NPFC-2024-SSC BFME05-WP18 Attachment 2

**Annotated Checklist of VME Peer-Reviewed Publications Consulted for the Scientific Basis of the US CMM Proposal [Updated 8 November 2024]**

**Papers that document the presence of Vulnerable Marine Ecosystems (VME) within the NPFC Convention Area**

* (Baco et al. 2020) provided evidence of the occurrence of VME taxa including dense patches of octocorals, scleractinian reefs, and deep-sea sponges on all four of the surveyed Northwest Hawaiian Ridge (NHR) and Emperor Seamount Chain (ESC) seamounts (Koko, Yuryaku, Kammu and Colahan). In many areas these taxa occur in sufficient abundance and densities to constitute reproductively viable populations and to be acting as habitat for other species of invertebrates and fishes. Out of the surveyed sites, areas that would qualify for VME designation based on observed abundance and density include, at a minimum, several locations on Koko Seamount, the southeast and northwest corners of Yuryaku Seamount, locations on Kammu Seamount, and the northwestern ridge of Colahan Seamount.
* (Dautova et al. 2019a) study on the deep-sea ecosystems of the Emperor Chain seamounts in the northwestern Pacific Ocean unveils crucial insights into the biodiversity and biogeography of these VMEs. The research, primarily focusing on Octocorallia corals and Hexactinellida sponges, revealed significant variations in coral fauna across latitudes and identified a biogeographic boundary within the region. Key environmental factors such as substrate type, depth, temperature, and bottom hydrodynamics were found to influence the distribution of marine life significantly. The study highlighted the biogeographic importance of the Emperor Chain, suggesting a migration of boreal Pacific species southwards and tropical species northwards along the chain. Such findings are pivotal in informing future conservation strategies enhancing the understanding and management of these unique and sensitive marine habitats.
* (Dautova et al. 2019b) documented presence of numerous VME taxa on Ojin, Jingu, and Koko Seamounts in the ESC, including Anthoathecata, Scleractinia, Antipatharia, Octocorallia, and Pennatulacea.
* (Galkin et al. 2020) observed significant diversity of VME indicator species, including Octocorallia and Hexactinellida, on Koko, Jingu, Ojin, and Nintoku Seamounts; and provides key findings that support the conservation of VMEs in the area of the Emperor Seamount Chain. It establishes a biogeographic boundary between coral faunas, which is believed to lie between 37° and 39° N, specifically around the Ōjin and Jingū guyots. This observation aligns with the previous work of Sirenko and Smirnov, which discussed the biogeographic boundaries between the boreal and Northwest Pacific regions based on echinoderm fauna analysis. Moreover, the study underscores the importance of delineating clear zoogeographic boundaries with specific reference to Hexactinellid sponges and sea urchins.
* (Miyamoto et al. 2017a) provided the number of genera of Stylasterina, Pennatulacea, Alcyonacea, Gorgonians, Antipatharia, and Scleractinia sampled based on fisheries observers, beam trawls, and dredge samples within the ESC-NHR (Suiko, Yomei, Nintoku, N. Koko, Koko, Kinmei, Yuryaku, Kammu, Colahan, and C-H Seamounts). For example, Koko Seamount, which had the most sampling hauls collected among seamounts in the study, was found to have 2 genera of Stylasterina, 2 genera of Pennatulacea, 9 genera of Alcyonacea (excluding gorgonians), 38 genera of gorgonians, 6 genera of Antipatharia, and 21 genera of Scleractinia.
* (Miyamoto and Kiyota 2017) focuses on identifying indicator taxa for VMEs in the ESC. The study used association analysis to evaluate the co-occurrence of benthic animals collected through scientific surveys. The research identified four clusters of benthic communities, each comprising sessile and mobile taxa. Gorgonians and Scleractinia were found to be effective VME indicators, co-occurring with various benthic taxa and representing key VME characteristics such as habitat provision, structural complexity, and sensitivity to disturbance. The study highlighted the importance of these taxa in representing the broader characteristics of VMEs in the ESC and NHR.
* (Baco et al. 2023) summarized knowledge of the extent of scleractinian reefs in the North Central Pacific through 2021, including occurences on Koko, Yuryaku, Kammu, and Colahan Seamounts.
* Watling et al. (2024) documented 44 octocoral haplotypes, as well as sponges, antipatharians, pennatuloids, and various other invertebrates, from numerous seamounts in the vicinity of the Main Gap 37 – 39 °N in the ESC. Eleven ROV dives were conducted in 2019, one on an unnamed seamount at the southern edge of Hess Rise, and 10 dives on seven seamounts along the Emperor Seamount Chain. Six dives were on seamounts north of the Main Gap, while four (including the dive on Hess Rise) were on the southern side. Of the six northern dives, three were at deeper depths (~2000 - 1800 m) and three were shallower (~1500 - 1100 m); of the southern dives two were at the deeper depths and two were shallower. One shallower dive occurred on Jingu Seamount, situated on the southern edge of the Main Gap. Analysis of the fauna from both collected specimens and annotations of the dive video produced four clusters that support a difference in the fauna with depth as well as across the gap. The bathyal fauna underwent a significant change from north to south across the area of the Main Gap and the adjacent Small Gap, in the area of 37 - 39 °N, covering distances as small as 75 km or as much as 400 km.

