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**Observer paper submitted by The Pew Charitable Trusts and the Deep Sea Conservation Coalition**

**Review of Scientific Papers to Understand Threats and Fishery Impacts on the Northwestern Hawaiian Ridge and Emperor Seamount Chain**

# **Background**

To support the Scientific Committee’s ongoing work to address [Recommendation 4.5.1](https://www.npfc.int/system/files/2023-07/Report%20of%202022%20NPFC%20Performance%20Review.pdf) to strengthen conservation and management measures (CMMs) relating to bottom fishing and protection of vulnerable marine ecosystems (VMEs), Pew and DSCC have prepared a literature review that synthesizes research on the environmental vulnerability of and fishery-related impacts to the northwestern Hawaiian Ridge and Emperor Seamount Chain (Annex I). This review, building on efforts presented in [NPFC-2023-SSC BFME04-IP08](https://www.npfc.int/system/files/2023-12/NPFC-2023-SSC%20BFME04-IP08%20Papers%20for%20US%20CMM%202023-05%20proposal.pdf), provides additional and recent scientific research to inform Members’ discussions under Agenda Items 9.1 and 10 on the Emperor Seamount Chain and Scientific Advice on the Management of VMEs, respectively. Based on this and the previous effort, some key points were clear:

* VME taxa, including dense patches of octocorals, scleractinian reefs, and deep-sea sponges, are present across the northwestern Hawaiian Ridge and Emperor Seamount Chain. These taxa are found at densities sufficient for reproductive viability and habitat provision for other species.
* Multiple habitat suitability modeling studies suggest the likely presence of VME taxa and predict high habitat suitability for deep-sea corals in several taxonomic groups across most of the surface area of the northwestern Hawaiian Ridge and Emperor Seamount Chain.
* Bottom contact fisheries cause significant adverse impacts to VMEs on northwestern Hawaiian Ridge and Emperor Seamount Chain.
* There is evidence that recovery of deep-sea coral VME taxa may be possible if protections are put into place.
* As trawling continues, any remnant populations will be further damaged, reducing recovery rates and overall recovery potential.
* A fisheries closure is a tool that could safeguard the ecosystem and, where needed, aid in its potential recovery.

# **Annex I: Review of Scientific Papers to Understand Threats and Fishery Impacts on the Northwestern Hawaiian Ridge and Emperor Seamount Chain**

Observer paper submitted by The Pew Charitable Trusts and the Deep Sea Conservation Coalition

# **Papers documenting the occurrence of** **Vulnerable Marine Ecosystems (VME) indicator taxa**

[***Observations of vulnerable marine ecosystems and significant adverse impacts on high seas seamounts of the northwestern Hawaiian Ridge (NHR) and Emperor Seamount Chain***](https://www.sciencedirect.com/science/article/pii/S0308597X19302611?via%3Dihub) *(Baco et al., 2020)* — The paper documents VME taxa, including dense patches of octocorals, scleractinian reefs, and deep-sea sponges, across all four surveyed seamounts (Koko, Yurykau, Kammu, and Colahan) of the northwestern Hawaiian Ridge and Emperor Seamount Chain. These taxa are found at densities sufficient for reproductive viability and habitat provision for other species. Areas meeting VME designation criteria include parts of Koko, sections of Yurykau, Kammu, and the northwestern ridge of Colahan. The frequency of the observations suggests VME taxa likely extend across unexplored seamount areas beyond national jurisdiction. Historic coral fishery data show that this region produced 90% of global coral harvests since 1965, with coral fisheries records of takes indicating a significant concentration of coralliid octocorals, enough for VME designation.

