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Seamounts on the High Seas Should Be Managed as Vulnerable Marine Ecosystems

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The ecological sustainability of fishing in the deep sea, in areas beyond national jurisdiction (ABNJ), rose to the attention of the member States of the United Nations and elicited action in 2004 and then more strongly in 2006 (Gianni et al., 2011). Mounting evidence of the effects of fishing in the deep sea, such as the destruction of deep sea coral communities at sites around the globe, and the slow growth, time to maturity and tremendous age reached by some species of deep sea fish, caused many to consider the sustainability of common fishing practices. United Nations General Assembly (UNGA) resolution 61/105 in 2006 called "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 [VMEs], 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."

International Guidelines for the implementation of the UN resolution, including criteria for identifying VMEs, were negotiated under the auspices of the UN Food and Agriculture Organization and subsequently endorsed by the UN through General Assembly resolution 64/72 (FAO, 2009). This resolution committed States to manage bottom contact fisheries to "prevent significant adverse impacts on such ecosystems consistent with the Guidelines or close such areas to bottom fishing." The key concept is vulnerability and this is related to "the likelihood that a population, community, or habitat will experience substantial alteration from short-term or chronic disturbance, and the likelihood that it would recover and in what time frame. These are, in turn, related to the characteristics of the ecosystems themselves, especially biological and structural aspects. VME features may be physically or functionally fragile." Further, the "vulnerability of populations, communities, and habitats must be assessed relative to specific threats. Some features, particularly those that are physically fragile or inherently rare, may be vulnerable to most forms of disturbance, but the vulnerability of some populations, communities and habitats may vary greatly depending on the type of fishing gear used or the kind of disturbance experienced." Finally, risks to VMEs are considered based upon vulnerability as well as the probability of the threat causing adverse impacts.

While the vulnerability of seamount faunas and threats from fishing activities have been well-documented (see Clark et al., 2016 for a recent review), how we determine what areas or features are VMEs remains an open question. Indeed, this is not an easy question to answer, but certain groups of animals are especially vulnerable to fishing gear, and so have been designated as VME "indicator" species. These are groups such as deep-sea corals and sponges, bryozoans, crinoids, xenophyophores, hydrothermal vent faunas, and other taxa that are either very long-lived and/or easily removed, damaged, or killed by fishing gear or other forms of direct disturbance, have low reproductive output, and low ecological resilience (FAO, 2009; Northeast Atlantic Fisheries Commission, 2014).

Seamounts serve as habitat for a large number of VME indicator species. They are true mountains under the sea, defined as being at least 1000 m high, but often are 3 or 4 km in height. Because they usually originated as volcanos, they are principally composed of basaltic lava with exposed surfaces that provide a stable substratum on which corals, sponges, and other species settle and grow (Rogers et al., 2007; Samadi et al., 2007; Clark et al., 2012).

By rising from the surrounding seafloor to such large heights, seamounts alter the flow of ocean currents, increasing flow rate, and enhancing the delivery of food particles to the suspension-feeding animals. Flow enhancement is most pronounced along the sides near the seamount summit, but also anywhere on the seamount where there is a feature, such as a ridge or pillar, that protrudes slightly above the local seafloor. On those features high densities of corals and sponges can be found (Genin et al., 1986). In fact, seamount benthic communities are characterized globally by octocorals, hard corals, sponges, and crinoids, among other suspension feeding invertebrate groups (McClain et al., 2010; Schlacher et al., 2014). A casual perusal of seamount images from web sites such as NOAA's Ocean Explorer (http://oceanexplorer.noaa.gov/) will illustrate this broad generality. None of the seamounts explored, particularly at fishable depths (<2000 m), have failed to produce spectacular images of octocorals and sponges, many of which are new to science (e.g., Watling et al., 2011).

As part of the commitment to manage high seas bottom fisheries, the UN resolutions have also called on States to conduct prior environmental impact assessments before permitting bottom fisheries to take place [paragraph 119(a) of UNGA resolution 64/72]. These are designed to determine whether VMEs are in an area where bottom fishing would be permitted and, if so, whether the fishing could be managed to prevent significant adverse impacts on VMEs in these areas. The Guidelines stipulate that the impact assessment should include the "identification, description, and mapping of VMEs known or likely to occur in the fishing area." These criteria, as well as the criteria in the Guidelines relating to identifying VMEs and determining whether significant adverse impacts are likely or not likely to occur from bottom fishing, have been largely incorporated into legally binding regulations for the management of bottom fisheries adopted by Regional Fishery Management Organizations (RFMOs). In spite of this however, in many of the high seas areas a number of countries have permitted bottom trawling on seamounts and ridge systems without having first mapped the areas and otherwise complied with the Guidelines to determine whether VMEs occur in these areas (Gianni et al., 2016).