***-> Collectively these lines of evidence document the presence of Vulnerable Marine Ecosystems (VME) within the NPFC Convention Area.***

**Papers that indicate VMEs are likely to be widespread across the ESC and NHR**

* Reviewed in (Baco et al. 2020) - The most obvious is the precious coral fishery, which had some of the highest takes in the world in this region. A key target of this fishery was the “Milwaukee Banks” where a “huge bed of *Corallium* (now *Pleurocorallium*) *secundum* was discovered at 400m” in 1965. The take in this area was up to 200,000 kg of coralliids per year over the next 20 years. During this period 90% of global precious coral takes came from the NWHI/Emperor bend region [reviewed in (Grigg 2002) ]. Both *Pleurocorallium secundum* and *Hemicorallium* (formerly *Corallium*) *laauense* were the target species at depths <600 m. The abundance and density of corals required to support such a large fishery for 2 decades imply a significant concentration of coralliid octocorals more than sufficient for a VME designation.
* Besides the coralliid octocorals, a high diversity of other octocorals, antipatharians, gold corals, stylasterids, and non-hermatypic scleractinians occur in significant concentrations to depths of at least 2000 m at a number of other Hawaiian Archipelago locations that have been explored (Grigg and Bayer 1976; Baco 2007; Parrish 2007; Parrish and Baco 2007; Long and Baco 2014; Schlacher et al. 2014; Morgan et al. 2015; Parrish et al. 2017). The species composition of these communities changes with depth and can vary within a single seamount (Long and Baco 2014; Schlacher et al. 2014; Morgan et al. 2015). These taxa generally occur in hard substrate areas at densities that would qualify as VMEs. Observations of coral communities, as well as octocoral and gold coral stumps on multiple seamounts(Baco et al. 2020), support the expectation that these communities of VME taxa also occur(ed) widely on the areas beyond national jurisdiction (ABNJ) seamounts of the North Pacific.
* (Miyamoto et al. 2017a) confirmed the presence of 78 genera of deep-sea corals, including VME indicator species, in the ESC and NHR, and noted they occurred “at high frequencies and with wide vertical distribution ranges”
* (Miyamoto et al. 2017a; Dautova et al. 2019b) both noted the fauna of the southern ESC are more similar to the Hawaiian Ridge fauna, supporting the expectation that baseline communities of the ESC and NHR seamounts would be (have been) as rich in VMEs as the current communities of the protected areas of the NWHI.
* Besides octocorals and antipatharians, deep-sea scleractinian reefs were discovered at depths of 530–750 m on six ESC-NHR and US EEZ NWHI seamounts, including Koko, Yuryaku, and Kammu Seamounts (Baco et al. 2017).
* (Baco et al. 2020) observed on Colahan Seamount sufficient reef density with visible faunal associations to be considered a VME. Additionally, expansive areas of rubble on Yuryaku, Kammu, and Koko Seamounts, with patches of live corals and recovering corals suggests these VMEs were once common on those seamounts as well.
* The study by (Dautova et al. 2019a) provided substantial evidence suggesting VMEs are widespread in the ESC . The research documented a diverse range of habitats and species, including significant populations of Octocorallia corals and Hexactinellida sponges across various seamounts within the chain. This diversity, along with the detailed observations of different biotic complexes and environmental conditions, indicates a broad presence of VMEs in the region.
* (Galkin et al. 2020) provided indications that VMEs, especially as characterized by Octocorallia and Hexactinellida, are likely to be widespread in the area of the ESC. The authors indicate the presence of diverse and widespread VMEs in the area warrants further species identification and research. The research identifies a biogeographic boundary between coral faunas, presumed to be located between 37° and 39° N. The identification of clear zoogeographic boundaries, particularly with regard to hexactinellid sponges and sea urchins, suggests a complex and potentially extensive distribution of these species. This implies the presence of diverse and widespread VMEs in the area, warranting further species identification and research
* (Watling and Auster 2017) argued that all seamounts should be considered VMEs.
* The NPFC VME taxa ID guide lists 88 coral taxa, most identified only to the genus level, that occur in the western part of the convention area. Most of these taxa are listed as occurring across multiple seamounts.