[***Present knowledge of the systematics and zoogeography of the Order Gorgonacea in Hawaii***](https://scholarspace.manoa.hawaii.edu/items/21780b2b-003e-4f64-b232-9e4f10bc7891) *(Grigg and Bayer, 1976);* [***Exploration for Deep-Sea Corals on North Pacific Seamounts and Islands***](https://www.jstor.org/stable/24860153) *(Baco 2007);* [***Density and habitat of three deep-sea corals in the lower Hawaiian chain***](https://www.researchgate.net/publication/233618737_Density_and_habitat_of_three_deep-sea_corals_in_the_lower_Hawaiian_chain) *(Parrish 2007);* [***Chapter 4 — State of Deep Coral Ecosystems in the U.S. Pacific Islands Region: Hawaii and the U.S. Pacific Territories***](https://www.researchgate.net/publication/242264282_State_of_Deep_Coral_Ecosystems_in_the_US_Pacific_Islands_Region_Hawaii_and_the_US_Pacific_Territories_pp_155-194) *(Parrish and Baco, 2007);* [***Rapid change with depth in megabenthic structure-forming communities of the Makapu'u deep-sea coral bed***](https://www.sciencedirect.com/science/article/pii/S0967064513002233) *(Long and Baco, 2014);* [***Seamount benthos in a cobalt-rich crust region of the central Pacific: conservation challenges for future seabed mining***](https://onlinelibrary.wiley.com/doi/10.1111/ddi.12142)*(Schlacher et al., 2013);* [***Deep-Sea Coral Taxa in the Hawaiian Archipelago and other U.S. Pacific Islands: Depth and Geographical Distribution***](https://repository.si.edu/handle/10088/34998) *(Parrish et al., 2017);* [***Benthic megafaunal community structure of cobalt-rich manganese crusts on Necker Ridge***](https://www.sciencedirect.com/science/article/pii/S0967063715001284) *(Morgan et al., 2015)* — These papers document a high diversity and concentration of octocorals, antipatharians, gold corals, stylasterids, and non-hermatypic scleractinians—down to depths of at least 2000 meters at various explored locations in the Hawaiian Archipelago. Species composition in these communities shifts with depth and can vary within a single seamount. These taxa generally inhabit hard substrate areas at densities qualifying them as VMEs.

[***The First Data on the Structure of Vulnerable Marine Ecosystems of the Emperor Chain Seamounts: Indicator Taxa, Landscapes, and Biogeography***](https://link.springer.com/article/10.1134/S1063074019060026)*(Dautova et al., 2019)* — The paper presents a detailed study of the biodiversity and biogeography of the Emperor Chain Seamounts VMEs, focusing on significant populations of Octocorallia corals and Hexactinellida sponges across various seamounts within the chain. The study revealed that deep-sea corals and sponges dominate the macrobenthic biodiversity in these regions, showing distinct changes in coral species along a latitudinal gradient. Environmental factors such as substrate type, depth, temperature, and bottom hydrodynamics significantly influence species distribution. The study underscores the Emperor Chain’s biogeographic role, suggesting northward migration of tropical species and southward migration of boreal Pacific species along the chain. The paper provides substantial evidence suggesting that VMEs are widespread in the Emperor Chain seamounts, documenting a diverse range of habitats and species, along with the detailed observations of different biotic complexes and environmental conditions.

[***Octocorallia as a key taxon in the vulnerable marine ecosystems of the Emperor Chain (Northwest Pacific): diversity, distribution and biogeographical boundary***](https://uat.npfc.int/system/files/2020-11/NPFC-2020-SSC%20BFME01-IP07%20Octocorallia%20Emperor%20Seamounts_0.pdf) *(Dautova 2019)* — This paper presents preliminary data showing the presence of several coral taxa across three seamounts in the southern Emperor Seamount Chain.

[***Biological Investigations of Emperor Seamount Chain Using a Remotely Operated Vehicle Comanche***](https://link.springer.com/article/10.1134/S0001437020010117) *(Galkin et al., 2020)* — This study highlights the ecological significance of VMEs in the Emperor Seamount Chain area, suggests their complex and potentially extensive distribution and provides data for their conservation. Using the ROV Comanche, the study documented diverse benthic communities across the summit and upper slopes of southern seamounts, with a particular focus on habitat-providing species such as gorgonians and sponges. A biogeographic boundary for coral fauna was identified between 37° and 39° N (around the Ōjin and Jingū seamounts), further reinforced by distinct distributions of hexactinellid sponges and sea urchins. The study underscores the need for targeted conservation strategies within these zoogeographic zones.

