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The extent and protection of Australia's deep sea

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ABSTRACT

Context. Australia has the third largest exclusive economic zone in the world, but little is known about its deepest parts because, historically, research has focussed on coast regions or in the top 1000 m. **Aim.** We aim to identify the extent of Australia's deep sea, the deepest locations in Australian waters, and investigate how much of Australia's deep sea is located within marine parks. **Methods.** We use altimetry-derived water depth to calculate the total area in 1000-m bins. **Key results.** The total area of Australian waters, excluding Antarctic waters, is 8 914 134 km^2, of which, 70.4% is deep sea greater than 1000 m and 48% is deeper than the 3000-m abyssal boundary. In total, 56% of Australian Marine Parks are deeper than 3000 m and 20 of 61 marine reserves include water deeper than 5000 m. **Conclusions.** The Convention on Biological Diversity calls for marine protected areas globally to increase from 7.7 to 30% by 2030: Australia has already placed over 40% of its waters under protection. Despite this, there are no long-term programs monitoring the deep sea and Australia has not produced a globally significant amount of deep-sea science. **Implications.** Herein lies opportunities for Australia to understand fully its largest habitat and become the global exemplar of deep-sea science and conservation.

Keywords: abyssal plain, Australian Marine Parks, Australian waters, bathymetry, deep sea, deep-sea mining, exclusive economic zone, hadal, manganese nodules.

Introduction

Australia is a continent rich in biodiversity, natural resources and splendour, on land and at sea. In August 1994, Australia and its external territories' Exclusive Economic Zone (EEZ) was established as prescribed by the 1982 United Nations Convention on the Law of the Sea (UN Genreal Assembly 1982). This EEZ extended from the 12-nautical mile territorial water limit to 200 nautical miles. Therefore, a little under 30 years ago Australia and its external territories gained a great deal of deep sea (here we define deep sea as >1000-m depth) that it did not have before. The Australian EEZ spans an area larger than its land and is the third largest behind the United States of America and France.

Currently, 4.0×10^6 km^2 of the Australian EEZ is represented by marine protected areas known as 'Australian Marine Parks' (AMP; formally Commonwealth Marine Reserves) established by Australian Federal, State and Territory governments. The first marine park in Australia, predating the adoption of the EEZ, was established at the Great Barrier Reef in 1975 by then Prime Minister Gough Whitlam, soon after he gave the Australian Government control over Australian waters and offshore resources, instead of State Governments. Since then, both State and Federal Governments have increased the coverage of marine parks, with the biggest proclamation occurring in 2012 as part of the Australian Government's contribution to the National Representative System of Marine Protected Areas (Buxton and Cochrane 2015). This significant expansion of marine protected areas received substantial public commentary and scientific investigation with varied points of view (Barr and Possingham 2013; Roberts *et al.* 2018; Cockerell *et al.* 2020). Some questioned whether large areas translate to meaningful protection of biodiversity from threats (Pressey *et al.* 2021; Turnbull *et al.* 2021).

Marine protected areas are typically associated with 'visible' coastal and shallower regions, designed to conserve iconic or vulnerable habitats and ecosystems, or unique or threatened biodiversity. Protected areas should represent the biodiversity of a region and protect this biodiversity from processes that threaten its persistence (Margules and Pressey 2000). In the absence of detailed biological inventories, managers often apply representation to comparable abiotic features assumed to reflect patterns of species distribution (Pressey 2004). This is acutely pertinent for the deep-sea where we know more about abiotic conditions (e.g. bathymetry, geology, geomorphology) than the biology and ecology. Marine parks regularly aim to protect 'key ecological features' considered to be important for biodiversity and ecosystem function, but, in the context of the deep sea, these are most often 'key geological features'. As the 200-nautical mile boundary of the EEZ was established, many marine parks have extended out to this limit to maximise the protection of large areas of the surface waters and processes therein, or key geological features, but having done so included very large swathes of deep seafloor.

Relative to nations such as the United States, Canada, Japan, and many European countries, the Australian deep sea is not well represented in the scientific literature. This presents somewhat of a paradox, whereby, with the exception of perhaps the past few years, relatively little deep-sea biological and ecological research has been undertaken from depths >2500 m off Australia, compared to other countries, yet much of the Australian deep sea is already protected.

