STATE OF DEEP CORAL ECOSYSTEMS IN THE ALASKA REGION: GULF OF ALASKA, BERING SEA AND THE ALEUTIAN ISLANDS

Robert P. Stone and S. Kalei Shotwell

I. INTRODUCTION

Alaska is the largest state in the U. S. and contains more than 70% of the nation's continental shelf habitat. The state has 55,000 km of tidal shoreline and the surface area of marine waters in the U.S. Exclusive Economic Zone (EEZ) measures approximately 3.3 million km^2. The region has a highly varied submarine bathymetry owing to the numerous geological and physical processes at work in the three main physiographic provinces – continental shelf, continental slope, and abyssal plain. 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. Coral distribution, abundance and species assemblages differ among geographic regions. Gorgonians and black corals are most common in the Gulf of Alaska while gorgonians and stylasterids are the most common corals in the Aleutian Islands. True soft corals are common on Bering Sea shelf habitats. Overall, the Aleutian Islands have the highest diversity of deep corals in Alaska, and possibly in the North Pacific Ocean, including representatives of six major taxonomic groups and at least 50 species or subspecies of deep corals that may be endemic to that region. In the Aleutian Islands, corals form 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).

A few coral species were described from Alaskan waters as early as the late1800's (Verrill 1865; Dall 1884), but the true magnitude of Alaska's coral resources was not realized until the U.S. Fisheries Steamship *Albatross* brought back evidence of rich beds of corals in 1888. The *Albatross* Expedition continued through 1906 in Alaskan waters and collections made during that period initiated the first detailed taxonomic work on Alaskan octocorals (Nutting 1912) and hydrocorals (Fisher 1938). With specific regard to hydrocorals Fisher (1938) noted that "the North Pacific is far richer in indigenous species than the North Atlantic." Collections made since that time, mostly opportunistic rather than from directed expeditions, have resulted in subsequent taxonomic work on octocorals (Bayer 1952; Bayer 1982; Bayer 1996), antipatharians (Opresko 2005), and a synthesis on scleractinian corals (Cairns 1994).

Most information on coral distribution in Alaska is based on fisheries by-catch and stock assessment survey data. Consequently, our knowledge of coral distribution is largely limited, and somewhat biased, to those geographic areas and depth zones where fisheries and stock assessment surveys have occurred. Nonetheless, given the widespread nature of existing fisheries and surveys in the state, the distribution of coral from these sources provides a fairly accurate depiction of the true distribution of corals. Few directed studies have been undertaken until recently to examine the ecology and distribution of deep corals. Cimberg et al. (1981) compiled a synthesis of coral records from Alaskan waters specifically to address concerns about oil and gas exploration and development on the outer continental shelf. Some information on coral distribution has been opportunistically collected during nearshore scuba and submersible surveys focused on fish stock assessments, fish habitat

Auke Bay Laboratory, Alaska Fisheries Science Center
National Marine Fisheries Service
11305 Glacier Highway
Juneau, Alaska 99801-8626

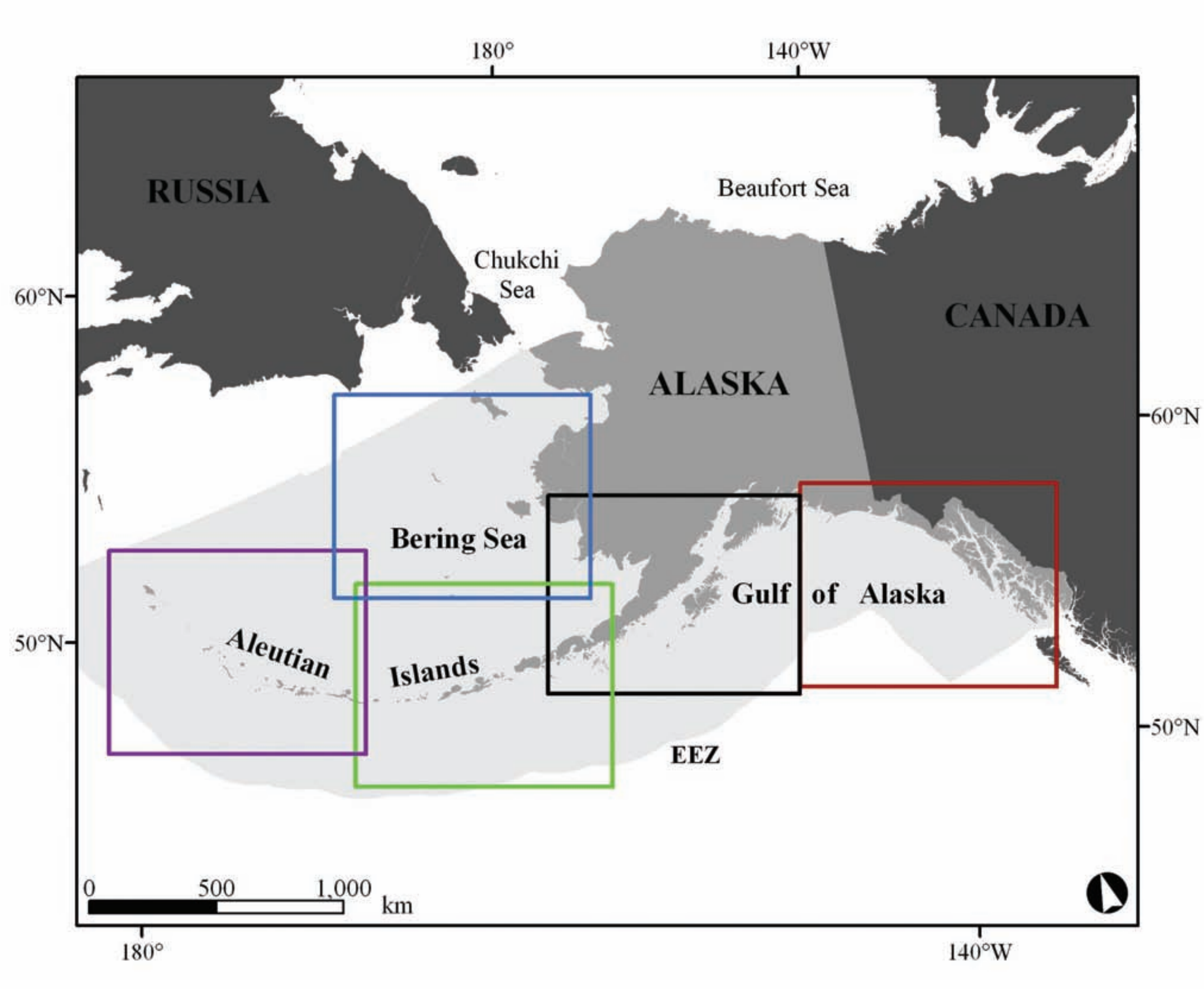


Figure 2.1. Map of Alaska showing the 5 broad geographical areas that were delineated for this report. From east to west – eastern Gulf of Alaska (red box), western Gulf of Alaska (black box), eastern Aleutian Islands (green box), western Aleutian Islands (purple box), and Bering Sea (blue box).

assessments, and studies on the effects of fishing gear on fish habitat.

Two major research programs were recently initiated in largely unexplored areas of Alaska and findings from those studies, although preliminary, have greatly increased our knowledge on the distribution of deep corals. Following an exploratory cruise in 2002, a multi-year study was initiated to investigate coral habitat in the central Aleutian Islands using the manned submersible *Delta* and the remotely operated vehicle (ROV) *Jason II*. The National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA/NMFS), the North Pacific Research Board (NPRB), and NOAA's Undersea Research Program (NURP) sponsored this research. In 2002 and 2004, a multi-discipline study using the manned submersible *Alvin* was launched to investigate seafloor habitat on North Pacific Ocean seamounts. A total of seven seamounts within the U. S. EEZ were explored during the two-year study. An additional seamount located south of the Alaska Peninsula was explored with the ROV *Jason II* in 2004. NOAA's Office of Ocean Exploration (OE) and NURP sponsored the seamount studies

In this chapter, detailed descriptions of deep coral habitat found in Alaskan waters are provided along with a discussion of their distribution, threats to deep coral habitat, and current management and conservation measures. Five broad geographical areas of Alaska (Figure 2.1) were delineated as follows: 1) the eastern Gulf of Alaska (GOA) including the inside waters of the

Alexander Archipelago, Southeast Alaska, 2) the western GOA including the Alaska Peninsula, 3) the eastern Aleutian Islands (Shumagin Islands to Seguam Pass), 4) the western Aleutian Islands (Seguam Pass to Stalemate Bank), and 5) the Bering Sea.

Coral records from these areas were categorized into the six major taxonomic groups. Three ecologically important groups of gorgonians, *Primnoa* spp., *Paragorgia* spp., and bamboo corals (Family Isididae) are categorized separately because their large size and conspicuous morphology greatly reduce the probability of inaccurate field identification.

The principal source of information on coral distribution is by-catch data collected during NMFS research trawl surveys (Resource Assessment and Conservation Engineering Database (RACEBASE)), Alaska Fisheries Science Center (AFSC), Resource Assessment and Conservation Engineering Division's Groundfish Assessment Program). Although RACEBASE includes records of research cruises since 1954, data collected prior to 1975 are not included in this report because the catch of corals was not always recorded and the accuracy of onboard coral identifications made before that time is questionable. By-catch data collected during the AFSC sablefish longline survey in 2004, published records, and unpublished *in situ* observations were also used to map coral distributions. There is very limited survey and fishery information from the Alaskan Arctic (Chukchi and Beaufort Seas).

II. GEOLOGICAL SETTING

The Gulf of Alaska

The Gulf of Alaska has a broad continental shelf extending seaward up to 200 km in some areas and contains several deep troughs (National Academy of Sciences 1990). In the eastern Gulf of Alaska, the Pacific Plate moves roughly parallel to the North American Plate, along the Fairweather-Queen Charlotte fault, and forms an abrupt continental slope with an abbreviated shelf (NURP 1996). In the northern and western parts of the Gulf of Alaska, the two plates slide, rather than slip past each other, and form a convergent margin and subduction zone (NURP 1996). Gulf of Alaska continental shelf habitats include steep rock outcrops, smooth turbidite sediment scapes, and methane seeps (NURP 2001). The nature of the seabed on the Gulf of Alaska shelf has been strongly influenced by glaciation and high rates of sediment deposition. The Gulf of Alaska also contains approximately 24 major seamounts arranged in three chains extending north from the Juan de Fuca Ridge. The seamounts are volcanoes rising from the abyssal plain that were likely formed as the Pacific Plate moved over mantle hotspots.

The Bering Sea

The Bering Sea is a shallow sea and has one of the largest continental shelves in the world – 1200 km long and 500 km wide (National Academy of Sciences 1990). The continental shelf breaks at approximately 170 m depth and seven major canyons, including the Zhemchug and Bering Canyons—the two largest submarine canyons in the world (Normark and Carlson 2003), indent the continental slope (Johnson 2003). The continental shelf is covered with sediment deposited by the region's major rivers (Johnson 2003) and therefore has limited hard substrate for coral attachment. The Aleutian Island Archipelago contains more than 300 islands and extends over 1900 km from the Alaska Peninsula to the Kamchatka Peninsula in Russia. The Archipelago is supported by the Aleutian Ridge and it forms a semi-porous boundary between the deep North Pacific Ocean to the south and the shallower Bering Sea to the north. The Aleutian Ridge is a volcanic arc with more than 20 active volcanoes and frequent earthquake activity that was formed along zones of convergence between the North American Plate and other oceanic plates (Vallier et al. 1994). The island arc shelf is very narrow in the Aleutian Islands and drops precipitously on the Pacific side, to depths greater than 6000 m in some areas, such as the Aleutian Trench.

The Alaskan Arctic

The Bering Strait separates the Bering Sea from the Chukchi Sea. The Chukchi Sea is a shallow shelf (only 20 to 60 m deep). The continental shelf in the Beaufort Sea is fairly broad (80-140 km wide) and is a submarine extension of the North Slope coastal plain (Horowitz 2002). Sediments on the continental shelf are predominantly soft and fine-grained and are redistributed by long-shore currents, wave action, entrainment in bottom-fast ice, ice gouging, ocean currents, and internal waves (Horowitz 2002).

III. OCEANOGRAPHIC SETTING

Major oceanic currents are found in all three subregions of Alaska and variations in their circulation control the climate and oceanic patterns in the North Pacific and Arctic Oceans. Currents likely influence larval dispersal and consequently the distribution of deep corals. Major oceanic currents influence the water temperature regimes in the subregions that may affect the growth rates for some species of deep corals.

The Gulf of Alaska

Two primary ocean currents exist in the Gulf of Alaska that flow around the Alaska Gyre. The Alaska Current is a wide (>100 km), slow moving (0.3 m s^{-1}) current that flows northward off the shelf of the eastern Gulf of Alaska. It becomes the Alaska Stream west of Kodiak Island where it narrows (<60 km), increases speed (1 m s^{-1}) and continues to flow westward south of the Alaska Peninsula and Aleutian Island Archipelago (Royer 1981). Continental shelf circulation is strongly influenced by freshwater input, and nearshore currents are additionally influenced by shelf bathymetry (Allen et al. 1983). Some areas of the Gulf of Alaska have among the largest tides in the world (Cook Inlet has the 2nd largest tidal amplitude in North America, after the Bay of Fundy in Atlantic Canada) and circulation is strongly tidally influenced in those areas. Several physical processes enhance regional nutrient supply and primary productivity and include costal upwelling, river discharge, tidal mixing, estuarine circulation, mesoscale eddy formation and transport, and recirculation around the Alaska Gyre (Whitney et al. 2005).

The Bering Sea

The Aleutian Archipelago forms the boundary between the deep North Pacific Ocean and the shallower Bering Sea. Deep water flowing northward in the Pacific Ocean encounters the Aleutian Trench where it is forced up onto the Aleutian Ridge and into the Bering Sea through the many island passes (Johnson 2003). Additionally, coastal water from the Alaska Stream enters through Unimak Pass in the eastern Aleutians and slowly (0.01 to 0.06 m s^{-1}) flows northeastward along the Alaska Peninsula. The Aleutian North Slope Current flows eastward on the north side of the Aleutian Islands towards the inner continental shelf of the Bering Sea. This is a swift current (0.5 m s^{-1}) and the steep continental slope forces much of the flow into the northwest flowing Bering Slope Current (Johnson 2003).

The Bering Slope Current flows northwestward off the shelf break and together with currents on the northern shelf flows northward through the Bering Strait and into the Chukchi Sea (Kinder and Schumacher 1981). Tidal currents dominate circulation in the southeastern shelf area of the Bering Sea (Kinder and Schumacher 1981). On the outer shelf currents flow along isobaths to the northwest at speeds up to 0.1 m s^{-1}.

The Alaskan Arctic

North Pacific waters flow from the Bering Sea, across the Bering Strait and into the Chukchi Sea in the Arctic. Consequently, the Chukchi Sea has more faunal affinities to the North Pacific than to the deeper Beaufort Sea. Different circulation regimes exist on the inner and outer continental shelves of the Beaufort Sea (Aagaard 1984). Circulation on the inner shelf is to the west and strongly wind-driven. Outside the 50-m isobath, the Beaufort Undercurrent slowly (0.1 m s^{-1}) flows eastward.

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

Coral communities in Alaskan waters are highly diverse and include six major taxonomic groups (Appendix 2.1): true or stony corals (Order Scleractinia), black corals (Order Antipatharia), true soft corals (Order Alcyonacea) including the stoloniferans (Suborder Stolonifera), sea fans (Order Gorgonacea), sea pens (Order Pennatulacea), and stylasterids (Order Anthoathecatae). One hundred and forty one unique coral taxa have been documented from Alaskan waters and include 11 species of stony corals, 14 species of black corals, 15 species of true soft corals (including six species of stoloniferans), 63 species of gorgonians, 10 species of sea pens, and 28 species of stylasterids (Appendix 2.1). Note that all taxa listed in Appendix 2.1 are believed to be unique and include 52 taxa with incomplete taxonomy, including several that have only recently been collected and likely represent species new to science. All corals found in Alaska are azooxanthellate and satisfy all their nutritional requirements by the direct intake of food. They are ahermatypic or non-reef building corals but many are structure forming. The degree to which they provide structure depends on their maximum size, growth form, intraspecific fine-scale distribution, and interaction with other structure-forming invertebrates (Table 2.1).

a. *Stony corals* (Class Anthozoa, Order Scleractinia)

At least 11 species of stony corals have been reported from Alaskan waters (Cairns 1994). All are solitary cups and the largest species measure less than 10 cm in total height. They require exposed, hard substratum for attachment. Unlike their tropical counterparts, they do not form significant structure used by larger fishes as refuge (Table 2.1). They are, however, contagiously distributed (i.e. aggregated or clumped) and dense patches may provide some structural habitat for some macro-invertebrates and juvenile fish (Figure 2.2).

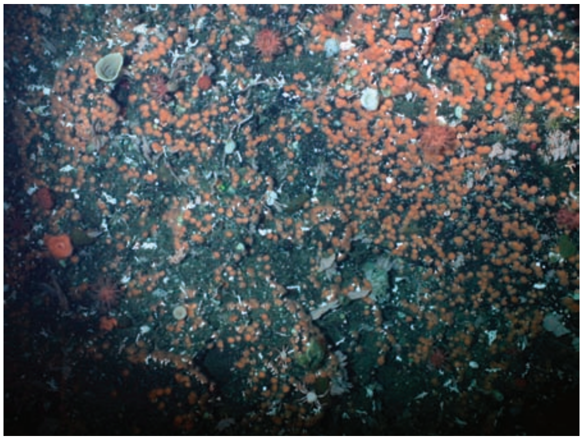


Figure 2.2. Scleractinians occasionally form dense patches, such as this one in Amchitka Pass (Aleutian Islands), that may provide refuge habitat for small fish and crustaceans. Photo by R. Stone, NOAA Fisheries.

b. *Black Corals* (Class Anthozoa, Order Antipatharia)

Black corals have some importance as structure-forming corals (Table 2.1) and at least 14 species are reported from Alaska (Appendix 2.1). They are locally abundant, contagiously distributed, and a few species such as *Dendrobathypathes boutillieri* (Opresko 2005) and *Parantipathes* sp. may grow over 1 m in height and/or width (Figure 2.3). Data from the NMFS sablefish longline survey indicate that several species

Table 2.1. Structure-forming attributes of deep corals in Alaska.