[***Application of association analysis for identifying indicator taxa of vulnerable marine ecosystems in the Emperor Seamounts area, North Pacific Ocean***](https://www.sciencedirect.com/science/article/abs/pii/S1470160X17301462) *(Miyamoto and Kiyota, 2017)* — This study confirms the presence of the VME taxa in the Emperor Seamount area and examines the ability of indicator taxa for VMEs in the Emperor Seamounts area to represent the local benthic communities. Using association analysis to evaluate the co-occurrence of benthic animals collected through scientific surveys, the research identifies four clusters of benthic communities, each containing both sessile and mobile benthos. Gorgonians and Scleractinia emerged as effective VME indicators, co-occurring with diverse benthic taxa and embodying VME characteristics such as habitat provision, structural complexity, and resilience to anthropogenic disturbances. The study underscores the significance of these taxa in reflecting the broader ecological traits of VMEs in the area.

[***Megafaunal composition of cold-water corals and other deep-sea benthos in the southern Emperor Seamounts area, North Pacific Ocean***](https://www.jstage.jst.go.jp/article/galaxea/19/1/19_19/_article) *(Miyamoto et al. 2017b)* — This paper documents the presence of numerous coral VME taxa on the seamounts of the northwestern Hawaiian Ridge and Emperor Seamount Chain, based on data from fisheries observers, beam trawls, and dredge samples. In further support of extremely high alpha diversity of VME indicator taxa, the study notes 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 northwestern Hawaiian Ridge and Emperor Seamount Chain seamounts. Additionally, the study highlights that the fauna of the southern Emperor seamounts closely resembles that of the Hawaiian Ridge.

[***Megafaunal composition of cold-water corals and other deep-sea benthos in the southern Emperor Seamounts area, North Pacific Ocean***](https://www.jstage.jst.go.jp/article/galaxea/19/1/19_19/_article) *(Miyamoto et al. 2017b);* [***The First Data on the Structure of Vulnerable Marine Ecosystems of the Emperor Chain Seamounts: Indicator Taxa, Landscapes, and Biogeography***](https://link.springer.com/article/10.1134/S1063074019060026)*(Dautova et al., 2019)* — These studies note that the fauna of the southern Emperors are more similar to the Hawaiian Ridge fauna, supporting the expectation that baseline communities of the ES-NHR seamounts would be (have been) as rich in VMEs as the current communities of the protected areas of the NWHI.

[***Defying Dissolution: Discovery of Deep-Sea Scleractinian Coral Reefs in the North Pacific***](https://www.nature.com/articles/s41598-017-05492-w) *(Baco et al., 2017) —* This paper reports the discovery of live scleractinian reefs on six seamounts in the Northwestern Hawaiian Islands and Emperor Seamount Chain, found at depths of 535–732 meters, below the aragonite saturation horizon (ASH), where high carbonate dissolution usually prevents reef formation. This unexpected finding suggests additional factors, like chlorophyll levels and currents, may support reef development, though they don’t fully explain the depth distribution. The discovery raises ecological concerns, as most reefs occur on actively trawled seamounts and show damage from fisheries gear, highlighting the need for further research and conservation efforts.

[***Chapter 10 — Deep-Sea Corals of the North and Central Pacific Seamounts***](https://link.springer.com/chapter/10.1007/978-3-031-40897-7_10#citeas) *(Baco et al., 2023)* summarizes knowledge of the extent of scleractinian reefs and explores the distribution and biodiversity of dense deep-sea coral ecosystems across seamounts in the North and Central Pacific. The chapter highlights their ecological importance, noting high biodiversity and habitat support for diverse marine life. It underscores conservation needs, given these corals' vulnerability to fishing and potential deep-sea mining. This baseline study calls for further research to understand environmental factors influencing coral distribution and to inform sustainable management strategies in these fragile marine ecosystems.

[***Report on hydrozoans (Cnidaria), excluding Stylasteridae, from the Emperor Seamounts, western North Pacific Ocean***](https://pubmed.ncbi.nlm.nih.gov/33903436/) *(Calder and Watling, 2021)* offers a detailed description of hydroids, alongside numerous specimens of octocorals and sponges, observed in the Emperor Seamounts area. Based on data collected during a biological expedition in summer 2019, it provides a taxonomic account of these species, establishing a critical baseline for understanding the largely undocumented hydrozoan biota in this area.

