State of Deep-Sea Coral and Sponge Ecosystems of the Alaska Region

Chapter 3 in The State of Deep-Sea Coral and Sponge Ecosystems of the United States Report

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Red tree coral with a school of juvenile Pacific cod. Courtesy of the Deepwater Exploration of Glacier Bay National Park expedition and UCONN NURTEC.

STATE OF DEEP-SEA CORAL AND SPONGE ECOSYSTEMS OF THE ALASKA REGION

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*Redbanded rockfish (*Sebastes babcocki*) taking refuge in a large red tree coral (*Primnoa pacifica*) detached from the seafloor in Dixon Entrance, eastern Gulf of Alaska.*

I. Introduction

The marine environment of the Alaska Region can be divided into three major geographical subregions – the Gulf of Alaska, the Bering Sea including the Aleutian Island Archipelago, and the Chukchi and Beaufort Seas in the Arctic. Deep corals are widespread throughout Alaska, including the continental shelf and upper slope of the Gulf of Alaska, the Aleutian Islands, the eastern Bering Sea, and extending as far north as the Beaufort Sea. The Aleutian Islands have the highest diversity of deep corals in Alaska, and possibly in the northern North Pacific Ocean, including representatives of all major taxonomic groups and at least 50 species or subspecies that may be endemic to that region (Stone and Shotwell 2007). Additionally, the Aleutian Islands harbor high density "coral gardens" that are similar in structural complexity to shallow tropical reefs and are characterized by a rigid framework, high topographic relief and high taxonomic diversity (Stone 2006). The Aleutian Islands also support the most abundant deep-water, ahermatypic (non-reef building) coral resources in high-latitude systems reported anywhere in the world (Stone 2014).

Stone and Shotwell 2007 (hereafter referred to as the 2007 Report) highlighted diverse coral communities in Alaskan waters including 141 unique coral taxa with gorgonians and stylasterid corals being the most species rich and abundant and demonstrated that each region of Alaska has important and unique coral habitats. Detailed descriptions of each major coral group were presented along with

figures for each sub-region based on catch records from National Oceanic and Atmospheric Administration (NOAA) research trawl surveys (1975–2004) and the 2004 sablefish longline survey, some published records from archived specimens, and in situ observations (R. Stone, unpublished records). The process revealed that very few records existed for the Alaskan Arctic (Chukchi and Beaufort Seas) and a limited but growing body of records existed for Gulf of Alaska seamounts. Both commercial and non-commercial fish and invertebrate species had been documented in deep-sea coral habitat at varying spatial degrees, but most documented associations were suspected to be facultative rather than obligatory.

The 2007 Report also concluded that the major stressor on deep coral communities in Alaska was commercial fishing activities with bottom trawls exhibiting the highest threat based on severity of effects, extent of effects, geographic extent of use, and overlap with coral habitat. Demersal longlines and long-lined pots ranked intermediate in terms of potential threat to deep coral habitats while mid-water trawls, single pot sets, and scallop dredges were considered to pose minimal threat to those habitats. The effects of other human activities on coral habitats were discussed with only climate change and associated effects of ocean acidification noted as being sources of real concern. Recent measures to protect coral habitat via Essential Fish Habitat (EFH) by the North Pacific Fishery Management Council were detailed with special reference to Habitat Areas of Particular Concern (HAPCs) that were implemented about the time the 2007 Report was published. Regional priorities to manage and conserve deep coral communities were outlined, with specific recommendations on future research activities that included studies on growth rates and reproductive ecology, taxonomy, the effects of ocean acidification and oil toxicity, the effects of specific fishing gear types on coral habitat, and a call for reconnaissance submersible dives in coral "hotspots" to assess their suitability as HAPCs. The 2007 Report also called for increased use of coral bycatch data from fisheries and stock assessment surveys as a source of mapping Alaska's coral resources but noted that this would require modifications to the way data were currently being collected and the implementation of new observer training programs and publication of new field guides. This update reviews and highlights new information since the 2007 report and through 2016.

II. Update on Scientific Information

II.1. New Research – Overview

Prior to 2012, few major field research efforts funded directly by NOAA had been initiated since the publication of the 2007 Report (see Figure 1). Several small programs, focused mostly on biological processes, have been established with limited funding from various sources. A major research initiative for Alaska was established for 2012–14 as part of NOAA's Deep Sea Coral Research and Technology Program. Here we report on new knowledge

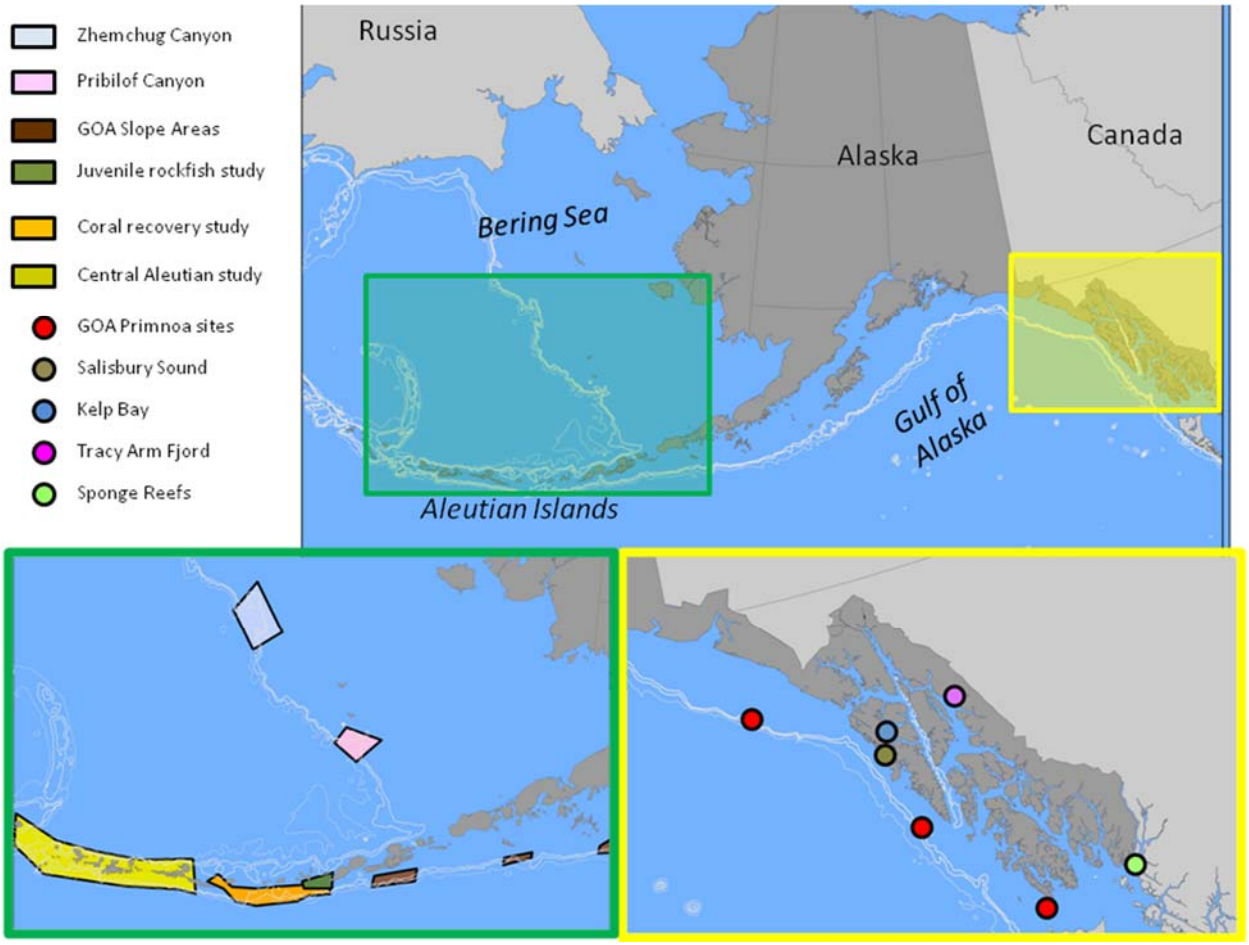

Figure 1. *Location of research projects completed or initiated since 2007.*

gained about deep corals (and sponges) in the past 8 years in Alaska that includes findings for studies done prior to the 2007 but excluded from the previous Report (Stone and Shotwell 2007), as well as new resource management measures, and we provide a new list of priorities for future research.

A major research program was initiated in 2003 to investigate coral habitat in the central Aleutian Islands using the manned submersible *Delta* and the remotely operated vehicle (ROV) *Jason II*. NOAA's National Marine Fisheries Service (NOAA/NMFS), the North Pacific Research Board, and NOAA's Undersea Research Program sponsored this research. A comprehensive report for this research was completed (Heifetz et al. 2007) with detailed manuscripts on damage to deep-sea coral and sponge habitats (Heifetz et al. 2009), modeling coral habitats (Woodby et al. 2009), and a comprehensive manuscript on the ecology of coral and sponge habitat (Stone 2014).

Greenpeace conducted research cruises to Pribilof and Zhemchug Canyons along the

Bering Sea continental margin in 2007 and 2012 to investigate seafloor habitats (Miller et al. 2012, Miller et al. 2015). NOAA scientists continue to collaborate with University of Maine scientists in studying the ecology of red tree coral (*Primnoa pacifica*) in shallow-water glacial fjord habitats. Additional small-scale field studies have been conducted on the biology of corals and associated species in areas closed to bottom trawling on the western Gulf of Alaska slope, rockfish habitat in the eastern Aleutian Islands and previously trawled areas in the eastern Gulf of Alaska.

II.1.i – The Alaska Coral and Sponge Initiative: a NOAA Deep Sea Coral Research and Technology Program regional fieldwork initiative in Alaska

From 2012–2015, NOAA's Deep Sea Coral Research and Technology Program and Alaska Fisheries Science Center conducted a field research initiative in Alaska to better understand the location, distribution, ecosystem role, and status of deep-sea coral and sponge habitats (Rooper et al. 2017). The initiative was developed in consultation with the North Pacific Fishery Management Council and targeted information that could inform management.

The Alaska Coral and Sponge Initiative was comprised of a series of research projects that began in the summer of 2012:

- One mapping cruise, two ROV cruises, and one drop-camera cruise to map areas of high abundance of *Primnoa* corals in the Gulf of Alaska and study the ecological function of these habitats.
- Two cruises to determine the distribution of high abundance and diversity areas of deep-sea corals and sponges in the Aleutian Islands through modeling and field sampling using towed/drift cameras.
- New estimates of the recovery rates and sustainable impact rate for *Primnoa* corals in the Gulf of Alaska through a landscape ecology approach.
- A field study to determine the productivity of commercial fishes from coral and non-coral habitats in the Gulf of Alaska.
- A field study to develop and test the feasibility of using a towed/drift camera system to estimate the effects of commercial long-line and pot fishing on deep-sea coral and sponge communities in the Gulf of Alaska.
- Conducted a genetic study of population connectivity of red tree corals (*Primnoa pacifica*) in the eastern Gulf of Alaska.
- Initiated collection of long-term data sets of oxygen and pH from summer bottom trawl surveys.
- Established a long-term monitoring station at a shallow-water fjord coral site in Southeast Alaska.
- Examined existing and newly collected data and specimens to improve the taxonomy of deep-sea corals and sponges and conduct paleoclimatological, reproductive ecology, trophic dynamics and marine natural products studies.
- Compiled a geologically based substrate map for the Gulf of Alaska and Aleutian Islands.

In addition to these projects, the Alaska Fisheries Science Center and the Deep Sea Coral Research and Technology Program collaborated on surveys and modeling of corals and sponges on the eastern Bering Sea slope and canyons at the request of the North Pacific Fishery Management Council.