This study aims to calculate the area of Australian waters that we classify as deep sea, understand where the deepest regions are in relation to the AMPs, and discuss the potential for Australia to become an important partner in global deep-sea science and conservation.

Materials and methods

Bathymetry data were obtained from General Bathymetry Chart of the Ocean (GEBCO, see www.gebco.net). The publicly available GEBCO_2021 grid (sup-ice topo/bathy dataset) provides elevation data on a 15-arc-second interval grid. These bathymetric data were reprojected to GDA94 and displayed using the geographic information system software, QGIS (ver. 3.2, see http://www.qgis.org/). All maps were produced using GDA94/Geoscience Australia Lambert coordinate reference system.

We used the '*Seas and Submerged Lands Act* 1973 – Australian Maritime Boundaries 2020 – Geodatabase' (Geoscience Australia 2020) to define 'Australian waters'. Here, we define Australian waters to include all coastal water, territorial sea, and the Australian EEZ, which includes amendments from the Perth Treaty 1997. Australian Antarctic waters were excluded from all analyses. Boundaries of AMPs were provided by the Australian Government Department of Agriculture Water and Environment (2022) and they include the recently established Christmas Island Marine Park and Cocos (Keeling) Islands Marine Park.

Bathymetric raster data were clipped to Australian waters and vectorised into 1000-m depth intervals. Total area of each depth class was calculated using the *Zonal Histogram* tool in QGIS and WGS 84 ellipsoid. Area was calculated for mainland Australia and offshore territories, and for each AMP Network.

Results

The total area of Australia waters is 8 914 134 km^2 (Table 1). Of which, 70.4% is deep sea >1000 m (6 271 160 km^2), 48% is deeper than the 3000-m abyssal boundary (4 246 601 km^2), and 0.2% is hadal (>6000 m; 15 038 km^2; Table 1). The deepest areas of Australian waters include the Christmas and Cocos (Keeling) Islands and surrounding seamount complex, the eastern Diamantina Fracture Zone (DFZ) off south Western Australia, and the south-western portion of the Macquarie Ridge (Fig. 1).

The western and southern coast of Australia have the deepest locations bordering Australia's continental margin. Three dominant abyssal plains, namely, Argo Abyssal Plain (5500–5800 m), Cuvier Abyssal Plain (5000 m), and Perth Abyssal Plain (4500–5700 m), are separated by basins and plateaux that extend the continental margin beyond Australian EEZ limits. The DFZ enters the south-western extent of Australian waters and its complexity creates hadal pools >6000 m. The deepest location off the continental margin of Australia is located at one of these hadal pools or possibly in a pool beyond the eastern edge of the DFZ, south of the Recherche Archipelago. Altimetry-derived bathymetric data at the Recherche Pool suggest this is the deepest location (6427 m), but these data should be interpreted with caution until higher-resolution bathymetry is acquired. Only 0.17% of Australian waters are beyond hadal depth.

Australian Marine Parks

In total, 82.2% of the area within AMPs is deeper than 1000 m, 56% is deeper than 3000 m, and 43% is deeper than 4000 m (Fig. 2, Table 2). Australian Marine Parks encapsulate the four deepest locations off Western Australia within the Argo-Rowley Terrace Reserve, Gascoyne Reserve, Abrolhos Reserve, and South-West Corner Reserve. However, the aforementioned Recherche Pool is located outside an AMP, between the South-West Corner Reserve and the Eastern Recherche Reserve.

Almost half (30) of the 61 marine reserves within AMPs have water deeper than 3000 m and 20 have water deeper than 5000 m. Three reserves, Christmas Island, Cocos

Table 1. Area (km^2) of Australian waters binned into 1000-m depth categories.