Instead, the approach often taken in such areas is to allow bottom fishing on large areas of seamounts and ridge systems and to "manage" the fisheries to prevent significant adverse impact by the use of a so-called "move-on" rule. This rule essentially requires that when VME indicator species are encountered the vessel must stop fishing and move some distance away from where the encounter occurred (Auster et al., 2011). The problem, of course, is how to define an "encounter" (generally based on a threshold weight or volume of an indicator species in the catch), and then stipulate how far the vessel should move (e.g., International Council for Exploration of the Seas, 2011). Such rules are established by RFMOs, bodies that are created by international treaties and governed by representatives of member nations, that are focused on managing fisheries activities on the high seas, across broad areas of the global ocean. For example, the South Pacific Regional Fisheries Management Organization (SPRFMO) extends from the vicinity of the equator in the north to 60°S, encompassing the whole of the South Pacific outside of the exclusive economic zones (EEZs) of surrounding countries.

The first encounter rules established in the NE Atlantic were based on the predominant deep sea reef-building species *Lophelia pertusa* and the large and heavy globular sponge, *Geodia* sp. Most seamounts, however, do not harbor massive reef building corals or very many dense, heavy sponges, although there are a few species in both categories in selected areas. Indeed most octocorals, sponges, bryozoans, and associated fauna in regional lists of indicator species (e.g., Northeast Atlantic Fisheries Commission, 2014) are small and, even those that are large, are exceedingly fragile (e.g., **Figure 1**). Most likely then, as the trawl goes over the bottom, the octocorals and sponges will be crushed and broken with the pieces left on the seafloor or falling through the mesh of the net (Waller et al., 2007; Williams et al., 2010; Clark et al., 2016), with the result being that the encounter limits will rarely be exceeded. Under some rules repeated encounters could eliminate the fauna of entire summit regions of seamounts without anyone knowing (Auster et al., 2011; International Council for Exploration of the Seas, 2011, 2012).

For a recent example, in the SPRFMO area, only 4 of 255 trawl tows made on the Louisville Seamounts showed "evidence of a VME" (New Zealand Ministry of Fisheries, 2008, p. 31). Some of these tows were in areas open to fishing, but others were outside the trawl footprint. A later series of camera tows on six of the Louisville Seamounts (Clark et al., 2015) recorded the presence of a number of VME indicator species, especially gorgonian octocorals and sponges, although in that report only scleractinians (hard corals) were assessed as VME indicator species, contrary to the criteria established in the International Guidelines (FAO, 2009). Under SPRFMO rules, an "encounter" with a VME indicator species (based on VME taxa scores from median weights obtained over several years of previous fisheries tows) would require the vessel to move 5 km away from the site of encounter. Since one or more typical VME indicator species were observed during virtually every camera tow, there would be nowhere on the seamount where trawling on the seafloor could occur. If a fishing vessel was required to survey with a camera an area where it wanted to trawl, rather than wait to see what comes up in the net, it would be difficult to find a place on the seamount that could be fished with bottom contact gear.

We suggest that two obvious conclusions emerge from this discussion. First, all seamounts that have so far been surveyed by