Taxa	Reef-building	Abundance	Maximum colony size	Morphology	Associations with other structure forming invertebrates	Colony spatial dispersion	Overall rating of structural importance
Scleractinia	No	Low	Small	No-branch	Few	Clumped	Low
Antipatharia	No	Medium	Large	Branch	Few	Clumped	Medium
Alcyonacea	No	Medium	Small	No-branch	Few	Clumped	Medium
Stolonifera	No	Low	Small	No-branch	Few	Clumped	Low
Gorgonacea	No	High	Large	Branch	Many	Clumped	High
Primnoa spp.	No	High	Large	Branch	Many	Clumped	High
Paragorgia spp.	No	Medium	Large	Branch	Many	Clumped	High
Isididae	No	Medium	Large	Branch	Many	Clumped	High
Pennatulacea	No	High	Large	Branch	Few	Clumped	Medium
Anthoathecatae	No	High	Medium	Branch	Many	Clumped	High

Table Key

Attribute	Measure
Reef-Building	Yes/No
Relative Abundance	Low/ Medium/ High
Size (width or height)	Small (<30cm)/ Medium (30cm-1m)/ Large (>1m)
Morphology	Branching/ Non-branching
Associations	None/ Few (1-2)/ Many (>2)
Spatial Dispersion	Solitary/ Clumped
Overall Rating	Low/ Medium/ High

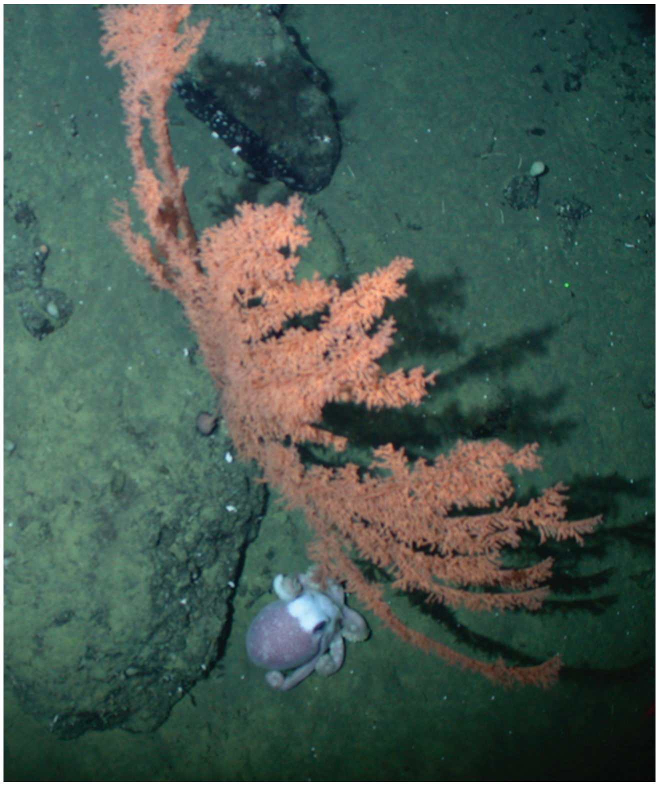


Figure 2.3. Some black corals such as this *Dendrobathypathes boutillieri* may reach heights over 1 m. An unknown species of octopus takes cover under the coral. Photo credit: R. Stone, NOAA Fisheries.

form dense patches in some areas of the Gulf of Alaska. Deep ROV observations in the central Aleutian Islands in 2004 confirmed that black corals are contagiously distributed with densities approaching 1 colony m^{-2} on some shelf habitats (R. Stone, unpublished data). They require hard substratum for attachment and by-catch specimens collected during NMFS groundfish surveys in the Gulf of Alaska were attached to small cobbles and mudstone.

c. *Gold Corals* (Class Anthozoa, Order Zoanthidae)

Gold corals or zoanthids are not known to occur in Alaskan waters but dense mats of zoanthid-like colonies similar to *Epizoanthus scotinus* known from British Columbia (Lamb and Hanby 2005) have been observed in eastern Gulf of Alaska habitats (R. Stone, personal observations).

d. Gorgonians (Class Anthozoa, Order Gorgonacea)

Gorgonians are the most diverse coral group in Alaskan waters – more than 60 species representing seven families have been reported (Appendix 2.1). Gorgonians are also the most important structure-forming corals in Alaskan waters (Table 2.1). They generally require exposed, hard substratum for attachment but recent observations in deep water (>450 m) indicate that the skeletons of hexactinellid sponges may be important attachment substrates in areas devoid of exposed rock (R. Stone, unpublished data). Gorgonians are locally abundant, contagiously distributed, and several species attain massive size. Gorgonians form both single- and multi-species assemblages. For example, *Primnoa pacifica* forms dense thickets in the Gulf of Alaska (Krieger and Wing 2002) while as many as 10 species are found in Aleutian Island coral gardens (Stone 2006). Some gorgonians are also extremely long lived. A medium-sized colony (197.5 cm length) identified as *Primnoa resedaeformis* (most likely *P. pacifica*) was aged at 112 years in the Gulf of Alaska (Andrews et al. 2002). *P. pacifica* attains a height of 7 m in the Gulf of Alaska (Krieger 2001) and *P. wingi* reaches a height of at least 1.5 m in the Aleutian Islands (R. Stone personal observations). The depth and geographical distribution of *Primnoa* spp. in Alaskan waters corresponds to the mean spring bottom temperature of 3.7^{o}C (Cimberg et al. 1981) suggesting that this might be the low temperature of its tolerance range. *Paragorgia arborea* can measure 2 m high and wide, (Figure 2.5) and other gorgonians such as *Plumarella* sp., *Fanellia* sp., and bamboo corals (Family Isididae) grow to over 1 m high (R. Stone personal observations). The northern distribution of bamboo corals suggests

Figure 2.4. This true soft coral (*Anthomastus* sp.) measures 20 cm across and provides shelter for a snailfish (*Careproctus* sp.). Photo credit: R. Stone, NOAA Fisheries.

a temperature tolerance of less than 3.0°C and their distribution also suggests a low tolerance for high sedimentation (Cimberg et al. 1981).

e. True Soft Corals and Stoloniferans (Class Anthozoa, Order Alcyonacea)

True soft corals (Suborder Alcyoniina) are not a diverse group in Alaskan waters – only nine species are reported (Appendix 2.1). They have some importance as structure-formers (Table 2.1). Colonies are encrusting or erect and a few species (e.g., *Anthomastus ritterii*) may reach 20 cm in height (Figure 2.4) They require exposed, hard substratum for attachment, are locally abundant, and have a contagious distribution. *Eunephthea rubiformis* (formerly *Gersemia rubiformis*) are locally abundant on the unconsolidated sediments of the eastern Bering Sea shelf (Heifetz 2002) and although small, colonies may be abundant enough to provide important refuge habitat for juvenile fish and crustaceans. Additionally, six species of stoloniferans (Suborder Stolonifera) are reported from Alaska (Appendix 2.1) and they generally have little importance as structure-formers (Table 2.1). They can form extensive mats on hard surfaces such as rock, other corals, and sponges (Stone 2006). They are locally abundant – a single species of *Clavularia* was measured at a density of 1.7 colonies m^{-2} in one Aleutian Island coral garden (Stone 2006).

f. Pennatulaceans (Class Anthozoa, Order Pennatulacea)

Ten species of pennatulaceans (sea pens) are reported from Alaskan waters (Appendix 2.1) and several are important structure-forming

Figure 2.6. Dense groves of the sea pen *Ptilosarcus gurneyi* are found on soft-sediment shelf habitats in the Gulf of Alaska and Aleutian Islands. Photo credit: P. Malecha, NOAA Fisheries.

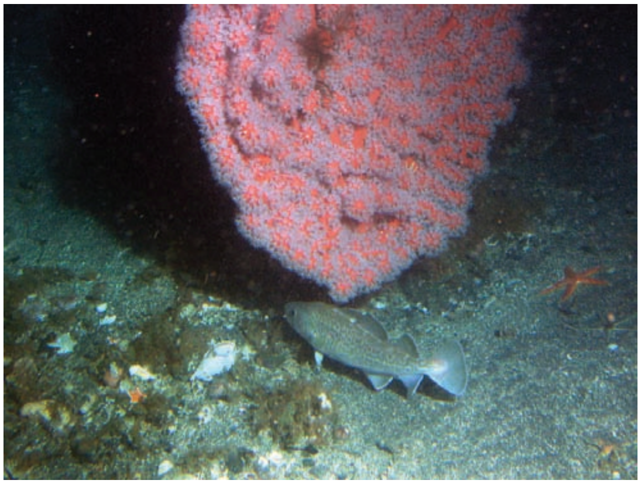


Figure 2.5. A large bubblegum coral (*Paragorgia arborea*) provides shelter for a Pacific cod (*Gadus macrocephalus)* in the central Aleutian Islands. Photo credit: R. Stone, NOAA Fisheries.

corals (Table 2.1). Many species are elongate and whip-like and one species, *Halipteris willemoesi*, attains a height greater than 3 m (R. Stone personal observations). At least three species form extensive groves in soft-sediment areas. *Protoptilum* sp. and *H. willemoesi* form dense groves (16 m^{-2} and 6 m^{-2}, respectively) in the central Gulf of Alaska (Stone et al. 2005). Dense groves of *H. willemoesi* have also been reported on the Bering Sea shelf (Brodeur 2001). *Ptilosarcus gurneyi* also forms dense groves on shallow shelf habitats throughout the Gulf of Alaska and Aleutian Islands (Figure 2.6).

g. Stylasterids (Class Hydrozoa, Order Anthoathecatae)

More than 25 species or subspecies are reported from Alaskan waters (Wing and Barnard 2004; Appendix 2.1) and many are important structure-forming corals (Table 2.1). They form erect (e.g., *Stylaster* spp.) or encrusting calcareous colonies (e.g., *Stylantheca petrograpta*), and require exposed, hard substratum for attachment (Figure 2.7). Some erect species, most notably *Stylaster cancellatus*, may grow to almost one meter in height and often display contagious distributions. Stylasterids, particularly *Stylaster campylecus*, are a major structural component of Aleutian Island coral gardens and are often encrusted with the demosponge *Myxilla incrustans* – together they form a rigid platform that other sedentary and sessile invertebrates use as an elevated feeding platform (Stone 2006). Encrusting species, such as *S. petrograpta*, have low value as structure-forming invertebrates.

V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITAT

Deep corals are widespread in Alaska and have been reported as far north as the Beaufort Sea (Cimberg et al. 1981). Corals are found over a broad depth range and occur from the shallow subtidal zone to the deep ocean trenches (Table 2.2). For example, pennatulaceans have been found as shallow as 3 m depth and antipatharians and gorgonians have been found at a depth of 4784 m on Gulf of Alaska seamounts. They are found in all megahabitats and mesohabitats as described by Greene et al. (1999). In addition to general factors controlling coral distribution such as current regimes and the presence of hard substrates, temperature tolerance appears to play a role in the geographic and depth distribution of some deep corals.

Eastern Gulf of Alaska

Deep corals have a widespread but patchy distribution on the continental shelf and slope in the eastern Gulf of Alaska (Figure 2.8). Approximately 46 species are reported from the area (Appendix 2.1). Only the Aleutian Islands support a higher diversity of corals. Corals include four species of stony corals, nine species of black corals, four species of true soft corals (including two stoloniferan species), thirteen species or subspecies of gorgonians, seven species of pennatulaceans, and nine species or subspecies of stylasterids (Appendix 2.1).

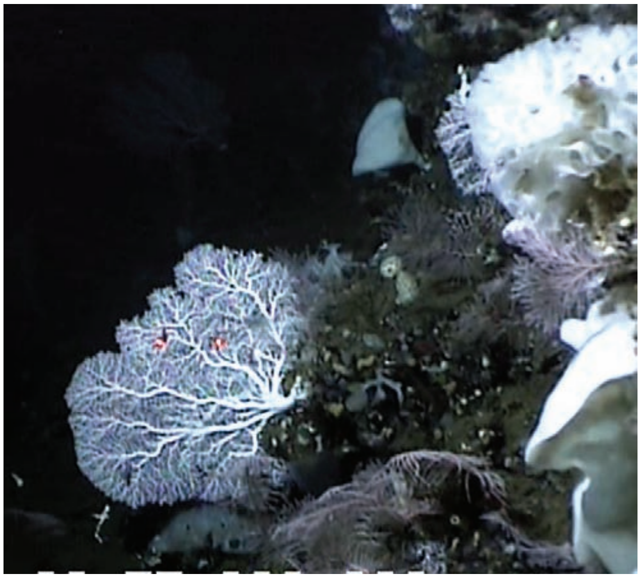


Figure 2.7. Large, erect stylasterids (*Stylaster* sp). grow on exposed bedrock with their central axis perpendicular to the current in the Aleutian Islands. Red laser marks are separated by 10 cm. Photo credit: R. Stone, NOAA Fisheries.

Corals range in depth from 6 m for *Primnoa pacifica* in the glacial fiords of Glacier and Holkham Bays (Stone et al. in preparation) to over 400 m on the continental slope. *P. pacifica* is found throughout the subregion and forms dense thickets in some areas, especially in the inside waters of Southeast Alaska and on high-relief rocky areas of the continental shelf (Figure 2.8A). It grows on bedrock and boulders and has been observed *in situ* at a depth of 365 m (Krieger 2001). Anecdotal information exists that it may grow as deep as 772 m in some areas of Southeast Alaska (Cimberg et al. 1981). Stylasterids are fairly common on the continental shelf and in some shallow areas of Southeast Alaska (Figure 2.8B). Black corals grow on the continental shelf at depths between 401 and 846 m (Figure 2.8C). Stony corals and soft corals are known from only a few locations (Figure 2.8D and 2.8E).

Calcigorgia spiculifera is another important gorgonian in Southeast Alaska that forms small groves on bedrock in shallow water areas (Stone and Wing 2001). The pennatulaceans, *Halipteris willemoesi* and *Ptilosarcus gurneyi* also form dense groves in some areas (Figure 2.8F) at depths between 20 and 200 m (Malecha et al. 2005). The most ecologically important coral feature in this subregion of Alaska is the *Primnoa* thickets on the continental shelf of the eastern Gulf of Alaska (Figure 2.8A). In July 2006, NMFS closed five small areas where *Primnoa* thickets have been documented via submersible observations to all fishing activities using bottom-contact gear.

Western Gulf of Alaska

Deep corals have a widespread but patchy distribution in the western Gulf of Alaska (Figure 2.9). Gorgonians are widely distributed on the continental shelf and slope (Figure 2.9A) and are represented by 13 species (Appendix 2.1). *Primnoa* sp. is the most common gorgonian with unconfirmed reports of dense thickets in the area of Chirikof Island (Cimberg et al. 1981). Bamboo corals are patchily distributed on the continental slope and records of *Paragorgia* spp. are rare (Figure 2.9A). Stylasterids are widely distributed (Figure 2.9B) but are not abundant or diverse. Only two species have been reported from this subregion (Appendix 2.1). Black corals, stony corals, and soft corals have only

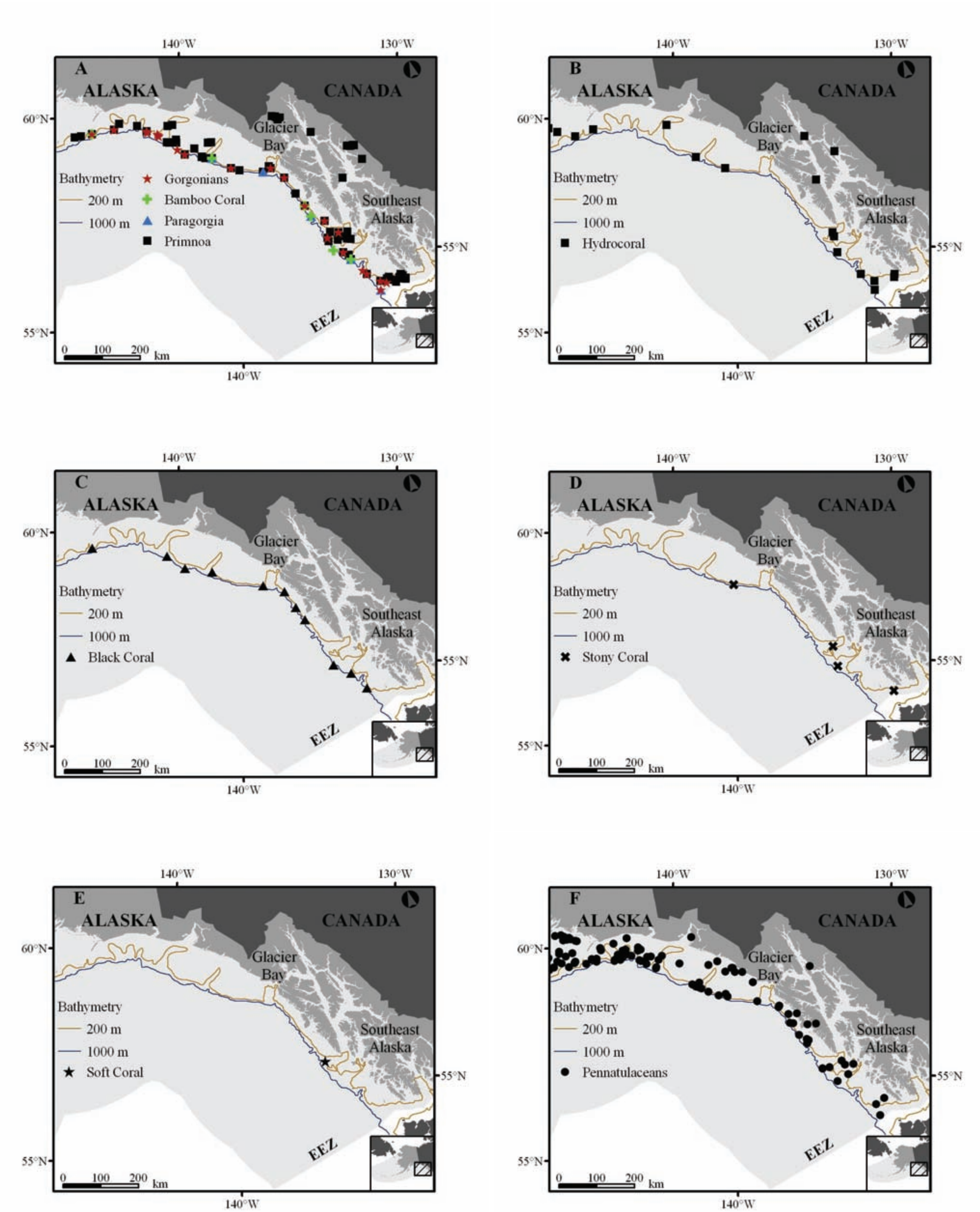


Figure 2.8. Distribution of corals in the eastern Gulf of Alaska A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

Table 2.2. Summary of species richness and depth range for seven major groups of corals found in Alaskan waters. Data sources for depth distribution: 1. A. Baco-Taylor, unpublished data; 2. Hoff and Stevens 2005; 3. Keller 1976; 4. R. Stone, unpublished data; 5. Stone et al. in preparation; 6. Stone 2006.

