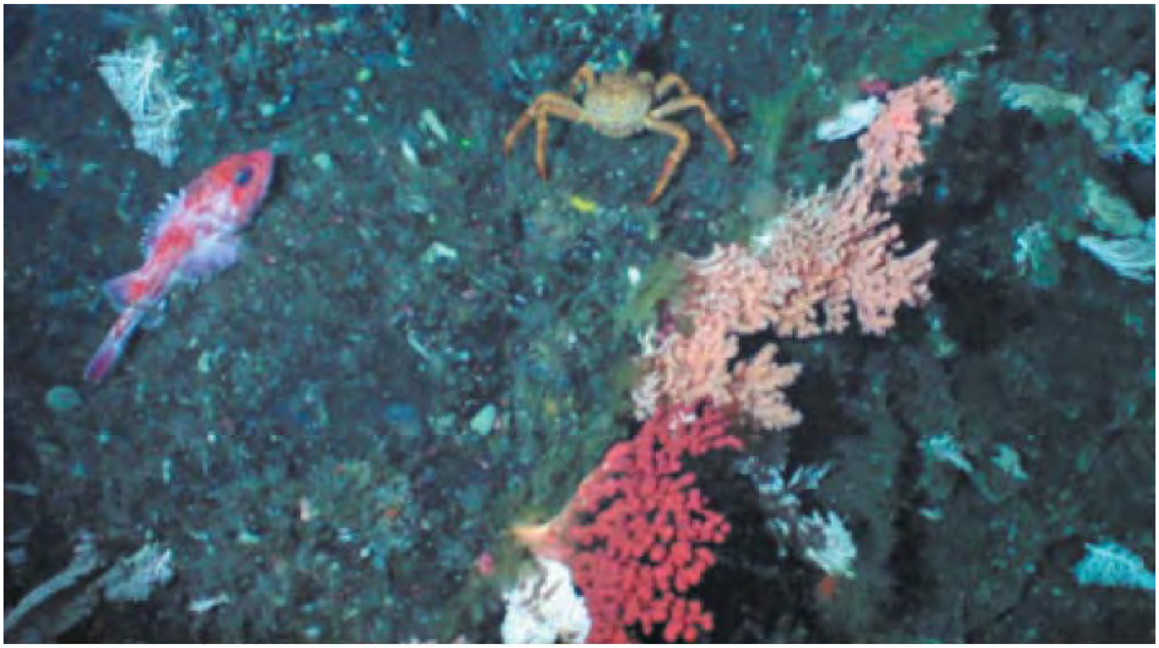
BEFORE THE SECRETARY OF COMMERCE

# PETITION TO LIST 43 CORAL SPECIES UNDER THE ENDANGERED SPECIES ACT



A shortspine thornyhead and a golden king crab rest on a bedrock ledge colonized by hydrocorals and gorgonians at a depth of 727 meters in the Aleutian Islands, Alaska. Source: Robert P. Stone (NOAA) 2005.

SUBMITTED AUGUST 20, 2012

## NOTICE OF PETITION

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Pursuant to Section 4(b) of the Endangered Species Act (“ESA”), 16 § 1533(b), Section 553(3) of the Administrative Procedures Act, 5 U.S.C. § 533(e), and 50 C.F.R. § 424.14(a), the Center for Biological Diversity (“Petitioner”) hereby petitions the Secretary of Commerce and the National Oceanographic and Atmospheric Administration (“NOAA”), through the National Marine Fisheries Service (“NMFS” or “NOAA Fisheries”), to list 43 coral species and to designate critical habitat to ensure their survival and recovery.

The Center for Biological Diversity (“Center”) is a non-profit, public interest environmental organization dedicated to the protection of native species and their habitats through science, policy, and environmental law. The Center has approximately 39,000 members, and over 378,000 members and online activists throughout the United States and internationally. The Center and its members are concerned with the conservation of endangered species, including coral species, and the effective implementation of the ESA.

NMFS has jurisdiction over this petition. This petitions sets in motion a specific process, placing definite response requirements on NMFS. Specifically, NMFS must issue an initial finding as to whether the petition "presents substantial scientific or commercial information indicating that the petitioned action may be warranted." 16 U.S.C. § 1533(b)(3)(A). NMFS must make this initial finding "[t]o the maximum extent practicable, within 90 days after receiving the petition." *Id*. Petitioner needs not demonstrate that the petitioned action *is* warranted, rather, Petitioner must only present information demonstrating that such action *may* be warranted. While Petitioner believes that the best available science demonstrates that listing the 43 coral species as threatened or endangered is in fact warranted, there can be no reasonable dispute that the available information indicates that listing these species as either threatened or endangered may be warranted. As such, NMFS must promptly make a positive initial finding on the petition and commence a status review as required by 16 U.S.C. § 1533(b)(3)(B).

The 43 coral species covered by this Petition are as follows:

1. ***Arthrogorgia otsukai***
2. ***Arthrogorgia utinomii***
3. ***Fanellia compressa***
4. ***Fanellia fraseri***
5. ***Narella abyssalis***
6. ***Narella alaskensis***
7. ***Narella arbuscula***
8. ***Narella bayeri***
9. ***Narella cristata***
10. ***Plumarella aleutiana***
11. ***Plumarella echinata***
12. ***Plumarella hapala***
13. ***Plumarella nuttingi***
14. ***Plumarella profunda***
15. ***Plumarella robusta***
16. ***Plumarella spicata***
17. ***Plumarella superba***
18. **_Primnoa pacifica_ var. _willeyi_**
19. ***Primnoa wingi***
20. ***Thouarella cristata***
21. ***Thouarella trilineata***
22. ***Alaskagorgia aleutiana***
23. ***Cryogorgia koolsae***
24. ***Cavernularia vansyoci***
25. ***Swiftia beringi***
26. ***Crypthelia trophostega***
27. ***Cyclohelia lamellata***
28. ***Errinopora dichotoma***
29. ***Errinopora disticha***
30. ***Errinopora fisheri***
31. ***Errinopora nanneca***
32. ***Errinopora undulate***
33. ***Errinopora zarhyncha***
34. ***Stylaster trachystomus***
35. ***Stylaster brochi***
36. ***Stylaster alaskanus***
37. ***Stylaster leptostylus***
38. ***Stylaster campylecus***
39. ***Stylaster crassiseptum***
40. ***Stylaster parageus parageus***
41. ***Stylaster repandus***
42. ***Stylaster stejnegeri***
43. ***Distochopora borealis***

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## EXECUTIVE SUMMARY

The world's corals are in crisis, and cold water corals are especially at risk. Scientists predict that seawater considered suitable for coral growth may vanish by 2070, when the atmospheric concentration of carbon dioxide ($CO_2$) is projected to reach 630 parts per million (ppm) (Steinacher et al. 2009). Today's atmospheric $CO_2$ concentration of approximately 400 ppm is far above that seen over the last 800,000 years and likely during the past 15 million to 20 million years (Prentice et al. 2001, Caldiera and Wickett 2003, Denman et al. 2007, Tripati et al. 2009). Warming ocean temperatures and ocean acidification due to anthropogenic greenhouse gas emissions threaten the continued survival of cold water corals and cold water coral ecosystems. Moreover, cold water corals face widespread threats from habitat destruction and degradation due to fishing activities and other anthropogenic benthic disturbances. Fishing disturbances are especially damaging in Alaska's Aleutian Islands, which contain some of the most abundant, diverse and pristine cold water coral ecosystems on earth. Additional areas of cold water coral density and diversity are found in the Bering Sea Canyons, on Gulf of Alaska seamounts, and along Alaska's continental shelf break. Scientists have found that cold water corals and other calcifying organisms will be some of the first to suffer collapse in the face of climate change.

This petition seeks to list 43 species of cold water corals that occur in United States waters and are threatened with extinction, and thus stand to benefit from listing under the U.S. Endangered Species Act ("ESA"). All of the petitioned species have a limited range, with all but three endemic to Alaska Exclusive Economic Zone ("EEZ") waters only. The best available science indicates that the petitioned coral species are threatened with extinction before mid-century due to expanded fishing activities, ocean acidification, ocean warming, changes in marine production, and other processes associated with anthropogenic greenhouse gas emission-caused climate change.

Anthropogenic greenhouse gas emissions are a major threat to the marine environment worldwide, and are resulting in serious and lasting changes in productivity and ecology (Guinotte and Fabry 2008). Alaskan waters are already showing widespread evidence of ocean acidification as a result of greenhouse gas emissions (Mathis et al. 2011a,b). Human actions over the next ten years will be critical in determining the long-term fate of fisheries and marine ecosystems throughout the world (Miller et al. 2009).

Climate change is occurring throughout Alaska. Evidence includes warming temperatures, changing precipitation patterns, altered stream flows, loss of sea ice, and coastal erosion, among others (Hinzman et al. 2005). In the Bering Sea, average surface air temperatures are predicted to increase by approximately one degree Celsius (C) to 1.5 degrees C in the next 10 years to 20 years and by three degrees C to four degrees C by the end of the century (IPCC 2007). Average surface warming in the Arctic is predicted to be even higher, at three degrees C to seven degrees C by the end of the century under a mid-level (A1B) emissions scenario (Meehl et al. 2007).

Cold water corals, especially those occurring at great depth, are extremely susceptible to changes in temperature. Even a minor increase in water temperature at depth, whether due to increased surface mixing, changes in seasonal regimes, or warming of ocean waters, may create an unsuitable habitat for these corals, resulting in widespread die-off (Linares et al. 2005, Yesson et al. 2012). Evidence from the fossil record shows major extinctions of deep-sea benthic taxa 65 million to 55 million years ago, which is associated with a rise in bottom temperatures (Rogers 2000, Zachos et al. 2005). This fossil evidence indicates that deep sea organisms are especially susceptible to increasing ocean temperatures, and that it is unlikely that the petitioned coral species would survive increases or fluctuations in ocean temperatures.

Climate change, especially increased temperatures, may change or shift the direction and velocity of ocean current regimes, and also disrupt normal seasonal water mixing patterns or stratification (Peterson et al. 2002, Mathis et al. 2011a). These currents and water mixing processes are critical to the marine ecosystem of Alaska, and are responsible for the exchange and delivery of nutrients in areas of high productivity including the coral-rich western Aleutian Islands, Bering Sea, Bering Sea Canyons, and the Gulf of Alaska (Menviel et al. 2012). Shifting currents may limit nutrients available to the petitioned species, result in further increases in temperatures of the deep sea, contribute to shoaling of the calcium carbonate horizon and increase sedimentation rates in areas of cold water coral. The results from these current shifts could be widespread death of cold water coral, or decreased growth, colonization and reproductive rates (Coma et al. 2009, Hofmann et al. 2010).

Ocean acidification due to anthropogenic $CO_2$ emissions is another major threat to Alaska cold water corals. The best available science indicates that atmospheric $CO_2$ concentrations must be reduced to at most 350 ppm, and perhaps much lower, to adequately reduce the synergistic threats of ocean warming, ocean acidification, and other impacts on cold water corals (Hansen et al. 2008, Donner 2009, Veron et al. 2009). Today's atmospheric $CO_2$ concentration of 400 ppm has documented detrimental impacts to coral (Veron 2008). Even more serious adverse impacts to corals will occur as atmospheric $CO_2$ concentration increases rapidly under a business-as-usual greenhouse gas emissions scenario. Undersaturation of seawater with respect to aragonite, a consequence of acidification, is already widespread in Arctic and North Pacific waters, with higher saturation horizons (shoaling) predicted in coming years (Orr et al. 2005, Mathis et al. 2011b). Undersaturation of seawater with respect to calcite is also occurring with widespread undersaturation predicted within the next 50 years. This may affect the growth and repair of not only the petitioned species, but also of the plankton that provide the corals' food and nutrient sources (Comeau et al. 2010). Lack of nutrition, declining availability of the crucial building block calcium carbonate, and changes in circulation patterns all threaten the continued existence of cold water corals. Immediate action is needed to reduce greenhouse gas concentrations to levels that do not jeopardize the petitioned coral species.

Physical disturbance by bottom trawls and other fishing activities have been and continue to be a major threat to Alaska cold water corals. In the Aleutians, over 82,000 kilograms (kg) of coral bycatch continues to be hauled to the surface each year, with over two million kg of bycatch recorded from 1990 to 2002 (Roberts 2000, Shester and Ayers 2005). NMFS estimates that an additional 6.2 metric tons of corals continues to be hauled to the surface annually by bottom trawls in the Gulf of Alaska. Although this is likely an underestimate (Watling and Norse 1998), even if it is accurate, this massive amount of cold water coral bycatch is unsustainable and irreplaceable. Many additional corals that are not carried to the surface as bycatch are uprooted, crushed or damaged by fishing gear. Bottom trawling is not the only problem. Pelagic (or midwater) trawls have been found to contact the sea bottom up to 44 percent of the time, with other reports much higher, at over 80 percent, while bottom longlines, strings of pots or traps, and scallop dredges may scour paths of destruction across the ocean floor (NMFS 2005a, Stone and Shotwell 2007, Miller et al. 2012). Because of their extremely long life spans, slow growth and re-colonization rates, and undocumented recovery, damaged corals are essentially removed from the ecosystem (Williams et al. 2010).

Re-colonization and recovery of coral communities where corals have been killed, broken, damaged and overturned is on the order of multiple decades to centuries at best, and may not occur at all due to each coral species' unique habitat requirements, structural fragility, slow growth rates, reproductive limitations, and extended life histories (Althaus et al. 2009, Hourigan 2009, Williams et al. 2010). Corals may live hundreds to thousands of years (Roark et al. 2009, Andrews et al. 2009). They are not adapted to disturbance, and have little genetic variation on which to fall back for re-colonization or recovery of disturbed areas (Hofmann et al. 2010, Miller et al. 2011). Therefore long-term commitments to coral protection are required if any meaningful recovery is to take place.

Regulatory mechanisms at the national and international level do not adequately address the impacts from climate change and ocean acidification to the petitioned coral species, nor require the greenhouse gas emission reductions necessary to protect the petitioned coral species from extinction. While existing laws, including the Clean Air Act, Energy Policy and Conservation Act, Clean Water Act, Endangered Species Act and others provide authority to executive branch agencies to require greenhouse gas emissions reductions from virtually all major sources in the United States, the federal government is either failing to implement or only partially implementing these laws for greenhouse gases. In addition, there are no binding international agreements governing greenhouse gas emissions in the years beyond 2012. Existing regulatory mechanisms are ineffective at preventing the decline of the petitioned coral species and mitigating other threats to these species, which are now on a trajectory toward extinction. Based on the rapid decrease in the saturation levels for aragonite and calcite, and on other changes occurring in North Pacific and Arctic waters, including ocean acidification, warming water, changes in circulation patterns, and changes in salinity, existing regulatory mechanisms are ineffective in protecting the petitioned species from the impacts of greenhouse gas emissions.

Further, fisheries activities continue to present a major threat to the continued existence of the petitioned corals. The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) requires that Fishery Management Plans (FMPs) identify Essential Fish

Habitat (EFH) for each fishery, minimize to the extent practicable adverse effects on such habitats caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat. EFH has been defined by the MSFCMA as “those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity.” Cold water coral habitat has been identified as EFH for some groundfish species, while other species are found to have a high association with cold water corals and likely are either obligatory or facultative users of cold water coral communities (Witherell and Coon 2000, Stone 2006). However, current protective measures fail to follow the MSFCMA mandates.

The North Pacific Fisheries Management Council (NPFMC) established EFH and Habitats of Particular Concern (HAPC) in the Aleutian Islands and Gulf of Alaska that by their description are supposed to protect deep-sea habitat from trawling, but these measures are ineffective in protecting the cold water corals that are a critical component of commercial fish habitats in Alaska waters. First, these measures do not include the Bering Sea Canyons, an area with rich coral growth, and thus fail to protect a critically important habitat area for the petitioned species (Miller et al. 2012). Second, these measures largely maintain the current trawling footprint in the coral-rich Aleutian Island region, and vast areas of diverse and dense cold water coral growth remain in the trawlers’ path. For example, the majority of the seafloor protected within the Aleutian Island Habitat Conservation Area (AIHCA) likely supports little cold water coral habitat and consists of a vast abyssal plain, with few species of commercial importance that would draw trawlers or commercial fisheries activities with or without implemented restrictions. Many coral rich areas close to the islands are exempted from the fishery restrictions, with over 90% of areas in the Aleutians with the highest coral bycatch still open to trawling activities (Shester and Warrenchuk 2007). Thus, despite EFH and HAPC establishments, harmful fishing activities continue within coral-rich areas, while the vast majority of the actual protected area is comprised of deep sea areas that support little species diversity or cold water coral growth.

Additionally, existing restrictions within EFH or HAPC areas do not adequately protect cold water corals from all types of fishing activities. Restrictions on just bottom trawling are not enough because pelagic trawling gear has been found to contact the sea bottom up to 44 percent of the time, with other reports much higher, at over 80 percent. Also, longlines and pot and trap fisheries may scour the open floor, creating vast paths of cold water coral destruction (Stone and Shotwell 2007).

For all of the above reasons, the petitioned coral species merit prompt listing under the ESA. Furthermore, pursuant to the ESA, NOAA Fisheries is required to designate critical habitat for these coral species concurrent with their listing. Critical habitat is a foundation of the ESA’s recovery system. A recent study found that species that have critical habitat protection are approximately twice as likely to have improving population trends than species without critical habitat (Taylor et al. 2005). For the petitioned coral species, critical habitat is particularly important because fisheries technology is continuing to expand in depth and total area of impact. Corals are sessile and long-lived and have minimal ability to re-grow or relocate once disturbed by fisheries activities. Also, critical habitat designations would have immediate benefits to species associated with cold water corals, including fish, invertebrates, and marine mammals. Protection of coral habitat is especially important for Alaska cold water corals, due to the likelihood of “silent extinction” where as yet un-described coral species are eliminated before they are even discovered. The habitats that support corals must be protected immediately while additional research is conducted and resilience-recovery-based management strategies are developed (Shester and Warrenchuk 2007).

Congress and the Supreme Court have obliged NOAA Fisheries to prioritize species survival and recovery “whatever the cost.” *See TVA v. Hill*, 437 U.S. 153, 154 (1978). Given their incalculable intrinsic value, their pivotal role in marine ecosystems, and their critical importance to survival of the human communities that rely upon them, the imperiled corals identified in this petition warrant immediate protection under the ESA.

The Petition is divided into three parts. Part I contains an introduction to the cold water coral species included in this petition. Part II contains species accounts organized by taxonomy, briefly summarizing the taxonomy, natural history, distribution, and status for each of the petitioned species, including a map of distribution for each species. Part III describes existing and future threats to these coral species in the context of the five statutory listing factors contained in the ESA. Part IV addresses the inadequacy of current regulatory mechanisms in adequately protecting cold water corals. Taken together, the information in these four sections demonstrates that each of the petitioned species warrants protection under the ESA.

## I: NATURAL HISTORY AND BIOLOGY OF ALASKAN COLD WATER CORAL SPECIES

## I. INTRODUCTION TO COLD WATER CORALS

Cold water corals have a worldwide but patchy distribution, and are often found in areas with highly productive fisheries (Rogers 1999, De Mol et al. 2002, Kenyon et al. 2003). Cold water corals occur from Antarctica to the Chukchi Sea over a broad depth range from the intertidal zone to over 6,000 meters deep (Freiwald 2002, Roberts and Hirshfield 2004). The patchiness of cold water coral distribution is likely due to their strict habitat specifications that require a hard substrate for attachment, low sedimentation rates, restricted temperature range (four degrees C to 12 degrees C), high surface productivity, availability of dissolved calcium carbonate, and current regimes that both keep the substrate clean of sediment and carry nutrients to the corals (Roberts et al. 2006, 2009). Unlike tropical corals, all cold water corals are azooxanthellate, meaning they lack light-dependent symbiotic algae, and filter nutrients directly from the surrounding seawater. These food particles either drop down from more shallow waters or are carried to the corals on currents (Roberts et al. 2006). Overall, more than two-thirds of all known coral species are cold water corals (Roberts and Hirshfield 2004, Cairns 2007).

In the past, the existence of cold water corals was only vaguely known, mainly by fishers who would bring up corals in their nets, or snag lines or nets on dense patches of red tree corals or other coral species. Only recently have scientists and researchers had the incentive, funding, and access to the technology to observe living communities of cold water corals via observation from manned submersibles and video from unmanned submersibles (also known as remote operated vehicles or ROV), which are also able to collect on-site specimens for species identification (Stone and Shotwell 2007). Photographs and video from these research expeditions show startlingly beautiful and unique images of cold water corals, many of which are new to science. Especially stunning are newly discovered lush coral forests or gardens sheltering a diverse array of sea life in the Aleutians. These cold water coral communities rival those of tropical coral reefs in species diversity and density of growth, and are the most abundant and diverse coral assemblages known from northern latitudes (Roberts and Hirshfield 2004). Cold water corals grow alone or in colonies, and come in a wide variety of colors, shapes and sizes (Stone and Shotwell 2007). Colors range from vibrant magenta, to purple, orange, yellow, salmon, white, and deep red (Wing and Barnard 2004). Sizes and shapes vary drastically, and include red tree corals that may grow over two meters tall, large graceful sea fans with intricate lace-like layers, feather-like sea pens, and tiny cup corals only a few millimeters across (Freiwald et al. 2004a).

Like most denizens of the ocean depths, cold water corals are slow-growing, and may live hundreds or even thousands of years (Andrews et al. 2002, Risk et al. 2002, Roark et al. 2009). Cold water corals are sessile organisms, and are specifically adapted for the relatively static marine environment of the cold and deep waters they inhabit, having evolved for survival in areas with very little ecological variation. Because of their sessile nature, especially prolific and diverse cold water corals are most commonly found in areas with high topographic relief, where currents are favorable for the transport of nutrients. Thus, cold water corals often occur in submarine canyon trenches, along the continental shelf breaks, or on seamounts (Roberts and Hirshfield 2004, Woodby et al. 2009)(Yesson et al. 2012). Cold water corals create a three-dimensional habitat that is important to many marine species, including commercial fish and invertebrates, such as rockfish and king crab, and some marine mammals, including the endangered monk seal in Hawaii (Heifetz 2002, Parrish et al. 2002, Miller et al. 2012).

Due to a complete lack of long-term observations of living cold water coral communities, little is known about their distribution, population dynamics and biology, or about how they function in providing habitat for other species (McDonough and Puglise 2003, Miller et al. 2012). Identification to the species level remains difficult because there are often few specimens available for observation, and these specimens are usually fragmented, incomplete, or long-preserved, and there are very few scientists with a working knowledge of coral taxonomy to accurately identify cold water corals to the species level (Cairns 2011b, Cairns and Lindner 2011). High degrees of endemism, especially at seamounts, further complicate species identification (Baco 2007). Scientists continue to discover new cold water coral species, and it is likely that many more species remain undiscovered and unidentified to the species level (Roberts and Hirshfield 2004, Miller et al. 2009). Recent exploration and research that has begun to search for, map, and observe cold water corals has found that these organisms are fragile, long-lived, slow-growing, very sensitive to physical or environmental disturbance and adapted for a specific environmental niche (McDonough and Puglise 2003). Once the habitat preferences for cold water corals are known, seafloor mapping can be used to estimate the potential locations of cold water corals, in order to identify areas where ROV dives should be focused for coral surveys (Woodby et al. 2009, Yesson et al. 2012).

## 2. OVERVIEW OF COLD WATER CORALS OF ALASKA

Alaska corals are highly diverse cnidarians that belong to two major classes: Anthozoa and Hydrozoa. Major taxonomic groups of Alaskan corals within class Anthozoa are: subclass Hexacorallia including true or stony corals (order Scleractinia) and black corals (order Antipatharia); and subclass Octocorallia including true soft corals (order Alcyonacea), stoloniferans (suborder Stolonifera), gorgonians (also known as sea fans or leather corals; order Gorgonacea), and sea pens or pennatuluceans (order Pennatulacea) (Stone and Shotwell 2007). Important families within these orders included in this petition are the Primnoidae and Plexauridae in the order Gorgonacea, which contain 21 and two species of petitioned coral, respectively.

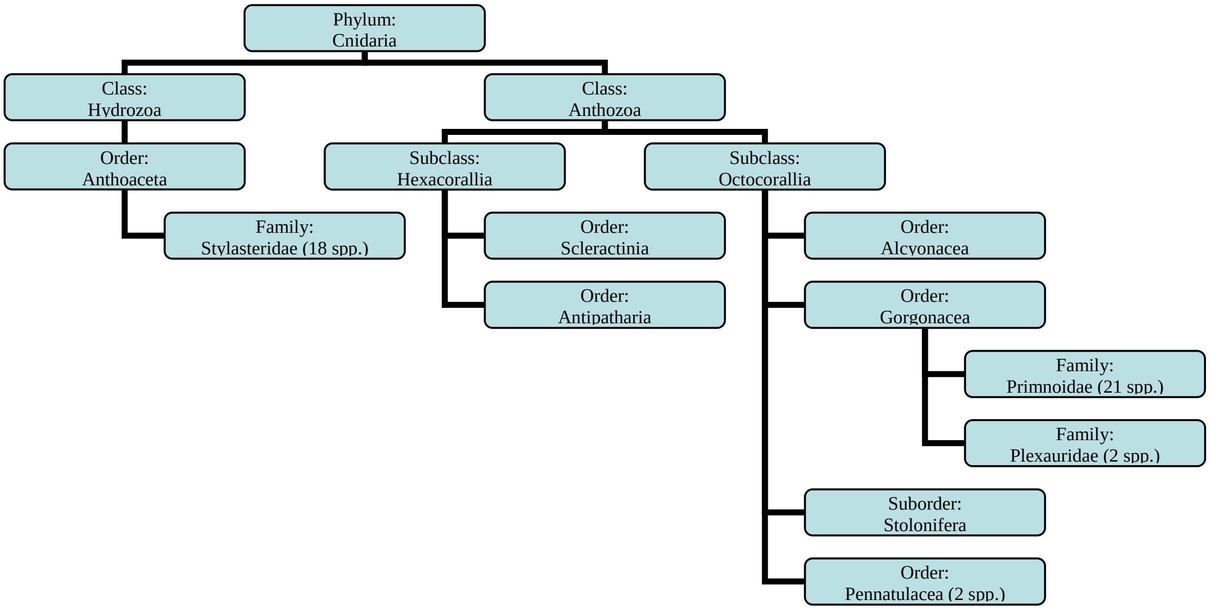


**Figure 1.** Taxonomic tree for the important Alaska coral species included in this petition, with number of petitioned species for each taxa included.

In class Hydrozoa, also called hydrocorals, the major taxonomic group in Alaska is the family Stylasteridae (also called stylasterids; order Anthoathecata), which contain 18 of the petitioned coral species. As detailed in Section II (Natural History and Status of Petitioned Corals), the 43 petitioned coral species include 23 species of gorgonians, two species of pennatulaceans, and 18 species of stylasterids.

In one of the first attempts to taxonomically quantify Alaska coral species, Stone and Shotwell (2007) identified 141 unique coral taxa in Alaska, with several reported likely new to science. However, many were not identified to the species level, and taxonomy may be uncertain (Cairns 2011b, Cairns and Lindner 2011). A lack of specimens and relatively few skilled coral taxonomists has limited the species identification of Alaska cold water corals (Cairns 2011b, Cairns and Lindner 2011).

Unlike some species of cold water corals in other areas of the world, corals in Alaska are ahermatypic, which means they do not build reefs. However, many Alaska corals, especially the gorgonians, and to a lesser extent stylasterids, are structure forming. Structure forming corals create communities that are similar in structural complexity to tropical reefs, and share several important characteristics, including underlying support by a rigid framework, positive topographic relief and high taxonomic diversity (Fagerstrom 1987, Freiwald et al. 2004a, Stone and Shotwell 2007). Unlike tropical or cold water coral reefs (*Lophelia*) where the reef is built upon coral skeletons, the underlying framework of coral gardens is mostly abiotic and composed of exposed bedrock, boulders, and cobbles, although there are substantiated reports of cold water corals using sponge skeletons as a substrate (Stone 2006). The degree of structural complexity depends on the corals' maximum size, growth form, intraspecific fine-scale distribution, and interaction with other structure-forming invertebrates (Stone and Shotwell 2007).

## a. History of Research on Alaskan Cold Water Corals

Fishers in Alaska waters have long known that cold water corals existed because they found corals tangled in nets or fishing lines. Especially interesting specimens were brought home as curios or souvenirs. The first scientific observations of Alaska corals were in the early 1800s, but the vast majority of research on cold water corals has taken place over the past ten years. This is due in part to the variety of bycatch recorded by fishers and by trawling surveys, as technology improvements allowed trawlers and fishers to cover more ground and to fish in deeper water. It is also because of heightened scientific interest in the link between corals and commercial fisheries, and in how destruction of coral areas may adversely impact fisheries. Only recently have improvements in submersible technology and the availability of funding for modern submersibles allowed for scientists to study these hard-to-reach corals (Krieger 2001). Prior to 2002, *in situ* studies on cold water corals in Alaska were limited in both area and scope due to constraints by the submersible used for these observations, and research was narrowly focused on two species of cold water gorgonian corals (Krieger 2001, Krieger and Wing 2002, Stone 2005), and corals found on seamounts in the Gulf of Alaska (Baco 2007). In 2002, NOAA instituted a research program to examine corals and associated communities around the Aleutian Islands (Heifetz et al. 2005, Stone 2006), and information from this research provided the additional data on the distribution and habitat associations of Alaska coral species.

Early cold water coral research focused on describing a variety of species dredged from the deep sea. Corals of the North Pacific and Alaska were first described after dredging expeditions in the 1800s (Ehrenberg 1834, Verrill 1866, Studer 1878, Dall 1884). Preserved coral specimens from the *Rurik* expedition (1816-1817) in the Bering Sea and eastern Aleutian Islands were used in the early works describing Alaska coral species (Cairns and Lindner 2011). A more comprehensive collection of preserved corals was provided by the *Albatross*, a U.S. Fish Commission scientific research vessel built in 1892. The ship traveled over much of the world's oceans, from Labrador to Tierra del Fuego, and throughout the eastern Pacific into the Bering Sea. The *Albatross* collected hundreds of new marine species as a biological research ship, and provided an extensive specimen collection to the Smithsonian Institute. Charles Nutting used this specimen collection for his 1912 publication that focused on octocorals, *Descriptions of the Alyconaria Collected by the U.S. Fisheries Steamer* Albatross *Mainly in Japanese waters, during 1906*. Fisher's *Hydrocorals of the North Pacific* (1938) also used specimens collected by *Albatross* expeditions and preserved in the Smithsonian. Numerous additional publications have made use of the *Albatross* collection at the Smithsonian (e.g., Wing and Barnard 2004, Cairns 2011a, Cairns and Lindner 2011). Two recent publications describing cold water stylasterids (hydrocorals) and primnods (octocorals) by Cairns (2011) and Cairns and Lindner (2011) updated Alaska cold water coral taxonomy.

After the *Albatross* expedition, and up until the past couple of decades, the majority of information on cold water corals and their habitats came from observations by the commercial fishing industry (Cimberg et al. 1981). Fishers brought unique cold water coral specimens to the surface entangled in fishing gear, with especially interesting specimens reported from the Aleutians and Gulf of Alaska (McDonough and Puglise 2003). NMFS scientists first visited the Aleutian Islands and Gulf of Alaska seamounts specifically to study cold water corals in 2002, using the manned submersible *Delta*. (Heifetz 2002, Stone 2005). *Delta* was limited to depths less than 367 meters and was used to observe living coral communities by focusing on locations with high coral bycatch (Figure 2; (Heifetz 2002).

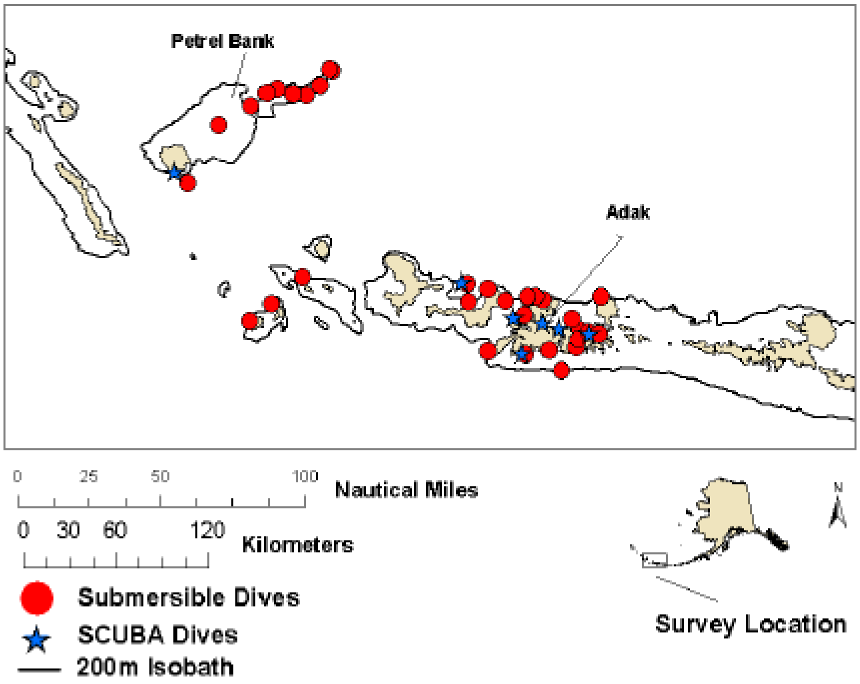


**Figure 2:** Submersible and SCUBA dive locations during the 2002 exploration near the Adreanof Islands and Petrol Bank. Source: (Heifetz 2002).

The 2002 expedition was the first to observe the high-density and high-diversity coral gardens similar in structural complexity and ecological importance to tropical coral reefs (Stone 2005). During this expedition, research was also conducted to investigate the effects of fishing gear on the seafloor habitat, in order to obtain information on how fishing activities may be impacting coral communities on the seafloor (Heifetz 2002). At least 51 endemic species or subspecies of hydrocrals and ocotocorals were described by researchers on this expedition, which indicated that the Aleutian Islands harbor some of the highest diversities of cold water corals in the world (Stone and Shotwell 2007). The incredible variety and density of coral found in the Aleutians, and the wide-scale evidence of fisheries destruction of corals and coral habitat in this region, prompted further research on Alaska corals.

From 2003 to 2004, a coalition of scientists from NMFS, Alaska Department of Fish and Game, the University of Alaska and several other institutions returned to the central Aleutian Islands with both *Delta* and a deeper diving ROV, *Jason II*. *Jason II* could dive to nearly 3,000 meters, and was used to document coral habitat in deeper waters. Observations from *Jason II* confirmed the presence of coral to depths of at least 3,000 meters, and found that corals were most abundant on exposed bedrock. Coral abundance and diversity was highest from 100 meters to 800 meters (Heifetz 2002). In 2007, the Greenpeace vessel *Esperanza*, carrying two human-piloted submersibles and one ROV, surveyed for the first time the depths of two massive canyons (Pribilof and Zhemchug) in the Bering Sea, down to 2,730 meters (Miller et al. 2012). The team, joined by NMFS and university scientists, found cold water corals, rock fish, sponges, and crabs, with the second highest diversity and abundance of cold water corals found in Alaska waters after those observed in the Aleutians (Miller et al. 2012). Preliminary findings were presented to the NPFMC, which oversees fishery operations in the Bering Sea (Miller et al. 2012). As a result of this research, the NPFMC took a unanimous vote to initiate scientific review of the canyons, in order to consider conservation measures to protect these important areas.

## b. Taxonomy

Taxonomy and identification of cold water corals in Alaska is difficult for a variety of reasons: the inaccessibility of the coral itself, and resulting limit to number of samples for each species; the age and fragmented status of many coral samples; the difficulty in obtaining a positive identification and the need to use microscopic imaging; incomplete or inaccurate taxonomy; and lack of researchers skilled and experienced in coral species identification (Cairns 2011a, Cairns and Lindner 2011). As a result, Alaskan cold water coral taxonomy is somewhat uncertain, although recent work has improved taxonomy for two of the most diverse coral families (Cairns 2011a, Cairns and Lindner 2011).

Most lists of species (Wing and Barnard 2004, Heifetz et al. 2005, Stone and Shotwell 2007) include a high percentage (almost half) of unidentified species and dated taxonomies, with questionable identification at the species level. Cairns (2011) and Cairns and Lindner (2011) updated and revised the taxonomy and identification of Alaskan stylasterids and primnoids. These recent revisions identified many new species and renamed or revised the taxonomy on others. According to Cairns (2011), Heifetz (2002) and Heifetz et al. (2005) lists of Alaskan species had “identifications [that] were not accurate.” Cairns also stated that the Wing and Barnard (2004) *Field Guide to Alaskan Corals* had incorrect taxonomy. As updated by Cairns (2011), there are 31 valid and named nonpennatulacean octocoral species in the Aleutian Islands.

In addition to Cairns (2011) and Cairns and Lindner (2011), several recent publications have described new species of Alaskan corals, including five octocorals in the genus *Narella* in Cairns and Baco (2005), two new species of octocorals described by Williams (2005), and one new octocoral described by Sanchez and Cairns (2004). In this petition, recent and confirmed taxonomy was used as much as possible, and the most updated revisions replace any older taxonomy for species identification. Endemism of the petitioned corals to Alaskan waters was based on Heifetz (2002), and also on range descriptions included in more recent publications, especially Cairns (2011) and Cairns and Lindner (2011).

### c. Range, Distribution, and Habitat Associations

Alaska contains more than 70 percent of the continental shelf habitat in the U.S, numerous areas of high underwater topographical relief, and fast moving currents, providing ideal habitat conditions for many coral species. The marine environment of Alaska is divided into five major geographical regions including the Gulf of Alaska, the Bering Sea, the Aleutian Island Archipelago, and the Chukchi and Beaufort seas in the Arctic Ocean.

Cold water corals are widespread, but with patchy distribution throughout Alaska, and are found on the continental shelf, upper slope, and seamounts in the Gulf of Alaska, the Aleutian Islands, the eastern Bering Sea including submarine canyons, and as far north as the Beaufort Sea (Baco 2007, Stone and Shotwell 2007). Cold water coral abundance, distribution, and species assemblages vary among geographic regions of Alaska waters (Stone and Shotwell 2007).

As described below, and in greater detail in Section II of this petition, cold water corals occur in greatest density and diversity in the Aleutian Islands west of longitude 169 degrees west, probably due to the nutrient rich currents and reduced bottom sediment in these areas (Stone and Shotwell 2007). Gorgonians and hydrocorals (stylasterids) are most common in the Aleutian Islands. Octocorals, particularly gorgonians, are most common in the Gulf of Alaska. Recently explored Bering Sea submarine canyons, including the Zhemchug and Pribolof canyons, primarily contain stylasterids and octocorals. Gulf of Alaska seamounts contain many endemic species, including octocorals (e.g., gorgonians).

### *Aleutian Islands*

A combination of unique geologic and oceanographic characteristics converge in the Aleutian region to provide three features that create habitat for cold water corals: exposed rock substrate, plankton and nutrient rich waters, and strong currents (Stone 2005). Combined, these conditions provide ideal habitat for the recently discovered dense aggregations of corals known as coral gardens or coral forests (Stone and Shotwell 2007). In the Aleutians, slope and offshore habitat characterized by exposed bedrock, boulders, and cobbles generally supports the highest abundance of corals.

Octocorals (order Gorgonacea and order Pennatulacea) and hydrocorals (family Stylasteridae) are both important components of Aleutian coral communities, because of their size, longevity, and importance as a component of coral gardens (Stone and Shotwell 2007). Cold water corals are especially abundant and widespread in the western and central Aleutian Islands, with coral gardens observed at seven locations in the central Aleutian Islands during submersible dives in 2002 (Stone 2005).

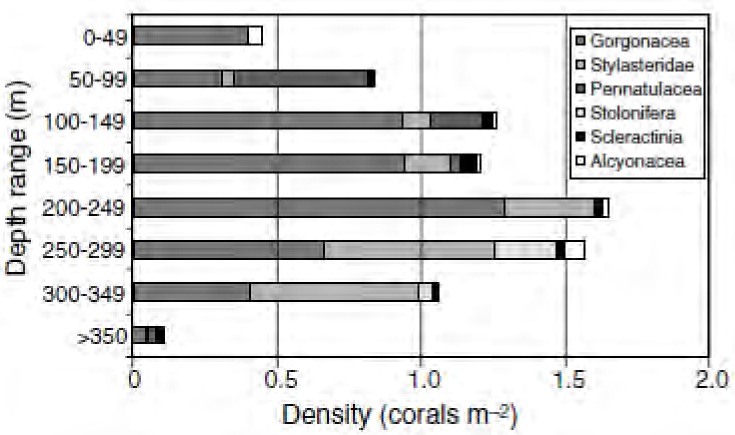


**Figure 3.** Density of corals by species in the central Aleutian Islands observed in 50-m depth zones with the submersible '*Delta*'. Source: (Stone 2006).

Corals in the western Aleutians tend to have a greater depth distribution than corals in other areas of Alaska (Figure 3). These deepwater corals include *Primnoa* (304 meters to 1,436 meters), bamboo corals (400 meters to 3,532 meters), *Paragorgia* spp. (27 meters to 1,464 meters), stylasterids (11 meters to 2,130 meters), and black corals (449 meters to 2,827 meters). However, the known distribution of cold water coral species may be more a product of research effort than actual distribution.

There is a decrease in the diversity of coral species east of 169 degrees west in the Aleutians, consistent with the hypothesis of an ecological boundary at Samalga Pass that divides the productive, ecologically diverse area to the west, from the less productive area to the east. At least 24 species of gorgonians, stylasterids, and stony corals that occur in the western Aleutians are not found east of the Samalga Pass area (Heifetz et al. 2005).

East of the Samalga pass area, gorgonians are widely distributed on the continental shelf and upper slope of the East Aleutians, including *Primnoa* and *Paragorgia* species. Stylasterids are also widely distributed, especially along the south side of the East Aleutian archipelago. Pennatulaceans are also widely distributed and form dense groves in some areas (Stone and Shotwell 2007).

### ***Coral Gardens***

Coral gardens are a recently discovered and unique habitat type in the North Pacific Ocean that support an especially high density and diversity of azooxanthellate cold water corals (Stone 2006). Gardens are typically located in small, discrete patches at between 117 meters and 338 meters in depth (Stone and Shotwell 2007). Coral gardens have extremely high coral abundance (3.85 corals/$m^2$), with gorgonians (1.78 colonies/$m^2$) and stylasterids (1.46 colonies/$m^2$) comprising an especially high percentage of species compared to other known geographic areas of cold water coral growth (Stone 2006). Coral gardens are similar in structural complexity to tropical coral reefs, sharing several key characteristics including underlying support by a rigid framework, positive topographic relief and high taxonomic diversity (Stone 2006). Hydrocorals are an important structural component of coral gardens and are often encrusted with the demosponge *Myxillla incrustans*, forming a rigid platform that other sessile (e.g., stolonifeans and actinarians) and mobile (e.g., holothurians, crinoids, and gorgonocephalid brittle stars) invertebrates use as an elevated feeding platform (Stone 2005, 2006). The vertical relief provided by the aggregation of coral and sponge species may exceed several meters (Stone 2006). Coral gardens support a vast number of diverse species, including commercial fish and invertebrate species, and are thus a target for fisheries that may damage and destroy these areas of coral growth (Figure 4). Major research efforts are underway to locate and conserve this unique cold water coral habitat type (Stone 2006).

**Figure 4**. (A) Coral garden off Adak Island (Aleutians) containing black corals (*Antipathes* sp.), gorgonian octocorals, sponges and a basket star. (B) Octocorals from Adak Canyon (Aleutians) with brittle stars. (C) Juvenile sharpchin rockfish between *Primnoa resedaeformis* from the Gulf of Alaska. (D) *Paragorgia arborea*, the home of associated shrimp and crabs, Gulf of Alaska. Source: (Freiwald et al. 2004a),

### *Gulf of Alaska*

The eastern Gulf of Alaska supports a wide diversity of cold water coral species that are patchily distributed along the continental shelf and slope (Stone and Shotwell 2007)). Only the Aleutian Islands support a higher diversity of corals. Corals include 13 species of gorgonians, seven species of pennatulaceans, and nine species of stylasterids (Stone and Shotwell 2007). The depth range for corals ranges from six meters for *Primnoa pacifica* in the glacial fjords to over 400 meters on the continental slope (Stone and Shotwell 2007). *P. pacifica* forms dense thickets in some areas, and is found in high relief rocky areas and on bedrock and boulders (Krieger 2001). In 2006, NMFS closed five small areas to all bottom contact fishing gear in an effort to protect *Primnoa* thickets. Stylasterids are also fairly common on the continental shelf.

In the western Gulf of Alaska, cold water corals have a widespread, patchy distribution. Gorgonians are distributed along the continental shelf and slope and consist of 13 species (Stone and Shotwell 2007). There are unconfirmed reports of *Primnoa* thickets near Chirikof Island (Cimberg et al. 1981). Stylasterids are widely distributed but neither abundant nor diverse, with only two species reported (Stone and Shotwell 2007). Pennatulaceans form extensive groves in the submarine gullies south and east of Kodiak

Island (Stone 2005), and in isolated locations in Prince William Sound (Malecha et al. 2005).

### *Gulf of Alaska Seamounts*

The Gulf of Alaska contains numerous seamounts that are home to a variety of marine species, many of which are localized or endemic (Baco 2007). Seamounts in the Gulf of Alaska are rich in coral habitat, with all major taxonomic groups except stylasterids present. Octocorals are the most dominant taxa (Baco 2007, Penn et al. 2006). Cold water corals are an integral part of the benthic fauna found on seamounts, and are often abundant, species rich, and create structurally complex habitat for a many invertebrates and fishes (de Forges et al. 2000, Rogers et al. 2007). Corals are most abundant near seamount summits (700 m) with *paragorgia* spp. and bamboo corals the most abundant coral fauna. Gorgonians (Primnoidae) are the most abundant corals at around 2,700 meters (Baco 2007). Relatively diverse fish and invertebrate communities have been found on the top and flanks of several seamounts off Alaska (Alton 1986, Hoff and Stevens 2005).

The gyrating currents that circle seamounts, along with the island-like nature of seamount habitat, mean that seamounts are surrounded by nutrients, and that colonization of new areas by coral or other sessile marine species is limited due to lack of dispersing currents. Due to their isolated locations, seamounts often have high rates of endemism, and one study found that between 29 percent and 34 percent of the species collected at seamounts were potential endemics or new to science (de Forges et al. 2000). Recently, five new species of *narella* octocorals in the primnoid genus were discovered on Gulf of Alaska seamounts (Cairns and Baco 2007).

### *Bering Sea and Arctic*

The Bering Sea contains one of the largest continental shelf breaks in the world, at approximately 1,200 km long and 500 km wide (Stone and Shotwell 2007). Seven major submarine canyons, including the Zhemchug and Bering canyons, cut into the shelf break. Although the majority of the area has not been surveyed for corals, it appears that diverse coral growth occurs in submarine canyons (Stone and Shotwell 2007, Miller et al. 2012). There is little hard substrate for coral attachment along most of the continental shelf break due to high sedimentation from the area’s rivers (Stone and Shotwell 2007). The coral fauna outside of canyons does not appear to be very diverse, with dense groves of the pennatulacean *H. willemoesi* reported from the outer continental shelf at depths of 195 meters to 240 meters (Malecha et al. 2005) and dense aggregations of soft corals (mostly *Eunephthea rubiformis*) occuring on the unconsolidated sediments of the continental shelf (Stone and Shotwell 2007).

In the Arctic, observations by Greenpeace indicates that dense aggregations of the cold water coral *Gersemia rubiformis* occur in the Chukchi Sea (Eilperin 2012). Until recently, only the soft coral *Eunepthea* species had been reported as patchily distributed on the shallow shelves of the Chukchi and Beaufort Seas to 71 degrees north (Cimberg et al. 1981, Stone and Shotwell 2007). Any other coral growth in the Arctic has not been documented, and there has been little to no focused surveying for corals in this region (Cimberg et al. 1981, Stone and Shotwell 2007). Diverse and dense aggregations of cold water coral and sponge communities are reported from Antarctic waters, and a lack of observations of Arctic cold water corals, may be due, at least in part, to very few wide-scale observations of the benthic communities of the Alaskan Arctic.

### *Bering Sea Canyons (Zhemchug and Pribolof)*

The Pribilof and Zhemchug canyons are huge submarine canyons located 25 miles southeast and 80 miles northwest of the Pribilof Islands, respectively, on the highly productive Bering Sea shelf break. Zhemchug may be the world's largest submarine canyon, by volume, at 1,300 $km^3$ (Miller et al. 2012). Greenpeace, in collaboration with NMFS, conducted ROV surveys of the seafloor habitat in the canyons in 2006 and 2007 (Miller et al. 2012). These surveys observed diverse coral habitats including relatively dense gorgonians, groves of sea whips, and large fan-like scleractinian corals or arborescent gorgonians on isolated cobble substrate or boulders.

The Zhemchug and Pribilof canyons lie along the high productive "green zone" on the edge of the Bering Sea Shelf. Upwelling provides a constant rate of nutrients, while hard substrate on canyon walls provides ideal attachment areas for cold water corals. The 2007 expedition to the canyons was the first *in situ* study investigating benthic growth. It recorded northern range extensions and new records for the region, including seven gorgonians. Researchers found that mean coral density in each canyon (.43 colonies per $m^2$) was about one third of that observed in the Aleutians (1.23 colonies per $m^2$). Density of corals in Pribilof Canyons was substantially higher than Zhemchug, at 0.92 colonies per $m^2$, which is just slightly lower than densities in the Aleutians. Cairns' (2011) revision of *primnoidae* includes data from the Greenpeace expedition to these canyons to expand the updated range for affected Alaska coral species.

The distribution of cold water corals in the canyons appeared to be substrate limited, with exposed rock on the shelf break and drop stones on the slope providing important coral habitat (Miller et al. 2012). Commercially important species, including Pacific Ocean Perch (*Sebastus alutus*) and several species of king crab, were observed in association with the coral and sponge habitat. Areas of corals that were damaged by trawling were also observed (Miller et al. 2012).

## d. Life History, Reproduction, Nutrition, and Growth

Most cold water corals have slow growth rates, extended life histories with extreme longevity, and niche-specific habitat requirements. Each species of petitioned coral has optimal conditions for reproduction, growth, and establishment, including temperature range, sediment load, salinity, pH, and currents (Cairns and Baco 2007, Yesson et al. 2012). Whether or not a coral species will survive, grow, and reproduce depends largely on how closely these optimal conditions are met. The best available biological information on the reproduction, nutrition, growth, and longevity of cold water corals is described below.

### *i. Reproduction*

Reproduction is energetically costly for cold water corals, and initiation of the process may be influenced by nutrient availability and the energetic status of corals (Heifetz et al. 2007b). Physiological changes and increased metabolic demands during reproduction may directly affect the ability of octocorals to obtain sufficient nutrients through feeding due to morphological changes, and corals must be able to survive this additional stress in order for successful reproduction to occur (Brito et al. 1997, Simpson et al. 2007, Simpson 2009). Although little is known about reproduction for each petitioned coral, recent research has been conducted on reproduction of Alaska gorgonians and on Alaskan stylasterids. It is likely that the petitioned species belonging to these taxa utilize similar reproductive strategies (Brooke and Stone 2007, Simpson et al. 2007).

Corals reproduce once they are sexually mature, which is often determined by colony size (Simpson 2009). Thus, habitat conditions that influence growth and calcification rates may play a key role in determining when a coral colony reaches maturity. There is currently not enough information on Alaska corals to determine size or age of reproductive maturity for each petitioned species, but these long-lived species have protracted life cycles and slow growth rates, and it is likely that the age at maturity is relatively advanced (Watling and Norse 1998, Turley et al. 2007, Andrews et al. 2009).

Upon reaching sexual maturity, the first stage of reproduction for the petitioned corals is production of gametes (gametogenesis). Research indicates that most of the petitioned coral species are likely gonochrostic (male and female colonies), with sexual reproduction, internal fertilization and internal or external brooding (Ostarello 1973, Brooke and Stone 2007, Simpson 2009, Mercier and Hamel 2011). Thus, successful reproduction requires the exchange of genetic material between male and female colonies.

The timing and frequency of reproduction events in cold water corals is likely influenced by seasonal food increases associated with phytoplankton blooms that enhance the flux of benthic carbon (Roberts et al. 2006). An abundance of nutrients is critical to initiation of successful reproduction of cold water corals. High surface productivity, along with adequate water circulation of currents that deliver these nutrients to the depth of coral growth, are important determining influences on reproductive success (Brooke and Stone 2007).

The timing or synchronicity of spawning has not been verified for the Alaskan hydrocorals or gorgonians analyzed to date, but may occur in the spring, during periods of high surface productivity (Brooke and Stone 2007, Simpson 2009). Recent studies on cold water octocorals have documented seasonal patterns of reproduction in correlation with environmental factors such as temperature, sedimentation, and lunar cycles (Mercier and Hamel 2011). For the Alaskan gorgonians studied to date, sperm appear to develop synchronously, indicating a single spawning period for these species (Simpson 2009). For Alaska hydrocorals, spawning appears to not occur as a single synchronized event, and is likely either continuous or seasonal and protracted (Brooke and Stone 2007).

Most of the hydrocorals and gorgonians included in this petition likely have internal or external brooding by the female colony once spawning and fertilization have occurred (Brooke and Stone 2007, Simpson 2009). Petitioned species that are brooders would retain the embryos to the stage of larval competency. This may take anywhere from a couple of days to weeks (Simpson 2009). After brooding is complete, and once released from the parent colony, larvae must locate a suitable habitat in which to settle. Little is known about how this larval dispersal occurs in the petitioned corals. If short-lived larvae are produced, as is common for other coral species (Ostarello 1973, Fritchman 1974), they would settle near the parent colonies, unless currents and conditions were sufficient for transport to a new site. Thus, larval retention and re-colonization likely depends on the currents and tides. Re-colonization of an area denuded of parent colonies by fisheries activities or other disturbance would require optimal currents and conditions for successful larval establishment to occur (Simpson 2009).

The observed reproductive strategies of sexual reproduction and internal brooding, along with advanced age of reproductive maturity, extended life cycles, and slow rates of growth, limit the re-colonization, or colonization potential of the petitioned species (Brooke and Stone 2007, Simpson 2009). If the distances between parent colonies are too large or contain conditions that are damaging to reproductive material, and gametes from male and female colonies cannot be exchanged, a lack of fertilization would lead to little to no reproductive potential of isolated colonies. Self-propagation of a coral colony is unlikely to occur, as it has not been observed that clonal growth occurs for cold water corals included in this petition, or that fragments of any of the petitioned species are able to grow into new colonies (Brooke and Stone 2007). Additionally, the brooding strategy that is likely utilized by the majority of the petitioned corals provides less potential for undisturbed corals to provide a source of larvae to areas where disturbance of coral colonies has been significant (Heifetz et al. 2005).

Corals occurring on seamounts, or in isolated locations on rock outcroppings, may be less likely to successfully reproduce than those located in dense coral gardens. Habitat fragmentation by fisheries activities, ocean acidification, increased sedimentation or other disturbances could fragment rich coral habitat, further limiting reproductive potential. Genetic variability may be an important factor in determining whether a species may be able to adapt to changing conditions, and analysis of other cold water coral species indicate that there is likely little adaptive potential in cold water coral species (Miller et al. 2011). Thus, post-impact ecosystem recovery, specifically in areas denuded by fisheries activities or other anthropogenic disturbance, is very limited.

### *ii. Nutrition*

Cold water corals are filter feeders, and likely depend on nutrients carried by currents and on particulate matter settling down the water column from surface waters (Kiriakoulakis et al. 2005). Recent research has linked cold water coral abundance at depth to surface productivity, and found that cold water corals are fueled by primary productivity in surface waters and subsequent food transport to the ocean floor (Freiwald et al. 2004b, Roberts et al. 2006). Little is known about the specific food sources for the petitioned species, but it is likely that microinvertebrates, especially plankton, provide the major food source for most of the petitioned coral species. Studies on food sources for cold water corals in the northeast Atlantic found that zooplankton comprised the primary source of nutrition for these species (Kiriakoulakis et al. 2005). Other studies indicate that detrital and re-suspended materials are likely to be important food sources for corals in deep waters (Naumann et al. 2011). Phytodetritus, fecal pellets and zooplankton were found to be the most substantial sources of particulate carbon available to cold water coral communities in the northeast Atlantic (Roberts et al. 2006). Although unconfirmed, it is also likely that diurnally migrating zooplankton and over-wintering populations of calanoid copepods are important prey items for cold water corals (Roberts et al. 2006).

The petitioned corals generally occur in areas of high surface productivity and current or upwelling activity, and are associated with some of the most productive fisheries in the world (Heifetz 2002). Thus, planktonic species are likely the primary food source for the petitioned corals, with delivery of these species to depth of coral growth critical for adequate nutrition.

### *iii. Calcification, Growth, and Repair*

The calcium carbonate in cold water coral skeletons is formed from dissolved organic and inorganic carbon found at the depths where corals occur. Depending on the species, cold water corals use one of three forms of calcium carbonate for growth and repair: aragonite, high magnesium calcite (HMC), or calcite (Thresher et al. 2011). Calcite is a less soluble and more stable form of calcium carbonate, and therefore has a deeper saturation depth than aragonite. It is generally preferred by deeper dwelling coral species, or those occurring in waters undersaturated with respect to aragonite, which is common for waters of the North Pacific and Arctic Oceans (Hofmann et al. 2010, Miller et al. 2011). Corals with a high percentage of magnesium to calcite in their skeleton are even more soluble than those containing aragonite, with depth of solubility depending on the ratio of magnesium to calcite (Andersson et al. 2008). Species differences in the forms of calcium carbonate required for growth, repair and other life history processes are critical, as saturation depths of aragonite and HMC are already shallow and becoming shallower due to ocean acidification in the areas where Alaska cold water corals occur (Orr et al. 2005). However, even calcitic coral species will be vulnerable to ocean acidification processes, as the saturation depth for less-soluble calcite is also becoming progressively shallower over time (Guinotte et al. 2006, Andersson et al. 2008).

The tissues of octocorals (order *Gorgonacea* and order *Pennatulacea*) have axial skeletons of calcitic sclerites, which are micro-skeletal elements that provide rigid support for the coral skeleton. The axes of octocorals are composed of the horn-like protein gorgonin infused with calcite, aragonite, HMC, or amorphous carbonate hydroxyapatite [Ca, (PCX, CO), (OH)] (Bayer and Macintyre 2001). Within the coral skeleton, the protein gorgonin and calcium carbonate components alternate in layers of what are believed to be annual growth rings (Heikoop et al. 2002). While octocorals' sclerties are composed only of magnesium calcite, the axial skeletons contain a mixture of aragonite and calcite, and the ratio of calcite to aragonite and the percentage of magnesium in the calcium carbonate layer is likely controlled by seawater temperature (Matsumoto 2007). Octocorals occurring in colder waters generally are expected to have a lower percentage of magnesium to calcium, but this relationship is not linear (Matsumoto 2007, Thresher et al. 2010).

Calcification processes critical to growth and repair, nutrition, and other factors important to life history of octocorals are dependent both on local conditions occurring at depth, and on productivity at the surface and other surface conditions (Thresher et al. 2011). Calcium carbonate used in the gorgonian coral skeleton is formed from dissolved inorganic carbon in seawater, while the carbon source for coral polyps and gorgonin is derived from particulate organic matter generated at the surface, sinking to depth (Griffin and Druffel 1989, Heikoop et al. 1998, 2002).

Stylaterids (18 petitioned species) form rigid skeletons of either aragonite, calcite or HMC. As an adaptation, most of the stylasterids in the Aleutians are likely composed primarily of calcite, although as of summer 2012, few of the petitioned species have been analyzed for mineral content (Cairns and Macintyre 1992). A calcite-based skeleton allows these species to survive at a wider range of depths because calcite has a deeper saturation horizon and is therefore less soluble in waters undersaturated with respect to aragonite. In addition to calcite, many Alaska stylasterids also utilize a more soluble form of calcium carbonate in their skeletal elements including HMC and/or aragonite (Cairns and Macintyre 1992, Guinotte et al. 2006).