***-> Collectively these lines of evidence indicate that deep-sea coral VMEs are likely to be widespread across the ESC and NHR.***

**Habitat Suitability Modeling indicate VMEs are likely to be widespread in ESC and NHR**

* (Tittensor et al. 2009; Davies and Guinotte 2011) show very high to extremely high habitat suitability for structure forming scleractinians on several currently fished NHR and ESC seamounts near the bend, especially Koko and Kammu, but also Yuryaku and Colahan.
* (Yesson et al. 2012) found extremely high habitat suitability for all 7 taxonomic groups of octocorals along the entire Hawaiian Ridge and Emperor Seamount Chain.
* In a higher resolution habitat suitability study, (Miyamoto et al. 2017b) found high habitat suitability for large octocorals in a broad depth band all the way around Colahan seamount, and in patches on Koko Seamount (the focal seamounts of their study).
* (Yesson et al. 2017) found extremely high habitat suitability for antipatharians along the entire Hawaiian Ridge and Emperor Seamount Chain.
* Cordes et al. (2023) using the highest resolution models to date, found very high habitat suitability for scleractinian reef forming species along the Hawaiian Ridge.
* Silva et al. (in prep), the first to incorporate scleractinian records from the (Baco et al. 2017) discovery of reefs, using 25m resolution data, found extremely high habitat suitability for scleractinian reef forming species along the northwestern end of the Hawaiian Ridge and into the southern end of the Emperor Seamount Chain.
* (Tong et al. 2023) Provided high resolution (500m) global HSM for 10 deep sea coral species. Of the 10 species, 6 can be found in the Pacific, 5 are Scleractinians and 1 is the octocoral *Paragorgia arborea*, a high latitude species that shows high suitability in the upper Emperors, continuing down past Koko. *Enallopsammia* is a widespread Pacific scleractinian species that shows high habitat suitability at many locations in the far end of the NHR, including Kammu and Yuryaku Seamounts and the lower end of the ESC, as well as some locations in the northern ESC. *Madrepora oculata* and *Desmophyllum (Lophelia) pertusum* (a primarily Atlantic species that has been found in the ESC-NHR) both show similar suitability at the same sites. *Solenosmilia* is a less common, primarily south Pacific scleractinian, that shows suitability at many of the same sites, with its highest suitability values on Koko, Kammu and Yuryaku. *Goniocorella* is so far primarily known from the south Pacific, but the HSM suggests it may be found on the shallowest parts of Koko and other seamounts. All seamounts of the ESC-NHR have high suitability for at least 1 species over a large portion of their area, with many seamounts have high suitability for 5 species.

