AMSA POSITION STATEMENT

The importance of taxonomy to marine science

Taxonomy is a dynamic discipline that is fundamental to all aspects of biology - it is the science that discovers, describes and classifies all living things. Australia is lagging behind other developed countries in understanding its unique biological diversity. Many Australian marine species have not been described and remain nameless, especially invertebrates. This has critical implications for the management of marine resources including environmental, economic, and social impacts related to monitoring, conservation, invasive species control, and bioprospecting. Concerningly, there is a dramatic loss of taxonomic expertise, and funding for taxonomy is declining in Australia. Australia has an international legal obligation to manage its marine territories and resources, and taxonomy is the foundation with which to achieve this.

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RECOMMENDATIONS

- AMSA recommends that due weight is given to the need for taxonomic expertise in order to deliver key national and international policy commitments such as control of invasive species, protection of biodiversity, bio-discovery, management of living resources, ecosystem based approaches to management and development of a sustainable 'Blue Economy'.

- AMSA recommends that the discipline of taxonomy must be taught at universities to address the critical lack of skills/resources and that taxonomy be integrated into national subject benchmarks for biology and environmental science.

- AMSA strongly encourages the government to recognise the importance of taxonomy and to increase funding to museums and herbariums to create new research positions, provide support for maintaining museum collections and cutting-edge equipment (e.g., molecular techniques, electron microscopes and 3D scanning) and supporting early career researchers (including PhDs) in taxonomy.

- AMSA strongly encourages collaboration between taxonomists, ecologists, conservationists, pest managers, marine park managers, ecological and environmental consultants, amateur naturalists, and bioprospectors to ensure that the correct species names are used in all outputs.

- AMSA recommends marine managers, ecologists, and other users of biodiversity data to appropriately collaborate with taxonomists and cost taxonomy in project planning.

- AMSA supports increasing funding to the Australian Biological Resources Study (ABRS), especially for early-career researchers.

- AMSA recommends the reversal of the decision that museum and herbarium researchers are unable to apply for ARC Discovery Projects.

- AMSA recognises molecular approaches as an important tool in taxonomy but one that must be underpinned by suitable morphological approaches. Molecular reference databases must be built in collaboration with taxonomists to ensure the correct species names are attached to the corresponding sequence data.

- AMSA recommends the development and prioritisation of marine species discovery and description to assess the effectiveness of marine zoning plans.

- AMSA strongly supports ongoing initiatives such as Taxonomy Australia (https://www.taxonomyaustralia.org.au/).

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1. Why is it important to understand species?

Taxonomy is a scientific discipline that **discovers, describes** and **classifies** all living things (extinct and extant), providing names which are accessible for everybody. This **dynamic** and **exciting** branch of science underpins all areas of biology and is performed by highly trained taxonomists (Box 1). The scientific name of a species is similar to an ID card which unlocks all the available data on that species. Each species has its own unique ecology, reproductive strategies, larval development, physiology and feeding habits.

Marine taxonomy directly contributes towards assessing biodiversity, effectiveness of conservation planning, implementation of biosecurity plans, and marine resource management. The benefits of taxonomy are considerable. A 2021 cost-benefit analysis on Taxonomy Australia's plan to document all Australian species indicated significant benefits of $3.7-$28.9 billion return on a $824 million investment over 25 years (Deloitte Access Economics 2021).

2. Australia's international legal obligations

Under the UN Convention on the Law of the Sea, Australia has the **legal obligation** to manage its offshore territories. Australia is one of 17 megadiverse nations of the world, and as the only developed country in this group, it

Box 1: A highly skilled workforce

Taxonomists hold invaluable specialist knowledge about specific groups of organisms. They undertake fieldwork to collect fresh material, record habitat and colour before fixing the material for morphological and molecular studies. This material is often compared with existing collections housed in museums or herbaria and via material borrowed from domestic and international institutions. Taxonomists are incorporating technologies such as molecular (DNA), Scanning Electron Microscopy (SEM), and 3D scanning data to better define and describe the species they work on. These studies better define geographical ranges of a described species or reveal species complexes, which are then formally described. Taxonomy is a dynamic discipline, and as more specimens become available it may necessitate moving species to a different genus or reveal that a species is a complex of multiple species. Taxonomists follow a strict set of internationally recognised rules and conventions when naming a species: the International Commission on Zoological Nomenclature (ICZN) (https://www.iczn.org/) and the International Code of Nomenclature for algae, fungi and plants (ICNAFP) (https://www.iapt-taxon.org/). Each newly named species has an associated voucher specimen (the 'holotype') deposited in a museum or herbarium, and increasingly with associated molecular data on online databases (e.g. GenBank, European Nucleotide Archive (ENA) & Barcode of Life Data System (BOLD)), thus making the data available worldwide.