Cold water corals grow only millimeters to a couple of centimeters a year (Andrews et al. 2002, Roark et al. 2009). The primnoid species *Primnoa resedaeformis* was found to grow just 1.6 cm to 2.32 cm per year in height, and 0.36 mm per year in width (Andrews et al. 2002). The particulars of growth rates for each petitioned species may be dependent on temperature, nutrient availability, forms of calcium carbonate available for skeletal growth and variations in ocean chemistry (Roark et al. 2006, Simpson 2009). Little is known about the growth and repair of new skeletal material, although it was found that new cyclosystems can regenerate on damaged branches in Alaska stylasterids (Ostarello 1973, Brooke and Stone 2007). It is likely that Alaska cold water corals grow and repair skeletal elements fastest under ideal conditions with ample nutrients and dissolved calcium carbonate. Stressed corals, or those in areas undersaturated with regards to the form of calcium carbonate used to build their skeletons, are likely to have reduced or very limited growth rates.

### *iv. Longevity*

The petitioned corals are extremely long lived, and may live to be hundreds and even thousands of years old (Andrews et al. 2002, Heifetz 2002, Roark et al. 2009). Cold water corals in the Gulf of Alaska were dated at 30 years old to over 200 years old (Andrews et al. 2002). Red tree corals (*Primnoa*) from southeast Alaska are 100 years old to 200 years old by the time they reach 6 feet to 10 feet in height, and the same species may live 300 years in Canada (Andrews et al. 2002). Radiocarbon dating studies estimated that colonies of gold coral may live for more than 2,700 years, and a deep-sea black coral colony in Hawaii was dated to 4,265 years (Roark et al. 2009). Other corals sampled from Alaska and Hawaii were dated to up to 2,700 years old (Roark et al. 2006). Heikoop et al. (2002) found that *Primnoa* cold water corals in Alaska live for several centuries, and further added that because of their extreme age, these corals may provide useful information on surface productivity, deep ocean temperature and chemistry.

## e. Species Associations

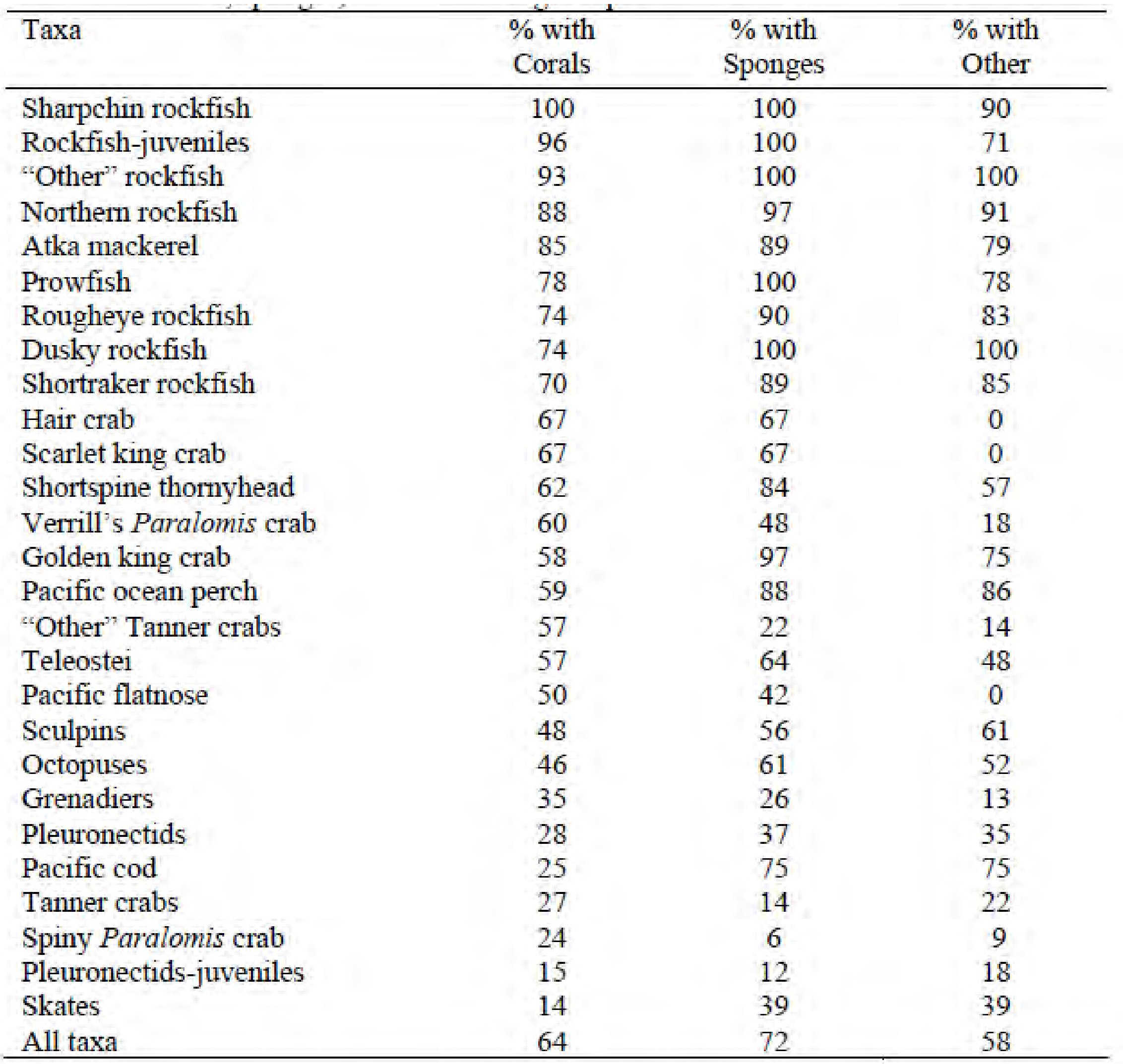
Cold water corals provide a three dimensional substrate on the often barren sea floor, which attracts fish and other species to areas of cold water coral, making these coral a critical part of the benthic ecosystem. The amount of biodiversity on the seafloor is generally correlated with the amount of three-dimensional habitat available, which is provided by living species including corals, and also non-living substrate like cobbles and boulders (Yoklavich et al. 1998, Krieger and Wing 2002). Corals and boulders often occur together, making it difficult to gauge the relative importance to associated species of the different substrates (Miller et al. 2012).

Cold water coral outcrops and “gardens” or “groves” and individual coral colonies comprise important habitat for adult fishes, crustaceans, sea stars, sea anemones, and sponges because they provide a high relief habitat that serves to protect these species from predators and shelters them from the strong currents that often occur in these areas (Krieger and Wing 2002). The gaps between coral branches or fans provide shelter and refuge for eggs, larvae, and juveniles of shrimp, crabs and fishes, and for many adult species (Krieger and Wing 2002, Roberts et al. 2009). Filter feeders use cold water corals as an elevated feeding platform for raising them into the currents above the seafloor where more food is available, and a variety of animals (including the endangered monk seal in Hawaii) forage in cold water coral areas (Krieger and Wing 2002, Buhl-Mortensen 2005). The availability of three dimensional habitat created by cold water corals is a vital determinant of the diversity, distribution, and abundance of valuable commercial species such as rockfishes (Pearcy et al. 1989, Carr 1991).

**Figure 5:** Rockfish hides in a dense bed of hydrocorals, demosponges, hydroids, and actinarians at a depth of 210 m. This habitat demonstrates typical bedrock and hard substrate relief favored by cold water coral for settlement. Source: Bob Stone NOAA fisheries.

Cold water corals may be a keystone species that, by their presence, determine benthic fish and invertebrate diversity and abundance (Tews et al. 2004, Heifetz et al. 2005). As discussed above, the three dimensional substrate habitat created by cold water corals provides protection from predators, shelter, feeding habitat, spawning habitat and breeding areas for these marine fish and invertebrate species, Observational studies show a strong association between cold water coral and commercial fish species (Krieger and Wing 2002). In this way, cold water corals function as ecosystem engineers that can provide living space, alter and ameliorate physical conditions, and affect biological interactions (Miller et al. 2012). Cold water corals also act as autogenic engineers that modify habitats through their physical presence alone. Cold water corals may provide food and shelter that is crucial to the survival of associated animals (Tews et al. 2004, Heifetz et al. 2005). Cold water corals may also serve as prey for some benthic animals, including starfish species, but these ecological processes remain little known.

Hotbeds of biodiversity around cold water corals have been documented in the Aleutians, Bering Sea and Gulf of Alaska, and a wide variety of fishes depend on cold water coral areas for food, protection, and as a place to lay their eggs (Heifetz 2002). Cold water corals are thought to provide important habitat for commercially important species, including rockfish, cod, and crabs (Krieger and Wing 2002). For example, Stone (2006) reported that 85 percent of the commercially important fish and invertebrate species, and 97 percent of juvenile rockfishes observed in the Aleutian Islands, were associated with coral-sponge communities. In southeast Alaska, 85 percent of observed large rockfishes were in or around red tree coral colonies (Krieger and Wing 2002). On average, 64 percent of all observed fish, crab and octopus taxa in the Aleutians were observed in association with corals (Table 1).



| Taxa | % with Corals | % with Sponges | % with Other |
|---|---|---|---|
| Sharpchin rockfish | 100 | 100 | 90 |
| Rockfish-juveniles | 96 | 100 | 71 |
| "Other" rockfish | 93 | 100 | 100 |
| Northern rockfish | 88 | 97 | 91 |
| Atka mackerel | 85 | 89 | 79 |
| Prowfish | 78 | 100 | 78 |
| Rougheye rockfish | 74 | 90 | 83 |
| Dusky rockfish | 74 | 100 | 100 |
| Shortraker rockfish | 70 | 89 | 85 |
| Hair crab | 67 | 67 | 0 |
| Scarlet king crab | 67 | 67 | 0 |
| Shortspine thornyhead | 62 | 84 | 57 |
| Verrill's *Paralomis* crab | 60 | 48 | 18 |
| Golden king crab | 58 | 97 | 75 |
| Pacific ocean perch | 59 | 88 | 86 |
| "Other" Tanner crabs | 57 | 22 | 14 |
| Teleostei | 57 | 64 | 48 |
| Pacific flatnose | 50 | 42 | 0 |
| Sculpins | 48 | 56 | 61 |
| Octopuses | 46 | 61 | 52 |
| Grenadiers | 35 | 26 | 13 |
| Pleuronectids | 28 | 37 | 35 |
| Pacific cod | 25 | 75 | 75 |
| Tanner crabs | 27 | 14 | 22 |
| Spiny *Paralomis* crab | 24 | 6 | 9 |
| Pleuronectids-juveniles | 15 | 12 | 18 |
| Skates | 14 | 39 | 39 |
| All taxa | 64 | 72 | 58 |

**Table 1:** Percentage of fish, crab, and octopus taxa that were observed in the same video frame with corals, sponges, and other emergent epifauna on 28 seafloor transects surveyed with the submersible Delta and the ROV Jason II. Source: (Stone and Alcorn 2007).

Two studies that have investigated the interactions between corals and other species are discussed in more detail here. Miller et al. (2012) examined the relationship between cold water corals and fish and invertebrate species in the Pribilof and Zhemchug canyons of the Bering Sea. This study found that commercially important fish species preferentially utilize corals for habitat. This is likely due to a combination of provision of shelter, and the availability of invertebrate and planktonic food sources trapped by cold water corals. The authors were unable to distinguish coral habitat from that provided by non-biological cobbles or boulders, as corals are usually associated with hard substrate habitat (Miller et al. 2012).

The relationship between coral habitat and juvenile commercial fish species was also examined in Rooper and Boldt (2005), and results showed a strong relationship between juvenile Pacific Ocean perch and the complex structure of coral habitat. This is one of few studies that have documented the importance of coral habitat to commercially important fish species, and linked areas of coral habitat to the catch of juvenile perch, which in other studies is generally documented in a qualitative, rather than quantitative manner (Heifetz 2002, Malecha et al. 2005). This study found that because many of the deep sea commercial fish species have long life histories, impacts to juvenile fish that may be the primary age-group to use cold water corals may have a delayed observed impact on fisheries catch. This emphasizes the importance of long-term and immediate protections for cold water coral habitat.

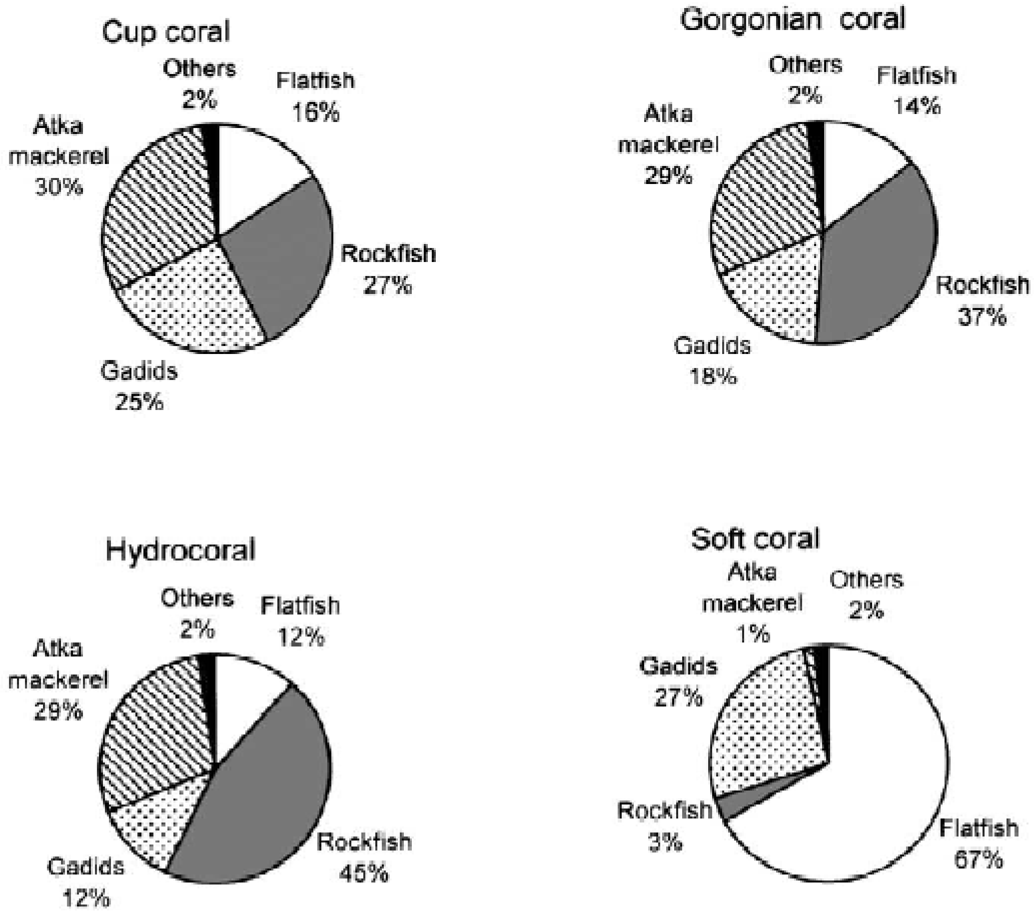


**Figure 6:** Commercial fish groups associated with corals based on NMFS trawl surveys, 1975-1998. Within a coral group, percentages are based on the proportion of the total fish catch per unit effort (CPUE) that was attributable to a particular fish group. Source: (Heifetz 2002).

High rates of coral bycatch occur where commercially sought-after species are strongly associated with corals. Coral bycatch is especially prevalent in the Aleutian Islands and parts of the Bering Sea (e.g., Zhemchug and Pribilof canyons), home to some of the most productive fisheries in the world. Destruction of cold water corals due to trawling and other fishing activities will no doubt have a negative impact on the coral substrate that supports these commercial fisheries, and on abundance of ocean invertebrates and other species that utilize cold water corals for feeding, shelter, and reproduction. Impacts may be difficult to quantify immediately, as it is possible that juveniles of long-lived fish species are most heavily impacted (Rooper and Boldt 2005).

Specifics of the functional relationships among coral, invertebrate and fish species may never be known. It is obvious, however, that fish and invertebrates utilize cold water corals preferentially to other benthic habitats. Thus, damage or removal of cold water coral, or habitat loss and degradation, may impact not just the petitioned coral species, but the entire marine ecosystem in which the corals reside. As a keystone species, cold water corals may play an integral role in maintaining the structure and diversity of an ecosystem.

### f. Value for medicinal use and as historical archives

Cold water corals are sessile and cannot move to avoid predators, and some species produce chemical defense mechanisms to protect themselves (Faulkner 2002). These compounds exhibit significant bioactivity with strong effects on living cells or organisms (Lebar et al. 2007). Some of these compounds show promise as treatments for human illness, and scientists are investigating their uses to develop new pharmaceutical products to fight cancer, Alzheimer’s disease, asthma, pain, and viral infections (Faulkner 2002, Etnoyer and Morgan 2003, Maxwell et al. 2005, Simmons et al. 2005, Lebar et al. 2007).

Compounds from cold water corals are also used in paints and other materials to prevent algae and invertebrates from growing on boat hulls, piers and bridges (Pawlik 1993, Morgan et al. 2006).

Cold water corals are also archives of the ocean’s history, and changes in ocean conditions are recorded in the skeletons of corals. Because of their very long life span, and wide distribution along depth and latitude, these corals provide a resource for information on ocean history (Risk et al. 2002). This may help reconstruct the history of changes in growth, temperature, and ocean chemistry at great ocean depths.

## II. NATURAL HISTORY AND STATUS OF PETITIONED CORALS OF ALASKA

There are a total of 43 Alaska coral species included in this petition: 23 gorgonians, two pennatulaceans, and 18 stylasterids. Of these, 40 species are endemic to Alaskan waters, with three species endemic to Alaska and Russia or Alaska and British Columbia. This section provides an overview of the taxonomy of the petitioned species, an overview of the distribution of the petitioned species and species accounts for each petitioned coral, including description, distribution, and status for each species as well as a description of the class, subclass, order, and family.

### A. OVERVIEW OF TAXONOMY OF THE PETITIONED CORALS

Corals are defined as "animals in the cnidarian class Anthozoa and Hydrozoa that produce either calcium carbonate (argonitic or calcitic) secretions resulting in a continuous skeleton or as numerous, usually microscopic, individual sclerites, or that have a black, horn-like proteinaceous axis" (Cairns 2007). All of the petitioned corals belong to phylum Cnidaria and to class Anthozoa or Hydrozoa with classification as follows:

- Class Anthozoa
  - Subclass Octocorallia
    - Order Gorgonacea (gorgonians)
      - Family Primnoidae: 21 spp
      - Family Plexauridae: 2 spp
    - Order Pennatulacea (sea pens)
      - Family Veretillidae: 1 sp
      - Family Paramuriceidae: 1 sp
- Class Hydrozoa
  - Order Anthoathecata (Filifera)
    - Family Stylasteridae: 18 spp

### B. OVERVIEW OF THE DISTRIBUTION OF THE PETITIONED CORALS

The known geographic distribution for 41 of the listed species is restricted to the U.S. EEZ Alaska waters, and these species are endemic to Alaska. Two of the petitioned corals have a limited range outside of U.S. EEZ waters. *Plumarella superba* is known to occur in both the U.S. EEZ of Alaska and the Russian waters near Sakhalin Island, and *Primnoa pacifica* var. *willeyi*'s known geographic range includes the U.S. EEZ of Alaska and the waters off British Columbia, Canada.

A map that estimates the range, or includes known collection points, is included for all but one (*Stylaster cancellatus*) of the petitioned coral species. There are two types of information provided on the species distribution maps: (1) red circles depict known points of collection for this species; and (2) yellow shading represents an estimate of this species' existing distribution based on known locations of sample collection, and described depth range and geographical distribution of these samples. There are several factors that play an important role in the distribution of Alaska coral species, including nutrient flows and productivity, water temperature, availability of hard substrate, currents and sediment load, and seawater chemistry make-up including salinity and calcium carbonate saturation state. These factors were not included in the mapping process as they are not readily available, and the specific interactions of these factors to each species' distribution are unknown. As corals are generally patchily distributed, the estimated distribution in yellow is simply a rough estimate of where a species may be located. For many species, the estimated distribution was not included due to the limited data set and lack of accuracy in defining range. Researchers have made efforts to map favorable coral habitat areas in Alaska and other parts of the world's oceans based on a variety of habitat characteristics, but primarily based on topography and geological compilation (type of substrate) of the seafloor (Woodby et al. 2009). These mapping efforts are likely to continue at a more concentrated scale in the Aleutian Islands in an effort to identify important areas of possible coral growth for further investigation using submersibles (Woodby et al. 2009). However, as stated above, many factors contribute to creating ideal habitat for each species, and substrate simply provides an estimate of where to look for corals, rather than an indication that cold water corals are present in an area.

## C. SPECIES ACCOUNTS

### 1. Class Anthozoa

Members of this class include corals and sea anemones, and are exclusively polypoid, with no medusoid stage. There are a total of 25 petitioned coral species in this class. In contrast, most members of the hydrozoan class retain both polypoid and medusoid stages in their life cycle (Etnoyer and Morgan 2003).

### *Subclass Octocorallia or Alcyonaria (soft corals)*

Octocorallia (octocorals or soft corals) are important members of the deep sea benthic communities of the North Pacific, and their abundance, diversity, and biomass often rival or exceed that of hard corals (Freiwald et al. 2004a, Freiwald and Roberts 2005). This subclass is comprised of the gorgonians and the soft corals, sea fans, sea whips and sea pens.

About 3,000 species of octocorals occur worldwide (Cairns and Bayer 2009). In Alaska, this is the most diverse class of corals, but also one of the most difficult to identify (Wing and Barnard 2004, Cairns 2011). The Aleutian Islands is the area with the highest diversity of coral in Alaska, with 31 named non-pennatulacean octocoral species (Cairns 2011a). Additional species have yet to be identified, and still more are likely completely unknown to science. Thus, the true species diversity of octocorals in Alaska is as yet unknown (Wing and Barnard 2004, Heifetz 2005, Cairns 2011).

Octocorals are recognized by their feeding polyps, each of which has eight feathered tentacles. The tissues of octocorals contain sclerites, which are calcitic micro-skeletal elements. The axes may be composed of calcite, aragonite, or amorphous carbonate hydroxylapatite (Bayer and Macintyre 2001). The importance of the calcium carbonate compositions of octocorals with regards to ocean acidification impacts will be discussed further in the listing factors section.

Nearly all octocorals form colonies, and these colonies create some of the largest sessile invertebrates found on Alaska's seafloor. The Alaskan octocoral colonies come in a wide variety of shapes and sizes from solitary cups to large, branching trees to multi-layered fans. They include *Stolonifera* (stolon corals), *Alyconacea* (true soft corals), *Gorgonacea* (leather corals or seafans), and *Pennatulacea* (sea pens and sea whips). The most common octocorals in the Aleutian Islands are the gorgonians, which occur in great diversity and abundance and, along with stylaterids, are a major component of the coral gardens in the Aleutians (Freiwald et al. 2004b, Stone 2006). Gorgonian colonies may range in age from several years (Koslow et al. 2001) to hundreds and even thousands of years (Rogers 2004). For example, measurements of radioactive isotopes in coral skeletons suggested that a two-meter tall paragorgia specimen is in excess of 500 years old (Andrews et al. 2002). The age range is due in part to the varied growth conditions present in each species habitat, with species found in deeper, colder waters generally experiencing slower metabolism and thus a longer life span (Thresher et al. 2010). Because of their extreme age and three-dimensional structures, octocorals provide established habitat for a vast array of bacteria and micro and macro organisms (Mortensen and Buhl-Mortensen 2005) and for specialized, symbiotic fauna including crustaceans and snails, along with associated invertebrates and fish (Krieger and Wing 2002, Risk et al. 2002). Octocoral species also provide important fisheries habitat for many commercial fish species in Alaska including Pacific cod, sablefish, Atka mackerel and rockfish (Heifetz et al. 2005). These octocoral habitats provide excellent habitat for invertebrates and fish, and support one of the most productive fisheries in the world (Sánchez and Cairns 2004).

Octocorals exist throughout the Aleutian Islands, with the highest density of corals located west of 169 degrees west, in the vicinity of Samalga Pass, between Chuginak and Umnak Islands. This dividing point in the Aleutians is also associated with a partitioning of seabird and zooplankton species, and a strong surface current. High octocoral densities are found near Attu Island, Amchitka Island, Agattu Island and Kiska Island and in the eastern Aleutians near Amlia Island (Heifetz 2002). In the Bering Sea, octocorals occur in scattered patches, mostly along the continental shelf and shelf break near the Pribilof Islands and St. Matthew Island, and are found in high densities in the Zhemchug and Pribilof submarine canyons (Miller et al. 2012). Octocorals are recorded in the central Gulf of Alaska, near the Kenai Peninsula, and in the eastern and southeastern Gulf of Alaska off Yakutat and in Dixon Entrance near the U.S.-Canadian border (Heifetz 2002).

Octocorals are also found in great abundance and with high rates of endemism on Gulf of Alaska seamounts (Penn et al. 2006, Baco 2007).

## ***Order Gorgonacea (sea fans)***

In Alaska, gorgonians are found on seamounts or deep shelves and form the backbone of the coral ecosystem (Freiwald and Roberts 2005, Heifetz et al. 2005). These corals often are a major component of the diverse, densely abundant assemblage of coral and sponge species in Alaska, described as coral gardens. In the Aleutian Islands, and on seamounts near the Aleutian Islands, coral gardens contain some of the highest diversity and abundance of corals found in northern latitudes (Cairns 2011a). Gorgonians require adequate currents for nutrient delivery and an exposed, hard substrate for attachment. Recent observations indicate that in water deeper than 450 meters, hexactillid sponges may be an important attachment substrate for gorgonians in areas without any exposed rock (Stone and Shotwell 2007).

### ***Family Primnoidae***

The Primnoidae is a diverse family of deep-water gorgonian octocorals consisting of 32 genera and about 207 species worldwide (Cairns 2011a). Currently, 26 valid Alaska primnoid species are described by science, with 19 occurring in the Aleutians and eight occurring in the Gulf of Alaska (Cairns 2011). The Aleutian Islands have a relatively high primnoid species component of octocorals at 61 percent, which is unique in that it is nearly double to triple the primnoid component of other deep-water octocoral regions (Cairns 2011). As a substantial component of Alaska octocoral regions, primnoids form important habitat for micro and macro fauna in the species-rich Aleutian coral gardens (Heifetz et al. 2002, Stone 2006).

Primnoid colonies grow in tree form, and can exceed two meters in height and seven meters in width (Krieger and Wing 2002). Primnoids are calcoxonians, meaning their flexible axis is solid, and composed of the protein gorgonin impregnated with large amounts of calcium carbonate, which may contain aragonite, calcite, and/or HMC (Roberts et al. 2009). This calcium carbonate skeleton supports branching colonies of individual red polyps that capture plankton with stinging cells (Krieger and Wing 2002).

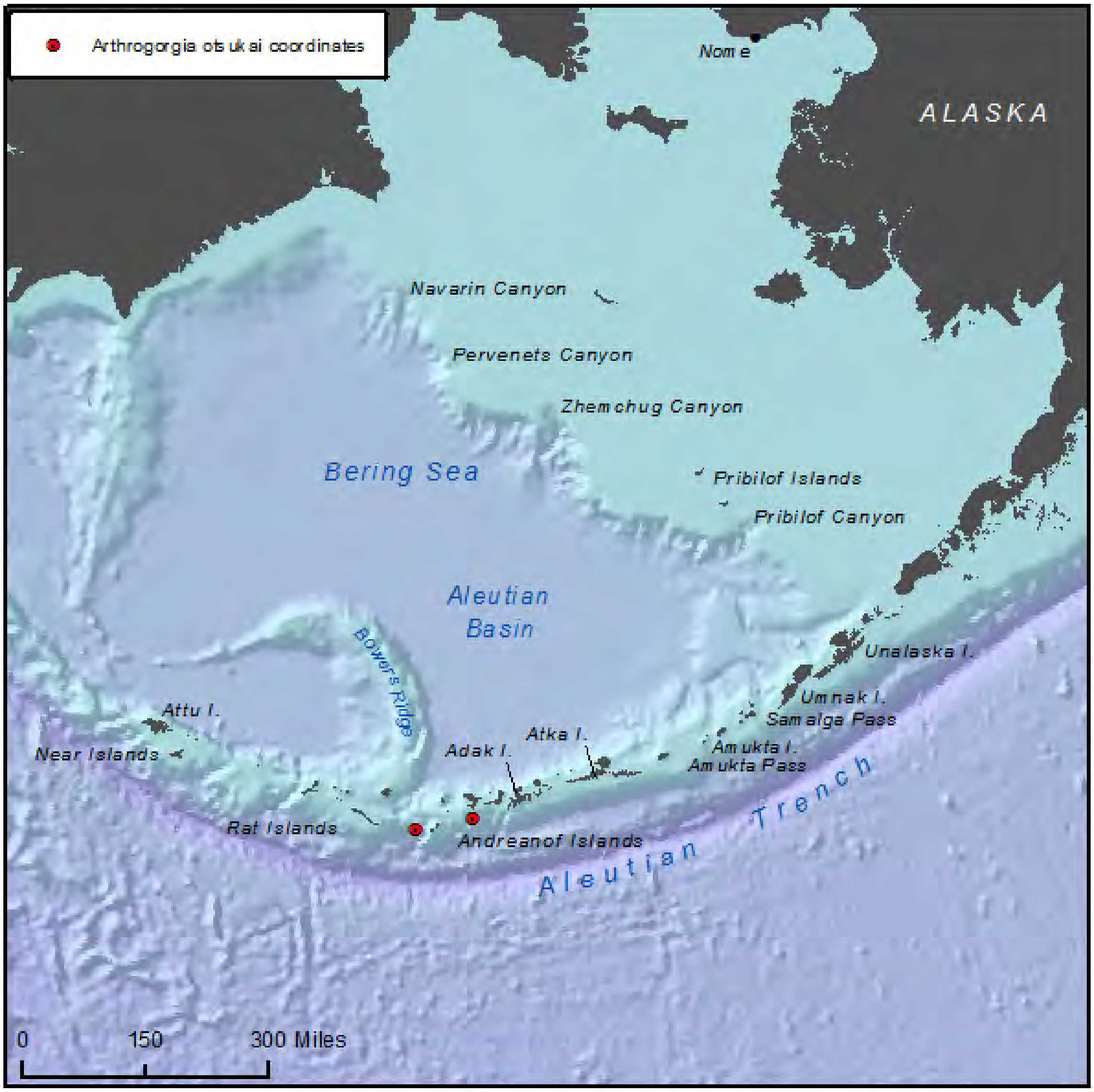
Most primnoids live at slope and abyssal depths from nine meters to 2,514 meters and form large deep water colonies, providing habitat for one of the most productive fisheries of the North Pacific (Stone 2006). In Alaska, primnoids have been reported from Dixon Entrance in southeastern Alaska, to Amchitka Island in the Aleutian Islands (Cimberg et al. 1981, Stone and Shotwell 2007). The minimal depth for Alaska primnoids appears to be 30 meters, and preferred habitat includes a substrate of large boulders or exposed bedrock, lack of turbidity, and yearly temperatures remaining above 3.7 degrees C (Cimberg et al. 1981, Stone and Shotwell 2007). The primnoid genus, *Narella*, first reported in Alaska in 2005, occurs at greater depths than all but one other primnoid genus in the world, with the Alaska coral *N. abyssalis* known from a depth of 4,594 meters (Cairns and Baco 2007).

Primnoid lifespan is estimated to be 100 years or more, with annual growth rates of approximately one cm per year (Cimberg et al. 1981). Using isotope dating, a five-cm primnoid specimen was aged at about 500 years old (Heikoop et al. 1998).

**Arthrogorgia otsukai** (Bayer 1952, Cairns 2011)

**Description**: Colonies are uniplanar and not bushy. Branching is dichotomous with the distal branches four cm to 15 cm in length. The largest known colony is 20 cm high and 10 cm wide. The axis is dark brown in color. Polyps are arranged in whorls of five to seven, directed downward with 11 to 13 whorls per branch length (Cairns 2011).

**Distribution**: This species is found in the Aleutian Islands, from Amchitka Pass and south of Kanaga Island at depths of 1,359 meters to 1,372 meters (Cairns 2011). This species is known only from Alaska waters and is believed to be endemic to Alaska (Heifetz et al. 2005, Cairns 2011).

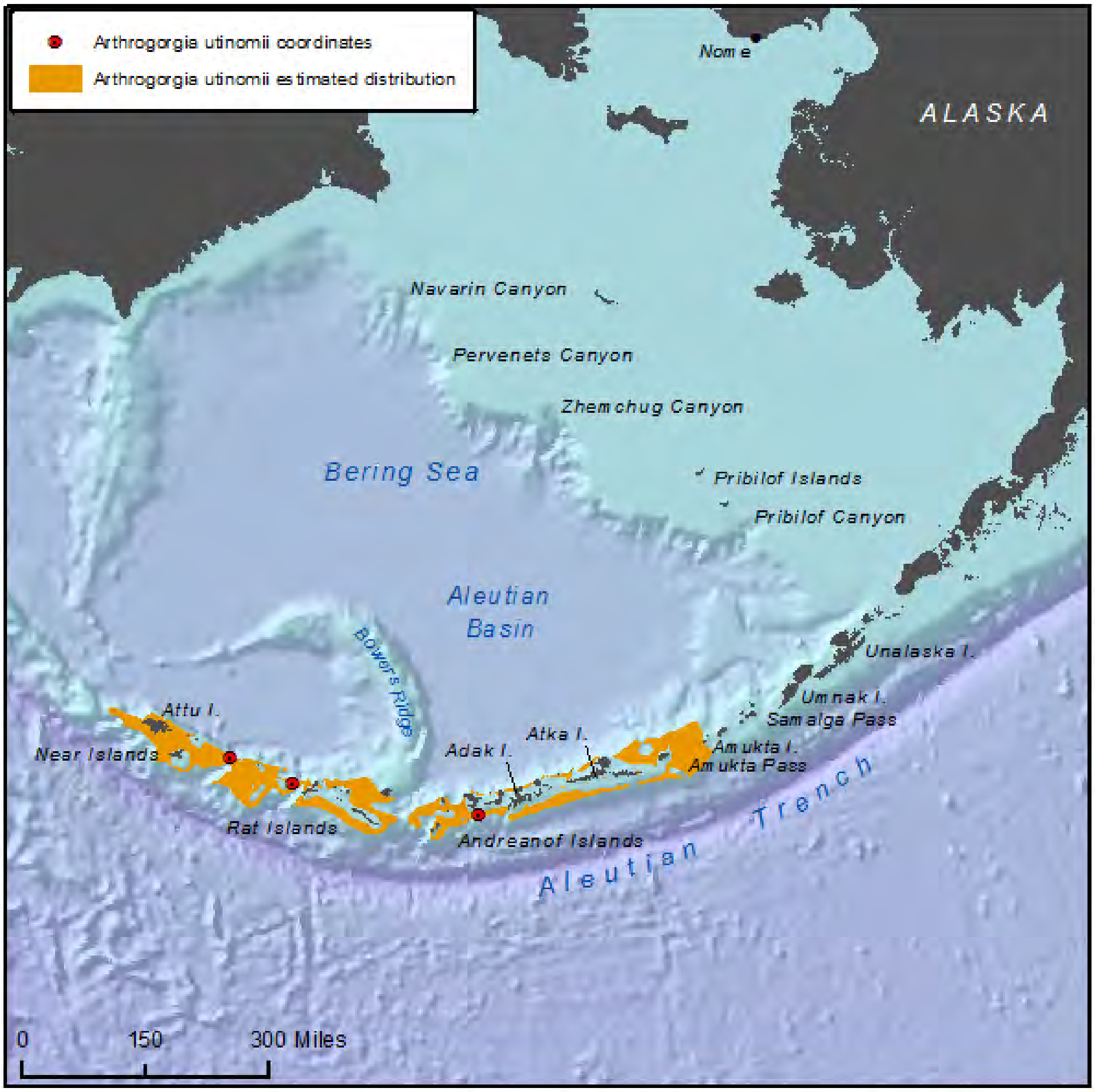


**Status**: There is very limited information on the status of this species. Based on known occurrence, this species is endemic to the Aleutian Islands and therefore has a limited range and is thus vulnerable to disturbance, or changes in its environment, and limited in ability to colonize or re-colonize an area if disturbed.

### **Arthrogorgia utinomii** (Bayer 1996, Cairns 2011)

**Description**: Colonies are uniplanar. Branching is equal and dichotomous, with distal branches up to 30 cm in length. The largest known colony is 30 cm tall. A thin web of tissue containing coenchymal sclerites occurs between each branching arm. The axis is brown to bronze in color, and the living colony is orange (Cairns 2011). This species is known only from Alaska waters and is believed to be endemic to Alaska (Heifetz et al. 2005).

**Distribution**: This species is found in the Aleutian Islands, from the Near Islands to off Amuka Island at depths of 163 meters to 882 meters. Most records are from 250 meters to 700 meters in depth (Cairns 2011).

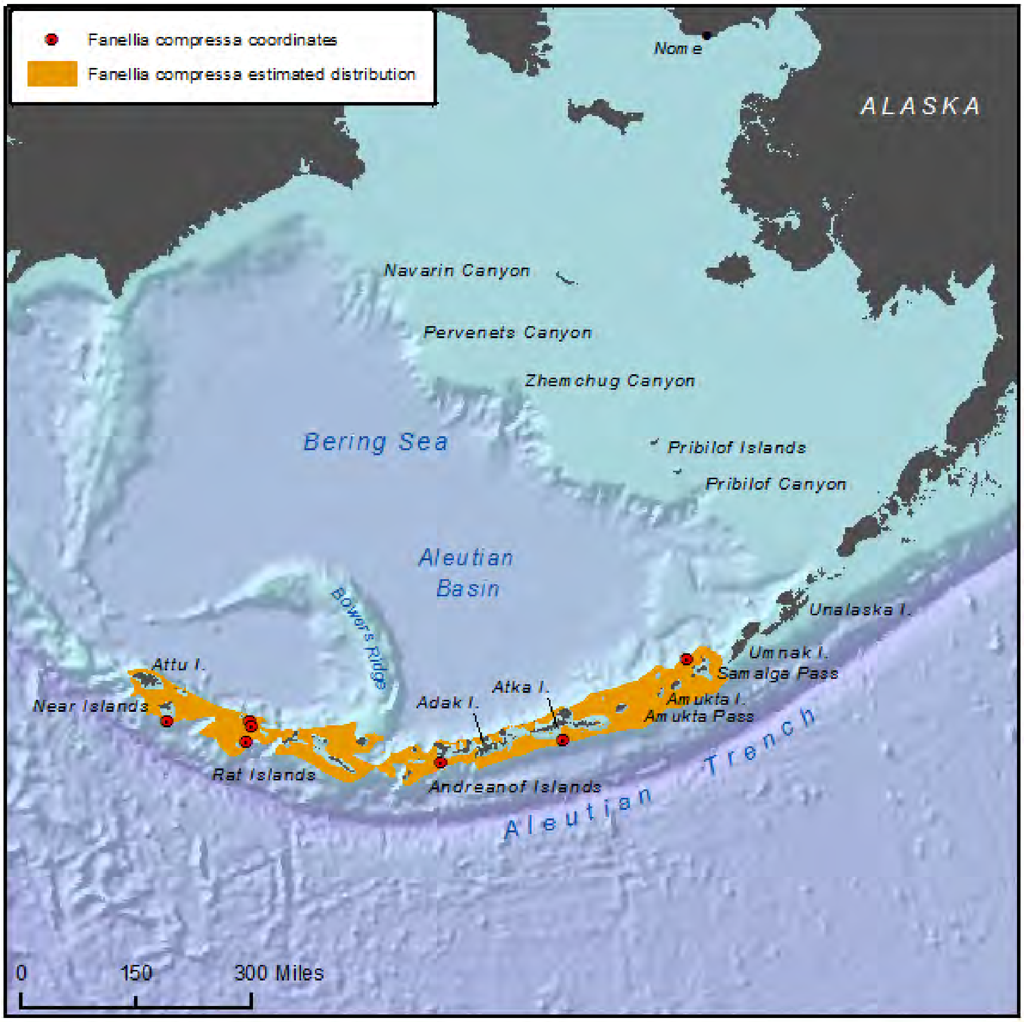


**Status**: There is very limited information on the status of this species. Based on known occurrence, this species is endemic to the Aleutian Islands and therefore has a limited range and is thus vulnerable to disturbance, or changes in its environment, and limited in ability to colonize or re-colonize an area if disturbed.

**Fanellia compressa** (Verrill 1866, Cairns 2011)

**Description:** Colonies are uniplanar, up to 80 cm high and 40 cm wide. The base measures 1.8 mm in diameter. Colonies branch every three to five cm, but most branching occurs in the lower third of the colony, with the end branches straight and up to 50 cm long. The branches at the edge of the colony sometimes divide into a series of smaller branches in quick succession. The dried tissue is pale gray in color, and the branch axis is metallic bronze. Polyps occur in close-spaced whorls on all branch surfaces, and approximate a spiral arrangement (Cairns 2011).

**Distribution:** This species is known only from the Aleutian Islands, from the Near Islands to Islands of Four Mountains, at depths of 82 meters to 1,061 meters, although most records are from 150 meters to 300 meters (Cairns 2011). This species is known only from Alaskan waters and is believed to be endemic to Alaska (Heifetz et al. 2005).

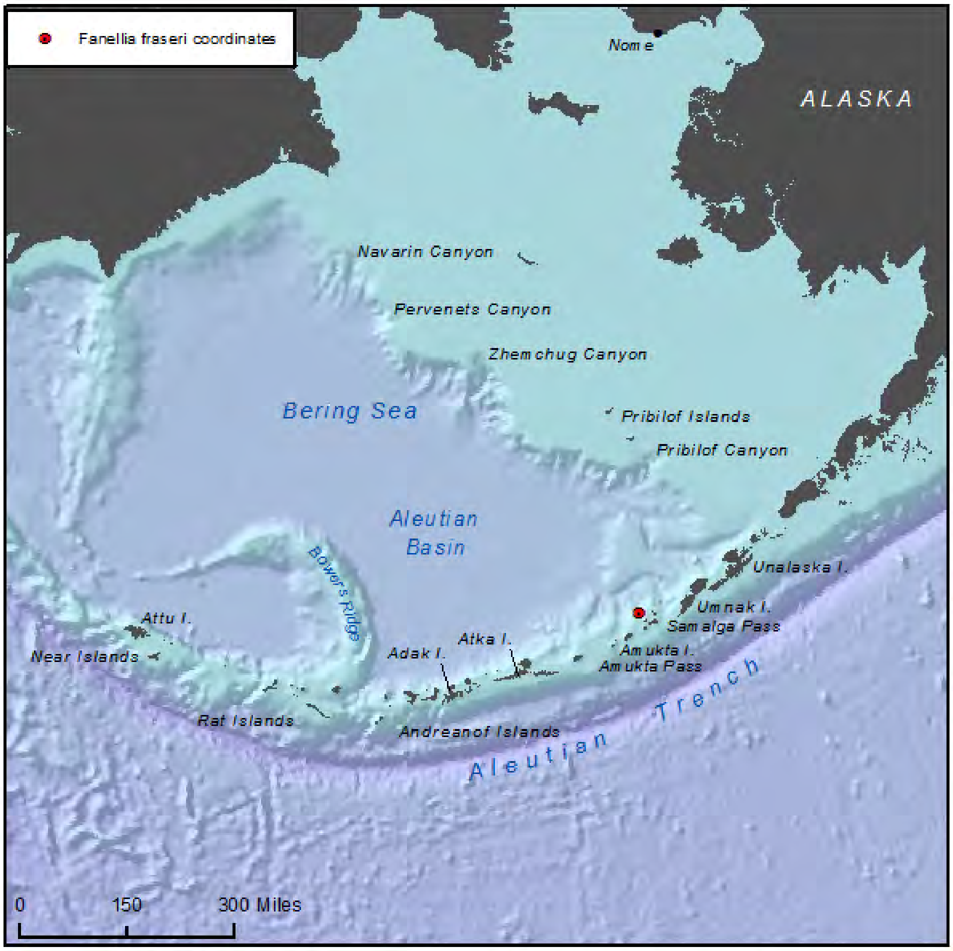


**Status**: Based on known occurrence, the species is endemic to the Aleutian Islands and therefore has a limited range and is thus vulnerable to disturbance, or environmental changes, and limited in ability to colonize or re-colonize an area if disturbed.

**Fanellia fraseri** (Hickson 1915, Cairns 2011)

**Description**: Colonies are uniplanar and are approximately equally tall as wide. Colonies grow up to 36 cm in height and 32 cm in width, and have a basal branch diameter of 9.5 mm. Branching occurs on either side of the axis, with a straight main branch, and sub-branches originating from the same side of a main branch separated by six to 14 mm. Branching occurs throughout the colony, resulting in short end branches that are usually less than 15 cm long. The dried tissue is pale gray, but pink when alive. The branch axis is a brownish yellow. Polyps occur in closely spaced whorls on all branch surfaces (Nutting 1912).

**Distribution**: This species is known only from Alaska, from Amchitka Pass to the Albatroke Bank northeast of Kodiak Island at depths of 86 meters to 1,341 meters, although most records are from 100 meters to 150 meters (Nutting 1912). This species is known only from Alaska waters and is believed to be endemic to Alaska (Heifetz et al. 2005).

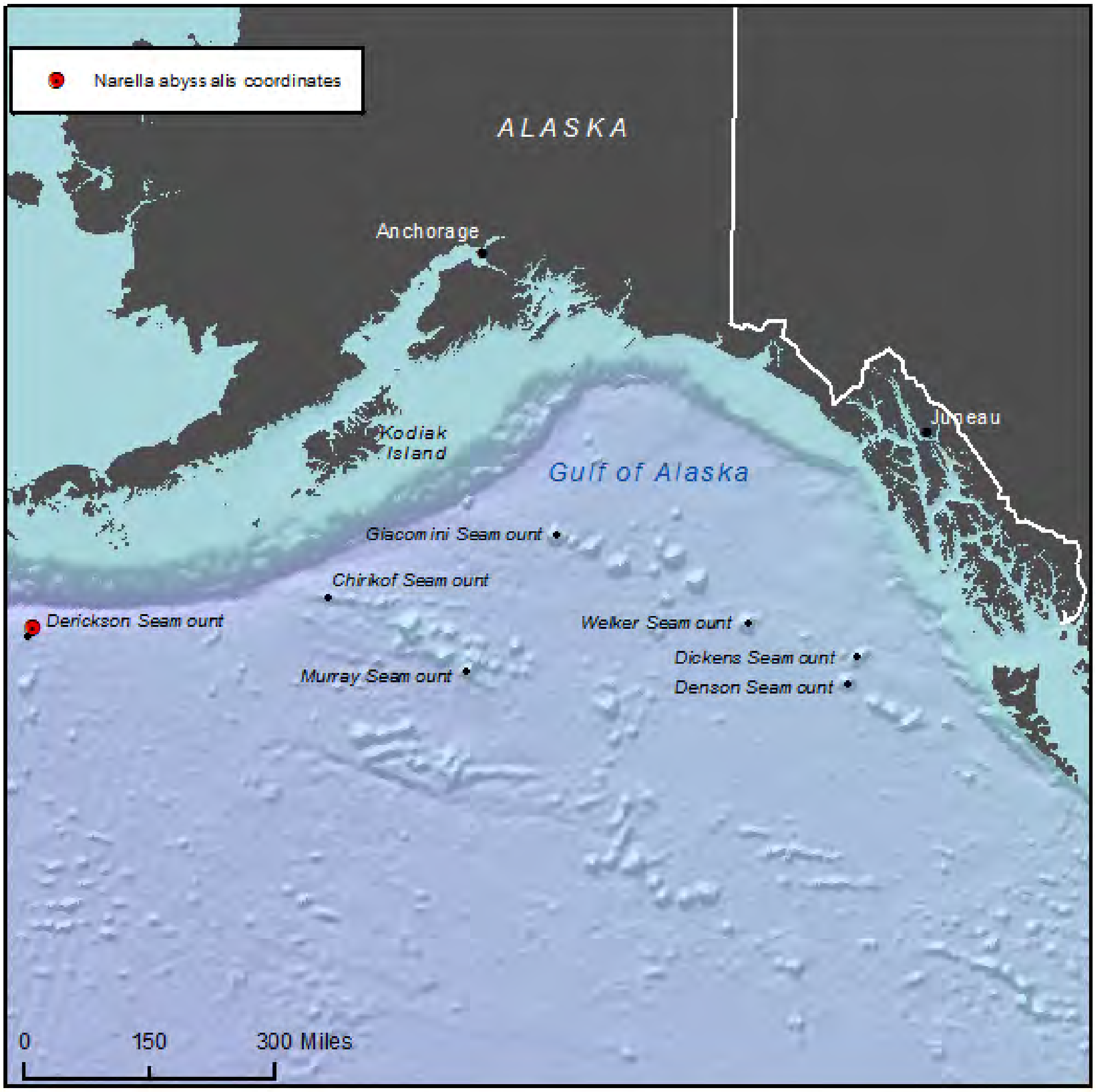


**Status:** There is very limited information on the status of this species. Based on known occurrence, this species is endemic to the  Aleutian Islands and therefore has a limited range and is thus vulnerable to disturbance, or environmental changes, and limited in ability to colonize or re-colonize an area if disturbed.

**Narella abyssalis** (Cairns and Baco 2007)

**Description**: The specimens available for species identification consist of about 20 branches and many detached polyps, all presumably from the same colony. The largest intact branch is 10 cm in length with four terminal branches. Branching appears to be sparse and uniplanar. The axis is golden yellow in color and quite brittle. Polyps are arranged in whorls of only two to four. One face of the colony usually contains no polyps. Whorls are well separated by 1.3 mm to 2.3 mm. This species is new to science as of 2007 and, based on known occurrence, is considered endemic to seamounts in the Gulf of Alaska (Cairns and Baco 2007).

**Distribution**: This speices is known only from one type locality in the Gulf of Alaska on Derickson Seamount, at 4,594 meters in depth (Cairns and Baco 2007).

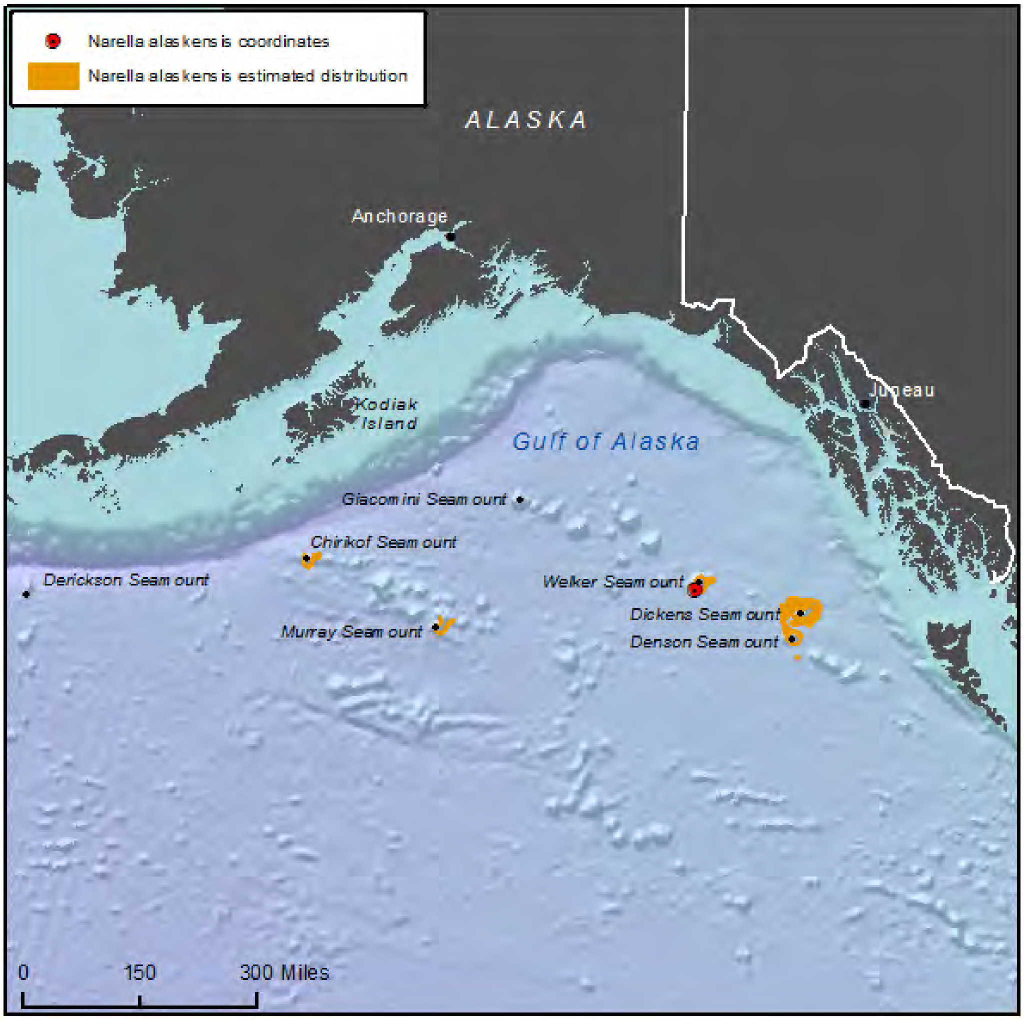


**Status:** There is very limited information on the status of this species. Based on the only known occurrence, the species is endemic to seamounts in the Gulf of Alaska and therefore has severely restricted range.

### **Narella alaskensis** (Cairns and Baco 2007)

**Description**: The colony is uniplanar, and is not bushy, with sparse branching. The axis is golden yellow, and up to 1.33 mm in diameter. Polyps on large diameter branches are arranged in whorls of seven to nine, with polyps of each whorl tightly packed against another and contiguous with those of the adjacent whorl. Only one branch segment, 11 cm long and seven mm in diameter, was available for species identification and description. This species is new to science as of 2007, and is considered endemic to Alaska (Cairns and Baco 2007).

**Distribution**: This species is found in the Gulf of Alaska on the Chirikof, Murray, Welker, Denson, and Dickins seamounts from 2,377 meters to 3,075 meters in depth. It is the most widespread and shallowest-dwelling species of *Narella* in the Gulf of Alaska (Cairns and Baco 2007).

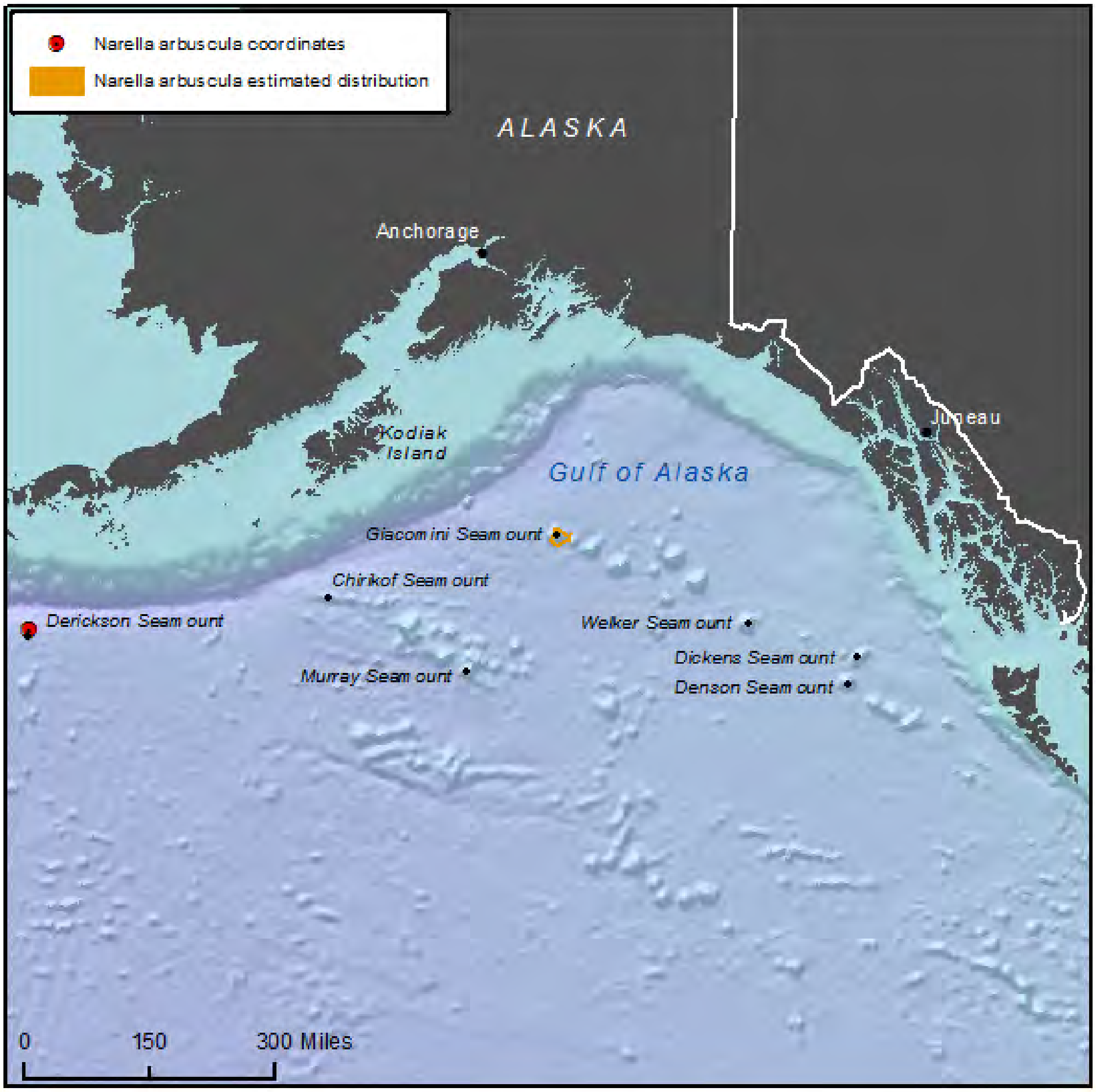


**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to seamounts in the Gulf of Alaska and therefore has a limited range.

**Narella arbuscula** (Cairns and Baco 2007)

**Description**: This description comes from a single specimen obtained by the submersible *Jason*. The colony is dichotomously branched, with the branches near the terminal end relatively long, at about 12 cm. The colony appears to be bushy in shape, rather than uniplanar. The axis is golden yellow and rigid, with a 1.8-mm diameter. Polyps are arranged in whorls of six to seven. Whorls are crowded, with each whorl directly adjacent to the next. This species is new to science as of 2007, and is considered endemic to Alaska (Cairns and Baco 2007).

**Distribution**: This species is known from the Gulf of Alaska, and was found on the Derickson and Giacomimi seamounts from 2,775 meters to 3,465 meters in depth (Cairns and Baco 2007).

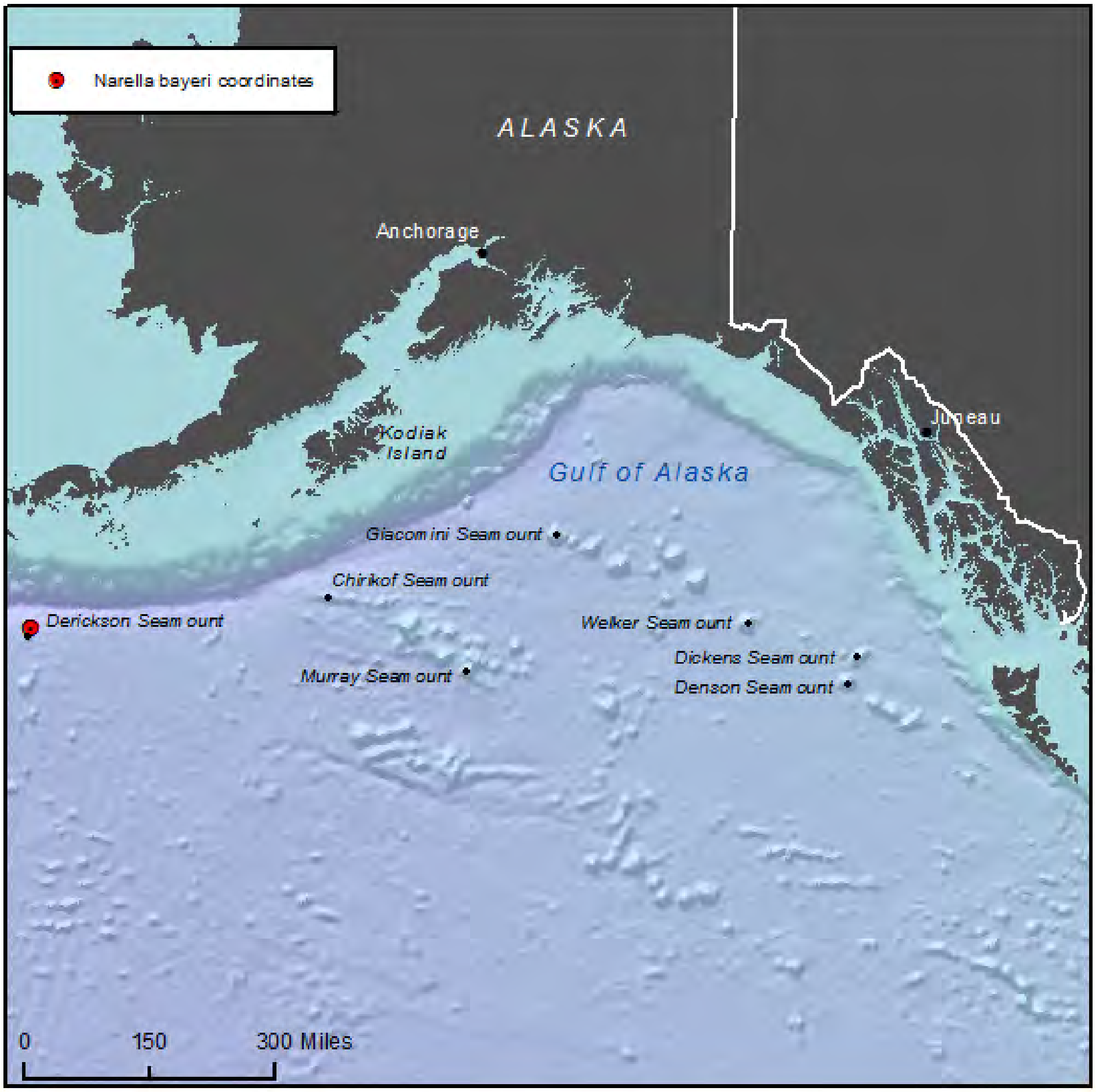


**Status:** There is very limited information on the status of this species. Based on the only known occurrence, the species is endemic to seamounts in the Gulf of Alaska and therefore has a severely limited range.