II.2. Taxonomy and Species Distributions

II.2.i – Corals

a. Coral taxonomy

The 2007 Report listed 141 unique coral taxa including 11 scleractinians, 14 antipatharians, 15 alcyonaceans (including six stoloniferan taxa), 63 gorgonians, 10 pennatulaceans, and 28 stylasterids. The list included 52 taxa with incomplete taxonomy and several taxa that were only recently collected and awaited formal description. Since that time, Cairns and Baco (2007) described five new species of *Narella* from Gulf of Alaska seamounts previously known only generically and Etnoyer (2008) described a new species of bamboo coral (*Isidella tentaculum*), a major structure forming coral, previously known only generically from deepwater areas of the Gulf of Alaska seamounts and the Aleutian Islands. Additionally two major revisions were undertaken – one on the Primnoidae from the Aleutian Islands and Bering Sea (Cairns 2011) and another on the Stylasteridae from Alaska and adjacent waters (Cairns and Lindner 2011) – both added many new species and eliminated numerous synonyms.

Advances in coral taxonomy have been made in Alaska in the past 8 years but there are still a few species to describe, both in hand and known from video footage. The updated list (Stone and Cairns 2017 – Online Annex) now includes 137 unique coral taxa (Table 1) known from Alaskan waters but still includes three dozen species with incomplete taxonomy.

Table 1. *Updated summary of species richness and depth range for seven major groups of corals found in Alaskan waters. Data sources and references are found in the Online Annex 1.*

TAXA	Number of Species	Depth Range (m)
Black corals (Order Antipatharia)	12	22–6328
Stony corals (Order Scleractinia)	12	401–4784
Soft corals (Order Alcyonacea, in part)		
Suborder Alcyoniina	8	10–3209
Suborder Stolonifera	6	11–591
Gorgonian corals (Order Alcyonacea, in part)	61	6–4784
Sea pens and whips (Order Pennatulacea)	14	3–2947
Lace corals (Family Stylasteridae)	24	10–2124
Total	**137**	**3–6328**

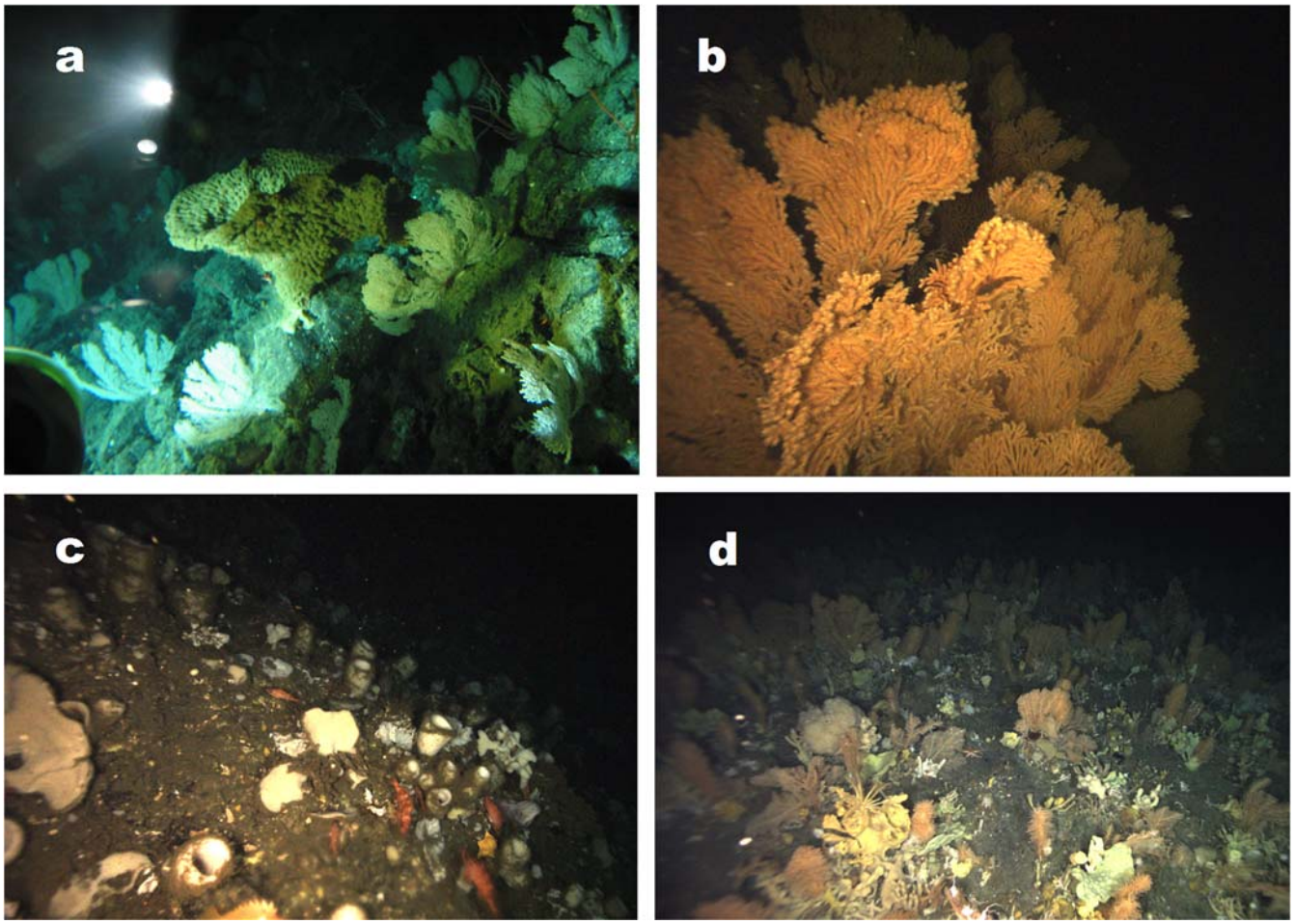

Figure 2. *Alaska seascapes: a) Rich sponge and coral habitat on Dickins Seamount in the Gulf of Alaska. b) Red tree coral (*Primnoa pacifica*) thicket on Shutter ridge in the Gulf of Alaska. c) Sponge habitat near Fairweather Ground in the Gulf of Alaska. d) Coral and sponge "garden" in the Aleutian Islands.*

Some taxa are still known only generically, possibly including some synonyms and names borrowed from other areas and used simply as placeholders. All major coral groups are in need of additional taxonomic work but the Alcyonacea and Pennatulacea are most in need of major revision. Additionally, the gorgonian families Plexauridae and Isididae are in need of taxonomic attention. Specimens are available to do the work but there is currently a shortage of taxonomists with expertise in these groups.

b. Coral distribution

The principal source of coral distribution information in Alaska continues to be catch data collected during annual research trawl surveys. Since the survey stations are located at the same approximate locations each year no new spatial information is available from that source when considered at the spatial scale of the surveys. These trawl surveys have been extended in recent years to cover new areas in the arctic and subarctic waters of the northern

Bering Sea, Chukchi Sea and Beaufort Sea. Trawl survey data are currently being used to develop models of coral and sponge distribution applicable to all Alaska regions (Rooper et al. 2014, Sigler et al. 2015). These trawl surveys have now been complemented by towed/drift camera surveys conducted in the Aleutian Islands (Goddard et al. in rev.) and eastern Bering Sea (Goddard et al. 2016).

Another tremendous source of coral distribution information is from commercial fisheries bycatch records maintained by the Alaska Fisheries Science Center and collected by observers as part of the Fisheries Monitoring and Analysis Division. Unfortunately, the taxonomic resolution presently used by observers provides little fine-scale information on coral distribution. NOAA initiated a pilot project in 2012 to improve the taxonomic identification capability of fisheries observers by providing them with training, a field guide, and a sampling protocol to test their ability (Stone et al. 2015). In general, the success of sample identification was low but highly variable. Long-term implementation of a coral identification protocol, like the one tested for this project, would require training resources beyond those currently available.

There have been few studies of population connectivity for Alaskan corals. Baco and Cairns (2012) concluded that haplotypes for corals of the genus *Narella* collected on seamounts in the Gulf of Alaska and Hawaii had relatively narrow depth and geographic ranges. Analysis of genetic connectivity for *Primnoa pacifica* in the eastern Gulf of Alaska is ongoing and genetic markers have been developed for this very important genus of octocorals (Morrison et al. 2015).

Spatial data from major projects completed prior to the 2007 Report are now available (e.g. Stone 2014, Stone et al. 2014a,b) and additional spatial data will also soon be available as part of another NOAA project to review the submersible-collected video archives throughout Alaska. Coral specimens with precise location data archived in the Auke Bay Laboratory (n = ~400) are also currently being re-cataloged and will soon be available for spatial analyses.

Bering Sea: The canyons and slope of the eastern Bering Sea were a major focus of new surveys and analysis. Greenpeace conducted a research cruise to Pribilof and Zhemchug Canyons along the Bering Sea continental margin in 2007 (Miller et al. 2012). High densities of corals (0.43 colonies m^{-2}) were reported from the canyons (combined) and principally included scattered groves of the pennatulacean *Halipteris willemoesi* and fields of the gorgonian *Plumarella aleutiana* on several transects. Miller et al. (2012) reported that Pribilof Canyon supported higher densities of corals (0.79 colonies m^{-2}) and sponges (0.53 individuals m^{-2}) than Zhemchug Canyon (0.07 colonies m^{-2} and 0.01 individuals m^{-2}, respectively). Most notably, the study documented several northern range extensions and new records for the region: 1) the scleractinian *Caryophyllia alaskensis* (a northern range extension); 2) the antipatharian *Lillipathes wingi* (northernmost record in the Pacific

