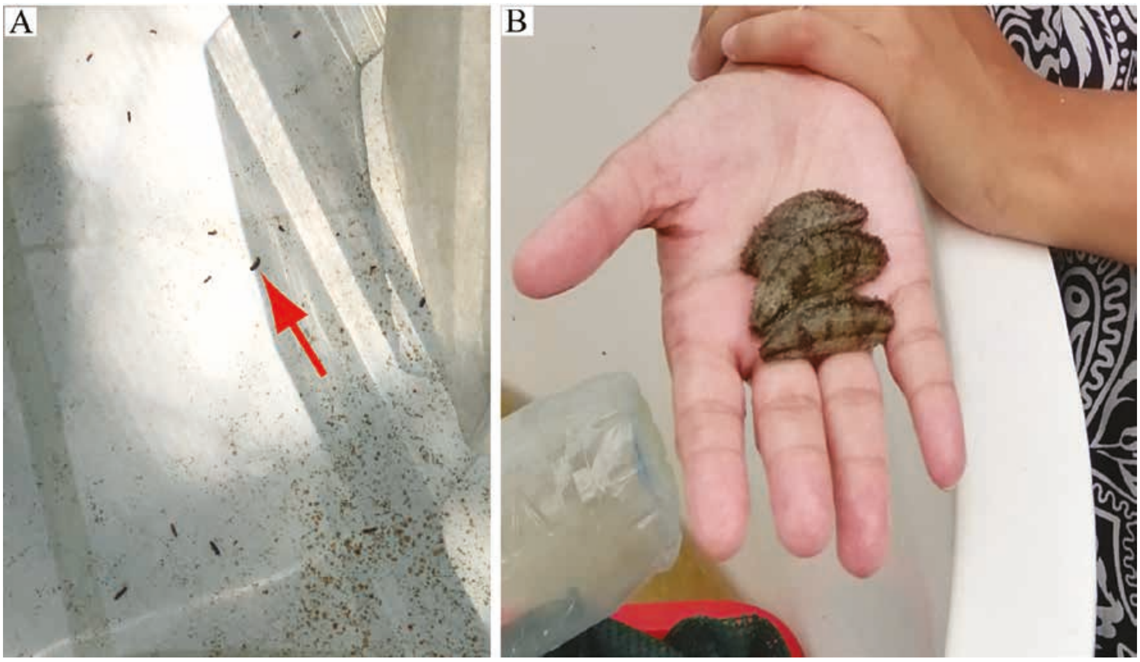

Figure 5. *Holothuria scabra*. Juvenile sandfish in the hatchery. A) Arrow shows an early juvenile from one culture tank after about one month post-settlement (0.5 cm long); B) 2–3 cm-long juveniles prior to transfer to the outdoor nursery

of aquarium heaters helped to a certain degree but even that affected larval development, resulting in non-homogenous cultures. This highlights the need for a proper temperature controlled and biosecure hatchery for the production of sandfish seeds.

Our results are comparable to other pilot-scale productions in the world knowing that our rearing conditions in the hatchery were suboptimal. The time from fertilisation to the pentactula stage was comparable to other cultures from Australia, Malaysia, Papua New Guinea, Madagascar, Philippines and Sri Lanka (Hamel et al. 2022). The survival rate from fertilised eggs to seeds (destined for nursery raceways) in our cultures ranged from 0.6% to 1.7%, which is equivalent to about one-third to one-half of the survival obtained from a commercial hatchery production in Madagascar (Eeckhaut et al. 2024; Hamel et al. 2022). This study mainly focused on hatchery seed production, with less focus on the nursery and outdoor grow-out. Although our results show that the broodstock was viable and capable of sustaining a pilot-scale production, and that production could operate almost year round, which are key factors to consider while assessing the feasibility of an aquaculture business, the next stage of juvenile grow-out could face some serious challenges due to conditions intrinsic to Mauritius.

Our trials showed that land-based nursery grow-out would take about two to three months before reaching a size suitable for grow-out in the *barachois*. Although the *barachois* consists of 46 ha of water, not all of the surface area is suitable for sandfish grow-out due to the type of sediment and the presence of predators such as crabs. Both conditions have been shown to affect sandfish juvenile grow-out (Plotieau 2012; Eeckhaut et al. 2020). Sandfish require an extensive surface area for grow-out to marketable size and this could be a serious limiting factor for farming around Mauritius. For example, the commercial company Indian Ocean Trepang in Madagascar has up to 400 ha of fenced enclosures in the ocean for grow-out. Production in China (Guangdong Province) is conducted from 300 ha of seawater ponds (Hamel et al. 2022). Mauritius does not have such extensive surface areas that meet all of the right conditions for sandfish grow-out. Farming in the lagoon in Mauritius is banned, and aquaculture is only allowed at prescribed sites as dictated in the Third Schedule of the Fisheries Act 2023. However, most of these sites are in deep water, which is more suitable for vertical farming than horizontal farming. The set up of sea pens for sea farming sandfish in Mauritius at these prescribed sites is challenging and potentially not profitable during scaling up. The set up of grow-out farms in the outer islands (St Brandon and Agalega) could be a possible solution, akthough their remoteness will make the operation difficult and risky. Sea ranching could also be a potential grow-out method for sandfish, however, this method will face two main issues: 1) the availability of suitable areas for grow-out such as seagrass beds, and 2) conflicts with other resource users.

The issues described above raise one main question: Is sandfish the right species for sea cucumber aquaculture in Mauritius? The intrinsic requirement of sandfish biology for grow-out will constitute a serious limitation that could be overcome by changing species, and using one that could be grown vertically; for example a species such as *Actinopyga* sp. or a species that could be ranched on the outer reef areas such as teatfish (e.g. black teatfish, *Holothuria nobilis*). Recent research in the breeding of teatfish (Burgy and Purcell 2024) and stonefish *Actinopyga lecanora* (Tanita et al. 2023) could provide the basic information to help us identify other sea cucumber species that will fit within the aquaculture conditions around Mauritius.

The future of sea cucumber farming for Mauricoast Ltd will be to focus on: 1) setting up a proper hatchery for sea cucumber breeding; 2) running some trials of sandfish grow-out in sea cages that could be placed under open-sea fish cages as a form of Integrated Multitrophic Aquaculture (IMTA); 3) studying the feasibility of sandfish grow-out at the outer islands, including Rodrigues; and 4) identifying another sea cucumber species that could be grown vertically, and developing its hatchery production protocol.

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Histological characterisation of the body wall of *Holothuria* (*Platyperona*) *sanctori* from the Mostaganem coast in Algeria

Zineb Lebouazda[1] and Karim Mezali[1*]

Abstract

Sea cucumbers are a common species in the Mediterranean Sea. To describe and characterise the body wall of *Holothuria sanctori*, we carried out a histological study of the entire integument, including the appendages (podia, papillea and tentacles). The results show that the integument and stems of each appendage are composed of epidermis, dermis, nerve plexus and mesothelium. The terminal parts of each appendage are modified according to their function into buds or discs, and consist mainly of epidermis, nerve plexus and connective tissue.

Keywords: sea cucumbers, integument, appendages, podia, tentacles, papillae

Introduction

Holothurians are benthic invertebrates that play a key role in organic matter remineralisation and seafloor oxygenation (Mangion et al. 2004; Isgoren and Gunay 2007; Navarro et al. 2012; Mercier et al. 2024). They are known for their flexible vermiform body, pentaradial symmetry masked by bilateral symmetry along the buccal-aboral axis, and their skeleton, which is reduced to ossicles (Purcell et al. 2023).

The integument of holothurians constitutes the main part of the body mass (Pawson et al. 2010). It is sold as a dry product, commonly known as bêche-de-mer (Pawson et al. 2010; Purcell et al. 2023). This integument contains bioactive molecules of pharmaceutical interests (Bondoc et al. 2013; Marchese et al. 2020; Mecheta et al. 2020; Khodja et al. 2024), and has multiple mechanical properties due to its mutable connective tissues (Byrne 2023; Wilkie and Candia Carnevali 2023; Bonneel et al. 2023; Candia Carnevali et al. 2024).

