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Integrating Science and Policy for recognising Seamounts as Vulnerable Marine Ecosystems

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Abstract

Seamounts, including knolls and hills, are vital deep-sea ecosystems that provide unique habitats and significantly contribute to marine biodiversity. The UN General Assembly resolutions from 2006 to 2022 have consistently emphasised the need to protect vulnerable marine ecosystems (VMEs), including seamounts, from significant adverse impacts. This paper examines whether these features meet the criteria for classification as VMEs under the FAO Deep Sea Fisheries Guidelines, which considers criteria such as functional significance, fragility, slow recovery, and structural complexity. To substantiate this classification, we review scientific evidence alongside definitions from the UN General Assembly, FAO Guidelines, Regional Fisheries Management Organisations and individual States. Additionally, we assess the effectiveness of current policies aimed at protecting seamounts as VMEs. Our findings reveal strong scientific support for classifying seamounts as VMEs, since surveyed seamounts meet at least four of the five VME criteria without exception. Visual studies have also repeatedly confirmed their capacity to sustain extensive VME communities. Consequently, the best available science supports a precautionary, ecosystem-based approach to protect seamounts, including their listing in Annex 9 of CMM 03-2023.

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**SEAMOUNTS
ARE THE
OCEAN'S LIFELINE**



Integrating Science and Policy for recognising Seamounts as Vulnerable Marine Ecosystems

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Integrating Science and Policy for recognising Seamounts as Vulnerable Marine Ecosystems

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1. Introduction

Seamounts are submarine mountains that rise from 100 metres to over 1,000 metres above the seafloor, and occur typically 200 metres or more below the ocean surface (Menard, 1964; Rogers, 2018; Staudigel & Clague, 2010). Seamounts encompass a range of complex morphologies, including hills (elevations <500 metres), knolls (elevations >500 metres), ridges, and fracture zones formed at transform faults (Staudigel & Clague, 2010). Despite their varied shapes and heights, these features exhibit similar biological and ecological functions (M. R. Clark et al., 2022; Howell et al., 2010; Yesson et al., 2011). Globally, it is estimated that there are approximately 38,000 seamounts that exceed 1,000 metres in height (Yesson et al., 2021) and this ubiquitous nature makes seamounts important deep-sea ecosystems (Costello, 2009). However, only a small minority 0.004% have been scientifically surveyed (Clark et al., 2010; Rowden et al., 2010) (Figure 1.). These expeditions have shown the seamount terrain comprises a varied landscape of hard substrates and geomorphologies, often in regions surrounded by abyssal plains, with vibrant communities living on them typically comprising slow-growing and long-living species (Auster, 2005).

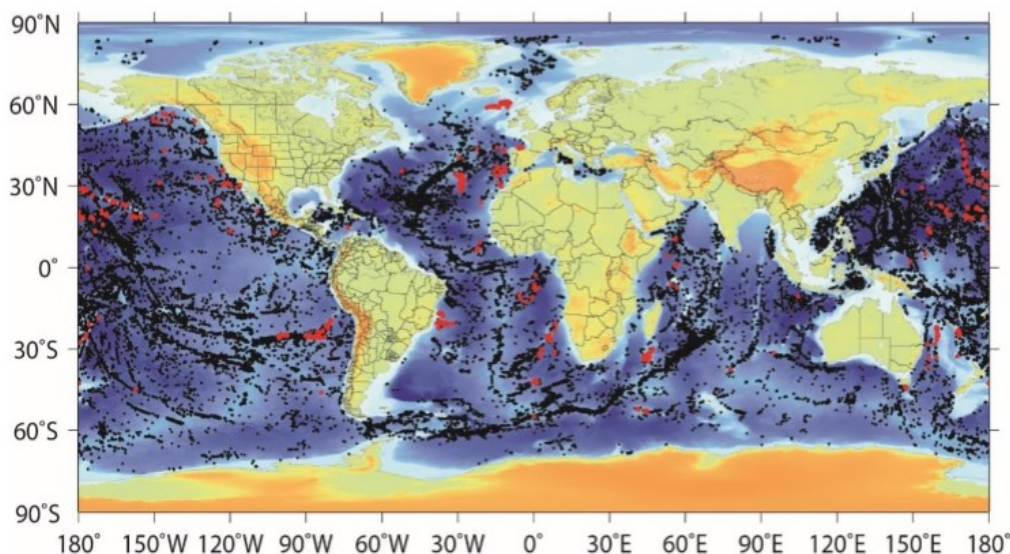


Figure 1. The global distribution of seamounts (black dots) based on 30 arc seconds bathymetry data overlaid with sampled seamounts data (red dots). The seamount distribution data is based on Yesson et al.

(2011) and the sampled seamount data is from Seamounts Online (Stocks, 2010). Note that the number of sampled seamounts is likely to be slightly higher, since the sampled data set only runs till 2009.

Consequently, seamounts are now recognised as biodiversity "hotspots," hosting abundant and diverse communities of fish and benthic species, with elevated species richness, biomass, and abundance compared to surrounding abyssal plains (de Forges et al., 2000; Samadi et al., 2006). This biodiversity is largely due to enhanced habitat heterogeneity and productivity on seamounts, which promote species coexistence and frequent turnover across habitats, often occurring over spatial scales as small as 100 metres (McClain et al., 2010; Victorero et al., 2018). In line with these findings, seamounts generally display greater biomass than other deep-sea areas (Rowden et al., 2010; Sautya et al., 2011).