***-> Collectively these lines of modeling evidence indicate an extremely high probability that deep-sea coral VMEs are widespread on all of the ESC-NHR seamounts.***

**Papers that document the occurrence of Significant Adverse Impacts (SAIs)**

* Assuming that VMEs are widespread in hard substrate areas of these seamounts as supported by the evidence above, then many lines of evidence for significant adverse impacts are documented in (Baco et al. 2019, 2020) for the NHR and ESC seamounts that are actively fished. These include 1) Large areas of hard substrate on each of the four seamounts that were devoid of fauna ((Baco et al. 2020) Figs. 7a and 8a). 2) These same areas showed numerous scars from bottom contact gear, with 19–29% of AUV survey images showing evidence of scars (Table 1). 3) Patches of coral stumps, from both gold corals and octocorals were observed (Fig. 9e). 4) Expansive areas of coral rubble from scleractinian reefs were observed on all four seamounts (Figs. 5a and 7b,e, 8b, 9a, c, 10c). 5) Evidence of both fishing and SAIs is further supplied by presence of lost gear observed on every seamount, including many observations of coral rubble in or around the nets, lines, floats, etc. entangled in corals or laying across the coral beds (Figs. 9 h, 10D, and (Baco et al. 2019)).
* (Dautova et al. 2019a) noted trawl traces and trash “in a number of places” on the top of Koko. In the areas of these anthropogenic impacts, “there is practically no bottom population”. They also note “In the shallow areas, Koko has a unique faunal coral complex as shown above. Therefore, damage or destruction of coral settlements here may be irreversible. Since there may be no similar settlements at great depths on this guyot and, therefore, there may not be a source for restoration of populations through larval settlement.”
* (Baco et al. 2020) argued evidence of SAIs on these seamounts can also be inferred from the extremely low abundances of coralliid octocorals. To have supported the high levels of and duration of coralliid harvest in this region (1960–1980s), coralliids likely were present in comparable or greater abundances to other high-density coralliid beds in the Hawaiian Archipelago. Based on data from (Parrish 2007), we can estimate densities of coralliids of 30–50 individuals per 100 m2 in hard substrate areas on the Milwaukee Banks (Kammu and Yuryaku), with substantial abundances likely on the extensive hard substrate areas of most of the other NHR and ESC seamounts at depths <600 m as well. Kammu, the larger of the Milwaukee Banks, had only 1 coralliid observed on 6 sub dives and two 30-h AUV dives (>100 h total bottom time, and well over 100 km of linear distance surveyed). Coralliids were also rare on the other surveyed seamounts, with *Pleurocorallium* nearly absent from all 4 seamounts studied (1 individual on Yuryaku) and *H. laauense* only found as small colonies in protected pockets. A density and abundance of coralliid octocorals which could support a documented fishery for over 2 decades clearly qualifies as a VME, and findings of few to no coralliids on those same seamounts 40 years after the peak of the fishery, cannot be defined as anything other than a significant adverse impact, across a significant spatial extent, to a VME taxon.
* (Baco et al. 2023) demonstrated that seamounts of the NWHR and ESC that have a history of trawling have lower abundances and smaller colony sizes of the coralliid octocorals *Hemicorallium laauense* and *Pleurocorallium secundum*. Both of these are VME indicator taxa and also former targets of fisheries in the region.
* (Baco et al. 2023) also demonstrated that some recovery is possible as outlined in the next section, however they note that “Kammu, one of the primary seamounts of the coral fishery, had only a single coralliid observed. The other primary coral fishery target, Yuryaku, had only a small number of coralliids in a steeply sloped area. These two actively Trawled seamounts do not appear to be able to recover under the current levels of fishing pressure.”
* (Auster et al. 2011) - provided some quantitative detail on how small amounts of fishing effort can easily impact seamount summits as well as the poor link between bycatch of VME indicator species and actual impacts to seafloor communities due to gear inefficiencies.