[***Finding boundaries in the sea: The Main and Small Gap of the Emperor Seamount Chain as a biogeographic boundary for bathyal benthic fauna***](https://www.sciencedirect.com/science/article/abs/pii/S0967064524000389) *(Walting et al. 2024)* — This study summarizes findings from a 2019 expedition designed to test the hypothesis of a biogeographic change near the Main Gap (37–39°N) along the Emperor Seamount Chain. Researchers conducted eleven ROV dives: one on an unnamed seamount at the southern edge of Hess Rise, and ten others across seven seamounts within the Emperor Seamount Chain. Six dives were completed north of the Main Gap and four on the southern side (including the dive on Hess Rise). Of the northern dives, three were at greater depths (~2000–1800 m) and three at shallower depths (~1500–1100 m). Similarly, southern dives included two deeper and two shallower dives, with one shallower dive on Jingu Seamount, located at the southern edge of the Main Gap. Analysis of both collected specimens and dive video annotations revealed four distinct faunal clusters, supporting differences in community composition by depth and across the Main Gap. The study concludes that bathyal fauna underwent a significant change from north to south across the Main Gap and the adjacent Small Gap, spanning distances from 75 to 400 km in the 37–39°N area.

[***Seamounts on the High Seas Should Be Managed as Vulnerable Marine Ecosystems***](https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2017.00014/full) *(Watling and Auster, 2017)* — The study argues that all seamounts surveyed to date using cameras show abundant populations of VME indicator species, including xenophyophores on sandy areas across their sides and summits. The distribution of VME species is far greater than indicated by fishery bycatch data. Given seamounts’ high susceptibility to damage from activities like fishing and mining, their ecological vulnerability, and their slow recovery, managing these areas as VMEs is essential for their protection.

[**NPFC VME taxa identification guide**](https://www.npfc.int/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.

Due to the area's high alpha diversity and ecological significance, the Emperor Seamounts and Northwestern Hawaiian Ridge have been designated as an [**Ecologically or Biologically Significant Area (EBSA**](https://chm.cbd.int/database/record?documentID=204131&_gl=1*fy4hty*_ga*NTQwOTQ1OTI5LjE3MjExNzk4ODM.*_ga_7S1TPRE7F5*MTczMTA0NDc1MS4xNS4xLjE3MzEwNDU2NTIuMi4wLjA.)**)** by UNEP and the CBD (UNEP 2016). The records indicate that the following papers were examined for the EBSA summary report, supporting the presence of widespread VMEs, among other: [***Habitat-forming deep sea corals in the Northeast Pacific Ocean***](https://marine-conservation.org/archive/mcbi/Etnoyer_and_Morgan_2005.pdf) *(Etnoyer and Morgan, 2005);* [***Decapod crustacea from the Emperor Seamount Chain***](https://www.jstage.jst.go.jp/article/rcustacea/8Suppl/0/8Suppl_KJ00003289387/_article) *(Sakai 1978);*[***Living Benthic Foraminifera of the Hess Rise and Suiko Seamount, Central North Pacific***](https://www.sciencedirect.com/science/article/abs/pii/S0967063700000819) *(Ohkushi and Natori, 2001).*

# **Habitat suitability modeling papers indicating VMEs are likely to be widespread**

[***Predicting global habitat suitability for stony corals on seamounts***](https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2699.2008.02062.x) *(Tittensor et al., 2009);* [***Global Habitat Suitability for Framework-Forming Cold-Water Corals***](https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0018483) *(Davies and Guinotte, 2011)* — these studies identified suitable habitats for structure-forming scleractinians on several fished seamounts along the northwestern Hawaiian Ridge and Emperor Seamount Chain, particularly around the bend near Koko and Kammu, as well as Yuryaku and Colahan.

[***Global habitat suitability of cold-water octocorals***](https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2699.2011.02681.x) (Yesson et al., 2012) — this study found extremely high habitat suitability for all 7 taxonomic groups of octocorals across most of the surface areas of the entire Hawaiian Ridge and Emperor Seamount Chain.