**Narella bayeri** (Cairns and Baco 2007)

**Description:** Colonies are uniplanar, rather than bushy or three-dimensional, and are sparsely and evenly branched, with the test specimen measuring 29 cm high and 20 cm wide, with a basal axis diameter of 4.7 mm. Early branching in the colony occurs at intervals of every 13 mm to 25 mm, and terminal branches are quite long, up to 17 cm in length. The axis is a yellow brown color with a woody texture. Polyps are arranged in whorls of five to seven, with six being the most common. This species is new to science as of 2007 and is considered endemic to Alaska (Cairns and Baco 2007).

**Distribution**: This species occurs in the Gulf of Alaska on the Derickson Seamount and from a seep west of that seamount, at depths from 3,277 meters to 4,091 meters (Cairns and Baco 2007).

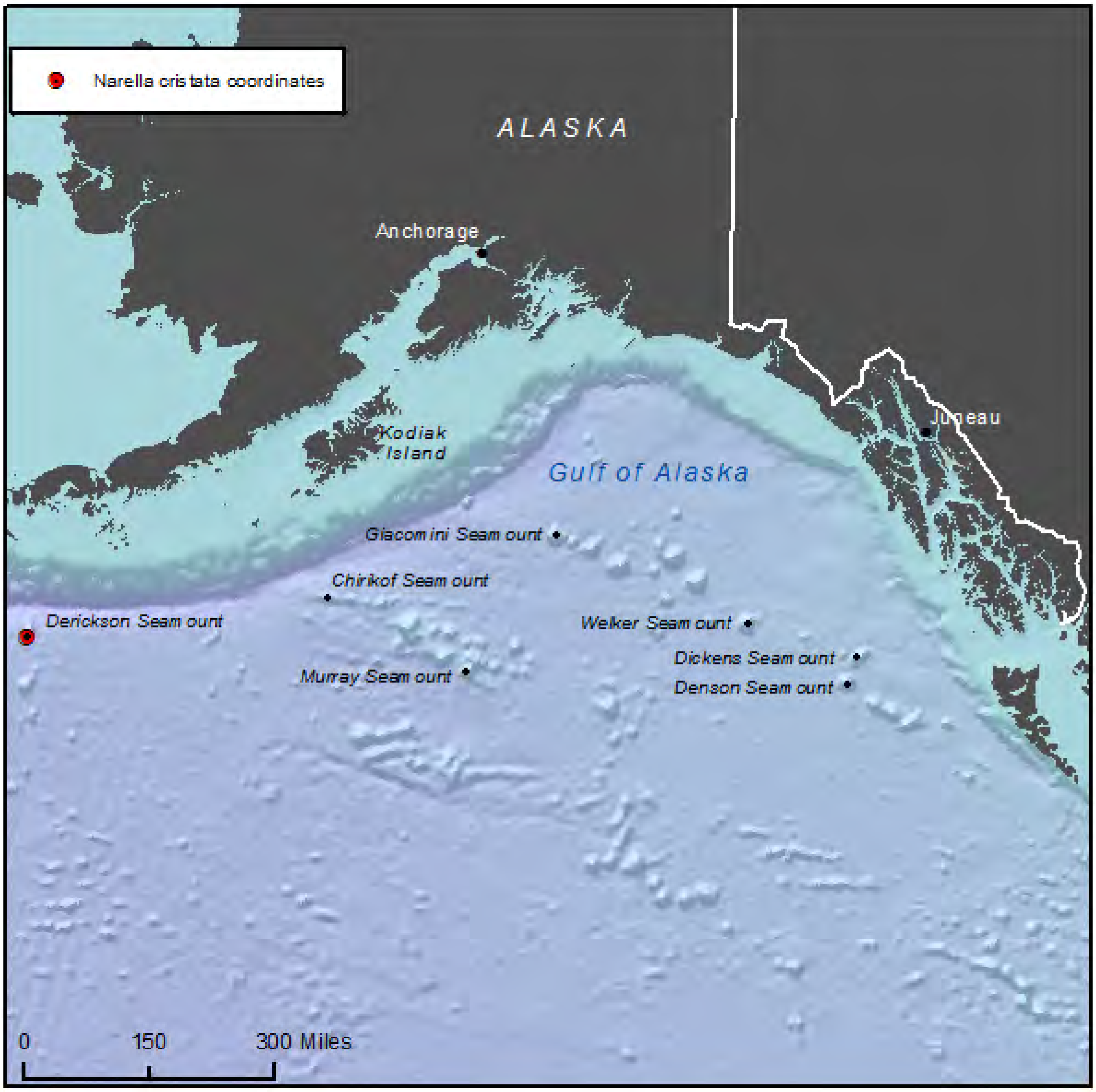


**Status:** There is very limited information on the status of this species. Based known occurrence, the species is endemic to seamounts in the Gulf of Alaska and therefore has a limited range.

**Narella cristata** (Cairns and Baco 2007)

**Description:** The holotype consists of about nine branches, with several short branches along with branch segments assumed to be from the same colony. The largest branch is 8.5 cm long with five terminal branches. Branching appears to be sparsely dichotomous and uniplanar. The axis is golden yellow and stiff, the largest branch having an axis diameter of only two mm. Polyps are arranged in whorls of only two to four, and one face of the colony is usually devoid of polyps. This species is new to science as of 2007 and is considered endemic to Alaska (Cairns and Baco 2007).

**Distribution**: This species is known only from the Gulf of Alaska, and a single type locality on the Derickson Seamount, at a depth of 3,385 meters (Cairns and Baco 2007).

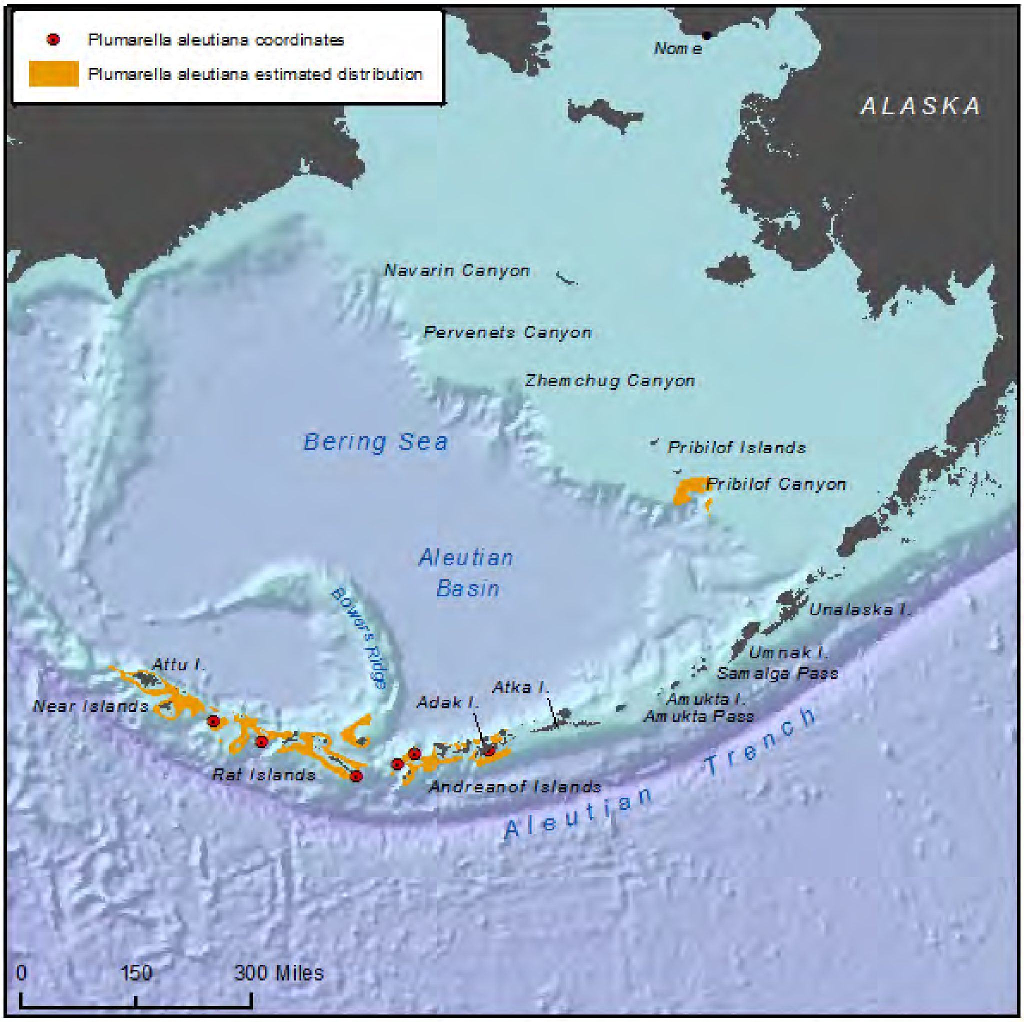


**Status:** There is very limited information on the status of this species. Based known occurrence, the species is endemic to seamounts in the Gulf of Alaska and therefore has a limited range.

**Plumarella aleutiana** (Cairns 2011)

**Description**: Colonies are uniplanar, and consist of relatively few main branches from which smaller branches originate in an alternative pinnate manner. The largest specimen is 50 cm high and 36 mm wide, and consists of 10 main stems or fronds. Smaller branches are only four cm to nine cm long, and have secondary branching. Smaller branches are arranged parallel to one another, on either end of the main stem, and occur every four mm to six mm. Branches and colonies are stiff. The branch axis is brown to black in color (Cairns 2011). This species is considered endemic to Alaska (Heifetz et al. 2005)

**Distribution**: This species is common throughout the Aleutian Islands from Near Island in the west to Unalaska to the east, and Pribolof Canyon, at depths from 79 meters to 517 meters (Cairns 2011).

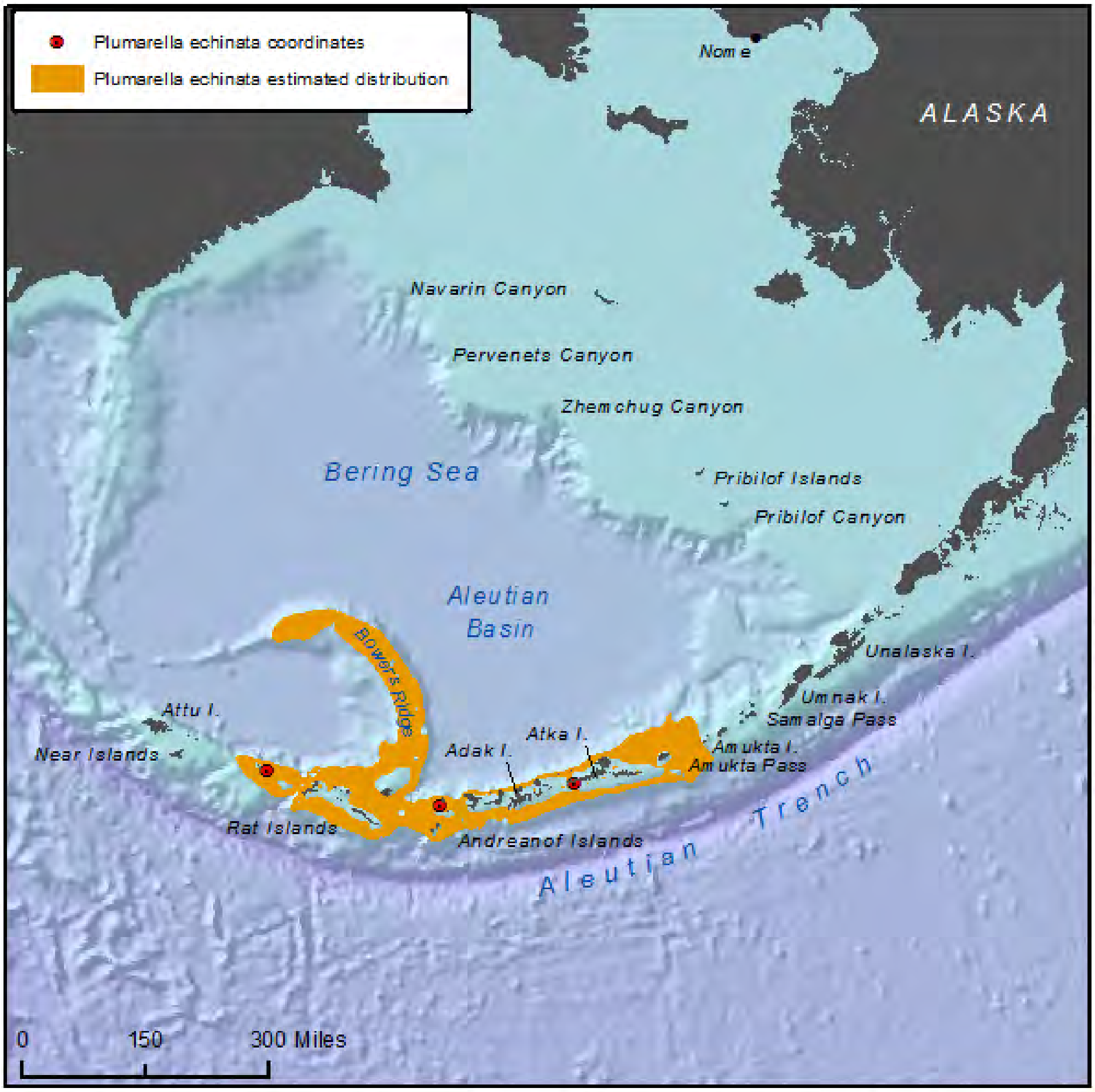


**Status:** There is very limited information on the status of this species. Based on known occurrence, this species is endemic to the Aleutian Islands and Pribilof Canyon and therefore has a limited range and is thus vulnerable to disturbance, and limited in ability to colonize or re-colonize an area if disturbed.

**Plumarella echinata** (Cairns 2011)

**Description**: Colonies are uniplanar, and consist of a moderate number of branches or fronds, from which smaller branches originate in an alternate pinnate manner. The largest colony observed was 25 cm high and 28 cm wide, consisting of 13 fronds. The adjacent fronds overlap, so that the full plane of the colony sieves the passing water current. The branch axis is bronze in color and the polyps are white. The colony branches are fairly flexible (Cairns 2011). This species is considered endemic to Alaska (Heifetz et al. 2005).

**Distribution**: This species is found in the Aleutian Islands, from off Buldir Reef (Rat Islands) to Amukta Pass, and Bowers Bank, at depths from 150 meters to 1,692 meters (Cairns 2011).



**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands of Alaska and therefore has a limited range and is thus vulnerable to disturbance, and limited in ability to colonize or re-colonize an area if disturbed.

**Plumarella hapala** (Cairns 2011)

**Description:** Colonies are uniplanar, consisting of a small number of branches from which branchlets originate in an alternate pinnate manner. The distance between branchlets on one side of a main branch ranges from seven mm to 11 mm. The holotype is 26 cm tall and 22 cm wide, with a basal branch diameter of 3.7 mm. Branchlets are four cm to five cm in length, occasionally with secondary branching. The branch axis is yellow-brown in color and relatively stiff. Polyps occur on all sides of the main branches and often contain an egg and are thus swollen in the body cavity. Polyps are rather fragile, and are covered in mucus (Cairns 2011).

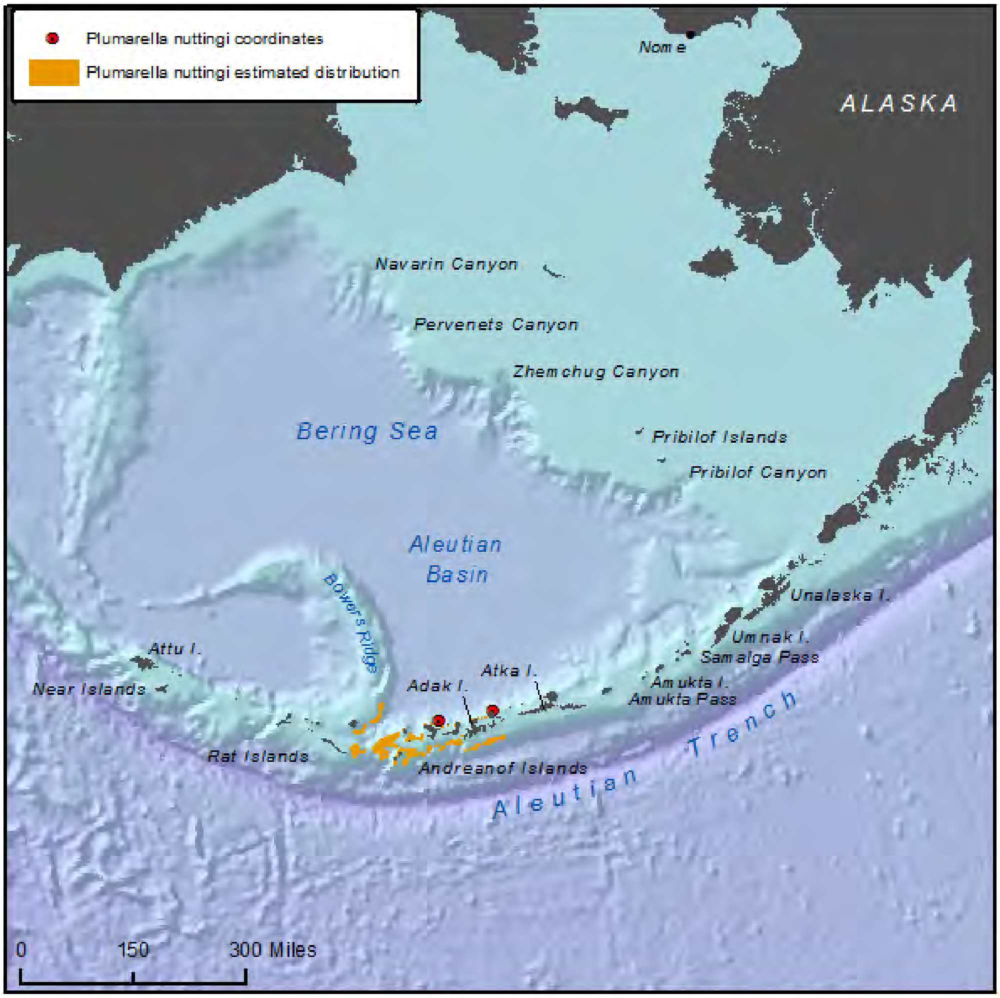
**Distribution**: This species is found throughout the Aleutian Islands from Western Rat Island to the Islands of the Four Mountains, at depths from 120 meters to 384 meters (Cairns 2011).

**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands and therefore has a limited range and is thus vulnerable to disturbance, and limited in ability to colonize or re-colonize an area if disturbed.

**Plumarella nuttingi** (Cairns 2011)

**Description**: Colonies are uniplanar, consisting of relatively few main branches from which branchlets diverge from all sides in a bottlebrush fashion. Longer branches growing in a plane of flabellum produce a compressed bottlebrush form. The largest colony (holotype) is 19 cm in height and width, with a basal branch diameter of 4.4 mm. Branchlets are up to seven cm in length, and usually not subdivided. The basal six mm to eight mm of each branchlet is often immersed in a thin coenchymal membrane that is continuous with the main branch. Coenchymal scales are present on this membrane. Polyps usually occur on all sides of the branches and branchlets and are large and flared distally. Polyps are fleshy, and often appear to unite basally in a fleshy internal web (Cairns 2011). This species is considered endemic to Alaska.

**Distribution**: This species occurs in the Aleutian Islands from Amchitka Pass to Great Sitka Island at depths from 492 meters to 888 meters (Cairns 2011).

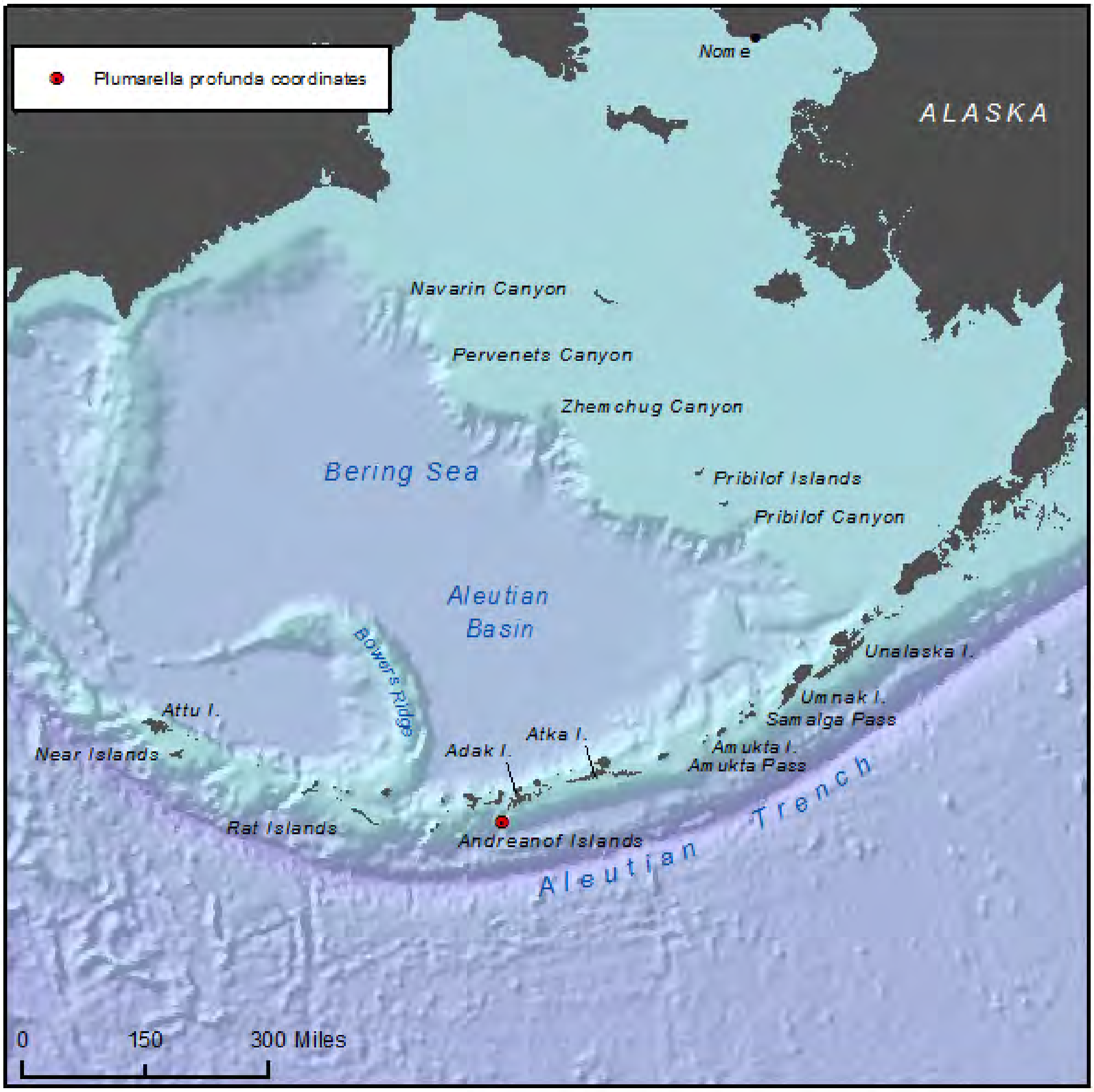


**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands and therefore has a limited range and is thus vulnerable to disturbance, and limited in ability to colonize or re-colonize an area if disturbed.

**Plumarella profunda** (Cairns 2011)

**Description**: Colonies are uniplanar and consist of relatively few main branches from which branchlets originate in a loose, alternating, pinnate manner. The distance between adjacent branchlets on one side of a branch is six mm to 12 mm. Branchlets are up to nine cm in length, and the entire colony is fairly flexible. The holotype is 18 cm in height and 11 cm in width, with a basal axis diameter of 1.8 mm. The branch axis and polyps are a pale yellow. Polyps occur on all sides of the branches and branchlets, and are widely spaced. This species is considered endemic to Alaska (Cairns 2011).

**Distribution**: This species is known only from type locality, in the Aleutian Islands, south of Kanaga Island, at a depth of 2,514 meters (Cairns 2011).



**Status:** There is very limited information on the status of this species. Based known occurrence, the species is endemic to seamounts in the Gulf of Alaska and therefore has a limited range.

**Plumarella robusta** (Cairns 2011)

**Description:** Colonies consist of one main branch, a uniplanar pinnate frond, from which branchlets originate in alternating pinnate fashion. Branchlets are seven cm to eight cm long toward the base of the colony, gradually increasing in length toward the middle of the colony and then decreasing to about four cm at the branch tip. All branchlets are simple. The largest colony examined was 25 cm tall and 13 cm wide. The colony is fairly flexible and pale yellow color when living (Cairns 2011)

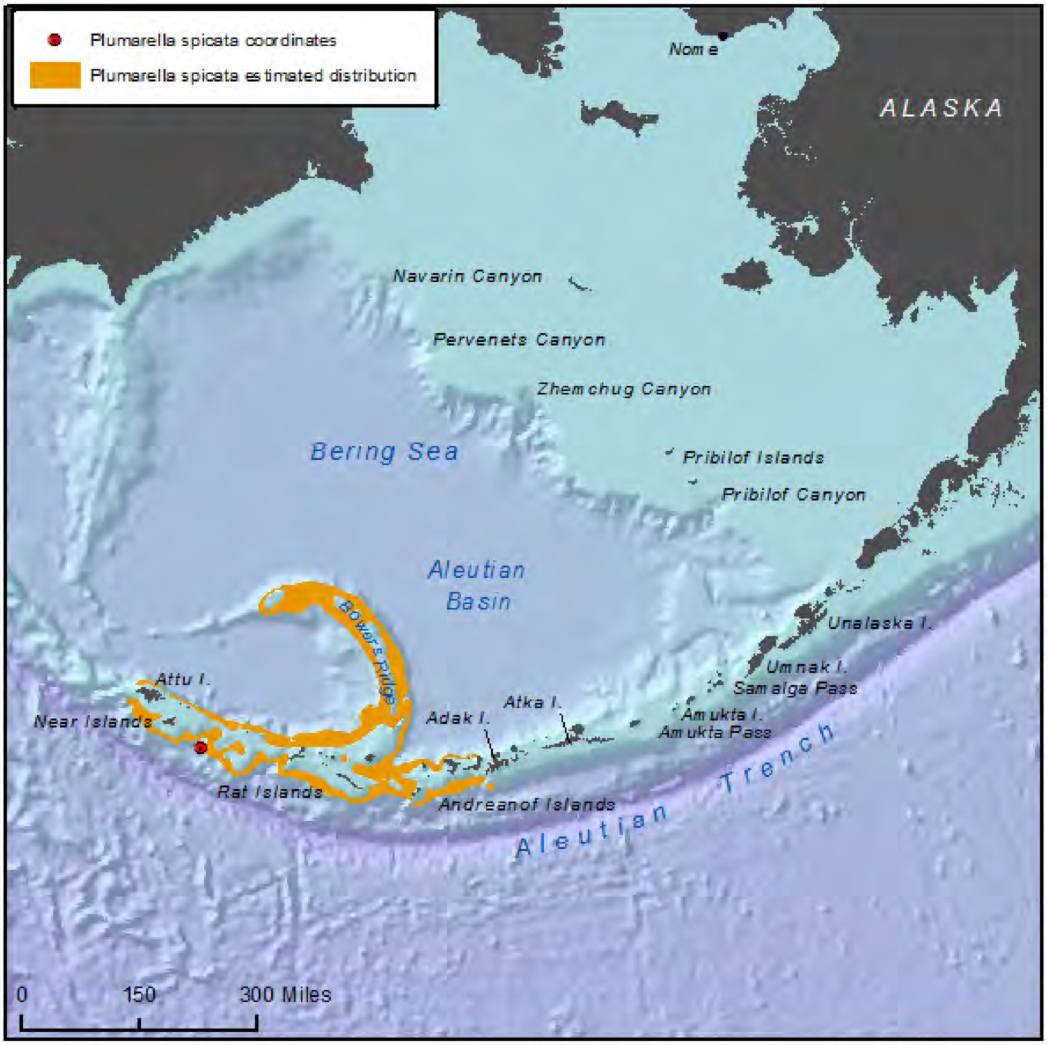
**Distribution:** This species is found in a relatively circumscribed region of the Aleutian Islands, from Amchitka Pass to Adak Canyon, at depths of 712 meters to 1,061 meters (Cairns 2011).

**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands and therefore has a limited range.

**Plumarella spicata** (Cairns 2011)

**Description**: Colonies are uniplanar, and consist of numerous branches arranged in a quasi-dichotomous manner, from which branchlets diverge in a quasi-dichotomous to loosely alternate pinnate fashion. Branchlets on the same side of the branch are eight mm to 15 mm apart. Colonies are delicate and flimsy, and are quite flexible because adjacent branchlets are not held rigidly parallel to one another. The largest colony (holotype fragment) is 14 cm tall and seven cm wide, with a basal branch diameter of only 1.2 mm. The branch axis is straw yellow in color. Polyps occur on main branches and branchlets in an alternating bi-serial arrangement in the plane of the colony flabellum (Nutting 1912, Cairns 2011).

**Distribution**: This species is found in the Aleutian Islands, from Near Island to Adak Canyon, including Bowers Bank, at depths from 712 meters to 1,912 meters (Nutting 1912).

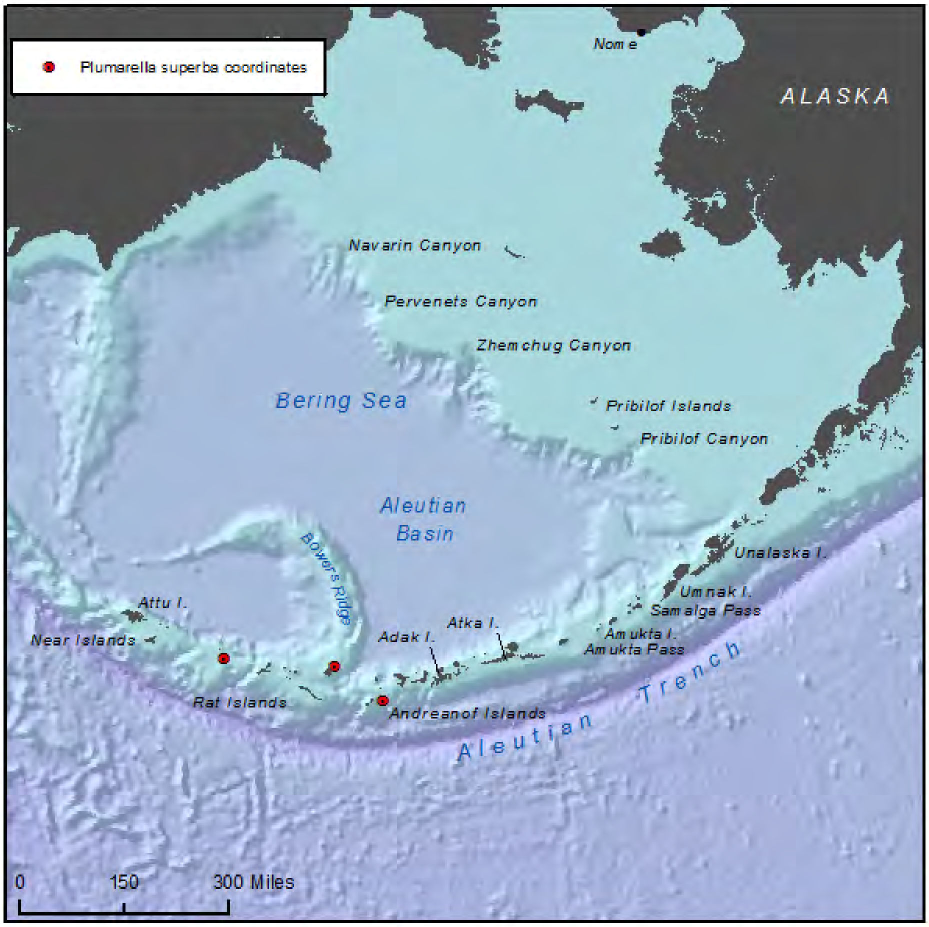


**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands and therefore has a limited range.

**Plumarella superba** (Nutting 1912, Cairns 2011)

**Description**: Colonies are uniplanar, and consist of relatively few main branches from which numerous branchlets originate in a modified bottlebrush arrangement. Short branches diverge from both sides of main branches in a plane of the colony, whereas even shorter branches diverge from anterior and posterior faces of flabellum, often slightly longer on the anterior face. Because of the unequal lengths of the branchlets on the main branches, the bottlebrush form is described as modified. Branches of the colony are somewhat rigid and wiry. The largest specimen examined is 26 cm tall and 32 cm wide, with a basal branch diameter of 8.3 mm. The axis is black and woody in diameter. Polyps occur on the main stems and on all side of branchlets in a crowded manner (Nutting 1912, Cairns 2011). This species is known from both Alaska and one location in Russia (Dautova 2007).

**Distribution**: This species occurs in the Aleutian Islands, from eastern Near Island to Umnak Island, including Petrol Bank and Pribolof Canyon, at depths from 40 meters to 1,258 meters. Also known from southeastern Sakhalin Island at 29 meters (Nutting 1912, Cairns 2011).

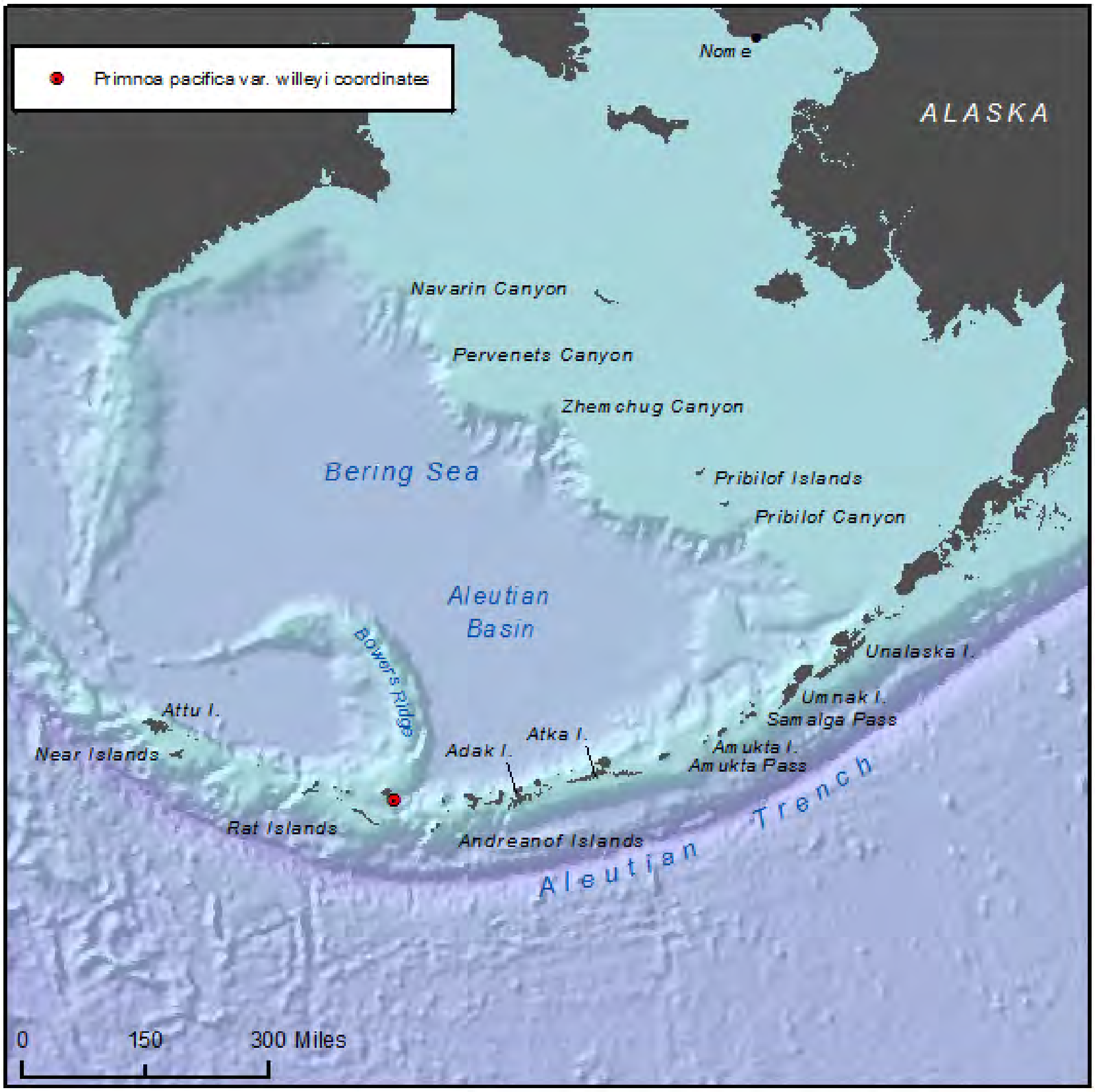


**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands of Alaska and Sakhalin Island in Russia and therefore has a limited range.

**Primnoa pacifica var. willeyi** (Cairns and Bayer 2005)

**Description:** Colonies are planar to slightly bushy in shape with a stiff, rigid axis, loosely and dichotomously branched. The largest colony (holotype) is 68 cm high, but larger colonies are known to exist, based on basal axis diameters of type fragments. Living colonies are scarlet orange in color (Cairns and Bayer 2005). This species is known from the North Pacific, from the northern coast of British Columbia to the Gulf of Alaska.

**Distribution**: Verified records are from British Columbia and the contiguous Alexander Archipelago, Alaska, but it is also known from Dickens Seamount in the western Gulf of Alaska and near Amchitka in the Aleutian Islands. Depth range is from 183 meters to 755 meters (Cairns and Bayer 2005).

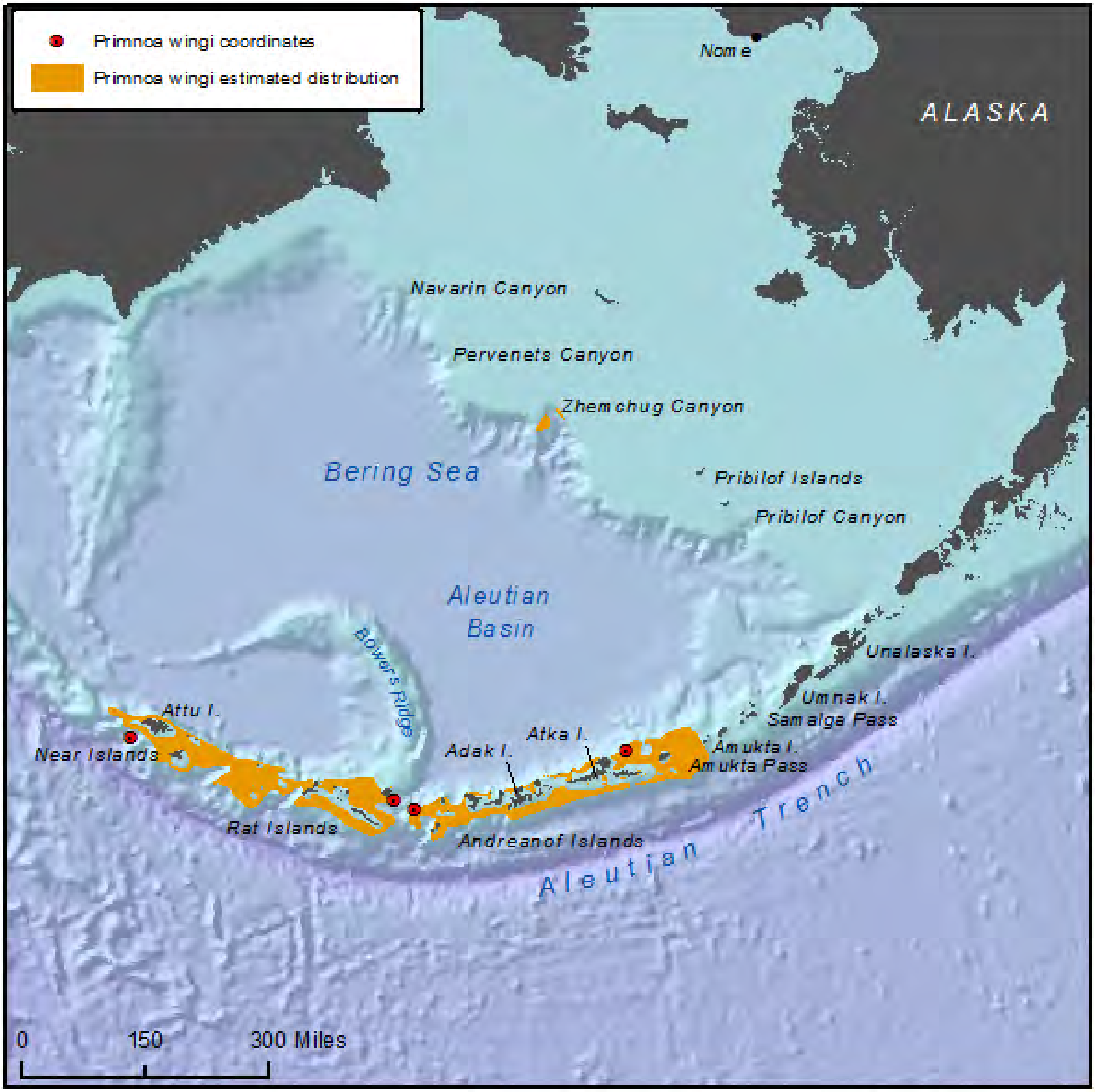


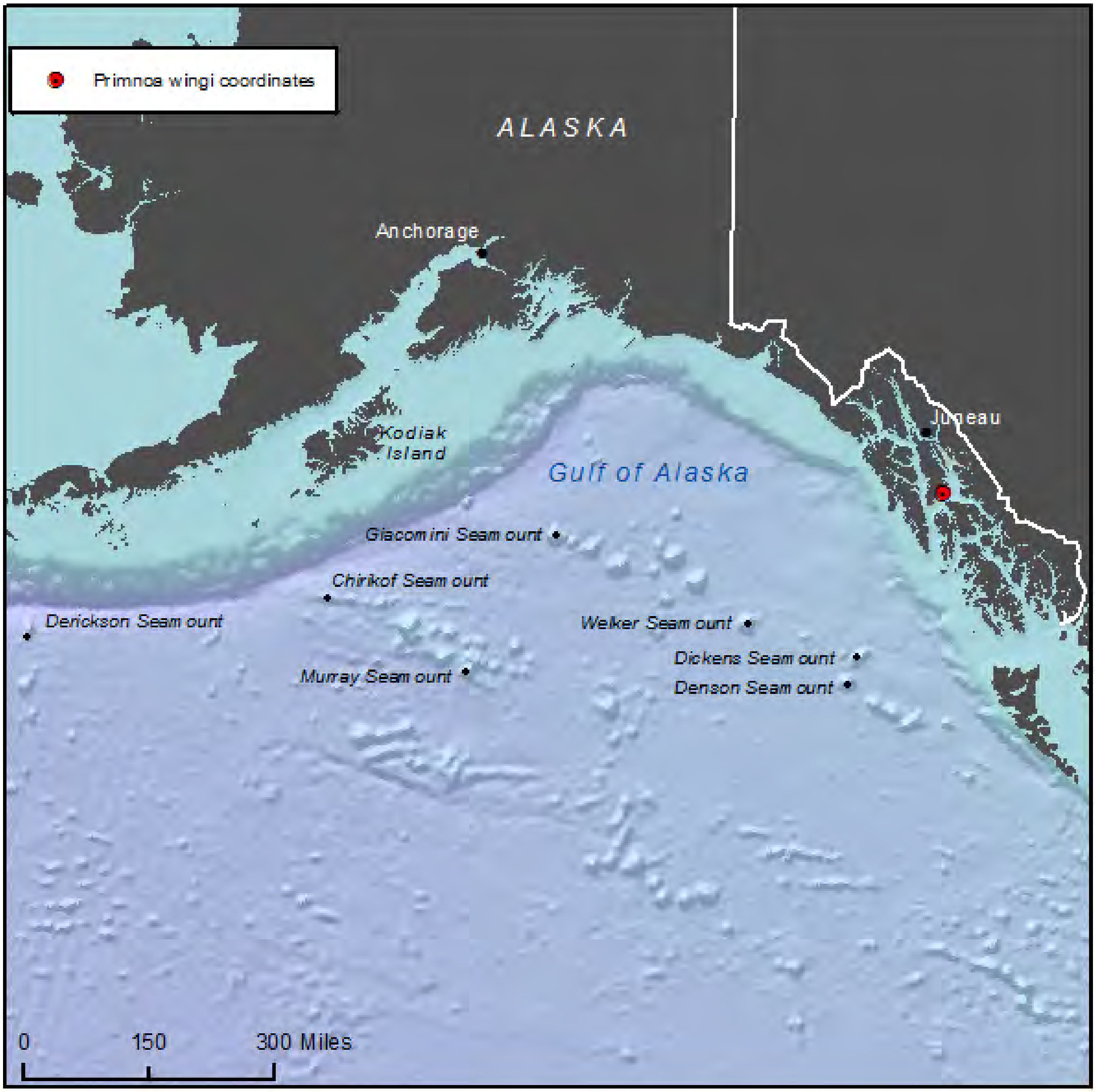
**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands of Alaska, the Gulf of Alaska, and the North Coast of British Columbia and therefore has a limited range.

**Primnoa wingi** (Cairns and Bayer 2005)

**Description**: Colonies are roughly planar in shape and dichotomously branched, although the frequency of branching is low--the largest specimen (holotype) has only seven branch axils along its 35 cm height. The axis is rigid in structure, striate, and colored black. Terminal branches, which are always covered in polyps, are 13 mm to 15 mm in diameter. The color in the living colony is reddish-orange (Cairns and Bayer 2005).

**Distribution**: This species is found in the Aleutian Islands from Near Island to Amukta Pass, Chatham Strait, and the Bering Sea (Zhemchug Canyon), at a depth of 110 meters to 914 meters (Cairns 2011).



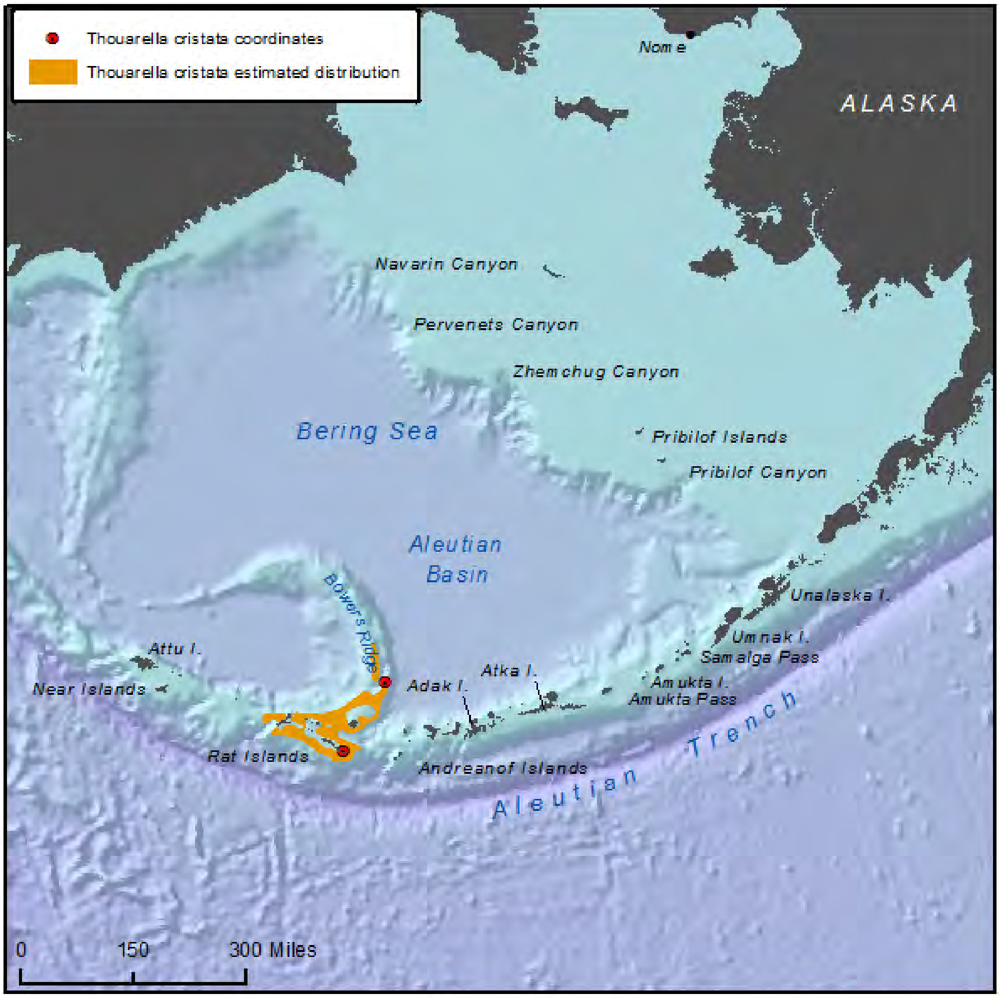


**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands, Zhemchug Canyon in the Bering Sea, and the Gulf of Alaska, and therefore has a limited range.

**Thouarella cristata** (Cairns 2011)

**Description:** Colonies are uniplanar, consisting of relatively few main branches, from which branchlets originate in an irregularly pinnate fashion also in the plane of the colony. An association with a commensal polychaete, which occasionally lives along one of the main branches, prompts a third set of branchlets to develop, causing the branches to appear somewhat bushy or bottleneck in shape. Branchlets are up to eight cm in length, are not further subdivided, and are usually arranged parallel to one another. The largest colony is 50 cm in height, with a basal branch axis diameter of 11 mm. The axis is pale yellow to brown-black in color (Cairns 2011). This species is considered endemic to Alaska (Heifetz et al. 2005).

**Distribution**: This species is known in the Aleutian Islands, including Rat Islands, Kiska, Amchitka, and Simsopochnoi Islands, and southern Bowers Bank, at depths from 94 meters to 768 meters (Cairns 2011).

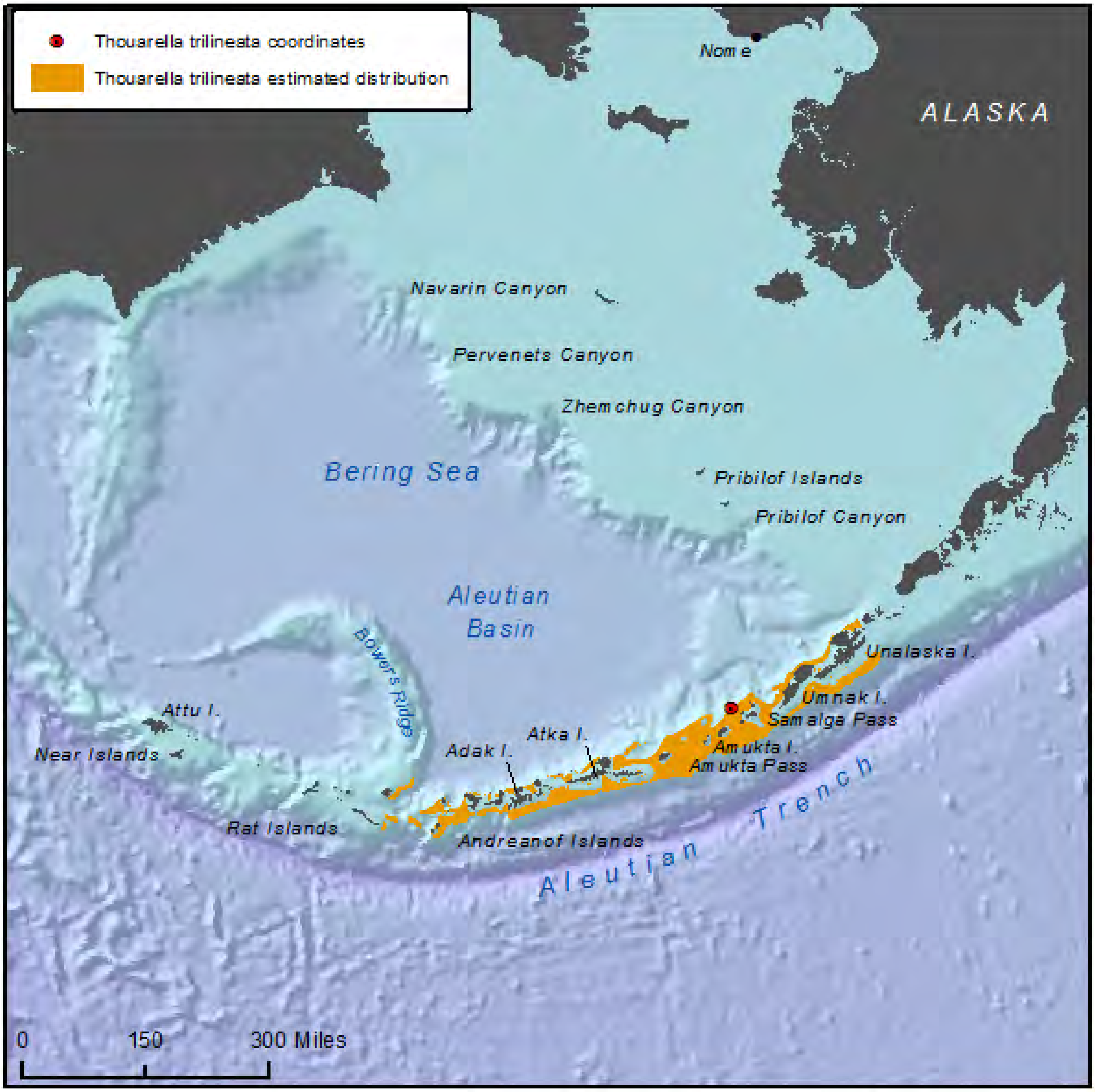


**Status:** There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands of Alaska and therefore has a limited range.

**Thouarella trilineata** (Cairns 2011)

**Description:** Colonies are uniplanar, consisting of relatively few main branches, from which branchlets usually originate in three rows, giving the main branches a bushy (bottlebrush) appearance. Branchlets up to six cm in length and not further subdivided, arranged in an alternating pinnate fashion on main branches. The largest colony is 23 cm in height and 14 cm wide, consisting of only two main branches. The axis is pale yellow.

**Distribution:** This species is found in the Aleutian Islands from Amchitka Pass to Unalaska, at depths from 97 meters to 642 meters.



**Status**: There is very limited information on the status of this species. Based on known occurrence, the species is endemic to the Aleutian Islands and therefore has a limited range.

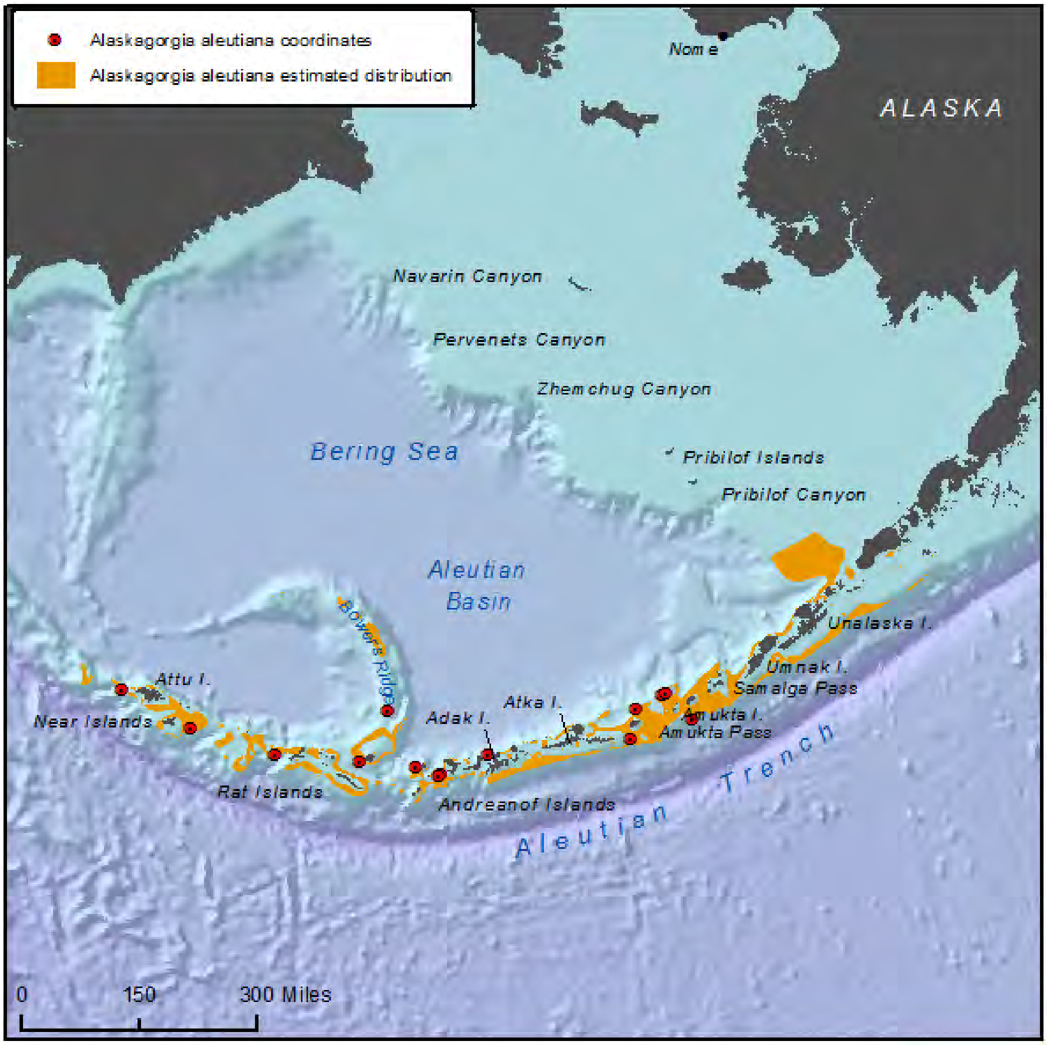
### ***Family Plexauridae***

The plexauridae is a taxonomically and morphologically diverse family of approximately 38 genera, with broad distribution in the Atlantic, Indian, Pacific, and Southern oceans. These gorgonian octocorals often form branched fans, but can also be sparsely branched, and rarely whip-like or unbranched (Williams and Lopez-Gonzalez 2005). The axis color is brown or black, and is often composed of a tough, fibrous, flexible material. Larger colonies have axes that are woody or relatively soft in texture. The axis is composed of a hollow, relatively wide, cross-chambered central core, with a surrounding area of concentric layers of the protein gorgonin containing open spaces that may be filled with calcitic calcium carbonate. The holdfast region may contain aragonitic calcium carbonate (Williams and Lopez-Gonzalez 2005). There are a total of two petitioned species in this family.