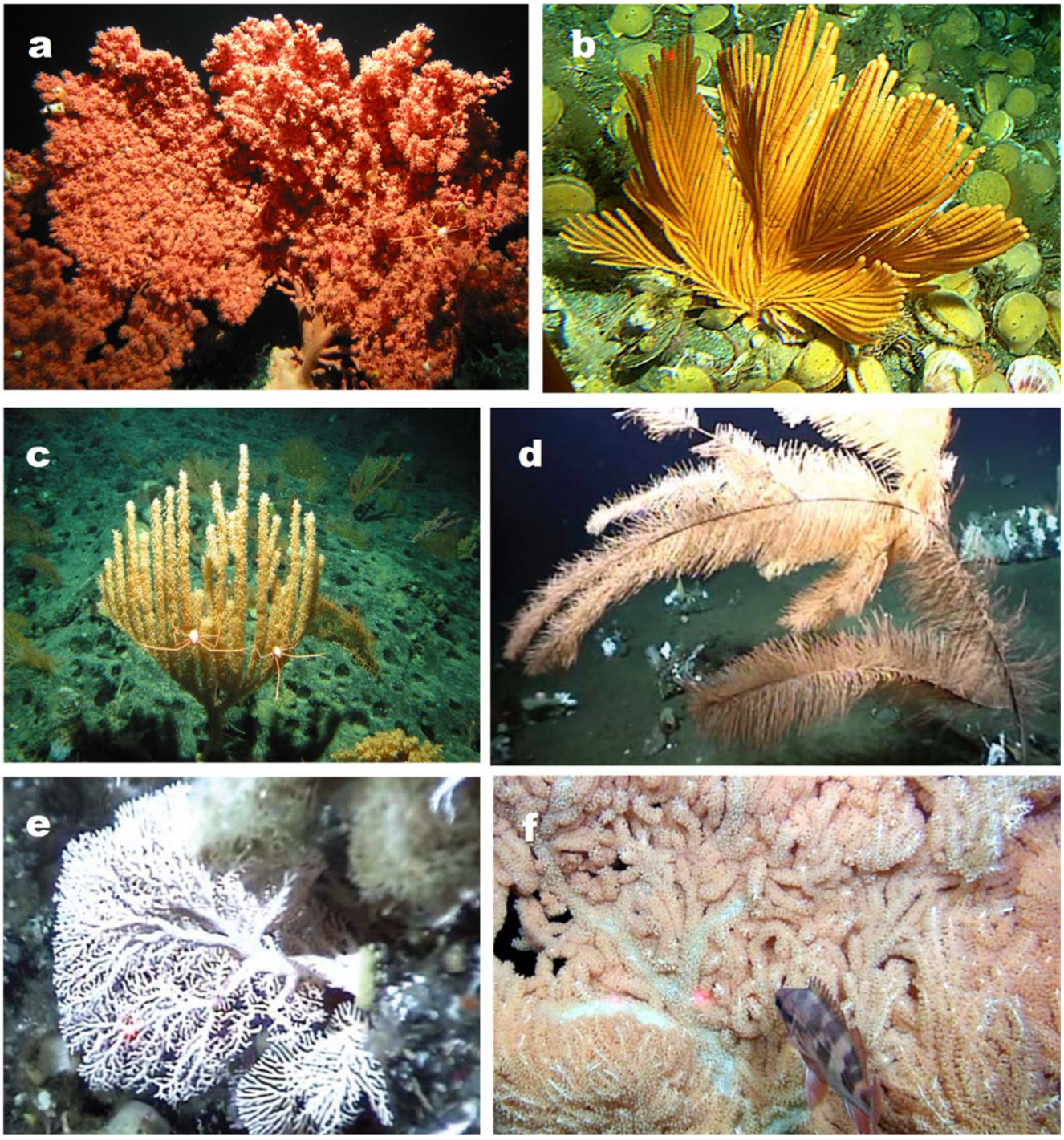

Figure 3. *Deep-sea corals of Alaska: a) Large bubblegum coral (*Paragorgia *sp.) from Pratt Seamount in the Gulf of Alaska. b) The gorgonian* Fanellia fraseri *in a bed of scallops, many encrusted with the sponge* Myxilla parasitica *in the Aleutian Islands. c) Gorgonian coral (*Isidella tentaculum*) with two galatheid crabs from Welker Seamount in the Gulf of Alaska. d) Black coral (*Parantipathes *sp.) at a depth of 1003 m in the Aleutian Islands. e) Stylasterid coral (*Stylaster campylecus*) at a depth of 681 m in the Aleutian Islands. f) Sharpchin rockfish in a large* Primnoa pacifica *in the Gulf of Alaska.*

Ocean); 3) the alcyonacean *Heteropolypus* sp. (=*Anthomastus* sp.; likely a northern range extension for the genus); 4) a stoloniferan *Clavularia* sp. (a new record for the region); 5) six gorgonians (*Plumarella aleutiana*, *Primnoa pacifica*, *P. wingi*, *Keratoisis* sp., *Swiftia pacifica*, and *Paragorgia arborea*) all representing new range extensions or new records for the region; and 6) two pennatulaceans (*Protoptilum* sp. and cf. *Pennatula* sp.), each representing a range extension.

Based on the findings of the Miller et al. (2012) study, the North Pacific Fishery Management Council requested analyses (Sigler et al. 2015, see below) and a model validation survey to determine if coral concentrations in two canyons in the eastern Bering Sea, Pribilof and Zhemchug, warranted further protection from fishing activity. The Council asked the AFSC to collect information on coral presence inside and outside the canyons, information on the height and density of corals, and the role of corals as fish habitat. They also asked scientists to document the presence and degree of fishing gear effects. The field survey was conducted in 2014 and the results were reported in Rooper et al. (2016), Goddard et al. (2016), and MacLean et al. (2017). A towed/drift stereo camera system was deployed at 250 randomly selected sites along the eastern Bering Sea shelf and outer slope. The results validated previous modeling and analysis work, confirming that coral habitat occurs both inside these two canyons and along the Bering Sea slope. In general, coral densities throughout our survey area were low where they occurred. This is not surprising as the eastern Bering Sea seafloor contains little (~2.8% of the total observed seafloor) of the rocky habitat that most corals require for attachment. The highest concentration of coral habitat was found in Pribilof Canyon and to the northwest along the slope. Sea whip densities were highest in sandy portions of the slope through-out our survey area. Most gorgonian corals observed were < 30 cm tall, while sea whips were as tall as 1.5 m. Direct evidence of fishing (mostly trawl tracks, but also derelict gear) was observed at 32 (12.8%) of the sample sites. In total, 2.9% of the corals and 0.3% of the sponges observed were damaged. About 9% of individual sea whips observed were classified as either damaged, dead or lying horizontal on the seafloor. It was difficult to determine if the damage was human-induced (e.g., fishing or other activity) or natural (e.g., sea star predation, ocean currents). There were very few places where both clear evidence of fishing activity (e.g., trawl tracks or fishing gear) and damaged coral, sponges or sea whips occurred (3.2% of the camera transects).

Aleutian Islands: The 2007 report identified the Aleutian Islands as the region with the highest abundance and diversity of corals in Alaska. Stone (2014) presented analyses of deep-sea coral and sponge habitats from video surveys conducted from 2002–2004 in the central Aleutian Islands, greatly expanding the geographic and depth (to 2947 m) range of earlier observations. Corals were widely distributed throughout the study area, with the highest density observed at depths between 400 – 700 m. An additional 18 coral and sponge gardens were identified.

In 2012 and 2014, camera surveys were conducted at 216 randomly-selected sites throughout the Aleutian Islands and Bowers Ridge, using protocols similar to those used on the eastern Bering Sea surveys. These surveys indicated that high-density coral and sponge communities were much more extensive than previously surveyed (Goddard et al., 2017). Survey data were used to ground-truth the coral and sponge distribution models developed for the Aleutian Islands (Rooper et al. 2014; see below).

Gulf of Alaska: In August 2010, there was an 8-day cruise aboard the chartered fishing vessel *Sea Storm* to investigate three slope areas closed to bottom trawling in 2007 in the western Gulf of Alaska. These slope areas (Shumagin, Sanak, and Unalaska) were identified by fishers to potentially contain coral and sponges in virtually pristine states, as fishing has not typically occurred in these areas. The objective of the cruise was to use video cameras to determine whether corals and sponges occurred in each of the three areas and to collect data that would allow predictive modeling of their distribution there. Upright sponges (vase or arborescent morphology) occurred at all three closed areas, although they were in relatively low abundances at the Unalaska and Shumagin areas. Deepwater corals were not found at the Shumagin area and were observed only at one site in Unalaska. Corals occurred at 14 of 30 sites in the Sanak area. Sponges were distributed across all depths where video was recorded, while corals were distributed only at the shallowest locations (< 150 m) in the closed areas. The corals observed were most commonly upright gorgonians with a fan-type morphology. Corals were present only where boulders were present and did not occur in areas with only sand and gravel substrates. Sponges occurred where both boulders and soft mud substrates were present, although they were also more likely to occur at locations with cobble or boulders present.

Areas supporting dense red tree coral (*Primnoa pacifica*) thickets in the eastern Gulf of Alaska, including the five small areas designated as HAPCs by the NPFMC in 2006, have been focal sites for studying some of Alaska's most important coral habitats. Extensive in situ work conducted there in 2005 (Stone et al. 2014a) revealed that seafloor habitats are dominated by red tree corals, hydrocorals (Stylasteridae), a few other octocorals (*Calcigorgia* spp., *Paragorgia* sp., and *Halipteris willemoesi*) in lower numbers, demosponges and in some areas dense sponge grounds of hexactinellids (mainly *Aphrocallistes vastus*, *Heterchone calyx*, and *Farrea occa*). The presence of red tree corals is highly associated with bedrock, high seabed roughness and slope (Masuda and Stone 2015) and the habitats formed by these corals and sponges provide essential habitat for some species of fish (Stone et al. 2014a).

Alaskan Arctic: New surveys conducted in the Chukchi Sea in 2009 and 2010 in association with proposed oil and gas leases (BOEM, 2012) revealed a patchy distribution of habitats structured by sedentary invertebrates. The soft coral (*Gersemia* sp.) was the primary coral species identified, with more diverse and dense coral and sea anemone communities at

nearshore sites and within Barrow Canyon. These findings were confirmed during a cruise in July 2012 led by Greenpeace.

II.2.ii – Sponges

a. Sponge taxonomy

NOAA's Deep Sea Coral Research and Technology Program provided funding for the publication of "A Guide to the Deepwater Sponges of the Aleutian Islands Archipelago" (Stone et al. 2011). The main purpose of the guide was to promote an awareness and appreciation of the importance of the sponge fauna in the North Pacific Ocean, particularly in the Aleutian Islands where the diversity and abundance of sponges appear to be extraordinary and where bycatch in existing fisheries continues to be a major concern for resource managers. The guide documented 196 sponge taxa from deep-water (> 80 m) in Alaskan waters (Table 2), but noted that the inventory is largely incomplete and that there are many species yet to be discovered in the region. Reiswig and Stone (2013) further described deep-water hexactinellid sponges from the central Aleutian Islands, including a new genus and eight new species in five families. A special collections project was initiated in 2012 to collect select sponge taxa in the Aleutian Islands aboard the biennial research trawl survey conducted there by NOAA. Nearly a dozen new species of sponges have already been discovered as part of this project (Lehnert et al. 2013; Lehnert and Stone 2014a, 2014b; Lehnert and Stone 2015).

Table 2. *Summary of species richness and depth range for classes of sponges found in Alaskan waters, based on Stone et al. (2011) and Reiswig and Stone (2013).*

CLASS	Number of Species	Depth Range (m)
Calcarea	12	5–250
Hexactinellida	52	20–2800
Demospongiae	130	0–2800
Homoscleromorpha	2	95–383
Total	**196**	**0 – >2800**