Taxa	Number of Species	Depth range (m)	Data source shallow - deep
Scleractinia	11	24 - 4620	4 - 3
Antipatharia	14	401 - 4784	4 - 1
Alcyonacea	9	10 - 3209	4 - 2
Stolonifera	6	11 - 591	6 - 4
Gorgonacea	63	6 - 4784	5 - 1
Pennatulacea	10	3 - 2947	4 - 4
Anthoathecatae	28	11 - 2130	6 - 4
Total	141	3 - 4784	

been reported from a few areas (Figures 2.9C, 2.9D, 2.9E). The most ecologically important coral feature in this subregion of Alaska is the extensive pennatulacean groves (Figure 2.9F) in the submarine gullies south and east of Kodiak Island (Stone et al. 2005) and in isolated locations in Prince William Sound (Malecha et al. 2005).

Gulf of Alaska Seamounts

Submersible observations in 2002 and 2004 confirmed by-catch records that seamounts in the Gulf of Alaska are rich in coral habitat and that all major taxonomic groups except stylasterids were present (Appendix 2.1) (A. Baco-Taylor, WHOI, pers. comm.). The absence of stylasterids from the Gulf of Alaska seamounts is notable since they are common on the seamounts near New Zealand (Cairns 1991; Cairns 1992). Pennatulaceans are also noticeably uncommon from the seamounts and are represented by a single unidentified species (Appendix 2.1). The submersible *Alvin* was used during a 2004 research cruise to five seamounts in the northern Gulf of Alaska (Dickens, Denson, Welker, Giacomini, and Pratt) to collect video footage and specimens on transects along three depth strata: 700 m, 1700 m, and 2700 m. Corals were most abundant near the seamount summits (700 m) where *Paragorgia* spp. and bamboo corals were the dominant coral fauna. Gorgonians (Primnoidae) were the most abundant corals at the 2700 m depth stratum. Corals were least abundant and diverse in the 1700 m depth zone where black corals and Primnoidae were dominant. Precious red coral (*Corallium* sp.) was collected from Patton Seamount and represented a northern range extension for the family Corallidae. Bamboo corals were a particularly diverse group with at least four genera collected on the seamounts (P. Etnoyer, Texas A&M University - Corpus Christi, pers. comm.).

Coral habitat on Derickson Seamount which crests at 2766 m south of the Alaska Peninsula was explored with the ROV *Jason II* in 2004. Black corals, bamboo corals, and other gorgonians (Primnoidae and Chrysogorgiidae) were observed on hard substrates at depths between 2766 and 4784 m (A. Baco-Taylor, WHOI, pers. comm.). Several specimens collected on this deep seamount represent species new to science and significant depth-range extensions. A single species of stony coral (*Fungiacyathus* sp.) was observed in soft-sediment areas. Species distribution differed between the eastern and northern flanks of the seamount and highlights the importance of circumnavigating seamounts during surveys of coral distribution.

The Aleutian Islands

The Aleutian Islands support the most abundant and diverse coral assemblages in Alaska (Appendix 2.1). A total of 101 coral species or subspecies have been reported from the Aleutian Islands (Appendix 2.1). Previous reports indicated that 25 coral taxa were endemic to the region (Heifetz et al. 2005) – our updated records however, indicate that as many as 51 species may be endemic to the region! Deep-water collections made with the ROV *Jason II* in 2004 may add dozens of corals – novel species and range extensions – to this list. Gorgonians and stylasterids are the most diverse groups with 45 and 25 species or subspecies reported, respectively (Appendix 2.1). Twelve species of true soft corals including three species of stoloniferans, six species of pennatulaceans, and ten species of stony corals have also been reported from the subregion (Appendix 2.1). Additionally, three species of black corals were collected from the area in 2004 (R. Stone,

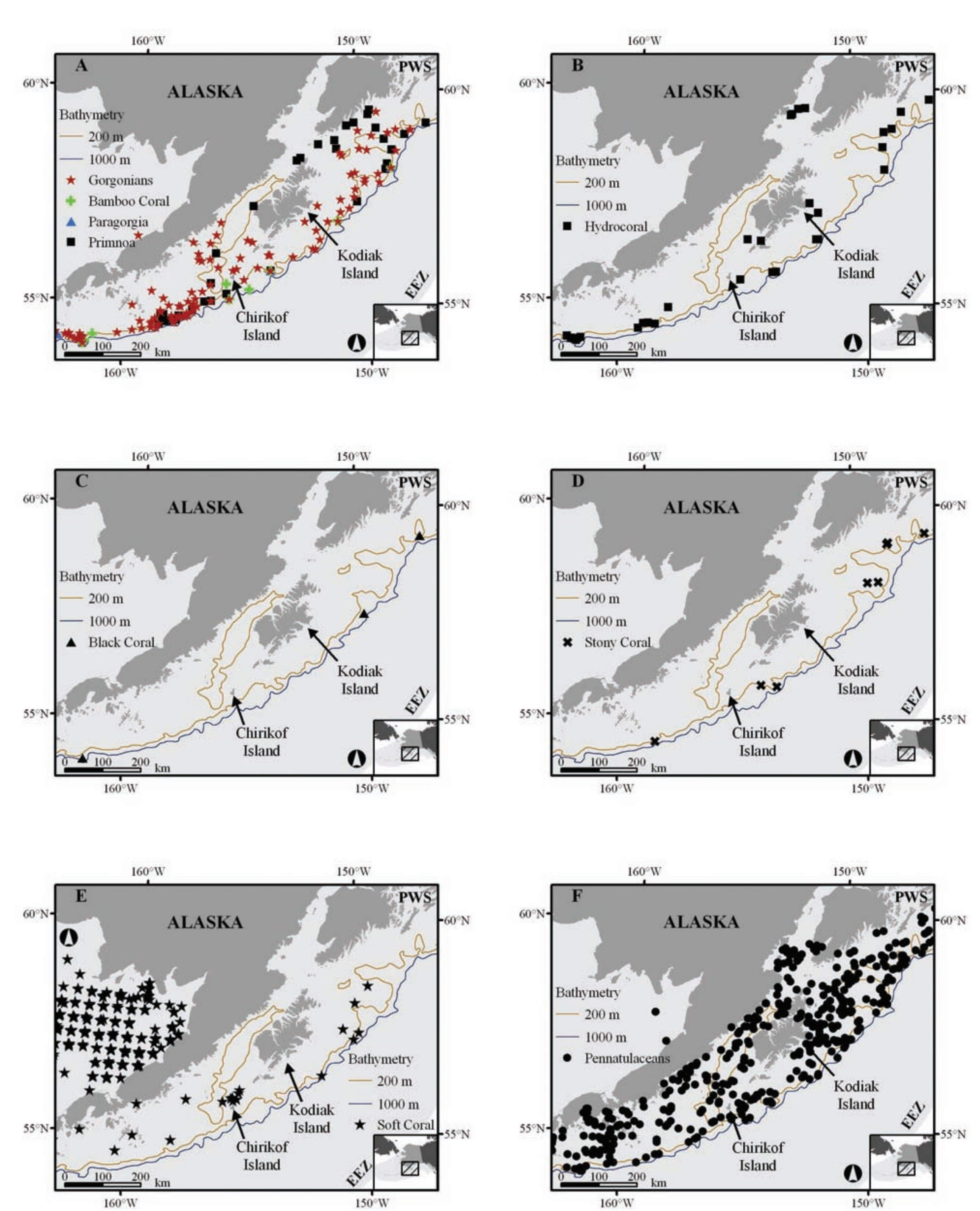


Figure 2.9. Distribution of corals in the western Gulf of Alaska A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

unpublished data) including *Dendrobathypathes boutillieri*, a species new to science (Opresko 2005).

Eastern Aleutian Islands
Data from NMFS stock assessment surveys indicate that a major shift in coral diversity occurs in the eastern Aleutian Islands at about longitude 169º W near the west end of Umnak Island (Heifetz et al. 2005). Approximately twelve species of stylasterids, nine species of gorgonians, and three species of stony corals found further west in the Aleutian Islands are not found east of this area (Heifetz et al. 2005).

Gorgonians are widely distributed on the continental shelf and upper slope (Figure 2.10A). *Primnoa* spp. and *Paragorgia* spp. are widely distributed but few bamboo corals have been reported from the area (Figure 2.10A). Stylasterids are widely distributed especially along the south side of the archipelago (Figure 2.10B). Few black corals have been reported (Figure 2.10C) but stony corals and soft corals are widespread and abundant in some areas (Figures 2.10D, 2.10E). Pennatulaceans are widely distributed and likely form dense groves in some areas (Figure 2.10F).

Western Aleutian Islands
Corals are abundant and widespread in the western Aleutian Islands (Figure 2.11). Coral gardens, a previously undocumented habitat feature in the North Pacific Ocean, were observed with the submersible *Delta* at six locations in the central Aleutian Islands during 2002 (Stone 2006). Gardens are typically located in small, discrete patches at depths between 117 and 338 m and are distinguishable from other habitats by extremely high coral abundance (3.85 corals m^{-2}), especially gorgonians (1.78 colonies m^{-2}), and stylasterids (1.46 colonies m^{-2}).

In general, corals appear to have a much broader depth distribution in the western Aleutian Islands than elsewhere in Alaska. The depth distribution of *Primnoa* spp. (304–1436 m) is substantially deeper than elsewhere in Alaska (Stone 2006; R. Stone, unpublished data). Bamboo corals and *Paragorgia* spp. also have a very broad geographical distribution (Figure 2.11A). Bamboo corals have been observed at depths between approximately 400 and 2827 m (R. Stone, unpublished data) and have been collected with a beam trawl at a depth of 3532 m (Cimberg et al. 1981). *Paragorgia* spp. has been observed *in situ* at depths between 27 m (Stone 2006) and 1464 m (R. Stone, unpublished data). Stylasterids are widespread (Figure 2.11B) and have been observed at depths between 11 m (Stone 2006) and 2130 m (R. Stone, unpublished data). Black corals appear to have a limited distribution (Figure 2.11C) and have been observed on bedrock, boulders, and cobbles at depths between 449 and 2827 m (R. Stone, unpublished data).

Stony corals have a fairly broad distribution in this region of Alaska (Figure 2.11D) and have been collected at depths between 24 m (R. Stone, unpublished data) and 4620 m in the Aleutian Trench (Keller 1976). True soft corals are also fairly common in this region of Alaska (Figure 2.11E) and have been observed at depths between 10 m and 2040 m (R. Stone, unpublished data). Pennatulaceans have been observed as deep as 2947 m and form extensive groves in some soft-sediment areas on both shelf and slope habitats (Figure 2.11F).

The Bering Sea
Deep corals have a patchy distribution in this region of Alaska and are largely limited to the broad, shallow continental shelf and along the narrow continental slope (Figure 2.12). The entire north side of the Aleutian Archipelago is technically within the Bering Sea but for the purposes of this report we have defined the Bering Sea as those areas of the shelf and slope not immediately adjacent to the Aleutian Islands (as illustrated in Figure 2.12 and including the inner shelf illustrated in Figure 2.9). This definition applies both to the discussions in the text and to the species list provided in Appendix 2.1.

The coral fauna of this region of Alaska has been poorly documented but does not appear to be particularly diverse. Sixteen species or subspecies of coral are known from the region and include three species of true soft corals (including one species of stoloniferan), six species of gorgonians, four species of pennatulaceans, and three species of stylasterids (Appendix 2.1). Additionally, at least one species of black coral, one species of stony coral, and one species of bamboo coral have been collected from the region but proper identifications were never made. These records effectively increase

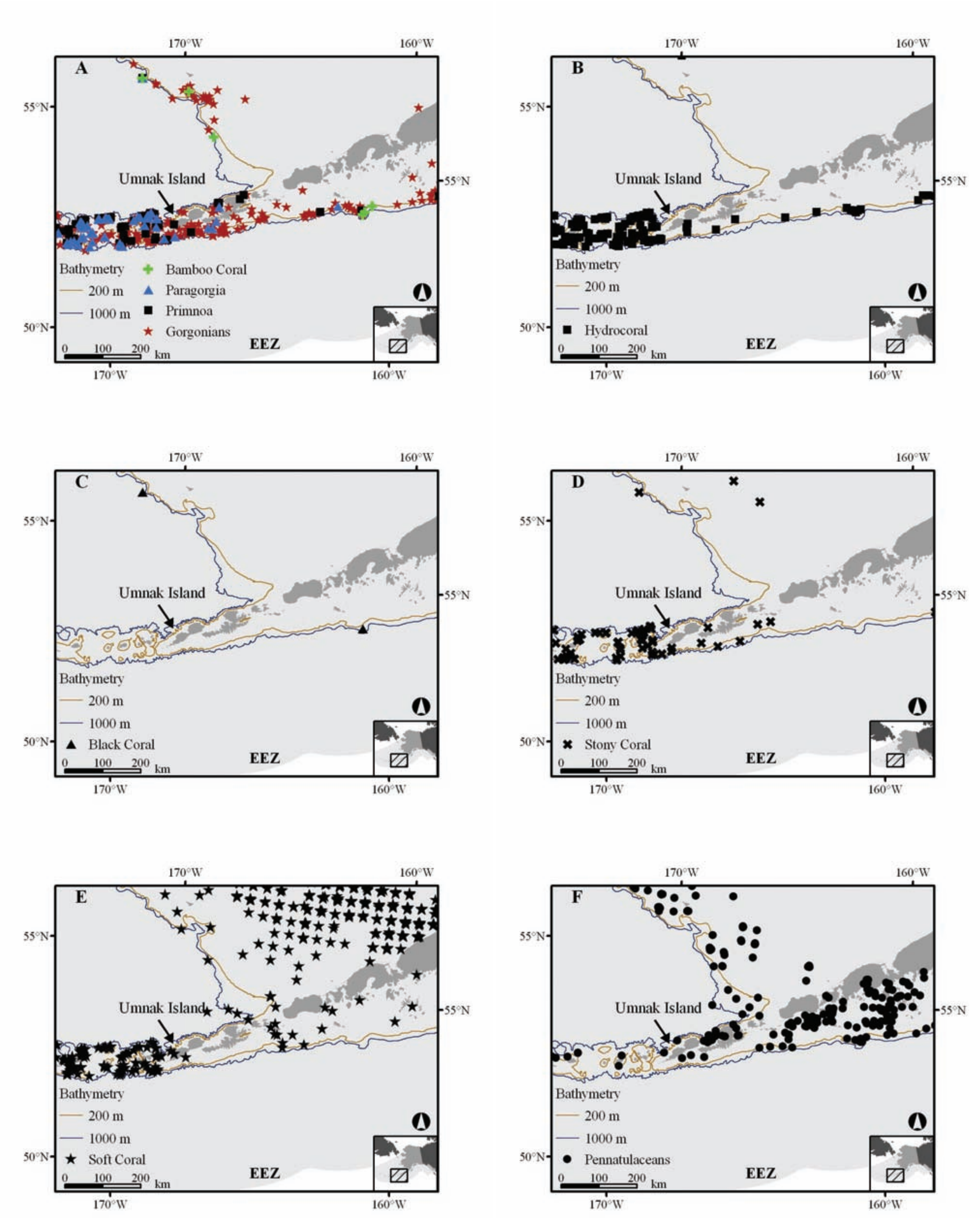


Figure 2.10. Distribution of corals in the eastern Aleutian Islands A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

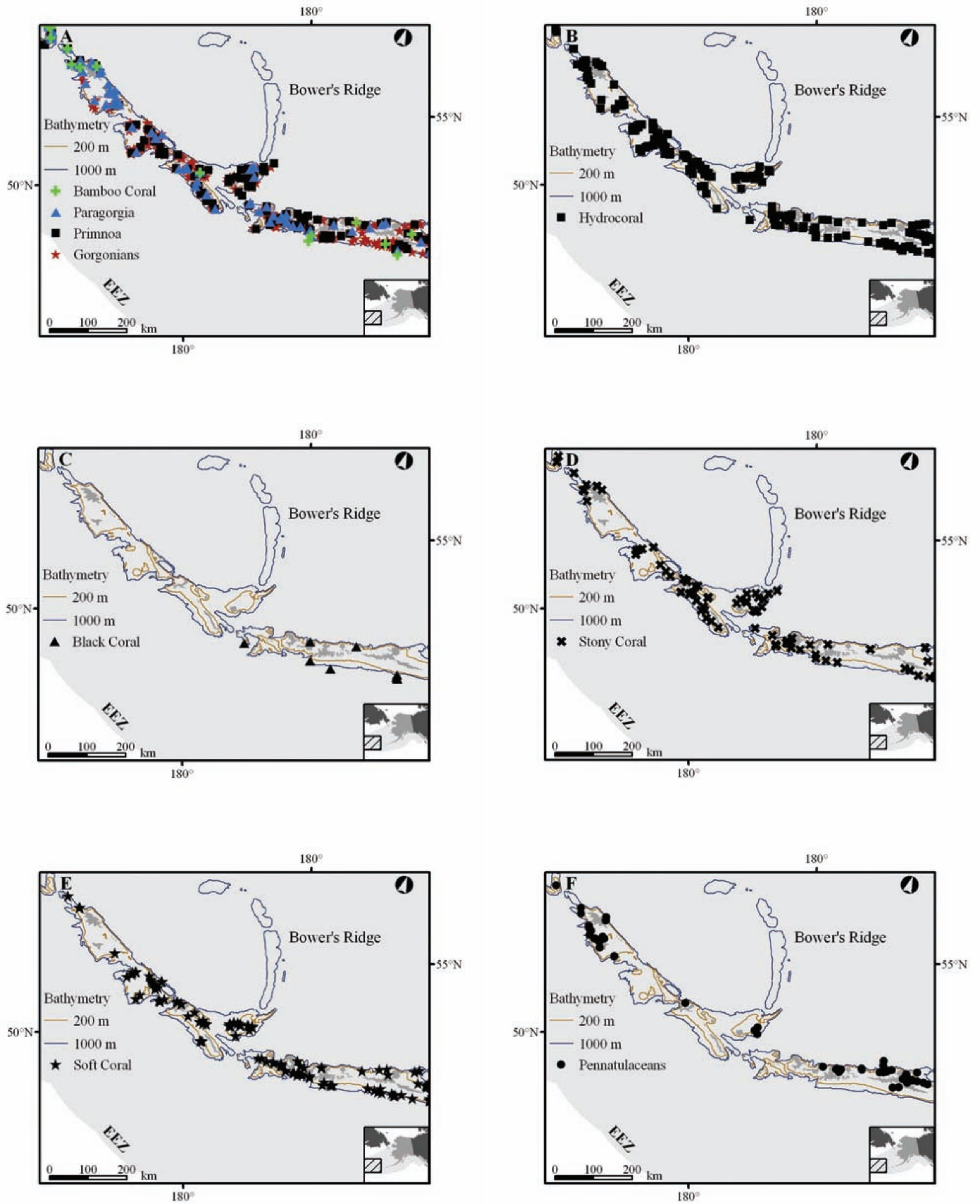


Figure 2.11. Distribution of corals in the western Aleutian Islands A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