bears considerable international responsibility for biodiversity conservation. Australia's marine Exclusive Economic Zone (EEZ) covers over 10 million sq km (including the Australian Antarctic Territory), larger than the Australian mainland (Geoscience Australia 2021). This EEZ is recognised and respected internationally and all the resources within this zone are under the control and jurisdiction of the Commonwealth of Australia.

3. Australia's uncharted marine biodiversity

Research into Australia's marine fauna remains in the **discovery phase**. Concerningly **Australia is falling behind many other countries** in understanding its own native endemic fauna. Much of Australia's marine jurisdiction is yet to be explored, particularly the deep sea (>200 m). Only ~25% of the Australian continental shelf has been mapped (Geoscience Australia 2021). Although some national (R.V. Investigator) and international (R.V. Falkor) vessels have explored the deeper slope (2000-5000 m), Australia does not have deep-sea remotely operated vehicles capabilities for independent research, largely relying on oil companies for exploration (Gates et al. 2017) or philanthropic international programs (e.g. Schmidt Ocean Institute).

Currently we cannot provide an accurate estimate of the diversity of Australia's marine biota. Based on rough estimates from national databases there are approximately 33,000 recorded marine species in Australia (Butler et al. 2010), over 34,000 Australian marine species are reported on OBIS (OBIS 2021), and an up-to-date inventory is urgently needed. Estimates of undescribed marine species range from 217,000 species (Butler et al. 2010) to 80% of marine biodiversity (Costello et al. 2010). Most of these undescribed species are invertebrates which are critical for ecosystem functioning (Kenchington and Hutchings 2018). Undescribed invertebrate species also include commercially important species such as fished squid, and rock oysters targeted for aquaculture (McDougall, 2020).

High numbers of undescribed species are found in the Australian deep-sea region (Poore et al. 2015, MacIntosh et al. 2018, O'Hara et al. 2020, Gunton et al. 2021). Yet, even in Australian coastal regions, much of the marine fauna species remain undescribed due to a lack of taxonomic expertise in many groups (e.g. sea anemones, zoanthids, black corals). **New species are still found on our doorstep**. In 2020, a new charismatic species of Pipefish *Stigmatopora harastii* was described from a popular dive site in Sydney Harbour (Short and Trevor-Jones, 2020). There are very serious taxonomic blind spots in the marine blue-green algae, with at least six highly conspicuous shallow-water species in Sydney, all with out-of-date or incorrect taxonomic names.

4. Loss of taxonomic expertise

There are serious declines in the number of active marine taxonomists with dire consequences for Australia's natural resource management if this expertise is lost. Taxonomic capacity has decreased by 10 % during the past 25 years from (Taxonomy Decadal Plan Working Group, 2018). Concerns of the imminent loss

of taxonomic expertise has been highlighted repeatedly (National Marine Science Plan 2015); however, nothing has changed, and in some cases the situation has deteriorated (Hutchings 2013).

Compounding the issue of an aging taxonomic workforce is that **taxonomy is no longer taught in universities**, making it difficult to recruit the next generation of taxonomists (Hutchings 2020). Few taxonomists are employed at universities, likely because they do not attract large grants or publish in high-profile journals, which are used as key indicators by university administrators (Hutchings 2021). Many Australian universities are no longer teaching whole organism biology, and few have courses on the major groups of marine animals, the invertebrates (Hutchings et al. 2012), meaning that students miss out on being exposed to the possibility of studying taxonomy and the driving life-long passion that this type of discovery engenders.

The **funding allocated to taxonomy has declined**. The funding for the Australian Biological Resources Study (ABRS) which provides grants for research on the taxonomy of the Australian biota or development of taxonomic tools, has decreased over time (Hutchings 2013). Furthermore, museum and herbarium researchers (where most taxonomists reside) can no longer apply for ARC Discovery Projects as principal investigators, and thus obtaining research funds for taxonomic research has become even more difficult. **Australian taxonomists are finding work abroad** due to lack of taxonomic positions in Australia.