Location	0–1000 m	1000–2000 m	2000–3000 m	3000–4000 m	4000–5000 m	5000–6000 m	>6000 m	Total
Mainland	2 521 227	850 050	760 174	612 291	1 382 021	720 102	1060	6 846 925
Macquarie Island	3275	7024	16 868	159 977	267 274	20 274	970	475 661
Norfolk Island	23 634	49 729	141 779	200 189	15 238	2	0	430 572
Christmas Island	256	1930	6053	15 665	69 306	179 154	4649	277 013
Coco (Keeling) Islands	1011	2026	5866	18 316	152 520	278 972	8359	467 070
Heard Island and McDonald Islands	93 570	96 165	86 897	85 236	55 027	0	0	416 894
Total	2 642 973	1 006 923	1 017 636	1 091 673	1 941 387	1 198 503	15 038	8 914 134
Proportion of total (%)	29.6	11.3	11.4	12.2	21.8	13.4	0.2	
Cumulative proportion from maximum depth (%)	100	70.4	59.1	47.6	35.4	13.6	0.2	

Area is presented around mainland Australia and offshore territories, excluding Antarctic waters.

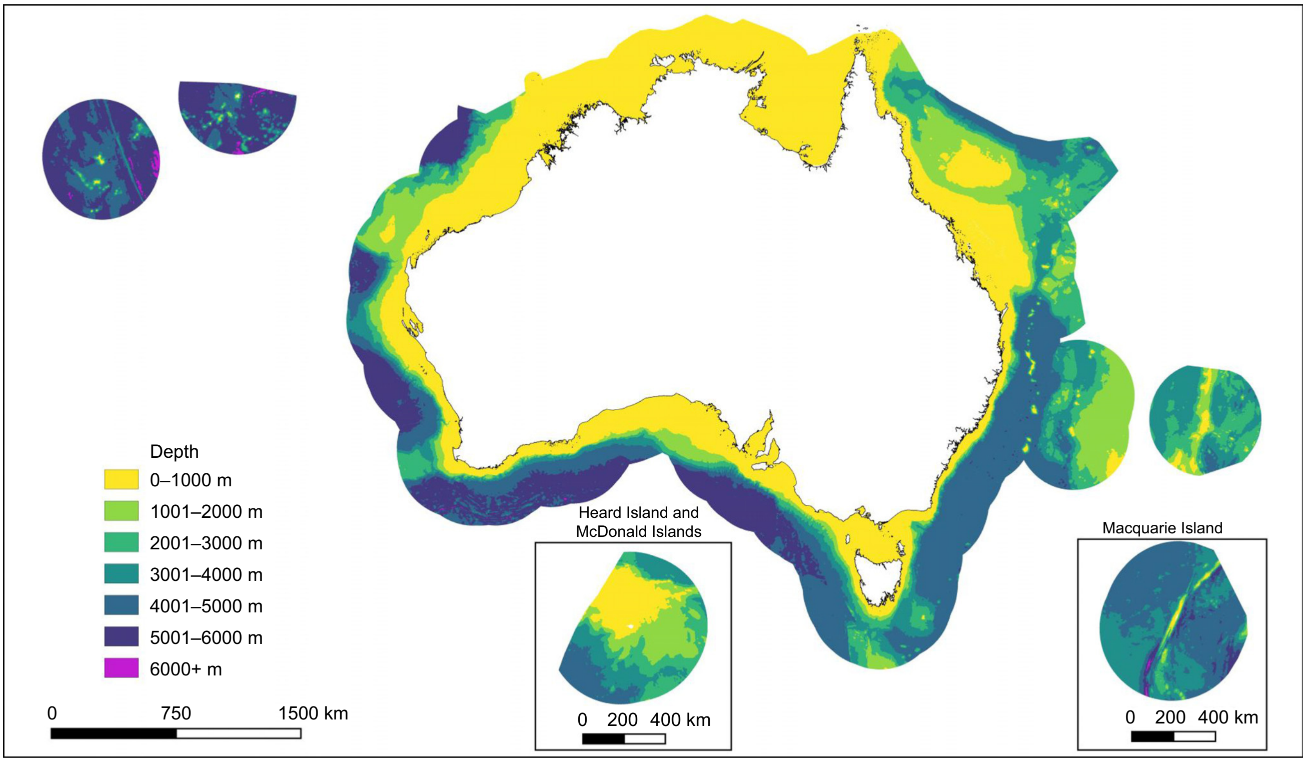

Fig. 1. Water depth in Australian waters binned at 1000-m intervals. Inset maps include Heard Island and MacDonald Islands and Macquarie Island. Coordinate references system: GDA94/Geoscience Australia Lambert.