The integument has three types of appendages: podia on the ventral side, papillae on the dorsal side, and tentacles surrounding the mouth. The last two are modified podia and the three appendages form part of the holothurian's water vascular system, and control respiration, feeding, locomotion and sensation (Mckenzie 1987, 1988; Flammang and Jangoux 1992; Vanden Spiegel et al. 1995; Liu et al. 2020).

Holothuria (*Platyperona*) *sanctori* Delle Chiaje, 1823 is a common sciaphilic species in the Mediterranean Sea, inhabiting hard substrate bottoms. It is known for its light, ring-shaped spots on the dorsal side and its defensive organs called Cuvierian tubules (Caballero 2007; Moussa and Wirawati 2018; Magdy et al. 2021). This species was rarely consumed as food and was mainly used as fishing bait (Mezali 2008; Aydin 2013), but the increasing demand for sea cucumbers on the global market has led to the exploitation of lesser economic value species, such as *H. sanctori* (Magdy et al. 2021; Conand et al. 2024).

Various studies on the histological structure of the holothurian integument have been conducted (Flammang and Jangoux 1992; Vanden Spiegel et al. 1995; Gao and Yang 2015; Guerrero and Rodríguez Forero 2018). These generally focus on a specific part of the integument, such as the epidermis (Aruga and Hirose 2021), nervous tissue (Nieves-Ríos et al. 2020), podia (Winarni et al. 2023) or tentacles (Bouland et al. 1982). A paper by Delroisse et al. (2020) details the anatomy and ultrastructure of the dorsal body wall of *Holothuria scabra* and compares a healthy and skin ulceration-diseased sample. The present study aimed to show a first sketch of the structure of the integument of *H.* (*P.*) *sanctori*, including appendages, and to compare the histological features observed in this species with other related species.

Methodology

Six adult specimens of *Holothuria* (*P.*) *sanctori* were collected by scuba diving in the Stidia area of Mostaganem, on the western Mediterranean coast (0°0.830' W; 35°50.06' N) (Fig. 1). Sampling was carried out during December 2023 in a depth <5 m. Individuals were transported separately in plastic containers and kept alive until processing. They were anaesthetised with 1% $MgCl_2$ solution in seawater (approximately 10 g/L) for 15 minutes at 4°C to relax the animal. Then, small pieces of the integument and appendages (buccal tentacles, podia, and papillae) were taken for histological analysis.

The tissues sampled were fixed in 4% formalin and decalcified following the method of Dietrich and Fontaine (1975), using a solution of 2% ascorbic acid and 0.3 M NaCl (V:V).

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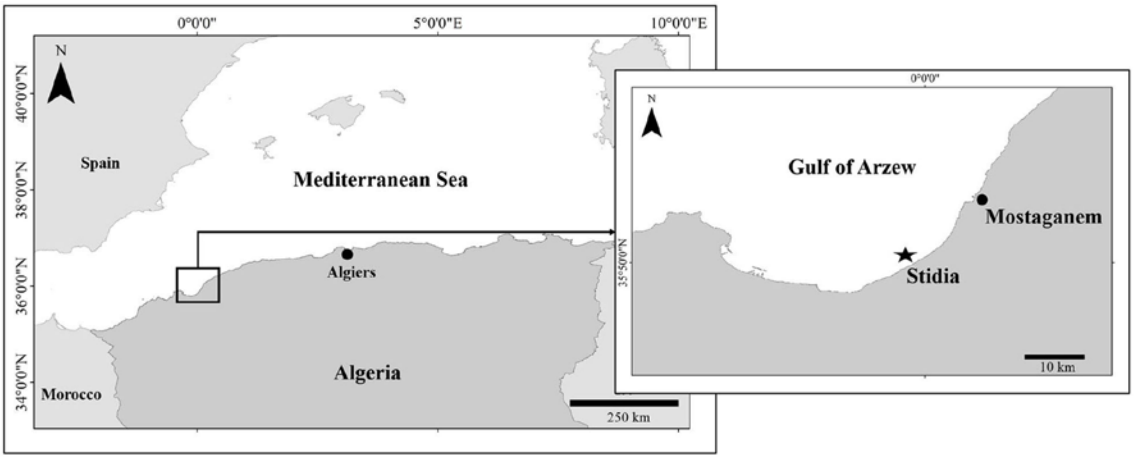

Figure 1. Sampling location of *Holothuria* (*Platyperona*) *sanctori* specimens marked with an asterisk on the west coast of Algeria.

The samples were then dehydrated through a graded series of alcohol baths, cleared with toluene, and embedded in paraffin wax. Sections 4 µm thick were cut using a Microm HM 340 E microtome. The sections were then stained with either Masson's trichrome or Heidenhain's Azan trichrome and examined under a Zeiss Axioscope A1 light microscope equipped with a Zeiss AxioCam 305 colour camera.

Results

Macroscopic aspect

Macroscopically, the integument of *Holothuria (Platyperona) sanctori* was rough and robust, coloured with brown and light ring-shaped spots surrounding the papillae on the dorsal side. The papillae were composed of a large, fleshy and conical stem with a hemispherical terminal bud (Fig. 2). Sometimes they were surrounded by a light ring (white to light brown). The podia consisted of a cylindrical stem about 250 µm, and a flat terminal disc 700 µm in diameter (measured from photographs). The tentacles consisted of a basal stem and a terminal crown, which divided into branches then into buds, producing a cauliflower-like structure.

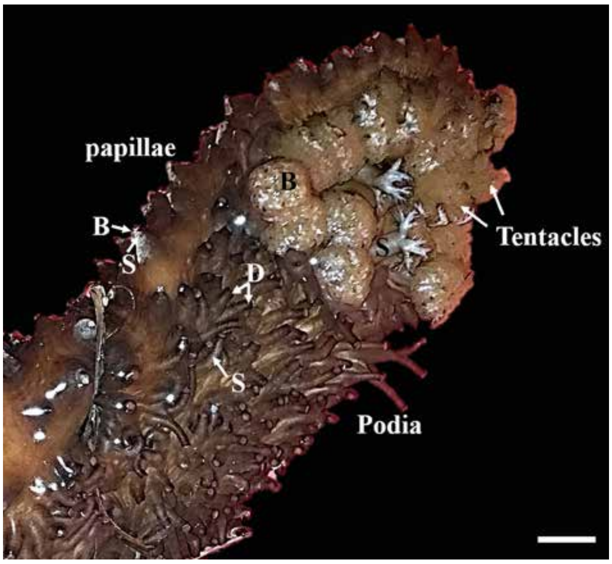

Figure 2. Macroscopic aspect of *Holothuria* (*P.*) *sanctori* integument and appendages: B is the bud, S is the stem, and D shows the disc. Scale white bar = 1 cm

Microscopic aspect

Integument

Microscopically, the integument of *H.* (*P.*) *sanctori* consisted of three layers: the cuticle, epidermis and dermis (Fig. 3). The cuticle was a thin, acellular layer approximately 3 µm thick that covering the entire integument. The epidermis (the uppermost layer of the integument) was stained brown (Fig. 3a and c) and was about 30 µm thick. The dermis comprised two sub-layers: 1) the loose connective tissue, and 2) dense connective tissue (Fig. 3c). The former holds ossicles and the latter represents the most important part of the integument, housing the ambulacral canals (Fig. 3b). Both are made up of collagen fibres.

Appendages

The appendages (tentacles; podia and papillae) were composed of a cuticle similar to that of the integument, two epithelia, the epidermis on the external side and the mesothelium surrounding the ambulacral lumen and the dermis.

The papillae were characterised by a dense mesothelium measuring approximately 30 µm, stained brown, and surrounded by a thin bundle of dense connective tissue named basal lamina which stained blue and measured about 2 µm. The loose connective tissue supports the ossicles, whereas the dense connective tissue contains the nerves. These nerves are classified into two types: 1) the longitudinal nerve, which extends along the length of the papilla with a diameter of approximately 98 µm, and 2) the nerve plexus, which encircles the papilla (Fig. 3d–e).