[***Effects of Bathymetric Grid-Cell Sizes on Habitat Suitability Analysis of Cold-water Gorgonian Corals on Seamounts***](https://www.tandfonline.com/doi/full/10.1080/01490419.2017.1315543) *(Miyamoto et al., 2017a)* — this paper identified high habitat suitability for large gorgonians in a broad depth band all the way around Colahan seamount, and in patches on Koko Seamount (the focal seamounts of the study).

[***The global distribution of deep-water Antipatharia habitat***](https://www.sciencedirect.com/science/article/pii/S096706451500435X) *(Yesson et al., 2017)* — this study pointed out extremely high habitat suitability for antipatharians along the entire Hawaiian Ridge and Emperor Seamount Chain.

[***Chapter 1 — A Global View of the Cold-Water Coral Reefs of the World***](https://link.springer.com/chapter/10.1007/978-3-031-40897-7_10) *(Cordes et al., 2023)* — This study, using the highest-resolution models to date, found exceptionally high habitat suitability for scleractinian reef-forming species along the Hawaiian Ridge.

[***Environmental drivers and the distribution of cold-water corals in the global ocean***](https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2023.1217851/full) *(Tong et al. 2023)* — This paper presents the highest-resolution (500m) global Habitat Suitability Model (HSM) for ten deep-sea coral species. Among these species, six are found in the Pacific, including five reef-forming scleractinians and the octocoral *Paragorgia arborea*, high-latitude species that show high habitat suitability across the upper Emperor Seamounts, extending past Koko. *Enallopsammia* is a widespread Pacific scleractinian species that shows high habitat suitability across numerous sites in the far end of the Northwestern Hawaiian Ridge, including Kammu and Yuryaku and lower end of the Emperor Seamounts, along with locations in the northern Emperors. *Madrepora oculata* shows high suitability at similar sites. *Desmophyllum (Lophelia) pertusum* is a primarily Atlantic species that has been found in the Northwestern Hawaiian Ridge and Emperor seamounts, showing suitability at the same sites. *Solenosmilia* is a less common, primarily south Pacific scleractinian, that exhibits moderate suitability across several of the same sites, with the highest suitability values on Koko, Kammu and Yuryaku. Additionally, *Goniocorella,* typically found in the South Pacific, may potentially inhabit the shallowest parts of Koko and a few other seamounts based on HSM predictions. A consensus model for all five Pacific scleractinian species (excluding Goniocorella) suggests that each seamount in the Northwestern Hawaiian Ridge and Emperor Seamounts Chain region has high habitat suitability for at least one species over extensive areas, with many seamounts supporting all five species.

# **Papers documenting occurrence of significant and adverse impacts (SAIs)**

[***Observations of vulnerable marine ecosystems and significant adverse impacts on high seas seamounts of the northwestern Hawaiian Ridge (NHR) and Emperor Seamount Chain***](https://www.sciencedirect.com/science/article/pii/S0308597X19302611?via%3Dihub) *(Baco et al., 2020);* [***Amid fields of rubble, scars, and lost gear, signs of recovery observed on seamounts on 30- to 40-year time scales***](https://www.science.org/doi/10.1126/sciadv.aaw4513) *(Baco et al., 2019)* — These papers document significant adverse impacts (SAIs) from bottom-contact fisheries across actively fished areas of the northwestern Hawaiian Ridge and Emperor Seamount Chain. Evidence includes extensive barren hard substrates scarred by bottom contact gear, stumps of arborescent corals, rubble from reef-forming corals, and lost fishing gear observed on every seamount surveyed. Additionally, SAIs are inferred from the extremely low abundances of coralliid octocorals, which were once abundant enough on these seamounts to support the world’s largest coral fishery.

[***Recent fishing footprint of the high-seas bottom trawl fisheries on the Northwestern Hawaiian Ridge and Emperor Seamount Chain: A finer-scale approach to a large-scale issue***](https://www.sciencedirect.com/science/article/pii/S1470160X20309900) ***(****Morgan and Baco, 2021)* – Researchers used satellite AIS data and Global Fishing Watch algorithms (2012–2018) to study trawling impacts on the Northwestern Hawaiian Ridge and Emperor Seamounts. They highlighted trawling as historically destructive, disturbing marine life, altering sediments, and reducing ecological diversity. Drifting longlines accounted for 84.43% of fishing activity, while trawling comprised just 1.31%, occurring mostly between 300–1000 meters.