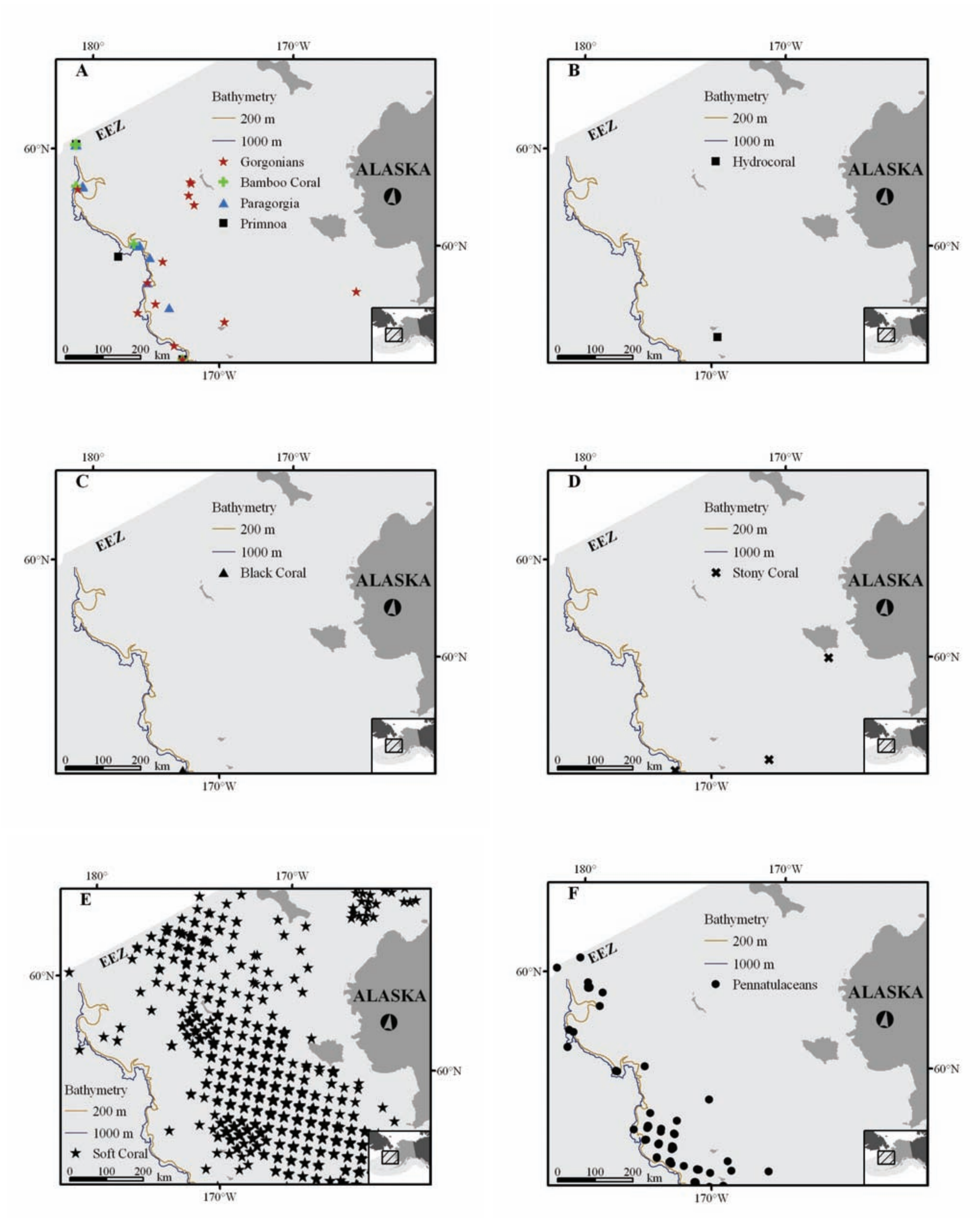


Figure 2.12. Distribution of corals in the Bering Sea A) gorgonians (bamboo corals – Family Isididae, *Paragorgia* spp., *Primnoa* spp. are plotted separately), B) stylasterids, C) black corals, D) stony corals, E) soft corals, and F) pennatulaceans.

the number of species in the region to at least nineteen. Gorgonians are distributed mostly on the continental slope and a few isolated shelf locations (Figure 2.12A). *Primnoa pacifica*, bamboo corals, and *Paragorgia* sp. have been collected from a few locations on the continental slope (Figure 2.12A). The bamboo coral specimens were collected during NMFS surveys and because definitive species identifications were not made they are not included in the species list (Appendix 2.1). Stylasterids have been reported from only a single location in the Pribilof Islands area (Figure 2.12B). Black corals have been reported from only a single location on the outer continental slope (Figure 2.12C) and stony corals are known from a few locations on shelf and slope locations (Figure 2.12D). The pennatulacean *H. willemoesi* forms dense groves on the outer continental shelf of the Bering Sea (Figure 2.12F) at depths between 185 and 240 m (Brodeur 2001; Malecha et al. 2005). The most important coral feature of the Bering Sea however, is likely the dense aggregations of soft corals (mostly *Eunephthea rubiformis*) on the unconsolidated sediments of the continental shelf (Figure 2.12E).

Alaskan Arctic

Only the soft coral *Eunephthea* sp. has been reported north of the Bering Sea (Cimberg et al. 1981). *Eunephthea* sp. is patchily distributed on the shallow shelves of the Chukchi and Beaufort Seas and has been reported as far north as 71º 24' N.

VI. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

In Alaska, many commercial fisheries species and other species are associated with deep corals. Most associations are believed to be facultative rather than obligatory. Fish and crabs, particularly juveniles, use coral habitat as refuge and as focal sites of high prey abundance. Some shelter-seeking fishes such as rockfish may use coral habitat as spawning and breeding sites.

Commercial Fisheries Species Associations

In Alaska, commercial species are managed with five Fishery Management Plans (FMPs)—Bering Sea and Aleutian Island (BSAI) Groundfish, Gulf of Alaska Groundfish, BSAI King and Tanner Crabs, Salmon, and Scallops. The commercial harvest of approximately 35 species (or species groups) is specifically managed with the FMPs. Most of these species (approximately 85%) are found during some phase of their life cycle in deep-water habitats including those inhabited by deep corals so the potential for associations between commercial fish species and corals is high (Figures 2.14 and 2.15).

Figure 2.13. A shortspine thornyhead (*Sebastolobus alascanus*) rests in a field of primnoid gorgonians. Photo credit: R. Stone, NOAA Fisheries.

Heifetz (2002) analyzed data from RACE survey hauls to determine large-scale (i.e., kilometers to tens of kilometers) associations of commercially targeted fish species with corals. Rockfish (*Sebastes* spp.), shortspine thornyhead (*Sebastolobus alascanus*), and Atka mackerel (*Pleurogrammus monopterygius*) were the most common fish captured with gorgonians, scleractinians, and stylasterids. Flatfish (Pleuronectidae and Bothidae) and gadids were the most common fish captured with soft corals.

Stone (2006) examined fine-scale (<1 m) associations of FMP species with corals and other structure-forming invertebrates from video footage of the seafloor collected in the central Aleutian Islands. At the sites surveyed, 84.7% of the commercially important fish and crabs were associated with corals and other sedentary structure-providing invertebrates. All seven species of rockfish (*Sebastes*) observed were highly associated with corals. Associations ranged from 83.7% for "other" rockfish to 98.5% for sharpchin rockfish (*S. zacentrus*). Ninety seven percent of juvenile rockfish were associated with corals. Over 20% of the FMP species were in physical contact with corals and other structure-forming invertebrates.

Observations from the manned submersible *Delta* in the eastern Gulf of Alaska have documented fine-scale associations (<1 m) of adult shortraker (*S. borealis*), rougheye (*S. aleutianus*), redbanded (*S. babcocki*), sharpchin, dusky (*S. ciliatus*), and yelloweye rockfish (*S. ruberrimus*), and golden king crabs (*Lithodes aequispina*) with red tree coral *P. pacifica* (Krieger and Wing 2002). Large schools of Pacific ocean perch (*Sebastes alutus*) have been observed in dense groves of the pennatulacean *H. willemoesi* on the Bering Sea shelf presumably feeding on dense aggregations of euphausiids or krill (Brodeur 2001).

Only 16 of the 24 named seamounts in Alaskan waters summit within the maximum depth range of FMP species (approximately 3000 m). Several FMP species have been documented on the seamounts but studies have not been undertaken to examine associations of commercial species and coral habitat. FMP species documented on Alaskan seamounts include sablefish, longspine thornyhead (*Sebastolobus altivelis*), shortspine thornyhead, rougheye rockfish, shortraker rockfish, aurora rockfish (*Sebastes aurora*), and golden king crabs (Alton 1986; Hughes 1981; Maloney 2004). Other species of potential commercial importance found on the seamounts include the deep-sea sole (*Embassichthys bathybius*), spiny dogfish (*Squalus acanthias*), and several species of grenadiers (Family Macrouridae).

Figure 2.15. An unidentified eelpout (probably *Puzanovia rubra*) displays cryptic coloration in a *Paragorgia* colony at 746 m depth in the Aleutian Islands. Photo credit: R. Stone, NOAA Fisheries.

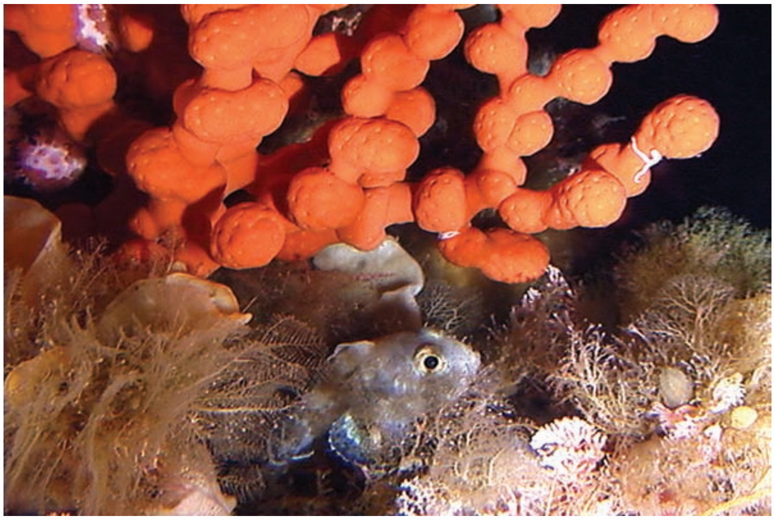


Figure 2.14. A darkfin sculpin *Malacocottus zonurus* rests under a bubblegum coral *Paragorgia arborea* in one of the seven coral gardens surveyed with the submersible *Delta*. Coral gardens are areas of extraordinary coral abundance and high species diversity. Photo credit: R. Stone, NOAA Fisheries.

Other Species Associations

Many non-commercially important species are associated with deep corals in Alaska. Both facultative and obligatory associations are likely common. Few obligatory associations have been described to date but recent collections of micro- and macro-associates of corals should reveal new examples of unique adaptations and symbiosis. For example, three species of Aleutian eelpouts (*Nalbantichthys* sp., *Opaeophacus* sp., and *Puzanovia* sp.) have developed specializations such as cryptic coloration for life as adults in *Primnoa* (Anderson 1994) and *Paragorgia* colonies (Figure 2.15).

Observations from the submersible *Delta* in the eastern Gulf of Alaska have documented fine-scale associations (<1 m) of sea anemones (*Cribrinopsis* sp., *Stomphia* sp., and *Urticina* sp.), the basket star (*Gorgonocephalus eucnemis*), the crinoid (*Florometra* sp.), and the nudibranch (*Tritonia exulsans*) with *P. pacifica* (Krieger and Wing 2002). All megafauna were in physical contact with the coral and were using it as an elevated feeding platform or as refuge. The spiny red sea star (*Hippasteria spinosa*) was documented preying on the coral. Macrofauna such as shrimp were also observed within the colonies but were not identified or enumerated.

Macrofaunal assemblages living on deep corals were studied during the Gulf of Alaska Seamount cruise in 2004. The chirostylid crab (*Gastroptychus iapsis*) and the basket star (*Asteronyx* sp.) were the most common macrofauna found on deep corals (T. C. Shirley, Texas A&M University, pers. comm.). Other macrofauna collected on corals included the hippolytid shrimp (*Heptacarpus* sp.), actiniarians, crinoids, ophiuroids, crustaceans, sea stars, pycnogonids, and nudibranchs. Taxonomic identifications are pending.

Macrofaunal assemblages living on deep corals collected during the Aleutian Island cruises in 2003 and 2004 were preserved and taxonomic identifications are underway. Crustaceans, ophiuroids, and polychaetes appear to be the most common macro-associates of octocorals (Les Watling, University of Hawaii, pers. comm.). The basket star *Asteronyx* sp. was highly associated with the deep-sea pennatulacean *Anthoptilum grandiflorum* and uses it as an elevated feeding platform (R. Stone, personal observations). Many sedentary and sessile taxa are found in close association with Aleutian Island corals and include sponges, hydroids, bryozoans, the crinoid *Florometra serratissima*, the sea cucumber *Psolus squamatus*, and the basket star *Gorgonocephalus eucnemis*. More than 100 different species of sponges, mostly demosponges, have been collected during the Aleutian Island studies and preliminary estimates indicate that more than 200 species of demosponges alone may occur in association with deep corals in the central Aleutian Islands (Stone 2006). Sea stars commonly found in Aleutian Island coral gardens include *Cheiraster dawsoni* and *Hippasteria spinosa* (R. Stone, unpublished data); the latter species is a documented predator of octocorals. Other predators of octocorals include snails of the genus *Otukaia* (family Calliostomatidae) that have recently been observed preying on bamboo corals in the Aleutian Islands (Figure 2.16).

Figure 2.16. Calliostomatid snails (genus *Otukaia*) prey on the soft flesh of an undescribed species of bamboo coral at a depth of 1227 m in the central Aleutian Islands. The snails were recently discovered and are currently being described by Dr. James McLean at the Natural History Museum of Los Angeles County. Photo credit: R. Stone, NOAA Fisheries.

There are no data regarding commercial fisheries or non-commercial species associations with coral habitat in the Arctic region of Alaska.

VII. STRESSORS ON DEEP CORAL COMMUNITIES

All known threats to deep coral communities in Alaska are directly or indirectly the result of human activities. While activities such as coastal development, point-source pollution, and mineral mining have the potential to affect nearshore habitats, the effects of these activities are geographically limited and occur or are likely to occur in areas with minimal coral habitat. Fishing activities, on the other hand, occur over vast areas of the seafloor and often in areas containing sensitive deep coral habitat. Human activities that may indirectly affect deep coral habitat include the introduction of invasive species and changes to the physical and chemical properties of the oceans due to global warming.

Effects of fishing

Diverse benthic communities on the continental shelf and upper slope of the Gulf of Alaska, Bering Sea, and Aleutian Islands support some of the largest and most important groundfish and crab fisheries in the world. Alaskan fisheries within the U.S. EEZ (3 to 200 nm offshore) are managed under five federal fishery management plans. Other important fisheries within 3 nm of shore are managed by the State of Alaska. Four types of bottom-contact gear are currently used that potentially affect coral habitat – otter trawls, longlines, pots, and scallop dredges. These fisheries are distributed from 27 m to about 1000 m, with most effort at depths shallower than

200 m (Stone 2006). The degree to which a particular gear affects coral habitat depends on its configuration (i.e., physical area of contact), operation (i.e., physical forces on the seafloor), spatial and temporal intensity of operation, seafloor bathymetry and substratum type, and the resilience of components of benthic communities (Table 2.3). Both direct and indirect effects from fishing activities on corals likely occur. Direct effects include removal as by-catch, damage caused by physical contact, and detachment from the seafloor and translocation to unsuitable habitat. Indirect effects include increased vulnerability to predation, especially for corals detached from the seafloor, and habitat alteration. Furthermore, there is some evidence that reproduction is suppressed in damaged shallow-water scleractinian corals due to a reallocation of energy reserves for tissue repair and regeneration (Wahle 1983) and similar effects may occur in deep non-scleractinian corals.