**Alaskagorgia aleutiana** (Sánchez and Cairns 2004)

**Description**: This recently identified species is an unusual, stout, tree-like coral that is similar in appearance to the robust gorgonians of Caribbean reefs (e.g., Plexaurella spp.). It could not be satisfactorily assigned to any genus, and was assigned the new genus *Alaskagorgia* and new species *aleutiana* by Sanchez and Cairns (2004). Identifying features of this species are stout, upright colonies that are laterally branched, with thick, club-like terminal branches. *A. aleutiana*'s major distinguishing feature is "its possession of tiny sclerites with stubby double heads, which occur in the outermost coencenchyme. Another distinguishing character is its oval capstans with elaborate ornamentation" (Sanchez and Cairns 2004). Based on collected specimens, this species appears to be endemic to Alaska, specifically the Aleutian Islands.

**Distribution**: The known distribution of this species is the Aleutian Islands, from depths of 125 meters to 512 meters (Sanchez and Cairns 2004).

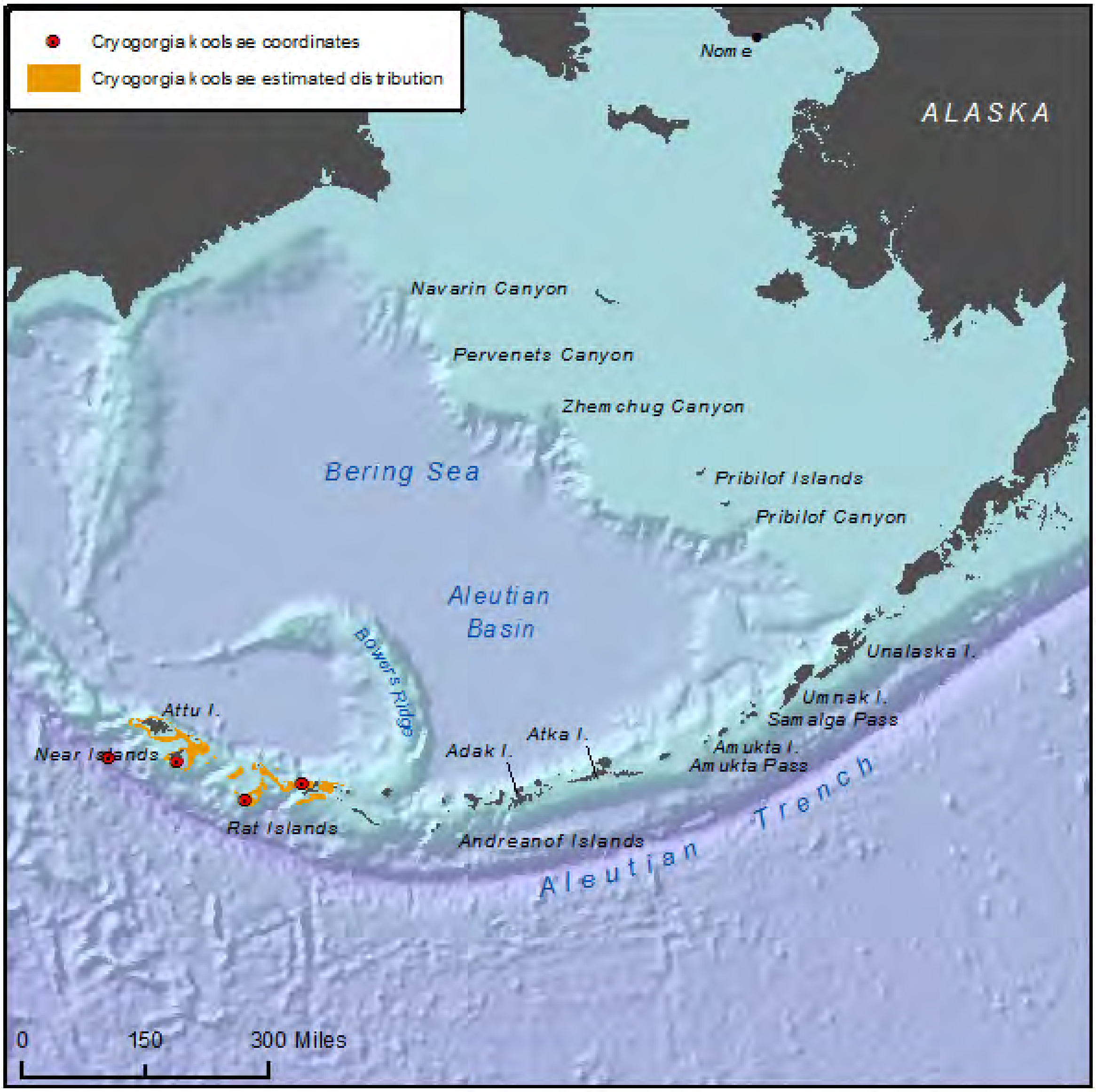


**Status**: Based on research this species is endemic to the Aleutian Islands, and thus vulnerable to disturbance, and limited in ability to colonize or re-colonize an area if disturbed.

**Cryogorgia koolsae** (Williams 2005)

**Description**: The holotype measures 370 mm long by 150 mm wide. Branching is relatively sparse, mostly lateral and irregular. Terminal branches are elongated, 30 mm to 100 mm in length, and somewhat clavate. The axis is proteinaceous and flexible, with a wide hollow core, dark brown to black in color. The coenenchyme and retracted polyps are grayish white to tan-white. The sclerites are colorless (Williams 2005). This species is considered endemic to Alaska.

**Distribution**: This species is presently known from four localities in the central Aleutian Archipelago of Alaska at 83 meters to 406 meters in depth (Williams 2005).



**Status:** Based on research this species is endemic to the Aleutian Islands, and thus vulnerable to disturbance, and limited in ability to colonize or re-colonize an area if disturbed.

### *Order Pennatulacea*

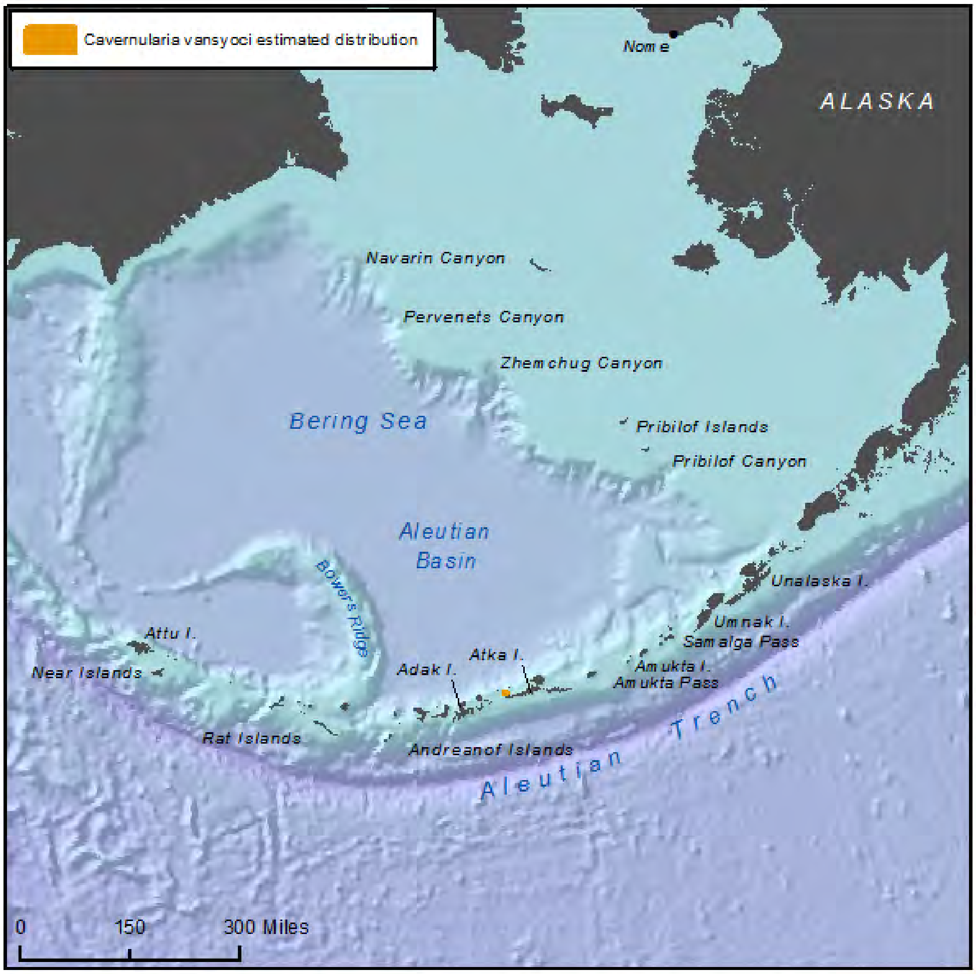
Pennatulacea are a distinctive group of octocorals often called “sea pens.” There are 16 families within the order, with a widespread, cosmopolitan distribution. Corals in this order are generally club-like or radiating forms, with a few actually appearing feather-like. They are distinguished by polyp dimorphism, where one polyp grows very large and looses all its tentacles, forming the central axis. Branching off the primary polyp are autozoioids, or feeding polyps, and larger and fewer siphonozooids, which serve as intake for water and help keep the colony upright. The colony is also supported by calcerious spicules and often by a central axial rod of calcium carbonate. Pennatulaceans reproduce by a coordinated release of sperm and eggs into the water, which may occur seasonally or throughout the year. Larvae drift freely for seven days, before settling on substrate. Pennatulaceans may live for hundreds of years.

## *Family Veretillidae*

**Cavernularia vansyoci** (Williams 2005)

**Description**: The colony is club shaped and 33 mm in length. The polyps are flush with the surface of the rachis and at no point do they extend past the surface. Calyces are absent. The polyps and polyp walls contain minute sclerites. In the center of the colony, several vertical canals are present, and a calcified axis is absent altogether. The sclerite component is composed of very small ovals, 0.003 mm to 0.007 mm in length. These minute sclerites are relatively dense in all parts of the colony examined. The color is grayish white throughout. The sclerites of the preserved specimen are colorless (Williams 2005). This species is considered endemic to Alaska.

**Distribution**: This species is known only from the type locality in the Aleutian Islands of Alaska, and occurs at depths of 86 meters to 93 meters.



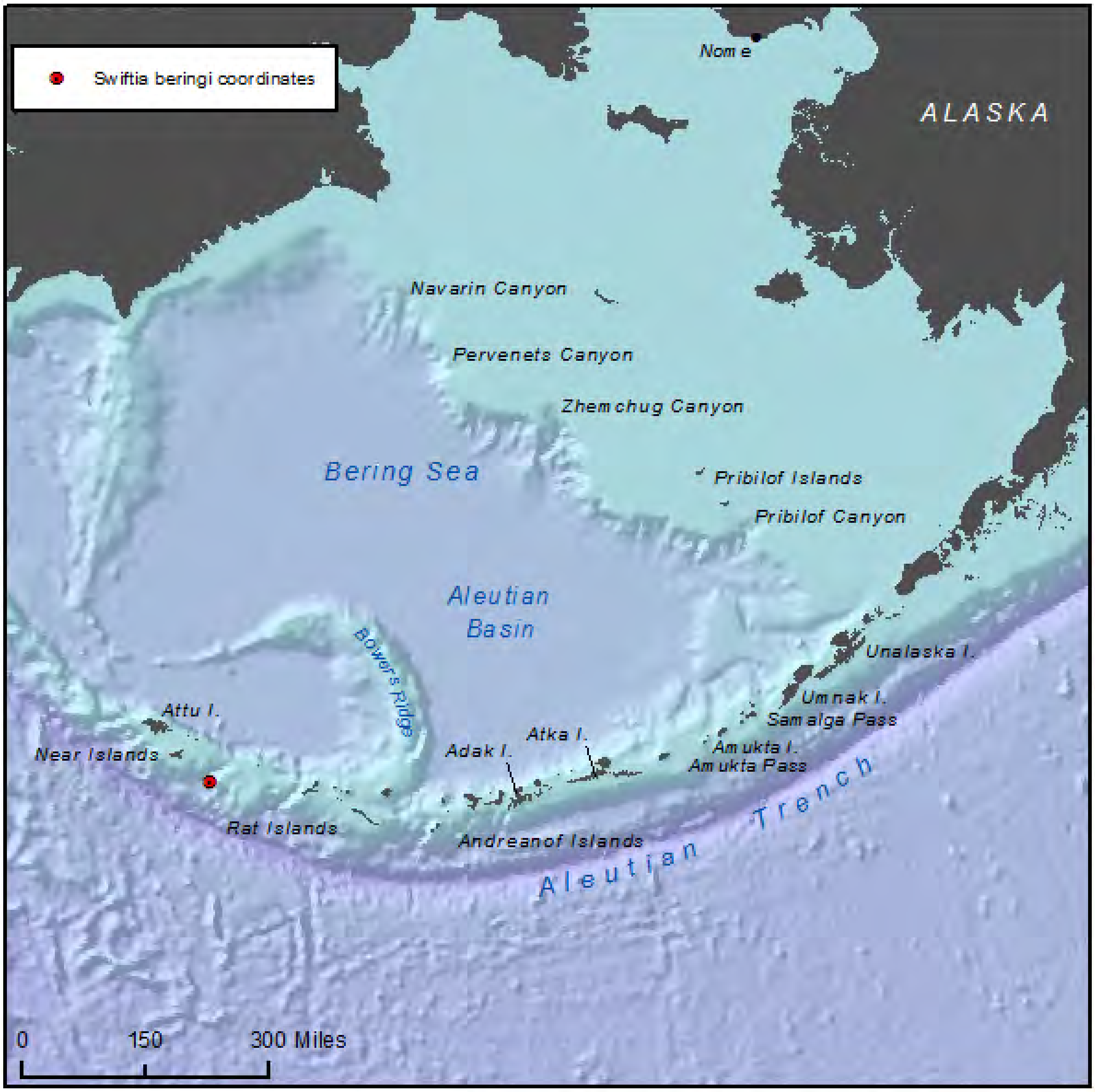
**Status:** Based on research this species is endemic to the Aleutian Islands, and thus vulnerable to disturbance, and limited in ability to colonize or re-colonize an area if disturbed.

***Family Paramuriceidae***:

**Swiftia beringi** (Nutting 1912)

**Description:** Colonies are fan shaped, and branch in several planes, standing 7.9 cm high and 7.2 cm wide. The stem is horny, and the colony a light yellowish, almost cream, color. The axis is dark brown proximally, lightening distally (Nutting 1912). This species is considered endemic to Alaska.

**Distribution**: This species is known from the Gulf of Alaska, Aleutian Islands and the Bering Sea at depths of 1,000 or more meters.



**Status:** Based on research this species is endemic to the Aleutian Islands, Gulf of Alaska, and Bering Sea, and thus vulnerable to disturbance, and limited in ability to colonize or re-colonize an area if disturbed.

## 2. Class Hydrozoa

Hydrocorals are colonial hydroids, characterized by a massive and relatively brittle limestone (calcium carbonate) skeleton with numerous pinpoint-sized pores from which emanate two kinds of hydroid-like polyps. Polyps are often finger-shaped with knob-like tentacles. The two kinds of polyps have a defensive function (dactylozoids) or a feeding function (gastrozooids) (Etnoyer and Morgan 2003). The colonies range in size from less than one cm in diameter or height to over 50 cm in height. Alaskan hydrocorals are often brightly colored, and come in various shades of brown, cream, orange, pink, purple or yellow (Wing and Barnard 2004). More than 20 species from seven genera have been reported from Alaska (Wing and Barnard 2004). At least 18 species or subspecies of hydrocorals are found in the Aleutian Islands (Heifetz et al. 2005).

### *Family Stylasteriidae*

Stylaster is a large genus that is often difficult to identify to the species level (Wing and Barnard 2004). This is partly because some species resemble bryozoans and others colonial scleractinians, which has caused much confusion in classification of both present day and fossilized specimens (Cairns and Lindner 2011). There are a total of 18 petitioned coral species in this family.

Stylasterid coloration includes pink, purple, orange, pale tan, and white. Their morphology is extremely varied and ranges from encrusting species to massive colonies with very fine dendritic branches or broad flat plates that are oriented into the current (Wing and Barnard 2004). Stylasterids have a calcareous exoskeleton, the coenosteum, which is covered in a thin layer of tissue. Coensteal texture varies between species and is used as a distinguishing character in phylogenetic classification. Alaskan stylasterids generally have slow growth rates, long life, and internal fertilization with brooded larvae (Brooke and Stone 2007, Cairns 2007).

Stylasterids are known from the Antarctic to the Arctic Circle, at depths from the intertidal zone to 2,789 meters. Ninety percent of species in this genus occur deeper than 50 meters (Cairns 2011b). Stylasterids are found primarily off small (less the 36,000 km$^2$) oceanic islands, and atolls, and on seamounts and submerged ridges of the appropriate depth, and only rarely off continental land masses. Cairns (2011b) hypothesized that this might be explained by the stylasterids' sensitivity to fluctuating salinity and sedimentation associated with that environment.

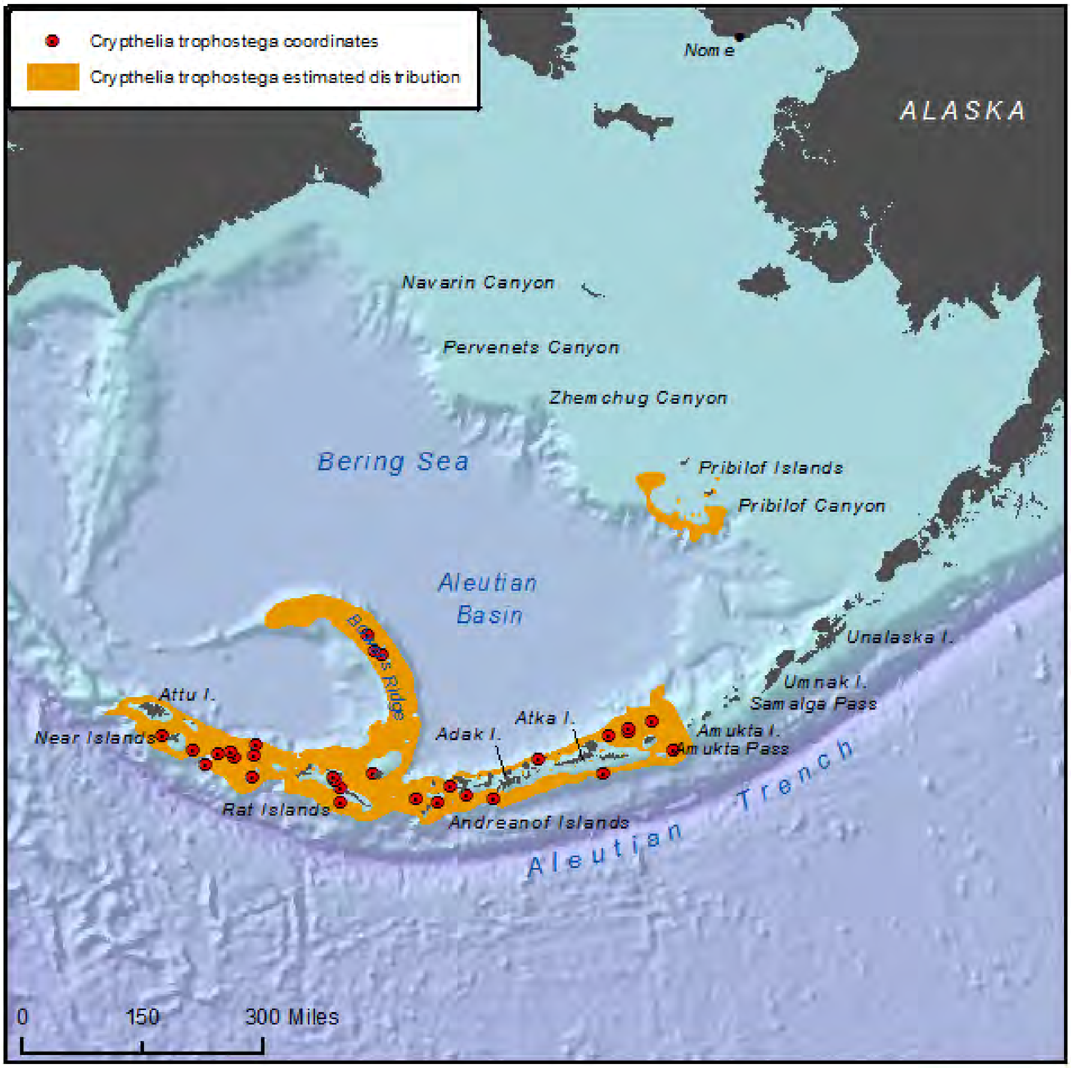
Most stylasterids (76 percent, according to Cairns and Macintyre (1992)) form rigid skeletons of the aragonite polymorph of calcium carbonate. The other 24 percent use the less soluble polymorph calcite or are partially calcitic (Cairns and Macintyre 1992). Six of the seven Aleutian Islands stylasterids analyzed by Cairns and Macintyre (1992) were calcitic, an unusually high percentage, which may be the result of the relatively shallow (approximately 150-meter) aragonite saturation horizon in the North Pacific. This relatively shallow aragonite horizon would favor a calcitic, rather than aragonitic skeleton, for corals growing at depths beyond 150 meters (Cairns 2011b, Guinnote et al. 2006).

Errinopora is one of the few stylasterid genera with species having calcitic, rather than aragonitic, colonies (Cairns and Macintyre 1992, Cairns 2011b), with *stylaster vererillii* the only other stylasterid species known to have mostly calcitic colonies (Cairns and Macintyre 1992). This confirms the prevalence of calcitic stylasterids in the North Pacific, possibly related to the shallower depth of the aragonite saturation horizon in this region (Guinotte et al. 2006).

**Crypthelia trophostega** (Cairns and Lindner 2011)

**Description:** Colonies are variable in shape, and usually uniplanar, but sometimes forming three-dimensional bushes or multiplanar colonies. The largest colonies are multiplanar, 20 cm tall and 12 cm wide. Branching is irregularly dichotomous and often anastomotic. The coenosteum has a linear-imbricate surface texture, and is white colored (Cairns and Lindner 2011). The corallum was found to be 100 percent aragonite (Cairns and Macintyre 1992). This species is considered endemic to Alaska (Heifetz 2005).

**Distribution**: This species is found around the Aleutian Islands from Near Islands to Amuka Pass, Petrel and Bowers Banks, off Pribilof Bank at depths of 146 meters to 1,913 meters, although most records are between 200 meters and 400 meters. Bottom substrate was black sand and rocks.

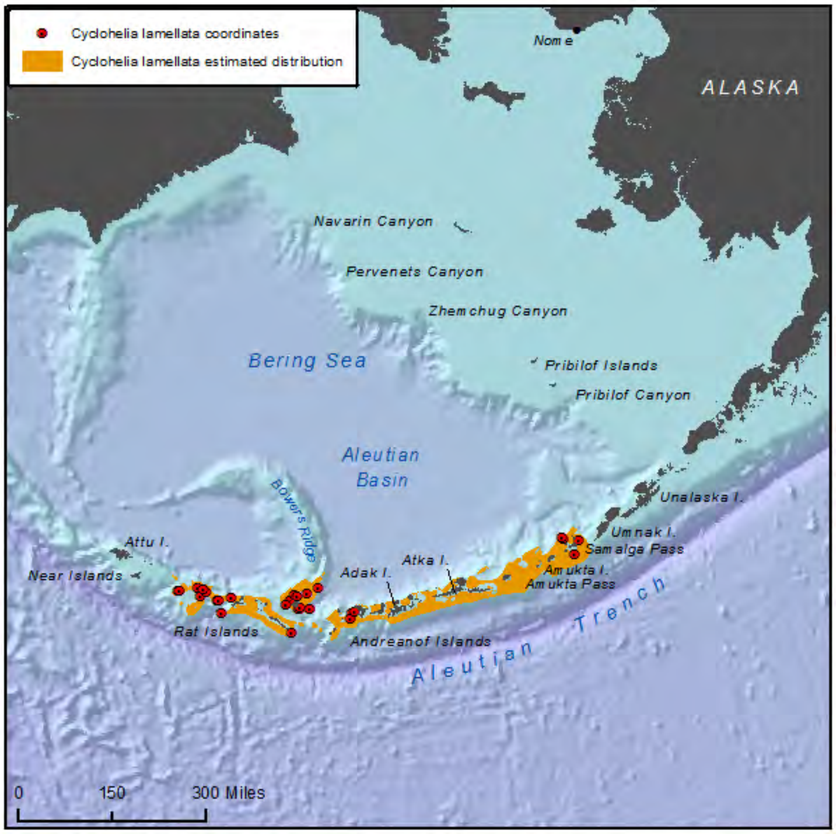


**Status:** Based on known occurrence, this species is endemic to the Aleutians, the Pribilofs, and Bering Sea Canyons, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Cyclohelia lamellata** (Cairns 1991)

**Description:** Colonies are usually firmly attached to a hard substrate by a robust cylindrical base and stem up to 2.5 cm in diameter, which, at the height of about two cm, bifurcates into two lamellae or sheets, each sheet increasing its surface area by folding and undulating its surfaces into a complex three-dimensional structure. Large colonies may attain a height of about eight cm and a width of 10 cm, colonies wider than tall being normal (Cairns and Lindner 2011). The reticular granular coensteum is reddish-orange, with a white central core and slightly less pigmented coensosteum overlying each ampullae (Cairns 1991). This species is considered endemic to Alaska (Heifetz 2005, Cairns and Lindner 2011).

**Distribution**: This species was first known from type locality, tangled in crab nets at about 1,800 meters depth off the Pribilof Islands in the Bering Sea (Cairns 1991). In addition to type locality, this species is common throughout the Aleutian Islands from the Rat Islands to the Islands of Four Mountains at 27 meters to 567 meters, although more commonly collected from the western part of this range at depths of 100 meters to 300 meters. The digitate form is known only from the western Aleutian Islands from 27 meters to 366 meters (Cairns and Lindner 2011).

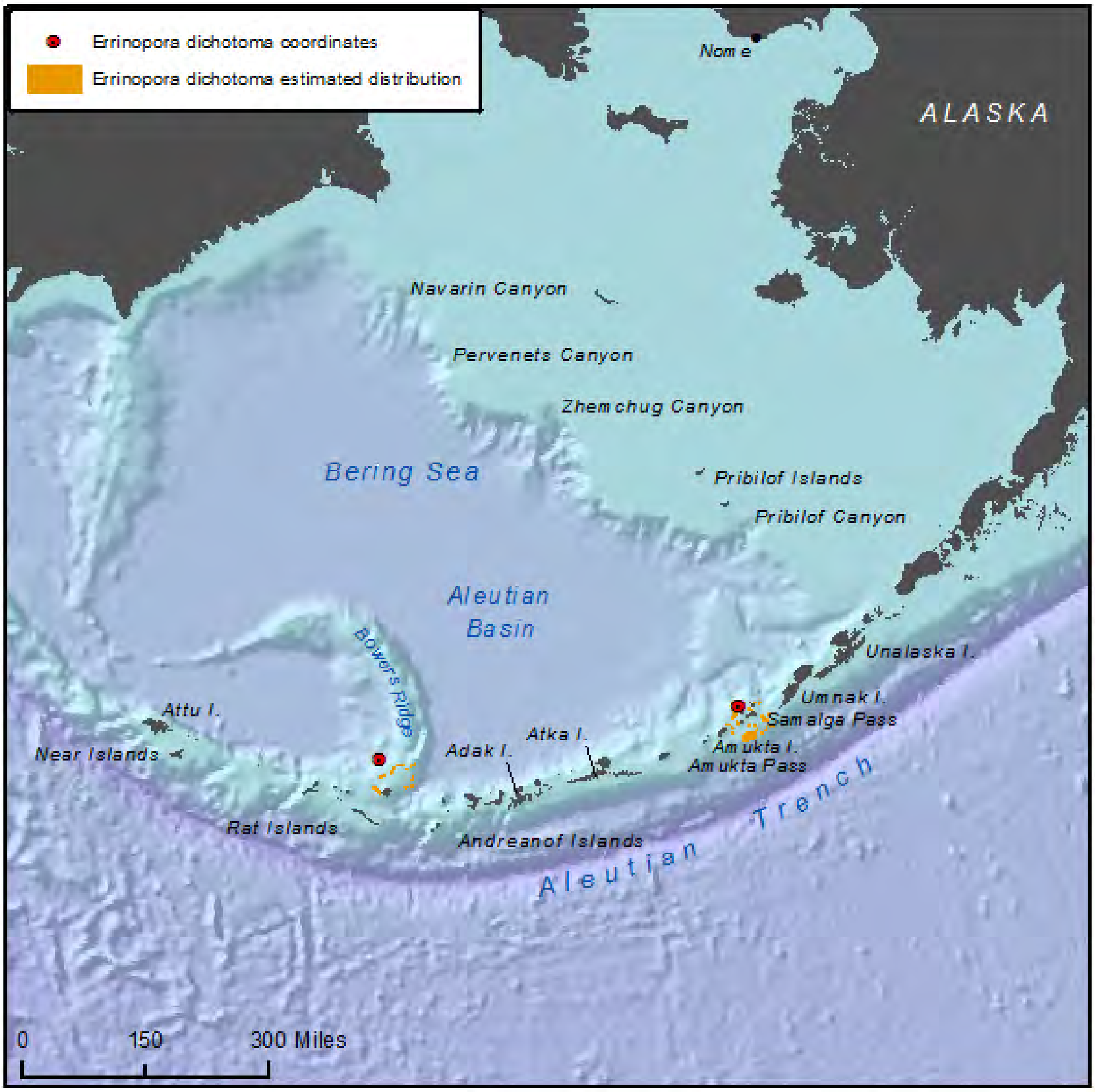


**Status:** Based on known occurrence, this species is endemic to the Aleutians and the Pribilofs of the Bering Sea, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Errinopora dichotoma** (Cairns and Lindner 2011)

**Description:** Colonies are three-dimensional, robust, and sparsely branched, branching equally and widely dichotomously, resulting in broad U-shaped axils. No branch anastomosis is present. The largest colony is 11.5 cm in height. Branches are circular to elliptical in cross section, attenuating to thick, blunt tips. The coenosteum is quite porous and composed of a reticulum of thin, spinose strips, separated by wide slits or series of pores. The coenosteum is orange, and the branch cores are white.

**Distribution:** This species is endemic to the Aleutian Islands off Petrel Bank and Islands of Four Mountains at depths of 178 meters to 217 meters (Cairns and Lindner 2011).

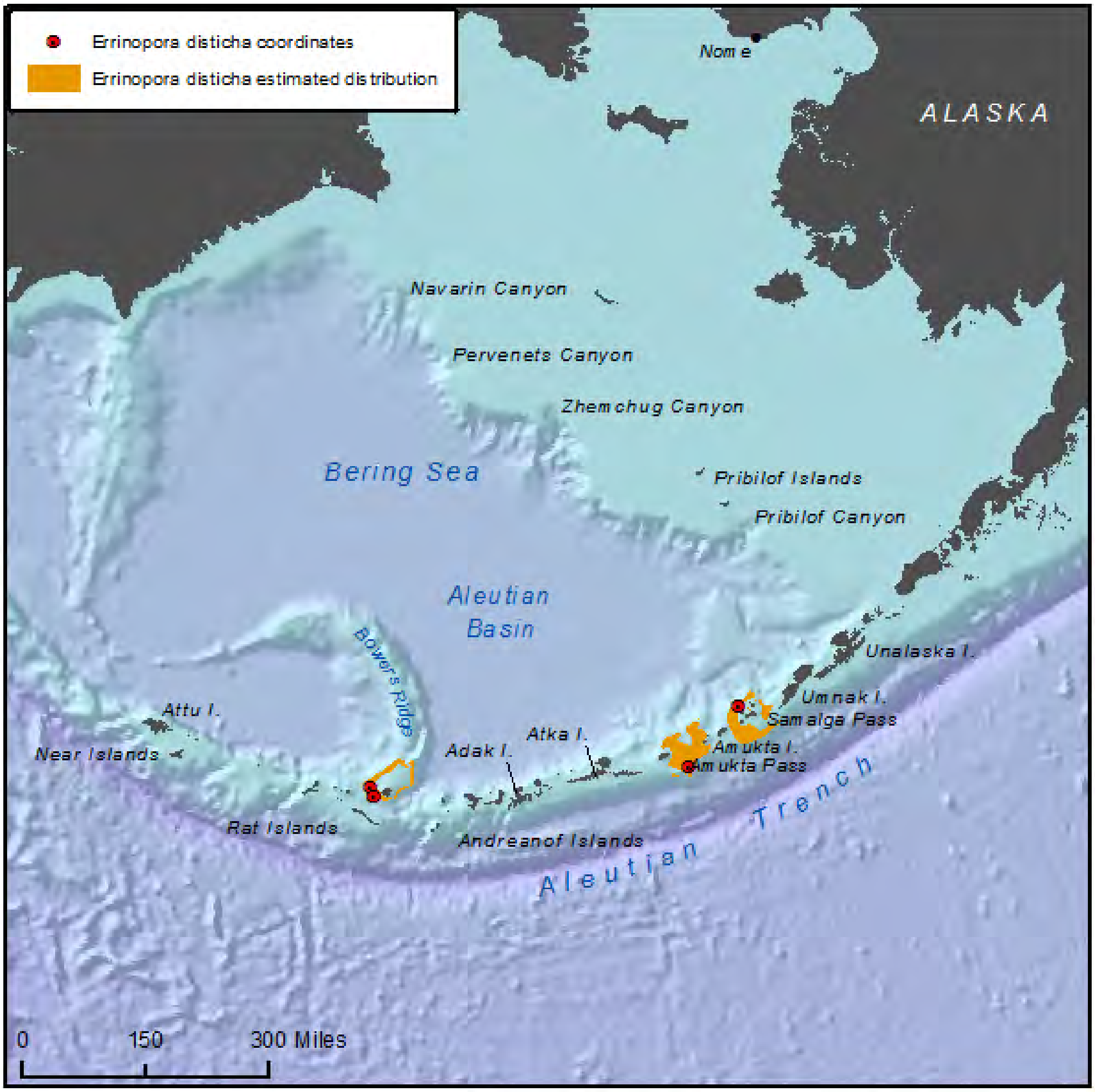


**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Errinopora disticha** (Cairns and Lindner 2011)

**Description:** Colonies are uniplanar to multiplanar, consisting of cylindrical to highly compressed branches, the greater axis of compressed branches oriented in the plane of the colony flabellum and reaching up to two times the length of the lesser axis. Branching dichotomous and non-anastomotic, terminating in blunt tips and forming U-shaped axils between branching. The holotype is 10 cm tall and equally wide, with the tallest specimen 13.5 cm in height. The coenosteum is very porous and light orange in color, while branch cores are white or a lighter orange.

**Distribution:** This species is known only from the Aleutian Islands off Petrel Bank, Amukta Pass, and Four Kings Islands at depths of 178 meters to 536 meters.

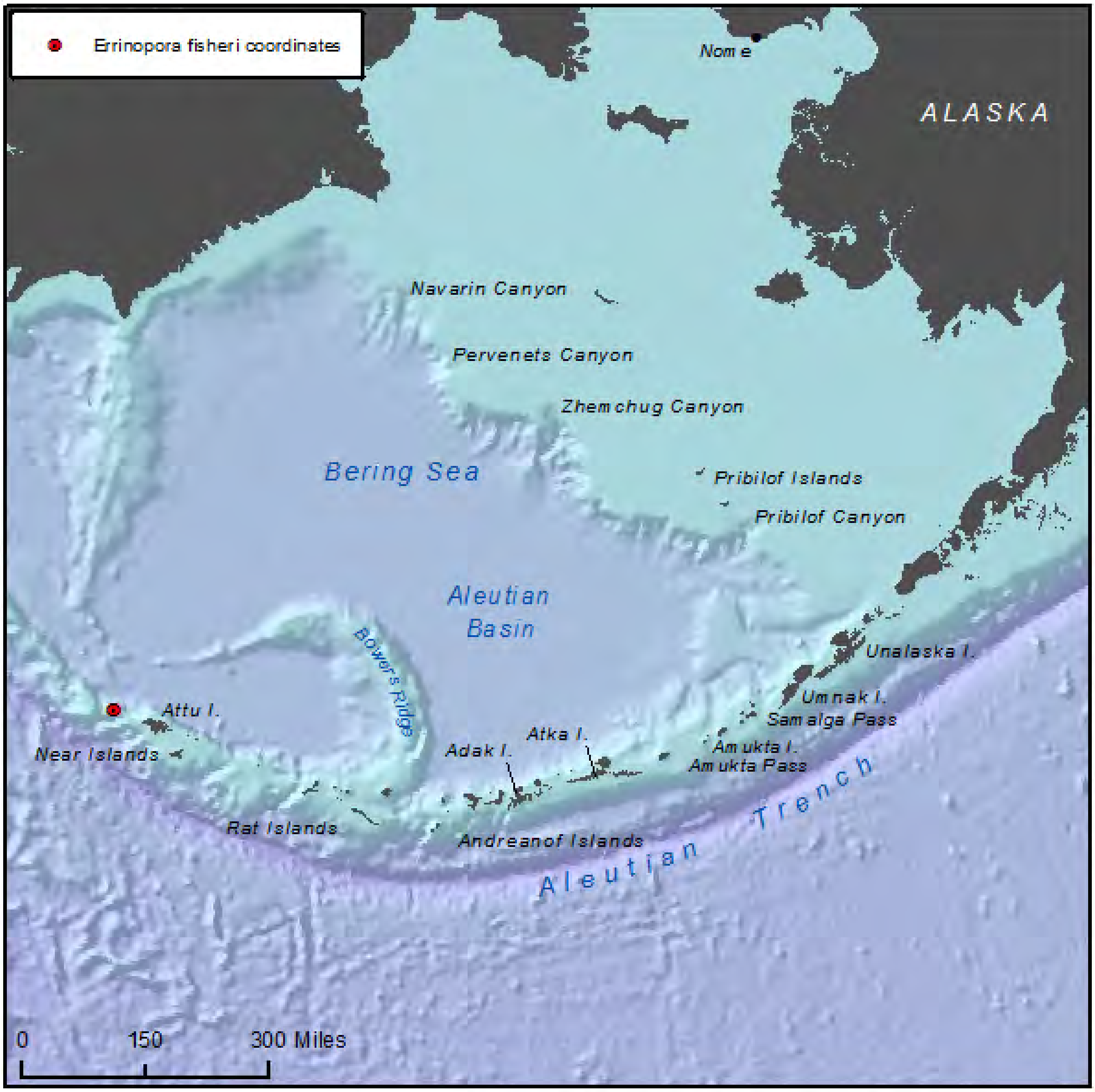


**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Errinopora fisheri** (Cairns and Lindner 2011)

**Description**: The holotype is uniplanar with a secondary flabellum at mid-height, nine cm in height and 6.5 cm in width. Branches are circular to slightly elliptical in cross section and irregularly dichotomous, small-diameter branches often diverging from larger main branches; branch anastomosis absent. The coensteum is light orange in color and reticulate-granular in texture.

**Distribution**: This species is known only from the Aleutian Islands, off Attu Island from 455 meters to 458 meters in depth.

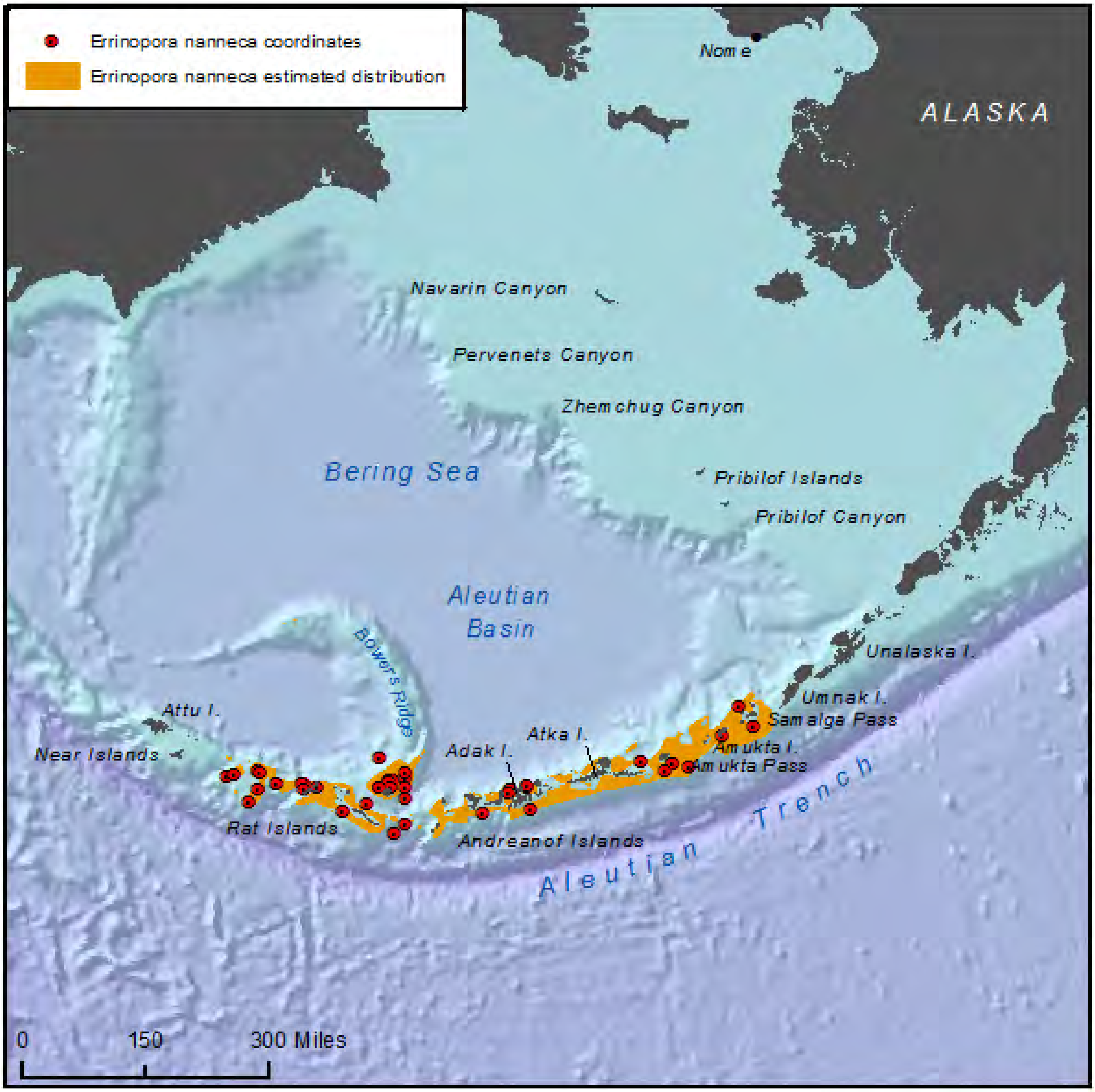


**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Errinopora nanneca** (Fisher 1938)

**Description**: The type colony is 130 mm high and 80 mm broad. The three main branches with their branchlets lie in the same general plane, so that the colony tends to be flabellate. The main trunk of the colony is 18 mm to 25 mm thick, slightly compressed beyond the base. The colony is yellowish buff in color, with extremely small gastropores (Fisher 1938).

**Distribution**: This species is known from a specimen in Bering Sea, in a substrate that was rock, fine sand, and shells, at a depth of 100.5 meters (Fisher 1938).

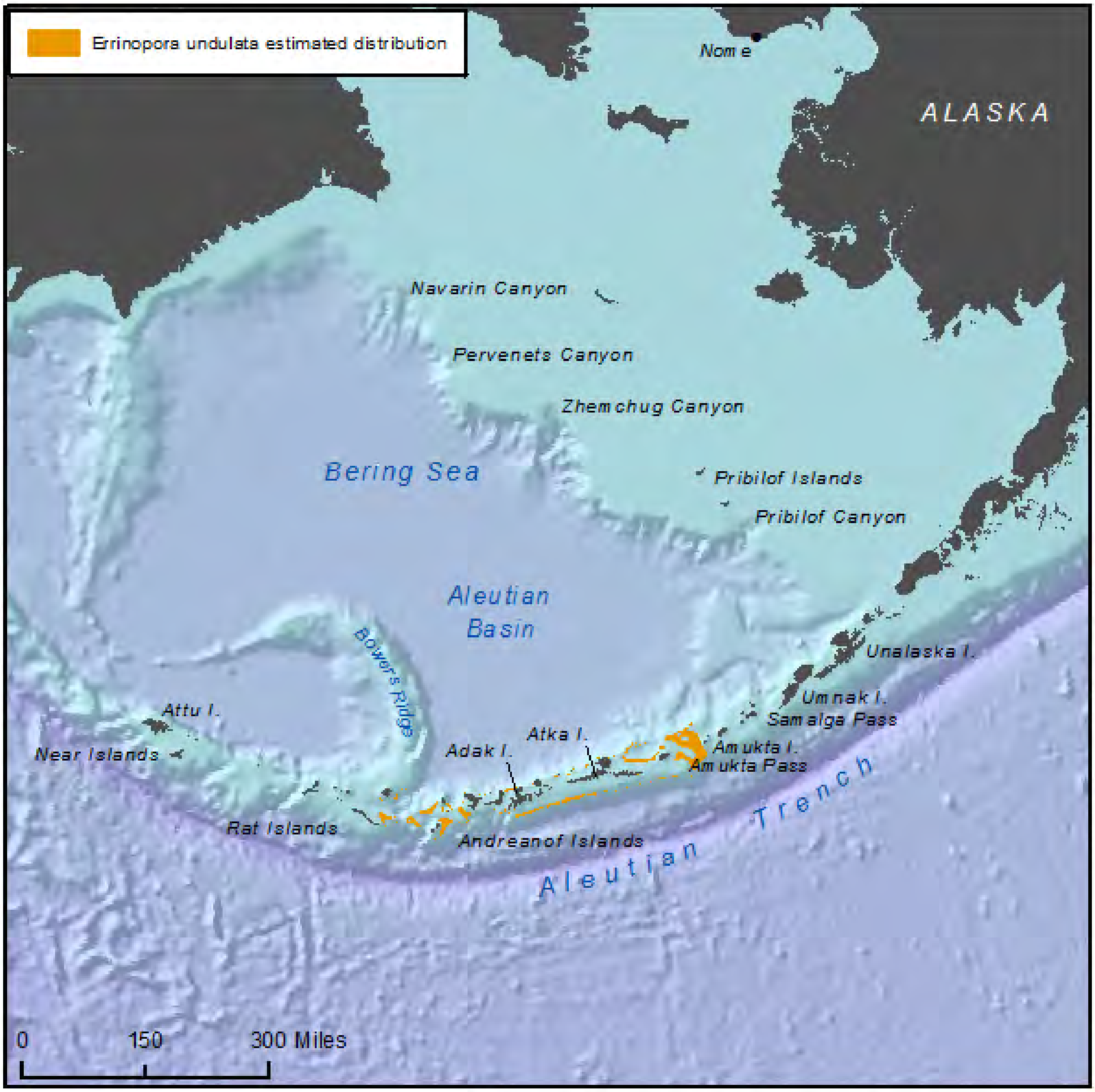


**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Errinopora undulata** (Cairns and Lindner 2011)

**Description:** Colonies lamellate, but wavy in construction resulting in a continuous, thin, sinusoidal distal edge. Largest colony is 13 cm tall and 15 cm wide, with a massive basal branch 4.5 cm by 2.5 cm in diameter. Coenosteum is quite porous, consisting of a reticulum of narrow spiny strips separated by even wider slits. Coenosteum is orange in color.

**Distribution:** This species is known only from the Aleutian Islands from Amutka Pass and south of Semisopochnoi Island at depths of 350 meters to 640 meters.

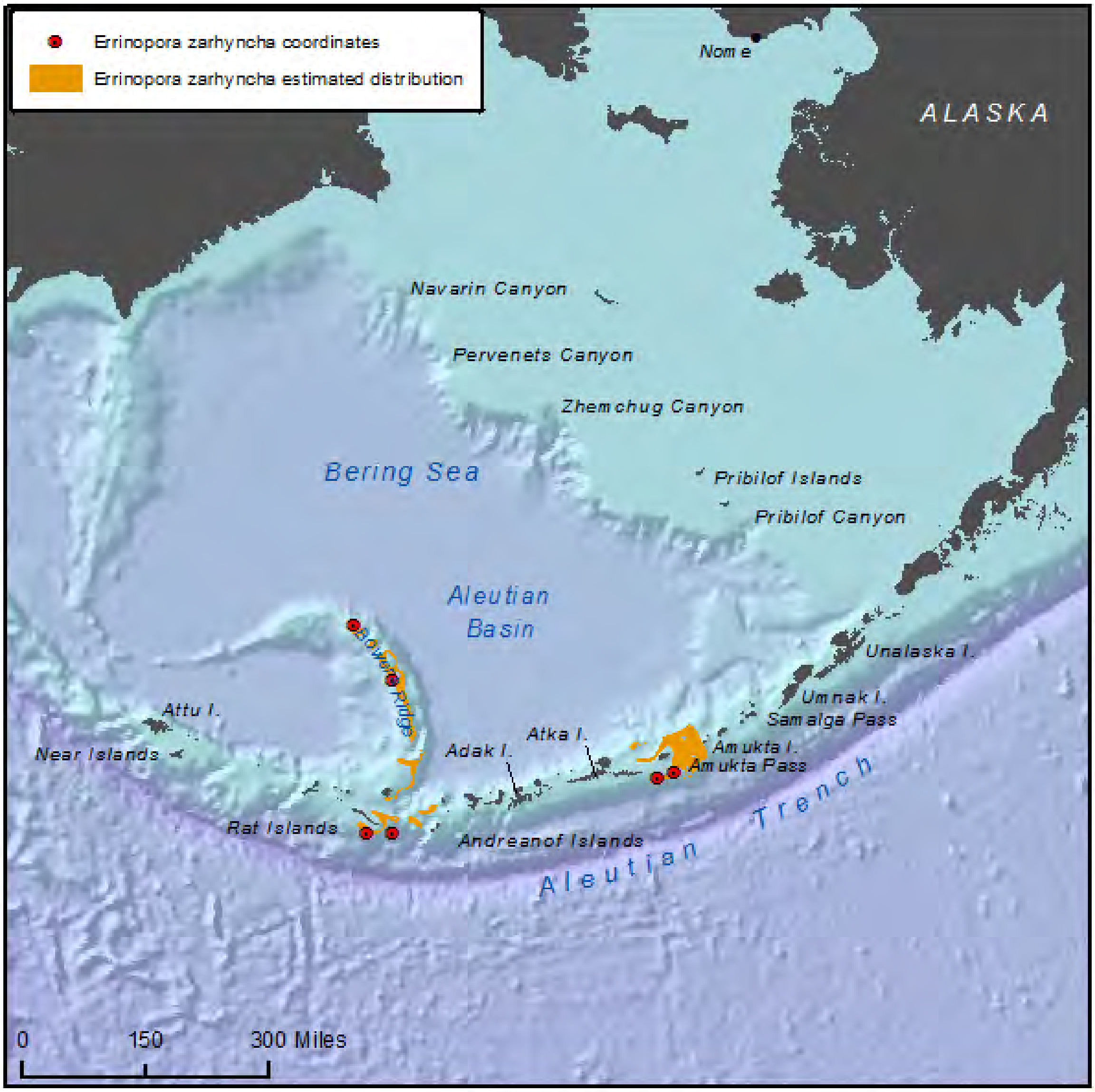


**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Errinopora zarhyncha** (Fisher 1938)

**Description:** The colony is branching, and strongly flabelliform. The branches are relatively massive, compressed, and a few time dichotomously divided. The type colony is 140 mm high and 185 mm broad and consists of a stout trunk and massive, compressed, dichotomously divided, terminally blunt branches lying in one plane so that the general form is strongly flabellate. The trunk is devoid of pores, but all surfaces of the branches are crowded with coarse dactylotomes standing singly or coalesced into groups of two to eight or 10. The color of the dried colony is ochroceaous-buff.

**Distribution**: This species is found in Amukta Pass, Aleutian Islands in black sandy, rocky substrate at a depth of 517 meters.

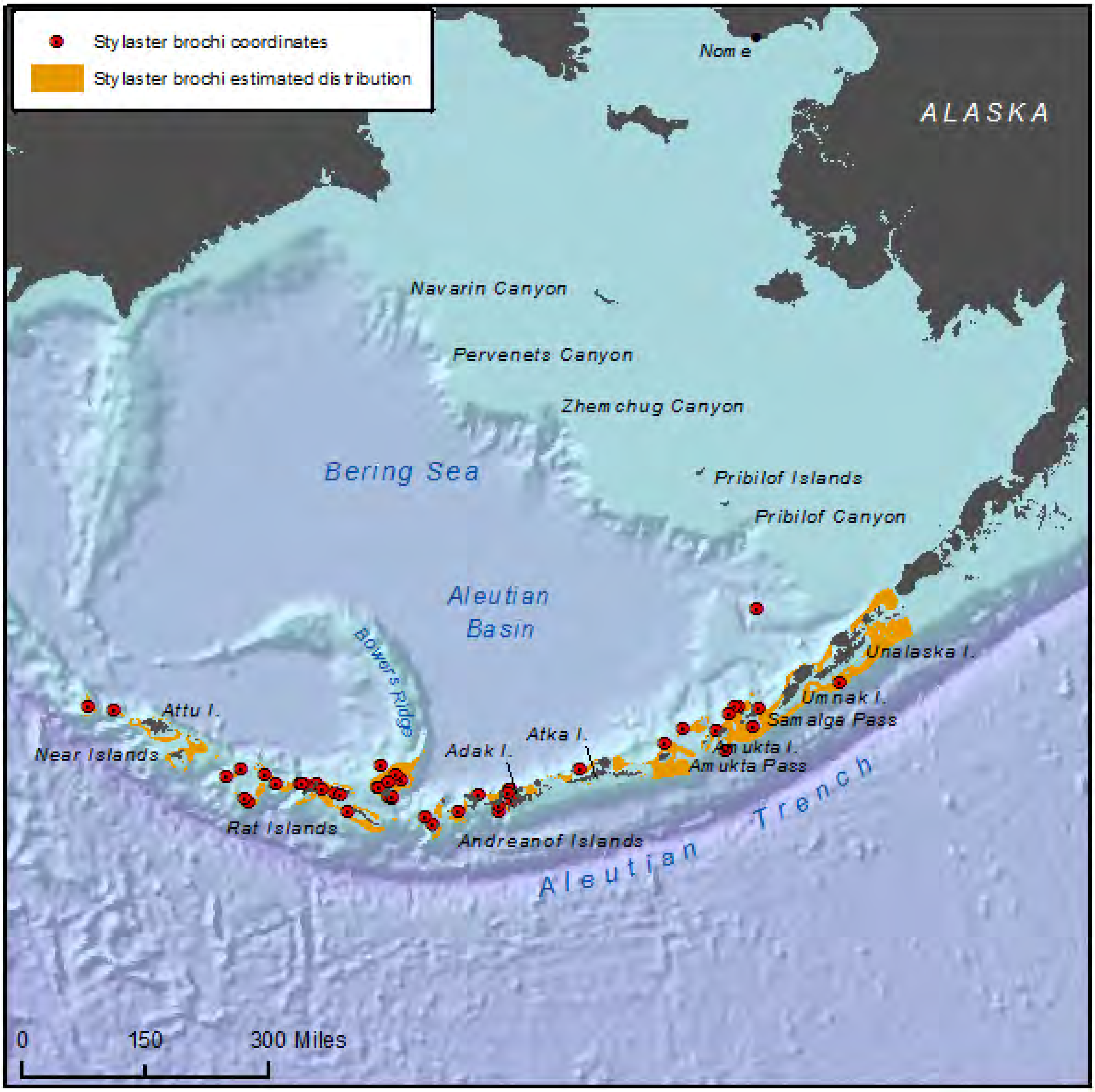


**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

## **Stylaster brochi** (Fisher 1938)

**Description:** Colonies are buff pink in color, small, with robust blunt branches produced in all directions and without a definite front and back. Cyclosystems are well spaced, protubent, distributed on all surfaces. The holotype is 80 mm high and 50 mm wide. The surface of the coenosteum is minutely porous and has a granulated appearance.

**Distribution**: This species is widespread throughout the Aleutian Islands from west of Attu Island to Unalaska (including Petrel Bank), with one disjunct record near Sharma (near Anchorage). It is found at depths of 75 meters to 351 meters, but most records are between 100 meters and 200 meters in a substrate of fine gravel.

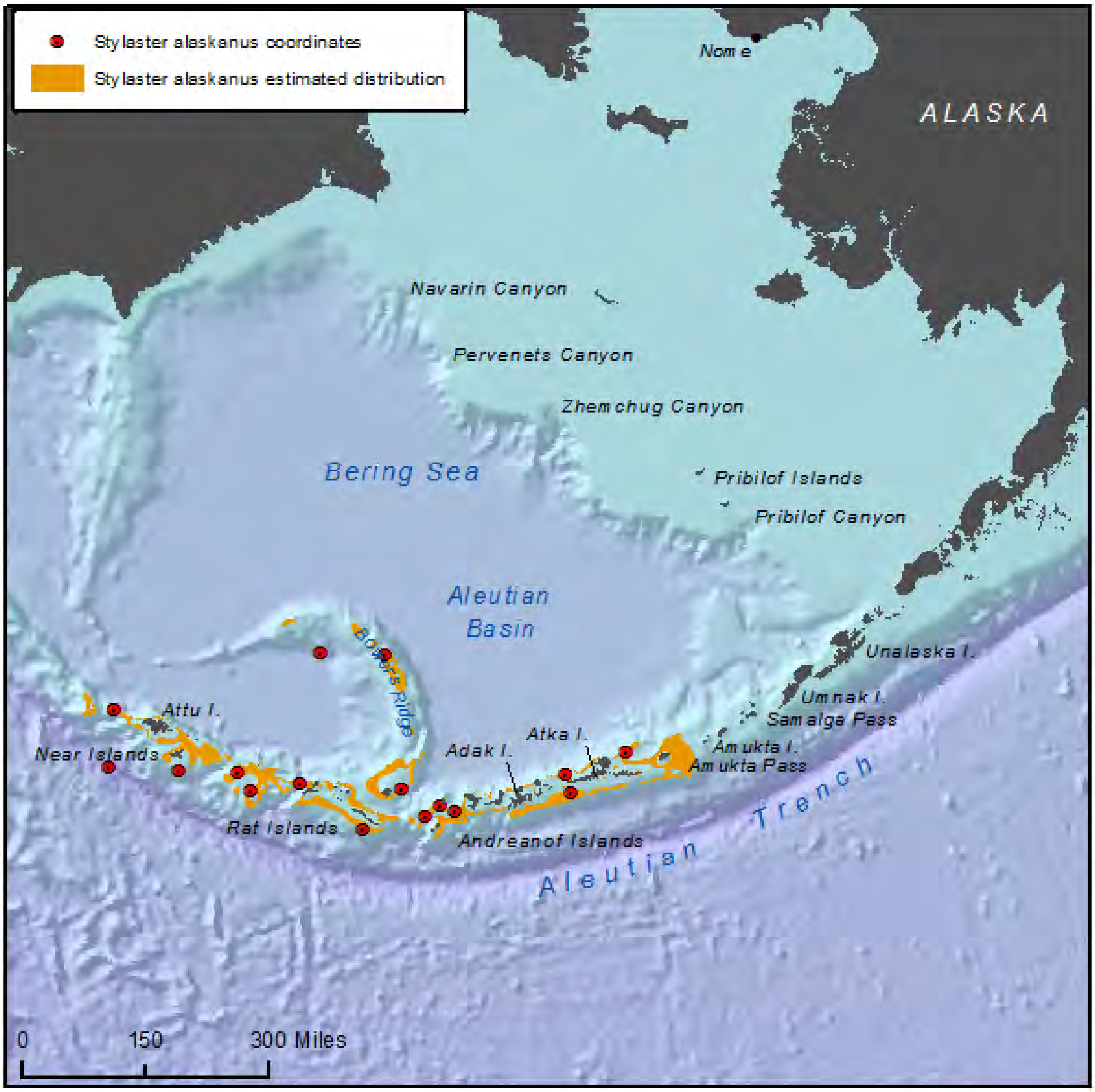


**Status**: Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster alaskanus** (Fisher 1938)

**Description**: Colonies are uniplanar or multiplanar, and additional flabella usually originate perpendicular to the original flabellum. Branches are highly anastomotic, smooth large-diameter branches forming a framework for infilling by smaller-diameter branches, resulting in sieve-like reticulum. The largest colony is 28 cm, with a massive, dense basal branch diameter of five cm. Distal branches are circular to rectangular in cross section. The coenosteum is reticulate-granular in texture, and colored light orange, pink or white (Cairns and Lindner 2011).