The podia consist of two main parts, the disc (186 µm thick) formed by a dense epidermis separated in the middle by a nerve, and a loose connective tissue containing the ossicles supporting the disc. The second part is the stem from the outside to the inside, consisting of an epidermis similar

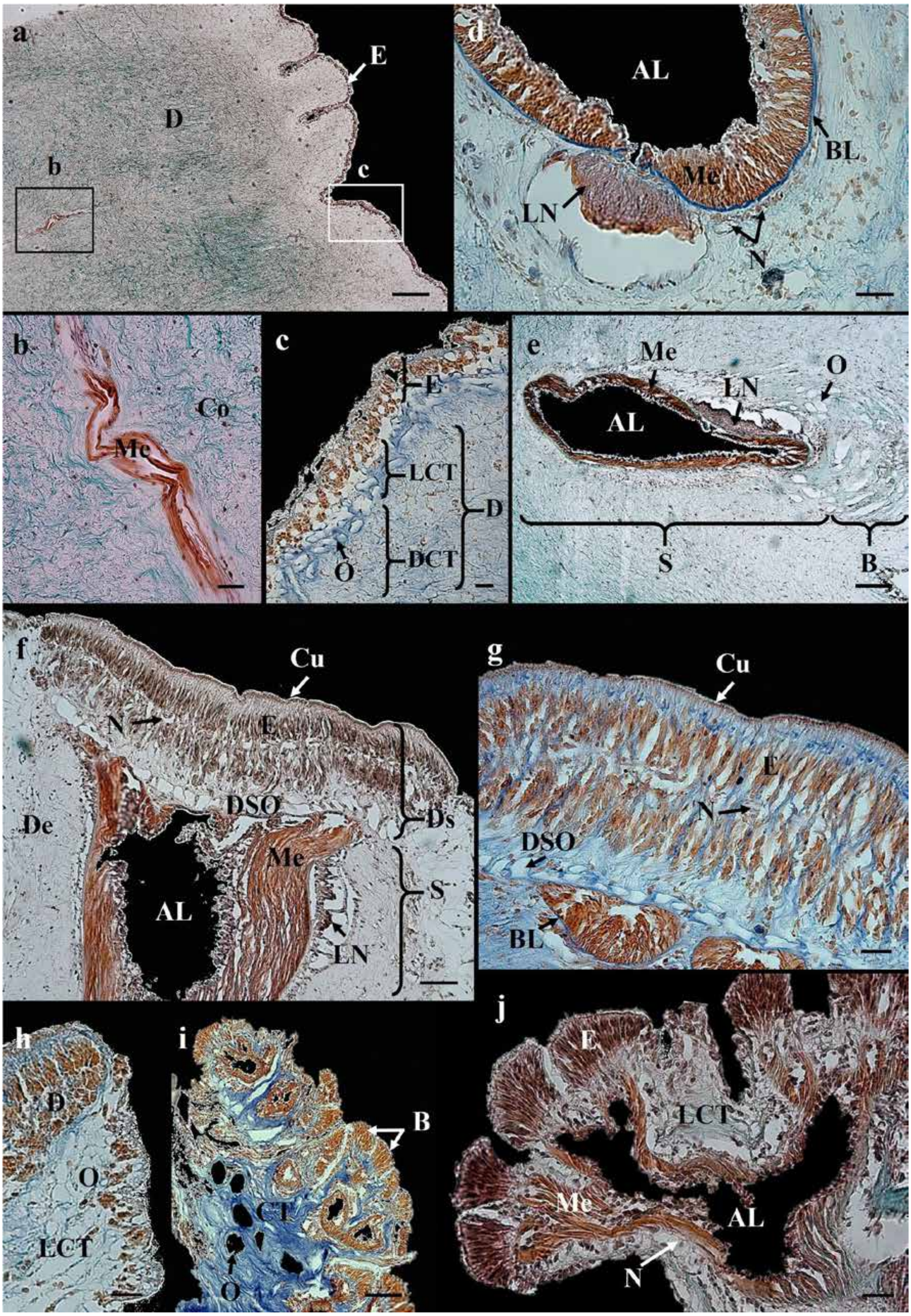

Figure 3. Histological section of the integument of *Holothuria* (*P.*) *sanctori* observed under light microscopy: a) and c) are transverse sections of the integument; b) a section through an ambulacral channel; d) a transverse section through the papillae; e) longitudinal section through papillae; f–h) show sections through the podia, disc and stem, respectively; i–j) illustrate the transverse sections of the tentacles. AL = ambulacral lumen, B = bud, BL = basal lamina, Co = collagen fibres, Cu = cuticle, D = dermis, Ds = disc, DCT = dense connective tissue, DSO = disc-supporting ossicles, E = epidermis, LCV = loose connective tissue, LN = longitudinal nerve, Me = mesothelium, N = nerve plexus; O = ossicles, S = stem. Scale bars: a = 200 µm; b, d, e, f = 50 µm, b, c, g, h, j = 20 µm; i = 100 µm

to the integument, a layer of loose connective tissue with ossicles, a dense connective tissue enclosing the longitudinal nerve (32 µm thick), a basal lamina and the mesothelium as an exchange area with the ambulacral lumen (Fig. 3f–h).

The tentacles are made up of buds and stems. The buds are about 93 µm thick and are characterised by a layer of epidermis and a loose connective tissue that connects them to the branches. The branches and stem are made up of dense and loose connective tissue that encloses the nerve and mesothelium. The ossicles exist only in the stem (Fig. 3i–j).

Discussion

The organisation of the different tissues within the integument of *Holothuria* (*Platyperona*) *sanctori* is similar to that of other holothurian species, such as *Thyone briareus* (Menton and Eisen 1970), *Apostichopus japonicus* (Gao and Yang 2015), *Isostichopus badionotus* (Guerrero and Rodríguez Forero 2018), *Holothuria scabra* (Delroisse et al. 2020) and *Holothuria arenicola* (Abdel-Ghaffar et al. 2022). Nevertheless, the size of the tissues and appendages of *H. (P.) sanctori* seem to be larger than those of other holothurians, such as *Holothuria (Panningothuria) forskali*, where the diameter of the disc measures about 1 µm, the longitudinal nerve about 5 µm, and the mesothelium about 10 µm (Flammang and Jangoux 1992; Vanden Spiegel et al. 1995) compared with 1.86 µm, 32 µm and 30 µm, respectively in *H.* (*P.*) *sanctori*.

From the outside to the inside, the body wall of *H.* (*P.*) *sanctori* consists of a cuticle, epidermis, dermis and mesothelium on the ambulacral canals. According to McKenzie (1987), the cuticle plays a protective role against environmental aggression and maintains the integrity of the epidermal cells. The epidermis is considered to be the interface for exchanges between the integument and the external environment, in particular gas exchange, excretion of active molecules (defence, antifouling, adhesion, etc.), sensation and protection (Yamamoto and Yoshida 1978; Flammang and Jangoux 1992; Mckenzie and Grigolava 1996; Liu et al. 2020). The epidermal cells of *H.* (*P.*) *sanctori* had a specific columnar shape on the disc and tentacular buds, which does not occur in the epidermis of the integument or papillae. This shape has been described in the tentacular bus and podia of *Parastichopus californicus* (Cameron and Fankboner 1984). The dermis, the main part of the integument, consists of mutable connective tissue. It is mainly composed of collagen fibres embedded in a proteoglycan matrix. It has considerable properties: reversible suppleness and stiffness, tensile strength, prolonged postural fixation (energy economy), and autotomy under nerve stimulation, all within a few seconds (Motokawa 2019; Bonneel et al. 2023; Candia Carnevali et al. 2024). The collagen fibres of *H.* (*P.*) *sanctori* were highly organised and closely packed such as those of *Thyone briareus* (Menton and Eisen 1970) and *Isostichopus badionotus* (Guerrero and Rodríguez Forero 2018). The mesothelium consists of two major types of cells, the peritoneal and myoepithelial. The latter contains muscle bundles formed by the aggregation of myocytes. This tissue plays an important role in various processes such as feeding, movement and respiration (Liu and Chen 2023).