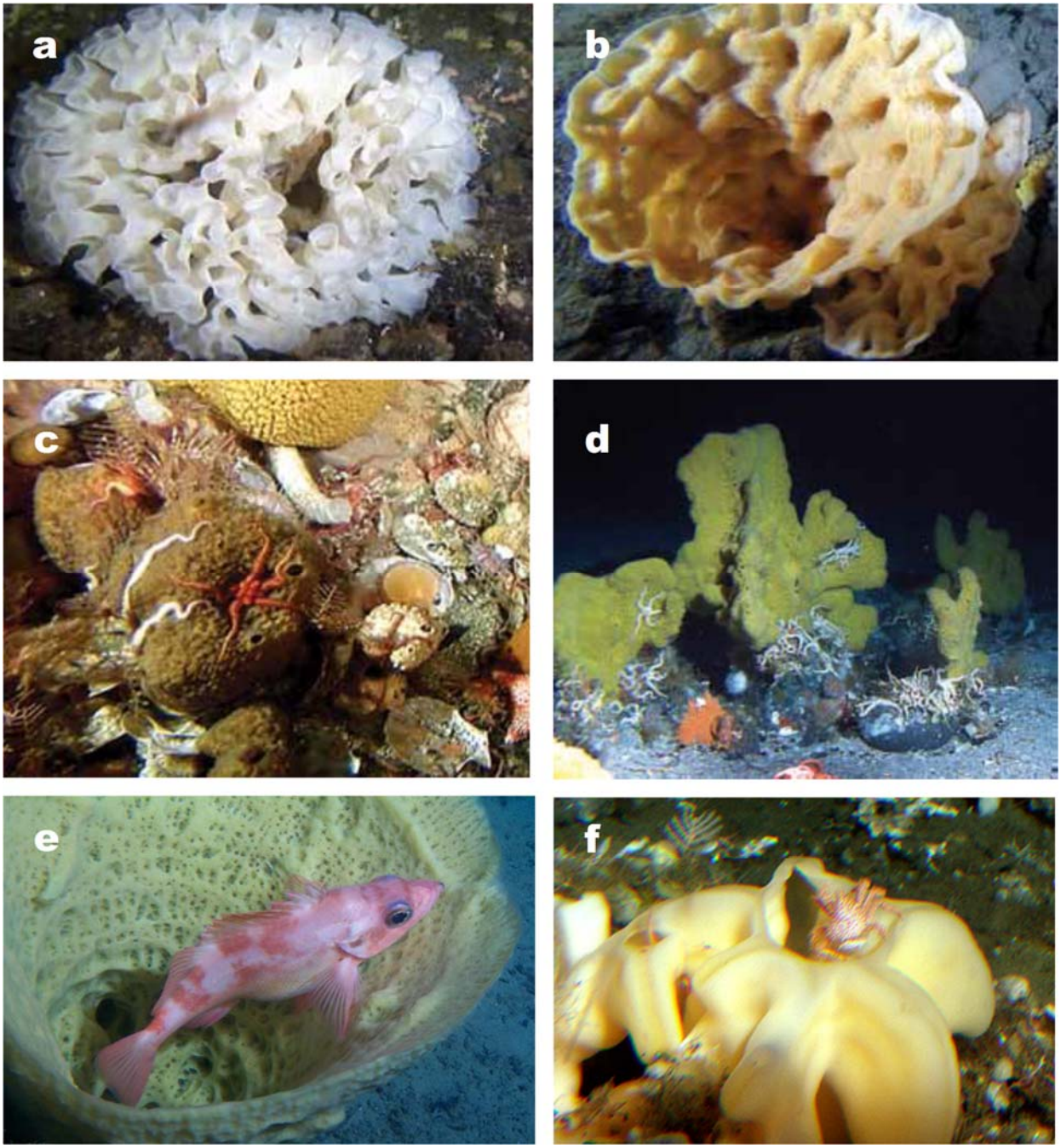

Figure 4. *Deep-sea sponges of Alaska: a) Hexactinellid sponge* Farrea occa occa *at a depth of 165 m in the eastern Gulf of Alaska. b) Glass sponge* Heterochone calyx calyx *at a depth of 181 m in the eastern Gulf of Alaska. c) Demosponge* Guitarra abbotti *at a depth of 146 m in the central Aleutian Islands. d) Demosponge* Mycale (Mycale) loveni *at a depth of 96 m in the central Aleutian Islands. e) Demosponge* M. loveni *with a gravid sharpchin rockfish (*Sebastes zacentrus*) at a depth of 170 m in the eastern Gulf of Alaska. f) Glass sponge* Aphrocallistes vastus *with a juvenile golden king crab (*Lithodes aequispina*) in pre-molt condition at a depth of 190 m in the central Aleutian Islands.*

b. Sponge distribution

Sponges are a major component of biogenic habitat or "living substrate" in the Gulf of Alaska, Aleutian Islands and the Bering Sea. Sponges are the most common taxon forming living substrate in the Gulf of Alaska and the Aleutian Islands (Malecha et al. 2005). Sponges reach high densities in the Aleutian Islands (Stone et al. 2011), and demosponges are a major component of the region's coral and sponge "gardens" (Stone 2014). Sponges are also common in the Bering Sea, with some areas of very high density in Bristol Bay. Sponges have also been reported from the Alaskan Arctic (de Laubenfels 1953, BOEM 2012), but appear to have occurred in low numbers at the sites sampled.

Bycatch in fisheries and fisheries-independent surveys is a major source of information on the location of the sponge fauna, and a source of specimens for study. The guide by Stone et al. (2011) served the additional purpose of providing fisheries observers and scientists with the information necessary to adequately identify sponge fauna so that the data can be included in existing databases. These data can be used to map areas of high abundance and the locations of indicator species of vulnerable marine ecosystems. The guide was also designed for use by scientists making observations of the fauna *in situ*, with submersibles including remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs).

A research cruise (March 2010) in Portland Canal along the border between Southeast Alaska and British Columbia, confirmed the presence of small sponge reefs detected a few years previously with sonar by the Geological Survey of Canada (Stone et al. 2014b). The reefs were similar in species composition to, but much smaller in size than, the massive bioherms reported farther south in British Columbia (Conway et al. 2005). Small patches of hexactinellid sponge reef, believed to be biohermal, were also observed in northern Southeast Alaska near Juneau, possibly indicating that these structures are more common than originally hypothesized.

II.2.iii – Modeling distribution and abundance of corals and sponges

Predictive habitat modeling for deep-sea corals and sponges provides an important tool for understanding the distribution of these organisms across Alaska's huge geographic regions. Since the 2007 report, there has been a significant expansion in the use and utility of predictive habitat models in Alaska (Guinotte et al., this report). These include presence-only models (Maxent) of coral taxa (grouped at the Order or suborder level) for the Gulf of Alaska, Aleutian Islands and eastern Bering Sea (Guinotte and Davies 2013); models for coral gardens in the Aleutian Islands (Woodby et al. 2009; Guinotte and Davies 2013); and models for coral and sponge presence, abundance and diversity in the Aleutian Islands (Rooper et al. 2014) and eastern Bering Sea slope and canyons (Sigler et al. 2015, Rooper et al. 2016). Rooper et al. (2016) presented one of the first examples of rigorous validation of coral and sponge habitat models, using camera surveys to assess the

accuracy of predictions from a model based on trawl surveys along the eastern Bering Sea slope.

The results of these modeling studies supported observations on the relative richness of coral and sponge habitats in the Aleutian Islands compared to most other regions, and predicted that these habitats were expected to be much more widespread in the Archipelago. The North Pacific Fishery Management Council utilized model results in its deliberations on potential protections for Bering Sea canyons.

II.3. Species Associations with Deep-Sea Corals and Sponges

In Alaska, commercial fisheries species are associated with deep corals and sponges at both fine-scales (less than 10 m, e.g. Stone 2006) and at the scale of existing fisheries (e.g. Heifetz 2002). Research conducted since or not reported in the 2007 Report continue to support earlier observations that fish and crabs, particularly juveniles, are associated with coral habitat throughout Alaska and are presumably using it as refuge and as focal sites of high prey abundance (Rooper and Boldt 2005; Rooper et al. 2007; Rooper and Martin, 2012; Miller et al. 2012; Stone 2014; Stone et al. 2014a). A study in the eastern Aleutian Islands found juvenile Pacific ocean perch used these habitats as nursery areas and were closely associated with boulders and rocky areas that were extensively covered with coral and sponge (Rooper et al. 2007). All of these studies have measured association at varying scales and have utilized different methods to test association but are noteworthy since these observations are not well quantified in many other regions and habitats where deep-sea corals occur. Not all demersal species are associated with coral habitat in Alaska. For example, Rooper and Martin (2009) found that shortspine thornyhead (*Sebastolobus alascanus*) catches were not associated with catches of corals and sponges in the Gulf of Alaska bottom trawl survey. Stone (2014) also found that some deep-water species in the Aleutian Islands are no more likely to occur with emergent epifauna than they are without emergent epifauna.

II.4. Ecological Studies (Growth, Reproductive Ecology, Microbial Ecology, and Marine Natural Products)

New studies on growth rates of Alaskan corals corroborated earlier observations from Alaska and elsewhere that they are slow-growing and consequently long-lived. Andrews et al. (2009) used ^{210}Pb techniques to determine the growth rate for two species of bamboo corals in the Gulf of Alaska (~1.4 cm y^{-1} axial growth rates for *Isidella tentaculum* and ~1.0 cm y^{-1} for *Keratoisis* sp.). Stone et al. (2017) analyzed the growth of tagged colonies of the shallow-water holaxonian *Calcigorgia spiculifera* in Southeast Alaska over a period of five years. The growth rate of 0.6 cm y^{-1} was the slowest rate reported for any gorgonian in Alaskan waters. Andrews and Stone (unpublished data) used growth ring counts to estimate a growth rate between 1.2–1.8 cm y^{-1} for the primnoid octocoral *Fanellia compressa* and Stone (unpublished data) used a

deglaciation record to estimate a growth rate for *Primnoa pacifica* that validated the rate previously established for the species (Andrews et al. 2002).

A study was undertaken on the reproductive ecology of stylasterid corals in the Aleutian Islands (Brooke and Stone 2007) that indicated that they are gonochoristic brooders with limited potential to provide sources of recruits to disjunct disturbed habitats. Studies on the reproductive ecology and ultrastructure of *P. pacifica* are being undertaken in shallow-water populations in the Tracy Arm fjords of Southeast Alaska (Waller et al. 2014) and should provide insights into the recovery dynamics of this important species.

The microbial ecology of corals was studied in both the Aleutian Islands (Gray et al. 2011) and on Gulf of Alaska seamounts (Penn et al. 2006). Both studies indicate that corals harbor unique and diverse bacterial communities that may provide the corals with a wide array of benefits including the facilitation of processes for a portion of their nutrition. The Alaska Fisheries Science Center and University of Mississippi have been routinely collecting sponges from survey trawls in the Aleutian Islands since 2004 and investigating their use as marine natural products, specifically as biomedicines. Dozens of sponge taxa have been investigated to date and a few have shown significant promise as antiviral, antimalarial, and antimicrobial agents (Na et al. 2010). Additional collections of demosponges from the Aleutian Islands are being analyzed and one species has already yielded extracts with evidence of bioactivity against opportunistic infectious diseases, malaria, and Hepatitis C (Abbas et al. 2011).

II.5. Research Priorities and Planned or Anticipated Research Activities

In preparation for the upcoming fieldwork under NOAA's Deep Sea Coral Research and Technology Program, a workshop was held in Anchorage in September 2010 to identify research priorities for the region, including critical information needs and research activities to address these needs (NOAA 2010). Key priorities included the following:

- Expanding our knowledge of the distribution of deep-sea corals and sponges and their habitats by analyzing existing information, new seafloor mapping and visual surveys, and by developing predictive habitat models. A geographic priority was placed on the Gulf of Alaska and Aleutian Islands.
- Determining the population characteristics of deep-sea corals and sponges, including growth rates, life history and reproductive traits, trophic dynamics, environmental tolerances, and population connectivity.
- Determining the key functions that deep-sea corals and sponges provide to managed species at different life stages.

These priorities were largely derived from ongoing research needs and objectives identified by the Program, the North Pacific Fishery Management Council, and the Essential Fish Habitat-Environmental Impact Statement process. They formed the basis of the 2012–2014 Alaska Coral and Sponge Initiative (Rooper et al. 2017).

III. Update on Management of Deep-Sea Corals and Sponges

III.1. New Information on Impacts and Stressors

III.1.i – Fishing

The 2007 Report indicated that the major stressor on deep-sea coral and sponge communities in Alaska was the impact of commercial bottom-fishing activities and new information continues to support this premise (Heifetz et al. 2009, Stone 2014, Rooper et al., this volume). Accordingly, studies on the effects of fishing on seafloor habitat continue to be a priority in Alaska with particular emphasis on the recovery rates of disturbed habitats. Studies were implemented to examine the recovery rate of sponges 13 years post-(experimental) trawling in low density sponge habitat in the eastern Gulf of Alaska (Malecha and Heifetz, unpublished data) and recovery from simulated trawl disturbance on the pennatulacean *Halipteris willemoesi* (Malecha and Stone 2009) and gorgonian *Calcigorgia spiculifera* (Malecha et al., unpublished data). In 2005, scientists used the submersible *Delta* to document ambient levels of disturbance to corals and sponges in eastern Gulf of Alaska *Primnoa* thickets set aside as HAPCs (Stone et al. 2014a). The HAPCs have been in an area closed to bottom trawling since 1998 so observations of disturbance represent those principally from longline fishing. Rooper et al. (2011) modeled the impacts of bottom trawling in the Aleutian Islands and subsequent recovery rates of corals and sponges and predicted recovery rates were slow, especially for corals, where the coral biomass would require decades to recover.