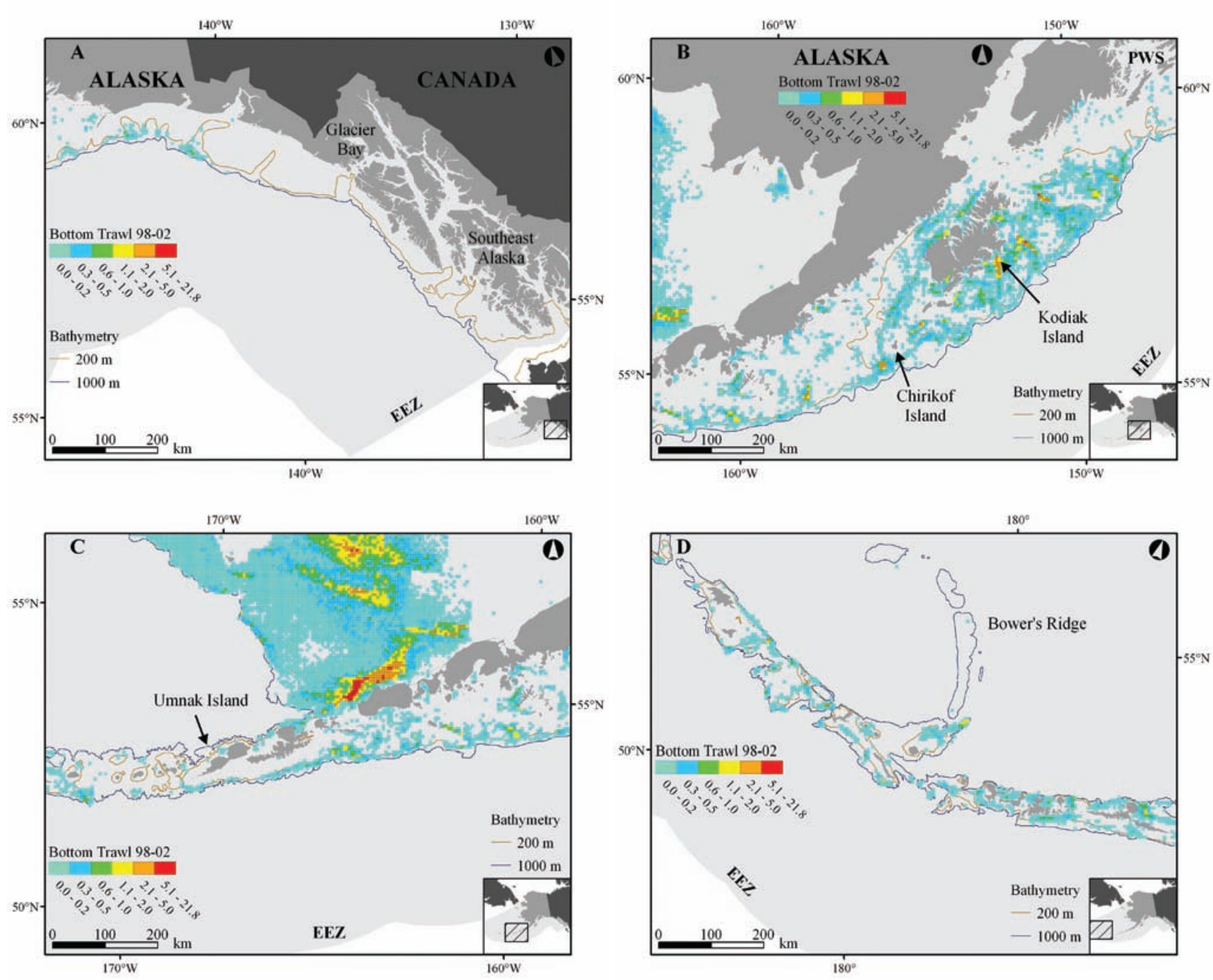
Disturbance from fishing activities is the greatest present threat to coral habitat in Alaska (Table 2.3). NMFS estimates that approximately 81.5 metric tons of coral were removed from the seafloor each year between 1997 and 1999 as commercial fisheries by-catch in Alaska (NMFS 2004). Approximately 91% of this by-catch occurs in the Aleutian Islands and Bering Sea and bottom trawls catch more than 87% of the total (NMFS 2004). Estimates of the amount of damaged or detached corals fishing activities leave behind on the seafloor are not available but may be substantial. In the central Aleutian Islands, disturbance to the seafloor from bottom-contact fishing gear was widespread and approximately 39% of the seafloor on video transects had been disturbed (Stone 2006). In total, 8.5% of the corals observed, mostly stylasterids and gorgonians, were damaged or otherwise disturbed (Stone 2006).

Bottom Trawls

Studies worldwide have determined that bottom trawling alters seafloor habitat and both directly and indirectly affects benthic communities (Jones 1992; Auster et al. 1996; Auster and Langton 1999; NRC 2002). In addition to removing target species, bottom trawling incidentally removes, displaces, or damages non-target species (Ball et al. 2000), changes the sedimentary properties of the seafloor (Churchill 1989), and reduces habitat complexity by physically altering biogenic structures, including corals, on the seafloor (Krieger 2001). Such changes can lead to population level effects on species of economic importance (Lindholm et al. 1999). Ultimately, the combination of effects may result in wide-scale ecosystem change (Gislason 1994; Goñi 1998). Directed studies on the effects of bottom trawling on deep coral habitat in Alaska have been limited to a few studies (Krieger 2001; Stone et al. 2005).

Bottom trawls have been extensively used in Alaskan fisheries since the 1930s. Bottom trawling has been prohibited east of 142º W longitude in the Gulf of Alaska (Figure 2.17A) including the inside waters of Southeast Alaska, since 1998 but intensive trawling occurred there prior to the closure. Bottom trawl effort elsewhere in the state is more continuously distributed (Figures 2.17B–2.17E). Small pockets of intense trawling for flatfish, Pacific cod, and Pacific ocean perch have occurred near Kodiak Island in the Gulf of Alaska (Figure 2.17B) and in the Aleutian Islands for Atka mackerel and Pacific ocean perch (Figures 2.17C and 2.17D). NMFS estimates that approximately 6.2 metric tons of coral are removed from the seafloor each year by bottom trawls in the Gulf of Alaska (NMFS 2004). Most of the Bering Sea has experienced some degree of exposure to bottom trawls (NMFS 2004) and several areas have been trawled on average more than five times per year (Figure 2.17E).

Most bottom trawling occurs on the continental shelf and upper slope at depths less than 500 m but some effort does occur to depths greater than 1000 m. Trawling occurs over a wide range of habitats depending on targeted species and does occur in areas of coral abundance. Total width of the trawl system while fishing may reach 110 m, but the area of the seafloor and associated epifauna contacted by the gear depends on the design of the otter boards and configuration of protective gear on other system components (Stone et al. 2005). Bottom trawling is a major threat to coral habitat because the area of seafloor contacted per haul is relatively large, the forces on the seafloor are substantial, and the spatial distribution of fishing is extensive (Table 2.3). Areas of the seafloor composed mostly of bedrock and boulders, and with irregular and steep bathymetry, are infrequently trawled due to the risk of damaged and lost gear. Such areas often support rich coral habitat and may serve as



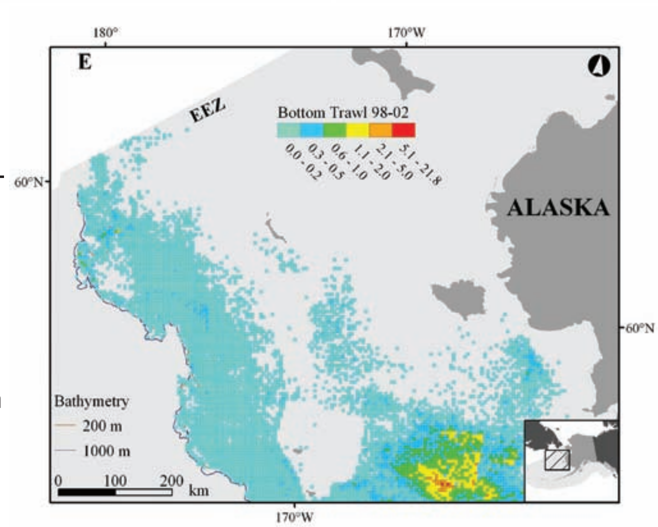


Figure 2.17. Average annual bottom trawl fishing intensity between 1998 and 2002 in A) the eastern Gulf of Alaska, B) the western Gulf of Alaska, C) the eastern Aleutian Islands, D) the western Aleutian Islands, and E) the Bering Sea (adapted from Rose and Jorgensen 2005). Trawl intensity is defined in NMFS (2005), Appendix B.

de facto sanctuaries from trawl disturbance.

Mid-water Trawls

Mid-water or pelagic trawls are modified bottom trawls (otter trawls) used to harvest groundfish near but not on the seafloor. Mid-water trawls are used exclusively to catch walleye pollock (*Theragra chalcogramma*) in the Bering Sea and are also used in Gulf of Alaska fisheries (see www.net-sys.com/trawlnets.htm for extensive descriptions of the various gear used in Alaskan waters). By regulation, the use of protective gear on the footrope is not allowed in an effort to discourage direct contact with the seafloor (NMFS

2004). However, the capture of sedentary benthic species with pelagic trawls is clear evidence that the gear does make at least occasional contact with the seafloor. Overall, pelagic trawls likely have little effect on deep coral habitat in Alaska since they are seldom fished on-bottom and typically in areas with minimal coral habitat (Table 2.3).

Gill Nets

Gill nets are used to harvest Pacific salmon in estuarine waters of Alaska but are not a threat to deep coral habitat because they are not used in areas known to support corals and seldom make contact with the seafloor.

Table 2.3. Potential effects of fishing gears on deep coral habitat in Alaska.

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

Bottom Longlines

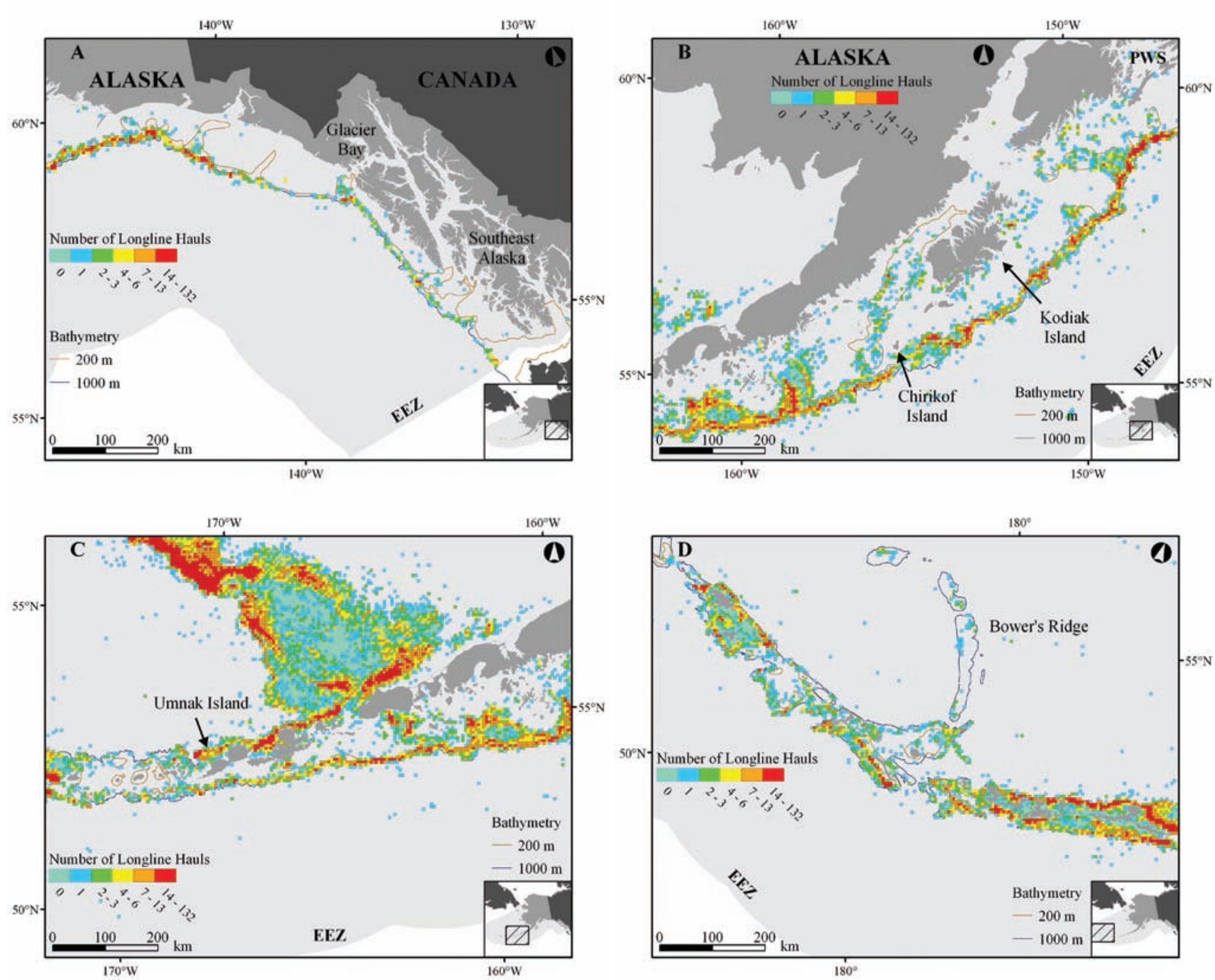
Longlines are used extensively throughout Alaskan waters to catch sablefish, Pacific halibut, Pacific cod, and several species of rockfish to a depth of at least 1000 m (Figures 2.18A-2.18E). Bottom (or demersal) longline systems consist of a mainline to which are attached 1000s of leaders and hooks (gangions), anchors, and buoyed lines. Mainlines often stretch 20 km or more across the seafloor and are often weighted in areas of rough bathymetry or strong currents. Both ends of the mainline are weighted with anchors and buoyed to the surface. No directed studies have been undertaken to study the effects of longlines on benthic habitat in Alaska. Longlines are thought to cause less of an effect on benthic communities than mobile fishing gear, but by-catch data and limited *in situ* observations clearly indicate that a significant interaction with coral habitat exists. Longlines are fished extensively in areas of known coral abundance and by-catch of corals is common in some areas. For example, corals, most notably *Primnoa*, were caught on 0.1% of the hooks (619 of 541,350) fished during the 1998 NMFS longline surveys in the Gulf of Alaska and Aleutian Islands (Krieger 2001). Longlines may entangle or hook corals during retrieval (High 1998), while fish attempt to escape during hooking (R. Stone, personal observations), and dislodge or damage corals from straining shear during retrieval (Stone 2006). Derelict longline gear has been observed entangled in *Primnoa* colonies in eastern Gulf of Alaska thickets (R. Stone, personal observations) and other gorgonians in Aleutian Island coral gardens (Stone 2006).

A small amount of longline fishing has occurred on Gulf of Alaska seamounts as evidenced by the recapture of tagged sablefish there (Maloney 2004). Sablefish tagged by NMFS as part of a stock assessment survey have been recovered by fishermen on Pratt, Surveyor, Murray, Durgin, and Quinn seamounts in the Gulf of Alaska. Scientists believe that the effort on the seamounts has been minimal and has occurred opportunistically while fishermen transit by the seamounts.

Longlines pose a moderate threat to coral habitat in Alaska (Table 2.3). They are used extensively over a broad depth range (Figures 2.18A-2.18E) and in virtually all habitat types including those that are typically too rough for trawling. The area of the seafloor contacted during typical fishing operations is low but can be more extensive during gear retrieval in adverse weather conditions. Straining shear and entanglement are the major forces on coral habitat and the seafloor. Longlines are often set in areas of irregular bathymetry and large arborescent corals such as *Primnoa pacifica*, *Paragorgia arborea*, and black corals are the most at risk to disturbance.

Pots and Traps

Pots are used extensively throughout much of Alaska to catch both fish and crabs and are deployed differently depending on the target species. Pots are fished singularly for Pacific



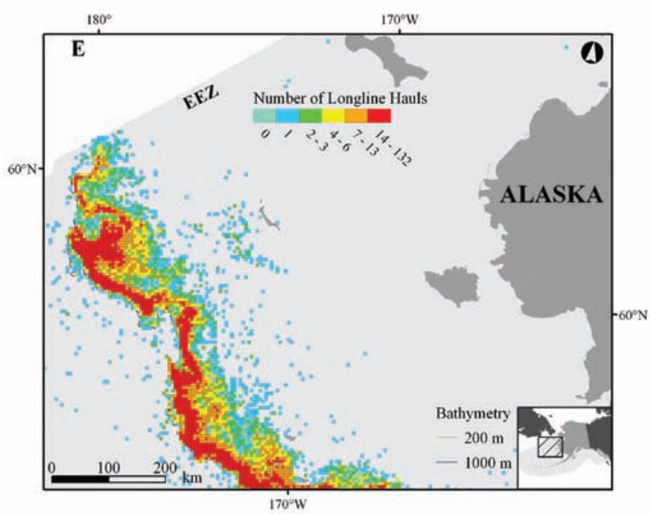
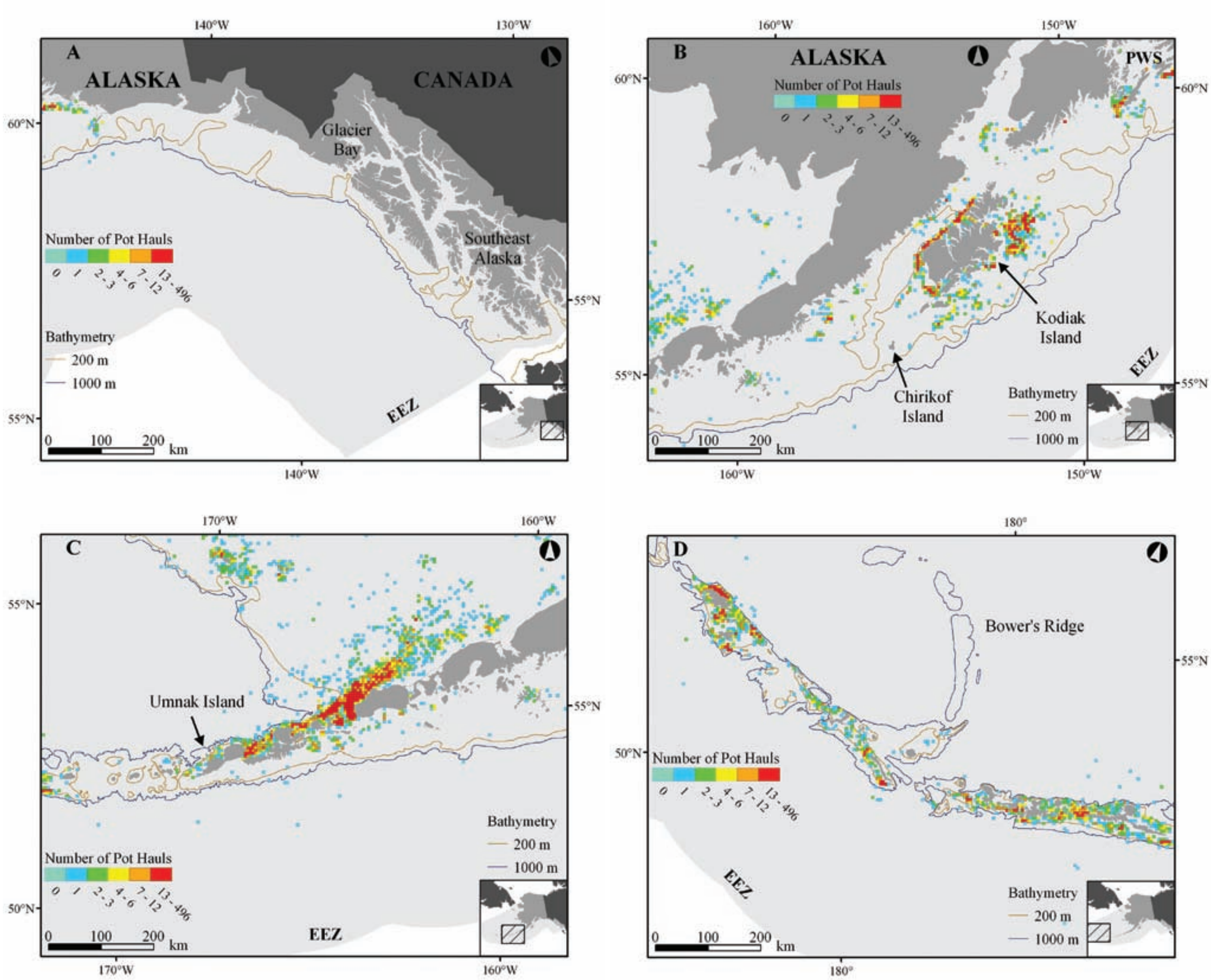