5. Critical importance of correct taxonomy

Data from studies on ecology, reproduction, behaviour and physiology become meaningless and a waste of resources if the incorrect name is designated. Each species has its own discrete distribution range, reproductive habits, thermal tolerances, toxic substance thresholds etc. **Conclusions drawn from research that is not supported by accurate and comprehensive taxonomy may be seriously compromised.** Millions of dollars have been spent researching the crown-of-thorns starfish on the Great Barrier Reef, yet the identity of this species is not resolved (Box 2).

When a species is incorrectly recorded from a locality and future researchers use the same species name without validation, this incorrect name is propagated throughout the literature resulting in erroneous species distributions. This proliferation of an erroneous name is seen in the sponge *Dendrilla rosea* (Lendenfeld, 1883) (Box 3). Incorrect records can influence predictions for broadscale biogeographic models leading to incorrect or inadequate management responses in the face of global changes such as warming ocean temperatures.

Protecting Biodiversity

Not knowing the correct identity of species in a community **severely limits our ability to compare different systems, monitor changes, manage, and therefore protect these communities** and the broader environment for future generations. Adequate understanding of what mechanisms support

and maintain biodiversity must be the scientific underpinning for policy decisions regarding the long-term maintenance of marine ecosystems, fisheries management and the conservation of threatened species. **How can we know if our management plans are working if we do not know the composition of the biodiversity?** Commercially important blood worms are managed as one species in Queensland, but research has shown there are at least three species with different ecological niches (Box 4). Similarly, conservation efforts were hampered by taxonomic uncertainty for tropical sea cucumbers, which are harvested globally for the high value bêche-de-mer product (Box 5).

It was possible to model the potential loss of terrestrial biodiversity following a catastrophic impact such as the 2020 bushfires. Sadly, this would not be possible for the marine environment due to an overwhelming lack of taxonomic information. Since 1903 there have been 27 documented major oil spills in Australia (AMSA 2020), but we are still only slightly closer to closing the gap on our understanding of the rich diversity of places where these impacts occurred.

Fast detection of invasive species

The annual cost of introduced or invasive species to the Australian economy is more than $10 billion (Hoffman and Broadhurst 2016, Bradshaw et al. 2021). The Northern Pacific sea star, *Asterias amurensis* (Lutken, 1871) from Japan has wrought havoc in the Derwent River, Tasmania and has spread to SE Australia (O'Hara and Byrne 2017) after having been misidentified as a native species. Accurate species determinations are essential for pest management, biosecurity at ports and borders. **The scarcity of biological baseline studies in Australia's shallow coastal zones means that in most cases we do not know the extent of introduced species**. Our incomplete knowledge of the native biota means that distinguishing between introduced and native species, including undescribed species, is often challenging.

The invasive species *Didemnum perlucidum* (Monniot 1983), described as a white colonial ascidian is listed as an invasive species in Australian waters known from the Atlantic (Muñoz and McDonald 2014). However, through taxonomic expertise, many of the specimens found in the Pacific resemble *Didemnum perplexum* (Kott, 2001), a species described from Australian waters (Kott 2001). The taxonomy of the highly invasive upside-down jellyfish *Cassiopea* spp. reaching New south Wales is also still unclear (Box 6).

Early detection and identification using expert taxonomic information can eliminate invasive species. The early detection of black striped false mussel *Mytilopsis sallei* (Récluz, 1849) a highly competitive native to the Caribbean islands and the Bay of Mexico was recorded from three enclosed marinas in Darwin at a cost of $2.2 million, plus unaccounted personnel costs mainly through chemical treatment of enclosed waters (Bax et al. 2002, Wells 2019). Eradication was possible because within two days of the mussel being discovered the specimens were identified by a taxonomist at the Museum and Art Gallery of the Northern Territory.

Box 2: *Acanthaster* crown-of-thorns starfish

Seastars in the genus *Acanthaster* are large (>40 cm diameter), multi-armed (>20 arms) and common throughout the Indo-Pacific and Red Sea where they are well known as major coral predators. Due to their dense cover of venomous spines they are called the crown-of-thorns starfish (COTS) (Fig. 1). They were all considered to be one species, *Acanthaster planci*, but this name is now known to include a complex of species (Haszprunar and Spies 2014). There are at least four COTS species, two in the Indian Ocean, one in the Red Sea and one in the Pacific Ocean (Haszprunar and Spies 2014, Haszprunar et al. 2017). These clades are supported by molecular phylogeny (Vogler et al. 2008, 2012). The original *Acanthaster planci* was from Goa, hence this is the name for the northern Indian Ocean species. The southern Indian Ocean species is *A. mauritiensis*.