(Keeling) Islands, and South-west Corner Marine Reserves, have hadal seafloors.

Discussion

Australia has an extensive area of deep sea directly off its continental margin and off its offshore territories. These deep-sea environments extend the full breath of Australia's latitudinal spread, a staggering 50 degrees and encompass a diverse array of historical and contemporary geomorphology that includes multiple abyssal plains, plateaux, submarine canyons, fracture zones, ridges and trenches (Heap and Harris 2008). However, these diverse geomorphic areas are rarely sampled for biota beyond 1500 m and comprise few published articles (e.g. Thresher *et al.* 2014; Williams *et al.* 2018; Farrelly and Ahyong 2019; O'Hara *et al.* 2020*a*, 2020*b*, 2020*c*; Gunton *et al.* 2021). The total area of hadal

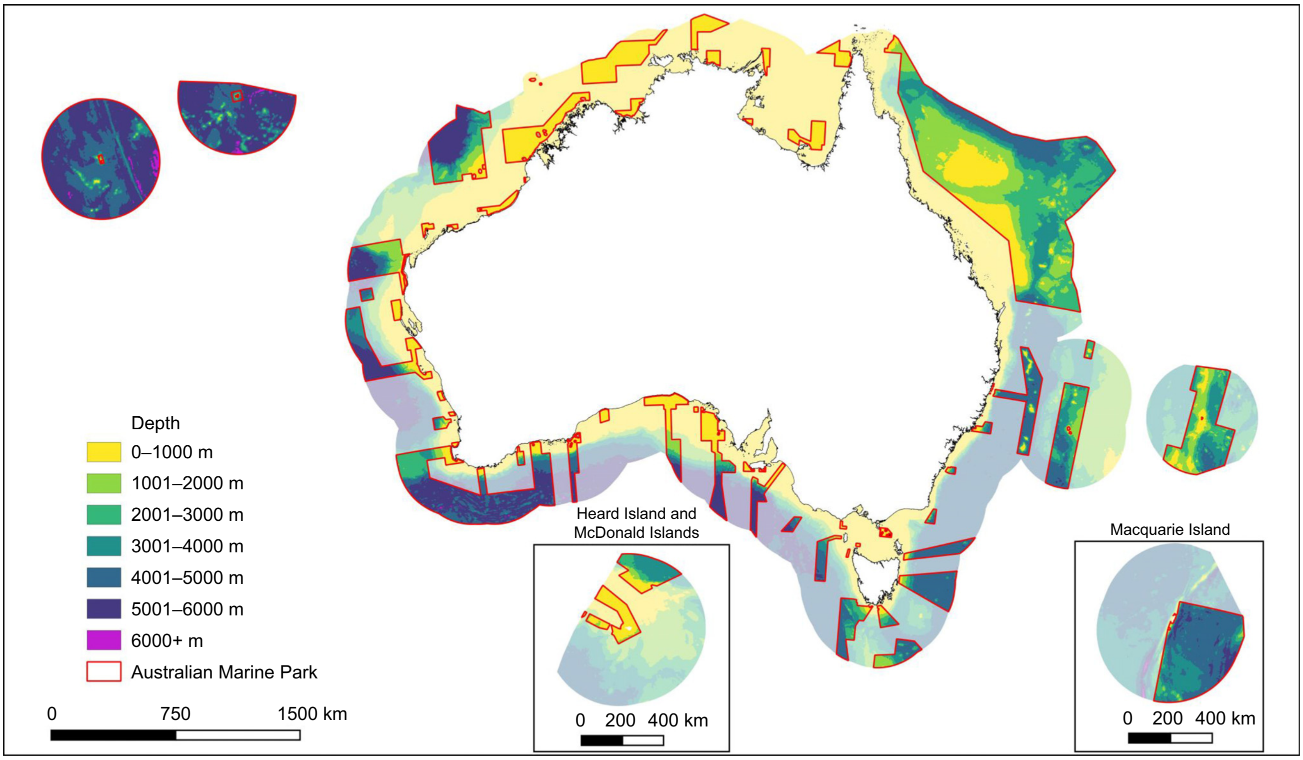

Fig. 2. Water depth in Australian Marine Parks (red boundary) displayed at 1000-m intervals. Inset maps include Heard Island and MacDonald Islands and Macquarie Island.