Figure 2.18. Number of longline hauls between 1973 and 1996 in A) the eastern Gulf of Alaska, B) the western Gulf of Alaska, C) the eastern Aleutian Islands, D) the western Aleutian Islands, and E) the Bering Sea (Adapted from Fritz et al. 1998). Methodology described in Fritz et al. 1998.

cod and sablefish in the Gulf of Alaska (Figures 2.19A and 2.19B) and additionally for Greenland turbot (*Reinhardtius hippoglossoides*) in the Aleutian Islands (Figures 2.19C and 2.19D) and Bering Sea (Figure 2.19E). Pot fishing is typically highly localized in these areas (Figures 2.19A-2.19E). Important fisheries with single pots for king crabs (*Paralithodes camtschaticus*, *P. platypus*, *Lithodes aequispina*), Tanner crabs (*Chionoecetes bairdi*), snow crabs (*Chionoecetes opilio*), and Dungeness crabs (*Cancer magister*) occur in the Gulf of Alaska and Bering Sea. Pot fisheries also occur for golden king crabs in the Aleutian Islands (Figures 2.19A and 2.19B). In



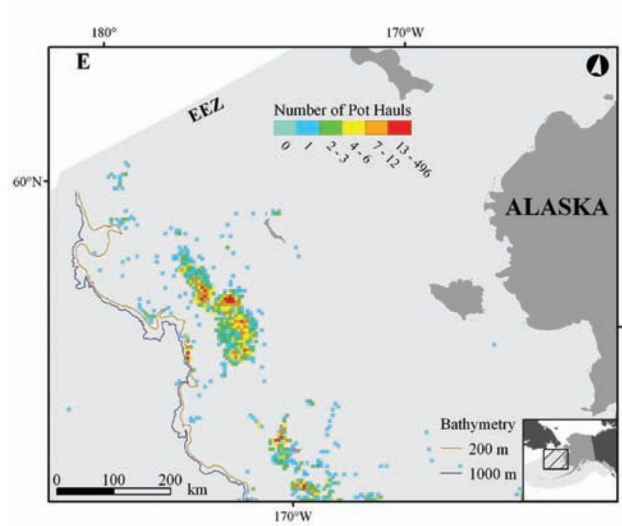


Figure 2.19. Number of fish pot hauls between 1973 and 1996 in A) the eastern Gulf of Alaska, B) the western Gulf of Alaska, C) the eastern Aleutian Islands, D) the western Aleutian Islands, and E) the Bering Sea (Adapted from Fritz et al. 1998). Methodology described in Fritz et al. 1998.

this fishery, however, pots are strung together in strings of 10 to 90 pots or more and total weight of the gear per string can exceed 30 metric tons. Pots are strung together with 1-inch or larger diameter polypropylene line and a single longline may stretch between 3 and 9 km. The fishery occurs at depths between 100 and 719 m and in a wide range of habitats on the slope, offshore banks, and offshore pinnacles that include rocky areas with irregular bathymetry.

No studies have been undertaken to study the effects of pot fishing on seafloor habitat in Alaska. Single pot fisheries likely have a minimal effect on

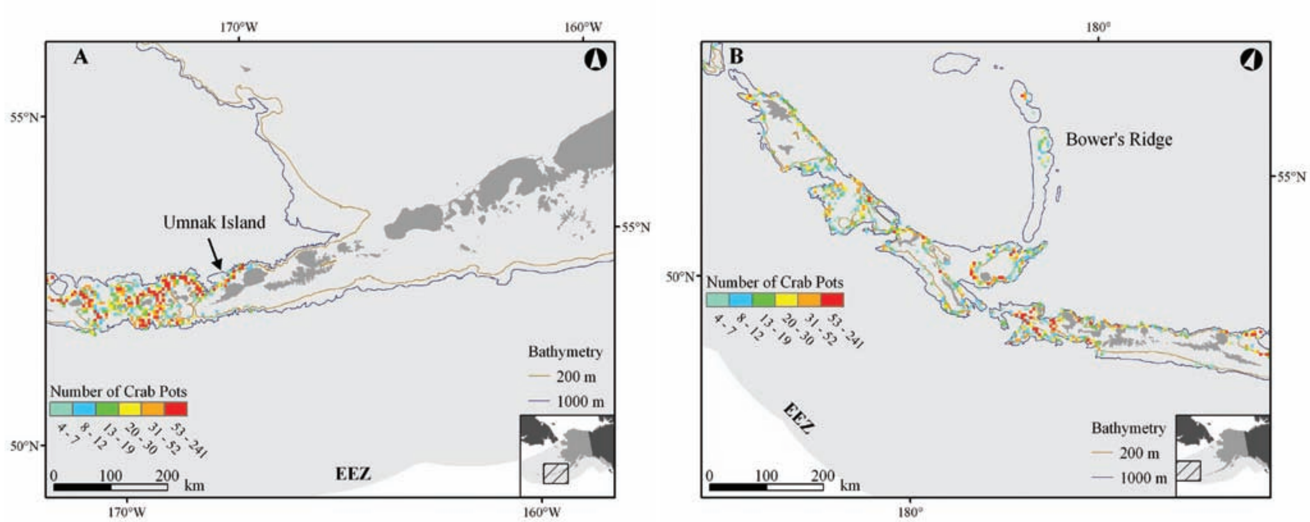


Figure 2.20. Number of observed crab pots during the golden king crab (*Lithodes aequispina*) fishery between 2001 and 2004 in A) the eastern Aleutian Islands and B) the western Aleutian Islands. Each area rectangle measures 0.05º latitude by 0.1º longitude. Source data: Alaska Department of Fish and Game.

coral habitat since they generally occur in soft-sediment areas with minimal coral habitat and because a relatively small area of the seafloor is contacted with the gear (Table 2.3). Pot longlines used in the Aleutian Island golden king crab fishery, however, have the potential to cause extensive damage to coral habitat (Table 2.3) since the spatial distribution of fishing is extensive in some areas of high coral abundance (Figures 2.20A and 2.20B). Depending on how the gear is retrieved, the area of seafloor contacted may be relatively large and the forces on the seafloor may be substantial. The gear is retrieved in a manner to minimize drag on the seafloor due to the strength limitations of the longline; however, under certain conditions the gear can be dragged like a plough across the seafloor. This situation can occur in areas of steep bathymetry and when strong winds and currents dictate that fishing vessels retrieve gear while being forced away from it. At one site in the central Aleutian Islands where disturbance from this gear was observed with the submersible *Delta* (Figure 2.21), the seafloor was scoured to bare substrate along 17 strips (Stone 2006). Aleutian Island coral gardens are at high risk to disturbance from this fishery.

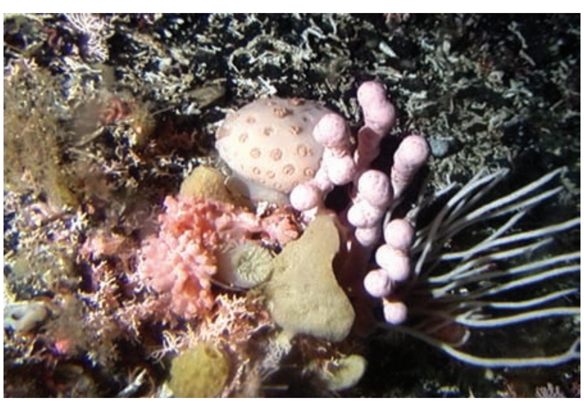


Figure 2.21. Coral habitat can be fragmented by fishing gear as evidenced by this small patch of coral in the path of heavy disturbance. A small bubblegum coral (*Paragorgia arborea*), soft coral (*Anthomastus* sp.), stoloniferan coral (*Clavularia* sp.), hydrocorals, demosponges, and a sea anemone reside at the edge of a path littered with hydrocoral skeletons. Photo credit: R. Stone, NOAA Fisheries.

Scallop Dredges

A small but important fishery has occurred for the weathervane scallop *Patinopecten caurinus* in the Gulf of Alaska and Bering Sea since 1967 (Shirley and Kruse 1995). The fishery occurs in relatively well-defined areas of unconsolidated soft sediments on the continental shelf and at depths between 60 and 140 m (Turk 2001; Barnhart 2003). Scallop dredges are dragged along the seafloor and designed to dig into the top layer of sediment. Dredges have a maximum width of 4.6 m. No directed research on the effects of scallop dredges on coral habitat has been undertaken in Alaska. Overlap does occur between the fishery and the known distribution of pennatulaceans, including ecologically important groves of *Halipteris willemoesi* in the central Gulf of Alaska (Masuda and Stone 2003). With the exception of pennatulacean groves, scallop dredges pose a minimal threat to coral habitat at the present time (Table 2.3). The spatial distribution of fishing is small and the area of the seafloor contacted per tow is relatively small. While the gear is intrusive, it is generally used in soft-sediment areas where coral abundance is low. Groves of pennatulaceans in the Gulf of Alaska are most at risk to disturbance from scallop dredges.

Effects of Other Human Activities

Oil and Gas Exploration and Extraction

Offshore oil and gas operations in Alaska include exploration, development, and production activities (NMFS 2005). Most of these activities presently occur in Cook Inlet in the Gulf of Alaska and on the North Slope (Beaufort and Chukchi Seas)—areas of Alaska that do not support significant deep coral communities. Disturbances from these activities that may affect coral habitat include physical alterations to habitat, waste discharges (well drilling cuttings and muds), and oil spills. Cimberg et al. (1981) discuss the potential effects of oil and gas development on deep corals in Alaska. They concluded that Alaskan corals are unlikely to suffer adverse effects from oil and gas development, because most of the known deep coral distributions do not occur in lease areas and areas where platforms will be placed. They further conclude that the most physiologically sensitive life history stage of deep corals, the planula larval stage, is brief and demersal, and therefore unlikely to be affected by oil spills (Cimberg et al. 1981). No directed research has been undertaken to study the effects of oil toxicity on any life history stage of deep corals found in Alaska. The potential for effects from these activities on coral habitat is likely to increase in the future as the world's demand for oil and gas products continues to increase.

Deployment Of Petroleum Pipelines And Communication Cables

Cook Inlet is the only area of the state where petroleum pipelines (specifically crude oil) have been deployed in benthic marine habitats. Fourteen pipelines totaling 141 km in length were deployed on the seafloor of Cook Inlet between 1965 and 1986 (Robertson 2000). Eight state and federal agencies have regulatory authority over pipelines in Cook Inlet. Accidental spills have occurred in the past and are likely to occur in the future as many of the pipelines reach the end of their expected life span (Robertson 2000). The benthic marine life in the immediate area of the pipelines has not been inventoried but the region is not known to support abundant or diverse coral resources.

Numerous communication cables have been deployed on the ocean floor throughout Alaskan waters since 1900. Thousands of kilometers of cables stretch along the seafloor between Alaskan communities and ports in Washington and Oregon. Cables have been deployed from the shoreline down to depths of 7000 m. There are no known regulations governing the placement of submarine cables but their locations are accurately mapped so that potential interactions with other seafloor uses (e.g., fishing) can be avoided. There are no known reports of cable deployments directly affecting coral habitat although there is some likelihood that cables have been placed in coral habitat, especially in the Aleutian Islands. Cables are typically laid on the seafloor where they remain exposed but may be buried using specially designed ploughs in areas where bottom fishing and other seafloor uses occur. In areas where cables are exposed they may provide attachment substrates for corals and other emergent epifauna and may therefore provide a known time-line for studies of recruitment and subsequent growth of emergent epifauna that settle on them (Levings and McDaniel 1974). No such studies have been conducted yet in Alaska but clearly the potential exists to use submarine cable deployments to gain insights into coral habitat recovery rates. Deployment of communication cables is presently a minimal threat to deep coral ecosystems in Alaska given the very small area of the seafloor that is contacted by them.

Pollution - Point-source Discharges

Point-source discharges that occur in coastal marine areas of Alaska have little potential to affect deep coral habitat. Coral habitat is sparse in coastal areas of Alaska where point-source discharges occur or are expected to occur in the near future but a few coastal areas near municipalities do support groves of pennatulaceans. The greatest threat to coral habitat from point-source discharges is the introduction of large volumes of untreated sewage and chlorine. Sewage discharge causes organic nutrient enrichment of receiving waters, rapid increases in biological production, and eutrophication through depletion of dissolved oxygen (Tomascik et al. 1997). High concentrations of phosphates in effluent may also cause algal blooms that are lethal to corals (Alcolado 1998). Chlorine is toxic to marine life, and chlorinated sewage effluent may subject marine biota, including octocorals, to either single-event acute exposures or to chronic exposures (Tomascik et al. 1997).

Fish Processing Waste
In Alaska, seafood-processing facilities are located both on shore and at sea onboard processing vessels. Coral habitat is sparse in coastal areas of Alaska where seafood-processing discharges occur and concerns to coral habitat there would be similar to those for point-source discharges. At-sea processors would have little effect on deep coral habitat unless they routinely discharged waste in areas of high coral abundance.

Harvest of Precious Corals
A directed fishery for precious corals never developed in Alaska despite the fact that several species have potential commercial value as jewelry (Cimberg et al. 1981). Corals found in Alaska with potential commercial value include *Primnoa pacifica*, *Primnoa wingi*, bamboo corals (Family Isididae), black corals, and a single species of precious red coral (Family Coralliidae) reported from Patton Seamount in the Gulf of Alaska (A. Baco-Taylor, WHOI, pers. comm.). However, many corals that are collected as by-catch, particularly *P. pacifica*, bamboo corals, and stylasterids, are often retained by fishermen as souvenirs and curios.

Mineral Mining
Mineral mining operations in Alaska have been limited to offshore placer mining for gold and barite off the coast of Nome in Norton Sound (northern Bering Sea) and at a single location near Petersburg in Southeast Alaska (Conwell 1976). Mineral mining activities could potentially affect deep coral habitat through increased sedimentation and turbidity near the seafloor but are unlikely to occur in areas of coral abundance in the near future.

Climate Change
Climatic regime shifts and cyclic environmental fluctuations associated with Pacific Decadal Oscillations, El Niño/Southern Oscillation Climate and La Nina events have had documented effects on oceanographic and biological processes in the North Pacific Ocean. Effects on corals of this interannual to decadal variability have not been reported. Long-term climatic change due to global warming could affect seawater temperature, salinity, density, sea level, and ambient light levels especially in shallow and nearshore waters. None of these changes is expected to cause direct mortality of deep corals or significantly alter their geographic or depth distribution but effects on growth rates and food supply (i.e., phytoplankton) are possible.

Increases in atmospheric carbon dioxide caused by manmade emissions have been linked to decreases in oceanic pH (Caldeira and Wickett 2003). Decreases in oceanic pH and resulting decreases in calcium carbonate saturation state and calcification could have devastating effects on marine organisms dependent on the extraction of calcium carbonate from seawater for skeletal building (Kleypas et al. 1999; Guinotte et al. 2006). Zooxanthellate corals in shallow waters will experience decreasing aragonite saturation states that could negatively affect their calcification rates and the stability of reef ecosystems (Guinotte et al. 2003). Numerous studies have shown substantial decreases in calcification rates (>40%) with relatively modest decreases in aragonite saturation state (Langdon et al. 2003; Langdon and Atkinson 2005). Some evidence suggests that deep-sea biota may be sensitive to changes in pH (Seibel and Walsh 2001; Guinotte et al., 2006; Roberts et al., 2006). Mounting evidence suggests that if CO_2 emissions continue as projected, undersaturated regions will develop in the sub-arctic and polar regions of Alaska by the end of the 21st century (Orr et al. 2005; Kleypas et al. 2006; Guinotte et al. 2006). Scleractinian corals would be most affected by this development, but are not important structure-forming corals in Alaskan waters. Octocorals, stylasterids and pennatulaceans however, are important structure-forming components of benthic ecosystems in Alaskan waters and will likely be affected by ocean acidification. The sclerites of octocorals are calcitic, but the axes may be composed of calcite, aragonite, or amorphous carbonate hydroxylapatite (Bayer and Macintyre 2001). The calcite saturation horizon, along with the aragonite saturation horizon, is moving to shallower depths over time (Feely et al. 2004), which could affect all corals in Alaska that use calcite to build skeletal tissue.

Invasive Species
The introduction of invasive species to Alaskan

waters is a real threat and the State of Alaska has developed an Aquatic Nuisance Species Management Plan to prevent introductions and identify and respond to threats (ADF&G 2002). Ballast water discharges from ships and barges are the single largest potential source of invasive species in Alaska. For example, tankers arriving from domestic ports at Port Valdez, Prince William Sound, release the third largest volume of ballast water of all U.S. ports (ADF&G 2002). Tankers arriving from foreign ports are required to exchange ballast water at sea (in waters at least 2000 m deep). The potential for introductions in coastal Alaska and the Aleutian Islands in particular is high given the high volume of ship traffic from ports around the world.

To date, the introduction of invasive species has been largely limited to a few species of freshwater fish and aquatic plants. There are no known invasive species of corals or predators of corals in Alaskan waters although the threat of introduction exists. The threat of introduction may increase if more favorable oceanic conditions related to climatic change develop in the future.

VIII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

The North Pacific Fishery Management Council (NPFMC) manages the fishery resources of Alaska with five Fishery Management Plans (FMPs). The Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) mandates that FMPs must include a provision to describe and identify essential fish habitat (EFH) for each fishery, minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat. EFH has been broadly defined by the Act to include “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” Deep coral habitat has been identified as EFH for some groundfish species (Witherell and Coon 2001) and several areas of Alaska have recently been designated as Habitat Areas of Particular Concern (HAPCs) and are presently afforded some protection from disturbance by fishing activities (described below). The Minerals Management Service (US Department of the Interior) oversees petroleum and mineral resource development in the offshore waters of the U.S. EEZ and implements studies designed to predict the effects of resource development on the marine ecosystem including deep coral habitat.