The identity of the Pacific Ocean COTS is not resolved. One name available for the widely occurring species in the Pacific, including from Japan, Guam and the Great Barrier Reef (GBR) is *Acanthaster cf. solaris*, which now often used by ecologists. This name originates from specimens collected in the Philippines (as *Asterias solaris*) (Haszprunar and Spies 2014). Another name *Acanthaster echinites* with origins from near Jakarta, Indonesia (as *Asterias echinites*), probably near Palau Seribu (Thousand Islands) is also available (Haszprunar and Spies 2014). The Jakarta region is also where the Pacific Ocean COTS overlap with *A. planci sensu stricta*. Due to the poor descriptions and absence of type material it is not clear which of these names, *solaris* or *echinites* can be used for the Pacific Ocean COTS. This conundrum will be difficult to resolve. A neotype for *Asterias echinites* from the type locality near Jakarta is needed to determine if *Asterias echinites* is a junior synonym of *A. planci* or as a senior synonym of *A. solaris*.

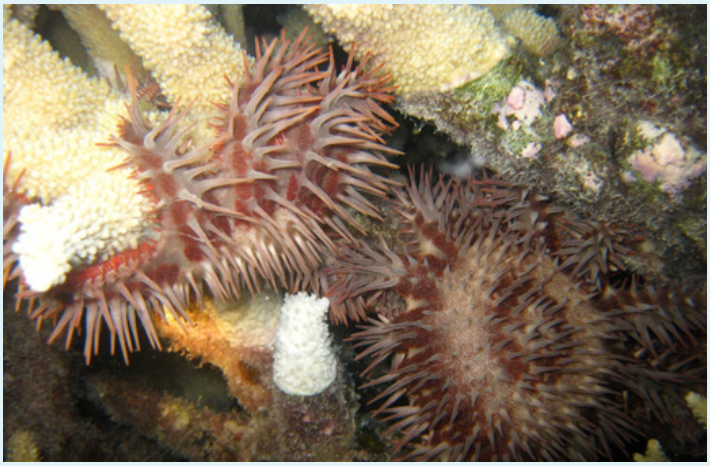

Figure 1. Crown-of-thorns starfish feeding
Photo credit: Steve Doo

Thus, despite its massive ecological importance, the plethora of papers published and the vast financial investment in research and management of COTS, we do not know the species identity of COTS on the GBR and elsewhere in the Pacific Ocean! The affinity of the species of COTS in Western Australia also has to be determined. Given that speciation in echinoderms often occurs at range edges, it will also be important to determine if the COTS that occurs on Lord Howe Island is actually the same species that occurs on the GBR.

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Bioapplications

Marine organisms represent a diverse resource for novel chemical compounds to treat serious disease and illness in humans. **Bioprospecting needs a solid taxonomic basis** for recollection of specimens from the wild and for research on the production of associated metabolites and their microbiomes, and above all, repeatability of experiments. Over 8500 new potential pharmaceutical products have been discovered in the past decade from marine organisms. Bioapplications developed from marine organisms can extend to pharmaceuticals, antivenom, food products, nutraceuticals, agricides and fertilisers. Drug discovery from marine invertebrates has led to an array of products being approved for use in humans for diseases such as cancer HIV, malaria and Alzheimer's Disease (Mcbride and Butler 2012, Trindade-Silva et al. 2010), psoriasis and lupus (Pennington et al. 2017), pain medication (Miljanich 2004) and a potential treatment for Type I diabetes (Xiong et al. 202). Anti-venom exists but more effective anti-venom needs to be developed for the Australian box jelly *Chironex fleckeri* (Southcott, 1956) (Piontek et al. 2020). In 2021 Australia recorded another death from envenomation by the box jelly.

Eliminating database errors

There is an increasing reliance on genetic identification tools for many species. However, this "big data" becomes a potential risk. This is highlighted by records uploaded onto the genetic sequence databases such as BOLD and GenBank, that are not correctly identified to species, genus or family level. This then renders the genetic identification tool inadequate and leads to **false and misleading outcomes** for research using

Box 3: *Aplysilla* or *Dendrilla*? Confusion with common sponges.