● Studies in other seamount coral beds in other parts of the world (e.g., Waller et al. 2007; Althaus et al. 2009; Clark and Rowden 2009; Williams et al. 2010) collectively indicate that bottom contact fisheries cause significant adverse impacts to VMEs

***-> Collectively these lines of evidence document the presence of Significant Adverse Impacts to VMEs on the ESC-NHR seamounts, and an extremely high probability that VMEs were widespread on all of the ESC-NHR seamounts prior to fisheries, indicating that bottom contact fisheries cause significant adverse impacts to VMEs on the NHR and ESC seamounts.***

**Papers that indicate VME Recovery is possible**

* (Baco et al. 2019) provided evidence for recovery following protection of NWHI seamounts including colonization of corals over areas with visible gear scars, coralliid and reef-forming scleractinians regrowing from fragments among the coral rubble surrounding and spilling out of lost nets, and counts of megafauna from replicated, quantitative AUV image tracks that show statistically significant higher levels of megafauna overall and higher levels of corals, on recovering seamounts in the US EEZ when compared the sites which are still trawled on the NHR and ESC.
* (Baco et al. 2020) provided additional images of remnant and/or recovering VME populations on all four currently fished seamounts. Koko and Colahan have the best developed coral communities with pockets of significant concentrations of VME taxa remaining. Kammu and Yuryaku are more heavily impacted, but have patches that suggest recovery is possible if protections are put into place. Observations included larger more mature octocoral colonies in areas with lost lines, gear and gear scars (Fig. 5f and g, 7c), observations of dense stands of remnant or recovering populations of octocorals on Koko Seamount; rare but observed images of young *Thouarella* (a primnoid octocoral) on Kammu; pockets of corals on Yuryaku; and pockets of healthy reefs on Colahan.
* (Baco et al. 2023) demonstrated that a portion of the individuals of *Hemicorallium laauense* on Koko Seamount, and a portion of the population of *Pluerocorallium secundum* on Bank 11 (a formerly trawled seamount now protected in the US EEZ), are likely to be newly recruited individuals.
* (Miyamoto and Kiyota 2017) discussed the concept of recovery in the context of VMEs, specifically relating to the fragility and slow recovery of certain taxa from physical damage. The study notes that gorgonians and Scleractinia, which are effective VME indicators, represent VME characteristics such as structural complexity and fragility, and they have a slow recovery from physical damage​​. Furthermore, the study mentions that due to their slow growth, long lifespans, and slow recovery from physical damage, cold-water corals are considered important components of VMEs. This indicates an understanding that these ecosystems, while fragile and slow to recover, have the potential for recovery if managed appropriately.​

***-> Collectively these observations provide evidence that recovery of deep-sea coral VME taxa may be possible if protections are put into place. Also, pockets of remnant VME populations exist on the currently impacted seamounts that are critically important towards the recovery process at those sites. As trawling continues any remnant populations will be further damaged or lost, reducing recovery rates and overall recovery potential.***

