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

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Abstract

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

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

Introduction

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

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

Teatfish names, taxonomy and CITES listings

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

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

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

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

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

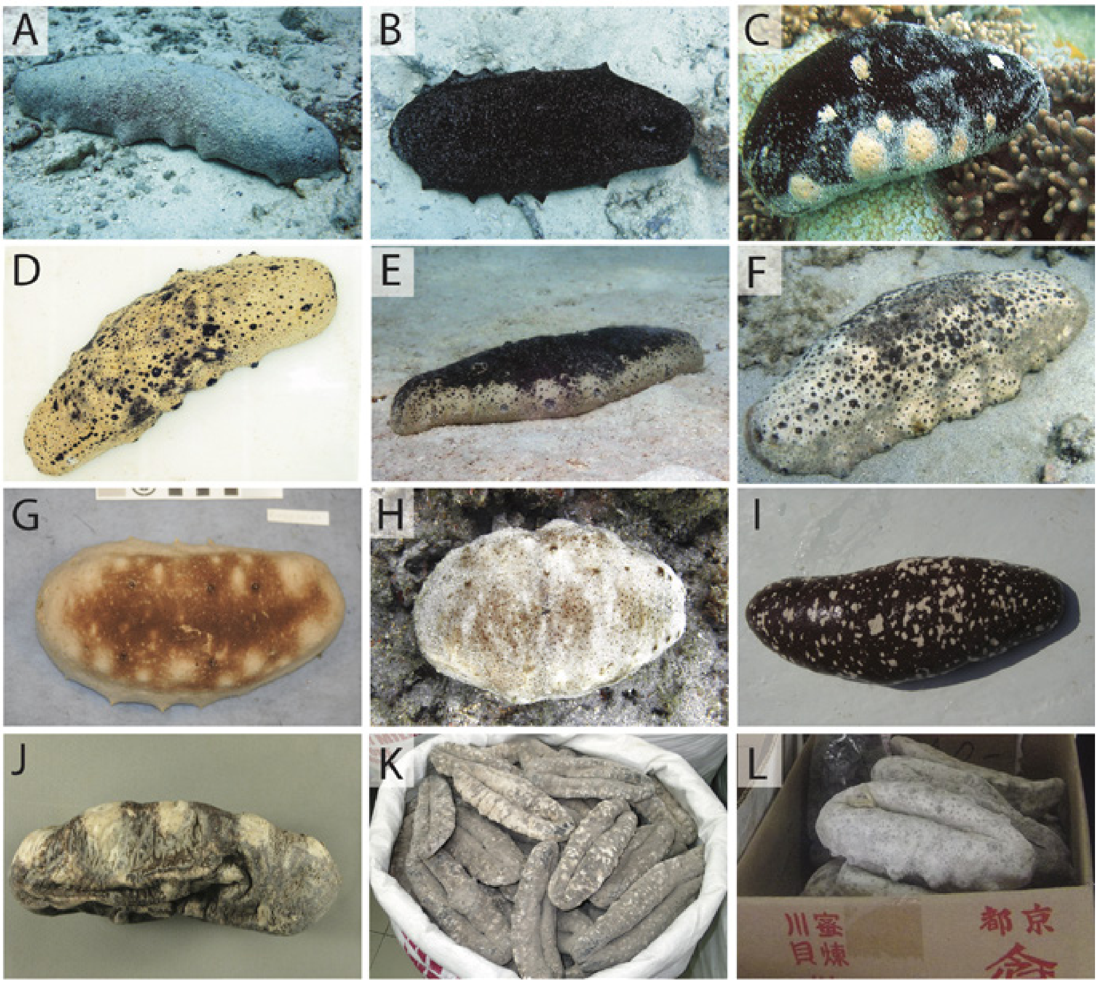

Figure 1. A,B: *Holothuria (Microthele) whitmaei*, black teatfish from the Pacific Ocean covered in sand (A) and free of sand (B) from Heron Island, eastern Australia. C: *H. (M.) nobilis* from the Red Sea. D-F: *H. (M.) fuscogilva* from Raine Island (D) and Lady Musgrave Island (E), eastern Australia,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