Identifications of similar sponges from opposite sides of the globe in the 1900s have caused confusion between the genera *Aplysilla* and *Dendrilla* in the family Darwinellidae. In 1876 Barrois named the pink encrusting sponge *Verongia rosea* (now *Aplysilla rosea* (Barrois, 1876)) from Saint Vaast in northern France. A few years later Lendenfeld named the pink encrusting sponge *Dendrilla rosea* (Lendenfeld, 1883) from Port Phillip Bay in Victoria. The Atlas of Living Australia (ALA) shows 88 records of the northern hemisphere sponge *Aplysilla rosea* occurring in Australia, and 69 records of *Dendrilla rosea* (Fig. 2). These records should all be attributed to the southern hemisphere sponge *Dendrilla rosea*. The World Register of Marine Species notes that "*Aplysilla rosea* is a species from NE Atlantic region and the Mediterranean area. Other records are inaccurate". *D. rosea* is also misnamed as *A. rosea* on the Port Phillip Bay Marine Life website https://portphillipmarinelife.net.au/species/7652. This misidentification has been made by sponge workers and naturalists across the board with *D. rosea* named as *A. rosea* in popular identification books (Edgar 1997, Gowlett-Holmes 2008) and on the Port Phillip Bay Marine Life website https://portphillipmarinelife.net.au/species/7652.

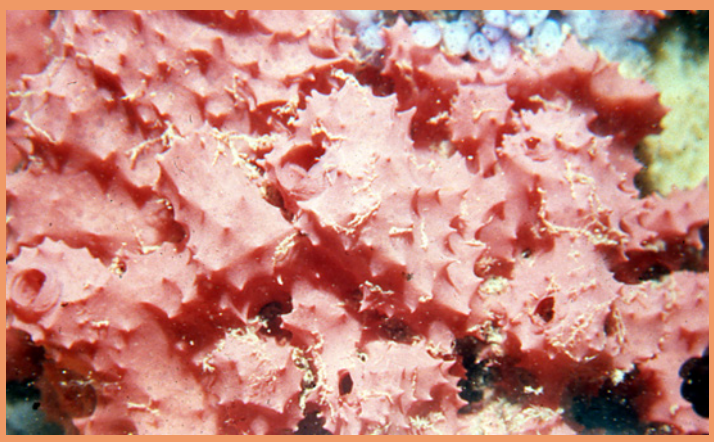

Figure 2. *Dendrilla rosea*
Image credit: Karen Gowlett-Holmes

Box 4: Consequences of misidentifications for marine resource management

Blood worms (*Marphysa* spp. F. Eunicidae) are collected commercially as bait for recreational fishing as well as by individuals for personal use (Fig. 3). Recreational fishing is increasing along the east coast of Australia and blood worms are highly prized for bait. Until early 2000, all blood worms on the east coast of Australia were called *Marphysa sanguinea* (Montagu, 1813), a species originally described by the Reverend Montague from intertidal rocky crevices in Devon, UK, in 1813. He provided a very simple illustration and did not designate a holotype (Fig. 4).

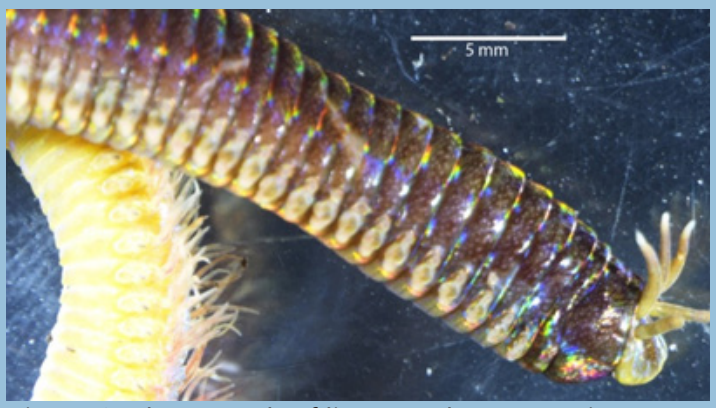

Figure 3. Photograph of live *Marphysa sanguinea*. Image credit: Nicolas Lavesque