Seafloor Mapping

Approximately 46,710 km^2 of seafloor habitat has been mapped in the Alaska region using multibeam sonar technology (Table 2.4). These efforts have been piecemealed together by several agencies including NMFS, Alaska Deparment of Fish and Game (ADF&G), National Park Service (NPS), University of Alaska Fairbanks, and Oregon State University. Additionally, about 27,780 km^2 of seafloor has been mapped by NOAA’s National Ocean Service (NOS) since 1994 for navigational purposes. No coordinated plan to map the seafloor within the EEZ currently exists and mapping efforts to date have been scattered from Southeast Alaska through the Aleutian Islands including some of the seamounts within the EEZ. Mapping has included 4,220 km^2 and 28,280 km^2 of seafloor on Gulf of Alaska shelf and slope habitats and Gulf of Alaska seamounts, respectively. An additional 14,150 km^2 of seafloor has recently been mapped in the Aleutian Islands.

While the purpose of the seamount and some of the Aleutian Island mapping efforts have been strictly to support detailed studies on deep coral habitat, most of the mapping efforts to date have been in support of studies on essential fisheries habitat and geological processes. Additional goals of these studies have been to determine the effects of fishing on benthic habitat, fish stock assessments, understanding basic ecological processes, and life history studies of benthic organisms (e.g., Shotwell et al. in press; O’Connell et al. in press).

Several of the mapping efforts have included the collection and subsequent interpretation of backscatter data and the detailed classification of seafloor habitats using the methods of Greene et al. (1999). Direct observations of the seafloor with occupied submersibles, ROVs, or towed cameras have been used to ground-truth habitat types and provide fine-scale resolution of habitat features. One goal of the Aleutian Island studies (see http://www.nprb.org/research/res_2003_projects_listing.htm) is to develop a model to predict where deep coral habitat is located throughout the region. Mapped areas were systematically

Table 2.4. Areas of Alaska that have been mapped with modern multibeam sonar technology. AI = Aleutian Islands, GOA = Gulf of Alaska, SM = seamounts, UAF = University of Alaska Fairbanks, NMFS = National Marine Fisheries Service, ADFG = Alaska Department of Fish and Game, OSU = Oregon State University, NPS = National Park Service.

Region	Name of area	Agency	Depth range (m)	Coral presence	Area (km^2)
GOA	Hazy Islands	ADFG	50-300	Yes	390
GOA	Cape Ommaney	ADFG, NMFS	30-300	Yes	275
GOA	Glacier Bay National Park	NPS	10-410	Yes	62
GOA	Fairweather Ground	ADFG	23-192	Yes	280
GOA	Yakutat Bay	ADFG	15-50	Unknown	20
GOA	Yakutat Bay	ADFG	15-50	Unknown	20
GOA	South Yakutat	NMFS	190-1045	Unknown	372
GOA	Pamplona Spur	NMFS	120-940	Yes	162
GOA	Portlock Bank	NMFS	100-750	Yes	790
GOA	Albatross Bank, Snakehead	NMFS	60-810	Yes	310
GOA	Albatross Bank, 8-fathom pinnacle	NMFS, NOS	20-716	No	17
GOA	Albatross Bank, 49-fathom pinnacle	NMFS	80-800	Unknown	32
GOA	Chirikof	UAF	100-600	Unknown	1,550
GOA, SM	Seamounts 2002	UAF, OSU	?	Yes	?
GOA, SM	Seamounts 2004	UAF, OSU	?	Yes	14,081
GOA, SM	Transit between seamounts	UAF, OSU	?	Unknown	9,000
GOA, SM	Derickson Seamount	UAF, OSU	2750-6800	Yes	5,200
AI	Akutan	UAF	78-482	Unknown	27
AI	Bogoslof	UAF	20-820	Unknown	28
AI	RV *Revelle* transit	UAF	90-4200	Yes	11,341
AI	Samalga Island, North	NMFS	107-323	Yes	11
AI	Samalga Island, South	NMFS	120-150	Yes	9
AI	Islands of Four Mountains, North	NMFS	144-223	Yes	13
AI	Islands of Four Mountains, South	NMFS	88-204	Yes	12
AI	Islands of Four Mountains, West	NMFS	116-218	Yes	11
AI	Aleutian Corals	NMFS	100-3000	Yes	2,697
AI	Track Lines	NMFS	30-4000	Yes	NA
Total					**46,710**

selected so that results can be extrapolated to unmapped areas. Habitats within the mapped areas are currently being classified through interpretation of the bathymetric and backscatter data. Submersible and ROV observations are being used to ground-truth the habitat types, map coral observations, and ultimately to provide data on coral densities relative to mapped habitat features.

Ongoing Research
Research activities in 2006 focused on completing taxonomic, genetic, and reproductive ecology analyses on more than 400 coral specimens collected during the 2003-04 Aleutian Island studies and 140 coral specimens collected during the 2004 Gulf of Alaska seamount cruise. Additionally, detailed examination of video footage collected from submersibles and ROVs during these studiesis underway and willto provide fine-scale data on coral distribution, habitat characteristics, species associations, and disturbance from both human and natural causes.

The submersible *Delta* was used in 2005 to delineate the extent of *Primnoa* thickets in two areas of the eastern Gulf of Alaska (Fairweather Ground and Cape Ommaney; Figure 2.22). The two areas were established as HAPCs by NMFS in July 2006 and the use of all bottom-contact fishing gear is now prohibited in those areas. The purpose of the research was to provide detailed data on the distribution of *Primnoa* in the areas so that the efficacy of the closures to protect the thickets from incidental disturbance can be predicted. Additional objectives of the research are to assess the present condition of the thickets, examine the fine-scale use of the coral habitat by FMP species, and collect specimens for taxonomic identification. A third site in Dixon Entrance near the maritime boundary with Canada was also investigated to determine if the *Primnoa* thickets reported from that region (Krieger 2001) warrant designation as a HAPC. The thickets in that region appear to be located in deeper water and in a region where both the U.S. and Canada claim jurisdiction. A joint research cruise by both governments may be planned in the future to examine coral habitat in that region.

A two-year study to examine shallow-water populations of *Primnoa pacifica* in Glacier Bay National Park was completed in April 2005. Populations of *Primnoa* were discovered in 2004 along bedrock walls recently exposed by retreating glaciers (Figure 2.23). The study is investigating the role of oceanographic processes in coral depth distribution and the potential use of an accurate deglaciation record to validate estimated growth rates for the species (Stone et al. in preparation). Thriving populations of *Primnoa* were discovered in two additional glacial fjords in Holkham Bay, Southeast Alaska during a research cruise in 2006. Samples were collected from 80 colonies from four spatially distinct “populations” during a second cruise to the fjords in 2007. Those samples will be used to develop microsatellite genetic markers to examine the population structure of *Primnoa* in the fjords and to address questions regarding larval dispersal and gene flow.

Planned or Anticipated Activities
No directed research or mapping activities are planned at the present time due to limited funding and personnel support. Several important areas of deep coral research remain a high priority for the region (discussed below) and those will be addressed as funding and support becomes available in the future.

North Pacific Fishery Management Council
The North Pacific Fishery Management Council has responsibility for developing fishery management plans for the nation’s groundfish resources in the EEZ of the Alaska region and oversees the implementation of measures to conserve and enhance essential fish habitat for those resources. Since 1987, 1,107,890 km^2 of seafloor habitat in the Bering Sea and Aleutian Islands has been afforded some protection from fishing activities (Figure 2.22). An additional 202,380 km^2 of seafloor habitat has been afforded some level of protection in the Gulf of Alaska (summarized in NMFS 2004). Most area closures are for specific gear types only, others are seasonal, and some closures go into effect only when a species by-catch cap has been reached. Year-round closures to trawl gear exist in both the Bering Sea and Gulf of Alaska to protect important crab habitat. Year-round closures also exist around Steller sea lion rookeries to protect forage species. A single area, the 8.1 km^2 Edgecumbe Pinnacles Marine Reserve (also known as the Sitka Pinnacle Marine Reserve) in the eastern Gulf of Alaska, was established in 2000 as the only no-take groundfish reserve in the state. A

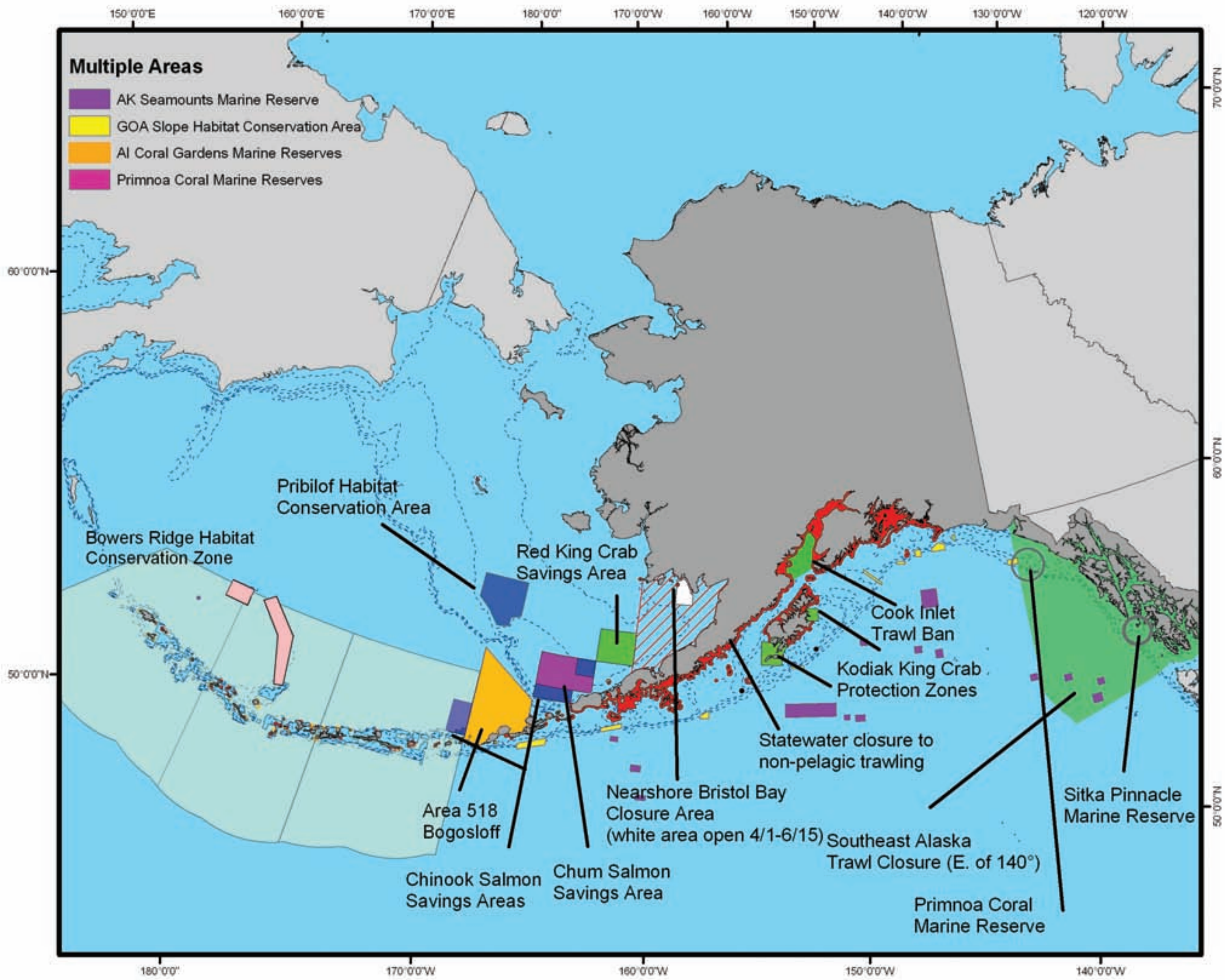


Figure 2.22. Areas of Alaska with some restrictions on fishing activities. Map credit: Cathy Coon, NPFMC.

comprehensive inventory and classification of Marine Protected Areas (MPAs) in Alaska and a brief history of their development is provided in Witherell and Woodby (2005).

In February 2005 the NPFMC voted unanimously to protect vast areas of seafloor habitat in the Gulf of Alaska and Aleutian Islands. NMFS approved the Record of Decision on the NPFMC essential fish habitat (EFH) environmental impact statement (EIS) containing these provisions on August 8, 2005 and the regulations were implemented in July 2006. The Aleutian Islands closures include a vast area (957, 361 km^2) of seafloor west of the Islands of Four Mountains (170° W) and includes nearly the entire EEZ in the region (Figure 2.24). The Aleutian Islands Habitat Conservation Area (AIHCA) is the largest bottom trawl closure in the U.S. and the first in the state directed at protecting sensitive deep coral habitat. Under the decision, areas that have been trawled in the past and have supported the highest groundfish catches will remain open (42,611 km^2), while largely unfished areas including Bowers Ridge in the Bering Sea, are closed to bottom trawling (Figure 2.24). Approximately 52% of the fishing grounds previously targeted by trawlers (defined as those habitats within the current depth range of trawl activities—1000 m depth), or about 100,000 km^2 of seafloor, are now closed to bottom trawling in the Aleutian Islands (Figure 2.24). The majority of the seafloor habitat within the closure has not yet been explored by scientists but much of it is deep abyssal plain that likely supports little deep coral habitat. Initial indications are that few species of commercial importance exist in these deep areas that would have put the habitat at risk to immediate or future trawling activities. Nonetheless, the closure effectively freezes the current footprint of trawling activities until scientists can determine the full scope of deep coral habitat and fisheries resources in the region. Perhaps the highlight of the AIHCA is the closure of six coral gardens (377 km^2 total) in the central Aleutian Islands where the use of all bottom-contact gear is now prohibited (Figure 2.24).

The NPFMC also voted to establish HAPCs in the Gulf of Alaska where the use of all bottom-contact fishing gear would be prohibited. These include five small areas (46 km^2 total) in the eastern Gulf of Alaska to protect dense thickets of red tree corals (*P. pacifica*), 7,155 km^2 of slope habitat and 16 seamounts (the majority in the Gulf of Alaska) to protect deep coral habitat (18,278 km^2 total).

the State of Alaska to regulate fishing vessels in the EEZ, even if not registered with the State, if they are operating in a fishery for which there was no FMP in place on August 1, 1996. In 2003, the State of Alaska adopted a regulation (5 ACC 38.062e) that states that no permits will be issued to commercially harvest corals or sponges. This regulation applies to both state waters and those within the EEZ.

Minerals Management Service

Offshore drilling activities are regulated by the U. S. Department of the Interior's Minerals Management Service and their proposed plan for outer continental shelf (OCS) oil and gas leasing

Figure 2.23. *Primnoa pacifica* thrives in the cold, dark glacial fjords of Southeast Alaska. This colony, at a depth of only 18 m, provides a resting platform for a blue king crab (*Paralithodes platypus*). Photo credit: R. Stone, NOAA Fisheries.

Directed Harvest

In April 2000, the NPFMC introduced a regulation defining all corals as prohibited species (Witherell and Coon 2001). The regulation would have effectively prohibited the sale, barter or trade of corals but the measure was never adopted by the NPFMC since it would only apply to federally licensed groundfish vessels and fishermen. Rather than adopt a measure that would not have applied to all fishing vessels, the NPFMC relegated management authority to the State of Alaska under provisions of the MSFCMA. Section 306(a)(3)(C) of the MSFCMA gives authority to

(2007 - 2012) includes two lease sales in the North Aleutian Basin. Offshore drilling in the OCS region of Alaska began in 1975 and since that time nearly 100 exploratory wells have been drilled. Twenty nine wells have been drilled in shallow-water (5 - 51 m depth) areas of the Beaufort Sea. Five wells have been drilled at depths between 42 and 46 m in the Chukchi Sea, 24 wells have been drilled in the Bering Sea Region (Norton Sound, Navarin Basin, and south of the Pribilof Islands) at depths between 11 and 165 m, and 25 wells have been drilled in the Gulf of Alaska including 13 in Cook Inlet at depths between 35

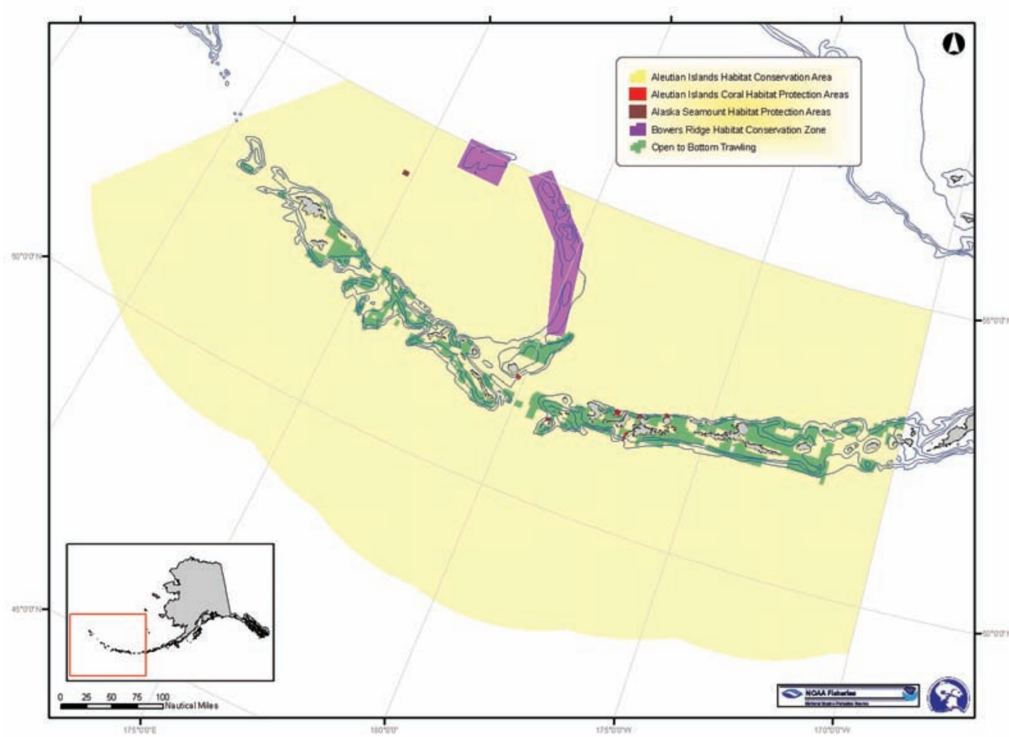


Figure 2.24. Closure areas in the Aleutian Islands, Alaska that were proposed by the North Pacific Fishery Management Council in February 2005 and approved by NOAA Fisheries in 2006. Map credt: Cathy Coon, NPFMC.

and 263 m. There are currently no regulations in place specifically to protect deep corals from these activities and most present drilling activities occur in areas not known to support abundant or diverse coral resources. In early 2007 however, the longstanding moratorium barring offshore oil and gas drilling in Bristol Bay and the southeastern Bering Sea was lifted by President Bush paving the way for oil and gas lease sales in this region of Alaska. While removal of the ban has caused the greatest concern over the potential effects offshore drilling may have on the area's rich stocks of salmon and groundfish, the area may also support important coral habitat, particularly beds of soft corals, that could be affected by any development in the region.