(>6000 m) environments is low, but with only partial subduction trenches in the Christmas Island and Macquarie EEZ, this is not surprising, although there is still 15 000 km^2 of hadal zone within Australia. What is perhaps surprising is that 46% of Australian seafloor (4 231 563 km^2) is abyssal (3000–6000 m). Although we have limited understanding of the biology and ecology at the deepest locations around Australia, almost half (47%) of it is protected by the extensive network of AMPs and classified into different zones with varying levels of protection that permit or exclude a range of activities, for example, mining, commercial or recreational fishing, tourism activities (see examples in Director of National Parks 2018). Many might argue that these parks are protecting parts of the deep sea we know nothing about, have not observed directly, and that is not under threat from acute pressures we can control by excluding local activities. This is not the first time unique habitats have been protected with limited understanding of their function.

The world's first National Park in the United States of America, namely Yellowstone, was established to protect against gold miners laying claim to the hot springs. This now iconic and symbolic park was protected in 1872 by policy-makers who had only seen photos and heard stories of its brilliance. Similarly, the first marine park in Australia, *Great Barrier Reef Marine Park Act* 1975, was established to stop resource mining in a region that scientists recognised as a critically important and unique. A world without these iconic parks seems unimaginable, but society has 'coped' without the mineral and petrochemical resources they still possess, instead prospering off their ecological function and the scientific advancement their presence provoked. Currently, direct effects on deep-sea environments include chemical contamination and plastic pollution (Jamieson *et al.* 2017, 2019; Blum *et al.* 2020), and resource extraction where certain minerals are present (Childs 2022; Sharma 2022; Fig. 3). Demersal fisheries are generally limited to depths >1500 m and Australia's oil and gas subsea well infrastructure does not currently exceed 1800 m (Petroleum Exploration Database, National Offshore Petroleum Titles Administration, Gesoscience Australia, see https://nopims.dmp.wa.gov.au/Nopims/GISMap/Map). However, the technological and economical viability of these activities in deeper water is ever increasing and the most pressing and acute local pressure that threatens to permanently destroy deep-sea habitats is resource extraction.

Deep-sea mining targets, among others, polymetallic nodule fields, also known as manganese nodules. The latter was first discovered in Australian waters off south-western Australia in 1970 by the research vessel USNS *Eltanin* and nodule occurrence and composition was described and discussed from subsequent voyages on USNS *Eltanin* and HMAS *Diamantina* (see Kennett and Watkins 1975; Frakes *et al.* 1977; Watkins and Kennett 1977). Consequently, manganese nodules were mapped across the entire DFZ to

Table 2. Area (km^2) within each Australian Marine Park or Marine Park Network in 1000-m bins.