**Distribution**: This is species is known from throughout the Aleutian Islands from west of Attu Island to Amukta Pass, including Bowers Bank. It is found at depths of 146 meters to 582 meters in black sand, rocky substrate (Fisher 1938, Cairns and Lindner 2011).

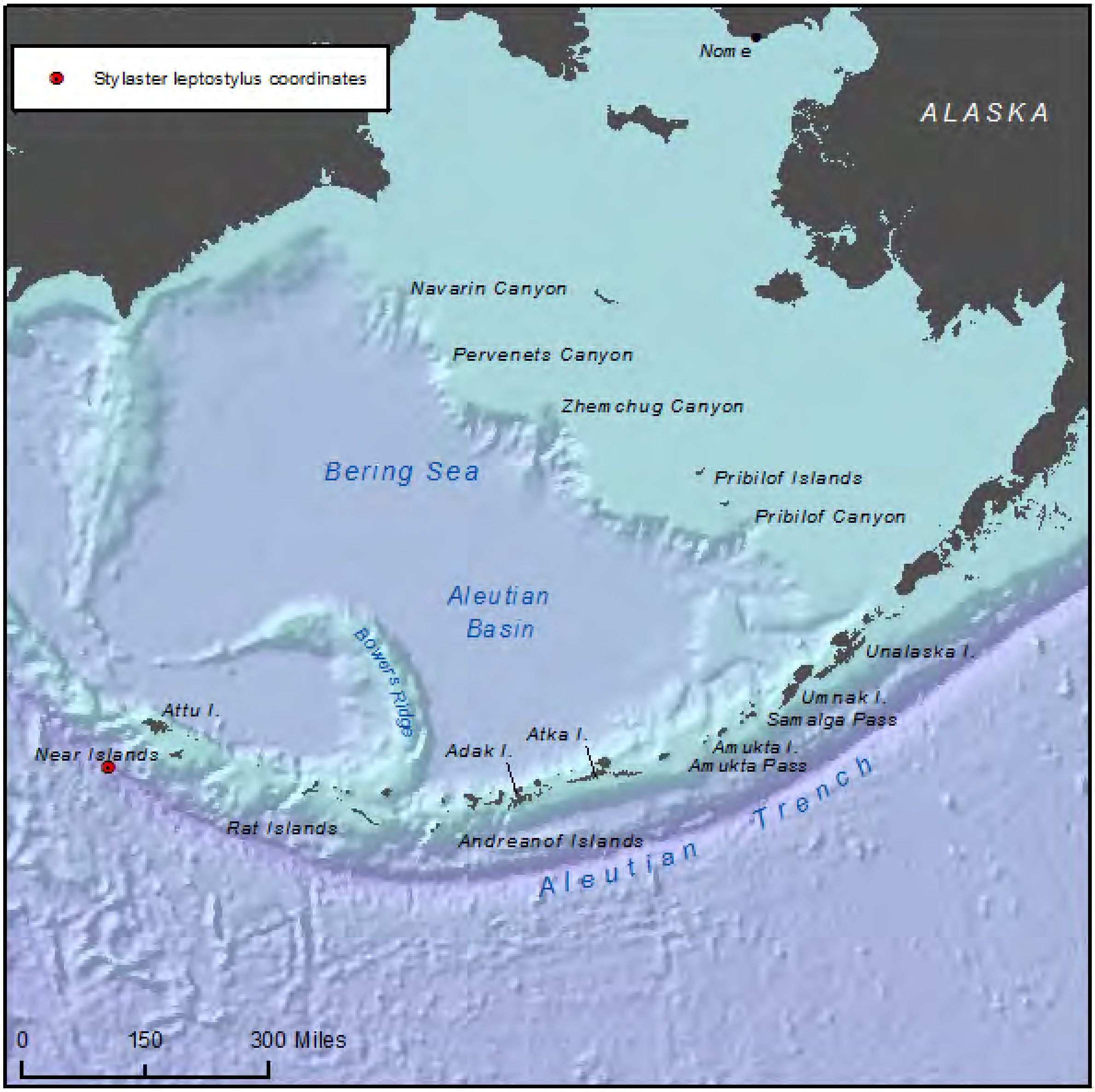


**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster leptostylus** (Fisher 1938)

**Description:** The colony is uniplanar, branching equal and dichotomous; no anastomosis of branches. Branchlets are irregular, flattened, and springing from sides of the principal stems, only a few from the concave front of colony, and occasionally a short abortive twig from the back. The coenosteum is reticulate-granular in texture, and white colored. The largest colony is 8.5 cm in height and seven cm in width, with a basal branch diameter of 8.4 mm (Cairns and Lindner 2011).

**Distribution**: This species is known only from one type locality off Seguam Island at Amukta Pass, at a depth of 518 meters.

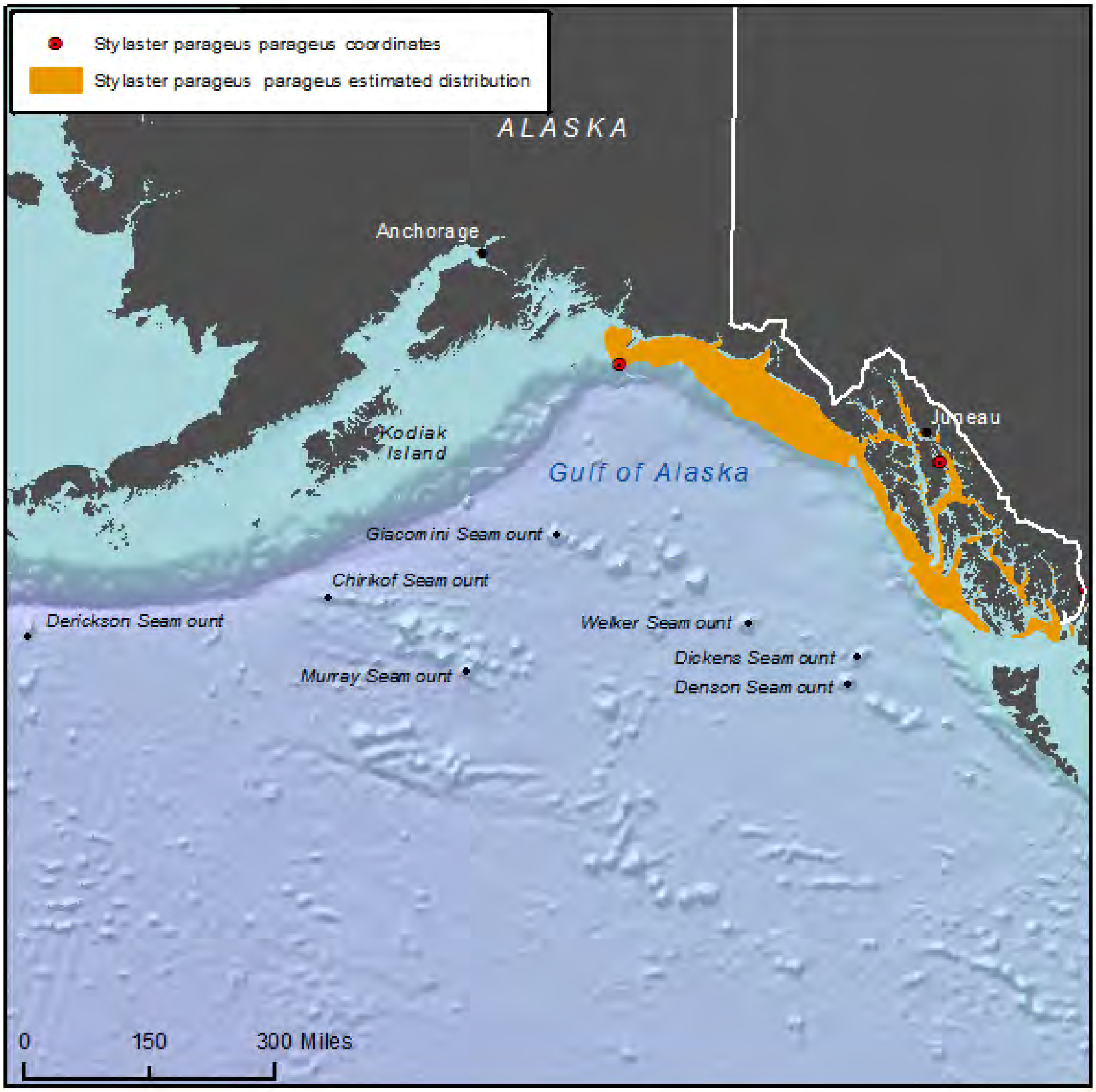


**Status**: Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster parageus parageus** (Fisher 1938)

**Description:** The corallum consists of overlapping flabella, with short branches oriented perpendicular to the flabella, producing a "flattened bush" (Fisher 1938). Branches do not anastomose, are circular to slightly flattened in cross section and are distally quite delicate. The largest colony is 13 cm tall and wide, with commensal spinoid worms common. The coenosteum is reticulate-granular in texture, and colored white (Cairns and Lindner 2011).

**Distribution:** This species is found in bays and inland passages of southeastern Alaska from off Kayak Island to just north of Dixon Entrance (Prince of Wales Islands and Portland Canal), at depths from 23 meters to 401 meters.

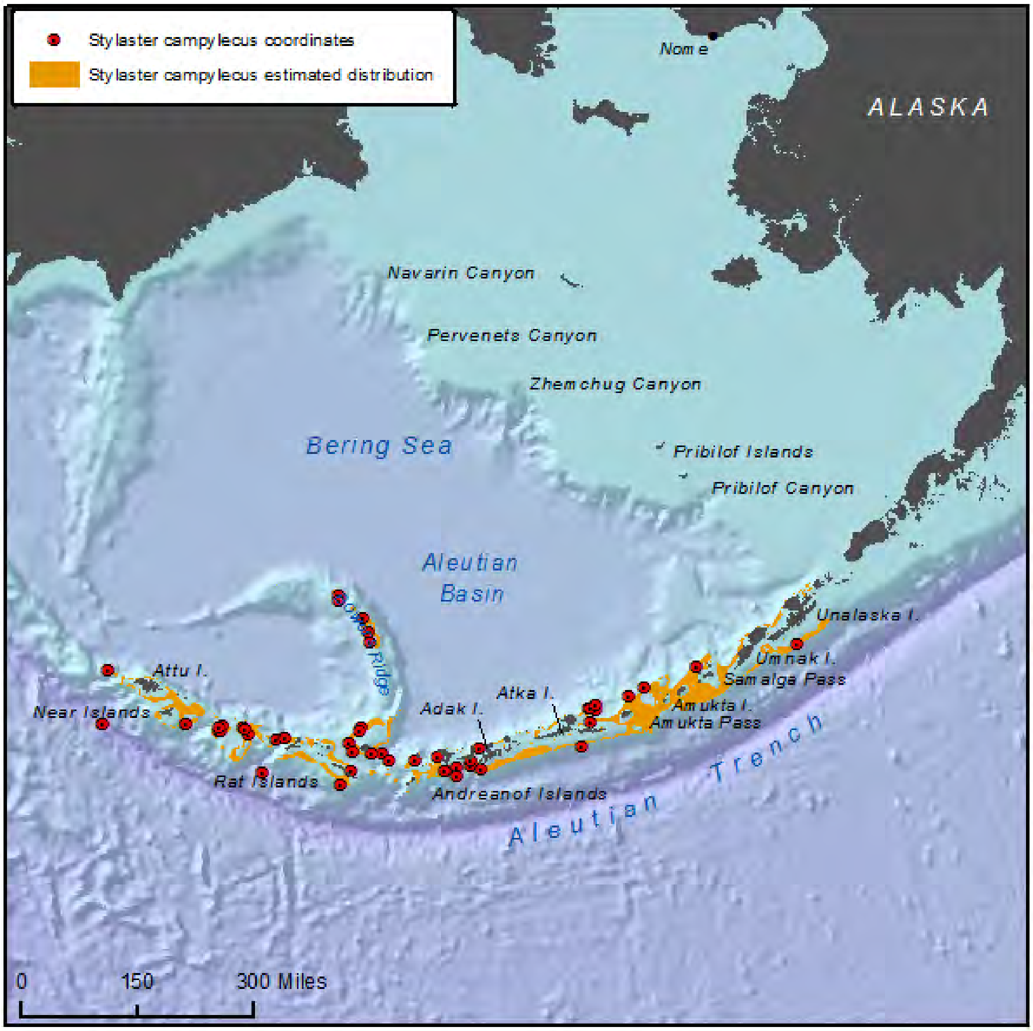


**Status**: Based on known occurrence, this species is endemic to the Gulf of Alaska and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster campylecus** (Fisher 1938)

**Description:** The corallum is essentially uniplanar or multiplanar, with occasional short side branches oriented perpendicular to the flabellum. The branches anastomose only in large colonies, the largest colony being the holotype, which is 28 cm tall and 35 cm broad, having a massive, dense basal branch diameter of 3.9 cm. Commensal spionid worms are not present. The coenosteum is reticular-granular in texture, and may be porcellaneous in some speciments and porous in others (Cairns and Lindner 2011). The color is white, pale orange, and pale pink. The corallum is 100 percent aragonite (Cairns and Macintyre 1992).

**Distribution:** This species is known from throughout the Aleutian Islands from Agattu Island to Unalaska, including Petrel and Bowers Banks and two disjunct records in Alexander Archipelago. It is found at 82 meters to 1011 meters depth, but most records are from 150 meters to 500 meters.

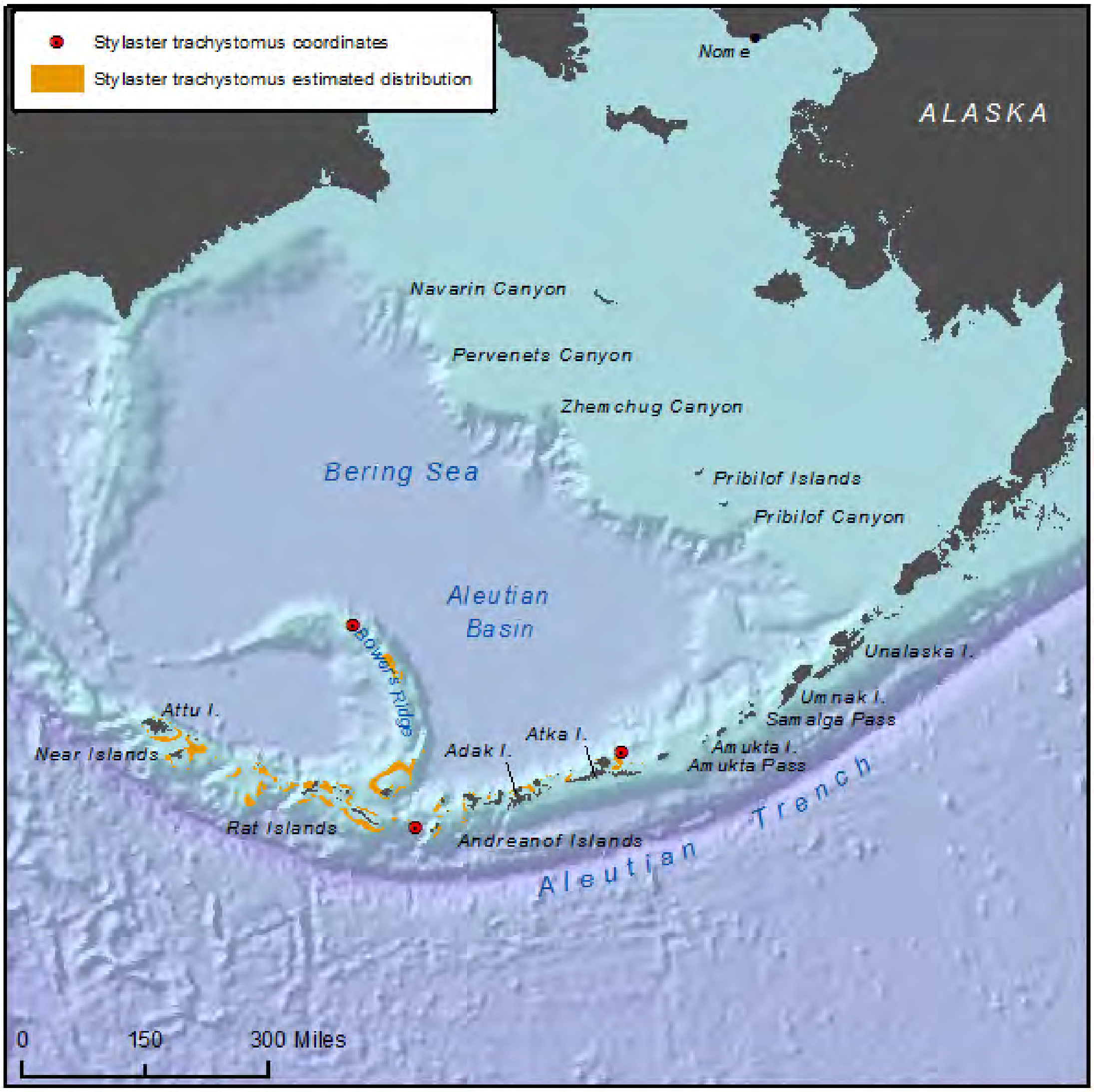


**Status**: Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster trachystomus** (Fisher 1938)

**Description:** The corallum is uniplanar, occasionally with short side branches oriented perpendicular to the flabellum. Branch anastomosis occurs only in large-diameter basal branches. The largest colony is 12 cm tall and eight cm wide. Commensal spinoid worms are common. The coenosteum is hard, with a roughened, porous surface, and pale pink-orange in color. (Fisher 1938, Cairns and Lindner 2011). Corallum is 100 percent aragonite (Cairns and Macintyre 1992).

**Distribution**: This species is found in the Aleutian Islands, from off Attu Island and North of Amalia Island (Andreanof Island), including Bowers bank. It is located at depths of 115 meters to 366 meters in a substrate of coarse pebbles (Fisher 1938, Cairns and Lindner 2011).

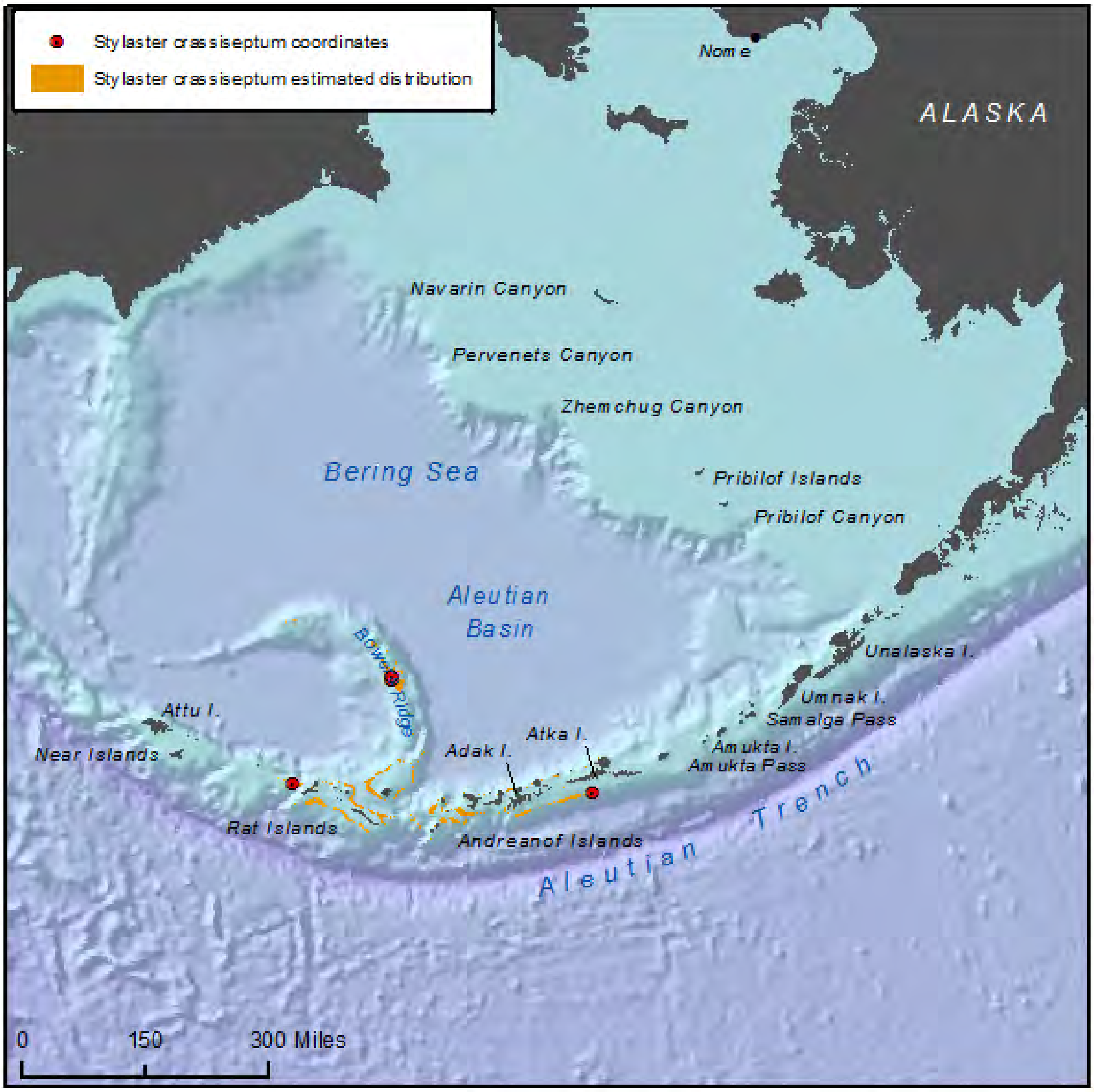


**Status**: Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster crassiseptum** (Cairns and Lindner 2011)

**Description:** Colonies are primarily uniplanar, with no branch anastomosis. The largest colony is 24 cm in height and 19 cm wide, with a basal branch diameter of 4.5 cm. Distal branches are circular in cross section, with the longer axis perpendicular to the colony plane; symbioitic polychaetes are absent. The coenosteum is low and smooth, with a porcellaneous texture on the branches. The coenosteum is dense and uniformly pale orange (Cairns and Lindner 2011).

**Distribution:** This species is found in the Aleutian Islands from off Kiska to off Atka Islands and Bowers Bank, at depths ranging from 291 meters to 531 meters.

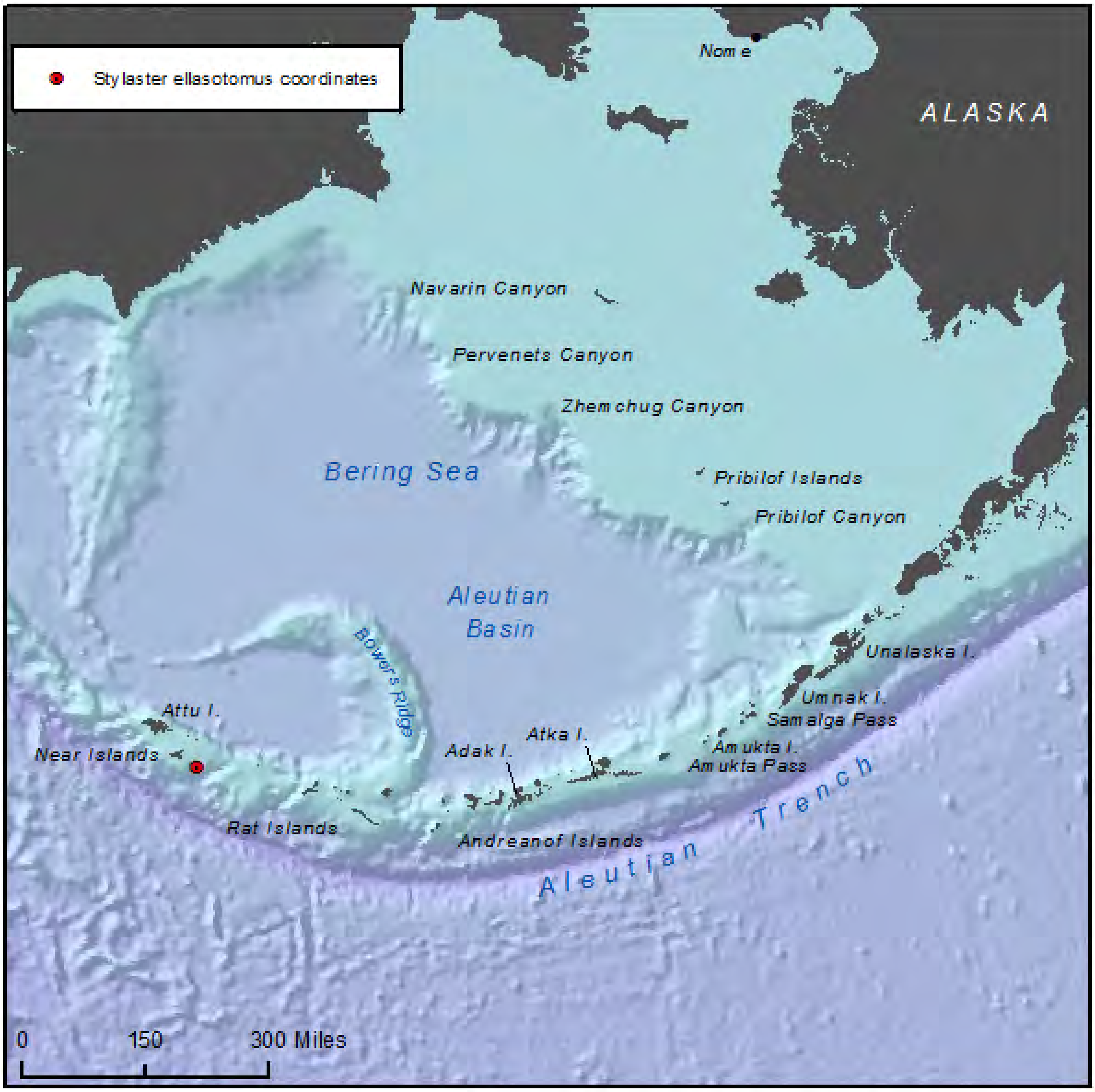


**Status and Threats**: Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster ellasotomus** (Fisher 1938)

**Description**: Holotype colony is bushy, 5.5 cm tall and 4.5 cm wide, attached by a basal branch six mm in diameter. Branches do not anastomose and are circular in cross section. The coenosteum is reticular-granular in texture, with spinoid worms absent. Color is white (Fisher 1938).

**Distribution**: This species is known from one type locality off Agattu Island, Aleutian Islands, at 881 meters in a substrate of fine gray sand with pebbles and a bottom temperature of 38.6 degrees F (Fisher 1938).

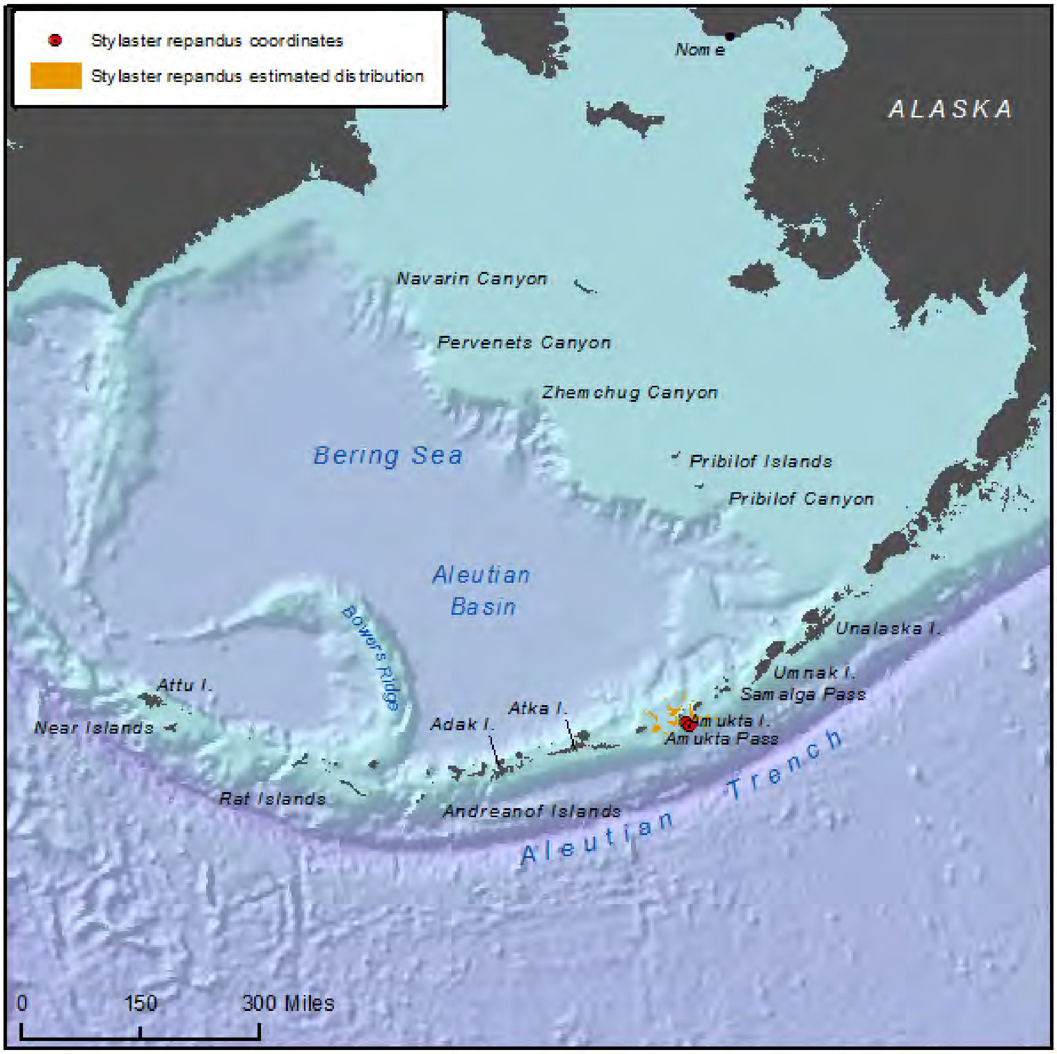


**Status and Threats**: Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster repandus** (Cairns and Lindner 2011)

**Description:** Colonies are attached to a hard substrate by a robust basal stem and encrusting base. Immediately above the basal stem the colony divides into two or three lamellae, each lamella (or sheet) of coenosteum increasing its surface area by folding its surfaces into a complex three-dimensional structure. Short (up to 15 mm) cylindrical branches project from the plane of the colony, always in response to housing a parasitic spionid worm tube. All colonies examined were heavily infested with spionid worm tubes. The holotype is 23 cm tall and 19 cm in width. Coenosteum is covered uniformly with small papillae. The coenosteum is light orange, but the central core is a light shade of pink.

**Distribution:** Known only from three localities in the vicinity of Amukta Island, Aleutian Islands, at a depth of 375 meters to 475 meters.



**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Stylaster stejnegeri** (Fisher 1938)

**Description:** The holotype is a small, arborescent colony six cm in height and seven cm in width, with a basal branch diameter of 9.3 mm. The branches are cylindrical and blunt-tipped, with tips measuring three mm to five mm in diameter. The coensosteum is reticulate-granular in texture, with binary spionid worm tubes present along the branch axes. The color is light orange to pink (Cairns and Lindner 2011).

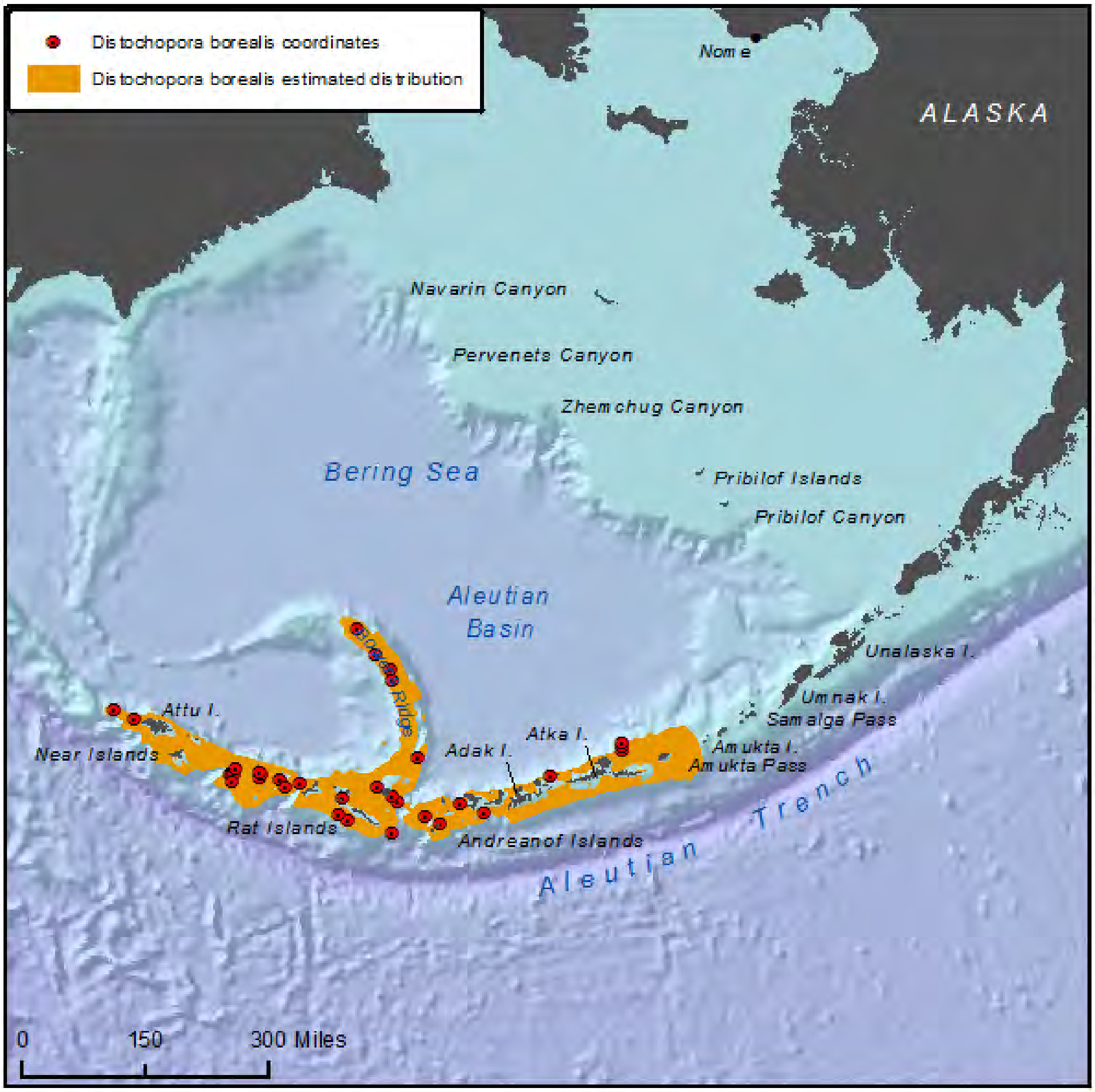
**Distribution**: Known from only one specimen at the type locality at Petrel Bank, Aleutian Islands, at 79 meters to 95 meters depth.

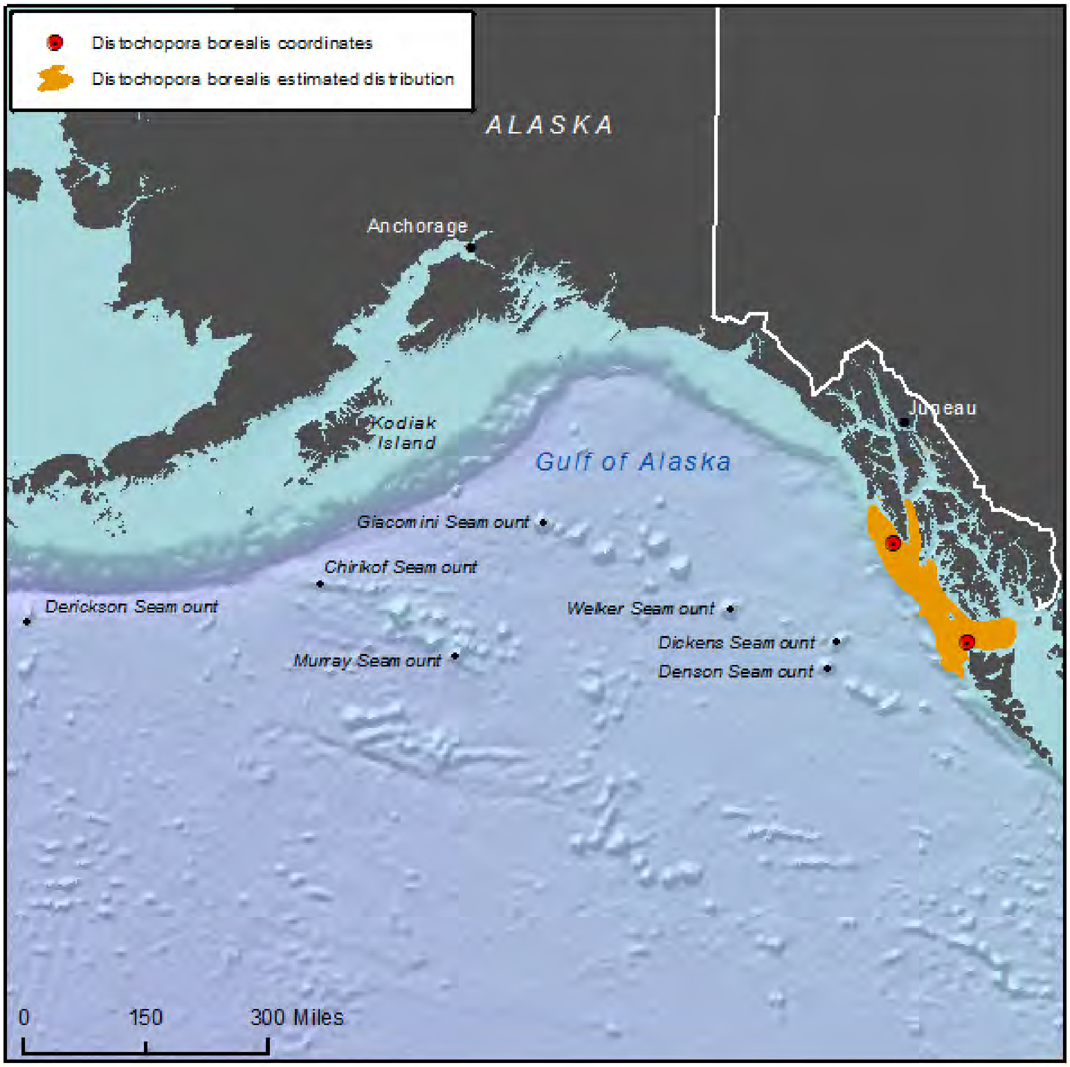
**Status:** Based on known occurrence, this species is endemic to the Aleutians, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances.

**Distochopora borealis** (Fisher 1938)

**Description:** Colony branches usually uniplanar but the branches are somewhat twisted or bent and occasionally multiplanar or arborescent. The largest specimen was 11 cm tall and 20 cm broad, and colonies broader than tall are not uncommon. The base of the colony is broadly encrusting. Branching is irregularly dichotomous, occasionally anostmotic. Branch tips are blunt and rounded. The surface of the coenostum is minutely speculated rather than uneven and glossy, and is white to light orange (Fisher 1938, Cairns and Lindner 2011).

**Distribution**: This species is found in one type locality in Amukta Pass, Aleutian Islands at 1,698 feet deep (Fisher 1938). It is also common in the Aleutian Islands from the Near Islands to Amutka Pass, including Bowers Bank; off Cape Ommaney, Alexander Archipelago, and Dixon Entrance, Queen Charlotte Islands, at depth distribution of 53 meters to 1267 meters, with the shallowest record from Cape Ommaney (Cairns 2011). It is found in a black sand, rocky substrate (Fisher 1938).





**Status:** Based on known occurrence, this species is endemic to the Aleutians and Gulf of Alaska, and is thus vulnerable to disturbance or changes in its environment, and limited in ability to repair damage, adapt to new conditions, or colonize an area in the face of such disturbances. .

# III. THE SURVIVAL OF THE PETITIONED CORAL SPECIES IS THREATENED BY ONE OR MORE THE ENDANGERED SPECIES ACT LISTING FACTORS

## A. CRITERIA FOR LISTING SPECIES AS ENDANGERED OR THREATENED UNDER THE ENDANGERED SPECIES ACT AND TIMELINE FOR THE FORESEEABLE FUTURE

Under the ESA, 16 U.S.C. § 1533(a)(1), NMFS is required to list a species for protection if it is in danger of extinction or threatened by possible extinction in all or a significant portion of its range. In making such a determination, NMFS must analyze the species' status in light of five statutory listing factors, relying "solely on the best scientific and commercial data available." 16 U.S.C. § 1533(b)(1)(A). When information is lacking, NMFS must "give the benefit of the doubt" to the listed species. *Conner v. Burford*, 848 F.2d 1441, 1454 (9th Cir. 1988). The listing factors are:

> (A) the present or threatened destruction, modification, or curtailment of its habitat or range;
>
> (B) overutilization for commercial, recreational, scientific, or educational purposes;
>
> (C) disease or predation;
>
> (D) the inadequacy of existing regulatory mechanisms;
>
> (E) other natural or manmade factors affecting its continued existence.

16 U.S.C. § 1533(a)(1)(A)-(E); 50 C.F.R. § 424.11(c)(1)-(5).

A species is "endangered" if it is "in danger of extinction throughout all or a significant portion of its range" due to one or more of the five listing factors. 16 U.S.C. § 1531(6). A species is "threatened" if it is "likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." 16 U.S.C. § 1531(20).

A "species" includes any species, subspecies, or a "distinct population segment" of a vertebrate species. 16 U.S.C. § 1532(16). Each of the petitioned taxa is recognized as a distinct species or subspecies, and therefore each qualifies as a "species" under the ESA.

While the ESA does not define the "foreseeable future," NMFS must use a definition that is reasonable, that ensures protection of the petitioned species, and that gives the benefit of the doubt regarding any scientific uncertainty to the species. As explained below, the minimum time period that meets these criteria for the petitioned coral species is the period through 2100.

Because climate change and ocean acidification are foremost threats to the petitioned coral species, NMFS should consider the timeframes used in climate modeling. Predictions of climate impacts in the next 100 years or more are routine in the literature, demonstrating that climate impacts within this timeframe are inherently "foreseeable."

As a primary example of the feasibility of a 100-year time frame, the Intergovernmental Panel on Climate Change ("IPCC"), a foremost world scientific authority on climate change, has provided climate change projections through 2100 under a range of plausible emissions scenarios. For the Fourth Assessment, the IPCC performed an unprecedented internationally coordinated climate change experiment using 23 models by 14 modeling groups from 10 countries to project future climate conditions. This large number of models ranging from simple to complex, running the same experiments, provided both quantification of future climate conditions through the end of this century and the uncertainty of the results. As stated by the IPCC itself, climate projections run through the end of the 21st century under different emissions scenarios, and accompanied by the range of uncertainty, were provided in its 2007 Fourth Assessment Report specifically because of their policy-relevance:

> Advances in climate change modeling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emission scenarios. Results for different emission scenarios are provided explicitly in this report to avoid loss of this policy-relevant information. Projected global average surface warmings for the end of the 21st century (2090–2099) relative to 1980–1999 are shown in Table SPM.3. These illustrate the differences between lower and higher SRES emission scenarios, and the projected warming uncertainty associated with these scenarios.
> (IPCC 2007b: 13).

The IPCC Fifth Assessment will use a suite of new emissions pathways, the Representative Concentration Pathways (RCPs), which similarly provide updated, high-resolution datasets for emissions trajectories and impacts analysis through 2100, with estimates of uncertainty (van Vuuren et al. 2011, http://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/index.html). The RCPs are supplemented with extensions (Extended Concentration Pathways) which allow climate modeling experiments through the year 2300 (van Vuuren et al. 2011), further demonstrating the foreseeability of climate change impacts in the coming centuries.

As additional support for defining the "foreseeable future" through the year 2100, NMFS determined in three recent listing-related decisions that the year 2100 represents the most appropriate, science-based timeline for the foreseeable future for considering climate change threats to species. In December 2010, NMFS defined the foreseeable future for assessing climate change impacts to two ice seal species as the end of the 21st century in the proposed listing rules for the ringed seal and bearded seal, which are both threatened by climate change:

> [N]MFS scientists have revised their analytical approach to the foreseeability of threats and responses to those threats, adopting a more threat specific approach based on the best scientific and commercial data available for each respective threat. For example, because the climate projections in the Intergovernmental Panel on Climate Change's (IPCC's) *Fourth Assessment Report* extend through the end of the century (and we note the IPCC's *Fifth Assessment Report*, due in 2014, will extend even farther into the future), we used those models to assess impacts from climate change through the end of the century. We continue to recognize that the farther into the future the analysis extends, the greater the inherent uncertainty, and we incorporated that limitation into our assessment of the threats and the species' response. For other threats, where the best scientific and commercial data does not extend as far into the future, such as for occurrences and projections of disease or parasitic outbreaks, we limited our analysis to the extent of such data. We believe this approach creates a more robust analysis of the best scientific and commercial data available.(75 Fed. Reg. 77477, 77497; emphasis added)

The proposed rules for these seals further conclude that climate projections through the end of the 21st century "currently form the most widely accepted version of the best available data about future conditions":

> NMFS scientists have recognized that the physical basis for some of the primary threats faced by the species had been projected, under certain assumptions, through the end of the 21st century, and that these projections currently form the most widely accepted version of the best available data about future conditions. In our risk assessment for ringed seals, we therefore considered all the projections through the end of the 21st century to analyze the threats stemming from climate change. (75 Fed. Reg. 77482, 77503; emphasis added).

The status reviews for these seals also concluded that the end of the 21st century is the foreseeable future for climate change threats for these species (Cameron et al. 2010, Kelly et al. 2010). For example, the ringed seal status review stated:

> In this review of ringed seal population status, the BRT recognized that the physical basis for some of the primary threats faced by the species have been projected, under certain assumptions, through the end of the 21st century, and that these projections currently form the most widely accepted version of the best available information about future conditions. Therefore, in the risk assessment that follows, the BRT used the full 21st-century projections as the basis for the foreseeability of threats stemming from climate change. (Kelly et al. 2010: 43; emphasis added).

NMFS reaffirmed this determination for "foreseeable future" in its peer-reviewed status review report for 82 coral species petitioned under the U.S. Endangered Species Act (Brainard et al. 2011). In this decision, NMFS scientists stated that "the year 2100 was used as the time horizon for this risk evaluation because this century was the timeframe over which the BRT [biological review team] had access to reasonable, scientifically vetted predications of key threats and their impacts," and "the IPCC collection of $CO_2$ emissions scenarios and climate models provided projections with adequate confidence to the year 2100":

> There is no formal definition in the U.S. Endangered Species Act for the term "foreseeable future" as used in the legal description of "threatened." However, agency policy guidance recommends linking the time horizon for the risk evaluation to the timeframe over which it is possible to scientifically predict the impact of the threats (U.S. Department of Interior, 2009). Both the petition and the BRT determined that climate change and ocean acidification probably pose significant extinction risk threat to corals. The year 2100 was used as the time horizon for this risk evaluation because this century was the timeframe over which the BRT had access to reasonable, scientifically vetted predictions of key threats and their impacts (see Chapter 3). In particular, the BRT determined that the Intergovernmental Panel on Climate Change (IPCC) collection of $CO_2$ emissions scenarios and climate models provided projections with adequate confidence to the year 2100 to reasonably support their use in evaluating Critical Risk Thresholds for the candidate coral species. Much of the scientific information available on the potential impacts of ocean acidification on corals has likewise been based on IPCC $CO_2$ emission scenarios and model projections.
> (Brainard et al. 2011: 100).

These determinations by NMFS scientists that climate projections through 2100 represent the best-available science on the foreseeable future for assessing climate change threats provides a solid basis for applying the same foreseeable future timeline to the petitioned coral species.

Additionally, in planning for species recovery, NMFS and its sister agency, the U.S. Fish and Wildlife Service, routinely consider a foreseeable future threshold of roughly 100 years, particularly when addressing climate change considerations. For example, the agencies jointly stated in the second revision of their recovery plan for the Northwest Atlantic population of loggerhead sea turtles:

> Research has identified sea level rise as one of the most important potential impacts of global climate change. The best available science indicates that *by 2100* South Florida seas will be approximately 20 inches higher than they were in 1990 (IPCC 2001). An increase of this magnitude would drastically alter the coastline, changing the extent, quality, and

> location of sandy beaches available for loggerhead nesting. In the short term, even small changes in sea level could be expected to exacerbate beach erosion and increase artificial beach/dune alterations meant to protect coastal properties. (NMFS and USFWS 2008 at II-53 (emphasis added)).

Furthermore, following a recent workshop on reclassification criteria for endangered large whale species, NMFS has adopted a policy guideline that “[a] large cetacean species shall no longer be considered endangered when, given current and projected conditions, the probability of quasi-extinction is less than 1% in 100 years” (NMFS 2005b).

Perhaps most importantly, the time period NMFS uses in its listing decision must be long enough so that actions can be taken to ameliorate the threats to the petitioned species and prevent extinction. *See Defenders of Wildlife v. Norton*, 258 F.3d 1136, 1142 (9th Cir. 2001) (quoting legislative history noting that the purpose of the ESA is “not only to protect the last remaining members of [a listed] species but to take steps to insure that species which are likely to be threatened with extinction never reach the state of being presently endangered”). Slowing and reversing impacts from anthropogenic greenhouse gas emissions, a primary threat to all of the petitioned coral species, will be a long-term process for a number of reasons, including the long-lived nature of carbon dioxide and other greenhouse gases and the lag time between emissions and climate changes. NMFS must include these considerations in its listing decision.

For all these reasons, the use of less than the year 2100 as the “foreseeable future” in this rulemaking would clearly be unreasonable, frustrate the intent of Congress to have imperiled species protected promptly and proactively, and fail to give the benefit of the doubt to the species as required by law.

As detailed throughout, neither anthropogenic greenhouse gas emissions nor any of the other threats to the petitioned coral species are speculative or too far in the future to understand or address. These new and modern threats are already here, and the impacts are already manifesting in coral populations. Urgent action, including listing under the ESA and dramatic cuts in greenhouse gas emissions levels, is needed now to ensure that these species do not become extinct in the foreseeable future. As described below, each of the petitioned coral species qualifies for listing under the ESA.

The survival of the petitioned coral species is threatened by anthropogenic climate change, fisheries activities, ocean acidification and oil spills and contamination. These anthropogenic impacts threaten the petitioned coral species by direct damage and removal, by degradation of habitat, and by changing ecosystem dynamics. The existing regulatory mechanisms provide inadequate protections from these threats for the petitioned corals. Each of these threats is discussed in detail below.

# B. THE PRESENT OR THREATENED DESTRUCTION, MODIFICATION OR CURTAILMENT OF HABITAT OR RANGE

Habitat loss and degradation is the primary cause of species extinction worldwide (Primack 2001). This is particularly true for the petitioned corals, as they occur in the North Pacific Ocean and Bering Sea, areas that are experiencing large and rapid changes in ocean chemistry and the marine ecosystem due to global climate change and ocean acidification directly resulting from anthropogenic greenhouse gas emissions (Orr et al. 2005, Steinacher et al. 2009, Feely et al. 2009). Cold water corals are especially vulnerable to climate change and ocean acidification because of biological characteristics common to organisms of the deep sea, including an extremely long life, spanning from decades to thousands of years (Risk et al. 2002, Roark et al. 2009, Andrews et al. 2009); slow annual growth rates of just millimeters a year (Heifetz 2002, Risk et al. 2002, Mortensen and Buhl-Mortensen 2005); advanced age of reproductive maturity (Simpson 2009, Mercier and Hamel 2011); infrequent reproduction; and limited ability for larval dispersal over distance (Brooke and Stone 2007). These biological characteristics mean that most cold water coral species have extremely narrow habitat requirements with limited ability to colonize new areas or shift their range, and very low genetic variation (Miller et al. 2011). Because of this, cold water corals have little scope for vertical adjustment that would allow them to shift their distribution in response to changes or disruptions in ocean chemistry, currents, and temperature (Andersson et al. 2008, Miller et al. 2011). As a result, the impacts of anthropogenic $CO_2$ emissions and climate change may cause these species to “simply disappear” (Poloczanska et al. 2007).

## 1. Anthropogenic greenhouse gas emissions resulting in ocean acidification and ocean climate change threaten the petitioned coral species

Global climate change and ocean acidification will impair biological and ecological functions of cold water corals, degrade habitat, and actively erode existing coral colonies (Orr et al. 2005, Hofmann et al. 2010).

The petitioned coral species are under severe, pervasive and growing threats from anthropogenic greenhouse gas emissions, which lead to ocean acidification and climate change (Hofmann et al. 2010). Climate change and ocean acidification result in undersaturation of calcium carbonate ions in seawater, leading to a shoaling of the aragonite and calcite saturation horizons (Doney et al. 2009). Climate change and ocean acidification also result in increasing ocean temperatures, changing current and ocean circulation patterns, changes in upwelling patterns and productivity, and changes in salinity (Mathis et al. 2010, 2011a, Masuda et al. 2010). This may result in large-scale effects, such as a breakdown in the ocean’s ‘biological pump’ (Feely et al. 2004, Orr et al. 2005), and a consequent decrease in the supply of organic particles to cold water corals that are critical to support their metabolism. Additionally, as rapid ocean warming inhibits deep ocean ventilation, there is likely to be decreased levels of dissolved oxygen that may also have adverse impacts on cold water coral ecoystems (McCulloch et al. 2012). During the Younger-Dryas period, rapid warming, decreased deep-water circulation, and changes in the supply of organic particles resulted in rapid demise of cold water corals (McCulloch et al. 2012). Thus, ecosystem-wide changes resulting from ocean acidification and climate change, will have significant and widespread impacts on Alaska corals.

As described in detail below, shoaling of the calcium carbonate saturation horizons and undersaturation of seawater with respect to aragonite, calcite, and other forms of calcium carbonate will impair coral calcification, growth, reproduction and other life history processes and result in huge swathes of lost habitat for the petitioned coral species (Andersson et al. 2008, Miller et al. 2011, Yesson et al. 2012). The availability of inorganic nutrients, phytoplankton, and microinvertebrates that cold water corals depend on for food and calcification will also decrease as a consequence of ocean acidification (Steinacher et al. 2009, Hofmann et al. 2010, Comeau et al. 2010, 2012). Additionally, more acidic seawater could actively dissolve existing cold water corals (Orr et al. 2005). Areas of the corals with direct contact with seawater, especially the holdfasts, may be especially vulnerable to small changes in pH (less than 0.1 unit pH), especially those at or near the aragonite saturation horizon (McCulloch et al. 2012). This applies to many of the corals in this petition.

Climate change will result in increased seawater temperature, changes in seawater salinity, and shifting ocean currents which may further impact cold water corals by degrading habitat quality, and limiting delivery of food and inorganic carbon material. This will result in reduced calcification rates and growth, and impede other biological processes (Guinotte et al. 2006, Maier et al. 2011). A reduction in available nutrients would impede cold water corals' ability to respond to the higher metabolic rate that would result from increased ocean temperatures (Thresher et al. 2011). Changing ocean chemistry and other impacts from climate change will result in increased energetic demands for obtaining calcium carbonate for growth and repair of skeletal elements (Hofmann et al. 2010). If these greater metabolic demands can not be met due to nutrient limitation, cold water corals may be unable to perform basic life processes.

Perhaps most significantly, the best available science to date indicates that the energetic limitations of cold water corals may be critical, as a 10% increase in energy output is required to maintain internal pH with each 0.1 drop in pH unit, with increasing seawater temperatures also resulting in an increase in calcification rates and energy requirements (McCulloch et al. 2012). As the supply of food particles to cold water corals may be inhibited with climate change, the petitioned corals would be unable to maintain a positive energy state resulting in breakdown of physiological processes, including reproduction, growth, and maintenance and repair of their skeletal structure. As a result, Alaska corals may experience rapid declines, threatening the survival of these endemic species.

## i. Ocean acidification

### *a. Ocean acidification processes worldwide*

The oceans are a massive reservoir for $CO_2$ and have absorbed nearly one-third of global anthropogenic $CO_2$ emissions since the year 1800 (Sabine et al. 2004). While the uptake of $CO_2$ by the oceans has buffered the effects of climate change, it has resulted in rapid changes in seawater chemistry. Ocean acidification occurs when $CO_2$ reacts with seawater to generate carbonic acid, which releases hydrogen ions to form bicarbonate and carbonate ions (Wolf-gladrow et al. 1999, Turley et al. 2007). This increases the concentration of hydrogen ions in seawater and lowers the pH, thus giving rise to the term “ocean acidification.” The ocean’s absorption of anthropogenic $CO_2$ has already resulted in about a 30 percent increase in the acidity of ocean surface waters, at a rate likely faster than anything experienced in the past 300 million years, and ocean acidity is projected to increase by 100 percent to 150 percent by the end of the century if $CO_2$ emissions continue unabated (Orr et al. 2005, Feely et al. 2009, Hönisch et al. 2012).

In addition to reduced pH, ocean acidification reduces the availability of calcium carbonate ($CaCO_3$) for calcifying organisms (Doney et al. 2009). As a result, the saturation state of the oceans with respect to aragonite and calcite is decreasing worldwide (Andersson et al. 2008, Orr et al. 2008). A decrease in the calcium carbonate saturation state stresses calcifying organisms including cold water corals by negatively impacting the mechanisms, abilities, and energetic costs for calcification, growth, and other essential biological processes including reproduction (Guinotte et al. 2006, Holcomb et al. 2010), acid-base regulation (Pörtner 2008), respiration (Rosa and Seibel 2008), and tolerances of other stresses (Pörtner 2008, Hutchins et al. 2009). Increased ocean acidity and calcium carbonate undersaturation also negatively affect calcifying microinvertebrates that form the basis of the marine food web and provide critical food and inorganic carbon sources for many marine species including cold water corals (Thresher et al. 2011). Any changes in abundance of these small invertebrates would impact cold water corals, shellfish, fish, and large marine animals (Cohen and Holcomb 2009, Flynn et al. 2012).

Predictions for the future of calcifying organisms in an acidifying and warming ocean are grim. Based on observations from cruise surveys, Feely et al. (2012) report that in the Pacific Ocean there has been a decrease of the saturation state of surface seawater with respect to aragonite and calcite as well as an upward shoaling of the saturation horizon by about 1-2 meters per year on average. They report that aragonite saturation state has declined 16% since the industrial revolution due, in large part, to anthropogenic $CO_2$ (Ishii et al. 2011, Feely et al. 2012). Due to shoaling of saturation horizons, saturation states for calcium carbonate will be especially reduced in the deep ocean, and at high latitudes, where the petitioned coral species occur (Roberts et al. 2006, Turley et al. 2007). Decreasing calcium carbonate saturation states have been shown to negatively impact cold water corals resulting in an over 50 percent reduction in calcification rates (Maier et al. 2009). All calcifying marine organisms tested to date have shown at least an initial negative response to decreasing carbonate saturation states (Kroeker et al. 2010).

In contrast to zooanthellate corals, in azooanthellate cold water corals, the over-riding control on calcification rates is physiological limitations of the corals which is largely based on nutrient availability (McCulloch et al. 2012). Alaska's oceans are in the midst of wide-scale changes that both alter the productivity and change the mixing processes that transport nutrients to the deep sea (Mathis et al. 2011a,b), both of which are likely to decrease the available nutrients and physiological functions of Alaska corals.

As Earth's oceans become less saturated over time, cold water corals are expected to build weaker skeletons and experience slower growth rates (Kleypas 1999, Guinotte et al. 2006). Both processes will make it more difficult for corals to withstand physical disturbances, to retain skeletal integrity, and to maintain a competitive advantage over other marine organisms. Only three percent of octocorals worldwide are found in areas undersatured with respect to calcite, with approximately 12 percent of octocorals found in water undersaturated with respect to aragonite (Yesson 2012). Surface waters in the Arctic are projected to become corrosive with respect to aragonite within the next few years, while parts of the North Pacific are already undersaturated with respect to calcite, with total water column aragonite undersaturation expected within the next couple of decades (Steinacher et al. 2009, Mathis et al. 2011b). As seen in Figure 7, saturation levels of aragonite have already dropped to the point where habitat for cold water coral is considere "low" to "extremely low" at saturation levels from 1.5 to 2, with saturation levels of 4 considered "adequate" and aragonite saturation of 5 considered "optimal". Reductions in saturation levels of calcium carbonate are critical in determining impacts on corals. The holdfasts of cold water corals, a critical skeletal element that connects corals to the seafloor, and allows them maintain an upright position for optimal feeding, may be especially vulnerable to dissolution by ocean acidification because they are directly exposed to seawater. Even a small change of less than 0.1 pH units may greatly increase the dissolution rates of corals living at or below the aragonite saturation horizon (McCulloch et al. 2012). Dissolution of this important skeletal element may result in a reduced lifespan and decreased reproductive success.