This increased benthic biomass attracts deep-sea fish, which use seamounts for spawning and other activities, further enhancing the biomass and ecological complexity of these features (Koslow, 1996). Globally, seamounts support at least 77 commercially important fish species and are estimated to host at least 1,222 fish and shark species in total (Kvile et al., 2014; Morato & Clark, 2007; Rogers, 1994). A study compiling data from 187 seamounts, using only described taxa, found 2,905 demersal invertebrate records spanning 27 animal taxa, along with records of 22 marine mammal species and 31 seabird species (Kvile et al., 2014). Based on intensive and comprehensive sampling, de Forges et al., (2000) reported more than 850 species associated with cold-water coral and sponge communities on seamounts in the Tasman and Coral Seas of the Southwest Pacific. A total of 237 taxa have been identified on the Davidson Seamount off the coast of California (Burton & Lundsten, 2008). The total number of species inhabiting seamounts is known to be high, but exact values remain unknown due to limited sampling and the rarity and inconsistencies in deep-sea global-scale data compilations (Higgs & Attrill, 2015).

In this paper, we review scientific evidence together with definitions from the UN General Assembly, FAO Guidelines, Regional Fisheries Management Organizations (RFMOs), and states that support the classification of seamounts as vulnerable marine ecosystems (VMEs). Concurrently, we analyse examples of policies aimed at protecting seamounts as VMEs, and illustrate the effectiveness of these protection measures. Throughout this paper, we demonstrate that there is currently no scientific evidence contradicting their classification as VMEs or their capacity to sustain VME communities, advocating strongly for a precautionary and ecosystem-based approach that includes the closure of seamounts to bottom-contact fishing.

2. Definitions and Criteria for VMEs

In response to increasing concerns over the impact of human activities on sensitive deep-sea ecosystems, the UNGA adopted Resolution 61/105 in 2006. This significant resolution recognised the immense value of deep-sea biodiversity and committed States, both individually and through RFMOs to protect areas with vulnerable marine ecosystems. The resolutions emphasised protecting areas where "*including seamounts, cold-water coral reefs*

and hydrothermal vents, are known to occur or are likely to occur based on the best available scientific information”.

The term "vulnerable marine ecosystems" (VMEs) refers to deep-sea areas that are particularly sensitive to human activities and environmental changes (FAO, 2009). VMEs include habitat-forming organisms such as deep-sea sponge clusters, cold-water corals, sea pens, crinoid fields, and significant features like seamounts and hydrothermal vents. The species that make up VMEs are typically fragile, slow-growing, and highly susceptible to damage from activities such as deep-sea fishing and mining, with very slow recovery rates (Auster et al., 1996; Clark et al., 2016; Watling & Auster, 2017). VMEs are characterised by high biodiversity, offering diverse habitats that lead to increased faunal richness, diversity, abundance, and biomass (Barrio Froján et al., 2016; Beazley et al., 2013; Buhl-Mortensen & Mortensen, 2005). Additionally, they provide essential areas for commercial fish populations and other species to aggregate, spawn, forage, and seek shelter (Baillon et al., 2012; Pham et al., 2015).

The FAO Guidelines (2009) (para 42) sets out five specific criteria for identifying areas as VMEs that require conservation efforts to protect their ecological integrity and biodiversity. The FAO Guidelines emphasises that only one of these criteria needs to be met for an area to be designated as a VME underscoring the importance of even single significant features in deep-sea conservation.

These criteria are:

1. Uniqueness or rarity
2. Functional significance of the habitat
3. Fragility
4. Life-history traits or component species that make recovery difficult
5. Structural complexity

While the UNGA resolution 61/105, along with the FAO Guidelines (2009) provide a comprehensive list of VME examples, including indicator taxa and geophysical features like seamounts, each RFMO can develop its own VME indicator lists. VME indicator taxa are faunal groups representing a wider range of species within an ecosystem, encompassing those that may not be directly considered or sampled, but are still affected by impacts (Watling & Auster, 2017). The presence of VME indicator taxa signifies the likely presence of a vulnerable marine ecosystem and underscores the importance of protecting the full diversity of interacting and vulnerable species within that ecosystem (Watling & Auster, 2017).

The VME indicator lists are tailored to the specific ecological and operational contexts of the regions they manage. This decentralised approach allows for regional adaptation and management, but it has been shown to lack consistency among RFMO regions regarding what is considered a VME (Baco, Ross, et al., 2023). More importantly, it risks overlooking the protection of certain areas and features. Such differences in protection are particularly evident with geophysical features like seamounts that are repeatedly acknowledged as vulnerable habitats to disturbance by bottom contact fishing gear, regardless of the region in which they

occur (Clark & Koslow, 2007). The FAO Guidelines provide further guidance on the aspect of vulnerability, stating: “*The most vulnerable ecosystems are those that are both easily disturbed and very slow to recover, or may never recover*”. In this context, referring to the ecosystem means that the VME concept includes the ecosystem where populations, communities, and habitats are nested and interact functionally (Watling & Auster, 2021). This means that geophysical features like seamounts are part of the ecosystem under the VME criteria.

However, the FAO Guidelines also state “*merely detecting the presence of an element is not sufficient to identify a VME. That identification should be made on a case-by-case basis through the application of relevant provisions of these Guidelines, particularly Sections 3.2 and 5.2.*” These sections outline the need for thorough assessments using the established criteria for identifying VMEs, including conducting impact assessments, applying the precautionary approach, and other operational requirements. Furthermore, the 2009 FAO Guidelines should be interpreted in conjunction with the evolving UNGA resolutions, which have consistently emphasised the need to protect seamounts. Each subsequent round of negotiations has built upon these 2009 guidelines, progressively advocating for more comprehensive measures to safeguard VMEs, including seamounts and their associated species (see Table 1).