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

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

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

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

Queensland, Australia sea cucumber fishery

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

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

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

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

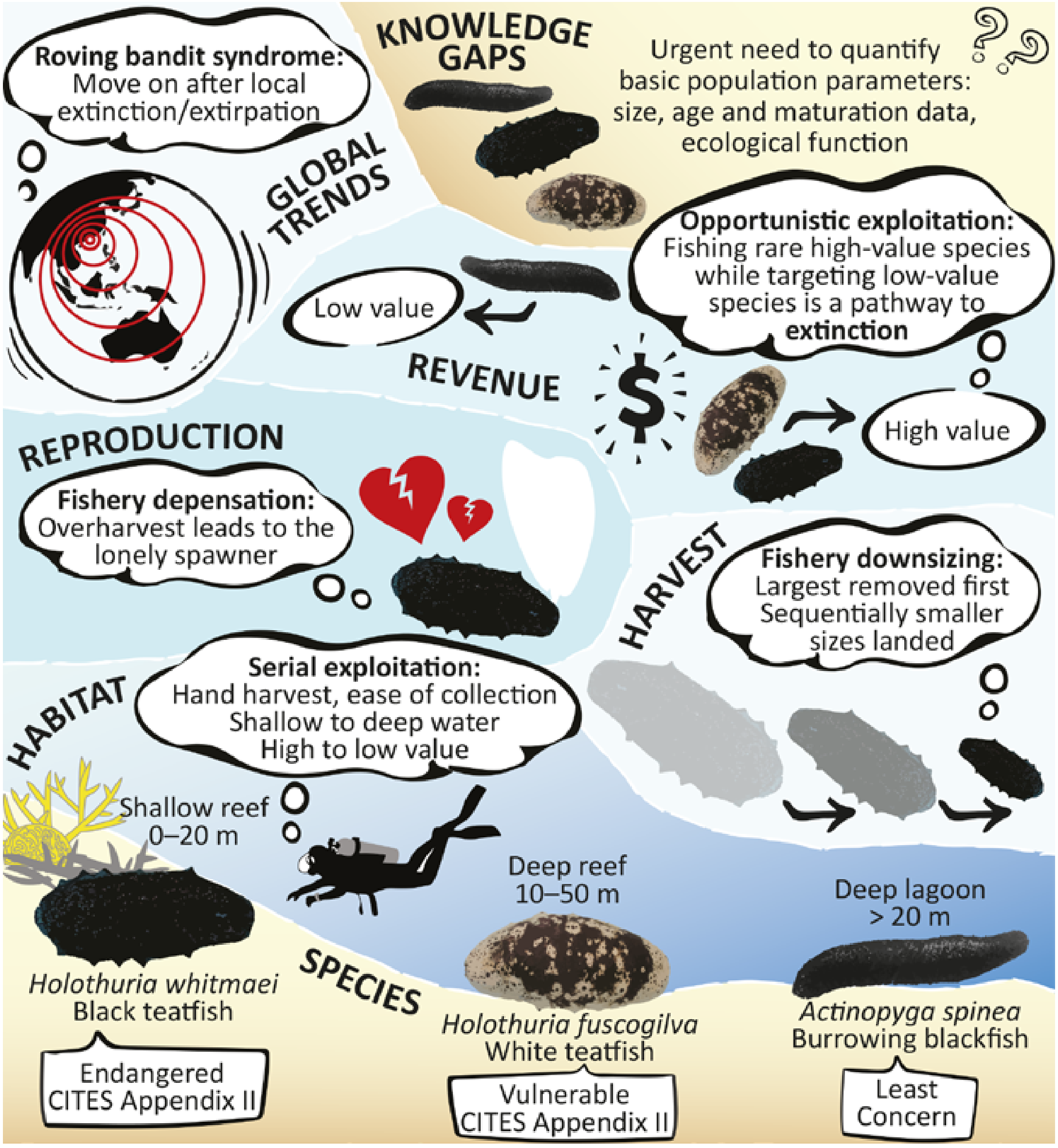

Figure 2. Schematic of conservation challenges for sea cucumber fisheries, with the Queensland fishery providing a model to illustrate the problems faced by fisheries of slow-moving marine invertebrates, globally, and the challenge to achieve sustainability. All images by Kennedy Wolfe, except scuba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

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

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

Conclusion

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

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

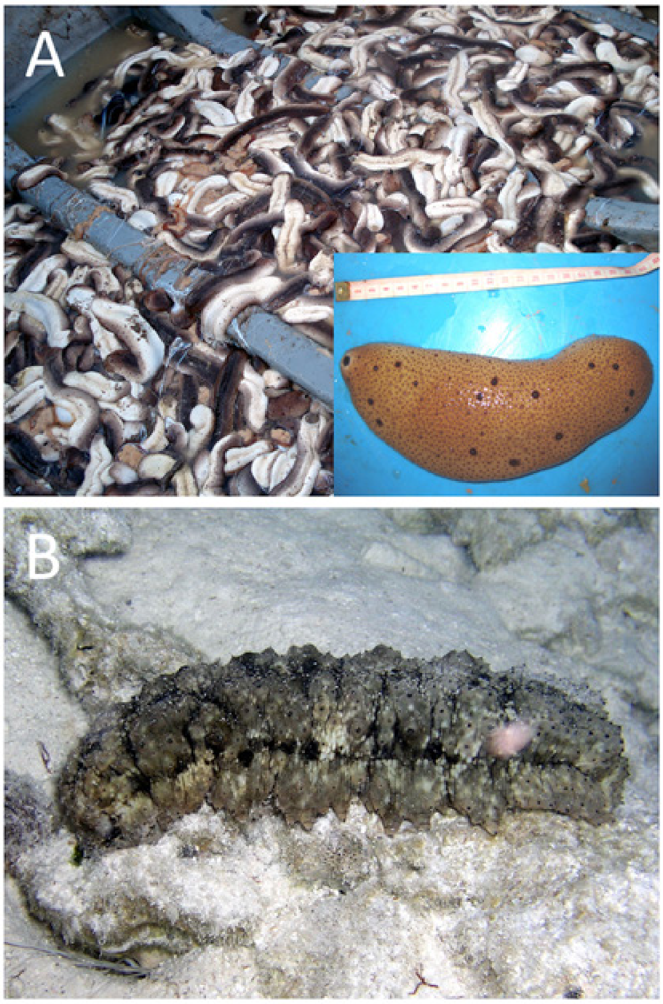

Figure 3. Further taxonomic studies are needed. A: An undescribed species in the genus *Bohadschia*, which is harvested in Sri Lanka. B: *Stichopus monotuberculatus* from Heron Island, eastern Australia. Photos: (A) D.C.T. Dissanayake; (B) S.W. Purcell.

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