 **Biodiversity, Biogeographic, and Connectivity Considerations**

* In a global analysis of corals on seamounts, (Rogers et al. 2007) concluded the Hawaiian Archipelago is a biodiversity hotspot for deep sea corals (alpha diversity).
* The NPFC VME taxa ID guide lists 88 coral taxa, most identified only to the genus level, that occur in the western part of the convention area. Many of these genera are known to have multiple species represented on the ES-NHR seamounts. This also indicates a very high alpha level of biodiversity of VME indicator taxa.
* In further support of extremely high alpha diversity of VME indicator taxa, (Miyamoto et al. 2017a) noted 78 genera of deep-sea corals and that they occurred “at high frequencies and with wide vertical distribution ranges” Many of these genera are known to have multiple species represented on the ES-NHR seamounts. They also note that the fauna of the southern Emperors are more similar to the Hawaiian Ridge fauna.
* Seamounts of the Hawaiian Archipelago also show extremely high levels of beta diversity for benthic invertebrate megafauna across small depth ranges and among sides of the same seamount (Long and Baco 2014; Schlacher et al. 2014; Morgan et al. 2015; Parrish et al. 2017).
* Similar to studies of benthic megafauna, studies of fishes in the NWHI also indicate high levels of beta diversity among sides of a single seamount and that one side of a seamount may have a more similar fish community to a different seamount than to another side of the same seamount (Mejía-Mercado et al. 2019; Mejía-Mercado and Baco 2022, 2023).
* Recognizing the high levels of alpha diversity and ecological significance of the area, the Emperor Seamounts and the Northwestern Hawaiian Ridge are recognized as an EBSA by UNEP and the CBD (UNEP 2016).
* (Calder and Watling 2021) documented numerous species of hydroids and other rare invertebrates in the ESC, including: previously unclassified species from Annei Seamount, Hess Rise, and Jingu Seamount; as well as new records of rare species outside their known geographic range at Jingu Seamount. Calder and Watling (2021) also provide support for the presence of a boundary dividing distinct biogeographic provinces between Jingu and Annei Seamounts.
* (Morgan et al. 2023) examined the genetic connectivity of *Hemicorallium laauense*, an octocoral that is presumed to be one of the dominant members of the baseline VME communities of the ES-NHR seamounts based on fisheries takes. They found that at unfished sites in the Hawaiian Archipelago this species has moderate levels of inbreeding and significant genetic structure among populations. Additionally, this species showed moderate genetic structuring among populations *within a single seamount* for populations separated by as little as 3 km. Consistent with the previous bullet, this study suggests that this key species has low levels of genetic connectivity which will lead to protracted recovery times in the absence of remnant populations.
* (Dautova et al. 2019a) detailed the biodiversity and biogeography of VMEs in the ESC. The research, primarily focusing on Octocorallia corals and Hexactinellida sponges, revealed significant variations in coral fauna across latitudes and identified a biogeographic boundary within the region. Key environmental factors such as substrate type, depth, temperature, and bottom hydrodynamics were found to influence the distribution of marine life significantly. The study highlighted the biogeographic importance of the ESC, suggesting a migration of boreal Pacific species southwards and tropical species northwards along the chain. Such findings are pivotal in informing future conservation strategies enhancing the understanding and management of these unique and sensitive marine habitats.
* (Galkin et al. 2020) suggested a biogeographic boundary between coral faunas in the ESC, which is believed to lie between 37° and 39° N, specifically around the Ōjin and Jingū guyots. This observation aligns with the previous work of Sirenko and Smirnov (1989, “Correction of biogeographic frontiers in thalassobathyal of Northern Pacific by benthic fauna of the Emperor Seamount Range”, Proceedings of the IV All-Russian Conference on Geography of the World Ocean), which discussed the biogeographic boundaries between the boreal and Northwest Pacific regions based on echinoderm fauna analysis. Moreover, the study underscores the importance of delineating clear zoogeographic boundaries with specific reference to hexactinelid sponges and sea urchins.
* (Watling et al. 2024) summarized results of an expedition to test the hypothesis that a biogeographic change would be found in the vicinity of the Main Gap 37 – 39 °N in the ESC. A total of 44 coral haplotypes were observed among the 83 octocoral colonies collected. Additional taxa identified included sponges, antipatharians, pennatuloids and various other invertebrates. Analysis of community structure of the fauna from both collected specimens and annotations of the dive video produced four clusters that support a difference in the fauna with depth as well as across the gap. It was concluded that the bathyal fauna underwent a significant change from north to south across the area of the Main Gap and the adjacent Small Gap, in the area of 37 – 39 °N, covering distances as small as 75 km or as much as 400 km.
* (Baco et al. 2016) reviewed available studies of population genetics and connectivity of deep sea species across habitats and found that the mean dispersal distances for deep-sea species are about 33km, which is smaller than the distance between most of the seamounts of the ES-NHR, suggesting limited connectivity among seamount populations.

***-> Collectively these lines of evidence indicate an extremely complex spatial pattern of VME taxa both upon and between ESC-NHR seamounts, suggesting that all portions of an individual seamount and all seamounts within a network are ecologically valuable for maintenance and recovery of local and broader populations.***

**Cultural and Historical Significance of Emperor Seamounts**

* (Delgado et al. 2024) provide a review of human activities around the Emperor Seamounts, including intentional navigation by indigenous people, accidental losses at sea, Japanese vessels caught in the Kuroshio Extension, and modern-era transit, exploration, whaling, fishing, and warfare. Although they identify historical accounts of vessels sinking in the Emperor Seamounts, they do not document any wrecks. The premise of the paper is that there are undoubtedly archaeological sites in the chain, but more so that the area has intrinsic value simply given the history of human activities.

***-> Available evidence indicates that the ESC-NHR seamounts possess significant cultural and historical value with respect to human activities, pre-dating modern fishing activities.***

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