Despite these provisions, certain RFMOs lack comprehensive assessments of vulnerability when an element is detected, creating gaps in VME protection. To ensure consistent protection of VMEs, their associated species, and the wider biodiversity in the deep ocean, it is essential that States and RFMOs recognise that, under both the UNGA resolutions and the FAO Guidelines, all seamounts are VME entities (Watling & Auster, 2017). This classification is further reinforced by the best available scientific evidence, which consistently shows the abundant presence of VME indicator species on seamounts.

Table 1. Overview of the UNGA resolutions focused on protecting VMEs, showing how the inclusion and protection of seamounts under the VME concept have remained central to the resolutions.

Resolution	Text concerning seamounts as VMEs
59/25 (2004)	Calls upon States, either by themselves or through regional fisheries management organizations or arrangements, where these are competent to do so, to take action urgently, and consider on a case-by-case basis and on a scientific basis, including the application of the precautionary approach, the interim prohibition of destructive fishing practices, including bottom trawling that has adverse impacts on vulnerable marine ecosystems, including seamounts , hydrothermal vents and cold water corals located beyond national jurisdiction, until such time as appropriate conservation and management measures have been adopted in accordance with international law;
61/105 (2006)	Calls upon States to take action immediately, individually and through regional fisheries management organizations and arrangements, and consistent with the precautionary approach and ecosystem approaches, to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts , hydrothermal vents and cold water corals, from destructive fishing practices, recognizing the immense importance and value of deep sea ecosystems and the biodiversity they contain; In respect of areas where vulnerable marine ecosystems, including seamounts , hydrothermal vents and cold water corals, are known to occur or are likely to occur based on the best available scientific information, to close such areas to bottom fishing and ensure that such activities do not proceed unless conservation and management measures have been established to prevent significant adverse impacts on vulnerable marine ecosystems;
64/72 (2009)	Calls upon States to take action immediately, individually and through regional fisheries management organizations and arrangements, and consistent with the precautionary approach and ecosystem approaches, to implement the 2008 International Guidelines for the Management of Deep-sea Fisheries in the High Seas of the Food and Agriculture Organization of the United Nations (“the Guidelines”) 23 in order to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts , hydrothermal vents and cold water corals, from destructive fishing practices, recognizing the immense importance and value of deep sea ecosystems and the biodiversity they contain;
66/68 (2011)	Calls upon States to take action immediately, individually and through regional fisheries management organizations and arrangements, and consistent with the precautionary approach and ecosystem approaches, to continue implementing the 2008 International Guidelines for the Management of Deep-Sea Fisheries in the High Seas of the Food and Agriculture Organization of the United Nations (“the Guidelines”) 26 in order to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts , hydrothermal vents and cold water corals, from destructive fishing practices, recognizing the immense importance and value of deep-sea ecosystems and the biodiversity they contain;
71/123 (2016)	Calls upon States to take action immediately, individually and through regional fisheries management organizations and arrangements, and consistent with the precautionary approach and ecosystem approaches, to continue to implement the 2008 International Guidelines for the Management of Deep-sea Fisheries in the High Seas of the Food and Agriculture Organization of the United Nations (the Guidelines) in order to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts , hydrothermal vents and cold water corals, from fishing practices with significant adverse impacts on vulnerable marine ecosystems, recognizing the immense importance and value of deep-sea ecosystems and the biodiversity they contain as documented in the First Global Integrated Marine Assessment;
77/118 (2022)	Calls upon States to take action immediately, individually and through regional fisheries management organizations and arrangements, and consistent with the precautionary approach and ecosystem approaches, to continue to implement the 2008 International Guidelines for the Management of Deep-Sea Fisheries in the High Seas of the Food and Agriculture Organization of the United Nations (the Guidelines) in order to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts , hydrothermal vents and cold water corals, from fishing practices with significant adverse impacts on vulnerable marine ecosystems, recognizing the immense importance and value of deep-sea ecosystems and the biodiversity they contain, as documented in the first World Ocean Assessment.

3. VME Indicator Taxa as a Defining Feature of Seamounts

Visual evidence for the distribution of VME indicator taxa is comparatively rare for fisheries management decisions (Baco et al., 2023). The presence of VME indicator taxa relies mostly on fisheries bycatch data, that is known to not accurately represent the community present, due to differences in catchability between taxa, or the extent of the impact on the seafloor (Gros et al., 2022; Knudby et al., 2013; Pitcher et al., 2019; Preez et al., 2016; Watling & Auster, 2017). While bycatch records of indicator species remain a valuable tool for identifying VMEs, they should not be the sole method used to ensure the protection of VMEs.

Mapping of VME indicator taxa through imagery-based studies of seamounts is relatively rare on a global scale due to the high costs involved. Moreover, it is uncommon for more than two or three ROV dives to be conducted on any single seamount (Kvile et al., 2014; Watling & Auster, 2017). The lack of data has often been leveraged to delay the implementation of protective measures, despite strong recommendations from the scientific community advocating for precautionary approaches in fisheries management to protect understudied marine systems (Garcia, 1994; Korseberg, 2018; Macdonald, 1995)

