STATE OF DEEP CORAL ECOSYSTEMS OF THE U.S. PACIFIC COAST: CALIFORNIA TO WASHINGTON

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I. INTRODUCTION

The U.S. Pacific coast marine region encompasses the continental margin off the states of California, Oregon and Washington. Deep corals were first reported here in the 1860s with descriptions by A.E. Verrill, including two stony corals, *Balanophyllia elegans* (1864) and *Paracyathus stearnsii* (1869), and one stylasterid, *Allopora californica* (1866). Because all three of the species occur in shallow waters, it is not surprising that they were the first in the region to be reported (Cairns 1994; Ostarello, 1973). Dall (1884) also provided early descriptions of hydrocorals off California and Alaska as well as accounts from fishermen of bycatch of *Stylaster* sp. off the Farallone Islands, California as early as 1873.

In addition to the taxonomic literature, records of deep corals in the region come from a variety of other sources including catch records from regional bottom trawl surveys, bycatch data collected by fishery observers and observations from underwater vehicles (e.g., submersibles and remotely operated vehicles (ROVs)). In the early 1970s, the Alaska Fisheries Science Center (AFSC) began conducting triennial bottom trawl surveys of demersal fishes in the region. Early surveys included records of pennatulaceans and a few gorgonians. Unfortunately, identifications down to any appreciable taxonomic level were initially very limited, typically only to order or sometimes family. In 1998, the Northwest Fisheries Science Center (NWFSC) began conducting annual bottom trawl surveys, but like the early AFSC surveys, identifications of corals were initially not a priority.

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Beginning in the 1960s and continuing into the current period, there has been an increasing use of drop camera systems, submersibles and, most recently, ROVs to make *in situ* observations. These underwater photographic platforms have been used to explore numerous seafloor features in the region including rocky banks (e.g., Pearcy et al 1989; Stein et al. 1992; Pirtle 2005; Tissot et al. 2006), canyons (e.g., Yoklavich et al. 2000), escarpments (e.g., Carey et al. 1990; Clague et al. 2001), seamounts (e.g., DeVogelaere 2005) and other rocky features (Hyland et al. 2004; Brancato et al. 2007). Many of these features are known to support deep coral communities.

The disparate data sources that will be referenced throughout this report have their strengths and weaknesses as they inform discussions of deep coral communities and their habitats. For example, trawl surveys in the region are limited to low relief, sedimentary habitats that support relatively few emergent epifauna as compared with hard-bottom habitats (Figure 3.1). Consequently, bottom trawls rarely sample stony corals and stylasterids, but have resulted in numerous records of pennatulaceans as well as fewer records of gorgonians, black corals and soft corals (Table 3.1). Furthermore, the level of identification during trawl surveys varied according to the priority given for sampling of invertebrates and the level of expertise of the biologists onboard. Despite these limitations, trawl surveys encompassed large portions of the continental margin (including shelf and slope depths). Consequently, they contribute to discussions of general zoogeography of some higher coral taxa (e.g., order and family levels). On the other hand, *in situ* photographic surveys in the region primarily target rocky, high relief structures that support diverse benthic communities, many of which include corals. Surveys of this type, while limited in extent, provide detailed information about the size, health and habitat affinities of corals, and their relationships between other invertebrates and demersal fishes. One limitation of photographic surveys is the challenge of making species-level identifications, however some platforms (e.g., submersibles, ROVs) provide specimen collection capabilities.

Records of deep corals off the U.S. Pacific coast span latitudes between 32 and 49°N and from the shoreline out to the seaward boundary of the exclusive economic zone (EEZ), including depth zones from the intertidal down to the bathyal (3900 meters). In total, 101 species of corals from six cnidarian orders have been identified within the EEZ including 18 species of stony corals (Class Anthozoa, Order Scleractinia) from seven families, seven species of black corals (Order Antipatharia) from three families, 36 species of gorgonians (Order Gorgonacea) from 10 families, eight species of true soft corals (Order Alcyonacea) from three families, 27 species of pennatulaceans (Order Pennatulacea) from eleven families, and five species of stylasterid corals (Class Hydrozoa, Order Anthoathecatae, Family Stylasteridae; Appendix 3.1).

This chapter includes discussion of deep corals in the region and their communities. Brief descriptions of regional geology and oceanography set the stage for discussions of coral zoogeography and general habitat characteristics. The authors attempted to identify all taxa known to occur in the region, and taxa that provide vertical structure as potential habitat for other organisms are highlighted. In addition, the chapter includes a review of potential impacts to corals in the region and related conservation measures enacted to protect coral communities