Location	0–1000 m	1000–2000 m	2000–3000 m	3000–4000 m	4000–5000 m	5000–6000 m	>6000 m
Christmas Island	241 (0.1%)	1930 (0.7%)	6053 (2.2%)	15 664 (5.7%)	69 306 (25.0%)	179 154 (64.7%)	4649 (1.7%)
Cocos (Keeling) Islands	956 (0.2%)	2026 (0.4%)	5866 (1.3%)	18 316 (3.9%)	152 521 (32.7%)	278 973 (59.7%)	8359 (1.8%)
Coral Sea	177 032 (17.9%)	269 455 (27.2%)	283 614 (28.7%)	169 298 (17.1%)	90 389 (9.1%)	–	–
Heard Island and McDonald Islands	35 746 (50.7%)	6448 (9.1%)	7494 (10.6%)	20 813 (29.5%)	–	–	–
North	157 453 (100%)	–	–	–	–	–	–
North-west	118 145 (35.2%)	40 944 (12.2%)	37 537 (11.2%)	23 678 (7.1%)	25 473 (7.6%)	89 542 (26.7%)	–
South-east	15 420 (4.0%)	16 687 (4.3%)	30 189 (7.8%)	75 543 (19.5%)	219 205 (56.5%)	31 029 (8.0%)	–
South-west	102 557 (20.2%)	21 505 (4.2%)	43 303 (8.5%)	39 288 (7.7%)	93 537 (18.4%)	207 371 (40.8%)	766 (0.2%)
Temperate east	30 867 (8.1%)	65 498 (17.1%)	98 260 (25.6%)	90 293 (23.6%)	96 672 (25.2%)	1627 (0.4%)	–
Total	638 418	424 491	512 317	452 895	747 103	787 697	13 774
Proportion of total area (%)	17.8	11.9	14.3	12.7	20.9	22.0	0.4
Cumulative proportion this depth and deeper (%)	100.0	82.2	70.3	56.0	43.3	22.4	0.4
Proportion of Australian waters in AMP (%)	24.2	42.2	50.3	41.5	38.5	65.7	91.6

Values in parentheses are the proportion of the marine reserve within the depth bin.

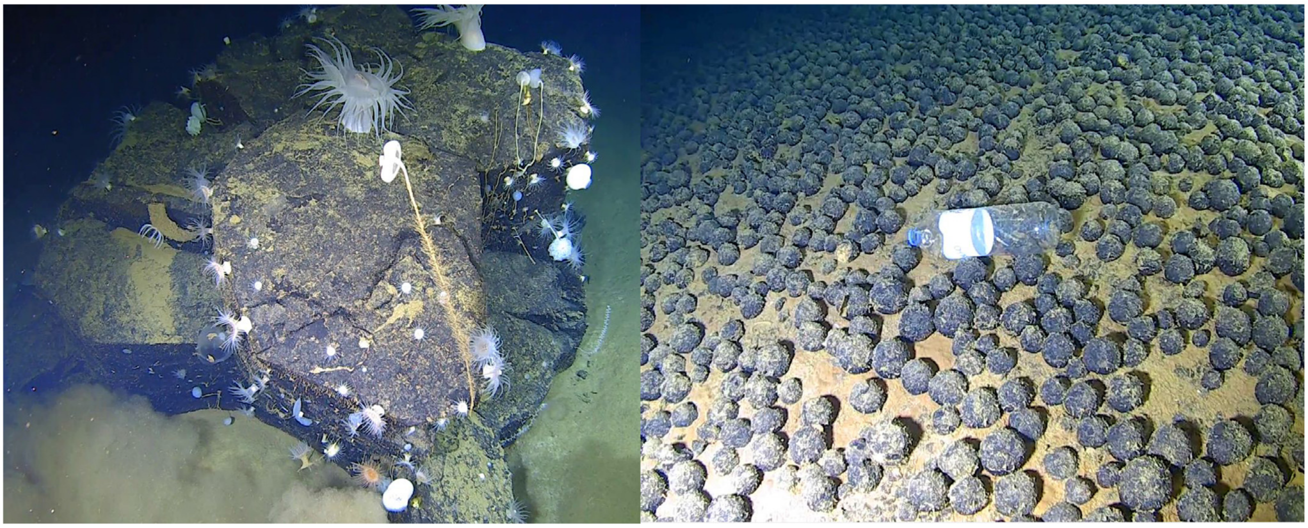

Fig. 3. Abundant and diverse sclerobionts at ~4500-m water depth in the North Australian Basin (left). Poignant image of a plastic bottle sitting on a dense field of manganese nodules at 5040 m in the Wallaby Zenith Fracture Zone (right). This ancient landscape may already be polluted with plastic, but it can still be protected from deep-sea mining. The bottle is ~22 cm long for scale.