The limited data, however, has shown that both pristine and degraded seamount landscapes consistently contain VME indicator taxa on all or parts of the seamounts. This has led to insights that VME indicator taxa are characteristic of seamount ecosystems. For example, seamounts where ROV dives have revealed VME indicator taxa include Kelvin (Lapointe et al., 2020) and Anton Dohrn (Davies et al., 2015) in the North Atlantic; and Tropic (Ramiro Sanchez et al., 2019), Anna, Knipovich, Vema Fracture Zone, and Vayda seamounts (Victorero, 2019) in the Equatorial Atlantic; Central Arctic seamounts (Morganti et al., 2022) and Schulz Bank on the Arctic Mid-Ocean Ridge (Morrison et al., 2020); Davidson (McClain et al., 2010) and Cobb (Preez et al., 2016) in the Northeast Pacific; Necker Ridge (Morgan et al., 2015) in the Central Pacific; the Graveyard seamounts on the Chatham Rise east of New Zealand (Clark & O'Driscoll, 2003); and four seamounts on the Mozambique Channel in the Indian Ocean (Hanafi-Portier et al., 2024). The Okeanos Explorer has dived around the world, consistently documenting extensive deep-sea coral and sponge habitats on seamounts. A recent study assessed VMEs from imagery across 27 study sites worldwide. Notably, 16 of these sites provided imagery of VMEs specifically from seamount ecosystems (Baco et al., 2023). All studied seamounts within the deep seas of the OSPAR region contained VME indicator species, according to a review of 100 seamounts and seamount-like features (Kutti et al., 2019). Modelling studies further support this pattern, demonstrating that stony coral reef VME habitats on Tasmanian seamounts form large, continuous aggregations predominantly concentrated on the peaks and flanks of the seamounts (Williams et al., 2020).

These examples, using the best available scientific data, demonstrate that while we do not have comprehensive coverage of each seamount surveyed and its varied landscapes, and are unlikely to achieve this, we can confidently deduce that seamounts are prime habitats for VME indicator taxa.

4. Assessing Vulnerability of Seamount Ecosystems based on Scientific Evidence

Paragraph 42 of the FAO Guidelines states, "A marine ecosystem should be classified as vulnerable based on the characteristics that it possesses. The following list of characteristics should be used as criteria in the identification of VMEs." In this section, we draw on scientific literature to evaluate how seamounts meet each VME criterion, providing examples from various regions worldwide to support their classification as VMEs. Notably, scientific research indicates that surveyed seamounts meet at least one to four of the five VME criteria without exception. Furthermore, existing evidence overwhelmingly supports their classification as VMEs, with the criterion of fragility consistently highlighted across all studies.

FAO Criteria 1 – Uniqueness or rarity

“An area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems”

New species are frequently discovered on seamounts, but determining their endemism is challenging due to the unexplored expanse of the deep ocean. Some degree of endemism is expected, through novel discoveries and cryptic fauna (McClain et al., 2009). Endemism on seamounts could arise from site-specific speciation due to the combination of depth gradients, different substrates, and physical oceanographic barriers, which together create dispersal barriers and promote adaptation (Rowden et al., 2010). There might also be regional differences in endemism. In the North-East Atlantic, less than 3% of the recorded antipatharian, scleractinian, and gorgonian corals are potentially endemic to seamounts (Hall-spencer et al., 2007). Conversely, in the SW Pacific, up to 39% of sampled *Chrysogorgia* haplotypes may be restricted to a single seamount (Pante et al., 2015). At the Josephine Seamount in the North-East Atlantic, five endemic species have been discovered (OSPAR, 2011). Additionally, 25% of the gastropod species sampled by Gofas & Beu (2002) on Josephine and surrounding seamounts were identified as either unknown or rare in nearby margin areas (OSPAR, 2011). Some observations indicate that recruitment to individual seamounts may be highly localised, resulting in predominantly self-recruiting populations (Rogers, 2018). However, a recent discovery highlights the broader ecological significance of seamounts. The rare Atlantic bamboo coral *Chelidonisis aurantiaca* was discovered for the *first* time in the Mediterranean Sea at Janua Seamount, emphasising the crucial role these ecosystems play in supporting unique marine biodiversity (Bo et al., 2020). Research into the hidden diversity of cryptic species in the deep ocean is a growing field, likely to reshape our understanding of endemism and rare species on seamounts. However, the true extent of endemism remains uncertain due to significant knowledge gaps and the limited reach of deep-sea exploration.

FAO Criteria 2 – Functional significance of the habitat

“Discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life-history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species.”

VMEs provide habitat for commercially fished species (Baillon et al., 2012; Pham et al., 2015) and, in some instances, can be classified as essential fish habitat (EFH) — habitats necessary for the survival of fish (Shester & Ayers, 2005). Many fish species, including commercially valuable ones like the slender armorhead and orange roughy, form spawning and feeding aggregations over seamounts, rises and ridges (Boehlert & Sasaki, 1988; Clark, 1999; Roberts, 2002).

Skates and rays in the deep sea are highly vulnerable due to their life history traits, with their extinction risk exacerbated by increased fishing efforts in deeper waters (Devine et al., 2006; Rigby & Simpfendorfer, 2015). The seamounts off Tasmania, Australia, serve as egg case nurseries for the boreal skate (*Amblyraja hyperborea*) and Richardson's skate (*Bathyraja richardsoni*), with eggs deposited within the skeletal matrix of the stony coral *Solenosmilia*

variabilis (Maguire et al., 2023). Similarly, sponge grounds at the summit of the Schulz Bank on the Arctic Mid-Ocean Ridge function as nurseries for the eggs and juveniles of the boreal skate (*Amblyraja hyperborea*) in the Arctic region (Meyer et al., 2019).