As with corals, the primary stressor on deepwater sponge communities in Alaska is likely physical disturbance by commercial bottom-contact fishing gear. The first National Bycatch Report (NMFS 2011) identified an average annual bycatch in 2003–2005 of over 525,000 lbs. (238,000 kg) of sponges. Bottom trawl fisheries in the eastern Bering Sea and Aleutian Islands fisheries had the highest sponge bycatch. Despite extensive bottom-trawl closures in the Aleutian Islands since 2006, updates to the National Bycatch Report (NMFS 2013, 2016) showed continued high levels of sponge bycatch in certain fisheries from 2010–2013.

III.1.ii – Other stressors

The effects of other human activities on coral habitats–deployment of pipelines and cables, point-source pollution discharges, fish processing waste disposal, mineral mining, and invasive species–continue to be of minimal or nonexistent concern, although interest in offshore petroleum drilling in the arctic regions of Alaska may present concerns regarding the presence of soft corals there. The Bureau of Ocean Energy Management (BOEM) approved a Shell Oil Chukchi Sea Exploration Plan; however, Shell Oil subsequently announced in September 2015 that it would cease exploratory offshore drilling in the Arctic. Climate change and the associated effects of ocean acidification on coral and sponge habitats continue to be sources of real concern, as discussed below.

III.1.iii – Climate change and ocean acidification

Decreases in oceanic pH and resulting decreases in calcium carbonate saturation state could have profound effects on corals dependent on the extraction of calcium carbonate from seawater for skeletal building. Corals will be affected differently depending on their skeletal composition (aragonite vs. calcite vs. magnesium calcite), geographical location, and depth relative to the already particularly shallow calcium carbonate saturation horizons in the North Pacific Ocean.

The skeletal composition is unknown for most species of deep-sea corals worldwide and is known for only a handful of the 137 taxa presently documented from Alaskan waters. To that end, a study was initiated in 2010 by sorting through the extensive archives at the Auke Bay Laboratories and Smithsonian Institution; 130 specimens comprising 61 taxa from all major groups of corals (scleractinians, gorgonians, true soft corals, stoloniferans, pennatulaceans, and stylasterid corals) were selected for laboratory analyses. Multiple specimens were selected for taxa of particular ecological importance (i.e. those that form large single-species assemblages), and specimens of the same species from multiple depth and geographic zones.

Laboratory analyses were performed at the Department of Geology and Geophysics at the Woods Hole Oceanographic Institution and the Center for Material Sciences and Engineering at the Massachusetts Institute of Technology. X-ray diffraction and full-pattern Rietveld data refinement were used to precisely determine the skeletal composition of Alaskan corals. Corals composed of high magnesium-calcite are the most soluble. Consequently, those corals, particularly those residing at depths deeper than the saturation horizon, are most at risk to decreases in oceanic pH unless they have adapted physiological processes to counter the effects.

The mineralogy data will be used in conjunction with species distribution data (depth and geographical) and the present and projected aragonite and calcite saturation horizons in Alaska to predict the effects of ocean acidification on coral resources of the North Pacific Ocean. At the completion of this project a comprehensive risk assessment will be conducted for all corals in Alaskan waters but physiological data are still needed for Alaskan coral taxa, probably in a laboratory setting, to determine if taxa respond as predicted by mineralogy and marine chemistry data. Principal Investigators of this research are Robert Stone (NOAA, AFSC), John Guinotte (Marine Conservation Institute), Angela Helbling and Anne Cohen (Woods Hole Oceanographic Institution), and Stephen Cairns (Smithsonian Institution).

III.2. New or Planned Management Actions

III.2.i – Fishing

A suite of closures were approved by the North Pacific Fishery Management Council in 2005, including the Aleutian Islands Habitat Conservation Area (AIHCA), and implemented on 28 July 2006. Since that time, five additional management activities involving spatial closures that potentially harbor deep coral and sponge habitat have been approved and implemented by the Council and NOAA.

Effective 20 March 2008, Amendment 88 to the Fishery Management Plan for Groundfish of the Bering Sea and Aleutian Islands Management Area revised the boundaries of the AIHCA to allow bottom trawling in a historically fished area (north of Agattu Island) and to prohibit bottom trawling in an area known to harbor coral and sponge habitat (west of Buldir Island). This action was intended to ensure that the intentions of the AIHCA to protect areas of coral and sponge habitat from the potential effects of bottom trawling were realized and to allow non-pelagic trawling to continue in areas

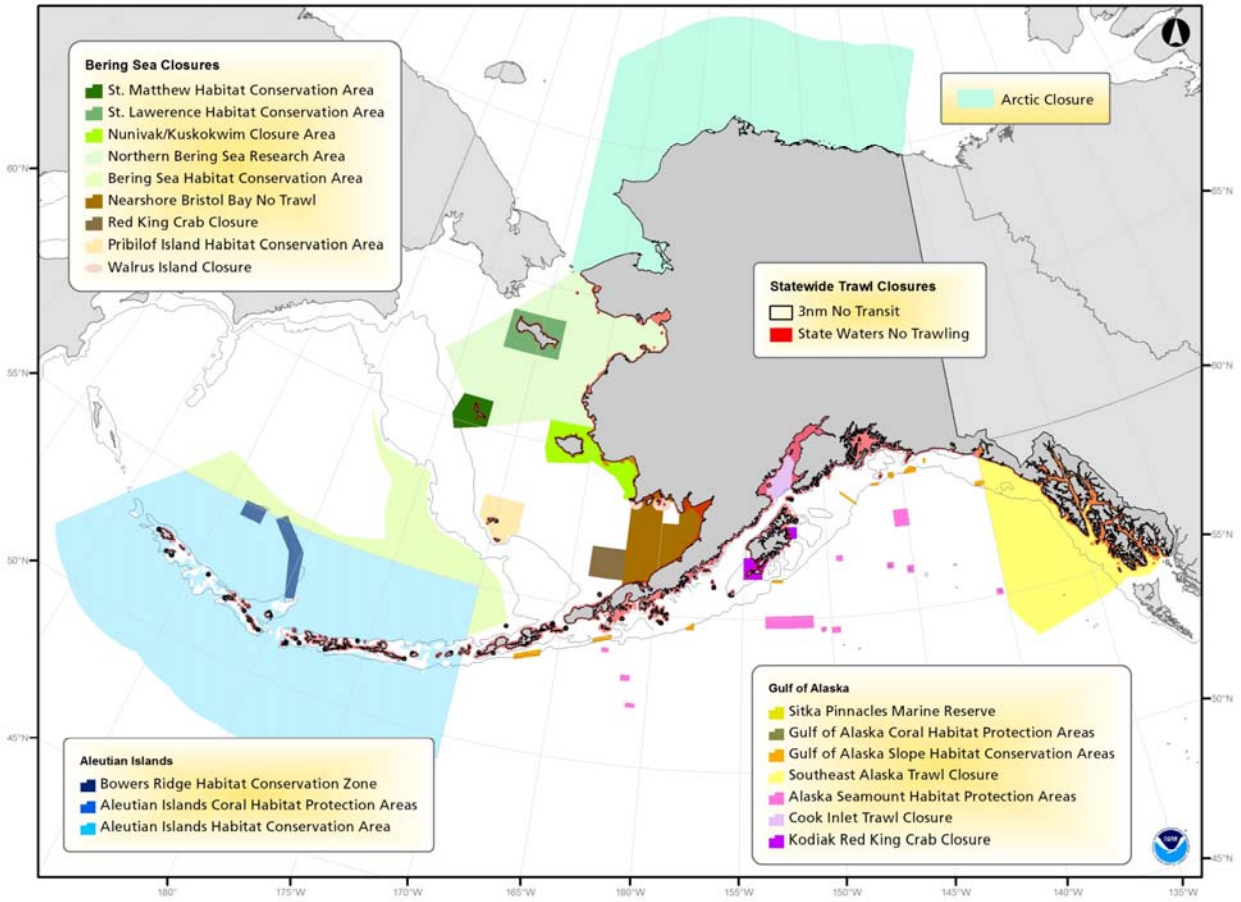

Figure 5. *Commercial fishing closures in Alaska (data provided by John Olson, NMFS-Alaska Regional Office, Anchorage, Alaska).*

historically fished. The opening of the area north of Agattu Island potentially puts coral and sponge habitat at risk since it has not yet been surveyed for coral and sponge habitat.

The Northern Bering Sea Research Area was implemented in 2008 and prohibited bottom trawling in a broad region there. The intention of the closure was to provide an opportunity to study the potential effects of bottom trawling on seafloor habitat before authorizing that activity there. The benthic fauna of the region is neither well studied nor known to harbor much coral or sponge habitat so the conservation relevance to these habitats is unknown.

In 2009, a new Arctic Fishery Management Plan for the Fish Resources of the Arctic Management Area (Chukchi and Beaufort Seas) was implemented, essentially closing all federal waters in the region to commercial fishing activities. The Council was concerned that changing ecological conditions could lead to the development of inadequately regulated commercial fisheries in the region that could have adverse effects including those on fish habitat. The benthic fauna of the region is not well studied and is not known to harbor much coral or sponge habitat, so the conservation relevance to these habitats is unknown.

In 2011, a trawl sweep modification requirement (Amendment 94) was implemented for vessels participating in the Bering Sea flatfish fishery that occurs exclusively on the broad and homogeneous continental shelf. The modification requires discs or bobbins providing 1–3" lift on the trawl sweeps to limit adverse effects on low-relief seafloor biota. This gear modification has been demonstrated to reduce impacts on patches of soft corals and sponges located in those habitats (Rose et al. 2013).

Effective 1 January 2011, trawling and longlining for two major forage species (Atka mackerel and Pacific cod) of endangered Steller sea lions were prohibited in the western Aleutian Islands. Concurrently, additional restrictions in 3-nautical mile (5.56 km) buffer areas around established sea lion rookeries went into effect in the central and eastern Aleutian Islands. The closures were not directly intended to protect seafloor habitat but will clearly provide sanctuary to coral and sponge habitat from bottom trawling in those areas.

The Council also examined whether habitat protections were warranted to conserve deep-sea corals in the Eastern Bering Sea canyons and slopes. Based on analyses by NOAA (e.g., Rooper et al. 2016), the Council concluded in 2016 that deep-sea corals in these areas are not at risk from fishing, and additional habitat protections were not necessary (MacLean et al. 2017).

NOAA is examining the effectiveness of the AIHCA to protect sensitive seafloor habitat from the damaging effects of fishing activities. The approach utilizes a geographic information system (GIS) to examine patterns of coral and sponge bycatch abundance and fishing intensity before and after the closures with particular reference to areas that have remained open to fishing.

III.2.ii – Other management actions

In 2016, the Department of Interior announced final regulations to ensure that future exploratory drilling activities on the Outer Continental Shelf within U.S. waters of the Beaufort and Chukchi Seas will be conducted under the highest safety and environmental standards and subject to strong and proven operational requirements.

IV. Conclusions

Research on corals conducted in Alaska since 2007, and particularly since 2012 with extensive new surveys under NOAA's Deep Sea Coral Research and Technology Program, continue to indicate that the region is home to diverse ecosystems supported by extraordinary coral and sponge resources. The resources appear to provide important habitat to fisheries of national and international importance. There are still many important gaps in our knowledge of these ecosystems and analysis continues.