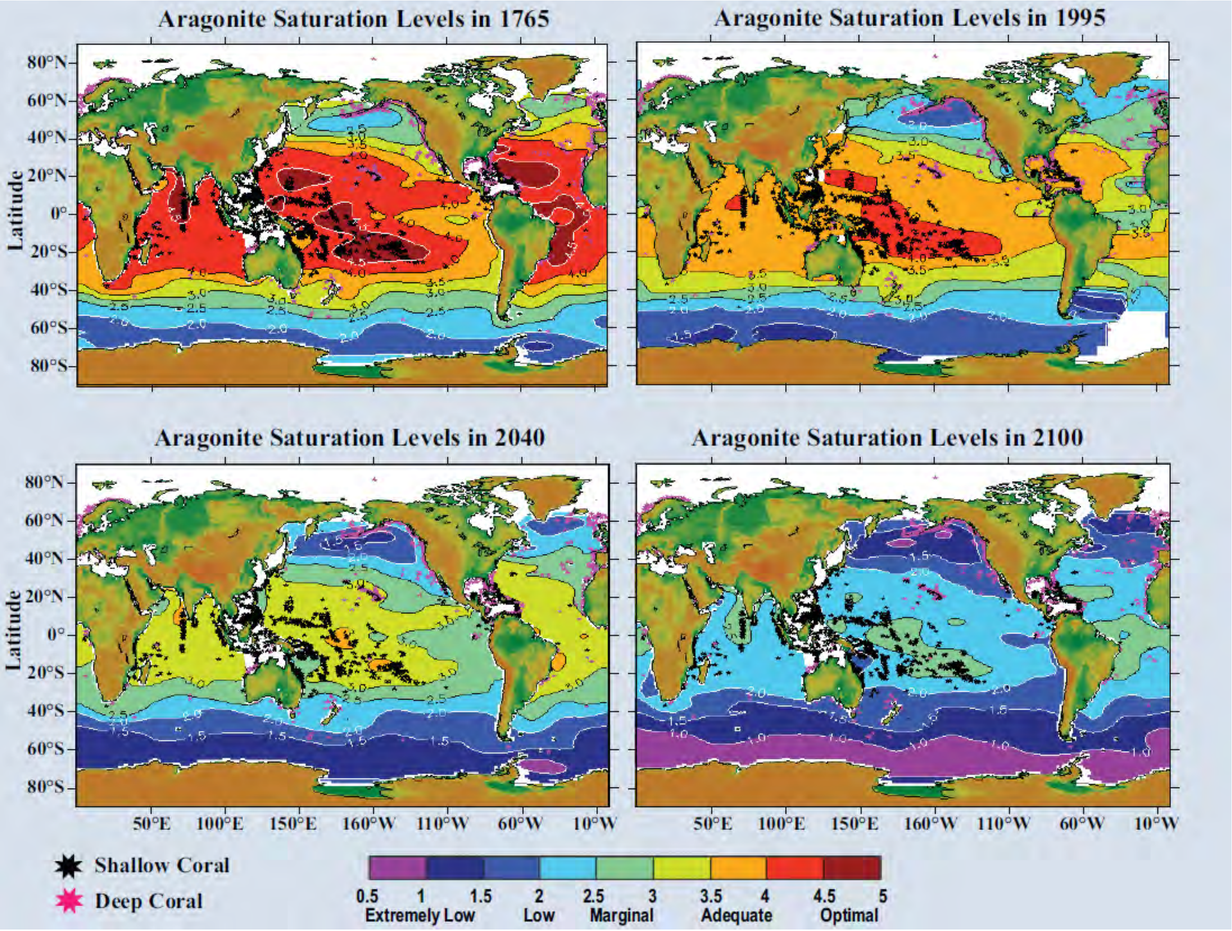


**Figure 7**. Estimated aragonite saturation states of the surface ocean for the years 1765, 1995, 2040, and 2100 (Feely *et al.*, submitted), based on the modeling results of Orr *et al.* (2005) and a Business-As-Usual CO2 emissions scenario. The distributions of deep-sea coral banks are from Guinotte *et al.* (2006). Source: (Kleypas et al. 2006)

The impacts of widespread calcium carbonate undersaturation on marine ecosystems may be very severe and result in massive die-offs of marine organisms. Historical records show mass extinctions of marine taxa during periods of total water column calcium carbonate undersaturation (Zachos et al. 2005). An ocean acidification event, combined with increasing temperatures, on the scale of projected future levels of ocean acidification resulted in extinction of a large proportion of benthic calcifiers 55 million years ago (Zachos et al. 2005). Impacts from this modern ocean acidification event, which would take place over mere decades to centuries, would result in a far more rapid rate of change than the historical event, and this rate of change in ocean acidification levels is unprecedented in the historical record (Hönisch et al. 2012). It is unlikely that marine species, especially those of the deep sea that are long-lived and have low reproductive rates would be able to adapt to such a rapid change. Many of the petitioned coral species are adapted for a specific niche in the generally static marine environment of the deep sea, with very strict temperatures, depth, and ocean chemistry requirements (Andersson et al. 2008). These species are extremely vulnerable to rapid changes in the marine environment, and likely have little genetic variability to fall back upon even if their life cycles were rapid enough to accommodate this process of genetic shift (Miller et al. 2011).

### *b. Waters of the North Pacific and Bering Sea are already undersaturated with respect to aragonite and calcite*

High latitude waters, including the North Pacific and Bering Sea, are the "bellwether" of ocean acidification because these will be the first ocean regions to become persistently undersaturated with respect to aragonite as a result of greenhouse gas pollution (Fabry et al. 2009, Steinacher et al. 2009). High-latitude waters have naturally lower carbonate ion concentrations and saturation states due to a combination of cold temperatures which increase the solubility of $CO_2$ and ocean mixing patterns (Fabry et al. 2009, Mathis et al. 2011b). Modern-day increases in $CO_2$ solubility in the Arctic and North Pacific result from a combination of increasingly warmer air and water temperatures, melting ice, and increased concentration of atmospheric $CO_2$, all of which result in increased absorption of $CO_2$ by waters in northern latitudes and a hastening of the ocean acidification process (Steinacher et al. 2009). Warmer temperatures also cause a more active hydrological cycle, bringing more low-mineral $CaCO_3$ to the outer-shelf, and increasing the rate of undersaturation (Mathis et al. 2011b).

Because of the natural high solubility of $CO_2$ at northern latitudes, aragonite and calcite thresholds are already very shallow in the North Pacific and Arctic oceans compared to other more temperate ocean areas, and are progressively moving higher as the concentration of anthropogenic $CO_2$ in the atmosphere continues to rise (Guinotte et al. 2006). In the North Pacific, the aragonite saturation horizon (ASH) is only 150-200 m, compared to 2,000 m in the North Atlantic Ocean (Feely et al. 2004, Guinotte et al. 2006). In the Aleutians the ASH currently stands at less than 150 m (Guinotte et al. 2006), and the calcite saturation horizon is at just 260 to 440 m (Orr et al. 2005).

Recent observations of calcium carbonate saturation states in the North Pacific and Bering Sea have found that full water column undersaturation of calcium carbonate due to ocean acidification is already prevalent. Mathis et al. (2011b) reported that extensive areas of bottom waters over the Bering Sea shelf are becoming undersaturated with respect to aragonite for at least several months (July to September), and some areas of bottom water were already observed to be undersaturated with respect to calcite (Fabry et al. 2009, Mathis et al. 2011b). Re-mineralization of organic matter exported from surface waters appears to increase bottom water $CO_2$ concentrations over the shelf in summer and fall, suppressing the calcite and aragonite saturation state ($\Omega$) values. In the surface waters, removal of $CO_2$ by high rates of phytoplankton primary production increases saturation state values between spring and summer, but these increases are partly counteracted by sea ice melt water and terrestrial river runoff that have low saturation state values and that are increasing with climate warming.

Mathis et al. (2011a) predict that ocean acidification will likely have profound impacts on benthic and pelagic calcifying species across the Bering Sea shelf in the near future. The researchers concluded that "the observed suppression and undersaturation of $\Omega$calcite and

Ωaragonite in the eastern Bering Sea are correlated with anthropogenic carbon dioxide uptake into the ocean and will likely be exacerbated under business-as-usual emission scenarios. Therefore, ocean acidification could threaten some benthic and pelagic calcifying organisms across the Bering Sea shelf in the coming decades." Mathis et al. (2011b) found that while natural environmental processes contribute to low saturation states, anthropogenic $CO_2$ has driven seasonal undersaturation of aragonite in broad regions across the shelf. The researchers predict that anthropogenic $CO_2$ combined with natural remineralization processes will cause undersaturation conditions to persist for longer periods. This also could mean that deep winter mixing could cause the entire water column to drop below the saturation horizon, leaving the springtime water column under the ice undersaturated in respect to aragonite. Mathis et al. (2011b) show that the by mid-century the Bering Sea will be persistently undersaturated with respect to aragonite on the current trajectory and subsequently calcite will become seasonally undersaturated. The study concluded that "the reduction in $CaCO_3$ mineral saturation states could have profound implications for several keystone calcifying species in the Bering Sea."

Under existing $CO_2$ emission rates, models predict that the surface waters of the Arctic Ocean and parts of the North Pacific will be undersaturated with respect to aragonite in the next 50 years, starting as early as 2016 (Orr et al. 2005). The surface waters of the Bering Sea are predicted to be persistently undersaturated with respect to aragonite by 2050, and most of the Arctic, including broad regions of the Bering Sea, will be undersaturated with respect to calcite by the end of the century (Fabry et al. 2009, Feely et al. 2009, Mathis et al. 2011a,b). This is critical, as many of the petitioned species likely use predominantly calcitic, rather than aragonitic elements, and undersaturation with respect to calcite may have severe adverse impacts on Alaska corals.

### *c. Rising saturation horizons for aragonite, calcite and high magnesium calcite are reducing habitat suitability for the petitioned corals*

Current worldwide distribution of cold water corals indicates that shifting ocean conditions due to climate change may restrict many species' distribution and result in massive extinctions of corals (Yesson et al. 2012). Yesson et al. (2012) used a database of 12,508 geo-located octocoral specimens and 32 environmental grids to determine worldwide habitat suitability for cold water octocorals. Temperature, salinity, slope, productivity, and oxygen and calcium carbonate saturation state were identified as important factors for determining habitat suitability. Based on the researchers' analysis, only three percent of octocorals worldwide were found in waters undersaturated for calcite and only 12 percent of octocorals worldwide were found in waters undersaturated for aragonite. Those octocoral species that occur in waters undersaturated with respect to aragonite likely have adapted to less soluble, calcite based skeletal elements, allowing them to survive in these waters (Yesson et al. 2012). Octocorals located in waters undersaturated with respect to calcite are found in very deep and cold waters, with a very slow life cycle and and slow growth rates. This extended life cycle limits the energy demands for these corals by reducing the food intake needed to fuel the ion transport required to maintain the internal pH for calcification in undersatured waters. A slow growth rate also limits the exposure of the more vulnerable growing skeletal elements to potentially corrosive waters. Rising saturation horizons, and increased seawater temperature may still impact the cold water corals at or below the current saturation horizon. This is because the increased energy demands that a lower saturation state or increased temperature would cause may not be supported by the nutrient-limited physiological processes of corals that have survived for centuries in a static environment (McCulloch et al. 2012). Based on current global distribution of octocorals, where few occur in areas undersaturated with respect to aragonite or calcite, many areas of Alaska now suitable for coral growth will become unsuitable for coral growth over the next 50 years with the shoaling of calcium carbonate saturation horizons, as described in more detail below.

### *d. Ocean acidification will result in decreased calcification rates necessary for growth and repair of the petitioned coral species*

Unless $CO_2$ emissions are abated, ocean acidification will impair the growth of high-latitude corals and will likely begin to result in dissolution of coral structures as seawater becomes understaturated with respect to aragonite and calcite. Ocean acidification poses a profound threat to the petitioned coral species by reducing the availability of carbonate ions (specifically aragonite, HMC and calcite) essential for building calcium carbonate skeletons, thereby impairing coral growth and repair (Guinotte et al. 2006, Hofmann et al. 2010). While the degree to which the calcification processes of petitioned species will be affected by ocean acidification may differ depending on their skeletal mineralogy, geographic and depth distribution, and biology; these corals will be adversely affected by acidification, and accompanying processes that limit food availability while increasing physiological demands (McCulloch et al. 2012).

The rate of calcification in cold water corals is directly related to the seawater carbonate saturation state (Turley et al. 2007, McCulloch et al. 2012). Studies have found that calcification rates of cold water corals decrease with undersaturation of calcium carbonate, with an associated decline in skeletal integrity (Turley et al. 2007, Maier et al. 2011). Impacts to coral calcification have been observed for most coral species studied to date at any degree of undersaturation (i.e., at saturation states less than 1) (Gattuso et al. 1999, Langdon et al. 2000, Marubini et al. 2003, Orr et al. 2005, Turley et al. 2007, Guinotte and Fabry 2008, Maier et al. 2009, Kroeker et al. 2010). Rather than a simple linear decrease in calcification rates, there may be a specific “tipping point” of calcium carbonate saturation at which point corals can no longer sustain a “normal” skeletal structure, composition and growth rate (Holcomb et al. 2010, Ries et al. 2010, Thresher et al. 2011). Food availability play a critical role in determining the degree of impact of undersaturation on cold water corals, as calcification is energetically expensive, consuming up to 30 percent of a coral’s resources (Thresher et al. 2011, McCulloch et al. 2012). Thus, a reduction in nutrient availability or increased energy demands such as that which may occur due anthropogenic climate change and ocean acidification could reduce the capacity of the petitioned corals to calcify in undersaturated conditions.

Reduced rates of calcification in the petitioned cold water corals may inhibit growth, resulting in weaker structures, making corals more susceptible to predation, breakage and erosion, and unable to compete with other calcifying organisms (Langdon 2005). As a result, the petitioned coral species may experience difficulty with growth, reproduction, recruitment and would be less likely to colonize new areas or re-colonize an area, and decreased pH in seawater may actively erode or destroy coral colonies. The critically important hold-fasts of cold water corals, which are in direct contact with seawater and not protected by tissue, may be the first to suffer dissolution due to ocean acidification. The dissolution of this critical skeletal element, that functions both to hold a coral colony upright and to fasten it to the seafloor, may be more pressing and important that reductions in calcification rates (McCulloch et al. 2012). A loss of a holdfast would result in the death of the coral colony.

Many of the petitioned species contain multiple forms of calcium carbonate (e.g., calcite and/or HMC and/or aragonite and/or amorphous hydroxylapatite[1]), although the details on skeletal composition for the majority of the petitioned corals is unknown. Impacts from ocean acidification on each species' biological processes and survival are likely to depend on the significance of the variants of $CaCO_3$ used by corals for mineralization, and on food availability (Turley et al. 2007). Petitioned coral species that use HMC and/or aragonite (e.g., some gorgonians and some hydrocorals) will experience reduced calcification rates and reduced skeletal integrity of these elements on a faster timescale than those that use calcite (Andersson et al. 2008). This is because aragonite is about 50 percent more soluble than calcite in seawater under conditions with increased dissolved $CO_2$. Although calcite is less soluble than aragonite, making it less susceptible to ocean acidification, the incorporation of magnesium into either calcite or aragonite increases their solubility (Andersson et al. 2008). Thus, HMC is still more soluble than aragonite, with solubility of this mineral increasing with an increase in the percentage of magnesium versus calcium in the chemical structure (Andersson et al. 2008). Despite being generally less soluble, calcitic corals with a low percentage of magnesium will not be immune from saturation changes because the depth of the calcite saturation horizon is also becoming progressively shallower over time (Guinotte et al. 2006), and areas of undersaturation for calcite have already been observed in Alaska (Mathis et al. 2011a, b). Surface waters of the North Pacific and Bering Sea are expected to become undersaturated with respect to aragonite within the next few decades (Orr et al. 2005), while seawater will be undersaturated with respect to many Mg-calcite (HMC) phases even sooner (Andersson et al. 2008). Thus, as seawater progressively becomes more acidic and undersaturated with respect to aragonite, the highest latitude at which coldwater corals and other calcifiers are found is likely to move progressively toward lower latitudes (Orr et al. 2005). As the saturation horizons with respect to various carbonate mineral phases become shallower, the maximum depth at which deep water corals are found will shoal (Feely et al. 2004, Guinotte et al. 2006, Turley et al. 2007). As

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[1] Amorphous carbonate hydroxylapatite is a form of calcium carbonate found in gorgonian corals. There is little information available on how corals containing amorphous hydroxylapatite might be impacted by changes in the saturation state and pH of seawater, but the timeline and spatial scale of impacts are likely similar to those for aragonite and HMC-utilizing corals, gorgonians specifically.

ocean acidification will occur in conjunction with ocean warming, cold water corals may become squeezed between calcium carbonate saturation horizons and warm seawater, with no suitable habitat in between the two un-survivable conditions, and not enough available energy resources to compensate for the increased physiological requirements that would allow them to possibly adapt to an undersaturated, acidic ocean environment.

A coral species' geographic and bathymetric range will also affect the degree to which the calcification processes of petitioned corals will be reduced by ocean acidification and undersaturation of calcium carbonate. Species in the Aleutians may be highly vulnerable, due to the already high, and the upward migration of saturation horizons for calcite, HMC and aragonite. Species that occur at great depth, such as *Narella* spp., may also be especially vulnerable to ocean acidification as saturation horizons are likely to rise above these corals' depth ranges in the near future. Additional environmental factors associated with great depth, including lower temperatures, lower pH, and increased pressure, are natural factors that promote the dissolution of $CaCO_3$ for corals at depth. Petitioned corals along the continental and Bering Sea shelf (of which there are many) may also be exposed to reduced aragonite and calcite saturation states in the waters they inhabit more quickly than corals in other areas due to changes in circulation and upwelling patterns (Mathis et al. 2011a,b, Sigler et al. 2008).

There is likely little genetic adaptation potential to reduced saturation conditions for the petitioned corals, as most studies have found that the genetic composition of the species, rather than environmental conditions, determine the form of calcium carbonate utilized by a coral (Cairns and Macintyre 1992) and because of the rapidity of the current anthropogenic changes to ocean chemistry, which are unparalleled by any conditions over the last 300 million years (Zachos et al. 2005, Hönisch et al. 2012). Cold water corals likely have very little genetic and morphological variability, even among distant populations of the same species, indicating few selective pressures over the course of their evolution and limited necessity for adaptation to localized conditions (Miller et al. 2011). Thus, there is low genetic variability for corals to fall back on when facing acidification and climate change impacts. There is also a low frequency of successful reproductive events that would facilitate adaptation to changing conditions, with a generation time on the scale of decades to centuries for most species. As a result, cold water corals cannot simply switch to a less soluble form of calcium carbonate (eg. low magnesium calcite) to adjust to changes in the saturation horizon, and would likely gradually lose condition with ocean acidification, or dissolve over time.

Overall, ocean acidification will result in a vast reductions in the amount of suitable habitat available to cold water corals, and will degrade existing habitat, likely resulting in widespread die-offs of the petitioned coral species, starting with species containing more soluble forms of calcium carbonate, and those located at great depth, or in areas of increasing upwelling undersaturation of aragonite and calcite (Linares et al. 2005, Mathis et al. 2011a,b).

### *e. Ocean acidification may impact reproduction, early growth, development, and settlement of the petitioned corals*

Increased anthropogenic atmospheric $CO_2$ and the subsequent increase in dissolved $CO_2$ concentration in seawater results in a number of physiological impacts to marine organisms' reproduction and larval survival (Tripati et al. 2009). The vulnerable early developmental and reproductive stages of the petitioned corals may be especially strongly impacted (Kurihara 2008, Dupont and Thorndyke 2009, Kroeker et al. 2010).

Corals in acidifying waters are likely to be in a nutritionally or energetically stressed state and thus less likely to initiate reproduction, or successfully reproduce, due to negative impacts of ocean acidification on all stages of the reproductive cycle (Maier et al. 2009, McCulloch et al. 2012). Additionally, the physiological costs associated with reproduction are more likely to result in the demise of the organism due to the compounding stressors from ocean acidification and climate change (Wood et al. 2008, Cohen and Holcomb 2009).

As elaborated on in Section I, corals reproduce once they are sexually mature, which is often determined by colony size. Human impacts that slow growth and calcification rates will slow down or stop a coral from reaching sexual maturity. A lack of sexually mature coral colonies will result in decreased recruitment for the population and a poor outlook for long-term species viability.

Studies have found that the rate of successful fertilization in sexually reproducing octocoral species appears to be strongly influenced by proximity of male and female colonies, with "a significant positive correlation between female reproductive success and the density and proximity of nearby males" (Brazeau and Lasker 1992, Coma and Lasker 1997). Given the strong relationships between fertilization success and the spatial distribution of male and female colonies within a population, ocean acidification could affect the ability of a population to reproduce, both by altering the sex ratio of a population and by increasing the distances between healthy male and female colonies (Simpson 2009).

Timing of spawning may be important, especially as waters warm and become undersaturated and more acidic. A change in seasonal conditions, such as earlier water warming or changing productivity cycles may negatively impact spawning Alaska coral species. These impacts may limit successful dispersal of sperm to female colonies and inhibit larval development, as discussed in more detail below.

The brooding strategy utilized by most Alaska corals examined to date is thought to provide less potential for post-disturbance recovery or adaptation to changing conditions because this strategy limits the distance larvae can travel away from the parent colony (Tyler and Stanton 1995, Simpson 2009). This reduces the potential for undisturbed coral areas to provide a source of larval recruits for significantly disturbed areas (Heifetz et al. 2007b). Other factors affecting settlement of larvae in cold water corals include substrate type and water motion such as currents (Simpson 2009). The very short dispersal capabilities for plannulae, both vertically and horizontally, results in isolated populations of cold water corals, with limited connections between discrete populations (Le Goff-Vitry 2004, Miller et al. 2010, Miller et al. 2011). This means that habitat degradation and destruction caused by ocean acidification and related processes could significantly impact reproductive success.

Once a coral plannulae locates a suitable location on which to settle, it undergoes metamorphosis into a feeding polyp. As young corals develop, their initial uptake of $CaCO_3$ often starts by depositing an amorphous calcium carbonate (ACC) crystal skeleton, which is known to be 30 times more soluble than the more stable forms of aragonite and calcite secreted as the larvae matures (Orr et al. 2005). The skeletal growth of young and fast-growing calcifying coral is also more negatively influenced by ocean acidification. One study found that as pH in seawater increased, young polyps showed a 59 percent reduction in calcification, compared to just a 40 percent reduction for older polyps (Maier et al. 2009). Thus, the petitioned corals' larvae and young corals are significantly more susceptible to ocean acidification than adults, and will likely show a higher degree of reduced calcification and growth with reduced pH, making young and larval corals less likely to survive to maturity as the ocean continues to absorb anthropogenic $CO_2$ and as climate change progresses.

Even without ocean acidification and climate change, most coral species have an extremely high observed mortality of new recruits once past the brooding stage, implying that successful settlement may be closely tied to water column and post-settlement survival (Lasker et al. 1998). The life history strategy of the observed coral *Plexaura kuna* is proposed by Coffroth and Lasker (1998) to depend on "large and long-lived genets," which may only achieve successful reproduction very infrequently over the course of the colonies' multi-decadal lifespan (Coffroth and Lasker 1998). As the petitioned corals are very long lived (Andrews et al. 2002, Risk et al. 2002), these species likely possess similar reproductive life history characteristics, with minimal successful reproduction, and small room for the additional decreased reproductive rates associated with anthropogenic $CO_2$ emission impacts on marine ecosystems (Simpson 2009).

Studies of the impacts of ocean acidification on tropical corals are instructive for understanding impacts on cold water corals. Ocean acidification has been shown to affect three sequential life history phases necessary for successful recruitment of tropical corals: (*i*) larval availability (by compromising fertilization), (*ii*) settlement ecology (by reducing settlement success), and (*iii*) postsettlement ecology (by impeding postsettlement growth) (Albright et al. 2010, Albright 2011a, 2011b). Albright et al. (2010) concluded that with increased $CO_2$ concentrations to those projected to occur in this centure (560 atm to 800 atm), the fertilization success of the tropical reef-building coral *Acropora palmata* decreased by 12-13%, settlement success reduced 45-69%, and linear extension was significantly reduced. The compounding effect of these impacts translated to 52-73% reduction in the number of larval settlers on the reef. Albright et al. (2010) predicted that the net impact on recruitment would actually be greater than that given that the depressed post-settlement growth is likely to result in elevated rates of post-settlement mortality. This corroborates other studies showing negative impacts on early-stage tropical corals.

Albright and Langdon (2011) tested the effects of ocean acidification on sexual recruitment of tropical corals. Larval metabolism was depressed by 27% at acidification levels expected by mid-century and 63% at end-of-century acidification levels. Settlement was also reduced 42-45% and 55-60% at the mid and end-of-century levels respectively, relative to controls (Albright and Langdon 2011). Another study of larvae of tropical corals showed that short-term or long term exposure of larvae to ocean acidification decreased their metamorphosis (Nakamura et al. 2011). This means that even when larval survivorship is unchanged, the success of recruiting new corals could be inhibited by ocean acidification (Id.). Additionally, under conditions of acidification planktonic larvae lose their preference for settlement on the optimal crustose coralline algae communities (Doropoulos et al. 2012). These studies, while conducted on tropical corals, raise cause for concern for cold water corals.

In sum, reproduction is critical to maintaining a healthy population, and the long-term impacts of ocean acidification on reproduction, especially on larval settlement and growth, may significantly reduce the petitioned corals' ability to recover or maintain a population in the face of human caused disturbances and anthropogenic $CO_2$ emissions. This would result in a lack of reproductive capacity, genetic bottlenecks, and population collapse (Dupont et al. 2010, Ross et al. 2011).

### *f. Increased seawater temperatures may exacerbate the impacts of ocean acidification on cold water corals*

Globally, water temperatures are rising in the deep sea due to anthropogenic climate change (Barnett et al. 2005, Levitus et al. 2010)). Increasing ocean temperature may reduce calcification rates of the petitioned corals, and has been shown to enhance and augment the process of ocean acidification in a synergistic manner in tropical corals (Reynaud et al. 2003, Hare et al. 2007, Findlay et al. 2008, Anthony et al. 2008, Byrne et al. 2009, Anlauf et al. 2011). It was found that the rate of calcification in the tropical scleractinian coral *Stylophora pisitillata* decreased by 50% under conditions of elevated temperature (28 degrees C) and high $CO_2$ concentrations (760 atm), with no effect found when only $CO_2$ concentration was elevated (Reynaud et al. 2003). Thus, based on studies on tropical corals, global sea temperature rise may augment the impacts from ocean acidification on the petitioned species, further threatening their survival.

Significant ecosystem-wide impacts in the areas where the petitioned species occur would further limit the availability of food necessary for coral's basic life functions. Increased temperature combined with elevated $CO_2$ concentrations has led to substantial increases in algae carbon fixation rates by phytoplankton in the Bering Sea (Hare et al. 2007). These observations suggest that increasing temperature in combination with rising $CO_2$ levels could cause a future community shift in the Bering Sea away from diatoms and towards nanophytoplankton groups. This could direct carbon and energy flow away from the productive food webs that currently produce one of the world's most productive fisheries and result in serious disruption to the productivity of the Bering Sea. Cold water corals would be impacted directly through interruption of their food and carbon sources, and by ecosystem dynamics changes. Alaska corals would suffer from lack of nutrition in combination with increased energetic demands, resulting in wide-spread die off and loss of many cold water coral species.

### *g. Ocean acidification will reduce calcification rates and increase malformation of marine planktonic species that serve as the primary food source for cold water coral*

Changing seawater chemistry will have significant negative impacts on the petitioned corals by limiting the amount of food and nutrients available to the benthic ecosystem where cold water corals are found. While very little is known about the nutrition of Alaska cold-water corals, studies indicate that cold water corals rely on food supplied directly from surface production (Dodds et al. 2009). For Alaska corals, calcifying planktonic organisms likely serve as the critical food source (Kiriakoulakis et al. 2005, Orr et al. 2005) and are also responsible for the majority of calcification occurring in the marine environment (greater than 80 percent). At high latitudes, these planktonic organisms are primarily comprised of pteropods and foraminifera, and are integral components of the marine food web and contribute to both organic carbon and $CaCO_3$ flux (Hofmann et al. 2010). These species typically occur in the upper 300 m of the water column where they may reach very high densities (Orr et al. 2008). Researchers have found that calcifying plankton have a reduced ability to form protective $CaCO_3$ shells with changes in ocean chemistry associated with anthropogenic greenhouse gas emissions (Gattuso et al. 1998, Langdon et al. 2000, Riebesell et al. 2000, Feely et al. 2004, Orr et al. 2005, Guinotte et al. 2006).

Effects of ocean acidification on plankton are already detectable in marine environments. Arctic pteropods (*Limacina helicina*) exposed to 765 ppm $CO_2$ exhibited a 28 percent decline in calcification rates as compared to controls (385 ppm $CO_2$) during a lab experiment (Comeau et al. 2009). Researchers have found similarly reduced growth rates and decreased calcification in other species of plankton, with declines of 25 percent to 66 percent in calcification rates occurring with increasing ocean acidification (Riebesell et al. 2000, Delille et al. 2005, Engel et al. 2005).

In the North Pacific and Bering Sea where the petitioned corals are found, the major planktonic groups that use calcium carbonate in their shells are calcite-forming coccolithopores and foraminifera, and aragonite-forming pteropods (Young et al. 2012, Orr et al. 2008, Doney et al. 2009, Comeau et al. 2011). The aragonite shells of pteropods are particularly sensitive to ocean acidification (Comeau et al. 2009) since aragonite undersaturation in the Arctic is predicted to become widespread in the next few decades, with 10 percent of Arctic waters undersaturated with respect to aragonite for one month per year starting as early as 2016 (IPCC 2007, Comeau 2011). As this process occurs, pteropods in parts of the Arctic may be unable to precipitate aragonite and could suffer drastic declines as early as the second half of this century. Studies of Antarctic species support these predictions. The shells of actively swimming subarctic pteropods started to dissolve within 48 hours when they were exposed to aragonite undersaturation levels projected for the Southern Ocean surface waters by 2100 (Orr et al. 2005, Fabry et al. 2009).

Calcite-forming foraminifera and coccolithophorids may fare better than pteropods in the short-term, but widespread calcite undersaturation at high latitudes is expected to lag behind aragonite by only 50 years (Orr et al. 2005, Fabry et al. 2009, Feely et al. 2009). Even under current calcite saturation conditions, these organisms are not immune to the negative effects of ocean acidification, as experimental evidence found that calcification rates decreased and malformation increased for coccilophores in waters with dissolved $CO_2$ levels at or below present concentrations occurring in northern latitude waters (Langer et al. 2006). In laboratory experiments with foraminifera, shell mass decreased as ocean acidification increased, declining by four percent to 18 percent compared to pre-industrial seawater values (Spero et al. 1997, Bijma et al. 1999). Shell weights of Southern Ocean foraminifera are already 30-35% lighter than those from the sediments, which is believed to be induced by acidification (Moy et al. 2009).

Changing seawater chemistry will also reduce the amount of calcium carbonate derived from calcifying plankton that sinks to depth, and which is important in regulating marine carbon cycling and ocean-air $CO_2$ exchange and provides an important source of aragonite or calcite in the deep sea (Holligan and Robertson 1996). Data from sediment traps indicate that empty pteropod shells exhibit pitting and partial dissolution as soon as they fall below the aragonite saturation horizon (Orr et al. 2008). Poorly formed or non-formed planktonic shells will not sink as readily into deeper waters, due to lighter weight and reduced density. This process will decrease the amount of dissolved calcium carbonate available for cold water coral calcification processes, resulting in growth, repair and survival consequences similar to those described under ocean acidification. (Comeau et al. 2010).

As ocean acidification and $CaCO_3$ undersaturation continue to progress in northern latitudes, pteropods will likely be the first calcifying planktonic species to experience widespread mortality, followed by foraminifera and coccolithophorids (Holligan and Roberson 1996, Moy et al. 2009, Comeau et al. 2010). It is unlikely that these critically important species at the base of the marine food web will continue to reach current population levels under conditions that will occur over much of the high-latitude surface ocean during the twenty-first century.

As demonstrated above, ocean acidification will result in changes in productivity for phytoplankton and zooplankton that occur primarily in surface waters. The survival of cold water coral is tightly linked to surface productivity (Heifetz 2002). The availability of planktonic species for consumption by the petitioned coral species as nutrition is likely critical to respiration, reproduction, calcification, and organic matter release of corals (Naumann et al. 2011). Changes in availability of food sources due to ocean acidification processes would slow down growth, and limit reproductive ability. These processes will threaten the continued existence of the petitioned coral species, and will severely limit amount of suitable habitat for cold water corals. A loss or decline in this critical nutritional source may also exacerbate the direct negative effects of climate change and ocean acidification on key physiological processes in the petitioned species.

### *h. The potential for adaptation to ocean acidification for cold water corals*

Scientific evidence indicates that cold water corals are unlikely to adapt to the rapid rate of ocean acidification and climate change that is currently occurring.

Several studies have addressed the ability of cold water corals to cope with increasing ocean acidity or sub-saturated waters. Form and Reibesell (2012) conducted a six-month study on the reef-building, aragonite-utilizing cold water coral *Lophelia pertusa* under high $CO_2$ conditions and a pH reduction of 0.1 units. The study found that *L. pertusa* experienced short-term declines in growth with reduction in pH. However, the coral was apparently able to adjust, with observed increased growth over the full six-month study period (Form and Riebesell 2012). The authors stated that the results were not unexpected because cold water corals are seasonally exposed to waters undersaturated with regard to aragonite, and thus have developed a tolerance for temporary exposure to sub-saturated waters. Thresher et al. (2011) found that, based on depth distribution of cold water corals on seamounts in Tasmania "the physiology of the coral appears able to cope with whatever costs or stresses are associated with skeletal accretion in a very low-carbonate environment." The authors also stated that "we found little evidence that carbonate under-saturation to at least -30% affected the distribution, skeletal composition or growth rates of corals." Finally, McCulloch (2012) found that cold water corals showed fairly strong "up-regulation of pH and consequent elevation of the internal carbonate saturation state at the site of calcification" which facilitates calcification at or below the aragonite saturation horizon. However the researchers cautioned that this up-regulation has significant associated energetic, and therefore growth-rate cost, of about 10% per 0.1 pH unit decrease. Furthermore, they stated that the shoaling of the aragonite saturation horizon will increase dissolution of the exposed skeleton (eg. holdfast) which will "ultimately limit [cold water corals] survival in the deep oceans" (McCulloch et al. 2012).

Based on the reasons discussed below, none of these studies indicate that Alaska cold water corals may be able to survive or adapt to acidified conditions in oceans with long-term elevated $CO_2$ concentrations.

First, nutritional status plays a major role in cold water coral's ability to adapt or adjust to corrosive waters (McColluch et al. 2012). Research shows that calcification is energetically costly, consuming up to 30 percent of a coral's available resources (Thresher et al. 2011). The corals in the Form and Reibesell study were consistently well-fed, while cold water corals under natural conditions experience strong fluctuations in their nutritional status because of seasonal changes in ocean circulation patterns and productivity. Warming waters, changes in marine productivity, and fluxes in surface-to-bottom ocean currents may further limit food supply for cold water corals as climate change progresses over the next several decades (Orr et al. 2005). For Alaska cold water corals, winter months are periods of reduced marine productivity, and ocean circulation patterns also vary widely seasonally (Mathis et al. 2011a), and most of the petitioned species probably experience at least several months without a food supply. These periods of no or limited nutrition may increase in length and periodicity with climate change and ocean acidification. Nutritionally stressed corals may be unable to respond to increased metabolic demands and the other stressors resulting from ocean acidification. Thus, food availability will be critical to maintaining physiological processes and calcification of cold water corals as the oceans warm and acidify (Dodds et al. 2007, Thresher et al. 2011).

Second, studies that have evaluated the ability of organisms to adapt to ocean acidification have found that an organism's biological or physiological adaptations to cope with ocean acidification, such as increased metabolism or increased calcification rates, come with trade-offs and long-term costs (Wood et al. 2008, Gooding et al. 2009, Ries et al. 2010). For example, calcification was found to increase under high $CO_2$ concentrations for the brittle star *Amphiura filiformis*, but this came at a substantial cost of muscle wasting, which would probably not be sustainable long-term (Wood et al. 2008). This type of trade off is likely for many marine calcifiers, including the petitioned corals, where increased metabolism or other compensatory mechanisms for the energetic and metabolic costs caused by ocean acidification results in declines in another important system, and demise of the organism in the long term. Thus, observations of increased or steady calcification rates for corals exposed to acidified waters during a trial study period likely do not reflect to overall impacts of ocean acidification on a coral species.

Third, the Form and Riebesell study measured only the actively growing branches of *L. pertusa*, which may be able to withstand increased $CO_2$ concentrations. The older parts of coral that are not covered in active polyps may be susceptible to undersaturated seawater with respect to aragonite or calcite, and may actively dissolve (Form and Riebesell 2012). Also, early life stages of coral have been found to be especially susceptible to ocean acidification (Albright et al. 2008, 2010), which would impact long-term survival of cold water corals. These early life stages are unlikely to be able to adapt to an acidified ocean. Thus, early life stages and the entire coral colony must be considered when determining ocean acidification's impacts on cold water coral growth and calcification.

Fourth, the susceptibility of cold water corals to increased ocean acidification is supported by historical records that show massive extinction of calcifying marine biota under periods of ocean acidification in the past (Zachos et al. 2005). Furthermore, the extremely rapid rate of ocean acidification may limit the ability of slow-growing, long-lived cold water corals to adapt, especially when the impacts from ocean acidification are compounded by other physical and biological stressors. One recent study argues that the predicted ocean acidification that will occur over the next 100 years will trigger a sixth mass extinction of tropical corals within the next couple of centuries (Veron 2008).

Fifth, while Thresher et al. (2011) found little connection between cold water coral growth and carbonate saturation state for corals on Tasmanian seamounts, the authors did find "evidence of dissolution of HMC gorgonian skeletons at depths below the likely HMC saturation horizon" and that "it is likely that ocean acidification will increase the dissolution rate of this skeletal material, and hence result in some shoaling and loss of HMC bioherms." Thresher et al. (2011) also state that increased dissolution of exposed coral skeleton due to dissolution by ocean acidification could shift the predator-prey balance in the deep sea, making cold water corals more susceptible to predation by predators, including sea stars. These are both important considerations for Alaska cold water corals, as most of the Alaska corals contain HMC elements, and occur near or below the saturation horizon. These locations make them especially vulnerable to dissolution of skeletal elements and possible shifts in predator-prey dynamics (Thresher et al. 2011, McCulloch et al. 2012).

Sixth, Thresher et al. (2011) observed corals that had been living in the same, unchanging environment for hundreds of years. These corals had not adapted to a changing environment, but rather had existed in the same static state for centuries. These observations tell us nothing about how Alaska corals may react to changing environmental conditions. Alaska corals have existed under very specific habitat conditions, including carbonate saturation states and nutrient availability, for thousands of years. Alaska corals are unlikely to be able to adapt to the changes in ocean chemistry and ocean ecology that will occur with climate change. Certainly, Alaska corals will not be able to reproduce or grow at a fast enough rate to adjust their depth distribution or switch to a more suitable habitat due to their slow reproductive rates, specific habitat requirement, and little genetic variability. Therefore, observation of existing cold water corals indicates little, if nothing, as to how Alaska corals would survive major ecosystem changes. As discussed in great detail in other parts of this petition, overwhelming evidence from the best available science indicates that Alaska cold water corals will not wide-scale shifts in ecosystem dynamics, ocean chemistry, and ocean temperature, that are predicted to occur under a business-as-usual emissions scenario.

Finally, long term impacts of ocean acidification can be predicted based on observations from areas of the ocean with naturally high $CO_2$ concentrations. These areas contain no stony corals, and a low abundance of calcareous organisms compared to nearby areas with normal $CO_2$ concentrations (Hall-Spencer et al. 2009). The vast majority of research to date has observed a consistent reduction in coral calcification in response to ocean acidification (Gattuso 1998, Marubini et al. 2003, Langdon 2005, Kleypas et al. 2006, Krief et al. 2010). These studies all demonstrate that ocean acidification will have negative or deadly consequences for cold water corals. While it is possible that some cold water corals may be able to adapt to ocean acidification in the short term, scientific evidence demonstrates that these adaptations are likely to not continue in the face of permanent changes in ocean chemistry. Long-term observations indicate that most corals do not and have not survived the widespread changes to ocean chemistry, temperature, and ecosystem processes that will result from increased $CO_2$ concentrations and climate change.

### *i. Conclusion*

Ocean acidification is a primary threat to the petitioned coral species and leads to reduced rates of calcification and more energetically costly calcification in cold water corals. This will inhibit the growth and repair of the corals' calcifying elements, resulting in weaker structures, and making corals more susceptible to predation or breakage (Langdon 2005).

As a result, the petitioned coral species would be less likely to colonize or recolonize an area. Decreased seawater pH and undersaturation of aragonite and calcite may also actively erode or destroy existing areas of coral growth. Ocean acidification will also impact the ability of cold water corals to reproduce successfully, or obtain adequate nutrition and inorganic carbon for growth, repair, and other biological processes. Negative impacts to the petitioned coral species from ocean acidification are expected to be significant. These impacts may range from decreased diversity, decreased growth and reproduction, lessened ability to compete for space and other important resources, and reduced metabolism, to complete death of cold water corals in an area, similar to "bleaching" die-off events currently occurring on temperate or tropical coral reefs (e.g., Kleypas 1999, Kleypas et al. 2006b, Kuffner et al. 2007, Andersson et al. 2008).

## ii. CLIMATE CHANGE IMPACTS ON PETITIONED CORALS: OCEAN WARMING, CHANGES IN CURRENTS, CHANGES IN SALINITY

### a. Effects of increasing ocean temperature on the petitioned corals

The earth has warmed more from 1976 to present than it has at any time during the last 1,000 years (Glover and Smith 2003, IPCC 2007). Global surface temperature has increased by 0.76 degrees C between the years 1850-1899 and 2001-2005 (IPCC 2007). Warming has also occurred in all major ocean basins at nearly every latitude during the last 50 years from the surface to the deep ocean to at least 2000 m (Levitus et al. 2012). Numerous studies have found that temperature increases can be a significant driver behind deep-sea biodiversity and ecosystem patterns (e.g., Moriaki et al. 2012).

Climate change is currently occurring throughout Alaska. Evidence includes warming temperatures, changing precipitation patterns, altered stream flows, loss of sea ice and coastal erosion, among others (Meehl et al. 2007). The average annual temperatures in Alaska have increased by 1.9 degrees C over the past 50 years, which is almost three times the global average over the same time period. In winter, the temperatures have increased by 3.5 degrees C over the same time period (USGCRP 2009). By the end of this century, the Arctic is expected to warm by an additional three degrees C to five degrees C over land and up to seven degrees C over the oceans under a mid-level (AIB) emissions scenario (Meehl et al. 2007). In the Bering Sea, average surface air temperatures are predicted to increase by approximately 1 degree C to 1.5 degrees C in the next 10 years to 20 years and by three degrees C to five degrees C by the end of the century (IPCC 2007).

Warming will also occur in the oceans at high latitudes in response to decreased salinity, changing current patterns, and melting sea ice. Models predict large-scale warming in the North Pacific, averaging 2.5 degrees C, accompanied by a surface air temperature rise of two degrees C (Menviel et al. 2012). These increases are likely to extend to the deep sea, due to surface mixing and large scale changes in ocean circulation patterns (Masuda et al. 2010).

Cold water corals, especially those occurring at great depth, are extremely susceptible to changes in temperature, as these corals only occur in areas where temperatures range from four degrees C to 12 degrees C (Maier et al. 2009). Elevated temperature is one of the major threats to cold water corals, and has also been shown to have detrimental effects on tropical corals and coral communities (Gattuso et al. 1999, Langdon et al. 2000, Maier et al. 2009), with similar negative effects in other benthic calcifiers (Hall-Spencer et al. 2008, Moriaki et al. 2012). Even a minor increase in water temperature, whether due to increased surface mixing, changes in seasonal regimes, or simple warming of ocean waters, may create an unsuitable habitat for these corals, making them vulnerable to widespread die-offs (Linares et al. 2005, Sigler et al. 2008, Coma et al. 2009, Maier et al. 2009, Thresher 2009).

Studies on tropical corals have found that coral calcification rates typically increase with temperature, reaching a plateau at or below the normal peak summer temperature, and then declining rapidly beyond that plateau (Jokiel and Guinther 1978, Marshall and Clode 2004). The optimum temperature for calcification varies according to the ambient temperature of the coral's environment, probably due to energetic constraints associated with high metabolic activity during periods of low food availability (Coma et al. 2009). Thus, while the petitioned coral species' calcification rates may initially increase with rising ocean temperature, that increase is unlikely to continue throughout a two degrees C to three degrees C rise, and the resulting physiological stress may result in mass mortality for the affected coral species (Coma et al. 2009).

Climate change will result in both ocean warming and decreased saturation levels for the forms of calcium carbonate used by cold water corals for growth and repair (Andersson et al. 2008, Steinacher et al. 2009) Studies on the combined impacts on coral calcification of undersaturation with regards to aragonite and increased temperature  found that calcification responses to temperature under low aragonite saturation are not additive (Reynaud et al. 2003, Hare et al. 2007, Findlay et al. 2008, Anthony et al. 2008, Byrne et al. 2009, Anlauf et al. 2011). This suggests that any increased metabolic activity from warmer ocean temperatures would not offset the negative impacts of associated ocean undersaturation with regards to aragonite or calcite, or other changes to the coral food sources and environment that are predicted to occur due to climate change, including changes in ocean current patterns and stratification (Coma et al. 2009).

Based on tropical corals, there are a wide range of negative effects of elevated temperature on coral metabolism, reproduction (Szmant and Gassman 1990), resistance to disease (Harvell et al. 2002), and larval settlement (Jokiel and Guinther 1978). All of these factors also affect calcification rates. Although this research is on tropical corals rather than cold water corals, similar impacts are expected for cold water corals, possibly to a greater extent because cold water corals do not naturally experience the same temperature fluctuations that shallow reef tropical corals do and are instead adapted to a very static environment (Guinotte et al. 2006).

Cold water corals are more nutrient limited than tropical corals (McCulloch et al. 2012). Food supply plays a crucial role in the calcification of cold water corals, which are significantly more restricted by energy resources than zooanthellate (tropical) corals. For example, at identical seawater temperatures, cold water corals in Chile with ample food supply had markedly higher growth rates than those in the Mediterranean where food supply was limited (McCulloch et al. 2012). Therefore, ultimate control of cold water coral calcification rates appears to depend on the physiological limitations of cold water corals, in particular their limited ability to uptake enough energy for ion transport required to maintain their internal pH and effectively calcify under acidic or higher temperature conditions (McCulloch et al. 2012). As pH decreases with ocean acidification, and seawater temperatures rise due to climate change, energy requirements will increase, with a 10% increase in energy calculated for each 0.1 unit drop in pH. This may be a significant impediment to energy-limited cold water corals, suppressing physiological processes including calcification, growth, and reproduction and ultimately leading to their demise.

Globally, sea temperatures are rising in the deep ocean, due to increasing amounts of $CO_2$ in the atmosphere (Barnett et al. 2005). Because temperatures in the marine waters at high latitudes are expected to increase rapidly, even at abyssal depth, compared to tropical or temperate waters (Steinacher et al. 2009, Masuda et al. 2010), cold water corals in Alaska are likely to experience a wide array of negative effects due to climate change including a decrease in diversity and a shift in important ecosystem processes (Thresher 2009).

Predicting changes from climate influences on the deep sea is difficult, due to uncertainties, but evidence from the fossil record shows major extinctions of deep-sea benthic taxa 65 million to 55 million years ago, which is associated with a rise in bottom temperatures and an associated decrease in diversity and ecological processes (Rogers 2000, Glover and Smith 2003, Masuda et al. 2010). This fossil evidence indicates that deep sea organisms such as cold water corals are especially susceptible to increasing ocean temperatures.

## b. Ocean currents, thermohaline circulation and changes in salinity are critical to the survival of cold water corals

Cold water corals in Alaska will be exposed to a range of additional stressors associated with global climate change, including increased freshwater input, associated changes in salinity, and changing current patterns (Menviel et al. 2012). A loss of sea ice and greater open water will cause shifts in productivity, and in the current exchange between upper and lower marine depths. These changes will impact cold water corals both directly, through degradation of habitat, and indirectly, through changes in availability of nutritional sources and inorganic carbon required for calcification.

The North Pacific and Arctic are becoming warmer and fresher due to global climate change, at a faster rate than many other marine ecosystems (Feely et al. 2008, Masuda et al. 2010). Northern latitude waters are becoming fresher due to inputs from increasing glacier and sea-ice melt and terrestrial run-off, including increasing river outflows, and these freshwater inputs are expected to increase as temperatures continue to rise (Clark et al. 2010, Richter-Menge et al. 2011). This influx of freshwater may slow down the circulation of water, reduce upwelling, and alter current patterns (Curry et al. 2003, Menviel et al. 2011).

Currents play a major role in Alaska waters, carrying nutrients and plankton that are the basis for marine productivity. Changes in currents and circulation patterns will have significant impacts on the Alaska marine ecosystem as a whole and on the petitioned coral species. Specific predictions are difficult to make, but it is likely that there will be major changes in the direction, speed, and width of Alaska's ocean currents (Clark et al. 2010, Richter-Menge et al. 2011). In the deep ocean, where many of the petitioned coral species are found, the driving force behind ocean circulation is water density, which is driven by temperature (Menviel et al. 2011). Changes in deep-water circulation are likely since climate change is altering both the temperature and density of ocean water. Overall, the cycling of surface and deep waters, and the relative abundance of organic particles falling from the surface and brought to cold water corals by currents, are likely to alter with global climate change.

The petitioned cold water corals are sessile organisms that depend on sinking or current-transported food material and organic carbon for skeletal components and are thus tightly linked to the productivity of the upper ocean waters (Glover and Smith 2003). Any change in the direction of speed of the currents could impact their survival and distribution by altering the availability of food and hindering reproduction and dispersal (Guinotte et al. 2006). In addition, changes in currents and circulation are likely to affect the coral's plankton prey species. It is difficult to predict exactly how and when each petitioned coral species may be affected by ocean warming associated with climate change, but it is known that these species have very limited ability to respond to any variation in environment. Long-term changes to freshwater input, thermohaline circulation and salinity will negatively impact cold water corals, both directly, by impacting reproduction or rendering habitat unsuitable, or indirectly, by impacting their primary food source of zooplankton (Glover and Smith 2006). These changes will adversely impact these species' growth, survival, and distribution.

## C. OTHER NATURAL OR MANMADE FACTORS AFFECTING THE PETITIONED CORALS' CONTINUED EXISTENCE

### 1. FISHING ACTIVITIES INCLUDING TRAWLING, DREDGING, LONG-LINING, AND POT-FISHING REMOVE AND DAMAGE THE PETITIONED CORAL SPECIES, DESTROY THEIR HABITAT AND LIMIT ANY POTENTIAL FOR RECOVERY

A major threat to the petitioned coral species is direct removal and damage, habitat degradation, and ecosystem changes resulting from fisheries activities, particularly trawling. Physical disturbances include breaking, crushing, and uprooting of the petitioned corals by trawls and fishing gear. Fishing activities also may degrade habitat to unsurvivable or suboptimal conditions for the petitioned species by fishing gear contact with the seafloor resulting in increased sedimentation (Pilskaln et al. 1998), fragmentation of habitat, mud or sediment covering up exposed rock substrate used by corals for attachment, and flattening of rough bathymetry substrate that often comprises preferred coral habitat (White et al. 2005, Miller et al. 2009). Trawling and other fishing activities remove vast swathes of coral growth and fragment coral habitat, which hinders the exchange of genetic material between remaining intact coral patches, because there are few recruits in undisturbed areas. This may result in genetic bottlenecks, due to a lack of exchange of genetic material between populations. This is especially an issue for cold water corals, which studies show have naturally low levels of genetic diversity within species (Miller et al. 2009, Miller et al. 2011). Low genetic diversity and fewer available recruits limits the ability of cold water species to adapt to the changing conditions caused by both fishing impacts and climate change.

The widespread damage and destruction of cold water corals in Alaska waters from trawling has been aptly compared to the clear cutting of old-growth redwoods in the forests of the Pacific Northwest (Watling and Norse 1998). Both old-growth logging and trawling destroy wide swaths of ancient, slow-growing and slowly reproducing species, which are unlikely to recover or re-colonize damaged areas on a human time scale, if at all (Watling and Norse 1998). Although huge in scale and ecosystem effects, the trawling-caused destruction of coral communities and individual corals is hidden from the public eye and little known or regulated (Watling and Norse 1998). This is because impacts are not readily visible, unlike the easily observed and highly publicized effects of redwood logging, which led, in part, to the creation of the first U.S. National Parks (Watling and Norse 1998). Recently, the scope of devastation and impacts to marine ecosystems has moved to the forefront of marine issues of concern, and the National Research Council (2002), Pew Oceans Commission (2003) and U.S. Commission on Ocean Policy (2004) all found that bottom fishing, especially trawling, is a major threat to seafloor communities and cold water coral habitats.

In the United States, bottom trawling is the leading cause of reduced habitat complexity along the North American continental shelf. Trawl gear can crush, displace, expose, and bury benthic invertebrates and other forms of marine life, and habitats that are trawled are likely to have reduced species diversity. Post-trawling, species composition is often reduced to “large numbers of a few opportunistic species” (Watling and Norse 1998). The extent of disruption to the complexity of the benthic habitat is dependent upon the length of time the area has to recover between trawl passes, the extent of damage from trawling gear, and whether the original habitat contained primarily long-lived, slow-growing species (e.g., cold water corals), or fast-growing, quick-to-recover species with shorter life histories (e.g., small invertebrates) (Watling and Norse 1998). A caveat to studies of damage from trawling is that many studies are conducted after trawling has already occurred. This means a baseline of species diversity, density, and habitat conditions pre-trawling is often not available.

Many studies have documented extensive damage and destruction of cold water corals from trawling activities. For example, in the North Atlantic, Hall-Spencer et al (2002) documented widespread trawling damage to cold water coral reefs (*Lophelia pertusa*) at 840 m to 1,300 m depths along the West Ireland continental shelf break and at 200 m depth off Norway. The trawled corals were at least 4,450 years old. Thirty percent to 50 percent of the cold water coral *Lophelia* reefs in Norway have been damaged by bottom trawling, and fishermen stated that catches are significantly lower in areas where reefs are damaged (Fosså et al. 2002). The collapse of the cod fisheries in the northeast Atlantic has been linked to widespread trawling in the region (Norse et al. 2012).

In Alaska, damage from trawling is evident in photo and video documentation from areas around the Aleutians, Gulf of Alaska and Bering Sea. As shown in Figure 8, damage can include complete destruction, resulting in a wide area littered with coral skeletons (Figure 8B), upturned corals, and broken corals. The coral in Figure 8A is unlikely to survive, although it remains rooted to the rock substrate, as it can no longer obtain the nutrients it requires due to limited access to waters above the seafloor where nutrient-rich currents are more prevalent (Heifetz 2009).

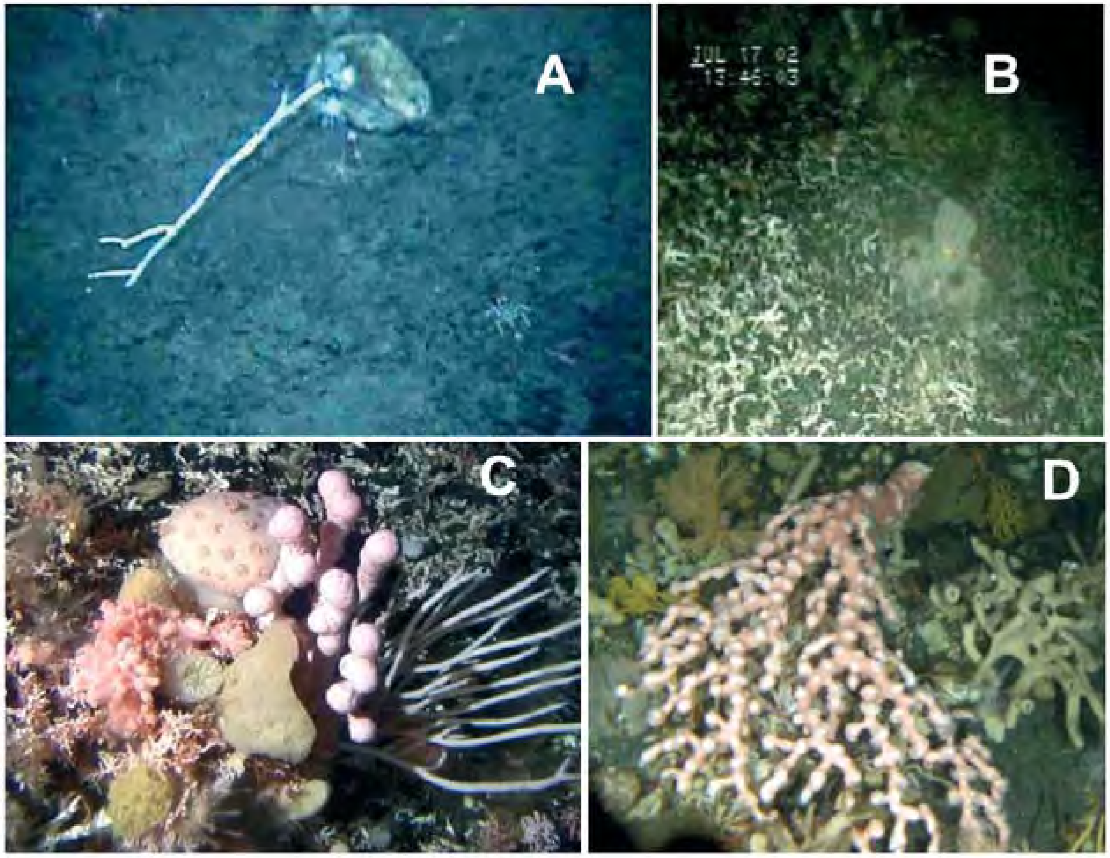
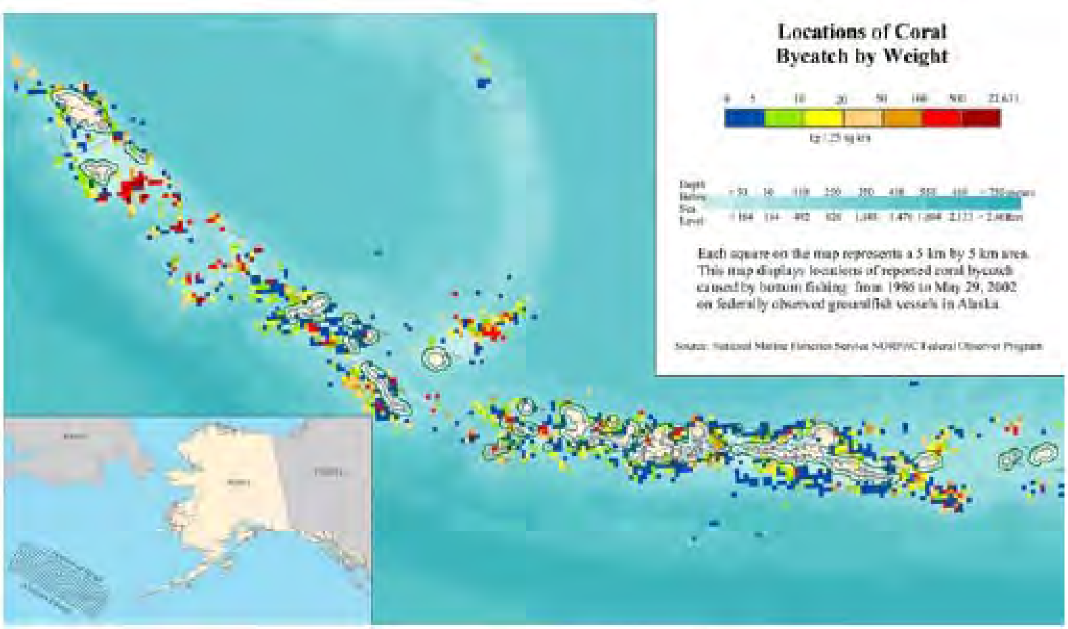


**Figure 8**: Examples of damage to coral in the central Aleutian Islands: A) bamboo coral attached but overturned and lying in contact with the seafloor; B) hydrocoral skeletons; C) a small bubblegum coral *Paragorgia arborea*, woft coral *Anthomastus* sp., stolon coral *Clavularia* sp., hydrocorals, demosponges, and a sea anemone residing at the end of a path littered with hydrocoral skeletons; D) *P. arborea* detached from the seafloor. Photos from (Heifetz et al. 2009).