The three appendages (podia, papillae and tentacles) have similar stem structures, and are composed of the epidermis, connective tissue enclosing ossicles on the upper part, nerves, then, mesothelium surrounding the ambulacral lumen. The distal part of the three appendages varies according to the organ (tentacle, papilla or podia) and its function (feeding, movement, adhesion or sensation), with buds in the tentacles and papillae and a disc in the podia. Tentacle buds lack ossicles, whereas disc and papilla buds possess them. The ossicles perform the same functions as skeletons in vertebrates. They resist mechanical forces by transmitting and dissipating them, and store elastic tension energy (Candia Carnevali et al. 2024).

Conclusion

The integument of *Holothuria* (*Platyperona*) *sanctori* is similar to that of other species of holothurians, being composed of different tissues that fulfil complementary or distinct functions. This study has shown the histological aspect of the integument, but this does not preclude other explorations, particularly ultrastructural and functional, for each type of tissue in this species.

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Some ecobiological observations about *Holothuria poli* and *Cucumaria syracusana* living in Boughrara Lagoon,Tunisia

Fatma Guetat[1] and Feriel Sellem[2]*

Abstract

This study complements the article by Sellem et al. (2019) about the sea cucumbers found in Tunisia's lagoons. We investigated two species – *Holothuria poli* Della Chiaje, 1824 and *Cucumaria syracusana* (Grube, 1840) – in three geographical areas of Boughrara Lagoon within 32 georeferenced stations. We observed *H. poli* in two areas, and assessed its maximal density per station to be between 16 and 24 individuals. Individuals of *Cucumaria syracusana*, however, were present in three areas, and we determined that the maximum number of individuals per station of this species to be between 10 and 35. Organic matter ranged between 3.6% and 15.21%.

Keywords: *Holothuria poli, Cucumaria syracusana,* Tunisia

Introduction

Few studies have been conducted on the various species and diversity of sea cucumbers in Tunisia, and basic references include outdated inventories (Le Danois 1925; Cherbonnier 1956). In response to this lack of information, we (Sellem et al. 2019) investigated the species of sea cucumbers present in two lagoon ecosystems on the Tunisian coast: Bizerte Lagoon and Boughrara Lagoon. Here, we give some information, especially ecological and biological data, of sea cucumbers populations in Boughrara Lagoon.

Methodology

Study region and sampling areas

Boughrara Lagoon –in the southwestern part of the Gulf of Gabès (32°28'–33°45' N, 10°45'–10°57' E) – has an area of 50,000 ha and an average depth of 5 m. The lagoon is surrounded by Djerba Island on the north side, and by the continent on the south. In the northwest, it is connected with the sea by the Ajim canal, and in the northeast by a small bridge in the middle of the Roman roadway. Boughrara Lagoon is subject to tides and currents (Guetat et al. 2012).

Three areas within the lagoon were selected for this study: the south (area 1), the east (area 2) and the west (area 3). Area 1 is farthest from the two main connections with the sea, and is considered to be the area where hydrodynamics and water renewal are the lowest. Nine stations were surveyed there (P1–P9). Area 2 is the transition area where current and circulation are low due to the Roman roadway. Stations (K1–K17) correspond to this area. Area 3 is the area with the greatest connection to seawater, where exchanges occur through the canal of Ajim-Jorf. Six stations were surveyed there (J1–J6).

Sampling

Sampling was carried out in the winter in three areas at 32 georeferenced stations (Fig.1)

Sea cucumbers were collected using a dredge (50 cm diameter). At low tide, samples were taken using a quadrat (50 cm per side). Sediment samples from the lagoon were analysed in a previous work by Guetat et al. (2012).

Results and discussion

The bottom of the lagoon is essentially sandy silt, with the sediment comprising medium and fine-grain sand. Average organic matter contents are, respectively, 9.38% in area 1 corresponding to the southern part, 15.21% in area 2 corresponding to the eastern part, and 3.67% in area 3 in the western part of the lagoon.

Area 1 is represented exclusively by *Cucumaria syracusana*. In areas 2 and 3, *Holothuria poli* and *Cucumaria syracusana* dominated, but *Holothuria sanctori, H. impatiens* and *H. tubulosa* were present in low proportions (see Sellem et al. 2019). Overall, this study shows that *Holothuria poli* and *Cucumaria syracusana* are the most abundant species, with *Holothuria poli* present at 48.15% and *C. syracusana* at 51.85%.

From a total of 23 surveyed stations *H. poli* was present at 10 stations, with the number of individuals ranging from 1 to 24. Moreover, for a number of specimens greater than 10 ind/station *H. poli* is present preferentially in stations K4, K5, J5 and J6 with, respectively, 18, 21, 14 and 11 individuals. Sizes and weights of *H. poli* individuals varied, respectively, between 9 and 15 cm, and 15.3 and 51.9 g.

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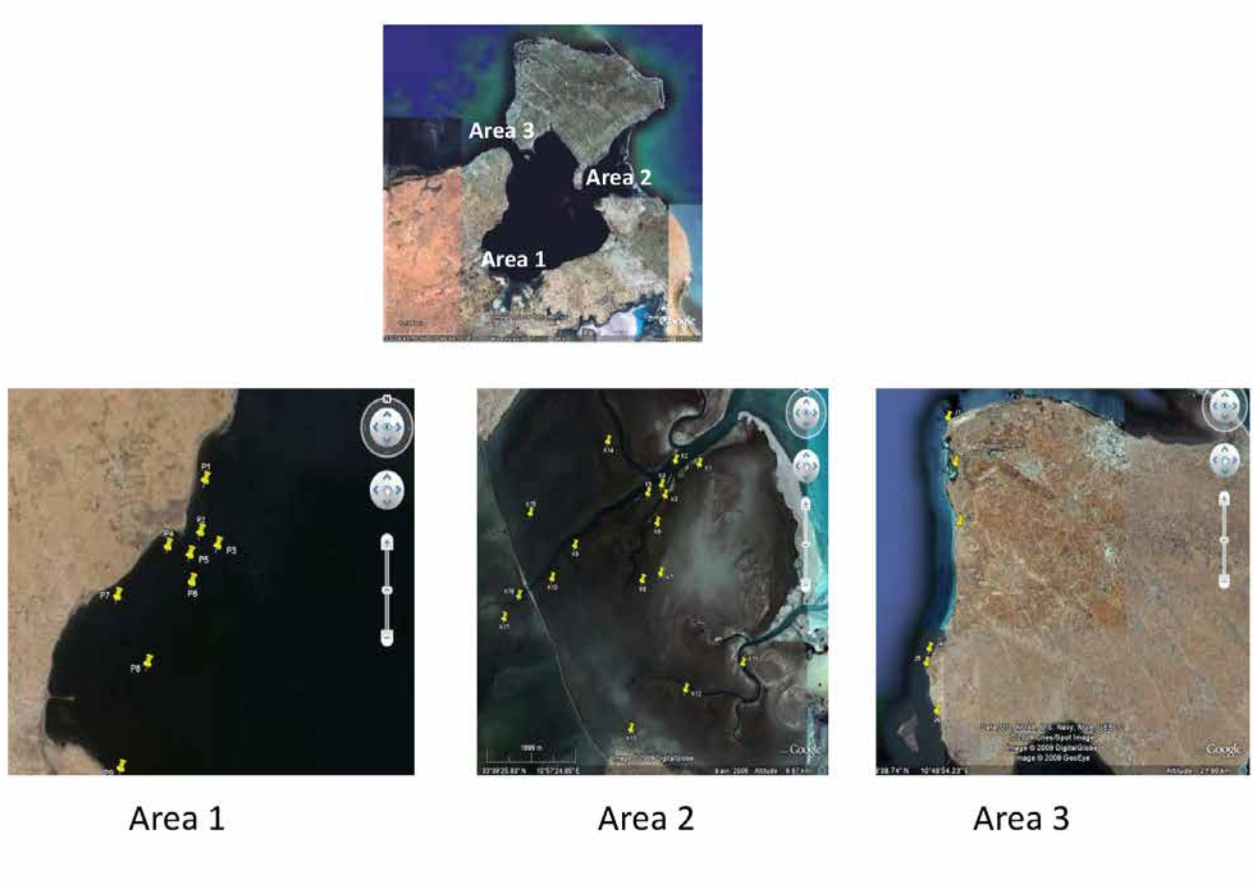

Figure 1. Boughrara Lagoon and the sampling stations in areas 1, 2 and 3.