In 2003, a *M. sanguinea* was redescribed and a neotype designated from the type locality of Devon. This allowed the species forming the basis of a lucrative fish bait industry in Moreton Bay, Qld, to be recognised as *M. mullawa*, a new species, living in *Posidonia* seagrass beds. Subsequently another species, *M. kristiana* was described from intertidal areas. Talking to local fishermen we also know that another blood worm is present in the mangroves, but so far we have not been able to obtain material to check its identity. Each of these species will presumably have different reproductive habits. In Moreton Bay, the three types are readily distinguished by bait diggers, as Mangrove worm (as yet undescribed), Rock worm (or rockies *M. kristiana*) and Cribb Island worm (*M. mullawa*) and these are listed in Queensland Fisheries marine worm guide. Thus, along the east coast of Australia, we have the bloodworms *M. mullawa* and *M. kristiana*, an undescribed species in Lakes Entrance and Moreton Bay and more may be discovered with additional sampling in protected bays, estuaries and rivers. Similarly, along our surf beaches we have several species of beachworms belonging to the family Onuphidae which are also widely collected for fish bait by recreational fishers.

If one has a Recreational Fishing license in NSW, one can collect up to 100 individuals of "worms", regardless of species; in Queensland, with a license one can collect up to 30 whole or part of beachworms and 50 blood worms of *Marphysa mullawa* (Cribb Island worms) with no limit for *M. kristiana* (Rockies) or for the yet undescribed mangrove blood worm. So the Qld authorities are relying on habitats to separate their worms and only limiting recreational collecting for *M. mullawa*. Queensland commercial fishers for the blood worms only targeting *M. mullawa*,

Figure 4. Illustration of *Marphysa sanguinea* by Reverend Montague from Devon, UK, in 1813.

harvest ranged from 550,000 in 2010, to 300,000 in 2015, the latest figures in Queensland marine worm Identification Guide (2017) and figures for beach worms ranged from 1000,000 in 2012 to 850,000 in 2015 and consisted of two species *Australonuphis parateres* and *A. teres*. Both industries have shown some decline but whether this is a reduction in effort or declining populations is unclear. All these worms are sold live as bait worms for recreational fishing.

In NSW, there are about 20 commercial beachworm fishers, and according to DPI the value of landings of beachworms declined from $1.2 m in 2009-10 to $0.5 in 2018-19, and whether this was due to less collecting effort or declining populations, or the availability of imported frozen bait worms from China is unclear.

Therefore, in both Queensland and NSW, these bait worms are managed by the relevant authorities, as if all species of eunicids or onuphids have exactly the same reproductive strategies which is highly unlikely. While the species of blood worms are very difficult to distinguish in the field, apart from habitat requirements, beachworms can be identified by collectors as "kingworms, stumpies, and slimies". Hannelore Paxton's work on these animals confirmed that "slimies" were an undescribed species, while "stumpies" were juveniles of the adult "kingworms". They occupy slightly different areas on the surf beaches and also have different reproductive strategies.

As the recreational fishing industry continues to expand, all these bait worms need to be better managed to ensure populations are maintained and we certainly have no estimates of population sizes of each of the species.

the data for modelling or evolution studies. Using this erroneous data will have future researchers continuing to draw incorrect conclusions if left unchecked.

The same is true for online species distribution databases, such as the Atlas of Living Australia. These are a valuable resource, but they are only as good as the data entered, and some of these records represent misidentifications. All these databases are dynamic and need to reflect advances in taxonomy.

6. Taxonomic tools

Molecular data must be combined with morphological data described by taxonomists (Leis 2015). Species diagnoses based on molecular data alone ignore the hundreds of years of previous species descriptions based solely on morphological data. Studies using this combined integrative taxonomy (morphological and molecular data) have shown that delineating a species is more complex than the assumption that the 'barcoding gap' will distinguish species (e.g. Meyer and Paulay 2005, Wiemers and Fiedler 2007). Furthermore, there are still large gaps in the molecular library databases, especially for southern hemisphere and deep-sea species. There is a global lack of barcoding records for marine species. From 207,821 known marine animal species, only 14.5% (NCBI) and 13.8% (BOLD) have COI barcodes. This inadequacy is particularly prevalent for the marine invertebrates (Mugnai et al. 2021).