V. Acknowledgements

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Online Annex – Comprehensive list of deep-sea corals in the U.S. Alaska region linked here: https://deepseacoraldata.noaa.gov/library/2017-state-of-deep-sea-corals-report

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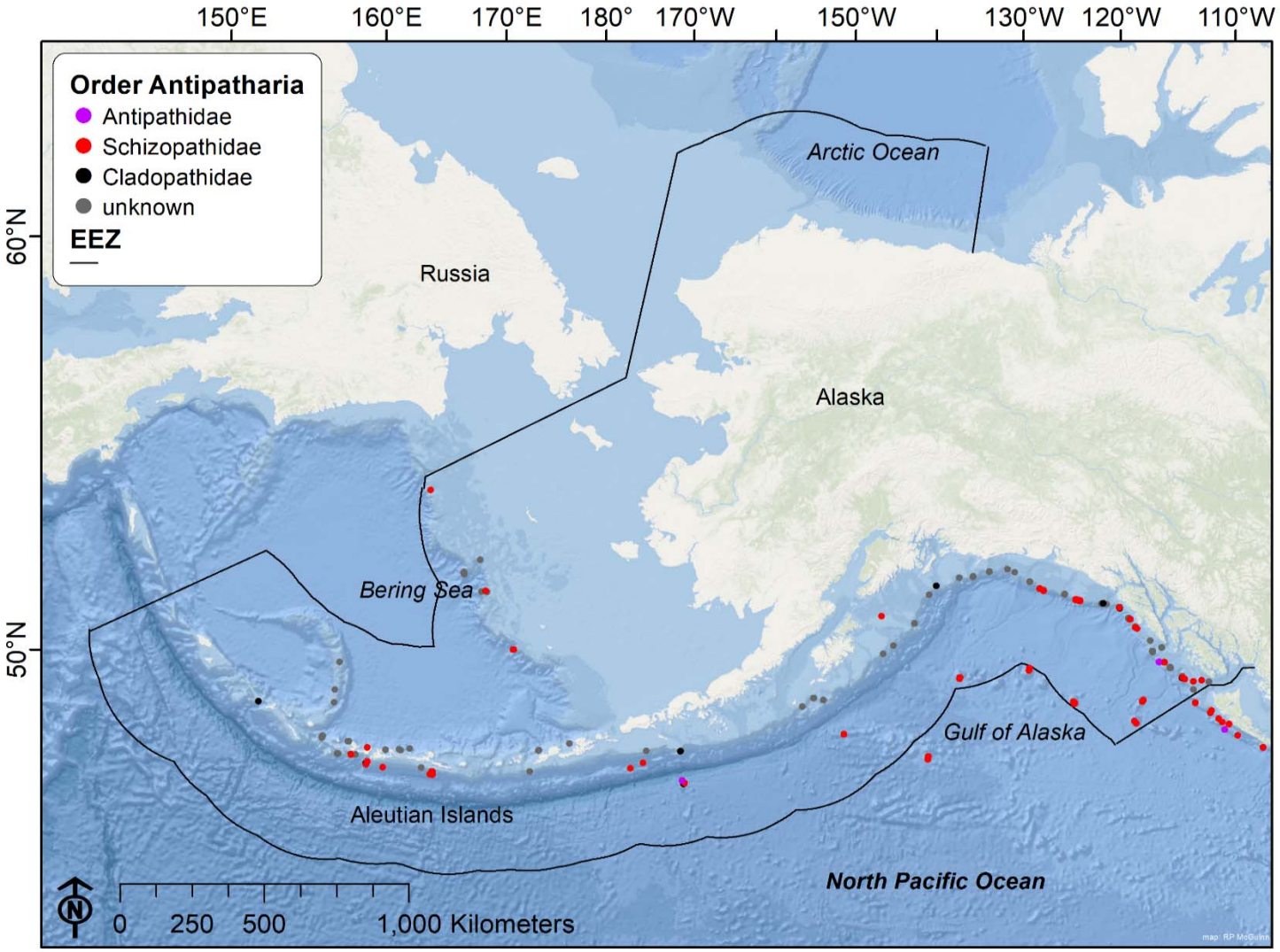
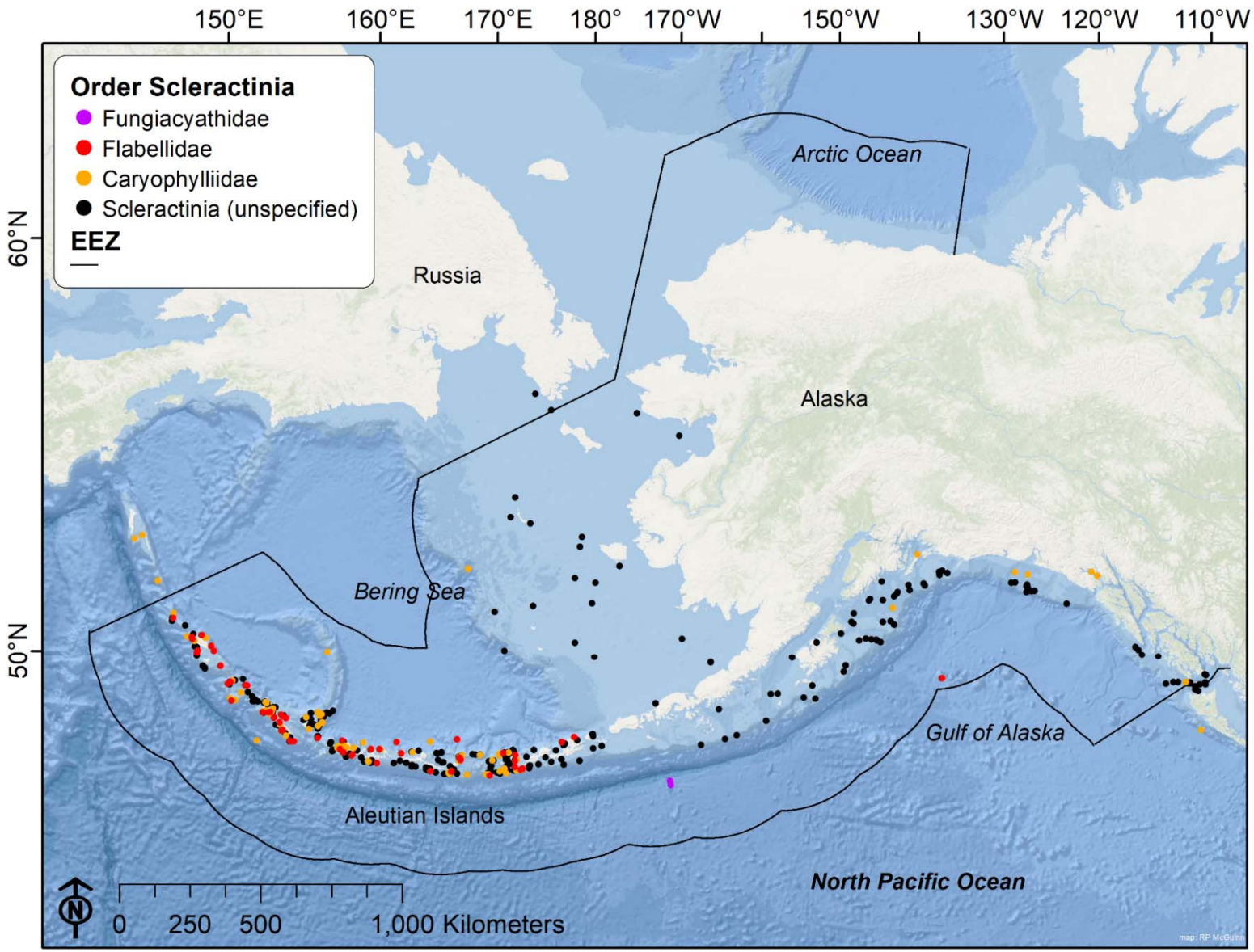
Online Annex 1. Deep-sea Coral Taxa in the U.S. Alaska Region: Depth and Geographic Distribution

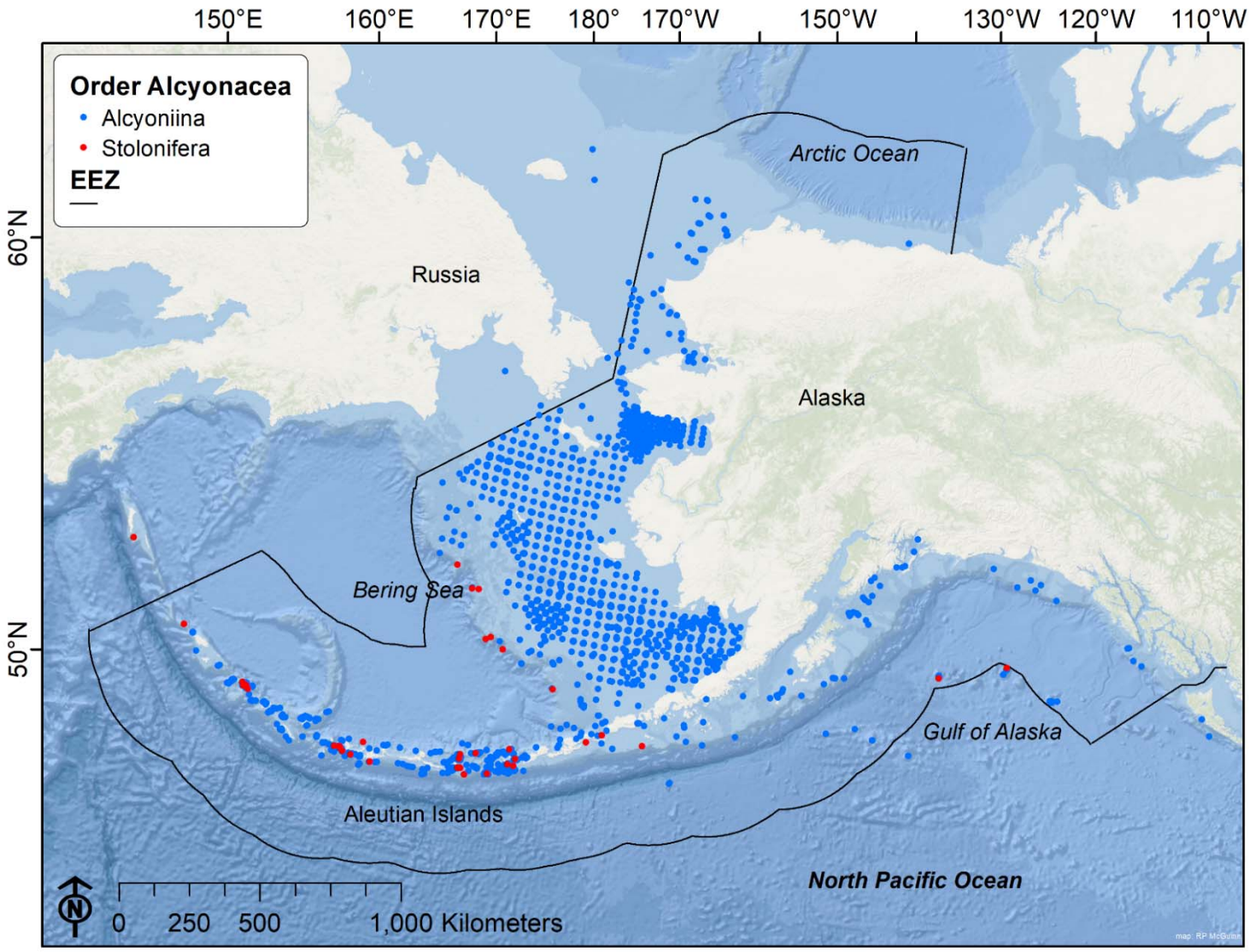
Appendix - Distribution maps for deep-sea corals and sponges in Alaska