The flanks of the Davidson Seamount off California host the "Octopus Garden," a 1.29-square-mile area estimated to contain over 20,000 individuals of the octopus *Muusoctopus robustus*, along with a rich megafaunal assemblage of corals and other invertebrates (Barry et al., 2023). This site provides a localised deep-sea heat source and serves as a nursery ground where octopuses incubate and hatch their eggs (Barry et al., 2023). Nearby, researchers also discovered a smaller breeding site for the same species that take advantage of the exposed rocky habitats on seamounts to reproduce (Barry et al., 2023). Based on this evidence, experts predict that other ridge-flank systems are likely to host similar nurseries.

FAO Criteria 3 – Fragility

“An ecosystem that is highly susceptible to degradation by anthropogenic activities.”

Several studies have documented the high susceptibility of seamount communities to degradation by anthropogenic activities, mainly deep-sea trawling and the challenges of recovery. Research indicates that routinely trawled seamounts have generally lost most or all of their coral and other suspension feeder communities on the summits and upper flanks (Clark & O’Driscoll, 2003; Clark & Tittensor, 2010; Koslow et al., 2001).

In the South-West Pacific, a regional assessment detected trawling damage on 88% (45 of 51) of seamounts in the fishery seascape off Tasmania (Williams et al., 2020). Several recovery studies in this area have illustrated how fragile seamounts are to the impacts of trawling. The Graveyard Knolls in the Chatham Rise have been closed to fishing over 15 years, yet the communities remain indistinguishable from those on currently heavily trawled features, suggesting very limited or no recovery (Clark et al., 2019). Despite the presence of neighbouring topographic features with coral coverage that should theoretically provide larvae, there is a severe lack of biodiversity (Clark et al., 2019). While a more recent survey has indicated some early signs of recovery, there is still little evidence of community function returning to pre-trawling levels (S. Goode et al., 2024). In this area, coral patches damaged by the orange roughy fishery are estimated to take over 100 years to recover (Probert et al., 1997). Althaus et al. (2009) observed a two orders of magnitude reduction in the cover of the cold-water coral *Solenosmilia variabilis* and a subsequent threefold loss of megabenthic species richness on trawled seamounts, with no signs of recovery on seamounts off Tasmania even after 10 years. Williams et al. (2010) found no indication of recovery in megafaunal assemblages on seamounts off New Zealand and Australia after 5–10 years, although some small and flexible species appeared to increase in abundance, suggesting they might have survived the trawling impacts.

In the North-Pacific, this fragility has been observed on the Emperor Seamount Chain, North-western Hawaiian Ridge, where extensive mapping by autonomous underwater vehicles revealed vast barren areas, scars on the seabed, and coral stumps, with very few observations of the

coralliid octocorals that formerly supported the world's largest precious coral fishery (Baco et al., 2020). Here, coralliid octocorals have been used as indicator taxa to assess the recovery state of seamounts following trawling activities (Baco, Morgan, et al., 2023). Research indicates that two seamounts still subjected to trawling have been unable to recover under current levels of fishing (Baco, Morgan, et al., 2023).

In the North Atlantic, Waller et al. (2007) surveyed the summits of two seamounts in the Corner Rise complex about 10 years after trawling ceased. The summits were denuded of large sessile fauna with small specimens of sponges and plexaurid corals, most less than 15 cm in height. In the Azores, fishermen report that coral bycatch is most prevalent across seamounts and that there has been a decline in coral bycatch over time, indicating habitat impacts from repeated fishing activities (Sampaio et al., 2012). Studies in the region have shown that organisms with complex morphologies are primarily impacted, potentially causing imbalances in ecosystem dynamics and long-term alterations in community structure (Pham et al., 2014; Sampaio et al., 2012). Deep-water shark populations on seamounts are also vulnerable to deep-sea fishing. Research on the Hatton Bank coral habitats revealed that discards from bottom longlines at depths of 750-1500 metres primarily consist of adult vulnerable sharks, contributing 84% of the total weight (Muñoz et al., 2012). Sharks are highly susceptible to being captured in intricate coral habitats, because such areas likely support greater shark abundance compared to other locations (Muñoz et al., 2012). Overall, the profound and long-lasting impacts of deep-sea trawling on seamounts are evident and underscore their fragility, emphasising the need for careful management and protection of these vulnerable ecosystems.

Seamounts are also becoming increasingly vulnerable to climate change (Jones et al., 2014; Ross et al., 2020). Globally, 82% of the 33,452 seamounts are projected to experience declines in biomass due to climate change (Jones et al., 2014). In the South Pacific, biomass reductions are expected on seamounts that support major fisheries already under significant pressure from heavy exploitation and human activities (Jones et al., 2014). A study of 47 seamounts in the Northeast Pacific revealed significant long-term chemical changes, including an expanding oxygen minimum zone (OMZ), a 15% decline in deep oxygen levels since 1960, and increasingly corrosive waters above the OMZ (Ross et al., 2020). The authors suggest that VME indicator species, particularly cold-water corals, are likely to face compounded impacts on their distribution, metabolism, growth, and reproduction, potentially threatening their survival or leading to local extinctions.

FAO Criteria 4 – Life-history traits of component species that make recovery difficult

“Ecosystems that are characterised by populations or assemblages of species with one or more of the following characteristics: slow growth rates; late age of maturity; low or unpredictable recruitment; or long-lived.”

Slow growing and fragile hard bottom communities on seamounts have been living in one place for centuries or even millennia (Fosså et al., 2002). For example, deep-sea corals can live for thousands of years, with individual seamount colonies of the gold coral *Gerardia* dated at 2,742 years and the oldest known specimen of black coral aged at 4,265 years (Roark et al., 2009). The

growth rates of these genera are extremely low, ranging from 4 to 35 μm per year (Roark et al., 2009). On the Tasmanian seamounts, *Solenosmilia variabilis* has been present for at least the last 47,000 years, with modern specimens exhibiting growth rates of 0.84 to 1.25 millimetres of linear extension per year (Fallon et al., 2014).