the Broken Ridge and named 'Cape Leeuwin Manganese Nodule Field' (LNF). Despite extensive work in the 1970s and a significant report on manganese nodules within the Department of Minerals and Energy Australia (Noakes and Jones 1974), including sections on *Composition* and *Economic Prospects*, research on manganese nodule habitats in Australian waters has discontinued. In fact, the *Australia state of the environment 2016: marine environment* reports 'None [manganese-cobalt nodules and crusts] in Australia . . .' (Evans *et al.* 2017, p. 48). Likewise, the LNF is not identified in the AMPs' South-west Marine Parks Network Management Plan (Director of National Parks 2018) or Implementation Plan 1 (Director of National Parks 2019). The LNF is also missing from more recent maps displaying the global distribution of nodules (Hein 2016; Miller *et al.* 2018). Although the LNF is not specifically identified for protection, the area of the field that enters Australian waters is protected within the South-west Corner Marine Reserve as a Habitat Protection Zone (IUCN IV). As such, no mining or exploration is allowed. If the nodule field continues along the western portion of the DFZ, which is likely, considering the depth and oceanographic conditions, it enters the Multi Use Zone (IUCN VI) of the South-west Corner Marine Reserve where mining is allowable, subject to assessment (Director of National Parks 2018). We strongly recommend a critical review of all data mapping the presence of nodules in south-western Australia, defining the true extent with new data, and extending the DFZ key ecological feature to include the full extent of the LNF. Furthermore, Australia must be proactive in establishing policy around its offshore mineral reserves and reassess the financial viability of mining its waters and the associated environmental risks.

Australia is now in an unusual position whereby the nodule fields within its waters are not only known of prior to contemporary industrial interest, but some of it is already under some level of protection within an AMP. Likewise, the general deep-sea benefits from an usually large degree of protection which is in line with the United Nations' Sustainable Development Goal 14. The total area protected by the marine parks as a percentage of Australian waters in the same depths shows that all 1000 m depth bins include >30% protection except for the 0–1000 m (24%), which happens to be the largest (Table 2). The Convention on Biological Diversity calls for marine protected areas to increase from 7.7 to 30% by 2030, in a plan called '30X30' (Albers and Ashworth 2022), but currently Australia has already placed over 40% of its waters under some degree of protection. But does Australia know what is in their deep-sea AMPs and can they monitor them for change?

Until recently, Australia's national capacity to undertake biological research beyond 2500 m was limited. The launch of RV *Investigator* in 2014 and RSV *Nuyina* in 2018 has provided Australian scientists with access to equipment capable of collecting biological specimens, dredge and sediment cores, and video footage beyond 4000 m. Consequently, Australian scientists have surveyed demersal and benthic fauna in the Commonwealth Marine Reserves off eastern Australia (O'Hara *et al.* 2020*a*) and the Great Australian Bight (MacIntosh *et al.* 2018), and undertaken geological surveys and dredging at the Kerguelen Plateau, William's Ridge and Broken Ridge (Coffin *et al.* 2021). Expeditions like these are incrementally increasing our knowledge of the deep sea off Australia; however, considering that 46% of Australian seafloor is abyssal (3000–6000 m), there is still much work to do. This is also highlighted in the most recent State of the Environment 2021:

> There is no ongoing monitoring of deep seafloor habitats in Australia, so biodiversity or oceanographic trends are unknown. [Trebilco *et al.* 2021, p. 195]

With so much deep sea in Australia, it is encouraging how much of it has already been placed under some degree of protection. The challenge now is to understand geological and oceanographic processes in Australia's deep sea, how these shape the biological community and determine whether this environment has or is changing. Much deep-sea science is still explorative and baseline, but understanding the full effects of anthropogenic impacts such as deep-sea mining, pollution and climate change should be forefront in future deep-sea projects. Furthermore, Australian research institutes must work collectively to think and work beyond single expeditions and develop long-term datasets at key locations. A clear research priority is the offshore territories, specifically biological surveys at Cocos (Keeling) Islands, Christmas Island, and Macquarie Island, which not only encompass hadal environments, but have immense areas of deep sea within AMPs. Additionally, developing long-term monitoring programs at the three abyssal plains within the AMPs offshore Western Australia is important. Herein lies opportunities for Australia to understand fully its largest habitat and become the global exemplar of deep-sea science and conservation.

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