In Boughara Lagoon, *Cucumaria* is more abundant, and was present at 28 stations with the number of individuals ranging from 1 to 35. Even so, we noted that the stations displaying a number of individuals more than 10 species were P1, P4, K8 and J1, record was respectively 35 (P1), 11 (P4), 10 (K8) and 13 (J1). *Caulerpa* and *Gracilaria* are consistent in these stations, and the sizes and weights of individuals of *Cucumaria* varied respecively between 2 and 4 cm, and 2.1 and 3.5 g.

This study, like the one by Sellem et al. (2019), shows that *Holothuria poli* and *Cucumaria syracusana* are the most abundant sea cucumber species in Boughrara Lagoon. Moreover, they are the most abundant species in each of the three areas of the lagoon. Notably, the Mediterranean endemic species *Cucumaria syracusana* was observed for the first time significant densities. The lagoon occupies an important place in Tunisian fisheries and aquaculture economy. Illegal fishing of sea cucumbers is increasing because collecting them is easy and straight forward for scuba divers. Harvesting is also increasing along Tunisia's coastline. If this type of practice is not stopped, the ecology of the subtidal zone is likely to be greatly affected.

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Fecundity patterns of two sea cucumber species from Mostaganem, Algeria

Hanane Zerroual and Karim Mezali[1]*

Abstract

The current study examines the reproductive capacity of two common sea cucumber species (*Holothuria poli* and *Holothuria tubulosa*) along Algeria's west coast. Monthly samplings (49 individuals of *H. poli* and 28 individuals of *H. tubulosa*) were carried out from May to December 2022 by scuba diving between 0.5 and 8 m at Sidi Lakhdar (Mostaganem). The oocyte diameter distribution and absolute and relative fecundity were analysed. The multimodal distribution of oocyte diameters suggests multiple spawning events for both species. The absolute and relative fecundity values indicate that *H. tubulosa* has a higher reproductive capacity than *H. poli*, thus supporting its potential as a candidate for aquaculture in the Mediterranean.

Keywords: sea cucumbers, absolute fecundity, relative fecundity, gonadal tubules, *Holothuria poli*, *Holothuria tubulosa,* oocyte diameter

Introduction

Many studies have focused on the valorization of sea cucumbers due to their economic importance and their high nutritional value (González-Wangüemert and Giomar Borrero 2012; Roggatz et al. 2017; Mecheta et al. 2020; Belkacem and Mezali 2022; Khodja and Mezali 2022; Atanassova et al. 2024; Belkacem et al. 2024; Bonneel et al. 2024; Conand et al. 2024; Eeckhaut et al. 2024; Khodja et al. 2024; Mercier et al. 2025). This has encouraged farmers all over the world to invest in sea cucumber farming (holothuriculture) (Toscano and Cirino 2018; Domínguez-Godino and González-Wangüemert 2019; Felaco et al. 2024; Hair et al. 2024; Juinio-Meñez et al. 2024; Kalashnikov 2024; Olvera-Nova et al. 2024; Slater 2024; Sykes and Marrs 2024).

Sea cucumber reproduction

To cultivate an animal, it is fundamental to understand its reproductive cycle and capacity (fecundity). Sea cucumbers exhibit high reproductive plasticity, they reproduce by sexual mode (broadcast spawning) and, in some species, asexually by fission (Conand 1990; Pandian 2018; Hamel et al. 2021; Uthicke and Conand 2024). Sexual reproduction is controlled by several ecological factors such as temperature, photoperiod, lunar cycle, and food availability (Mercier et al. 2007; Mezali et al. 2014; Marquet et al. 2017; Pandian 2018; Toscano and Cirino 2018; Tolon and Serhat 2019; Hamel et al. 2021). Asexual reproduction, uncommon among sea cucumber species, is an additional reproductive mode that does not require gametes and spermatozoids (Uthicke and Conand 2024). This reproductive strategy occurs due to environmental stress, population dispersion, or to specific injuries leading to regeneration processes. The organism ensures genetic continuity through fission, with minimal energy expenditure (Uthicke et al. 2001; Pandian 2018; Uthicke and Conand 2024).

Many studies have been conducted on sea cucumber reproduction in the Mediterranean Sea (Uthicke 1997; Navarro et al. 2012; Mezali et al. 2014; González-Wangüemert et al. 2016; Rakaj et al. 2018; Slimane-Tamacha et al. 2019; Bahida et al. 2022; Mezali et al. 2022; Pasquini et al. 2022; Engin et al. 2024), examining several parameters. In general, sea cucumbers reproduce by releasing their gametes into the surrounding water, and reproductive success is directly related to the density of adults, which ensures sufficient production of spermatozoids and oocytes for effective fertilisation (Conand 1993). Conand (1981, 1990) and Marquet et al. (2017) used absolute fecundity as a key parameter to assess the reproductive capacity of species, as well as the distribution of oocyte diameter, which is necessary to determine whether spawning is unique or fractional during the same sexual cycle.

Despite the numerous studies on sea cucumber reproduction in Algeria (Mezali et al. 2014; Mezali and Soualili 2015; Slimane-Tamacha et al. 2019; Mezali et al. 2022), studies on fecundity are almost non-existent. Thus, the present work aimed to study the fecundity of *Holothuria (Roweothuria) poli* Delle Chiaje, 1824 and *Holothuria (Holothuria) tubulosa* Gmelin, 1791, commonly found along the coast of Sidi Lakhder in Mostaganen, Algeria and to compare and to compare the results with data from the literature.

Methodology

Our study was conducted in the western region of Algeria, specifically at Sidi Lakhdar (36°12'25.8''N, 0°22'29.9''E) (Fig. 1). Sampling was conducted over six months (May, June, September, October, November and December 2022) by scuba diving, at depths ranging from 0.5 to 8 m. We chose this period because the most holothurian species reach maturity between March and June, while spawning events begin in July and extend until September (Slimane-Tamacha et al. 2019). This allowed us to calculate the number of germinal cells ready to be spawned, as defined in the concept of fecundity (Conand 1986). The absence of data during the summer period (July and August) is attributed to the migration of sea cucumbers to deeper waters, where they seek refuge from stress and high shallow-water temperatures (Domínguez-Godino and González-Wangüemert 2020; Zerroual pers. obs.).

Sea cucumber individuals were transported to the laboratory, then anesthetised with magnesium chloride ($MgCl_2.6H_2O$) for 10 minutes (Mezali 2008), after which measurements were made (anesthetised length AL, body wet weight BWW). Each individual was dissected longitudinally, from the mouth to the cloacal opening. The gonads were carefully removed, drained on blotting paper, weighed, and stored in a modified Gilson solution to facilitate the separation of oocytes. The oocytes were observed under an optical microscope (40X magnification) equipped with an integrated camera and subsequently photographed using Optika Lite software.

Sex was determined through microscopic observations of spermatozoa and/or oocytes in the gonadal tubules. The maturity stages were identified for each individual according to the maturity scale established by Conand (1981). This step aimed to identify mature females (stages III: growth IV: maturity and V: post-spawning) that was used to estimate absolute and relative fecundity.

The analysis of oocyte diameter distribution allows for the identification of the sexual maturity stage of the individuals, determining whether there is a unique or fractional spawning during the same sexual cycle. To measure the diameter of the oocytes in the gonadal tubules, we selected four mature females. Measurements were obtained by analysing the photos of gonadal tubules using an optical microscope (40X magnification) and the calibrated image analysis software, ImageJ. Absolute fecundity corresponds to the number of total germinal cells contained in a female's ovary just before spawning. Oocytes were counted using the gravimetric sampling method, a technique that estimates the total number of oocytes based on the weight of ovarian subsamples.