However, recruitment patterns in cold-water coral communities remain largely unknown, with reproductive aspects documented for only 4% of all known species (Waller et al., 2023). Research on the Tasmanian seamounts has shown that three species of scleractinians have effective population sizes of just 20-60 individuals (Zeng et al., 2017), indicating that only a few colonies contribute to reproduction. This makes these species extremely vulnerable to human impacts. The lack of understanding of this fundamental reproductive process limits our ability to gauge the capacity of coral species to recover from disturbances (Waller et al., 2023).

Seamount fisheries typically last only a decade often leading to overfishing, as seen in the Pelagic armorhead fishery on the Emperor Seamounts and the Orange roughy fishery on the Tasmanian Seamounts (Clark & Koslow, 2007). Similar depletion patterns have been documented across other seamounts, such as the Madeira-Canary, South Azores, Ob and Lena, Corner Rise, and Namibian seamounts (Clark & Koslow, 2007). Deep-sea fish, characterised by their longevity, late reproductive age, and low fecundity, exhibit reduced reproductive outputs, particularly as habitat depth increases (Drazen & Haedrich, 2012). Consequently, the potential for population growth declines with habitat depth. These characteristics render deep-sea fish populations particularly vulnerable to overfishing and significantly limit their capacity for rapid recovery. Many species that inhabit seamounts also tend to aggregate socially, which increases their vulnerability, as fishing often removes spawning individuals, hindering population replenishment and making these species prone to rapid depletion (Morato et al., 2006). For instance, species such as the orange roughy and roundnose grenadier, which inhabit seamounts, can live for over 200 years and 60 years, respectively (Horn & Maolagáin, 2019; Kelly et al., 1997). Both species are listed on the IUCN's Red List due to significant population declines from intensive deep-sea fishing, with the orange roughy classified as Vulnerable in the North Atlantic and the roundnose grenadier as Critically Endangered (Collette et al., 2015; Iwamoto, 2015).

FAO Criteria 5 – Structural complexity

“An ecosystem that is characterised by complex physical structures created by significant concentrations of biotic and abiotic features. In these ecosystems, ecological processes are usually highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms.”

On seamounts, there are significant concentrations of both biotic and abiotic features. The seamount landscape itself comprises complex geomorphological structures, primarily composed of basalt rock, forming ridges and flat plains, as well as vertical cliffs with slopes of varying angles. This diverse landscape creates highly heterogeneous habitats that support abundant populations of habitat-forming species, such as deep-sea corals, sponges, and other vulnerable organisms (Auster et al., 2005).

Deep-sea sponges are vital in linking benthic and pelagic zones, facilitating energy, mass, and nutrient exchange. Their abundance suggests they significantly influence global biogeochemical cycles, including the marine silicon cycle (Hanz et al., 2022; Maldonado et al., 2019). Through filtration, sponges contribute to nitrogen cycling, help maintain oxygen levels in deep waters (Pham et al., 2019), and support benthic food webs by producing detrital waste and recycling dissolved organic matter (Bart et al., 2021). At Schulz Bank, several sponge species actively remove bioavailable nutrients such as ammonium and nitrate from the marine ecosystem through denitrification and coupled nitrification–denitrification processes (Rook et al., 2020). Recently, extensive sponge grounds exceeding 15 km² were discovered on the Karasik Seamount in the Arctic Ocean, representing the most northerly and densest *Geodia* community documented to date (Morganti et al., 2022). These sponge grounds play a crucial role in local biodiversity, hosting a rich variety of fauna, including octocorals and bryozoans, while also contributing to benthic-pelagic coupling and biogeochemical cycles (Morganti et al., 2022).

An analysis of over 5,000 seafloor images reveals that the average biomass of epibenthic megafauna on 20 seamounts in the southwest Pacific is nearly four times higher than that of the adjacent continental slope at comparable depths (Rowden et al., 2010). Diverse seamount communities in Australia and New Zealand, for example, are associated with a matrix formed over geological times by the scleractinian coral *Solenosmilia variabilis* (Williams et al., 2010). Rowden et al. 2017 found that starfish and crinoids exhibit parallel distribution to that of the stony coral *Solenosmilia variabilis* over several seamounts. On the Louisville Seamount Chain, camera tows repeatedly recorded VME indicator species with corals being observed at depths deeper than anticipated (Clark et al., 2014).

Further evidence suggests that seamount assemblage structures can differ from neighbouring habitats. For example, coral assemblages on North-East Atlantic seamounts are distinct from those on the continental slope (Hall-spencer et al., 2007). The relative abundance of taxa between Davidson Seamount and the adjacent slope is markedly different (McClain et al., 2009). Additionally, equivalent samples of ophiuroids in terms of depth and area showed different community compositions between seamounts and nearby continental slope areas. This variation is due to certain ophiuroid species on seamounts being repeatedly associated with *Solenosmilia variabilis* and a higher presence of cryptic species (O’Hara et al., 2008).