The damage from trawling is widespread and often overlaps areas of cold water coral abundance due to the strong associations between cold water corals and commercial fish and invertebrate species (Heifetz 2002). NMFS estimates that 82 metric tons of coral is removed from the seafloor of the U.S. EEZ off Alaska each year by commercial groundfish fisheries (NMFS 2004, Stone 2006). This amounted to 2,176,648 kg of coral and sponge bycatch in the Aleutian Islands alone from 1990 to 2002, with 90 percent of this removed by bottom trawling (Freiwald and Roberts 2005). Coral bycatch is highest when trawling moves into a previously unfished area, and then rapidly declines. Reduced coral bycatch in an area is therefore not necessarily a good sign, and cannot be used to demonstrate that this area did not contain corals, or that a type of fishing is not damaging to corals (Norse et al. 2012). The vast majority (91 percent) of coral bycatch occurred in the Aleutian Islands and the Bering Sea (NMFS 2005a). These areas harbor the highest known diversity and abundance of corals in Alaska, and contain the majority of the petitioned coral species (Hiefetz 2002, Stone 2006). They are also subject to widespread fisheries.

Figure 9 illustrates coral bycatch by weight taken from the Aleutian Islands. Because this figure is based on coral brought to the surface as bycatch only, meaning any recorded corals are removed and no longer living, this figure gives an estimate of historic coral densities, but not necessarily current coral density. Today's coral densities, especially in areas with the highest bycatch weights, are significantly lower, and it is likely that habitat functionality, complexity and diversity has been drastically reduced due to fishing activities (Kaiser et al. 2000).


Locations of Coral Bycatch by Weight

Each square on the map represents a 5 km by 5 km area. This map displays locations of reported coral bycatch caused by bottom fishing from 1986 to May 29, 2002 on federally observed groundfish vessels in Alaska.

Source: National Marine Fisheries Service NORPAC Federal Observer Program

**Figure 9:** Coral bycatch in the Aleutians by weight aggregated from 1986 to 2002. Data provided by NMFS NORPAC Federal Observer Program. Map produced by Conservation GIS Support Center, Anchorage, AK. Source: (Shester and Ayers 2005).

Commercial fisheries currently operating in the Aleutians use four types of bottom-contact gear, including bottom-contact trawls, pots, and longlines with hooks or longlines with crab pots. These fisheries occur between depths of 27 m and 929 m, with the most intense trawling operations in the Aleutian Islands occurring at depths from 100 m to 800 m, with peaks around 170 m, 400 m and 650 m (Heifetz et al. 2009). Most bottom-contact trawl gear is used at depths from 27 m to 680 m. In shallow water, trawl efforts focus on flatfish, Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theregra calacogramma*), and Atka mackerel (*Pleurogrammus monopterygius*). Deeper trawling hauls focus on rockfish (*Sebastes* spp.). Pots are used to catch Pacific cod at depths between 51 m and 166 m, and for sablefish (*Anoplopoma fimbria*) at depths between 347 m and 887 m. Longlines for Pacific cod and flatfish are used over a wide depth range from 33 m to 929 m, with most effort concentrated in waters less than 200 m. The pot fishery for golden king crab occurs over a wide depth range between 100 m to 719 m, with highest effort between 200 m and 500 m (Stone 2006). These depth ranges for fishing effort heavily overlap depths with the greatest cold water coral abundance.

Figure 10 illustrates the coral and sponge bycatch rates by gear type from groundfish fisheries in Alaska between 1990 and 2002. Bottom trawling has by far the highest bycatch rates, with longline and pot/trap much lower.

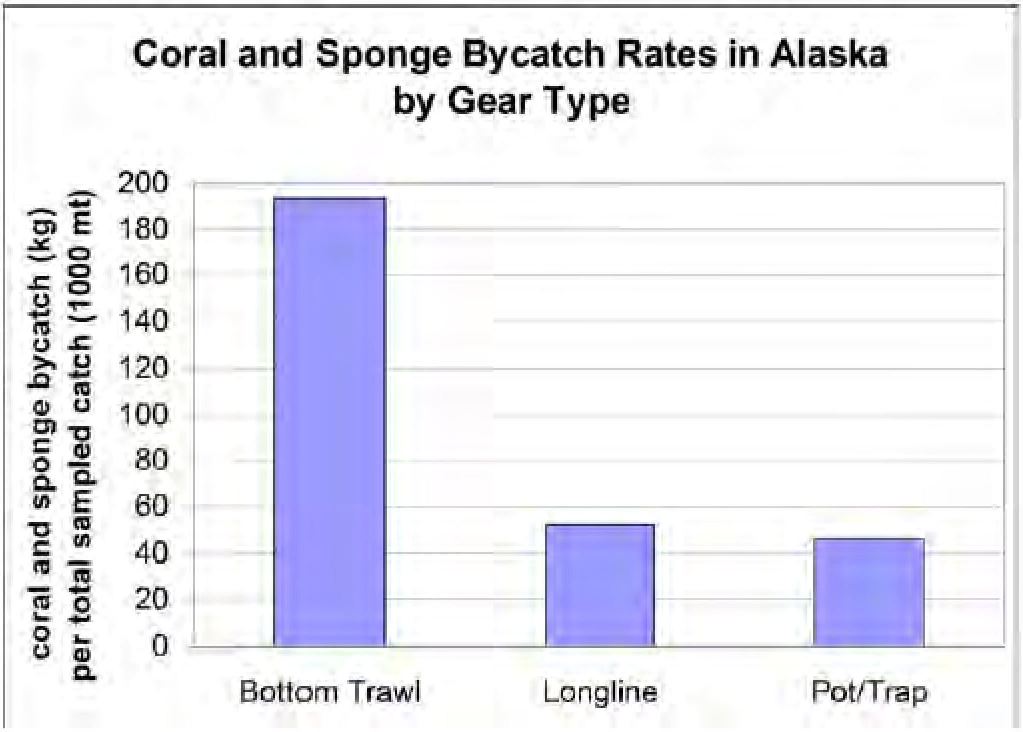


**Figure 10**: Bycatch rates for groundfish fishing gears in Alaska, based on data from 1990 to 2002. Bycatch rates are defined as the weight of reported bycatch divided by the weight of total sampled catch. These rates may not reflect actual damage to seafloor since fishing gears may not retain all corals and sponges that

are impacted, or corals and sponges may already have been removed from the area by pre-1990 trawl passes. Data source: NMFS 2002. Graph taken from Shester and Ayers (2005).

### a. Damage from trawling and other bottom-contact fisheries is widespread in Alaska waters with long-term impacts on the petitioned corals

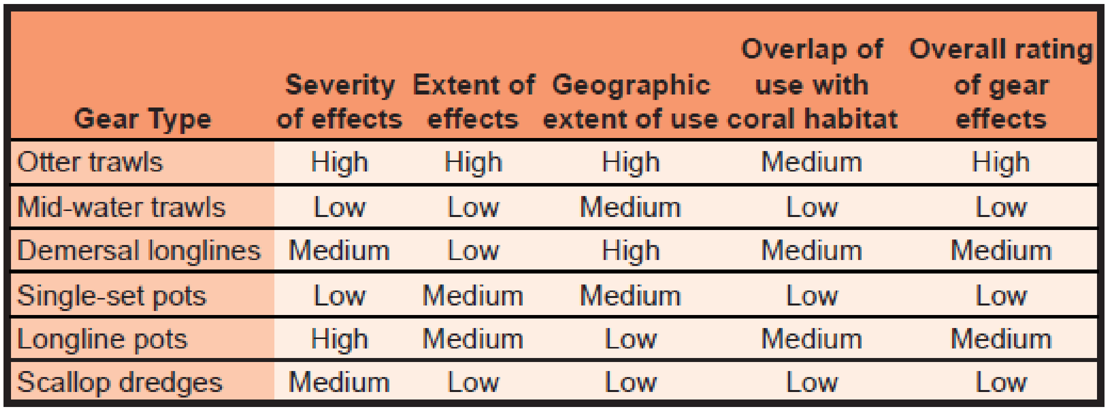
*In situ* observations of trawling damage are limited in area of the seafloor covered, due to the time and cost associated with surveys. Although the total area surveyed is limited, submersible surveys have found extensive damage to the seafloor in Alaska due to bottom-contact fishing activities, including damage, detachment, and areas of deep-sea coral rubble (Heifetz 2009). Fisheries bycatch records for Alaska corals are available for numerous years, but this data represents only a fraction of the unseen habitat damage and direct damage to corals on the seafloor, as many broken, crushed or uprooted corals are not retrieved to the surface by fishing gear. Thus, bycatch data underestimates the abundance and fisheries-associated destruction of cold water corals. Species level identification is rarely made for corals subject to bycatch, and the precise location of the coral's original growth is unknown. Because coral bycatch is highest at the first pass of the trawl and declines drastically with subsequent passes, coral bycatch numbers do not provide a good parametric for determining fisheries impacts in an area, or for estimating coral abundance in an area (Krieger 2001). Instead, *in situ* surveys are required, but economic and practical considerations limit the applicability of this effort, and a miniscule percentage of possible coral containing areas in Alaska have been surveyed for coral presence and abundance.

To date, the most intensively *in situ* surveyed area in Alaska is the Aleutian Islands, but even there, only 3.2 km$^2$ of the seafloor has been surveyed specifically for cold water corals via video transects, with the highest frequency of surveys occurring at 200 m to 500 m (Woodby et al. 2009). Depth restrictions are primarily due to equipment and funding limitations. Despite the relatively small area covered by surveys, video transects in the central Aleutians found evidence for extensive damage, with 39 percent of the seafloor disturbed by fishing activities (Stone 2006). Trawling in the Aleutians is estimated to damage up to 23 percent of gorgonian corals in high-intensity trawled areas, and 8.5 percent of all corals on all observed transects (Stone 2006). A Bering Sea canyon expedition in 2007 found evidence of damage from fishing on 13 occasions, at depths from 154 m to 966 m (Miller et al. 2012). Krieger (2001) used a submersible to observe the effects of bottom trawl gear on *Primnoa* coral during a resource trawl survey in the Gulf of Alaska from 1989 to 1997, and found that a single pass of a trawl removed 30 percent of corals. This survey covered depths from 161 m to 365 m at 11 dive sites (Krieger 2001). Longline-pot gear was observed to have scoured the seafloor to bare substrate along 17 strips in the central Aleutian Islands (Krieger 2001). In sum, the total amount of seafloor in Alaska coral-containing waters that has been surveyed for *in situ* damage is limited, but the evidence for significant damage from fishing activities is clear.

**Figure 11.** Red tree corals (*Primnoa* sp.) caught with trawl gear in Alaska waters. This specimen was caught during a NOAA fisheries groundfish stock assessment survey in Dixon Entrance, Gulf of Alaska. Source: (NOAA 2010).

Other types of fishing activities including longlines and pots also damage corals. Damage from longline gear (both pot and demersal) to coral habitat can be extensive, due to the large spatial distribution of longline fisheries, and overlap with areas of high cold water coral abundance, as shown in Figure 12 (Stone and Shotwell 2007). Bycatch of coral occurs some areas fished with longlines, with corals observed on 0.1 percent of longline hooks (619 out of 541,350) fished during NMFS longline surveys in the Gulf of Alaska and Aleutian Islands (Krieger 2001). As discussed above, a decrease in bycatch may simply indicate that corals in this area have already been removed or damaged by fishing gear. In areas of steep bathymetry and in strong winds and currents, longline gear can be dragged like a plough across the seafloor, scouring the surface in a manner similar to benthic trawls (Stone and Shotwell 2007). In these cases, most of damaged or uprooted coral would not be brought to the surface.

Evidence of longline gear damage is commonly observed at many sites in Alaska waters. Longline gear tipped and dragged rocks and small boulders that served as a substrate for cold water coral *Primnoa* species at a 260-meter site off Alaska (Witherell and Coon 2000). Submersible observation found that longline gear snagged large branches and corals, often breaking off hard corals (e.g., *Primnoa* sp.) (Stone and Shotwell 2007). Longlines also catch and retain gorgonians and other corals in Alaska waters (Witherell and Coon 2000), and hooked fish can move the longline for a distance of 50 ft or more on either side as they struggle to free themselves, which could disturb corals in their path (NMFS 2004). The Alaska golden king crab pot fisheries snag gorgonian cold water corals in the Aleutians, and crab pot fisheries overlap areas of high coral abundance, including coral gardens. Longlines scoured the seafloor to bare substrate along 17 strips in the central Aleutian Islands (Stone 2006). Coral gardens of the Aleutians are at high risk from longline activities, and many coral gardens remain unprotected due to the current policy of maintaining the fishing "footprint" in these areas. Longline damage has been observed in Gulf of Alaska *Primnoa* coral thickets, and a small amount of longline fishing occurs on Gulf of Alaska seamounts (Stone and Shotwell 2007). Reports from (Risk et al. 1998) describe red tree corals entangled in prawn pots of British Columbia as bycatch, and the disappearance of these cold water corals removed as bycatch in just six years of fishing impacts (Witherell and Coon 2000). During the 2007 submersible transect surveys of the Bering Sea Canyons, researchers observed evidence of bottom longline damage and derelict fishing gear, including tangles of lines and netting (Miller 2012). Longlines pose a moderate threat to Alaska cold water corals, and continue to damage cold water corals in high density coral areas (Figure 12).



| Gear Type | Severity of effects | Extent of effects | Geographic extent of use | Overlap of use with coral habitat | Overall rating of gear effects |
|---|---|---|---|---|---|
| Otter trawls | High | High | High | Medium | High |
| Mid-water trawls | Low | Low | Medium | Low | Low |
| Demersal longlines | Medium | Low | High | Medium | Medium |
| Single-set pots | Low | Medium | Medium | Low | Low |
| Longline pots | High | Medium | Low | Medium | Medium |
| Scallop dredges | Medium | Low | Low | Low | Low |

**Figure 12**. Potential effects of different fishing gear on cold water coral habitat in Alaska. Source: Stone and Shotwell 2007.

## b. Coral damage is greatest in areas with the highest bottom-contact fishing activity

The damage to cold water corals increases with increased fishing intensity, although even one pass of a trawl can be very damaging to cold water corals (Krieger 2001). Studies have found that areas of the Alaska seafloor at depths that experience the highest trawling intensities suffered the greatest damage to cold water corals. Thus, fishing activities, depth, and intensity can predict impacts to cold water corals. Gear type also correlates strongly with the intensity and extent of coral damage. Certain species or taxa of coral may be prone to greater breakage and damage than others, due to weaker skeletal structure, or higher profile which makes them more prone to snagging by fishing gear. Gorgonians and hydrocorals, which comprise the vast majority of the petitioned coral species, are especially susceptible to breaking and snagging due to their tree-like and branching skeletal structure.

As illustrated in Figure 13, the depth distribution of fishing effort in the Aleutian Islands overlaps known cold water coral abundance to a great extent. Cold water corals occur in greatest density from 200 m to 300 m with coral gardens known from depths of 150 m to 350 m (Stone 2006). This overlaps the most damaging form of fishing, bottom trawling, with a peak in trawl effort around 150 meters. As technology allows for greater depth distribution for trawls, impacts to corals occurring at greater depths will become more prevalent.

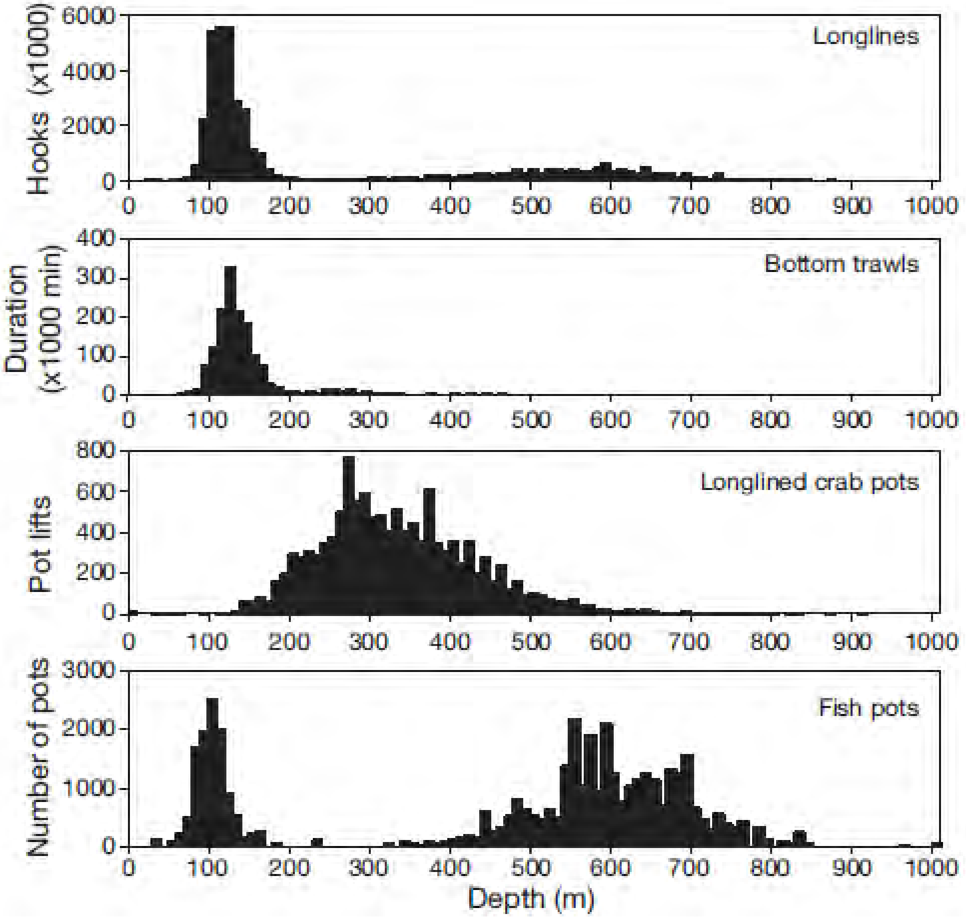


**Figure 13**. Depth distribution of observed fishing effort in the central Aleutian Islands during 2000 to 2004 (Heifetz et al. 2009).

Stone (2009) surveyed transects of the seafloor of the Aleutian Islands in 2003 and 2004, at depths ranging from 56 m to 2,987 m in order to examine whether seafloor disturbance and damage to corals was more frequent in heavily fished areas than in areas with little or no fishing. The total area sampled was 64,895 $m^2$. Damaged corals were observed on all video transects, with 14 percent of coral species damaged overall. Hydrocorals had the highest incidence of damage, at 22 percent, followed by sea whips and sea pens at 18 percent (Figure 14). Disturbance to the seafloor was evident at 88 percent of video transects. Importantly, coral damage and seafloor disturbance was greatest in areas most affected by fishing. The incidence of coral damage was greatest at depths under 400 m, but damage was also recorded at depths over 800 m. Areas fished with bottom trawls contained the highest percentage of damaged corals. Damage to corals at depths over 800 m was likely due to longlines and pot fisheries since these are the only fishing operations at those depths in the Aleutians. Seafloor disturbance was greatest at depths where most commercial fishing occurred, as illustrated in Figure 14. Between 700 m and 1,000 m depth, average seafloor disturbance was light, and there was virtually no seafloor disturbance observed at depths greater than 1,000 m. Overall, the ecological impacts are considered to be substantially greater for bottom trawls than pots and longlines (George et al. 2007). Where the terrain is too steep for trawling, corals continue to thrive, but are still subject to impacts from longlines and pot fisheries.

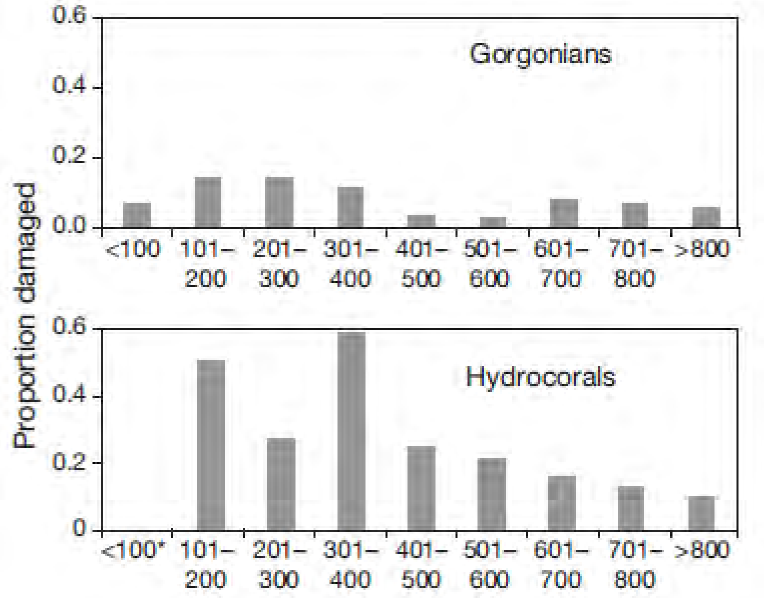


**Figure 14**. Proportion of coral taxa with damage by depth in the central Aleutian Islands. Depths with no data for a particular taxon are denoted by an asterisk (Heifetz et al. 2009).

Similarly, Stone (2006) found overlap and interaction between highest fishing effort and coral density. The depth range of highest coral density (200 m to 300 m) was slightly deeper than that of highest fishing effort, which was 100 m to 200 m, but there was extensive overlap and interaction between highest fishing effort and coral density, with the highest density of cold water corals, and the highest fishing effort overlapping for at least 100 m.

More intensely trawled areas have the highest proportion of damaged corals, but even one pass of the trawl can extensively damage cold water corals, especially at previously untrawled sites (Witherell and Coon 2000, Krieger 2001). During a 1996 study Freese (1999) observed that 67 percent of vase sponges were damaged with just a single pass of a bottom trawl. Similarly, Krieger (2001) found that a single pass of a research trawl off Dixon Entrance in Alaska at a depth of 365 m removed or broke 30 percent of the corals in its path, amounting to 1,000 kg worth of coral. It is likely that some of the coral species that were observed uprooted in this study are included in this petition. A remote operated vehicle found that 10 percent of fan gorgonians were removed with each pass of the trawl in Australia (Pitcher et al. 1999). As illustrated by these studies and by post-trawling research in Alaska waters, the impacts from bottom trawling are immediate, destructive, and long-term.

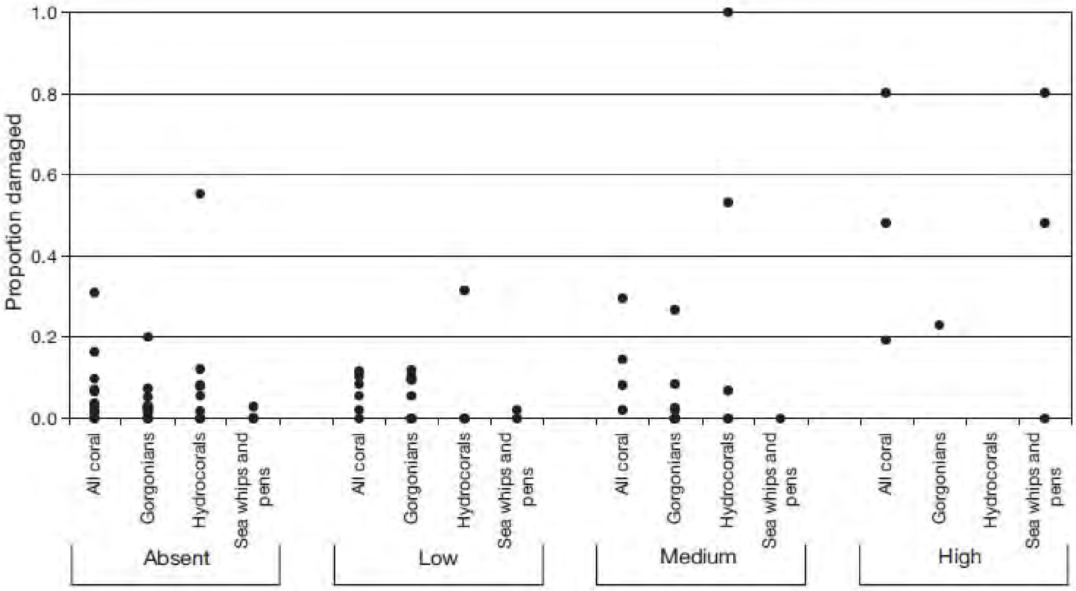


**Figure 15**. Proportion of coral damage by bottom trawl fishing intensity in the central Aleutian Islands. Data points are for individual dive transects. Source: Heifetz et al. (2009).

Coral species that are taller, branch extensively, or have fragile skeletons may be more prone to breakage and damage by fishing gear. Gorgonians included in this petition are often fairly tall and branching, and thus prone to snagging or breakage by fishing gear. This is also one of the most common taxa retrieved as bycatch from fishing gear (Stone and Shotwell 2007). As illustrated in Figure 16, hydrocorals (hydrozoa), including the 19 petitioned species in the family Stylasteridae, are also especially vulnerable to trawling. At trawling intensity level three (the highest intensity), hydrocorals were no longer present (Heifetz 2009). This indicates that hydrocorals cannot survive trawling intensity above level two, and that they are exceptionally vulnerable to trawling impacts due in part to their fragile structure (Stone 2009). Reproductive traits of hydrocorals, including internal fertilization and brooding, may further limit the potential for hydrocorals to recolonize areas impacted by fishing gear (Brooke and Stone 2007). Gorgonians may be somewhat more resistant to fishing impacts due to a relatively more robust skeletal composition and structure.

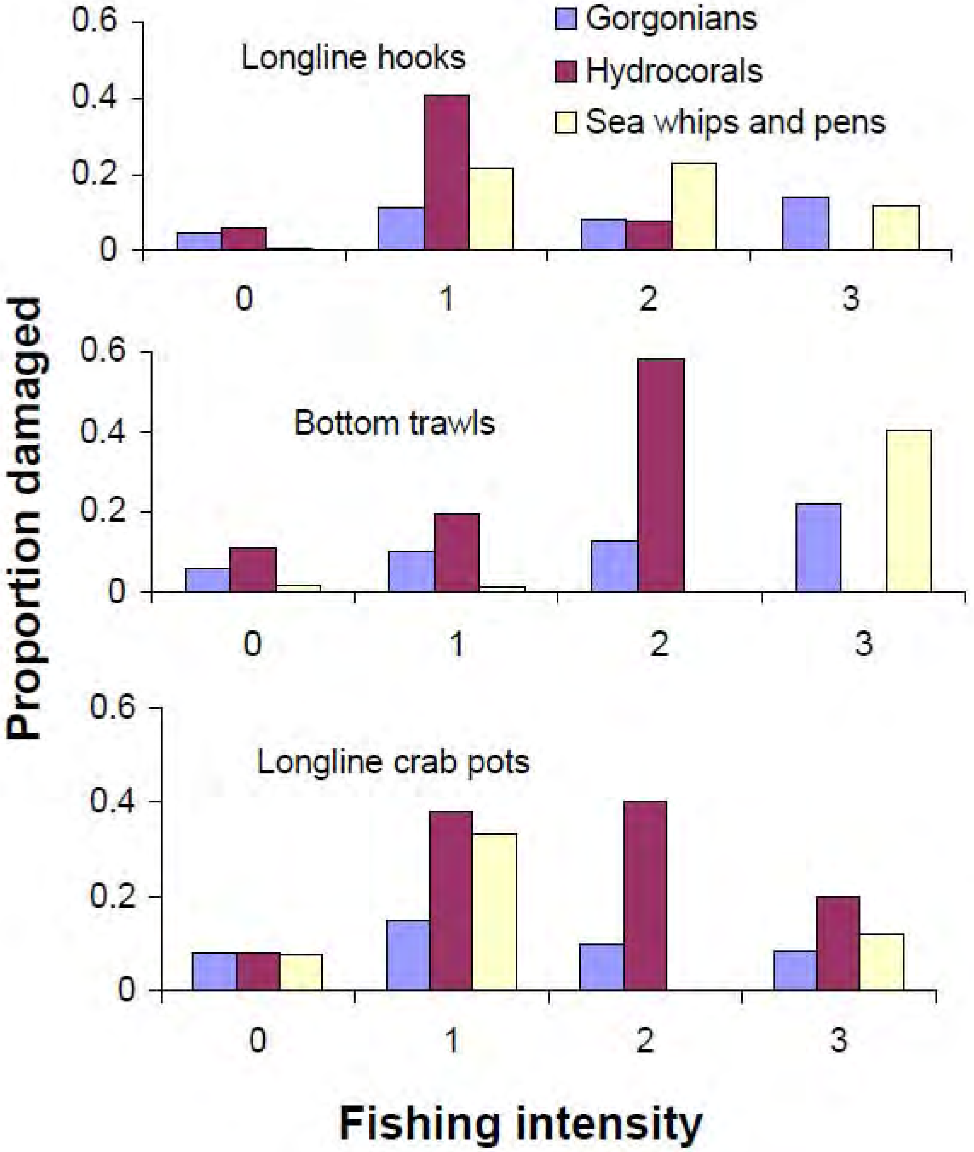


**Figure 16**. Proportion of coral taxa damaged by gear type and fishing intensity. Hydrocorals were not present in areas with intensity level 3 bottom trawling. Source: (Heifetz et al. 2007a).

## c. Trawling impacts occurring on Gulf of Alaska Seamounts and Bering Sea Canyons

In addition to the heavily studied Aleutian coral areas, seamounts in the Gulf of Alaska and undersea canyons along the Bering Shelf break, where many petitioned species are located, have high rates of endemism and are one of the few deep-sea habitats where currents are strong enough to prevent sediment accumulation. These currents also carry food, supporting the development of diverse assemblages of cold water corals and other benthic taxa. A constant food supply also attracts large aggregations of fish, which in turn attract fishing activities.

NMFS established seamounts in Alaska as Habitat Areas of Particular Concern (HAPC) areas because they contain unique ecosystems with endemic stocks or species (De Forges et al., 2000), including corals (Tsao 2005), and are thus particularly vulnerable to human activities such as fishing. Many commercial fish species congregate for spawning or feeding over seamounts, and these fish have increasingly become the target of bottom-contact fishing gear, as fishing fleets exploit less accessible areas further offshore (Koslow 2000).

Of the 24 named seamounts in Alaska waters, 16 rise to fishable depths of less than 3,000 m. Commercial fish species managed under fisheries management plans (FMPs) occur on seamounts, but there are no studies examining the relationship between these fish species on Alaska seamounts and cold water corals.

The Gulf of Alaska has been subject to extensive fishing impacts, including bottom trawling, since the 1930s. In 1998, bottom trawling was prohibited in Gulf of Alaska waters east of 142 degrees longitude. The 8.45 $km^2$ Sitka Pinnacles Marine Reserve was closed to fishing for groundfish and anchoring in the year 2000, to protect high relief habitat for red tree corals. In 2004, NMFS estimated that approximately 6.2 tons of cold water coral bycatch continued to be removed by bottom trawls in the Gulf of Alaska every year (NMFS 2004). In 2006, further protections for Alaska seamount habitat were enacted under EFH measures, and the North Pacific Fisheries Management Council voted to prohibit all bottom contact fishing by federally managed fisheries on the 16 seamounts in the EEZ off Alaska named on NOAA charts: Brown, Chirkikof, Marchand, Dall, Denson, Derickson, Dickins, Giacomini, Kodiak, Odessey, Patton, Quinn, Sirius, Unimak, and Welker. As a group, these marine protected areas comprise the Alaska Seamount Habitat Conservation Zone, with a total combined area of 18,278 $km^2$ (5,329 n.mi.2) These protections were established in recognition of the importance of Alaska seamounts as isolated habitats that may serve as stopover points for migratory species or become habitat for endemic species settling into these habitats far offshore of slope and shelf habitat (Hourigan 2009).

Bottom contact gear as defined by NMFS includes pelagic trawls that contact the bottom, bottom trawls, dredges, and troll gear that contacts the bottom (includes dinglebar gear). Pelagic gear may continue to damage cold water corals, as studies have found that pelagic gear continues to contact benthic habitat up to 44 percent of the time, due to the bathymetry of areas where is used and storm events or currents present when retrieving the gear (NMFS 2005a). Longline gear also impacts seamount corals to some extent, although no studies have been conducted (Stone and Shotwell 2007). It is imperative that bottom contact fisheries restrictions remain in place, as recovery of seamounts post-fishing is limited. Shoaling of the aragonite and calcite saturation horizons as the ocean acidifies will reduce the lower depth limit of corals on seamounts, further emphasizing the need to preserve shallow seamounts from any fisheries impacts (Althaus et al. 2009).

Bering Sea canyons are rich in coral abundance and diversity, and a 2007 expedition observed dense areas of coral growth, second only to the Aleutian Islands in abundance and diversity observed at northern latitudes (Miller et al. 2012). Both canyons support significant cold water coral habitats (Miller et al. 2012). Damage from trawling was evident on several dives, suggesting that bottom contact fishing activities damage and destroy cold water corals in Pribilof and Zhemchug canyons. Despite their importance as fish habitat, and high densities of corals, these canyons remain unprotected from bottom trawling or other bottom contact fishing activities. Petitioned coral species in these canyons are subject to death, damage and widespread destruction from trawling, and require protection immediately, as trawling is instantly damaging, and recovery post trawling is limited to non-existent.

As discussed above, petitioned corals at seamounts and in canyons have a high potential for extinction due to fishing-related damage (Roberts 2002). While seamounts in the Gulf of Alaska were closed to bottom contact fishing gear and anchoring in 2006 (but see discussion on pelagic trawl and longline impacts), the Bering Sea canyon areas remain unprotected from and vulnerable to fisheries impacts.

## d. Coral ecosystems can undergo type conversion by frequent trawling

Frequent trawling converts a biologically diverse seafloor community into an artificial, man-made community adapted to regular fishing disturbance and essentially changes the function of the ecosystem in a process known as “type conversion” (Lindeboom and de Groot 1998). This process is similar to the conversion of rainforest to cattle pasture where species diversity and functioning of the ecosystem is drastically changed. Many petitioned species, including all hydrocorals (family stylasteridae) can not survive at all, or do not function in a natural manner, in this type of denigrated ecosystem (Tillin et al. 2006). Non-functioning species experience inhibited growth and decreased reproductive success, and do not form the vibrant, coral-sponge communities so valued by other benthic species. If trawling is allowed to continue, these coral communities comprised of the petitioned species may never recover.

## e. Coral life history processes limit recovery

Re-colonization of trawled areas where most or all coral species have been damaged or destroyed occurs in one of two ways: by recruitment of larvae from healthy corals in surrounding patches to the disturbed areas, and by re-growth of damaged corals. Both processes pose severe difficulties for the petitioned species.

An extended life history, adaptation to a static environment with little natural disturbance, and limited reproductive dispersal mean that cold water corals have little or very prolonged recovery potential. Cold water corals may live hundreds to thousands of years and have a very slow life history, due in part to the cold, dark, and static environment in which they live (Andrews et al. 2002). The process of re-growth of damaged corals is slow, as most corals grow at a rate of just millimeters to centimeters a year, and the loss of feeding polyps due to fishing related damage, and resulting loss of nutrients and energy for calcification or reproduction would reduce this growth further (Roark et al. 2006). Recovery is further impeded by non-coral-friendly changes to the benthic environment resulting from the physical impacts of bottom trawling, including increased fragmentation of habitat, increased sedimentation, and changes to the hard substrate preferred by cold water corals, such as the burying of exposed boulders, shearing off of higher hummocks, filling in of low spots, and changing of bottom configuration (McAllister and Spiller 1994). Global climate change and associated changes in productivity, ocean acidity, freshness and currents, may singly or cumulatively limit or destroy deep-sea corals' chances for growth or colonization in benthic areas disturbed by fishing activities.

Re-colonization of cold water corals from undamaged areas into coral areas damaged by trawling is limited because of restricted dispersal distance for corals, and sparse availability of reproductive corals as a source of recruits. Many cold water corals do not reproduce successfully each year (e.g., Dorjes, J. 1986, Lundalv 1986). Coral larvae likely have little ability to swim or disperse large distances, and require specific conditions for settlement (Brooke and Stone 2007). Because of this, recruitment of coral to damaged areas is limited if there are no thriving, reproductive colonies nearby.

The rate of recovery after a disturbance that kills cold water corals can be delayed by slow recruitment, spatial patchiness of recruitment, and slow post-recruitment growth. All processes can be further impeded by sub-optimal conditions caused by fishing activities at the disturbed site, including higher rates of sedimentation, changes in the invertebrate sea life at the site to species that may prey upon young corals, and processes associated with global climate change. Re-colonization is further limited because many cold water coral species are found only within the depth range of current fishing activities. This means there are likely no deep-water (more than 1,000 m) or shallow water (less than 50 m) coral recruits from un-disturbed deeper or shallower areas available to re-colonize disturbed habitats (Stone and Alcorn 2007, Miller et al. 2011). Coupled with the long life cycle and slow growth of coral, the limited source of recruits from other areas to replace corals uprooted and killed by trawling, would mean that the possibility of recovery for petitioned species is extremely limited, if not non-existent. Exposure to any additional trawling passes during recovery would uproot, damage, or cover young coral, which emphasizes the need for long-term bans on bottom contact fisheries that cover a large area of the seafloor.

No studies have yet been conducted for the length of time necessary to observe long term, complete individual or climax community recovery rates post-trawling for the petitioned coral species. Short term observations include a 1997 study in the Gulf of Alaska that used a manned submarine to observe an area where up to one ton of coral had been removed by a trawl. Seven years post-trawling, of the 31 living red tree coral colonies that had been growing in the half-mile long trawl path prior to trawling, many of the large colonies that had survived the initial trawl were missing 95 percent to 99 percent of their branches, and two smaller colonies were still missing 80 percent of their polyps. There were no young coral re-colonizing the trawled areas to replace the dead or damaged colonies (Krieger 2001). In other area, five to ten years after trawling activity had ceased on seamounts in Tasmania, Althaus et al. (2009) found no evidence of recovery or re-growth of cold water corals, and instead found large areas of bare seafloor.

Due to a dearth of long-term *in situ* studies, modeling is used to estimate recovery times for cold water corals. Analysis by Rooper et al. (2011) using various parameters for cold water coral growth rates and potential re-colonization, found that recovery for trawl-damaged cold water corals would take decades to centuries, and would be difficult to measure or monitor effectively. Cold water coral and sponge communities in the Antarctic, where more studies have been conducted, are estimated to take from 250 years to 500 years to recover fully to a climax community after a fisheries related trawling disturbance (Cooper et al. 2012).

As discussed above, trawling is a major cause of damage and destruction to Alaska corals and severely impedes any recovery. Unless bottom contact fishing gear is banned from areas where cold water corals occur, the petitioned species have no chance for a meaningful recovery. No degree or amount of licensing or catch limits, or limited fishing activities will provide the protection cold water corals require (Hourigan et al. 2009). The only solution to ensure protection from fishing activities, and to allow for any sort of recovery, is to establish coral habitat areas for each petitioned coral vulnerable to fishing impacts that are completely off-limits to any fishing activities, and remain so for a matter of centuries (Watling and Norse 1999).

## 2. OIL SPILLS MAY SIGNIFICANTLY IMPACT COLD WATER CORALS

Even a small oil spill in coral rich habitat in the Aleutians, Gulf of Alaska or Bering Sea could result in massive and long-lasting impacts on cold water corals, coral habitat and coral food sources. Oil discharged into the water from a source on the water surface typically breaks up into a floating component, a sinking component and a volatile component (Suchanek 1993). The volatile component is most likely to impact plankton on the water surface, while the sinking component may severely impact benthic communities, which include cold water corals (Suchanek 1993). When there is excess oil in the marine environment, natural weathering and consumption by indigenous bacteria is unable to consume the oil fast enough to reduce biological impacts.

Climate change will increase the amount of oil contamination in Alaska waters, due to increased shipping traffic that is predicted with sea ice melt, Arctic oil exploration, and the opening of the Inside Passage (Borgerson 2008). Oil contamination will occur as discharges or spills from oil tankers, cargo ships, and cruise ships travelling to or from the approved and pending offshore oil leases in the Chukchi and Beaufort Seas, or navigating the proposed Arctic shipping route that will open with melting sea ice (Law and Stohl 2007, Borgerson 2008). The typical route of travel to the Bering Sea and Arctic Ocean passes through Unimak Pass, near the continental shelf break. This area contains one of the most productive fisheries areas in the world and is home to a variety of cold water coral species (Heifetz et al. 2005). There is also a risk of oil contamination from tankers and other ships in the Gulf of Alaska, passing from Valdez or other Alaskan ports to the lower 48 states and Canada. With future melting sea ice, there will be an increase in tourism in these regions, as cruise ships begin to travel to the Arctic. If the offshore waters of Bristol Bay were opened to oil development, corals in the Bering Sea could be exposed to oil spills directly from wellsites, such as the *Deepwater Horizon* blowout.

Oil discharges from ships at sea commonly result from accidental or intentional dumping of oily bilge residues that build up during the normal operations of any ship. These oil leakages account for at least 22 percent of the oil annually discharged into ocean waters (Suchanek 1993). These discharges are described as chronic oil pollution, and are often assessed by the number of dead oiled birds washed up on seashores (O'Hara and Morgan 2006). While discharges for chronic oil pollution are not at the scale of massive oil spills from ship groundings, increased ship traffic in Alaska will result in more numerous ships and thus more numerous oil discharges in the waters where some of the densest assemblages of Alaska corals occur, especially the Aleutian coral gardens.

If a ship travelling in Alaska waters runs into trouble, it is likely that a minor incident could result in a major oil spill, and that a minor spill could turn major due to lack of infrastructure, remoteness of the region, and necessary delayed response of specialized emergency services for oil spill clean-up. The North Pacific and Arctic oceans are remote and undeveloped, and vessels traveling through the region will have little or no emergency response infrastructure or support. Spills that may be cleaned up relatively easily in waters off the continental U.S. will be much harder to control in remote Alaskan waters. Even a minor breakdown could lead to an oil spill, because in many areas along the shipping routes travelled by oil tankers or cargo ships, there are no nearby logistical support services for salvage and emergency response. Approved spill plans are in place for drilling platforms in the Beaufort and Chukchi seas, but spills resulting from associated vessel traffic, pipelines, shoreline facilities, and infrastructure are common. Thawing of summer sea ice in the Arctic is opening up shipping lanes that will pass through the Bering Sea and Gulf of Alaska, but melting ice also presents future hazards to navigation including moving ice floes, unsettled weather, and erratic wave patterns. With rescue and salvage delayed by the remoteness and lack of infrastructure in the region, a simple engine blowout could result in shipwreck, causing a major oil spill on the level of the Exxon Valdez.

In 2004, the Selendang Ayu, a cargo ship with a load of soybeans, spilled more than 350,000 gallons of oil and 66,000 tons of soybeans into the Bering Sea near Unalaska Island on the Aleutians. Six crew members died during a rescue attempt. The carcasses of more than 1,600 birds and six sea otters were recovered from beaches along the western shore of Unalaska Island following the spill. This incident highlights the difficulties in emergency response, and containment of an oil spill in these waters.

Cold water corals can be negatively impacted by oil spills. Most recently, 86 percent of cold water corals at a depth of 1,370 m located 11 km from the blowout site for the

Deepwater Horizon disaster exhibited severe population-level impacts from the oil spill, with 46 percent showing at least half of the colony sustaining impacts, and 23 percent of the corals showing more than 90 percent of the colony impacted (White et al. 2012).

Oil compounds affect corals through direct physical contact and by impacts to physiological processes. Laboratory and field studies have shown that an oil spill may impact corals in a variety of ways, ranging from immediate mortality to sub-lethal effects. Direct lethal effects include physical smothering by oil, which prevents coral respiration, killing most or all of a colony. Indirect mortality from oil toxicity generally occurs as a function of amount of dissolved oil in the water, with lethal effects observed at concentrations of one ppm to 100 ppm (Hyland and Schneider 1976). Larval and juvenile corals are more sensitive to oil concentrations, showing lethal effects at 0.1 ppm to 1.0 ppm. Sublethal effects observed for corals include diminished reproduction, which is manifested as decreased ovaria and planula per polyp, reduced female gonads per polyp, degeneration of the ova, and lack of gonadal development altogether (Suchanek et al. 1993). Other sublethal impacts include abnormal growth, premature expulsion of planulae, altered feeding behavior and stimuli responses, loss of polyps on some or all of the colony, and death of part of the colony (Suchanek et al. 1993, White et al. 2012).

Dispersants commonly used at oil spills also pose a severe toxic threat to corals (Shafir et al. 2007). A study on tropical corals found that dispersants were more toxic to corals than the oil itself, and had a variety of negative impacts including reduced reproductive success, reduced growth and direct mortality of a coral colony (Shafir et al. 2007). Thus, oil and oil dispersants may have lasting and serious impacts on the petitioned corals.

Alaska cold water corals may be exposed to surface oil contamination because cold water corals occur in sediment-free areas with moderate current regimes that are highly linked to surface productivity through water circulation patterns (Stone and Shotwell 2007). During a surface oil spill, currents and upwelling in the North Pacific and Arctic Ocean would circulate the surface oil plume in the same direction that these currents circulate nutrient-laden waters. These currents would therefore be likely to transport oily water to cold water coral sites. Upwelling and mixing of surface waters is increasing in Alaska waters due to climate change and increased freshwater input, and this process would further contribute to the mixing of oily surface waters and deeper waters (Mathis et al. 2011a). As a result, cold water corals and their food source could be severely impacted. Evidence from the Gulf of Mexico supports this conclusion (White et al. 2012).

As the Arctic shipping routes are predicted to become more heavily used, with offshore oil development and ice-free waters, oil spills may become a major concern for the North Pacific and Arctic Oceans. Oil on the surface or oil in the water column could negatively affect cold water coral food sources, or directly effect coral, causing massive die-offs and hindering many biological processes important to coral health and survival. As observed with the Exxon Valdez spill, ecological impacts may continue for decades to centuries.

# 3. OIL AND GAS EXPLORATION AND PRODUCTION IMPACTS TO CORALS

Worldwide, there are many regions where exploration and production of oil and gas takes place in cold water coral areas, such as the North Sea, off northwestern Scotland, off Muaritania, and in the Campos Basin off southeast Brazil (Freiwald et al. 2004a). Offshore oil and gas exploration and development is on the increase in Alaska, and a recent observations of high density growth of the coral *Gersemia rubiformis* at proposed drilling sites in the Chukchi Sea, indicate that Alaska corals may be at risk from drilling activities (Eilperin 2012). Greenpeace researchers stated that the density and coverage of cold water corals at the drill site were similar to those observed in tropical coral reefs (Eilperin 2012). Cold water coral surveys throughout most of Alaska waters are non-existent, and therefore data on coral distribution is limited, facilitated primarily by fisheries bycatch.  Surveys are hindered by lack of funding, and difficulties with surveying such an immense area of the seafloor in an extreme, often hostile marine environment. Given the recent Greenpeace observations of cold water corals that until now have received little or no public attention or environmental protective measures, it is very likely that additional areas of cold water coral growth occur within oil and gas leases in the Alaskan arctic, and at other locations throughout Alaska waters. These cold water corals may be adversely impacted from oil and gas exploration and development in a variety of ways.

Even in the absence of a major oil spill, oil and gas exploration and production could severely adversely impact cold water coral habitats through physical placement of structures (e.g., platforms, pipelines, anchors), or impacts from discharges of drill cuttings, drilling fluids and chemicals (Olsgard and Gray 1995), oil leakages or spills and discharges from the wells. Studies have found that corals exposure to drill cuttings and drilling mud can have a variety of impacts including death of the coral colony from smothering, alteration of feeding behavior, disruption of the normal pattern of polyp expansion and retraction, alteration of coral physiology, morphological changes, and disruption of coral calcification (Rogers 1999).

Researchers have found that cold water corals may suffer significant adverse impacts from oil and gas drilling activities. In the Northeast Atlantic, discharges of drill cuttings and drilling mud from the drilling of exploration, appraisal, and production wells has been identified as a significant threat to cold water coral species (Rogers 1999, Colman et al. 2005). The abundance of a species of cold water coral was reduced following drilling off California (Hyland et al. 1994). Sedimentation resulting from drill cuttings would also have a significant impact on faunal communities associated with cold water corals, both through death of the corals themselves, and directly, particularly for those that are also suspension feeders (Rogers 1999, Colman et al. 2005).

Freiwald et al. (2004) found that drilling discharges impacted growth and development of some cold water corals and not others. Impacts likely depend on the amount and composition of drill cuttings (Freiwald et al. 2004a).

Laying of underwater cable and pipeline infrastructure for offshore oil and gas activities may also negatively impact cold water corals through direct physical disturbance, increased sedimentation, and impacts similar to trawling if a cable is accidentally snagged by fishers (Freiwald et al. 2004).

# IV. THE INADEQUACY OF EXISTING REGULATORY MECHANISMS

Existing regulatory mechanisms are inadequate to curb the threats to the petitioned cold water corals posed by greenhouse gas emissions and fishery activities, especially trawling. Regulatory mechanisms addressing greenhouse gas emissions that would limit the impacts to petitioned corals from associated ocean warming and ocean acidification are woefully inadequate. Unless strong near-term emissions reductions are implemented in short order on national and international levels, it is likely that the petitioned coral species will be committed to extinction. This section reviews regulatory mechanisms addressing greenhouse gas emissions as well as regulatory mechanisms directed at non-greenhouse gas related threats to cold water corals and cold water coral ecosystems, especially the pervasive and serious threat posed by trawling.

A lack of scientific knowledge of cold water corals can not be used as an excuse to limit protections. Where the best available science is minimal pertaining to a specific species, FWS must "give the benefit of the doubt" to the listed species. *Conner v. Burford*, 848 F.2d 1441, 1454 (9th Cir. 1988). In 1992, the United Nations in its Rio Declaration on Environment and Development defined the precautionary principle as follows, "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." The complicated ecosystems of the deep sea may be out of sight, but their importance to the marine ecosystem means that they can no longer remain out of mind and subject to such destructive practices as fishery activities, climate change, and ocean acidification. All present evidence indicates that anthropogenic greenhouse gas emissions have led to the beginning of long-term ocean acidification. Without immediate action to curb emissions and stop destructive fishing practices in areas of cold water coral growth, these delicate ecosystems that are intricately linked to the health of the marine environment face a significant risk of extinction.

## A. REGULATORY MECHANISMS ADDRESSING GREENHOUSE GAS EMISSIONS, CLIMATE CHANGE, AND OCEAN ACIDIFICATION ARE INADEQUATE

Greenhouse gas emissions pose the primary threat to the continued existence of the petitioned coral species through impacts from climate change and ocean acidification. However, regulatory mechanisms at the national and international level do not adequately protect the petitioned corals from these impacts, nor do they require the greenhouse gas emissions reductions necessary to protect the petitioned coral species from extinction.

NMFS has acknowledged that regulatory mechanisms are inadequate to regulate greenhouse gas emissions to levels that do not threaten species. In its 2010 proposed listing rules for the ringed and bearded seal, NMFS stated that "there are currently no effective mechanisms to regulate GHG emissions, which are contributing to global climate change and associated modifications to [ringed and bearded] seal habitat. The risk posed to [ringed and bearded] seals due to the lack of mechanisms to regulate GHG emissions is directly correlated to the risk posed by the effects of these emissions" (75 Fed. Reg. 77508). Similarly, NMFS acknowledged in its 2012 *Management Report for 82 Corals Status Review under the Endangered Species Act* that no countries are reducing emissions enough to keep the increase in global temperature below 2 degrees C; and the top ten emitters including the United States, accounting for over 60% of the global emissions, are performing poorly or very poorly at meeting needed greenhouse gas reductions (NMFS 2012). As detailed below, the continued failure of the U.S. government and the international community to implement effective and comprehensive greenhouse gas reduction measures places the petitioned coral species at ever-increasing risk of extinction.

## 1. Global greenhouse gas emissions are tracking the worst IPCC emissions scenario

The atmospheric concentration of $CO_2$ reached ~392 parts per million (ppm) in 2011[2] compared to the pre-industrial concentration of ~280 ppm. The current $CO_2$ concentration has not been exceeded during the past 800,000 years and likely not during the past 15 to 20 million years (Denman et al. 2007, Tripati et al. 2009). Atmospheric $CO_2$ emissions have risen particularly rapidly since the 2000s (Raupach et al. 2007, Friedlingstein et al. 2010). The global fossil fuel $CO_2$ emissions growth rate was 1.1% per year during 1990-1999 compared with 3.1% during 2000-2010, and since 2000, this growth rate has largely tracked or exceeded the most fossil-fuel intensive emissions scenario projected by the IPCC (A1FI) (Raupach et al. 2007, McMullen and Jabbour 2009, Global Carbon Project 2011). The $CO_2$ emissions growth rate fell slightly in 2009 due largely to the global financial and economic crisis; however, the decrease was less than half of what was expected and was short-lived (Fiedlingstein et al. 2010). Global $CO_2$ emissions increased by 5.9% in 2010 resulting in a record 33 billion tons of $CO_2$ emitted (Olivier et al. 2011), and $CO_2$ emissions reached another record high in 2011 (*See* International Energy Agency, *Global carbon-dioxide Emissions Increase by 1.0 Gt in 2011 to Record High,* http://www.iea.org/newsroomandevents/news/2012/may (last visited June 5, 2012).

In order to preserve a likely chance of limiting overall temperature increases to 1.5° or 2°C above pre-industrial levels, recent scientific assessments have found that global emissions must peak within the next several years, decline very sharply thereafter, reach zero net emissions by mid-century, and become net-negative after 2050 (i.e. where more carbon is removed from the atmosphere than is produced) (Höhne et al. 2009, UNEP 2010). Scientists have estimated that cumulative $CO_2$ emissions must not exceed 1000 $GtCO_2$ (gigatonnes $CO_2$) between 2000 and 2050 in order to have a 75% chance of staying below 2°C (Meinshausen et al. 2009, NAS 2010); and must not exceed 750 to 824 $GtCO_2$ between 2000 and 2050 to meet a 350ppm $CO_2$/1.5°C target (Ackerman et al. 2009, Baer et al. 2009). Because pathways for 1.5°C and 2°C require staying within a tight cumulative carbon budget, continuing increases in greenhouse gas emissions and

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[2] *See* National Oceanic and Atmospheric Administration, *Trends in Atmospheric Carbon Dioxide*, www.esrl.noaa.gov/gmd/ccgg/trends/global.html (last visited June 5, 2012).

corresponding delays in reaching a global emissions peak make it increasingly difficult to meet these targets. For example, global emissions from 2000 to 2010 accounted for roughly 360 $GtCO_2$, which is a third of the allowed emissions until 2050 consistent with a 75% chance of staying within 2°C and nearly half of the allowed emissions until 2050 consistent with staying within 1.5°C (Höhne et al. 2009). Thus, global emissions in the past decade have eliminated a large portion of the available carbon budget, and every year at current emissions (~33 $GtCO_2$) consumes a significant share and makes meeting this budget less feasible. Every additional contribution to global greenhouse gas emissions, especially over the next few decades, means that meeting a 1.5°C or 2°C target becomes less likely as does the likelihood of survival of the petitioned corals.

### 2. Greenhouse gas emissions reductions needed to protect the petitioned coral species

The best available science indicates that the current atmospheric $CO_2$ concentration of 400 ppm is already detrimental to coral species (Veron et al. 2009). Atmospheric $CO_2$ concentrations must be reduced to at most 350 ppm, and perhaps much lower (300 to 325 ppm $CO_2$) in order to adequately reduce the synergistic threats of ocean warming, ocean acidification, changes in current and upwelling patterns, and other threats to corals (Hansen et al. 2008, Donner 2009, Veron et al. 2009).

### 3. U.S. measures to reduce greenhouse gas emissions are insufficient

While existing domestic laws including the Clean Air Act, Energy Policy and Conservation Act, Clean Water Act, Endangered Species Act, and others provide authority to executive branch agencies to require greenhouse gas emissions reductions from virtually all major sources in the United States, these agencies are either failing to implement or only partially implementing these laws for greenhouse gases. For example, the EPA has issued a rulemaking regulating greenhouse gas emissions from automobiles that will reduce greenhouse emissions emitted per vehicle mile traveled by passenger vehicles in the future, but because the improvements are modest and more vehicles are projected to be driven more miles in the future, the rule will not reduce emissions from this sector overall but will only slow the rate of increase somewhat compared to what it would be without the rule. EPA, Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, 75 Fed. Reg. 25,324 (May 7, 2010). Meanwhile even the government concedes that “these reductions in emissions are not sufficient by themselves to reduce total HD vehicle emissions below their 2005 levels by 2020.” NHTSA, *Medium- and Heavy-Duty Fuel Efficiency Improvement Program – Final Environmental Impact Statement* (June 2011). This means that the vehicle rule is far from achieving emissions goals agreed to by the US in the Copenhagen Accord, which aim to keep global warming below 2˚C.

The EPA has also to date issued only a single proposed rule under the new source pollution standard program for stationary sources of pollution, for electric generating units (power plants). While there is enormous potential to reduce emissions through this program overall and through the power plants rule in particular, the EPA has instead proposed a weak and flawed rule that it admits will not reduce emissions from these sources between now and 2020 compared to what would be expected without the rule. EPA, Standards of Performance for Greenhouse Gas Emissions for New Stationary Sources: Electric Utility Generating Units, 77 Fed. Reg. 22392, 22430-33 (April 13, 2012). Indeed, in the rulemaking the EPA conceded that new power plant rule on greenhouse gas emissions “will not have direct impact on U.S. emissions of greenhouse gases under expected economic conditions.” *Id*. at 22401.

While full implementation of our flagship environmental laws, particularly the Clean Air Act, would provide an effective and comprehensive greenhouse gas reduction strategy, due to their non-implementation, existing domestic regulatory mechanisms must be considered inadequate to protect the petitioned coral species from climate change and ocean acidification.

### 4. International measures to reduce greenhouse gas emissions are inadequate

International initiatives are also currently inadequate to effectively address climate change. The United Nations Framework Convention on Climate Change, negotiated in 1992 at Rio de Janeiro, Brazil, provides the forum for the international negotiations. In the Framework Convention, signed and ratified by the United States, the world agreed to take the actions necessary to avoid dangerous climate change. Parties to the Convention also agreed as a matter of fairness that the world’s rich, developed countries, having caused the vast majority of emissions responsible for the problem, would take the lead in solving it. It was not until the 1997 meeting in Kyoto, Japan, that the first concrete, legally binding agreement for reducing emissions was signed: the Kyoto Protocol. The Protocol requires the world’s richest countries to reduce emissions an average of 5 percent below 1990 levels by 2012, while developing nations also take steps to reduce emissions without being subject to binding emissions targets as they continue to raise their standard of living. The United States has been a major barrier to progress in the international negotiations. After the Clinton administration extracted many concessions from the rest of the world in exchange for the United States signing on in Kyoto, the Senate rejected the equity principles behind the Convention, saying the United States shouldn’t agree to reduce its own emissions unless all other countries — regardless of their responsibility or ability — were similarly bound. Citing the same excuses, President George W. Bush repudiated the Kyoto Protocol entirely. Thus the United States is the only industrialized country in the world that has yet to ratify the Kyoto Protocol. The United States negotiating team under both the George W. Bush and the Obama administrations has pursued two primary objectives in the international talks: to refuse any legally binding emissions reduction commitments until all other countries— but particularly China and India — do so, and to push back the date for a new agreement. Not surprisingly, the United States had failed to meet its (never ratified) Kyoto pledge to reduce emissions to 7.2% below 1990 levels by 2012; to the contrary, U.S. emissions have increased by 10.5% since 1990 (EPA 2012).

Moreover, Kyoto Protocol’s first commitment period only sets targets for action through 2012, and there is still no binding international agreement governing greenhouse gas emissions in the years beyond 2012. While the 2009 U.N. Climate Change Conference in Copenhagen called on countries to hold the increase in global temperature below 2°C (an inadequate target for avoiding dangerous climate change), the *non-binding* "Copenhagen Accord" that emerged from the conference, and the subsequent "Cancún Accords" of 2010 and "Durban Platform" of 2011, failed to enact binding regulations that limit emissions to reach this goal.[3] Even if countries were to meet their Copenhagen and Cancún pledges, analyses have found that collective national pledges to cut greenhouse gas emissions are inadequate to achieve the 2°C target, and instead suggest emission scenarios leading to 2.5°C to 5°C warming (Rogelj et al. 2010, UNEP 2010, 2011). As of May 2012, many governments were not implementing the policies needed to meet their inadequate 2020 emission reduction pledges, making it more difficult to keep global temperature rise to 2°C and likely leading to a temperature rise of at least 3.5 °C (Höhne et al. 2012). As noted in the NMFS *Management Report*, the U.S. has yet to issue regulations to limit greenhouse gas emissions in accordance with its pledge under the Copenhagen Accord (NMFS 2012).