[***Bottom-contact fisheries disturbance and signs of recovery of precious corals in the Northwestern Hawaiian Islands and Emperor Seamount Chain***](https://www.sciencedirect.com/science/article/pii/S1470160X23001528) *(Baco et al., 2023)* — This paper reports a decline in the abundance of coralliid octocorals *Hemicorallium laauense* and *Pleurocorallium secundum* on the areas of northwestern Hawaiian Ridge and Emperor Seamount Chain with a history of trawling. The study demonstrates lower abundances and smaller colony sizes of these species, which are VME indicator taxa and former fishery targets in the region.

[***Octocorallia as a key taxon in the vulnerable marine ecosystems of the Emperor Chain (Northwest Pacific): diversity, distribution and biogeographical boundary***](https://uat.npfc.int/system/files/2020-11/NPFC-2020-SSC%20BFME01-IP07%20Octocorallia%20Emperor%20Seamounts_0.pdf) *(Dautova 2019)* — This study reports the presence of trawl marks and trash “in a number of places” across the summit of Koko Guyot. In the areas of these anthropogenic impacts, the research indicates “practically no bottom population”. The authors also highlight that Koko’s shallow regions host “a unique faunal coral complex”. Damage or destruction of these coral communities could be irreversible, as there are likely no similar habitats at greater depths on the guyot to serve as sources “for restoration of populations through larval settlement.”

[***Chapter 23 - Threats to Seamount Ecosystems and Their Management***](https://www.sciencedirect.com/science/article/abs/pii/B9780128050521000188)*(Rogers 2019)*– This book chapter reviews seamount biodiversity and the severe impact of bottom fishing, identifying it as the greatest threat to these ecosystems. Industrial fishing, particularly in the 1960s and 1970s, led to extensive depletion, with over 800,000 tons of pelagic armorhead harvested from the Emperor Seamounts since the late 1960s. Pink corals, including *Pleurocorallium (Corallium) secundum*, were intensively exploited, with annual catches dropping from over 550 tons in 1981 to less than 5 tons by 2014. The author concludes that due to “both the failure of the fishery and the lack of evidence of surviving coral patches in the area” the seamount ecosystem showed little recovery even decades later.

[***Bathymetric segregation among demersal benthos and its contributions to the differences in the bycatches on bottom fisheries in the Emperor Seamounts area, Northwestern Pacific Ocean***](https://www.sciencedirect.com/science/article/pii/S2352485523004516)*(Osawa et al., 2023)* – This study examines the effects of fishing operations and investigates the distribution patterns of demersal benthic species using data collected during fishing trips. It focused on the bycatch of four VME indicator taxa designated by the NPFC: three coral types—Antipatharia, Scleractinia, and Alcyonacea—and sponges (Porifera). Analyzing bycatch trends from bottom trawls and gillnets, the study revealed distinct bycatch patterns between the two fishing gears, suggesting that gear-specific conservation measures, such as encounter thresholds, could improve VME management. However, bycatch trends also varied across vessels, even with similar gear. Depth, topography, geographic location, and bathymetric range were found to influence bycatch more than gear type.

[***Anthropogenic impacts on the Corner Rise seamounts, north-west Atlantic Ocean***](https://www.cambridge.org/core/journals/journal-of-the-marine-biological-association-of-the-united-kingdom/article/abs/anthropogenic-impacts-on-the-corner-rise-seamounts-northwest-atlantic-ocean/01FCFE2B43B936959A4B21E51F57F649) *(Waller et al., 2007);* [***Effect of deepwater trawling on the macro-invertebrate assemblages of seamounts on the Chatham Rise, New Zealand***](https://www.sciencedirect.com/science/article/pii/S0967063709000776) *(Clark and Rowden, 2009*[***); Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting***](https://www.researchgate.net/publication/250219632_Impacts_of_bottom_trawling_on_deep-coral_ecosystems_of_seamounts_are_long-lasting) *(Althaus et al., 2009);* [***Seamount megabenthic assemblages fail to recover from trawling impacts***](https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1439-0485.2010.00385.x) *(Williams et al., 2010)* — These studies demonstrated that bottom-contact fisheries cause significant adverse impacts to VMEs in seamount coral beds worldwide.