In addition to providing habitat for a wide array of species, seamounts could play a crucial role in deep-sea ecological processes by facilitating long-distance dispersal across ocean basins (Rowden, Dower, et al., 2010). Their vibrant communities may also serve as larval sources for nearby non-seamount habitats, contributing to ecological connectivity and enhancing regional biodiversity in deep-sea environments (McClain et al., 2009). For example, in the Tasmanian Seamount Region, the cold-water coral *Desmophyllum dianthus* exhibits gene flow across hundreds of kilometres, with intermediate seamounts acting as "stepping stones" for its widespread distribution (Miller & Gunasekera, 2017). Conversely, the same study found that *Solenosmilia variabilis* shows high genetic differentiation among populations from different seamounts over small spatial scales, supporting the idea that seamounts function like isolated islands in the deep ocean, at least for this species.

Beyond the benthos, some seamounts possess unique physiographic and biological characteristics of considerable value to ocean systems that can influence species diversity at spatial scales as far as 40 km from summits (Fiori et al., 2016; Morato et al., 2010). Numerous studies have demonstrated relationships between seamount summit depths and productivity, with shallower summits, particularly those within the euphotic zone (<200–400 m), inducing substantial changes in benthic assemblage structure and supporting higher abundances of pelagic species (Hann et al., 2016; McClain & Lundsten, 2015; Morato et al., 2008). A recent study suggests that seamounts are crucial in the active transport loop of organic matter from the euphotic zone downward to the mesopelagic-benthic zone through the daily migration of zooplankton, influencing depths up to 600 metres and extending their impact over 30 kilometres horizontally (Wang et al., 2024). This transportation of organic matter to the depths induces ecological oases within the oligotrophic areas (Wang et al., 2024). On a global scale, nearly half of seamounts with summit depths above 100 m exhibit long-term, persistent, seamount-induced chlorophyll enhancements (Leitner et al., 2020). These productivity enhancements enable seamounts to support greater biomass (Morato et al., 2006). A large-scale analysis using fisheries data from the Pacific found that seamounts have higher pelagic megafauna species richness than coastal or oceanic areas (Morato et al., 2010). Species such as tunas, sharks, and other pelagic fish are attracted to seamounts, where they aggregate, and it is likely that seamounts serve as migratory pathways (Morato et al., 2010).

Seamounts are increasingly recognised as critical features in a rapidly changing seascape, not only for their vulnerability but also for their potential to act as refuges. Their slopes may help mitigate the effects of ocean warming on benthic fauna by providing migration routes that allow species to stay within their thermal limits (Tittensor et al., 2010). Additionally, remote seamounts serve as some of the last refuges for marine predators in the Indo-Pacific, offering protection from human pressures (Letessier et al., 2019).

The variability within seamounts, driven by their different shapes, summit depths, sizes, locations, and evolutionary histories, leads to these features altering their local environments in distinct ways, even in neighbouring areas (Rowden et al., 2005). Clark et al. (2011) developed a classification system using biological and environmental data, dividing the estimated 10,604 large seamounts globally into 194 groups spread across 14 bathyal biogeographic provinces as identified by Watling et al. (2013). For instance, in the biogeographic province where the Louisville seamounts are located, there are 517 seamounts categorised into 17 distinct groups. This classification illustrates the differences in biological communities on seamounts within the same bathyal or abyssal province and region, highlighting the structural complexity of seamount ecosystems despite hosting similar higher-level taxa.

5. Policy and Regulatory Frameworks for Seamount Protection as VMEs

The conservation of deep-sea biodiversity on the high seas, including the protection of seamounts, dates to 2004 with States committing to several UNGA resolutions (including paragraphs 119 and 120 of resolution 64/72). That year, CBD COP 7 Decision VII/5

recommendations stressed the urgency for rapid action to address threats on the basis of the precautionary approach and the ecosystem approach, in marine areas beyond the limits of national jurisdiction, in particular areas with seamounts, hydrothermal vents, and cold water corals, and other vulnerable ecosystems and certain other underwater features, resulting from processes and activities in such areas.

With limited progress, the 2021 UN's 2nd World Ocean Assessment highlighted that *“Fishing, especially bottom trawling, constitutes the greatest current threat to seamount ecosystems”* (Keynote points, pg. 439) (Clark et al., 2021). In 2022, reiterating the need to implement actions from previous resolutions, the UNGA resolution 77/118 urged States to take immediate action *“to sustainably manage fish stocks and protect vulnerable marine ecosystems, including seamounts, hydrothermal vents and cold water corals, from fishing practices with significant adverse impacts on vulnerable marine ecosystems, recognizing the immense importance and value of deep-sea ecosystems and the biodiversity they contain, as documented in the first World Ocean Assessment”* (UNGA, 2022).

Resolution 77/118 also reminds States to rely on the best available scientific information to ensure the wide application of the precautionary and ecosystem approaches. It emphasises that VMEs must be protected from the significant adverse impacts of bottom fishing, and that adequate measures remain in place until the knowledge gaps highlighted in previous resolutions are addressed, impact assessments consistent with the FAO Guidelines are conducted, and the actions called for in both the 2022 and previous UNGA resolutions are effectively implemented. The resolution calls for assessing the impacts of bottom fisheries on all species associated with or dependent on VMEs, emphasising comprehensive biodiversity protection rather than merely protecting percentages of overall taxonomic groups.