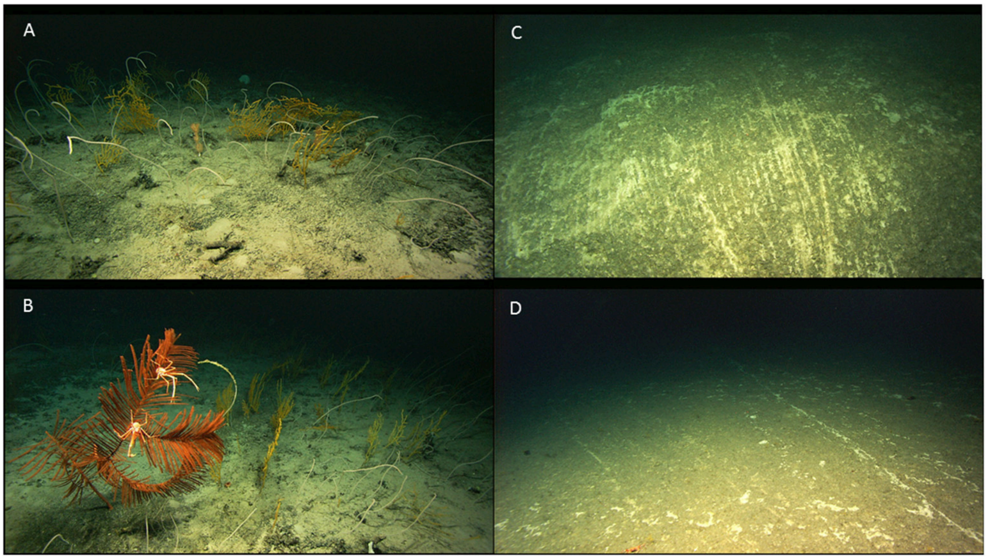

FIGURE 1 | Coral communities are widespread on the summits and upper slopes of seamounts, with an example here of a coral community from the Corner Rise seamounts in the Central Atlantic. (A) Soft coral community on the summit of Corner Seamount (1220 m) composed of *Paramuricea* sp., *Calyptrophora* sp., and *Chrysogorgia* sp., along with patches of coral rubble that form complex interstices that function as habitat for diverse taxa; **(B)** Other species in this same area, such as this black coral *Leiopathes* sp., have patchy distributions and illustrate the functional role of corals as physical habitat for other taxa, here with galatheid crabs amongst the coral branches; **(C)** Dense scars from what appear to be multiple passes of mobile fishing gear remain visible on the rock substratum along sloped peak edge at Kükenthal Seamount (725 m); **(D)** Note the absence of attached fauna, coral rubble, and sediment in both this and previous image, presumably due to repeated disturbance by mobile gear (see Waller et al., 2007 for more detail on this area).

cameras, either towed or mounted on maneuverable submersible vehicles, have been found to have abundant VME indicator species (including xenophyophores on sandy areas) distributed on their sides and summits (**Figure 1**). Second, and most important, the distribution of VME indicator species is far more extensive than fishery bycatch data would suggest. The lack of VME species in virtually all trawl catches on seamounts is due entirely to their fragility and brittleness. While some large pieces of VME species encountered might be retained in the coarse meshes of a commercial trawl net or snagged on fixed gears such as longlines, the biomass would rarely be high enough to trigger an official "encounter" as most are surely broken into small pieces and fall to the seafloor before reaching the deck of the ship (Auster et al., 2011). This must have been the case in the Louisville Seamount fishery as the towed camera data would infer.

The only rational decision, then, would be to stop using VME indicator species and associated encounter and move-on rules in particular cases such as seamounts, and accept the fact that seamounts are, in the language of UNGA resolution 61/105, VMEs, and manage them as such. They are islands of rich megafaunal biodiversity in the deep ocean, they are home to untold numbers of fragile and long-lived species that can easily be destroyed by indiscriminate trawl gear, and they also may harbor large numbers of smaller species so far undiscovered (George and Schminke, 2002). We know little about patterns of reproduction and dispersal, genetic connectivity, functional role, and the direct and indirect responses of seamount species that could be triggered by their removal (e.g., reduction or local extinction of linked coral populations and populations of associated commensal species, reduced role of corals providing prey subsidies to mobile predators with bioenergetic effects on growth and reproduction). In fact, while seamount faunas have varying degrees of heterogeneity within and between seamounts (Kvile et al., 2014; Clark et al., 2015), the degree of uncertainty associated with attempts to extrapolate limited data in order to quantify vulnerability to human activities is sufficiently large (Taranto et al., 2012), suggesting the highest levels of precaution are necessary for management. While most RFMOs have designated closures around some seamounts, the footprint of fishing remains large and many seamounts remain vulnerable to fisheries that are extending their geographic range into deep water. As true and functional VMEs, all seamounts should be protected in perpetuity from mobile bottom tending fishing gear and other forms of direct human disturbance including the mining of manganese crusts and other rare metals. International obligations under resolution 61/105, and other UNGA resolutions related to sustainable use of the global oceans and conservation of biological diversity, would make this the most rational decision.

AUTHOR CONTRIBUTIONS

The paper was conceived by LW and written by LW and PA.

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