National Marine Sanctuaries

No National Marine Sanctuaries exist in Alaskan waters.

IX. REGIONAL PRIORITIES TO MANAGE AND CONSERVE DEEP CORAL COMMUNITIES

Directed research on deep coral habitat has been undertaken only during the past decade in the Alaska Region. Geographical areas known to support abundant and diverse deep corals, such as the Aleutian Islands and Gulf of Alaska seamounts, have been the first priority for exploration and specimen collection. While specimen collections and direct observations of deep corals in those areas will provide important foundation studies on coral ecology and systematics, many research priorities remain for the region.

Recently, NMFS recommended that the NPFMC pursue three courses of action regarding the effects of fishing on essential fish habitat in Alaska (NMFS 2005) and these apply directly to deep coral habitat:

1. The NPFMC and NMFS should continue to analyze how implementation of fisheries management measures affects seafloor habitats.
2. The NPFMC should continue to support research to improve scientific understanding of the effects of fishing on seafloor habitat, the ecological processes linking habitats and managed species, and the recovery rates of seafloor habitats disturbed by fishing gear.
3. The NPFMC should take specific precautionary management actions to avoid

additional disturbance to fragile seafloor habitats that may be especially slow to recover.

The third course of action recommended by NMFS has already been met to a large degree through the recent closure of vast areas of seafloor to fishing activities. These closures now provide an excellent opportunity to pursue the first and second courses of action to some degree. In support of these courses of action we have identified the following priorities for future deep coral research and conservation in the Alaska Region.

- **Research**

Studies on the growth rates and reproductive ecology from representative corals of the major taxonomic groups need to be undertaken to provide estimates of recovery rates for coral habitat. These data will provide a better understanding of the ability of species to recover from disturbance and recolonize areas set aside as mitigative measures such as HAPCs or MPAs. Growth rates are known for only three octocoral species that occur in Alaska (*Calcigorgia spiculifera*, *Halipteris willemoesi*, and *Primnoa* sp.) and range from approximately 5.8 mm yr^{-1} to 23.2 mm yr^{-1} (Stone and Wing 2002; Wilson et al. 2002; Andrews et al. 2002). Whether these rates encompass the full range of growth rates for other octocorals or for other taxonomic groups (e.g., antipatharians) is unknown. Additional growth rate studies are needed for representative species from each major structure forming taxonomic group and for those taxa that form single-species assemblages that provide important habitat in certain regions. The following taxa are excellent candidates for growth studies: 1) the gorgonians *Fanellia* spp., *Plumarella* spp., *Thouarella* spp., and *Keratoisis* spp. or *Isidella* spp., 2) the stylasterids *Stylaster cancellatus* and *S. campylecus*, 3) the antipatharians *Chrysopathes formosa* and *C. speciosa*, and 4) the true soft coral *Eunephthea rubiformis*. Studies on the reproductive ecology of deep corals have been limited to Aleutian Island stylasterids (Brooke and Stone in press) and a few species of Aleutian Island gorgonians (Anne Simpson, University of Maine, unpublished data). Reproductive ecology studies should be undertaken for *Primnoa* spp. and all of the taxa listed above.

Taxonomic studies need to be expanded so that accurate identifications of by-catch can be made in the field. Gorgonians, stylasterids, black corals, pennatulaceans, and true soft corals are abundant and important structure-forming corals in the Alaskan Region yet their taxonomy is still poorly understood despite the fact that extensive collections have now been made throughout much of the region. The taxonomy for 52 of the 141 unique taxa of deep corals (nearly 37%) documented from Alaska have not been accurately identified to species.

Studies on the effects of ocean acidification and oil toxicity on deep corals should be undertaken now. Ocean acidification could have serious consequences on deep corals in areas of the North Pacific Ocean where the aragonite and calcite saturation horizons are already quite shallow and predicted to become shallower in the near future (Guinotte et al. 2006). Studies should include monitoring shallow-water populations of the scleractinians *Javania borealis*, *Caryophyllia alaskensis*, and *Balanophyllia elegans* in the central Aleutian Islands (Stone 2006) and also laboratory manipulative experiments that subject cold water corals to the more acidic conditions they are likely to encounter in the coming decades. New deep-sea technology (e.g. free ocean CO_2 enrichment systems or FOCE systems) is currently being developed that will allow scientists to monitor calcification rates of corals *in situ* while carefully controlling and manipulating pH (Bill Kirkwood, Monterey Bay Aquarium Research Institute, pers. comm). When fully developed this technology will be a highly valuable tool for studying the effects of ocean acidification on deep corals in Alaska. Oil and gas exploration and extraction is likely to increase in the marine environment of Alaska in the near future. Laboratory manipulative experiments should be conducted to determine the toxicity effects of oil on both the adult and larval stages of deep corals. The soft coral, *Eunephthea rubiformis*, is an excellent candidate for such studies.

Studies on the effects of specific fishing gear types on coral habitat need to be undertaken so that we can better understand the effects of certain fisheries on coral habitat. Experiments on gear modifications to reduce coral by-catch and contact with the seafloor should be a high priority. Further studies need to be conducted on the use of coral habitat by managed groundfish species.

Limited research to date clearly indicates that many FMP species are associated with coral habitat but the nature of the associations is still unknown. Additional research is necessary to examine in detail how these species use coral habitat (i.e., to accomplish which life processes) so that estimates of changes to overall fisheries productivity can be made following disturbance.

Reconnaissance submersible dives should be undertaken in coral "hotspots" to assess their suitability as HAPCs. Coral hotspots include areas of abundant and diverse by-catch and areas known or suspected by scientists to support assemblages of gorgonians, pennatulaceans, and antipatharians. Hotspots include areas along the shelf and upper slope of the Gulf of Alaska where stock assessment surveys indicate the presence of *Primnoa* thickets and patches of bamboo corals and black corals. Other hotspots include several of the canyons on the Bering Sea shelf where survey by-catch records indicate the presence of *Primnoa* sp, *Paragorgia* sp., bamboo corals, and groves of pennatulaceans—the northernmost records for these corals in the North Pacific Ocean.

Reconnaissance submersible dives should also be made on areas of Bowers Bank in the Bering Sea that were recently closed to all bottom trawling as part of the recently established Aleutian Islands Habitat Conservation Area. The Bank is completely unexplored and is one of the few regions of Alaska that has received very little fishing pressure but is thought to contain extensive deep coral habitat based on its geographical proximity to the Aleutian Islands and Petrel Bank where rich coral habitat has been documented.

- **Seafloor mapping**

Multibeam mapping technology is very expensive (i.e., recent efforts in the Aleutian Islands were approximately $30,000 per day and on average about 80 km^2 could be mapped per day) and consequently only a fraction of 1% of the seafloor in the Alaska Region has been mapped to date. Some of the recent mapping effort has been in support of submersible operations with the directed coral studies. Other efforts have been in heavily fished areas in the Gulf of Alaska that do not support abundant coral resources but are important areas for the study of gear effects on seafloor habitat. Many areas of high coral abundance, based on by-catch records, have not been mapped and they should rate as a high priority for the limited funds available for that purpose. The coral hotspots listed above are a high priority for mapping.

- **Coral by-catch database**

Coral by-catch in fisheries and stock assessment surveys will continue to be an important data source in mapping Alaska's coral resources and interactions with fisheries. Databases for these surveys are well established and maintained and are a tremendous source of data (e.g., Heifetz 2002; Etnoyer and Morgan 2005). While the databases are currently in a usable format some restrictions regarding confidentiality do limit their usefulness at the present time. Fisheries observer databases could be greatly improved by including more precise locations of fishing effort and coral by-catch. Coral by-catch from the surveys is also a tremendous, and largely untapped, source of specimens for taxonomic, paleoclimatological, and ecological analyses. Specific collection requests for these purposes are occasionally accepted by the survey teams but little time is typically available for these purposes and proper identification of requested taxa are often difficult. Training in coral identification should be made available to all fisheries observers and the publication of additional field identification guides should be undertaken to facilitate these requests.

X. CONCLUSION

Deep corals are an important component of benthic ecosystems in Alaska. Highly varied submarine geology, persistent water currents, and plankton rich waters support at least 141 species from six major taxonomic groups. Deep corals have a broad geographical and depth distribution within the region. The Aleutian Islands support the highest diversity and abundance of corals in Alaskan waters but other subregions, such as the Gulf of Alaska and Bering Sea, support important single-species assemblages of gorgonians, pennatulaceans, and true soft corals. Many are important structure-forming species due to their large size, branching morphology, and patterns of distribution.

Fishing gear that contacts the seafloor is presently the single largest threat to coral habitat in Alaska. Evidence from research submersible observations and coral by-catch data collected during fisheries and stock assessment surveys indicate that interactions between coral habitat and current fisheries occur in many areas. The NPFMC and NMFS have taken significant steps to address this interaction by recently implementing extensive closures specifically to protect coral habitat from disturbance caused by fishing activities.

Most of the commercial species currently harvested in Alaska (approximately 85% of all FMP species or species groups) spend all or part of their life cycle in deep habitat where corals are potentially found. As the world population continues to grow and the demand for seafood increases in the future, conservation of Alaska's deep coral resources will be a major challenge for managers striving to maintain sustainable fisheries. NOAA recognizes the value of both shallow and deep coral habitat conservation in that endeavor and has listed it as one of nine programs within the Ecosystems goal in its strategic plan—the only taxa explicitly listed in the Strategic Plan and the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 mandates continued research, mapping, and protection of deep coral communities.

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Appendix 2.1. Geographical distribution of corals in Alaska waters. EG = eastern Gulf of Alaska, WG = western Gulf of Alaska, AI = Aleutian Islands, BS = Bering Sea, SM = seamounts. ● = documented, ○ = not documented. Adapted from Heifetz et al. (2005).

Taxa	EG	WG	AI	BS	SM
Phylum Cnidaria, Class Anthozoa, Order Scleractinia (Stony Corals)	●	●	●	●	●
Balanophyllia elegans	●	●	●	○	○
Caryophyllia alaskensis	●	●	●	○	○
Caryophyllia arnoldi	●	●	●	○	●
Crispatotrochus foxi	○	○	●	○	○
Flabellum sp.	○	○	●	○	○
Fungiacyathus marenzelleri	○	○	●	○	○
Fungiacyathus sp. A	○	○	○	○	●
Javania borealis	○	●	●	○	●
Javania cailleti	●	●	●	○	○
Leptopenus discus	○	○	●	○	○
Paracyathus sp.	○	○	●	○	○
Order Antipatharia (Black Corals)	●	●	●	●	●
Bathypathes alternata	●	○	○	○	○
Bathypathes patula	●	○	○	○	●
Bathypathes sp. A	●	○	○	○	●
Bathypathes sp. B	○	○	○	○	●
Chrysopathes formosa	●	○	○	○	○
Chrysopathes speciosa	●	○	○	○	○
Dendrobathypathes boutillieri	●	○	●	○	●
Heliopathes pacifica	○	○	○	○	●
Lillipathes lilliei	●	○	○	○	○
Lillipathes wingi	●	○	○	○	●
Parantipathes sp.	●	○	●	○	●
Stichopathes sp.	○	○	○	○	●
Trissopathes pseudotristicha	○	○	●	○	●
Trissopathes tetracrada	○	○	○	○	●
Subclass Octocorallia, Order Alcyonacea, Suborder Alcyoniia (True Soft Corals)	●	●	●	●	●
Alcyonium sp.	○	○	●	○	○
Anthomastus japonicus	○	○	●	●	○
Anthomastus cf. *japonicus*	○	○	●	○	○
Anthomastus ritteri	●	●	●	○	○
Anthomastus sp. A	○	○	●	○	●
Anthothela cf. *grandiflora*	○	○	●	○	○
Eunephthea rubiformis	●	●	●	●	○
Eunephthea sp. A	○	○	●	○	○
cf. *Eunephthea*	○	○	●	○	○

Taxa	EG	WG	AI	BS	SM
Suborder Stolonifera (Stoloniferans)	●	●	●	●	●
Clavularia armata	○	○	○	○	●
Clavularia moresbii	●	●	●	○	○
Clavularia rigida	○	○	○	○	●
Clavularia sp. A	○	○	●	○	○
Sarcodictyon incrustans	●	○	●	●	○
Sarcodictyon sp. A	○	○	○	○	●
Order Gorgonacea (Gorgonians)	●	●	●	●	●
Acanella sp.	○	○	○	○	●
cf. *Acanthogorgia*	○	○	●	○	○
Alaskagorgia aleutiana	○	○	●	○	○
Amphilaphis sp. A	○	○	●	○	○
Amphilaphis sp. B	○	○	●	○	○
Amphilaphis sp. C	○	○	●	○	○
Arthrogorgia ijimai	○	○	○	○	●
Arthrogorgia kinoshitai	●	●	●	●	○
Arthrogorgia otsukai	○	○	●	●	○
Arthrogorgia utinomii	○	○	●	○	○
Calcigorgia beringi	●	○	●	○	○
Calcigorgia spiculifera	●	●	●	○	○
Calcigorgia sp. A	○	○	●	○	○
Calyptrophora japonica	○	○	○	○	●
cf. *Chrysogorgia*	○	○	●	○	●
Chrysogorgia sp. A	○	○	○	○	●
Corallium sp.	○	○	○	○	●
Cryogorgia koolsae	○	○	●	○	○
Fanellia compressa	○	○	●	●	○
Fanellia fraseri	○	●	●	○	○
Isidella elongata	○	○	○	○	●
Isidella paucispinosa	●	●	●	○	○
Isidella sp. A	○	○	●	○	●
Keratoisis profunda	●	●	●	○	○
Keratoisis sp. A	○	○	○	○	●
Keratoisis sp. B	○	○	○	○	●
Lepidisis sp. A	●	●	○	○	○
Lepidisis sp. B	○	○	○	○	●
Muriceides cylindrica	○	○	●	○	○
Muriceides cf. *cylindrica*	○	○	●	○	○
Muriceides nigra	○	○	●	○	○
Muriceides sp. A	○	○	●	○	○
Narella sp. A	○	○	●	○	○
Narella sp. B	○	○	○	○	●
Narella sp. C	○	○	○	○	●
Narella sp. D	○	○	○	○	●
Narella sp. E	○	○	○	○	●

Taxa	EG	WG	AI	BS	SM
Narella sp. F	○	○	○	○	●
Paragorgia arborea	●	●	●	●	○
Paragorgia pacifica	●	○	○	○	○
Paragorgia sp. A	○	○	○	○	●
Paramuricea sp.	○	○	●	○	○
Parastenella sp. A	○	○	●	○	●
Parastenella sp. B	○	○	○	○	●
Plumarella flabellata	○	○	●	○	○
Plumarella longispina	●	●	●	●	○
Plumarella spicata	○	○	●	○	○
Plumarella spinosa	○	○	●	○	○
Plumarella sp. A	○	○	●	○	○
Primnoa pacifica	●	●	●	●	○
Primnoa pacifica var. *willeyi*	●	●	●	○	●
Primnoa wingi	○	○	●	○	○
"*Pseudisidella*" sp.	○	○	●	○	●
Radicipes verrilli	○	○	●	○	●
Swiftia beringi	○	○	●	○	○
"cf. *Swiftia*" *marki*	●	●	●	○	○
Swiftia pacifica	●	●	●	○	●
Swiftia simplex	○	○	●	○	●
"cf. *Swiftia*" sp. A	○	●	●	○	○
Thouarella hilgendorfi	○	○	●	○	○
Thouarella striata	○	○	●	○	○
Thouarella superba	○	○	●	○	○
Thouarella sp. A	○	○	●	○	○
Order Pennatulacea (Sea Pens)	●	●	●	●	●
Anthoptilum grandiflorum	○	○	●	●	○
Anthoptilum murrayi	○	○	●	●	○
Cavernularia vansyoci	○	○	●	○	○
Halipteris californica	●	○	○	○	○
Halipteris willemoesi	●	●	●	●	○
Pennatula phosphorea	●	○	○	○	○
Protoptilum sp.	●	●	○	○	○
Ptilosarcus gurneyi	●	●	●	○	○
Umbellula lindahli	●	●	●	●	○
Virgularia sp.	●	○	○	○	○
Class Hydrozoa, Order Anthoathecatae (Stylasterids)	●	●	●	●	○
Crypthelia trophostega	○	○	●	●	○
Cyclohelia lamellata	○	○	●	●	○
Cyclohelia sp. A	○	○	●	○	○
Distichopora borealis	●	○	●	○	○
Distichopora sp. A	○	○	●	○	○
Errinopora nanneca	○	○	●	○	○

Taxa	EG	WG	AI	BS	SM
Errinopora poutalesii	●	●	●	○	○
Errinopora stylifera	○	○	●	○	○
Errinopora zarhyncha	○	○	●	○	○
Errinopora sp. A	○	○	●	○	○
cf. *Stenohelia*	○	○	●	○	○
Stylantheca papillosa	○	○	●	○	○
Stylantheca porphyra	●	○	○	○	○
Stylantheca petrograpta	●	○	●	○	○
Stylaster alaskanus	○	○	●	○	○
Stylaster brochi	○	○	●	○	○
Stylaster campylecus campylecus	●	●	●	○	○
Stylaster campylecus parageus	●	○	○	○	○
Stylaster campylecus trachystomus	○	○	●	○	○
Stylaster campylecus tylotus	○	○	●	○	○
Stylaster cancellatus	●	○	●	○	○
Stylaster elassotomus	○	○	●	○	○
Stylaster moseleyanus	○	○	●	○	○
Stylaster polyorchis	○	○	●	○	○
Stylaster stejnegeri	○	○	●	●	○
Stylaster venustus	●	○	○	○	○
Stylaster verrillii	●	○	●	○	○
Stylaster sp. A	○	○	●	○	○