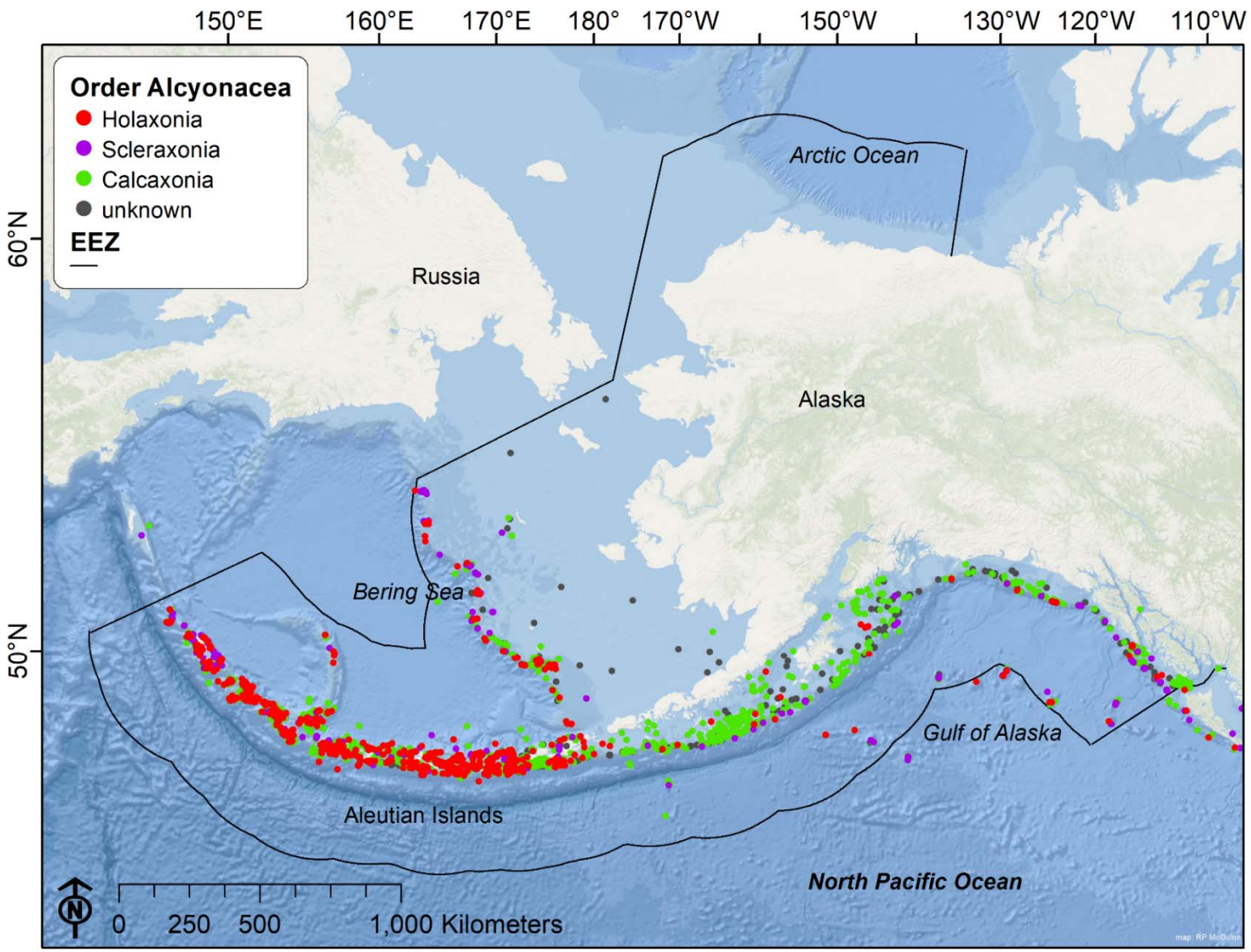
Map 1. *Locations of black corals (Order Antipatharia) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*



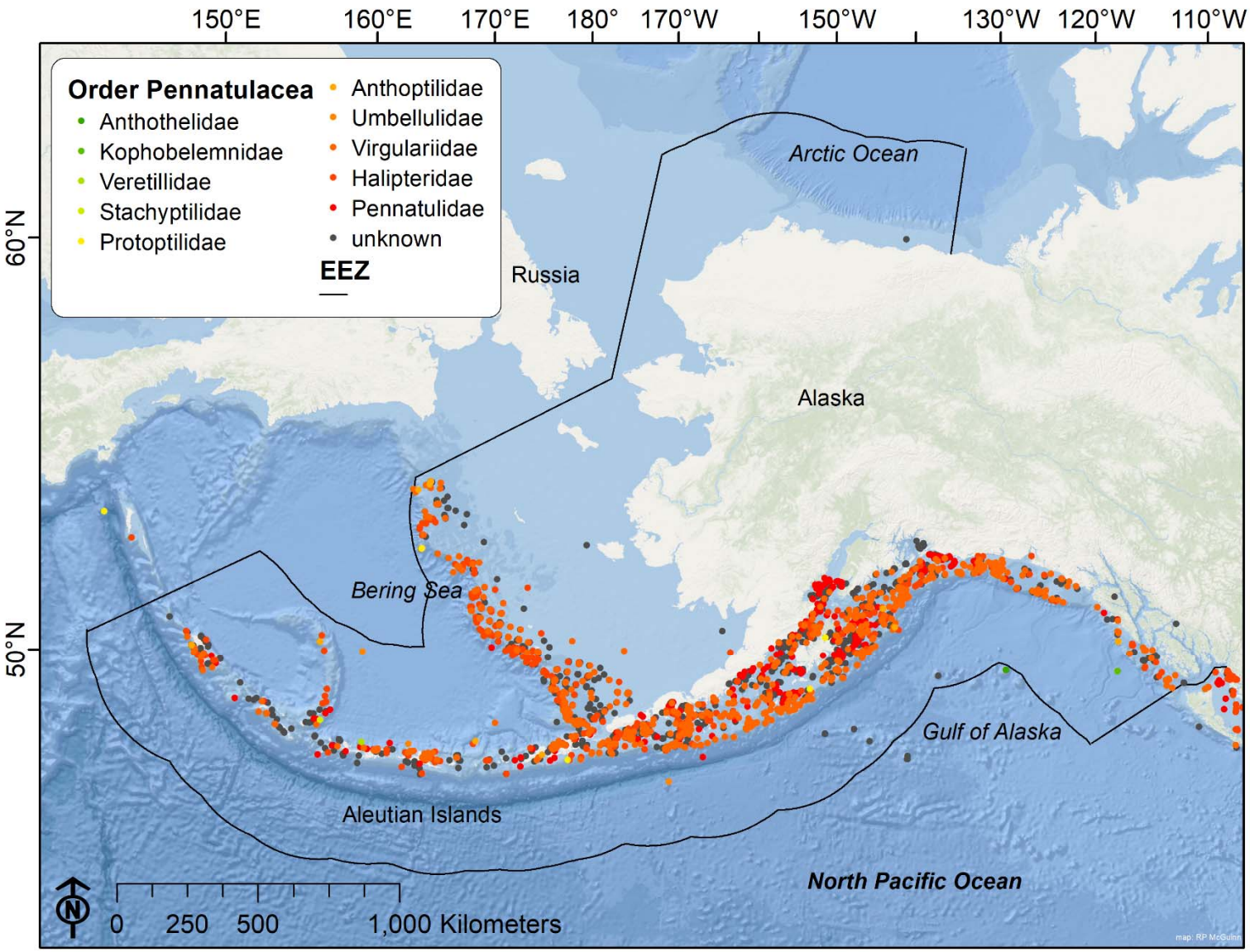
Map 2. *Locations of stony corals (Order Scleractinia) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*



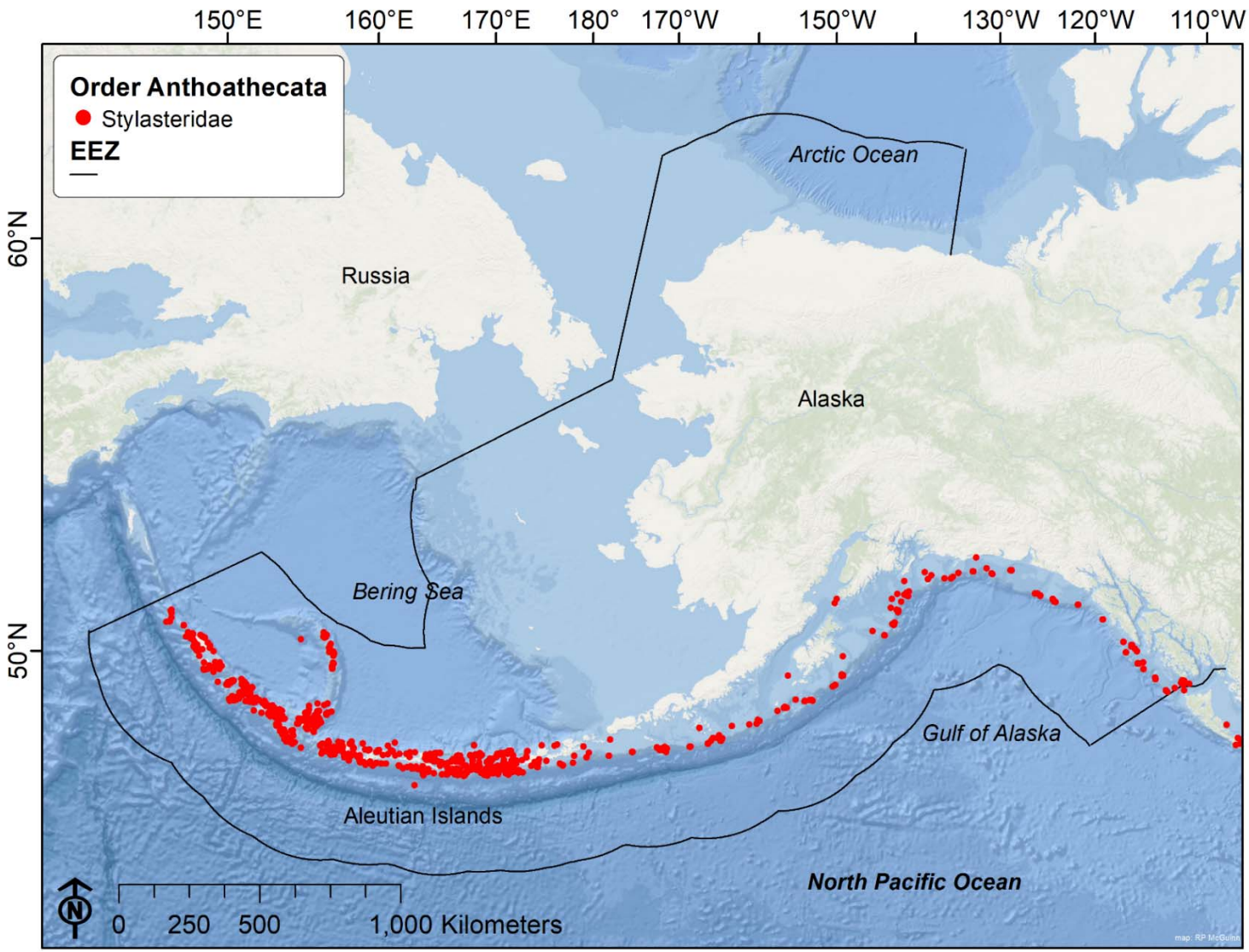
Map 3. *Locations of true soft corals (Order Alcyonacea) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*