# **Papers documenting signs of potential ecosystem recovery**

[***Recent fishing footprint of the high-seas bottom trawl fisheries on the Northwestern Hawaiian Ridge and Emperor Seamount Chain: A finer-scale approach to a large-scale issue***](https://www.sciencedirect.com/science/article/pii/S1470160X20309900) ***(****Morgan and Baco, 2021)* – Researchers analyzed satellite AIS data and Global Fishing Watch algorithms from 2012 to 2018 to assess trawling impacts on the Northwestern Hawaiian Ridge and Emperor Seamounts. Findings showed that biodiversity on the Yuryaku and Kammu seamounts was highest in areas with rugged terrain that had experienced minimal trawling. In contrast, on Koko Seamount, historically trawled zones—although not actively fished during the study period—still showed some overlap with existing fauna, suggesting potential recovery with reduced fishing pressure. The study concludes that while bottom-contact fishing gear harms vulnerable habitats, closing seamounts to fishing can aid conservation without substantially impacting fishery yields.

[***Amid fields of rubble, scars, and lost gear, signs of recovery observed on seamounts on 30- to 40-year time scales***](https://www.science.org/doi/10.1126/sciadv.aaw4513) *(Baco et al., 2019)* — This paper provides evidence of recovery in seamount coral communities following long-term protection. The Northwestern Hawaiian Ridge and Emperor Seamount Chain, sites of historically intensive fisheries, now display clear signs of ecological recovery on protected seamounts, which have been safeguarded for over 30 years. Observations include coral colonization over gear-scarred areas, coralliid and reef-forming scleractinians regrowing from fragments, and increased abundance of megafauna as shown by AUV image surveys. Protected sites within the U.S. EEZ exhibit higher coral and megafauna levels compared to actively trawled sites on the Hawaiian Ridge and Emperor Seamount Chain. These findings indicate that, contrary to previous assumptions, seamount deep-sea coral communities can exhibit early signs of recovery over 30- to 40-year timescales with sustained protection.

[***Observations of vulnerable marine ecosystems and significant adverse impacts on high seas seamounts of the northwestern Hawaiian Ridge (NHR) and Emperor Seamount Chain***](https://www.sciencedirect.com/science/article/pii/S0308597X19302611?via%3Dihub) *(Baco et al., 2020)* — This paper provides images of remnant and recovering VME populations across four actively fished seamounts. Koko and Colahan have well-developed coral communities with substantial VME taxa, while Kammu and Yuryaku, though more impacted, show patches suggesting potential for recovery with protection. Notable observations include mature octocoral colonies among lost gear, dense octocoral stands on Koko, young *Thouarella* (a primnoid octocoral) on Kammu, and pockets of healthy reefs on Colahan.

[***Bottom-contact fisheries disturbance and signs of recovery of precious corals in the Northwestern Hawaiian Islands and Emperor Seamount Chain***](https://www.sciencedirect.com/science/article/pii/S1470160X23001528) *(Baco et al., 2023)* — The study demonstrated that a portion of *Hemicorallium laauense* species on Koko Seamount and a segment of the *Pleurocorallium secundum* population on Bank 11 (a previously trawled seamount now protected within the U.S. EEZ) are likely newly recruited individuals.

[***Application of association analysis for identifying indicator taxa of vulnerable marine ecosystems in the Emperor Seamounts area, North Pacific Ocean***](https://www.sciencedirect.com/science/article/abs/pii/S1470160X17301462) *(Miyamoto and Kiyota, 2017)* — This paper examines the concept of VME recovery, focusing on the fragility and slow recovery of taxa like gorgonians and *Scleractinia*, key VME indicators known for their structural complexity and vulnerability to physical damage. The study suggests that, although these ecosystems are fragile and slow to recover, they hold recovery potential with proper management.

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