Increasingly, environmental DNA (eDNA) analysis, the detection of species-specific DNA fragments in the environment, are used in marine biodiversity studies. Whilst this is a

Box 5: Names of the bêche-de-mer teatfish species and current status of the fishery on the Great Barrier Reef, Australia

Tropical sea cucumbers of the Order Aspidochirotida are harvested globally for the high value bêche-de-mer product (dried body wall) largely for the Chinese luxury sea food market. Bêche-de-mer is one of the oldest forms of trade in the Pacific and is of great socioeconomic importance as the main source of income for many fishing communities in developing nations (Conand and Byrne 1993). This fishery also operates in a few developed nations, including on Australia's Great Barrier Reef (GBR). Common names such as green fish, blackfish, curryfish and teatfish are used by fishers and natural resource managers, but many fishery names include several species and the names used differ across regions. As the high demand bêche-de-mer species became rarer, they become more valuable and so, as the rhinos of the sea, are at a high risk of extinction. Bêche-de-mer product exported from Australia has an estimated value of $22 million Aus, with most of this from the GBR fishery, with the teatfish being the most valuable (United Nations Comtrade Database, https://comtrade.un.org/data). As sea cucumbers are relatively sedentary their harvest can be a mining exercise leading to local extirpation.

Conservation efforts were hampered by taxonomic uncertainty. Clarification was needed before listing on the International Union for the Conservation of Nature (IUCN) and the Convention on International Trade in Endangered Species (CITES). Efforts focussed on the taxonomy of the highest value and most imperilled species, the teatfish. Unlike many bêche-de-mer species, teatfish are readily recognised in the sea food trade in the live and dried form due to having distinct lateral "teats" along the body which also assists in identifying black market product.

Figure 5: *Holothuria whitmaei*

The species called the black teatfish encompassed several varieties with a range of colours from totally black, to black with large white spots, black and white mottled forms and some that are mostly white. Clearly, this was a species complex, as further indicated by differing reproductive biology and body wall skeleton. Scientists working in New Caledonia recognised that sympatric all black and the mottled forms were distinct species and Cherbonnier (1980) listed the black form as *Holothuria* (*Microthele*) *nobilis* and described a new species, *H. (M) fuscogilva*, for the mottled form which is harvested as the white teatfish. This left the black teatfish as *H. 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 while the variety in the Pacific was all black. Rowe and Gates (1995) pointed out that Selenka's material contained two colour forms and molecular phylogeny confirmed this presence of two species (Uthicke et al. 2004). As the original illustrations were of the black and white specimen the specimen in the Museum of Comparative Zoology (MCZ 819), was designated as the lectotype (Rowe and Gates 1995). Thus, the Indian Ocean black and white species was *H. nobilis* and the taxonomy of the all black species from the Eastern Indian Ocean (including Western Australia) and Pacific Ocean needed to be clarified. Bell (1887) described a black specimen from Samoa as *Holothuria whitmaei* (Fig. 5) and Rowe and Gates (1995) noted that the holotypes of *H. whitmaei* (BMNH 1875.10.2.6) are completely black and used this name for the totally black teatfish. Thus, the species harvested as the black teatfish across regions is *H. whitmaei* and this was supported by molecular analysis (Uthicke et al. 2004). The taxonomy of at least one more teatfish remains to be determined, the pale coloured variety known at "pentard" in the Indian Ocean.

With clarification of the taxonomy of the teatfish and a few other species, due to their precarious state, with declines over global distributions, 14 bêche-de-mer species were listed in 2014 on the IUCN Red List as vulnerable or endangered to extinction (Conand et al. 2014). After years of negotiations three teatfish species (*H. whitmaei*, *H. nobilis*, *H. fuscogilva*) were listed under CITES Appendix II effective from August 2020. For the Australian fishery, this listing, triggered the EPBC Act and the fishery is now required to show a Non Detriment Finding (NDF) to continue to harvest teatfish as a Wildlife Trade Operation. To achieve the CITES and IUCN listings extensive taxonomic clarifications were required. These listings provide the impetus to improve management of the bêche-de-mer trade to conserve the species.

In Australia the black teatfish (BTF) *H. whitmaei* and white teatfish (WTF) *H. fuscogilva* are harvested from the GBR. As a shallow water reef top species, the BTF was easy to collect by free divers and was overfished with the fishery closed in 1999, then the fishers moved into deeper water to harvest the WTF using SCUBA. This approach from shallow to deep water harvest and local depletion is similar to the boom-bust pattern seen for bêche-de-mer fisheries globally (Eriksson and Byrne 2015). Despite the IUCN, and most recently the CITES listing of the teatfsh, the BTF fishery on the GBR was reopened in 2020. While Australia as an exporting country has to show a NDF to continue its teatfish trade, high uncertainty on key biological traits, distribution, reproductive biology and growth rates of the teatfish impair the ability to assess the impact and ecological risk of the Queensland fishery. This emphasises the need to apply the precautionary principle to the fishing of endangered sea cucumbers, so not to continue global patterns of serial exploitation.