A subsample of oocytes was taken from the anterior part of the gonadal tubule and weighed (WWi with a precision of 10^{-4}). The number of germinal cells in this subsample (Ni) was recorded. Three replicates were performed for each gonad. Absolute fecundity was estimated using the following equation:

$$F_a = N_{germinal\ cells} = \frac{N_i}{WW_i} \times GWW$$

Where *Fa* is the absolute fecundity of a female; *Ni* is the number of germinal cells contained in a subsample; and *GWW* is the initial total weight of the gonad tubules of one female.

The average fecundity between the three replicates was calculated for each female. For all the females studied, the maximum fecundity was selected.

Relative fecundity represents the number of germinal cells per gram of body weight of the breeder. It was calculated using the following formula:

$$F_r = \frac{\sum \frac{F_a}{BWW}}{n}$$

Where *Fr* is the relative fecundity; *Fa* is the absolute fecundity of one individual; *BWW* is the body wet weight of one individual; and *n* is the number of individuals.

For species with fractional reproduction, we first eliminated the oogonies (a cohort that can only reach maturity) using a synthetic filter to obtain a more accurate estimate of fecundity.

Results

The size of individual *Holothuria poli* ranged from 13.4 to 17.2 cm and the weight between 55.6 and 88 g. For *H. tubulosa*, the size ranged from 10.5 cm to 22.1 cm, and

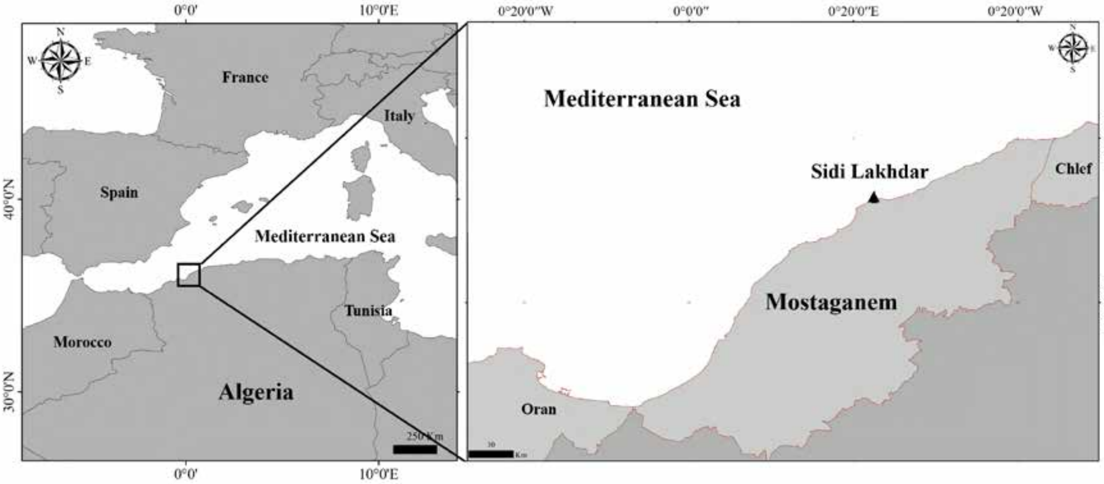

Figure 1. Geographical locations of the sampling station represented by a black triangle.

Table 1. Biometric data for *Holothuria poli* and *Holothuria tubulosa*.

	Holothuria poli				*Holothuria tubulosa*			
	N	MAL	MBWW	MGWW	N	MAL	MBWW	MGWW
May 2022	11	14.891	65.968	0.730	5	18.120	111.844	1.531
June 2022	9	14.256	61.701	1.136	2	10.500	32.510	0.373
September 2022	4	17.250	55.593	-	4	19.625	89.568	-
October 2022	3	14.633	77.146	0.041	3	22.180	96.593	2.908
November 2022	11	15.986	88.023	2.104	6	17.917	95.920	-
December 2022	11	13.408	83.363	0.789	8	19.140	125.842	2.419

N is the sample size; MAL is the mean anesthetised length; MBWW is the mean body wet weight; and MGWW is the mean gonad wet weight. (-) means an absence of gonads.

the weight between 32.5 and 125.8 g (Table 1). The mean gonad wet weight of *H. poli* ranged from 0.041 to 2.104 g, with two peaks in June and November. For *H. tubulosa*, mean gonad wet weight ranged between 0.373 and 2.908 g, with two peaks in May and October.

Macroscopic and microscopic observations of the gonadal tubules revealed four stages of maturation in all the females analysed of *Holothuria poli* and *H. tubulosa* (Stage I: immature, Stage II: resting, Stage III: growth, Stage IV: maturation, Stage V: post-spawning).

Oocyte diameter

Holothuria poli showed four distinct batches of germinal cells (Fig. 2A). The first batch peaked at 258 cells, with diameters ranging from 12 to 13 µm. The second batch peaked at 240 cells, with diameters between 15 and 16 µm. The third batch peaked at 198 cells, with diameters between 18 and 19 µm, while the fourth batch reached a peak of 8 cells with diameters between 25 and 26 µm. For *H. tubulosa*, the first batch corresponded to the oogonies with diameters ranging from 3 to 4 µm, in addition to four other batches: 101 oocytes with diameters ranging from 11 to 12 µm, 86 oocytes with diameters from 13 to 14 µm, 80 oocytes with diameters from 16 to 17 µm, and 3 oocytes with diameters between 28 and 29 µm (Fig. 2B).

Absolute and relative fecundity

The gonads of *Holothuria poli* weigh between 0.02 and 2.63 g, with an absolute fecundity of 450,658 germinal cells

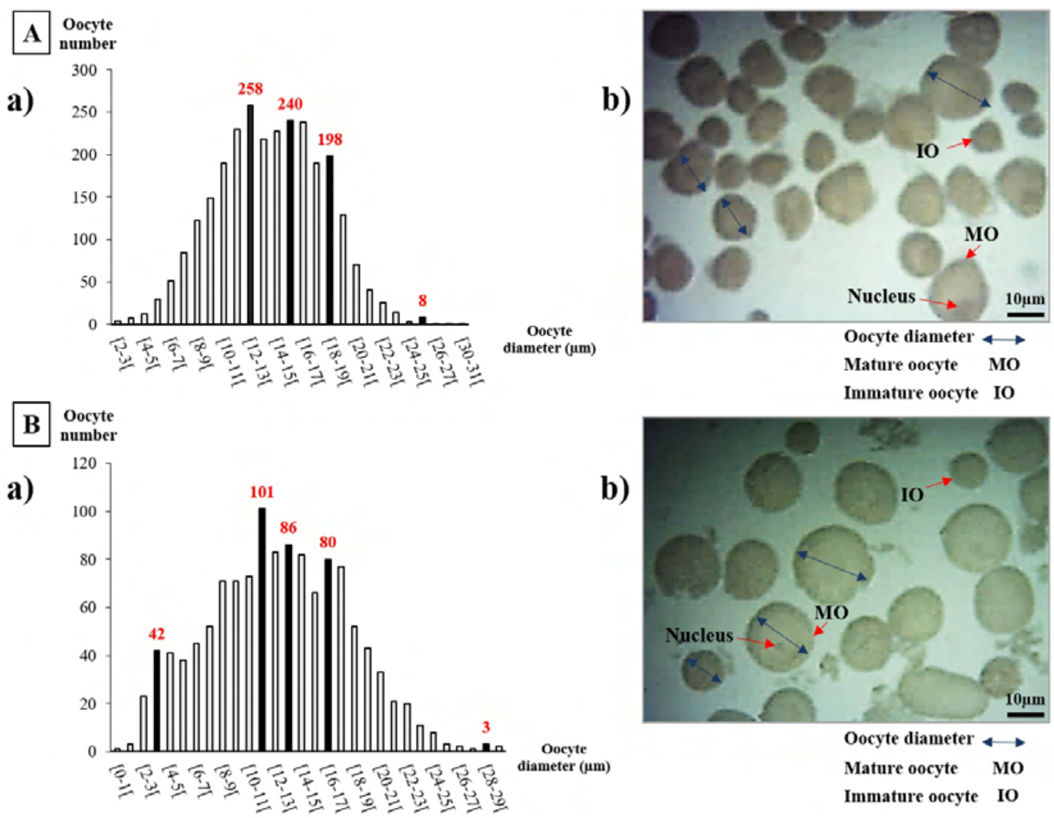

Figure 2. Histogram of oocyte diameter frequencies in (A.a) *Holothuria poli*, (B.a) *H. tubulosa* with their microscopic appearances (A.b; B.b), respectively. Values in red correspond to the modes of each spawning event; MO. Oocyte with a nucleus.

and a relative fecundity of 10,552 cell/g. The gonads of *H. tubulosa* weighed between 0.334 and 4.048 g, with an absolute fecundity of 1,961,560 cells and a relative fecundity of 1055 cell/g.