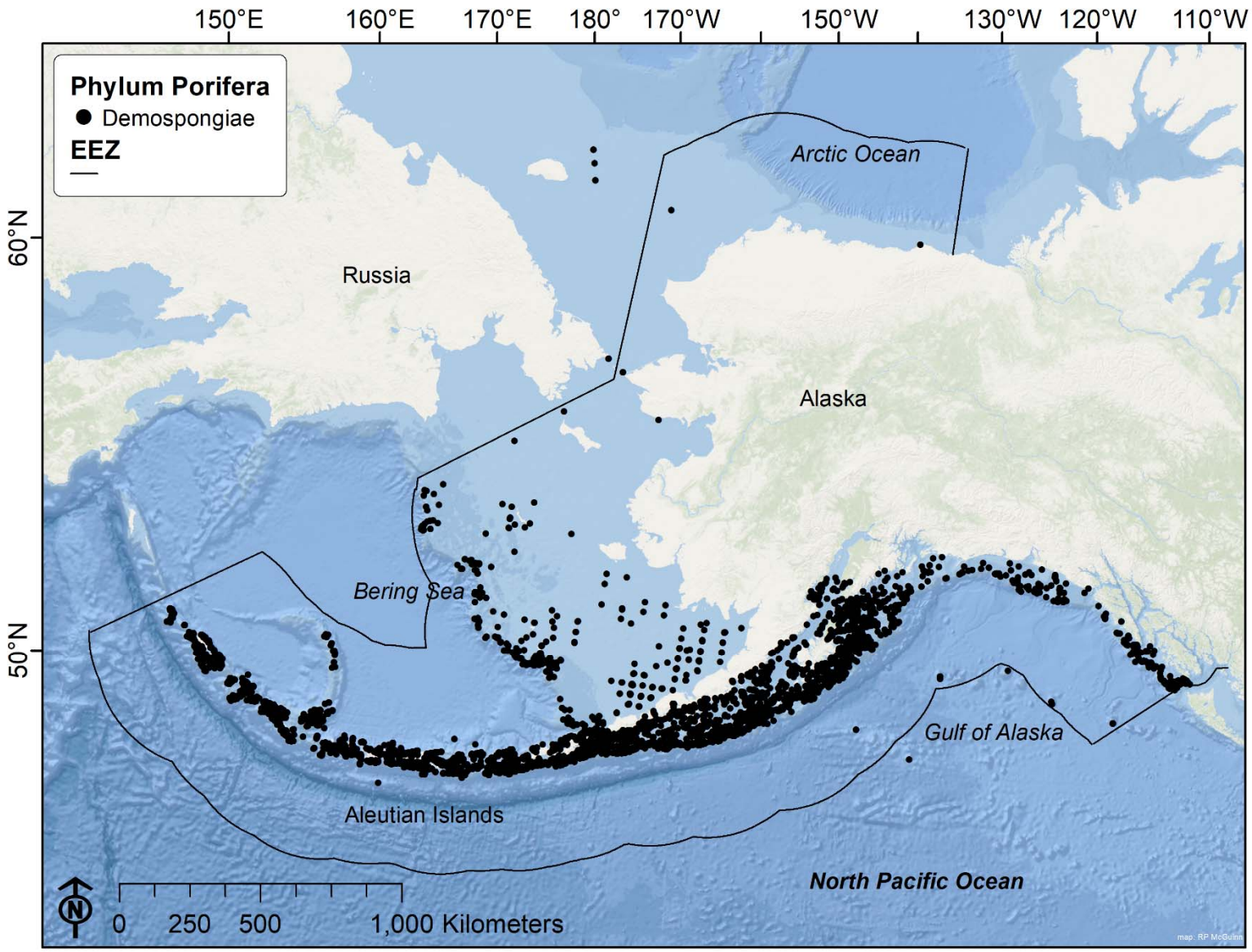
Map 4. *Locations of gorgonian corals (Order Alcyonacea, in part; formerly Gorgonacea) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*



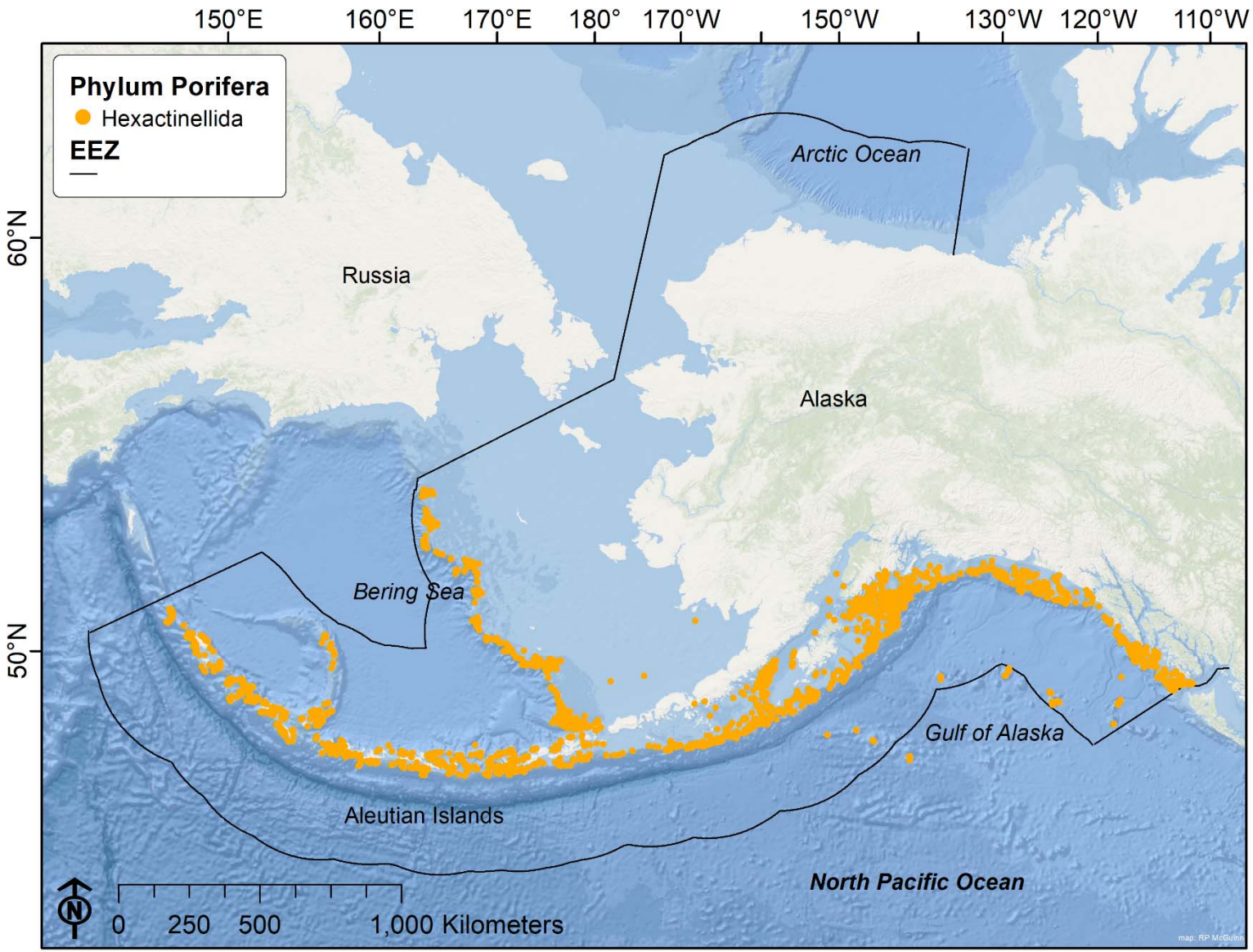
Map 5. *Locations of sea pens (Order Pennatulacea) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*



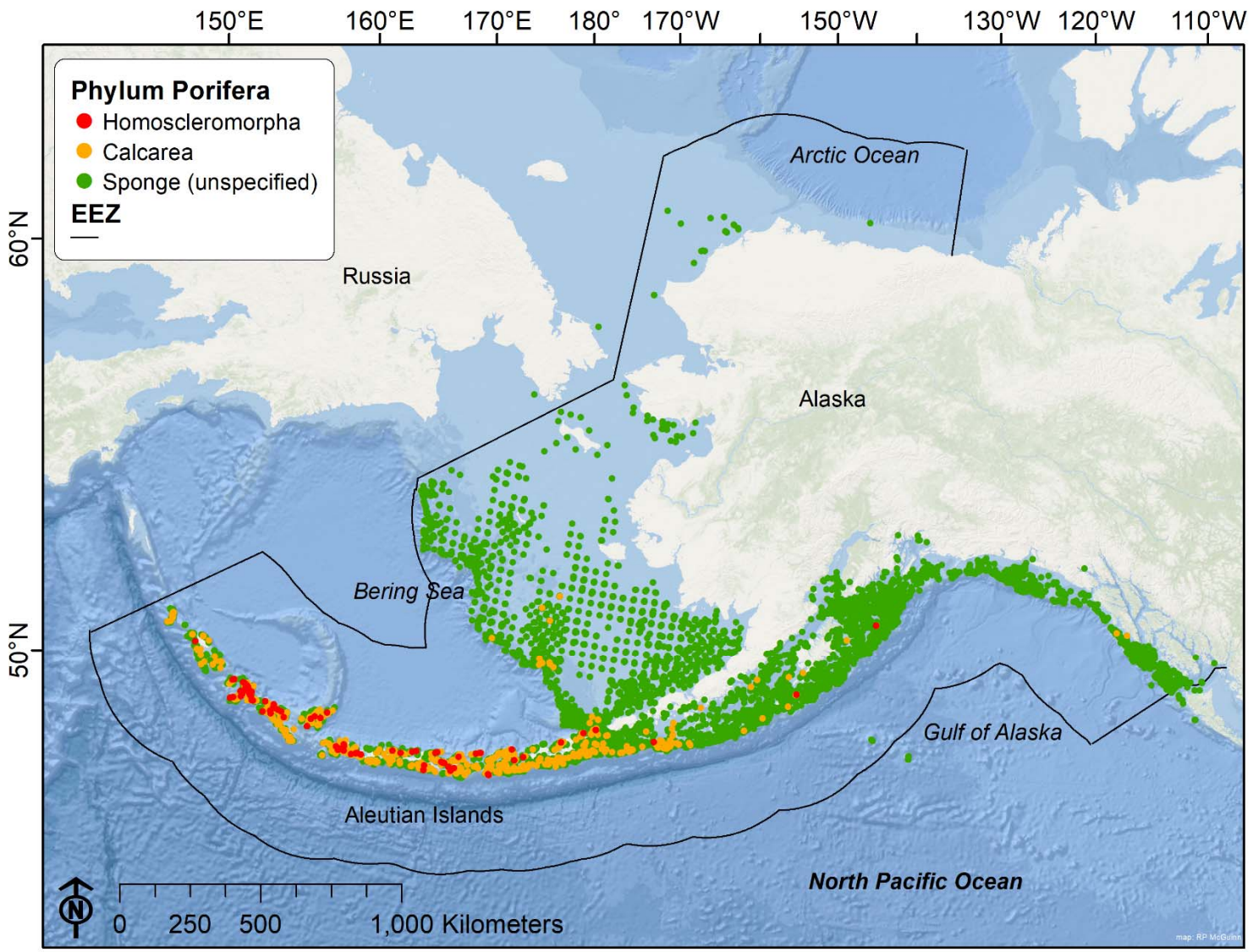
Map 6. *Locations of lace corals (Class Hydrozoa, Order Anthoathecata, Family Stylasteridae) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*



Map 7. *Location of demosponges (Phylum Porifera) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*



Map 8. *Location of glass sponges (Class Hexactinellida) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*



Map 9. *Location of calcareous (Class Calcarea) and unidentified sponges (primarily from trawl surveys) recorded in the National Deep-Sea Coral and Sponge Database (as of November 2017).*