Box 6: Invasive species *Cassiopea* spp.

The unusual upside-down jellyfish, *Cassiopea* spp. (Fig. 6), are considered to be highly invasive, with densities up to 168 individuals/m2 being recorded (Zarnoch et al. 2020). *Cassiopea* are successful invaders because of their high reproductive rates and ability to reproduce both sexually and asexually. They are also considered to be ecosystem engineers with the benthic medusae stage altering community structure through direct impacts including predation on zooplankton, or indirect impacts such as competition (Gershwin et al. 2013, Stoner et al. 2014). *Cassiopea* spp. typically occur in tropical to sub-tropical regions in shallow and sheltered habitats, such as coral reefs or mangrove forests. In Australia, there are new records of *Cassiopea* occurring in temperate coastal lakes in New South Wales, including Wallis Lake in 2009, Lake Illawarra in 2013, and Lake Macquarie in 2017, with at least two species recorded. However, *Cassiopea* is a cryptic genus, with species difficult to distinguish based on morphological characters alone. Due to the potential negative impacts that *Cassiopea* can have in novel environments, it is essential that *Cassiopea* spp. be identified reliably through the combination of genetics and morphology as this can help identify where the new records of *Cassiopea* may have originated and by what means they are expanding their range.

Figure 6: Photograph of up-side-down jellyfish, *Cassiopea* sp. from NSW

useful tool, successful taxonomic identification in eDNA-based studies relies on good coverage of species reference databases. These reference databases might be adequate for vertebrates but are incomplete for marine invertebrates. Species reference databases need to be built up in collaboration with taxonomists to ensure the correct species names are attached to the corresponding sequence data.

7. Actions for end users of taxonomy

- Collaborate with the relevant taxonomists before undertaking major ecological studies, oceanographic surveys. Ensuring that taxonomists are involved from the early stages of planning biodiversity studies and expeditions.

- Ensure adequate funds are made available to sort, identify and catalogue the material collected by building taxonomic identification into grant applications and budgets of projects. This will tremendously increase the impact/ profile of such studies.

- Deposit representative voucher specimens

in relevant museums and herbariums after performing ecological surveys including molecular studies which have associated sequences. This should be done in consultation with collections managers for the correct protocol as per national marine sampling best practices (Przeslawski and Foster 2020). This can allow future verification or revision of outcomes based on the ability to revisit species identifications.

- Acknowledge and cite sources used to identify your material. This will validate the research and improve the citation indices for the taxonomists. Currently, the time-consuming and specialised work of taxonomists is undervalued.

- Upload verified species data onto open access online databases with appropriate meta data. This ensures the databases are kept up to date, the data can be checked and is widely disseminated.

8. Actions for taxonomists

- Promote taxonomic research and its value.

- Prioritise species descriptions from areas of importance (e.g. in sanctuary zones and Marine Parks or those from commercially important or publicly engaging species). Realistically we are not going to be able to identify every marine species so we must prioritise to get the best value out of all taxonomic studies.

- Develop easy to use, well-illustrated and regularly updated interactive keys, to help the end users (ecologists, conservationists, pest managers and amateur naturalists) in correctly identifying biota. The availability of these must be highly publicized and easily accessible.

- Organise taxonomic workshops to aid researchers in the identification of species.

- Interact with more university students to help students learn appropriate skills and correctly identify their material. Build partnerships with universities, be willing to provide a component of teaching courses and field courses and help universities to rediscover the value of taxonomy and describing the natural world.

- Build partnerships with private enterprise to seek opportunities to collaborate with environmental consultants and private enterprise.

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This document was compiled by:

- Laetitia Gunton (Australian Museum)
- Pat Hutchings (Australian Museum, Macquarie University)
- Penny Berents (Australian Museum)
- Allison Broad (University of Wollongong)
- Maria Byrne (The University of Sydney)
- Andy Davis (University of Wollongong)
- Rachel Downey (The Australian National University)
- Michela Mitchell (Queensland Museum)
- Rachel Przeslawski (NSW Department of Primary Industries)
- Claire Rowe (Australian Museum, Sydney University)
- Stephen Skinner (National Herbarium of NSW)
- Robert Sobczyk (University of Lodz)
- Shirley Sorokin (South Australian Museum)
- Simon Walker (Ecological Service Professionals Pty Ltd.)

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