Discussion

The results of sea cucumber biometrics, including body wet weight, gonad weight, and oocyte diameter, are essential for assessing their reproductive potential. For both *H. poli* and *H. tubulosa*, the increase in gonad weight is associated with tubule weight, which correlates with a higher number of germinal cells. This suggests that larger diameter oocytes are generally more mature and ready to be fertilised (Fig. 2. A.b, B.b). The increased gonadal tubule weight correlates with the higher number of germinal cells, enhancing fertilisation success and larval survival.

The results of absolute and relative fecundity confirmed that *Holothuria tubulosa* has a higher reproductive capacity than *H. poli*. Pandian (2018) suggests that the variable absolute fecundity can be influenced by factors such as individual size, food resource availability, and environmental conditions. Absolute fecundity of *H. poli* and *H. tubulosa* was compared with that estimated by Marquet et al. (2017) for *H. arguinensis* in southern Portugal (Table 2). Absolute fecundity values of *H. poli* and *H. tubulosa* in Sidi Lakhdar (Algeria) are within the range reported by Marquet et al. (2017) for *H. arguinensis.* The range found by Marquet et al. (2017) is wider than what our results show. This discrepancy could be due to different oocyte counting methods. This difference could also be attributed to the sampling period, sampling size, and the lack of data between July and August, which is part of the spawning season of our species (i.e. *H. poli*, Slimane Tamacha et al. 2019).

We can also link these differences to variations in the habitat quality between the two sites, which would influence the food availability for holothurians. In fact, in southern Portugal, the sheltered habitats (such as *Zostera noltii* meadows on sandy-muddy bottoms), and the Atlantic Ocean, which is rich in nutrients compared to the Mediterranean Sea, promote good physical conditions and high fecundity for *Holothuria arguinensis* (Domínguez-Godino and González-Wangüemert 2020). The seasonal migration of holothurians to deeper waters in summer also protects individuals from thermal stress, thus optimising their reproduction. These ecological characteristics are consistent with the high fecundity values reported by Marquet et al. (2017).

Combining our results with those of Rakaj et al. (2018, 2019), who counted the number of mature oocytes released into the spawning tanks, confirms that *H. tubulosa* has a higher reproductive capacity than *H. poli*, making it a target species for holothuriculture. The authors demonstrated that the culture techniques of *H. tubulosa* successfully produced larvae up to the juvenile stage, making it an ideal species for aquaculture. Furthermore, the increasing demand by Asian markets for high-quality sea cucumbers (i.e. *H. tubulosa*, which has a thicker integument) offers significant economic opportunities for farming this species (Chryssanthi and Vafidis 2011). Implementing sustainable farming practices for this species could help meet this demand in Algeria while reducing fishing pressure on wild populations.

Conclusion

Our results focused on the months corresponding to gonadal maturation and spawning events, providing an overview of the fecundity of the two studied species. The results indicates that the reproductive capacity of *Holothuria tubulosa* is higher than that of *H. poli*, making it more advantageous for holothuriculture. Extending the sampling over a multi-year period would be appropriate to confirm our findings.

Such studies are also important for developing conservation and stock enhancement strategies for sea cucumbers, which are currently in decline due to illegal fishing, thus ensuring sustainable management of sea cucumber populations in Algeria.

Acknowledgements

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Table 2. Comparison of the absolute fecundity of the studied species compared with the one obtained by Marquet et al. (2017).

	F_a (No. of oocytes)	N (Sample size)	Region	Period	Method	References
Holothuria poli	366,433–450,658	49	Mostaganem (Algeria)	May–Jun, Sep–Dec (2022)	Gravimetric	Present study
Holothuria tubulosa	196,620–1,961,560	28	Mostaganem (Algeria)	May–Jun, Sep–Dec (2022)	Gravimetric	Present study
Holothuria arguinensis	270,000–12770000	63	Algarve (Portugal)	May 2013 – Apr 2014	Volumetric	Marquet et al. 2017

F_a = absolute fecundity; N = sample size

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COMMUNICATIONS

A new sea cucumber conservation group

The role of the IUCN Species Survival Commission Sea Cucumber Specialist Group, formed in late 2022, is to raise global awareness on the diversity and importance of sea cucumbers. The group comprises experts from around the world who are leading a concerted effort to generate more data, exchange knowledge, and help implement management measures that can benefit marine conservation more broadly. The targets of the group for its first cycle (2022–2025) include an update of the Red List assessments of priority species, and producing a synthesis of threats to and pressures on sea cucumbers, and management measures (and their implementation) for sea cucumber conservation, to provide technical advice to relevant governing bodies. Additionally, in the long term, the group aims to help untangle taxonomic issues, adjust Red List assessment criteria, update the status of sea cucumber fisheries worldwide, and bring together scientists, young researchers and other stakeholders who share an interest in the preservation of sea cucumbers.

We are excited to announce that you will be able to follow the goals and achievements of the group in this bulletin. Of course, you do not need to hold formal membership to make a difference. There are many ways through which we might be able to help support local and global initiatives, so just reach out and let us know how you are currently engaging with sea cucumber knowledge and conservation.

Co-chairs:

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Facebook: https://www.facebook.com/profile.php?id=61557189781720

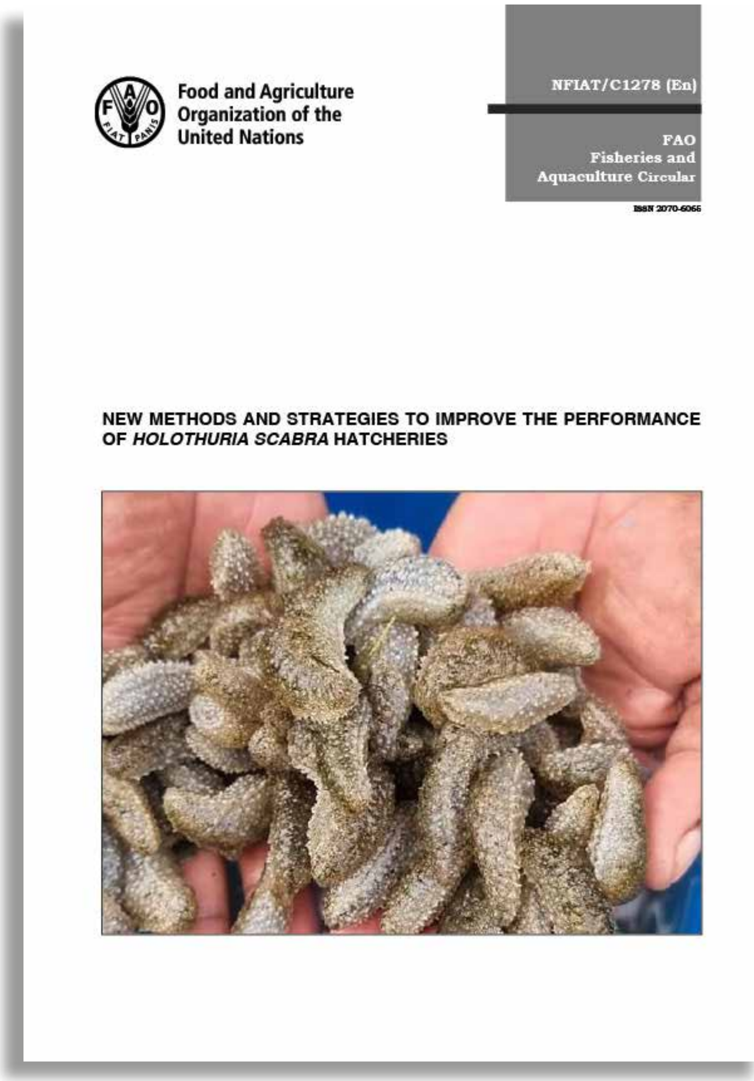
Twitter: https://twitter.com/IUCN_CukeSG