## B. REGULATORY MECHANISM ADDRESSING NON-GREENHOUSE GAS RELATED THREATS TO COLD WATER CORALS AND COLD WATER CORAL ECOSYSTEMS PROVIDE INADEQUATE PROTECTION TO THE PETITIONED SPECIES

The petitioned species have an intrinsic value as individual species and as an integral component of marine biodiversity independent of any role they play in maintaining fisheries stocks. However, most management that includes cold water corals thus far has been for the benefit of fisheries, and enacted toward the goal of maintenance of commercial fish species, rather than for the corals themselves and their role in supporting marine biodiversity. Cold water corals have intrinsic value in maintaining ecological complexity and biological diversity, may harbor cures for human diseases, and are uniquely valuable for scientific study. These species form highly complex, beautiful structures that have captured the attention of both the public and marine scientists, and prompted renewed interest and increased funding for research on deep sea ecosystems. Scientists are just beginning to understand cold water corals and the role they play in the marine ecosystem. Measures to protect corals must be proactive, protecting areas with potential coral growth rather than half-measures that do little to protect those areas containing the richest coral growth.

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[3] The non-legally binding Copenhagen Accord of 2009 and Cancún Accords of 2010 recognize the objective of limiting warming to 2°C above pre-industrial, but do not enact binding regulations to achieve this goal (http://cancun.unfccc.int/cancun-agreements/main-objectives-of-the-agreements/#c33; unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf). According to the Durban Platform, developed and developing nations agreed to a process to develop a "new protocol, another legal instrument, or agreed outcome with legal force that will be applicable to all Parties to the UN climate convention"; this legal instrument must be developed as of 2015 and will not take effect until 2020 (unfccc.int/resource/docs/2011/cop17/eng/l10.pdf).

NOAA researchers consider corals communities in the Aleutian Islands to be a potential ‘keystone species’ that, by their presence, determine benthic fish and invertebrate biodiversity and abundance (Tews et al. 2004, Heifetz et al. 2005). Like the removal of a building’s cornerstone, removal of a keystone species, like Alaska corals, would result in a dramatic shift in ecosystem dynamics, with a major decrease in benthic biodiversity and productivity. A loss of these diverse and vulnerable species would have long-term impacts on the functioning of the marine ecosystem as a whole, with impacts up the food chain to salmon and marine mammals (Roberts et al. 2009). Loss of deep sea benthic habitat provided by Alaska corals would also significantly impact fisheries stocks of many important commercial fish and invertebrate species.

To date, most regulatory mechanisms have included coral protection only as a by-product of regulations put in place by NOAA/NMFS under recommendations from the North Pacific Fisheries Management Council (NPFMC) under the Magnuson-Stevens Fishery Conservation and Management Act (MSA). Under the MSA, enacted in 1976, NOAA has established some areas of known coral abundance as Essential Fish Habitat (EFH) or as Habitats of Particular Concern (HAPC). EFH specifically for coral protection includes the Aleutian Islands Coral Habitat Protection area, covering 93,230 acres, and the Gulf of Alaska Coral Protection Area, covering 11,442 acres. Thus far, none of these measures includes even the most minimal protections for the petitioned coral species from threats including climate change, ocean acidification, and fishing activities. Additionally, the practice of maintaining the current trawling footprint in the Aleutians means that many of the most productive fishing areas, which are linked to the most abundant cold water coral assemblages, remain exempt from fisheries restrictions. This means that the acreage covered by EFHs under-represents the total area that is actually protected coral habitat, because over 90 percent of the known coral areas in the Aleutian Islands remain open to fishing (Shester and Warrenchuck 2007). The majority of the acreage included in protected areas is deep abyssal plain, containing little suitable benthic habitat or conditions for coral growth, with few commercial fish species or cold water corals. This petition discusses the inadequacy of protections offered under the MSA, as well as other regulatory mechanisms.

## 1. Magnuson-Stevens Fishery Conservation and Management Reauthorization Act

In response to concern about the destruction of marine habitat, the U.S. Congress in 1996 passed the Sustainable Fisheries Act, which required fishery managers to minimize to the extent practicable the adverse impacts to EFH caused by fishing. Under the 2007 amendments to the MSA, fisheries management agencies must identify and describe EFH for marine fishes. These EFHs are described as habitat essential for spawning, feeding, breeding, or growth to maturity (16 U.S.C. 1802(10), NOAA 2007). Marine fishes and invertebrates have been linked to the presence of benthic invertebrates, with cold water corals being described as a probable keystone species that by their presence determine benthic fish and invertebrate biodiversity and abundance (Tews et al. 2004, Heifetz et al. 2005), although the specific mechanisms of the relationship are unknown (Krieger and Wing 2002, Rooper and Boldt 2005, Rooper et al. 2011). Based on observed associations between cold water corals and marine fish species, it is generally assumed that this relationship benefits the fish species through increased growth and decreased mortality, especially in the juvenile stages (Rooper and Boldt 2005). Thus, protection of cold water corals is coupled with enhancement of fisheries habitat.

Under the MSA, HAPCs are defined on the basis of ecological importance, sensitivity, exposure, and rarity of habitat (NOAA 2007). Cold water corals and coral communities in Alaska epitomize this type of sensitive and special habitat, warranting protection under the MSA, which was established to protect rare or fragile fish habitats from anything more than “minimal and temporary” disruption. Trawling is very much more than minimal and temporary, because a single pass of the heavy trawl doors, or a fishing pot and connected line, can level coral and sponge habitats that take centuries to recover. In order for cold water corals to be adequately protected under the MSA through HAPC designation, NOAA would have to immediately designate cold water coral areas as “habitats of special concern” that are closed to trawling and other fishing activities that impact the seafloor. It would also be required to survey new areas believed to hold new colonies and to fund research efforts. The fishing industry argues that courts have already ordered regulators to produce comprehensive regional plans for protecting fish habitats and that the current process is sufficient. However, these plans do little to protect cold water corals specifically, and draft plans by the NPFMC have made the inaccurate conclusion that trawling damage to cold water corals has little adverse impact on fish population.

### *a. NOAA Deep Sea Coral Research and Technology Program*

The 2006 MSA reauthorization included a requirement to establish the “Deep Sea Coral Research and Technology Program.” Section 408 (b) of the reauthorized Act tasked NOAA with submitting, in consultation with the Fishery Management Councils, “biennial reports to Congress and the public on steps taken by the Secretary to identify, monitor, and protect deep sea coral areas, including summaries of the results of mapping, research and data collection performed under the program.”

In 2009, NMFS began implementation of the Deep Sea Coral Research and Technology Program. The primary goal of the program is to improve the understanding, conservation, and management of cold water coral and sponge ecosystems. Based on criteria developed to identify future priority geographic regions for new field research, the next regions for major new field activities are Alaska and Northeast United States (NOAA 2012). One of the biggest challenges is the lack of information on cold water coral distribution.

To date, the Deep Sea Coral Research and Technology Program has submitted three reports to congress, in 2008, 2010 and 2012. The Program will begin a three-year field study in Alaska in 2012 in order to understand coral distribution and taxa, especially in the Aleutian Islands. The Program is also in the process of building a national geodatabase that houses spatial records of deep-sea corals. This database can be used by the NMFPC to “protect deep sea corals from physical damage of fishing gear or to prevent loss or damage to such fishing gear from interactions with deep sea corals" under its discretionary authorities provided by MSA Section 303 (b)(2)(B).

The Deep Sea Coral Research and Technology Program has identified several locations where deep sea coral habitats are in areas open to bottom fishing with gear that can damage corals. These areas include parts of the Bering Sea, some of the Aleutian Island coral areas not currently protected, and Gulf of Alaska *Primnoa* coral habitats outside of protected areas. However, these described areas are still subject to the impacts of trawling despite extensive evidence of the damage from trawling, the limited recovery potential for cold water corals and the important ecological role cold water corals play in the marine ecosystems. The three-year field study starting this summer (2012), should greatly add to the knowledge of known coral distribution and species identification.

### *b. Essential Fish Habitat*

Under Section 303(a)(7) of the MSA, NMFS is required to take steps to minimize to the extent practical adverse effects of fishing on essential fish habitat (EFH). Figure 17 illustrates areas of Alaska designated with some form of protection from fishing activities as of January 2011, as approved by NMFS and in collaboration with the NPFMC. NMFS has put forth little effort to observe the habitat where ongoing fisheries occur and to record damage or recovery of cold water coral species. Because of this, NMFS has limited knowledge of bottom habitat and the benthic biota overlapping major fisheries, and this limits the amount of information available to obtain approval for protections for coral areas from the NPFMC and other entities. Due to pressure from fisheries, most of the areas already trawled in Alaska waters remain open to trawling. This continues the destruction of corals, and removes any potential for recovery of corals in already trawled areas.

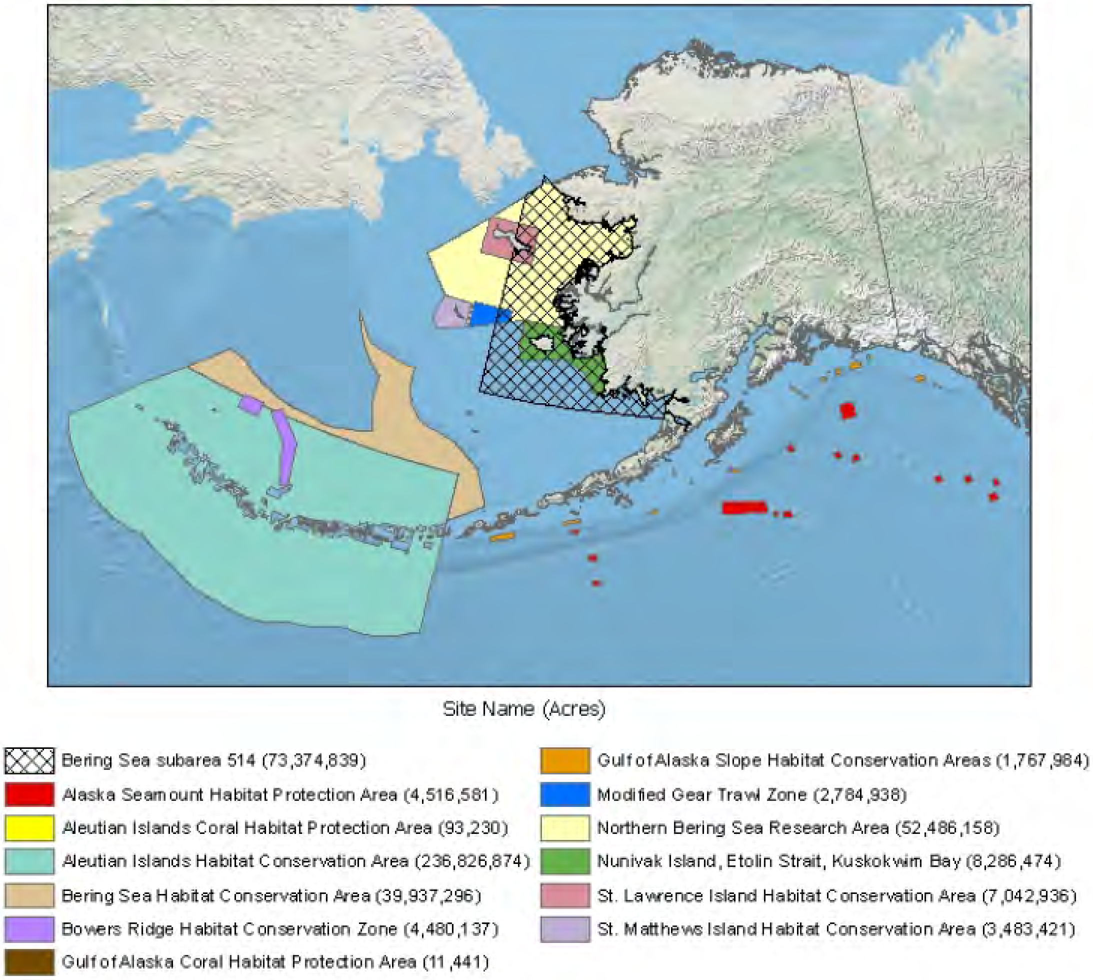

**Figure 17:** Map of the Essential Fish Habitats designated in Alaska waters updated January 2011. Downloaded from: http://alaskafisheries.noaa.gov/npfmc/conservation-issues/hapc.html

Even as designated, the current EFH areas do not fully protect the petitioned species from fisheries impacts. The protected areas do not contain all known coral areas, protections are patchy, and enforcement is difficult. Most area closures are for specific gear types only, others are seasonal, and some closures go into effect only when a species bycatch cap has been reached.

The first pass of a trawl or other bottom contact fishing gear causes significant and long term damage to cold water corals and other benthic invertebrates (Hall-Spencer et al. 2009). Subsequent passes of the trawl further contribute to damage, and impede recovery of cold water coral and other benthic species. Because of this, recovery from disturbances may take decades to centuries, if it occurs at all. Therefore, it is important to protect areas containing petitioned coral species from any bottom contact fishing activity, rather than attempting to continue fisheries activities in these areas at a reduced rate.

Figure 18 illustrates the known locations of structure-forming cold water corals off Alaska, but has little data for corals other than stony and gorgonian corals, including hydrocorals, which constitute nearly half of the petitioned coral species and are especially vulnerable to trawling impacts. Even so, it is obvious that vast areas of known coral abundance are still subject to bottom trawling and other damaging fishing activities. Additionally, vast areas of the seafloor remain open to trawling, with NPFMC considering opening even more areas to trawling as climate change results in possible northern expansion of fish habitat and sea ice melt.

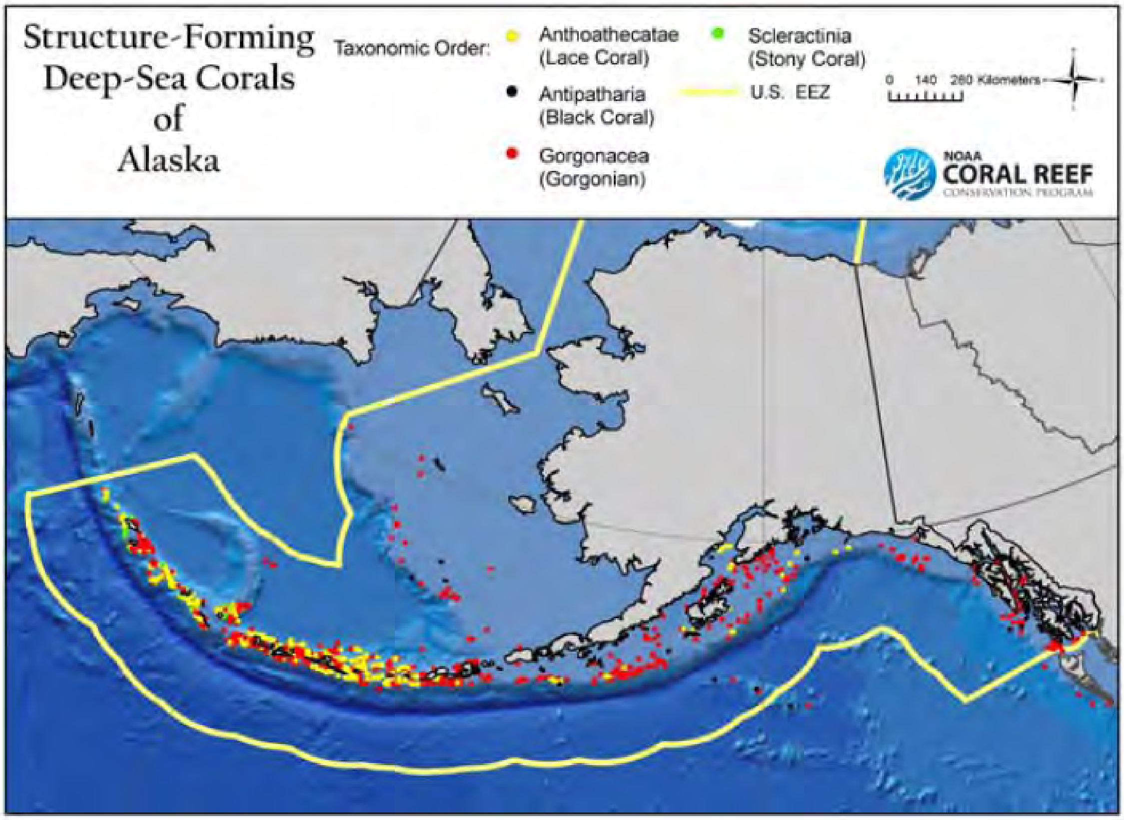

**Figure 18:** Known locations of structure-forming cold water corals off Alaska. The data represent known locations of major structure-forming species of lace corals, black corals, gorgonian corals, and colonial stony corals. Location data are particularly incomplete for corals other than stony and gorgonian corals. Source: (NOAA 2010).

|  | Site Name | Area (Acres) | Fishery Mgmt Action | FMP | 50 CFR | Regs published |
|---|---|---|---|---|---|---|
| 1 | Alaska Seamount Habitat Protection Area | 4,516,582 | Bottom contact gear and anchoring prohibited | BSAI Groundfish Am 78 & 65<br>GOA Groundfish Am 73 & 65<br>BSAI King and Tanner Crab Am 16 & 12<br>Scallop Am 7 & 9<br>Salmon in AK EEZ Am 7 & 8 | 679.7 (a)(20),<br>679.22 (a)(12),<br>679.22 (b)(8) | 6/28/2006 |
| 2 | Aleutian Islands Coral Habitat Protection Area | 93,230 | Bottom contact gear and anchoring prohibited | BSAI Groundfish Am 78 & 65<br>GOA Groundfish Am 73 & 65<br>BSAI King and Tanner Crab Am 16 & 12<br>Scallop Am 7 & 9<br>Salmon in AK EEZ Am 7 & 8 | 679.2,<br>679.7 (a)(20),<br>679.22 (a)(13) | 6/28/2006<br>11/9/2007 |
| 3 | Aleutian Islands Habitat Conservation Area | 236,826,873 | Nonpelagic trawl gear prohibited | BSAI Groundfish Am 78 & 65<br>GOA Groundfish Am 73 & 65<br>BSAI King and Tanner Crab Am 16 & 12<br>Scallop Am 7 & 9<br>Salmon in AK EEZ Am 7 & 8 | 679.2, and<br>679.22 (a)(14) | 6/28/2006<br>11/9/2007<br>2/19/2008 |
| 4 | Bering Sea Habitat Conservation Area | 39,937,297 | Nonpelagic trawl gear prohibited | BSAI Groundfish Am 89 | 679.22 (a)(16) | 7/25/2008 |
| 5 | Bering Sea Subarea | 73,374,839 | Modified nonpelagic trawl gear required for directed flatfish fishing | BSAI Groundfish Am 94 | 679.7 (c)(5) | 10/6/2010 |
| 6 | Bowers Ridge Habitat Conservation Zone | 4,480,137 | Mobile bottom contact gear prohibited | BSAI Groundfish Am 78 & 65<br>GOA Groundfish Am 73 & 65<br>BSAI King and Tanner Crab Am 16 & 12<br>Scallop Am 7 & 9<br>Salmon in AK EEZ Am 7 & 8 | 679.22 (a)(15) | 6/28/2006 |
| 7 | Gulf of Alaska Coral Habitat Protection Area | 11,442 | Bottom contact gear and anchoring prohibited | BSAI Groundfish Am 78 & 65<br>GOA Groundfish Am 73 & 65<br>BSAI King and Tanner Crab Am 16 & 12<br>Scallop Am 7 & 9<br>Salmon in AK EEZ Am 7 & 8 | 679.7 (a)(20),<br>679.22 (b)(9) | 6/28/2006 |
| 8 | Gulf of Alaska Slope Habitat Conservation Area | 1,767,985 | Nonpelagic trawl gear prohibited | BSAI Groundfish Am 78 & 65<br>GOA Groundfish Am 73 & 65<br>BSAI King and Tanner Crab Am 16 & 12<br>Scallop Am 7 & 9<br>Salmon in AK EEZ Am 7 & 8 | 679.22 (b)(10) | 6/28/2006 |
| 9 | Modified Gear Trawl Zone | 2,784,938 | Directed fishing for groundfish prohibited unless using modified nonpelagic trawl gear | BSAI Groundfish Am 94 | 679.22 (a)(21) | 10/6/2010 |
| 10 | Northern Bering Sea Research Area | 52,486,158 | Nonpelagic trawl gear prohibited | BSAI Groundfish Am 89 | 679.22 (a)(17) | 7/25/2008<br>10/6/2010 |
| 11 | Nunivak Island, Etolin Strait, and Kuskokwim Bay Habitat Conservation Area | 8,286,474 | Nonpelagic trawl gear prohibited | BSAI Groundfish Am 89 | 679.22 (a)(18) | 7/25/2008 |
| 12 | St. Lawrence Island Habitat Conservation Area | 6,033,426 | Nonpelagic trawl gear prohibited | BSAI Groundfish Am 89 | 679.22 (a)(19) | 7/25/2008 |
| 13 | St. Matthews Island Habitat Conservation Area | 3,483,421 | Nonpelagic trawl gear prohibited | BSAI Groundfish Am 89 | 679.22 (a)(20) | 7/25/2008<br>10/6/2010 |

**Table 2:** EFH Areas Protected from Fishing in the US North Pacific Ocean. Downloaded from: http://alaskafisheries.noaa.gov/npfmc/conservation-issues/hapc.html

Current protections do little to aid species recovery, and it is likely that unknown areas of coral growth continue to be destroyed due to major gaps in the EFH regulations. For example, the Aleutian Islands Habitat Conservation Area (AIHCA) includes a vast area of seafloor (957,361 square km) and is the largest bottom trawl closure in the United States. However, under the decision approved by NMFS and voted on unanimously by NPFMC, areas within the AIHCA that have been trawled in the past and have supported the highest groundfish catches will remain open to trawling (42,611 square km). As discussed above, there is a high association (up to 85 percent) between commercial fish species and cold water coral. It is likely that previously trawled areas contain damaged corals that could recover with time if left untrawled. The mandate to allow trawling where it has occurred previously, with the exception of small areas for coral gardens, is simply business as usual, and trawling in these areas continues to destroy and damage vast areas of coral growth. Areas that are already largely unfished, like Bowers Ridge, remain closed to bottom trawling. However, this has little impact on cold water coral protections, as these areas are not thought to contain many coral species (hence low fish catch rates) and were largely unfished regardless of any regulations.

### *c. Habitat areas of particular concern (HAPC)*

HAPCs are specific subsets of EFH that highlight specific habitat areas with extremely important ecological functions and/or areas that are especially vulnerable to human-induced degradation. In an attempt to limit the impacts of bottom trawling on fisheries and cold water coral habitat, in 2006 the NPFMC voted to establish HAPCs in the Gulf of Alaska where the use of all bottom-contact fishing gear would be prohibited. These HAPCs were proposed and implemented by NMFS. These HAPCs include seamounts, slope habitat and small coral protection zones to protect known *Primnoa* thickets. There are also coral protection zones in the Aleutians. However, NPFMC did not close many areas of the Aleutian Islands with the highest recorded coral bycatch. Only 4% of observed coral bycatch records (9% by weight) occurred in areas now closed to bottom trawling (Shester and Warrenchuck 2007). Thus, over 90 percent of the most productive coral areas, based on bycatch records, remain open to bottom trawling.

Enforcement of bottom trawling bans in HAPC is an especially important consideration, as designated Alaska HAPCs may still be subject to illegal or inadvertent trawling. Even one pass of a trawl could destroy centuries worth of coral growth, which may never recover. An example of lax enforcement is Oculina Bank, off of Florida, which was designated as a HAPC in 1984, but is now over 90 percent destroyed due to lack of enforcement of the trawl ban (Morgan et al. 2005).

Figures 19 illustrates in greater detail the limited scope of areas in the exceptionally coral rich waters off the Aleutians that are closed to trawling. This map includes six known coral gardens, totaling 377 square km, where bottom trawling is prohibited. The Bower’s Ridge Habitat Conservation Zone is closed to all mobile bottom trawling fishing gear. However, this area was largely unfished historically and is not thought to have high concentrations or diversity of cold water corals. Known coral gardens (in red) are protected from bottom trawling but surrounded by areas open to bottom trawling (in green). Therefore, statistics from implementation of the new regulations, stating that approximately 52 percent of the fishing grounds previously targeted by trawlers (down to 1,000 m depth) are now closed to bottom trawling in the Aleutians Islands (Stone and Shotwell 2008), are deceptive because the richest fishing grounds, and those likely containing the highest density and diversity of coral species, remain open to trawling. Areas that remain open to trawling produce over 90% of known coral bycatch by weight, indicating that fishing activities continue to impact the vast majority of corals occurring in the Aleutians.

Outside of the productive waters near the Aleutians, the vast majority of the seafloor within these closures is deep abyssal plain that likely supports little cold water coral habitat with few commercial fish species found in those areas. As such, these areas would not have been targeted by fisheries regardless of protections. This means that the Aleutian Islands Habitat Conservation Zone protects few coral species (less than 10% of total known coral area), while the coral habitat protection zones protect only known coral gardens, leaving unprotected those that have not yet been discovered.

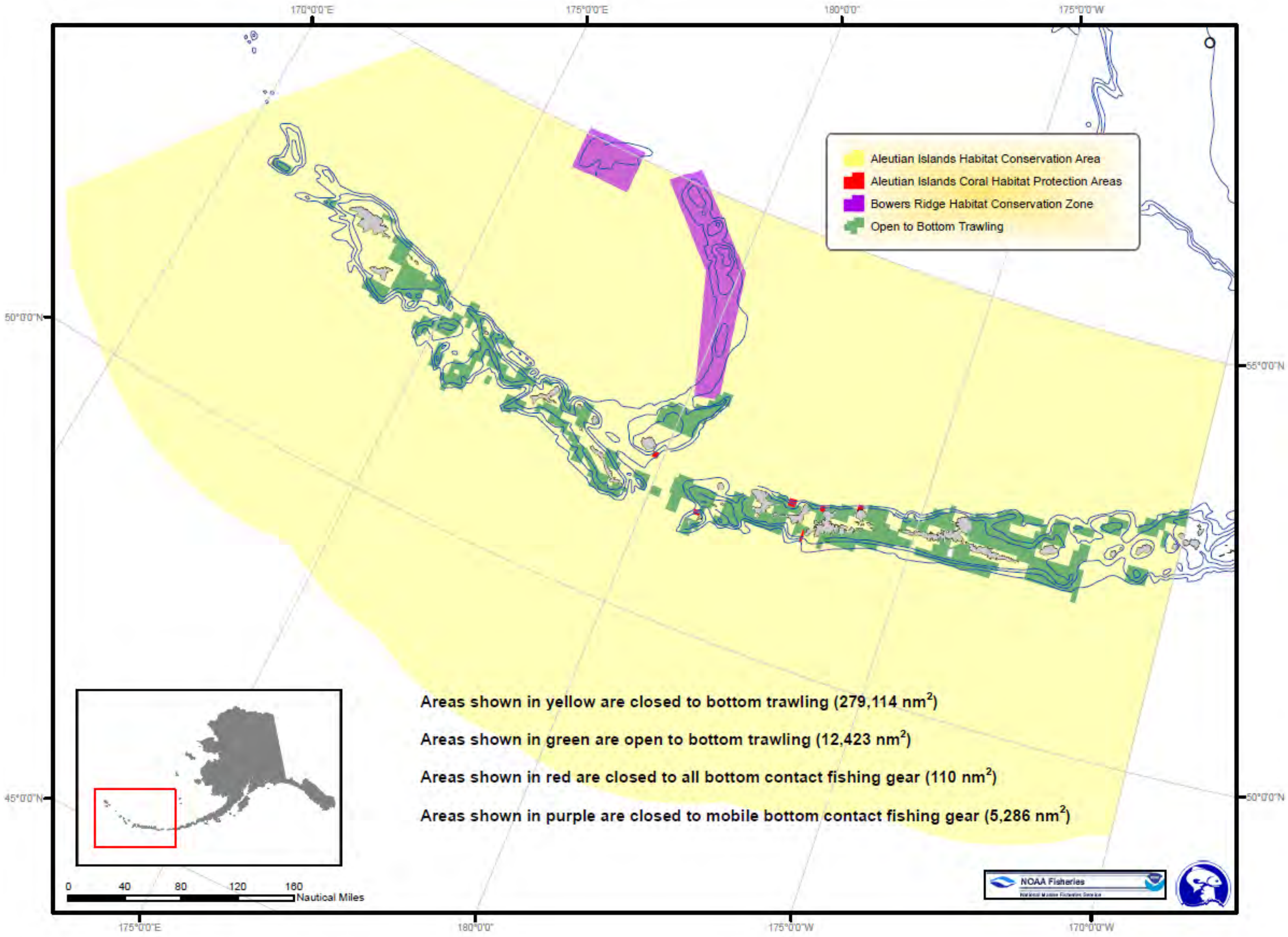

**Figure 19:** Closure areas in the Aleutian Islands, Alaska, that were proposed by the NPFMC in February 2005 and approved by NOAA Fisheries in 2006. Source: NOAA, accessed at: http://www.fakr.noaa.gov/habitat/efh/regs.htm.

As discussed in great detail above, this type of patchy protection creates a desert-island type of ecosystem, with small areas of coral density and diversity surrounded by deserts of trawled area. Recovery potential of coral species in these continually trawled areas is very low. It is likely that, over time, diversity in these areas will decrease, and fast growing, opportunistic species will prevail.

Figure 20 below is a more detailed map of protected coral garden areas. Enforcement of many of these designated HAPCs may be difficult due to the very small size of many of these protected spots.

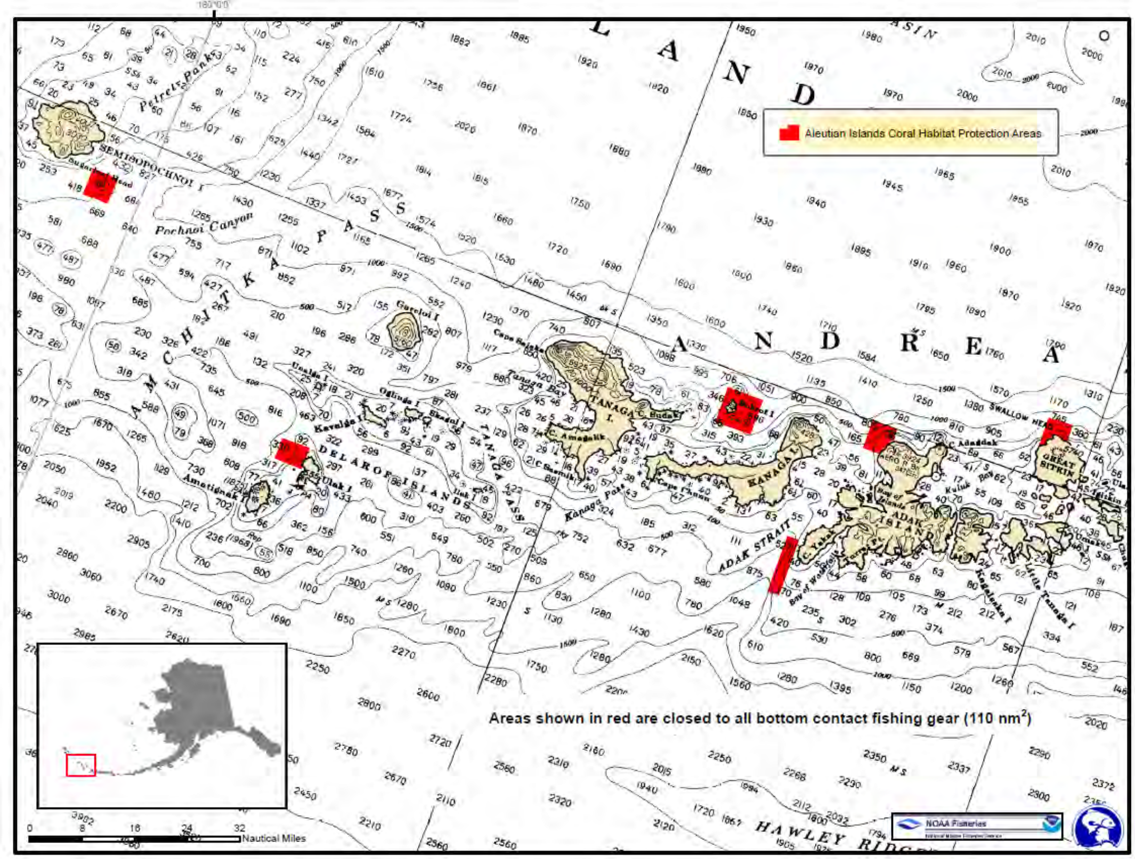

**Figure 20:** Aleutian Island Coral Habitat Protection Areas. Source: NOAA, accessed at: http://www.fakr.noaa.gov/habitat/efh/regs.htm

Specific seamounts in the Gulf of Alaska, totaling 5,329 square miles, are protected from bottom contact fishing gear,.

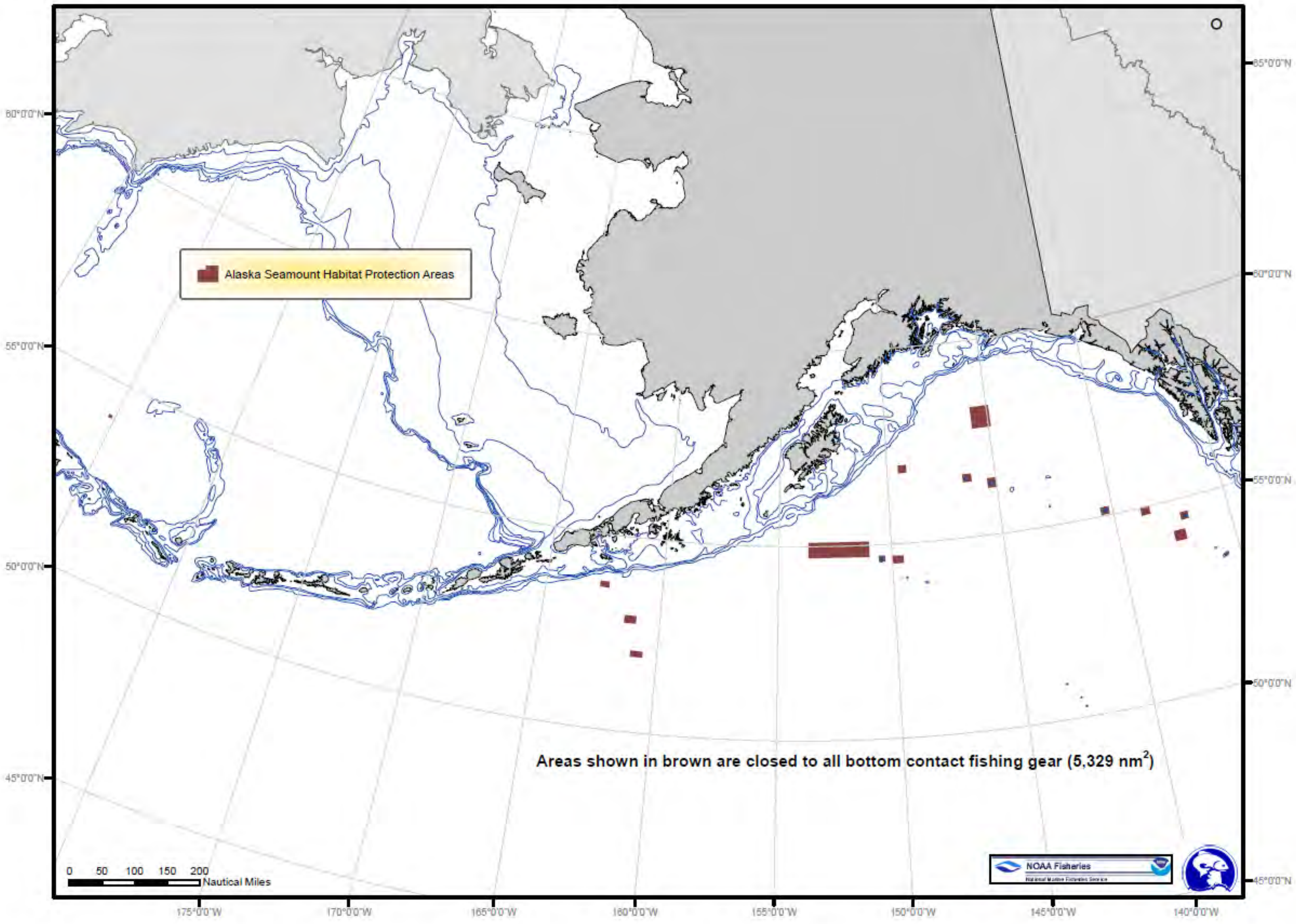

**Figure 21:** Gulf of Alaska Seamount Habitat Protection Areas. Source: NOAA, accessed at http://www.fakr.noaa.gov/habitat/efh/regs.htm.

There are small coral protection areas in the Gulf of Alaska totaling only 13.5 square miles. These were specifically designed to protect known thickets of *Primnoa* red tree coral. It is likely that unknown coral-rich areas continue to be trawled, and these protections are inadequate.

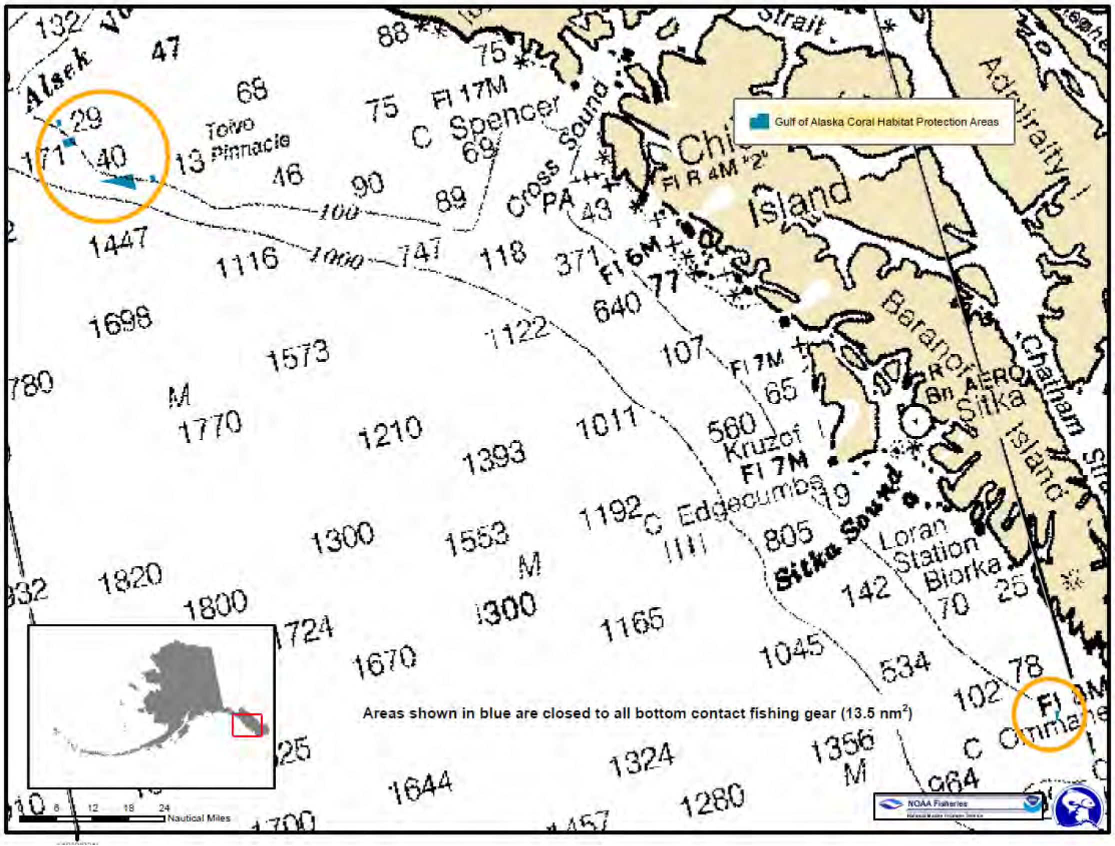

**Figure 22:** Gulf of Alaska Coral Habitat Protection Areas. Source: NOAA, accessed at http://www.fakr.noaa.gov/habitat/efh/regs.htm.

In the Gulf of Alaska, another 2,086 square nautical miles are closed to bottom trawling to protect slope habitat. However, these protections do not prevent coral snagging, breakage, and crushing that may occur with pelagic fishing gear or with long line and pot fishing.

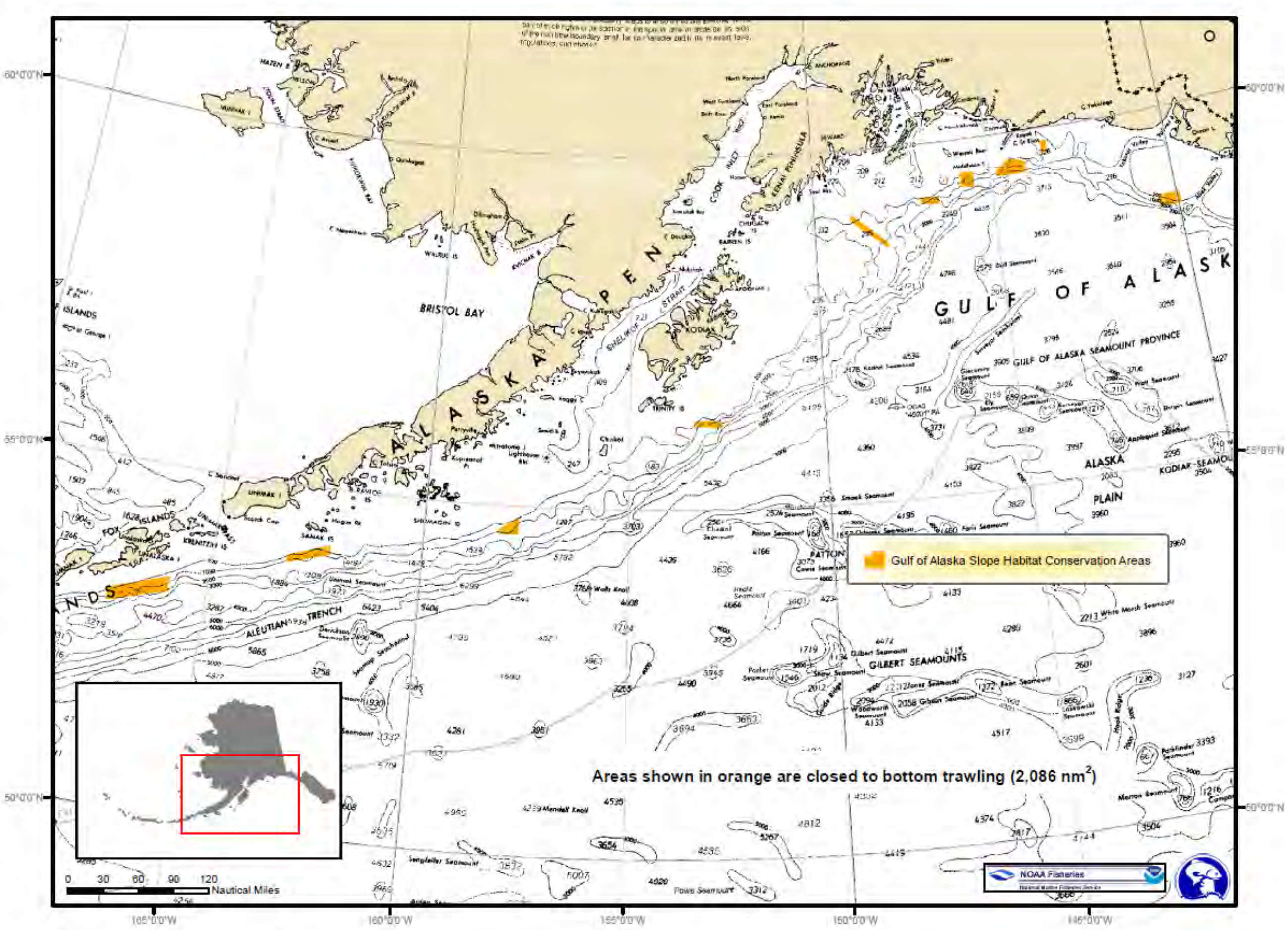

**Figure 23:** Gulf of Alaska Slope Habitat Conservation Areas. Source: NOAA, accessed at http://www.fakr.noaa.gov/habitat/efh/regs.htm.

Established coral protection areas often are tiny, oddly shaped patches of seafloor, surrounded by a vast area open to trawling. Even if all areas in Alaska waters that are currently closed to bottom trawling were to be have strict enforcement, this would not be enough to protect coral species from destruction and extinction. Corals occur in small, often very dense patches and very little of the seafloor in Alaska has currently been mapped for coldwater coral habitat suitability, or surveyed via submersibles for corals. Thus, NMFS, under NOAA, must preemptively close areas that likely contain coral growth, as a proactive measure, to protect these sensitive, slow to recover, species from destruction.

Closure to just bottom trawling does not fully protect these benthic areas from disturbance, as pelagic fishing gear is often deployed as close to the seafloor as possible (NPFMC 2012). Benthic species are often caught as bycatch in pelagic fishing gear, confirming that this gear often operates at or near the seafloor (Stevenson and Lewis 2010). Bycatch of corals is often recorded by fisheries observers for pelagic gear (NMFS 2005), and it is estimated that pelagic trawl gear contacts the seafloor approximately 44 percent of the time it is deployed (NMFS 2005). Thus, current closures not only do not protect areas with the vast majority of coral growth, but they also do not provide adequate measures to protect corals from impacts from fisheries activities.

Recent data and observations on other areas of rich coral growth in Alaska emphasize the need for NMFS to take proactive measures in protecting possible coral areas. The Pribilof and Zhemchug canyons are huge submarine canyons located 25 miles southeast and 80 miles northwest of the Pribolof Islands, respectively, on the highly productive Bering Sea shelf break. These canyons support a wide variety of benthic marine life, including vast swathes of cold water coral and sponge assemblages, which were only recently surveyed by Greenpeace scientists (Miller et al. 2012). The canyons are part of one of the largest and most productive fisheries in the world. Despite their importance to the U.S. economy, the ecological value of these canyons was, and remains, little understood. NPFMC has not adopted any measures to protect these areas from trawling and fishing gear. Greenpeace lobbied for protection of these canyons in 2012, after surveys revealed extensive coral and sponge habitat in 2006, which prompted NPFMC to approve a measure to gather information on the habitat in these canyons as a top priority for research. At this time, the area remains open to trawling, and the recently observed coral areas in the canyon are subject to destruction unless trawling closures are put in place. Destructive fishing activities in these canyons continues to wipe out cold water corals, with very little chance for any meaningful recovery of these corals to occur at any point within the next 100 years or more.

### *d. Northern Bering Sea Research Area*

In 2007, the NPFMC closed the northern Bering Sea to bottom trawl fishing to protect essential fish habitat. In addition to the closure, federal fishery managers established the northern region as the Northern Bering Sea Research Area (NBSRA). Ecological studies are currently being proposed for this area, and the NPFMC states that, in time, this area is likely to be opened to fishing activities, including bottom trawling. Historically, no trawling has occurred in this area. Cold water coral occurrence in this area is unknown, although recent observations of cold water corals in the Chukchi Sea indicate that this area may contain dense assemblages of cold water corals. Areas of high productivity and little ice scouring may contain cold water coral species, including petitioned species. Recent research in Bering Sea canyons expanded the northern range of many cold water coral species. It is possible that these species are also found in suitable habitat in the northern Bering Sea and Arctic Ocean. Although the current temporary fishing closure protects these species, there are no permanent protections in place. Given the rapid increase in interest in exploitation of the natural resources of the Alaskan Arctic, cold water corals must be considered when establishing fishery regulations in this delicate, and relatively unknown ecosystem.

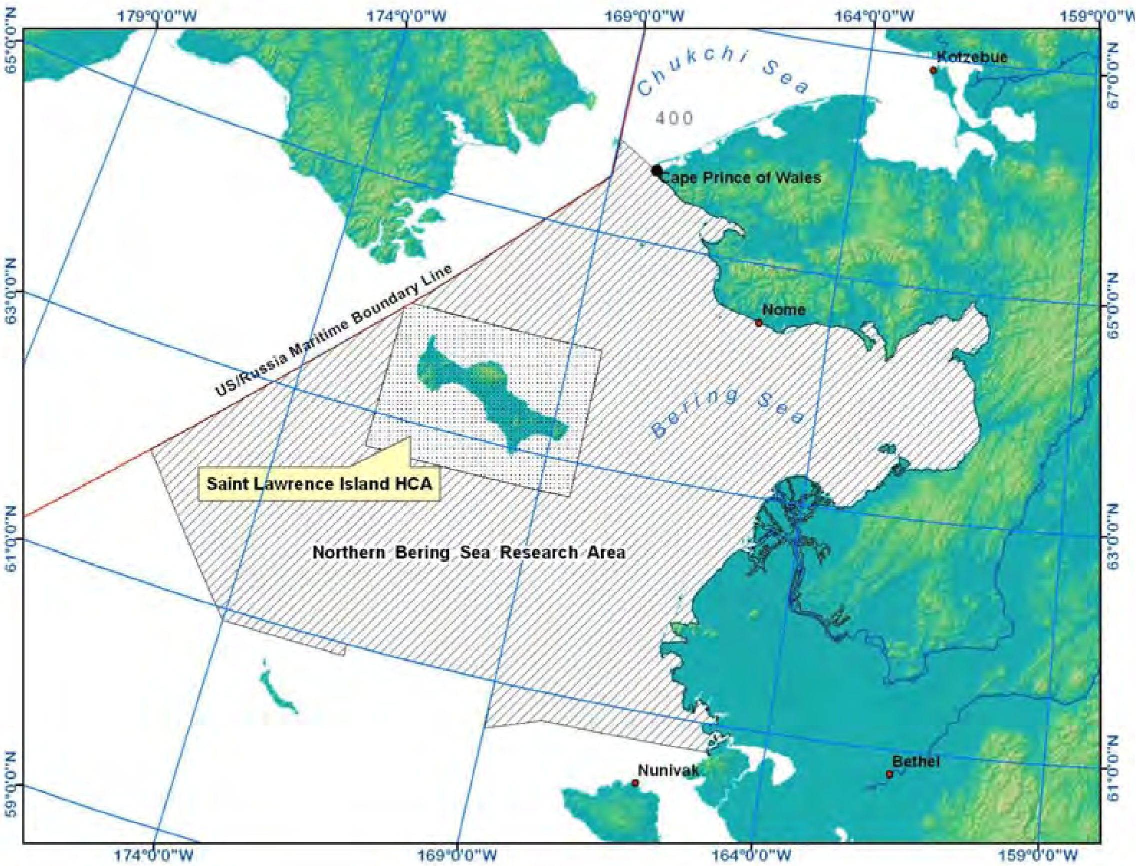

**Figure 24:** The Northern Bering Sea Research Area where future trawling is expected to be allowed if fisheries move farther north with ocean warming and sea ice melt. Figure from NOAA at http://www.fakr.noaa.gov/habitat/efh/regs.htm

In sum, vast areas of known coral growth, including the Bering Sea Canyons and waters near the Aleutians, remain open to bottom trawling, which results in destruction of many corals and degraded ecosystem function. Current protections for the petitioned species are therefore inadequate.

## 2. OTHER PROTECTIONS

### *a. Arctic Fishery Management Plan*

The entire Arctic Ocean was closed to commercial fishing in the Arctic Fishery Management Plan (FMP) in 2009. This would primarily protect true soft corals in the Arctic from future fishing. However, the Arctic FMP does not apply to the Gulf of Alaska or Bering Sea and therefore does not protect the known range of the petitioned coral species.

### *b. North Pacific Research Board*

The North Pacific Resource Board (NRPB) was established by Congress in 1997 to develop a comprehensive science program that provides a better understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems and their fisheries. NPRB's largest project to date examined cold water coral distribution and habitat in the central Aleutians Islands and was funded at $1.3 million. This was primarily a mapping project using submersibles, but it also examined the importance of coral and sponge habitat for commercially important species of fish, crab, and octopus, as well as impacts of fishing gear. These studies helped provide background information to the NPFMC when it approved closing large areas to trawling to protect coral and sponge habitats in the Aleutians in 2005. However, the NPRB has no power itself to enact protections and instead merely provides scientific information that the NPFMC.

### *c. National Marine Sanctuaries Act*

The National Marine Sanctuaries Act (NMSA), was passed in 1972. 33 U.S.C. §§ 1401 *et seq.* The NMSA authorizes NMFS to designate marine sanctuaries and promulgate conservation and management regulations for those areas. The NMSA includes a provision that allows NMFS to fund habitat restoration within sanctuaries, including coral reefs, with cost recovery from responsible parties. Recovered funds may be used to restore the damaged habitats or other habitats within national marine sanctuaries. *Id.* There are currently thirteen sanctuaries managed under the National Marine Sanctuaries Program, at least five of which contain coral communities (US Commission on Ocean Policy 2004). Coral research, monitoring, and management activities are conducted in these sanctuaries. However, there are currently no marine sanctuaries in Alaska.

Moreover, the NMSA has no provisions for projects designed to prevent physical or long-term chronic damages to reefs or coral communities from global warming, ocean acidification, nutrient overloading, or disease. (US Commission on Ocean Policy 2004). The continued loss of corals in marine sanctuaries indicates that the designations alone are not sufficient to arrest the decline and encourage the recovery of species. The designation of a sanctuary and its boundaries does not lessen the key threats such as bleaching and impaired calcification. Bleaching, and changes in the marine ecosystem that will impact the physiological processes of cold water corals, especially nutrient availability, will occur whether or not a coral is within a sanctuary. Thus, while the designation of marine sanctuaries and other marine protected areas is crucial to prevent some forms of direct human damage, the designation cannot protect corals from larger long-term global threats.

# GLOSSARY OF TERMS

ABYSSAL: Pertaining to water depths 2000-6000 m.

AHERMATYPIC: Corals that do not contribute to reef structure, most of which lack zooxanthellae.

ANASTOMOSES: The connections of separate parts of a branching system to form networks, as veins in leaves.

ANTHOZOAN: Member of the class Cnidaria including corals and sea anemones.

AMORPHOUS HYDROXYLAPATITE: A mineral with the formula [Ca10(PO4)6(OH)2; HA] that is a skeletal component of gorgonian octocorals.

ARAGONITE: A mineral form of calcium carbonate that is the major component of many coral skeletons. Aragonite is polymorphous to calcite, meaning they both contain the same main chemical elements, but have different crystal structures. Aragonite is more soluble than calcite in the seawater.

ARAGONITE SATURATION HORIZON (ASH): Depth boundary in the ocean between undersaturation and supersaturation of aragonite, below which aragonite goes into solution.

AXIAL: Extending from or related to the central coral structure.

AZOOANTHELLATE: Corals that do not contain endosymbiotic algae (zooxanthellate) but gain nutrients from catching organic particles and prey from the water.

BAMBOO CORAL: A type of octocoral in the family Isididae.

BATHYL: Pertaining to water depths 200-2000 m.

BENTHIC: Pertaining to the seabed.

BIOGENIC: Formed by the activity of living organisms.

BIOHERM: Body of rock generated by, and composed of, mostly sedentary organisms e.g. hard corals, calcareous algae or mollusks.

BROADCAST SPAWNING: Where corals release massive numbers of eggs and sperm into the water column. These gametes fuse in the water column to form planktonic larvae (planulae).

BROODING: May be internal or external where coral brood planulae within (internal) or on the surface (external) of the coral body. In contrast to broadcast spawning, which produces large numbers of eggs and planulae, brooding results in fewer, larger and better developed planulae.

BUSHY: Colonies with abundant branches arising immediately above the holdfast and not forming an obvious main stem.

BYCATCH: Non-target fish or other animals caught in fishing gear.

CALANOID: A zooplankton in the order of copepods that are dominant components of plankton in many parts of the ocean and important to marine food webs.

CALCITE: A form of calcium carbonate that is a component of octocorals sclerites and other coral skeletons. Calcite in coral often contains magnesium (Mg). Calcites with less than four mole percent $MgCO_3$ are known as low magnesium calcites, while those containing 4 to 30 percent are known as high magnesium calcite (see HMC).

CNIDARIAN: Member of the phylum Cnidaria, which includes all corals as well as hydroids, jellyfish and sea anemones.

COENENCHYME: The tissue-like layer connecting coral polyps. Also known as the coenosarcs.

COLD WATER CORAL: Azooanthellate corals that live in cold and often deep water.

COLLAGEN: A fibrous protein used to connect and support coral skeletal elements. A primary component of the axial skeleton of gorgonian corals.

CONTINENTAL SHELF: Deep-water edge of the continental shelf.

CORAL THICKET: Dense association of corals.

CYCLOSYSTEMS: The circular arrangement of pores in some stylasterid corals.

DENDROID: Possessing a branching structure like a tree.

DEMOSPONGE: The largest class of sponges in the phylum Porifera. These sponges have skeletons that are made of the protein sponging, the mineral silica, or both.

ENCRUSTING: Colonies consisting of a thick fleshy layer covering a hard substrate.

ENDEMIC: Species that only occur in one geographical area.

EPIFAUNA: Animals that live attached to the surface on the seabed.

FLABELLATE: Fan shaped.

GAMETE: Haploid cell that fuses with another gamete during fertilization in sexually reproducing organisms. Each gamete contains half the genetic information required to make the new (diploid) cell.

GAMETOGENESIS: Production of gametes

GASTROPORE: Pores in the hard skeleton of a hydrocoral (aka stylasterid) that accommodate the feeding polyps.

GONOCHROSTIC: Coral colonies that produce either all male or all female gametes. Not hermaphroditic where one colony may produce both male and female gametes.

GORGONIN: A complex protein that makes up the horny skeleton of gorgonian corals.

HMC: High magnesium calcite found in corals that contains 4 to 30 mol percent magnesisum (Mg). Corals in polar regions often have a higher percentage of HMC, which is related to changes in temperature and seawater saturation of carbonate ions. Corals with a higher percentage of HMC are more vulnerable to ocean acidification and decreasing calcium carbonate saturation concentrations than corals with aragonite or lower magnesium calcite skeletons.

HORNY: Resembling the material that makes up the horns of cattle.

HYDROCORAL: (synonym = stylasterid) Hydrozoan family of the phylum Cnidaria, including lace corals and the family Stylasteridae.

INTERTIDAL ZONE: (also called littoral zone) an area that is above the water at low tide and under the water at high tide.

PALMATE: Having a shape similar to a hand with fingers extended.

PENNATULACEAN: The common name for corals in the order Pennatulacea, also known as sea pens. Pennatulaceans are grouped with the octocorals (subclass Octocorallia), together with sea whips and gorgonians.

PHYTODETRITUS: Decaying organic matter originating from plants that slowly sinks to the ocean depths and is a food source for deep-sea benthic communities.

PLANULAE: Planktonic larvae produced by corals after gametes have fused

POLYP: Any individual of a cnidarian colony regardless of anatomical structure; a cylindrical body and an oral opening usually surrounded by tentacles.

PRIMNOID: Common name for corals belong to the family Primnoidae in subclass Octocorallia, order Gorgonacea.

ROBUST: Powerfully built, sturdy.

SATURATION HORIZON: The depth at which calcium carbonate becomes undersaturated with respect to aragonite, calcite and HMC. Waters deeper than the saturation horizon are undersatured, waters shallower than the saturation horizon are saturated.

SCLERACTINIAN: Stony corals that may be solitary or compound, with a skeleton composed of aragonite.

SCLERITE: A calcareous plate or spicule found in octocorals, and composed of calcite.

SCLERITIZATION: Hardening of the coral skeleton.

SESSILE: Fixed in one place or immobile.

SPICULE: A small needle-like structure of silicate or calcium supporting soft tissue.

THERMOHALINE CIRCULATION: Density-driven convective circulation system of the world’s oceans.

UNIPLANAR: Occurring in one plane

WHORL: An arrangement of three of more branches or polyps radiating from a single node.

ZOOPLANKTON: Plankton (free floating, drifting organisms) from the animal kingdom

ZOOXANTHELLAE: Endosymbiotic dinflagellate algae living within marine invertebrates including corals, sea anemones and giant clams.

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