It is worth noting that the vulnerability of seamounts and the urgent need for their conservation were first highlighted 20 years ago. Both the UNGA (Table 1) and the CBD have established standards to which Member States have committed, requiring them to pursue sustainable development and biodiversity conservation, including the conservation of seamounts. The 2004 IUCN Resolutions also emphasised the protection of seamounts in the high seas, recognising their ecological importance as biodiversity hotspots (IUCN, 2004). Meanwhile, research studies on seamounts have documented that the recovery period following significant adverse impacts from bottom trawling extends well beyond what can be considered temporary. According to the FAO Guidelines, temporary impacts are defined as those occurring over a temporal scale of 5-20 years (FAO, 2009). However, no recovery has been observed within this timeframe (Goode et al., 2020). In the North Pacific, signs of recovery on seamounts have only been observed after 30-40 years of protection, highlighting the significant adverse impacts that occurred but also demonstrating that long-term protection can potentially lead to recovery (Baco et al., 2019). Similarly, in the South Pacific, evidence suggests that certain seamount coral communities are in the early stages of post-trawling recovery 20 years after closures (Goode et al., 2024)

Despite the well-documented vulnerability of seamounts to bottom trawling (Goode et al., 2020), the implementation of seamount protection by RFMOs remains inconsistent. Using the UNGA resolutions and the FAO Guidelines as a reference, certain RFMOs have acknowledged the

importance of seamount protection. For instance, the Northwest Atlantic Fisheries Organization (NAFO) has recognised seamounts as VME indicators and has implemented closures for all seamounts within its management area at fishable depths to bottom trawling (NAFO, 2022). Similarly, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) has identified seamounts as VMEs, prohibiting all trawling on the high seas in its convention area (CCAMLR, 2008). The North East Atlantic Fisheries Commission (NEAFC) has designated seamounts as VME elements (ICES, 2013), resulting in several seamount closures to bottom trawling. The General Fisheries Commission for the Mediterranean (GFCM) has also recognised seamounts as VME indicator features (GFCM, 2007). The South East Atlantic Fisheries Organisation (SEAFO) has closed at least 12 seamounts to all fishing gear (FAO, 2015). Individual States have also designated seamounts as VMEs. Fisheries and Oceans Canada (DFO) designated all Canadian Pacific seamounts as VMEs and Ecologically or Biologically Significant Areas (EBSAs) within the marine protected area (MPA) process. Following this designation, a significant Offshore Pacific Area of Interest (AOI) was established to strengthen their protection and conservation efforts (Ban et al., 2016; DFO, 2020, 2021). In 2015, Chile implemented the precautionary approach by closing its 117 seamounts to trawling (Ministerio de Economía, 2015). Nearly a decade later, a 2024 Schmidt Ocean Institute expedition to these seamounts uncovered abundant VMEs, including deep-sea coral reefs and sponge gardens, as well as the discovery of more than 100 new species to science.

Conversely, the South Pacific Regional Fisheries Management Organisation (SPRFMO), the Southern Indian Ocean Fisheries Agreement (SIOFA), and the North Pacific Fisheries Commission (NPFC) have not yet recognised seamounts as VMEs. Despite the best available scientific knowledge, these organisations have not acknowledged or adopted the precautionary approach framework to close seamounts to bottom trawl fisheries. This is notable given that these RFMOs share some of the same contracting parties who implement seamount protection measures in accordance with UNGA resolution and FAO guidelines in other ocean regions. To ensure consistent protection of VMEs, associated species, and the wider biodiversity in the deep ocean, it is important that States recognise that under the UNGA resolution and the FAO Guidelines, all seamounts are VME entities (Watling & Auster, 2017).

In cases of incomplete or uncertain data, applying the precautionary approach widely, as required by the UN Fish Stocks Agreement, ensures that decisions are based on the best available scientific evidence. This principle calls for the implementation of protective measures to prevent potential harm, even in the absence of comprehensive data.

Globally, only 1.5% (n = 581) of seamounts are located within VME closed areas, with most of these closures situated in the Atlantic Ocean (Kerry et al., 2022). However, the management of the high seas is undergoing a rapid transformation due to the BBNJ (Biodiversity Beyond National Jurisdiction) agreement. While achieving the "30 by 30" global conservation target—mandated by the CBD's Kunming-Montreal Global Biodiversity Framework (Target 3) and aimed at combating biodiversity loss, mitigating climate change, and safeguarding natural systems (CBD, 2022)—may be challenging, significant progress can still be made by leveraging existing frameworks. Protecting seamounts within RFMO convention areas can be a crucial step towards achieving these protection goals and ensuring that VMEs are fully protected, as mandated by the UNGA

resolutions. This approach enables RFMOs to exercise their competence over these areas, rather than deferring management responsibilities to the BBNJ agreement. Estimates suggest there are 22,040 seamounts on the high seas that rise at least 1,000 metres from the seabed (Kerry et al., 2022, Yesson et al., 2021), with average seamount size of 860 km² in area (Harris et al., 2014; Yesson et al., 2021). Seamount protection alone could potentially achieve roughly up to 9.4% of the "30 by 30" high seas conservation target.

Recommendations

It is recommended that the SPRFMO Scientific Committee:

1. Recognises the importance of seamounts as essential deep-sea ecosystems that provide unique habitats and significantly contribute to marine biodiversity.
2. Acknowledges that VME indicator taxa are characteristic features of seamounts.
3. Recognises that scientific evidence unequivocally supports the classification of seamounts as VMEs, based on the FAO Guidelines VME criteria - including functional significance, fragility, life-history traits of component species that make recovery difficult, and structural complexity. Therefore, seamounts should be recognised as VMEs and managed accordingly.
4. Recommend that the Commission identifies seamounts as VMEs and registers them in Annex 9 under paragraph 48 of CMM 03-2023, in alignment with UNGA resolutions concerning VMEs.
5. For seamounts lacking visual evidence of VMEs, apply a precautionary approach to safeguard seamount ecosystems.
6. Advises that the Commission develops robust protection policies to maintain the long-term sustainability of seamounts, broader deep-sea biodiversity and their ecological functions.

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