New publication

New methods and strategies to improve the performance of *Holothuria scabra* hatcheries

Eeckhaut I., Rasolofonirina R., Lavitra T., Dissanayake C. and Lovatelli A. 2024. New methods and strategies to improve the performance of *Holothuria scabra* hatcheries. FAO Fisheries and Aquaculture Circular, No. 1278. Rome, Italy: Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd1258en

The tropical sea cucumber *Holothuria scabra*, commonly known as sandfish, is an important commercial species in the Indo-Pacific region. In Sri Lanka, where it is locally known as *jaffna attaya*, this species is widely distributed in seagrass meadow along inshore areas and lagoons. In the 1970s, a lucrative fishery started in and around Puttalam Lagoon but collapsed in the mid-1980s due to overexploitation and a lack of proper management measures. Similar declines were observed in Sri Lanka's northern provinces, impacting the livelihoods of numerous fishing communities. In response, various initiatives were launched to manage and restore sandfish populations. One such initiative involved the National Aquaculture Development Authority (NAQDA), which introduced the grow-out culture of wild-collected sandfish, a practice that gained traction in the areas of Kalpitiaya, Mannar and Jaffna. Unfortunately, conflicts among fishers led to the 2011 ban on fattening small sandfish. To address the shortage in seed supply, Sri Lanka initiated a sea cucumber aquaculture programme over a decade ago. While breeding efforts by organisations such as the National Aquatic Resources Research and Development Agency (NARA) and NAQDA, along with some private hatcheries, have seen success, production still falls short of meeting demand. As a result, both hatchery-reared juveniles and wild-caught subadults are stocked into grow-out pens set up in lagoons and shallow coastal waters. To ensure sustainable expansion, the industry must secure a consistent supply of viable juveniles. This necessitates advancements in seed production technologies. Recognising this need, the Food and Agriculture Organization (FAO) of the United Nations, in collaboration with Sri Lanka's national authorities, has conducted training sessions for both public and private technicians. These sessions focused on conventional breeding methods like thermal shock spawning and innovative approaches like in vitro fertilisation (IVF), a technique developed in Madagascar in 2007 and generously shared with hatchery operators in Sri Lanka. This publication is tailored for hatchery operators, providing comprehensive guidance on both thermal shock spawning and in vitro fertilisation processes. Subsequent chapters delve into embryonic and larval rearing, early juvenile production, and offer practical insights into water management, feeding regimes, and disease control measures. The spawning and rearing techniques described in this guide are applicable in hatcheries established across the geographical distribution of the sandfish.



Interaction and Aquaculture of Marine Economic Organisms, a Chinese-Belgian joint laboratory to study sea cucumber biology

Libin Zhang[1] and Igor Eeckhaut[2]

The Interaction and Aquaculture of Marine Economic Organisms (IamEO) is a new joint laboratory between the Institute of Oceanology, Chinese Academy of Sciences (IOCAS), and the University of Mons (UMONS). Both are renowned institutions in their respective regions, each with a rich history of academic excellence and groundbreaking research. IOCAS stands as a leading research institute in marine science research, contributing significantly to our understanding of oceanic ecosystems and environmental dynamics, while UMONS has distinguished itself through its commitment to interdisciplinary education and research. IOCAS has been at the forefront of marine science research in China and beyond. With a focus on exploring the vast and intricate marine environments, IOCAS conducts cutting-edge research in areas such as marine biology, oceanography, marine geology, and environmental science.

IOCAS's commitment to advancing knowledge and addressing pressing environmental issues has earned it international recognition and acclaim. Additionally, IOCAS is a leading institution in the fields of mariculture and marine ecological ranching, developing innovative techniques to enhance sustainable seafood production, and creating artificial habitats to support marine life, thereby contributing to the global efforts in sustainable aquaculture and marine resource management. On the other side of the globe, UMONS, in Mons, Belgium, through its Biology of Marine Organisms and Biomimetics Laboratory, has been developing research in ecology, physiology, and aquaculture of marine organisms. In addition, UMONS is actively involved in marine science research in Madagascar, focusing on the island's unique marine biodiversity. Their work includes studying coral reef ecosystems, assessing the impacts of climate change on marine habitats, and developing sustainable aquaculture practices to support local communities. IOCAS and UMONS decided to establish the joint China-Belgium joint IamEO laboratory.

The joint laboratory aims to build a new model of green development of mariculture and bio-resource utilisation from fundamental research to industrialisation of marine aquaculture. Joint research will focus mainly on 1) understanding the behavior and physiology of key marine economic organisms; 2) understanding the interactions between key marine economic organisms in a changing ocean; 3) developing efficient breeding technology of marine economic organisms; and 4) constructing green aquaculture technologies.

UMONS and IOCAS have successfully applied for two joint projects: one funded by the Ministry of Science and Technology of China and Wallonie Bruxelles International, and the other between the National Natural Science Foundation of China, and the National Fund for Scientific Research Belgium. Scientists from both sides are conducting several scientific research projects and have achieved very good results. Scientists are also exchanging ideas and have jointly published scientific paper. The joint lab will serve as a platform for fostering international collaboration and strengthening research networks in the field of marine science. By forging partnerships with other institutions, governmental agencies, and industry stakeholders, the lab can amplify its impact and contribute to the development of innovative solutions to pressing marine conservation and sustainability challenges. The establishment of the joint lab between IOCAS and UMONS represents a significant step forward in advancing marine science research and fostering international collaboration in this important field. Through shared expertise, resources, and a commitment to excellence, the lab is poised to make meaningful contributions in the near future to our understanding of the world's oceans and the sustainable management of marine resources for future generations.

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The Chinese delegation at the Indian Ocean Trepang nursery in Madagascar.

Professors Igor Eeckhaut (UMONS) and Libin Zhang (IOCAS) in the sea pens of the Indian Ocean Trepang company with newly transferred individuals from the nursery.

Dr Jérôme Delroisse of the Mons delegation in China enjoying Chinese culinary delicacies.

A shop at Shangai airport showing Chinese sea cucumbers sold as luxury products.

The Chinese delegation to UMONS for the official signing of the joint laboratory.

Signature between the vice-rector of UMONS, Laurence Ris, and Prof Fan Wang (Director of IOCAS). Also present behind at the center is Prof Yaping Zhang, vice president of the Chinese Academy of Sciences.

Meetings and conferences

17th International Echinoderm Conference and 2nd International Hemichordate Meeting

14–19 July 2024, Puerto de la Cruz, Tenerife

Abstracts from the 17th International Echinoderm Conference, which took place in July 2024 in Tenerife are available at:

https://www.researchgate.net/publication/384689085_17_International_Echinoderm_Congress_Second_International_Hemichordate_Meeting

11th European Conference on Echinoderms

October 2023, Lyon, France

Bertrand Lefebvre, Jenifer Croce and Thomas Saucède are happy to announce that the papers from the 11th European Conference on Echinoderms, in Lyon October 2023 are now published in a special volume of Cahiers de Biologie Marine (vol. 65, issue 4) 2024. They are downloadable in open access

https://cbm.sb-roscoff.fr/cbm/issue.htm?execution=e3s1