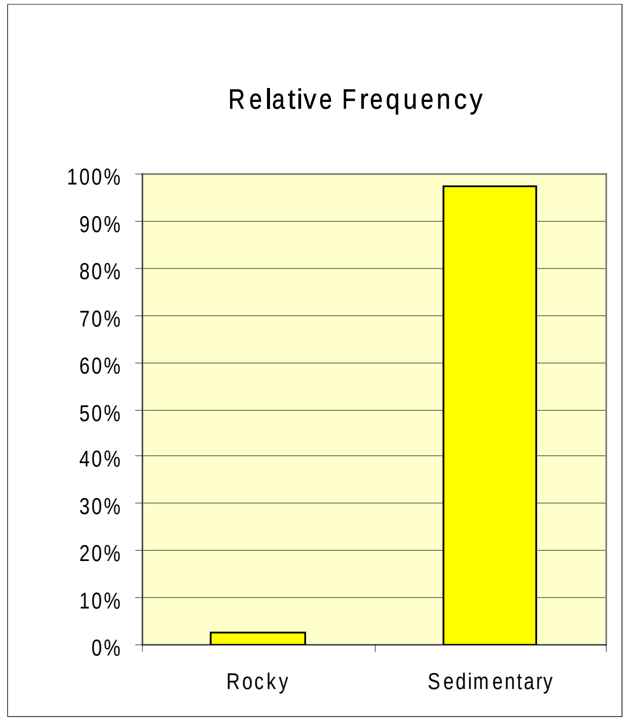

Figure 3.1. Distribution of general seafloor lithologies transected by bottom trawls conducted by the Northwest Fisheries Science Center (NWFSC) from 2001-2003 during surveys of groundfish off the coast of Washington, Oregon and California. Only trawls where the position of the fishing gear was known were used for analysis. Lithology information for the continental margin off Washington and Oregon was provided by the Active Tectonics and Seafloor Mapping Lab at Oregon State University. Lithology information for off California was provided by the Center for Habitat Studies at Moss Landing Marine Laboratories.

Table 3.1. General statistics on deep corals sampled during National Marine Fisheries Service (NMFS) bottom trawl surveys, which were conducted off the coasts of Washington, Oregon and California by the Alaska and Northwest Fisheries Science Centers between 1980 and 2005. A total of 10,526 trawl catch records were queried.

	# Trawls with Corals	% Trawls with Corals	% Coral Records
Pennatulaceans	1683	16.0%	74.5%
Gorgonians	202	1.9%	8.9%
Antipatharians	197	1.9%	8.7%
Alcyonaceans	150	1.4%	6.6%
Scleractinians	26	0.2%	1.2%
Stylasterids	1	<0.1%	<0.1%
Total	2259		100.0%

and their habitats. Finally, the authors provide recommendations for future research to improve our understanding of these organisms.

II. GEOLOGICAL SETTING

The marine region off the coasts of Washington, Oregon and California accounts for about 7% (778,628 km^2) of the total area of the U.S. EEZ (NMFS 2007 in prep). The continental margin in this region is characterized by a narrow (5-40 km) shelf and steep continental slope, with the shelf break at approximately 200 meters water depth. The outer continental shelf off Oregon and parts of California are marked by large rocky banks (Figure 3.2), some of which were at or near the surface during the lower sea level stands of the glacial epochs. Several of these banks as well as other bathymetric features such as pinnacles and seamounts create localized upwelling conditions that concentrate nutrients, thus driving a high level of biologic productivity. For example, Heceta Bank, which rises over 100 meters above the edge of the continental shelf and to within 70 meters of the ocean surface, diverts the main flow of the California Current, introducing eddies and other instabilities that affect areas downstream and along the Oregon coast. Smaller rocky banks are located off southern California in what is called the continental borderlands, a geologically complex region characterized by deep basins and elevated ridges, some of which breech the surface to form the Channel Islands. Throughout the region, many of these high relief, bathymetric features have been found to support coral communities (see Love et al. 2007; Tissot et al. 2006; Tissot et al. in prep; Strom 2006).

The shelf and slope are cut by numerous submarine canyons, including one of the deepest and largest on the west coast of North America - Monterey Canyon (Figure 3.2). Deep corals have been discovered at numerous sites here, and also within another large canyon – Astoria – located directly off the mouth of the Columbia River. Other major canyons include Juan de Fuca, Quinault, Bodega, Pioneer and Sur Canyons.

Beyond the slope, a number of seamounts rise above the abyssal plain including Thompson, President Jackson, San Juan, Rodriquez, Taney, Guide, Pioneer and Davidson (Figure 3.2). The seamounts off the west coast of North America have formed over the past tens of millions of years by hotspot volcanism and by enhanced melting in association with the migration of the spreading centers over a heterogeneous mantle (Davis and Karsten 1986). One of the largest seamounts – Davidson – has been the site of several ROV surveys that have discovered a diverse coral community (see DeVogelaere 2005). A number of additional seamounts that are known to support deep corals lie just to the west of the EEZ boundary, including Cobb, Brown Bear, Fieberling and Jasper.

Other megascale (i.e., km to 10s of km, Greene et al. 1999) structural features in the region that contribute hard-bottom habitats include the Mendocino and Gorda Ridges (Figure 3.2). The Mendocino Fracture Zone is a 3000-km long transform fault extending from Cape Mendocino, California across the Pacific Plate. A prominent hard-bottom feature associated with this fault is the Mendocino Ridge, which shoals to 1100 meters water depth and drops 2100 meters to the north-south trending Gorda Ridge. To the south, the Mendocino ridge slopes 3300 meters to the abyssal plain. In contrast to the Mendocino Ridge, the Gorda Ridge is a seafloor spreading center where two plates are moving apart, allowing molten magma to rise up to form new oceanic crust. It extends 300 km and is bounded by the Mendocino Fracture Zone to the south and the Blanco Fracture Zone to the north. The Gorda Ridge rises to a maximum height of >1500 meters above the axial valley floor, which ranges from 3200 to >3800 meters water depth. Like other spreading centers, hydrothermal vents that support unique communities of chemosynthetic organisms exist nearby. Morphology of the Mendocino and Gorda Ridges were described by Fisk et al. (1993) and Clague and Holmes (1987), respectively.

III. OCEANOGRAPHIC SETTING

Oceanographic circulation in the region is well described and was summarized recently by NMFS (2007 in prep). The U.S. Pacific region is one of the major upwelling areas of the world, where nutrient-rich waters support high levels of biological productivity. Physical oceanography varies seasonally and during El Niño and La Nina events or periods of interdecadal climate regime shifts. Major oceanographic currents

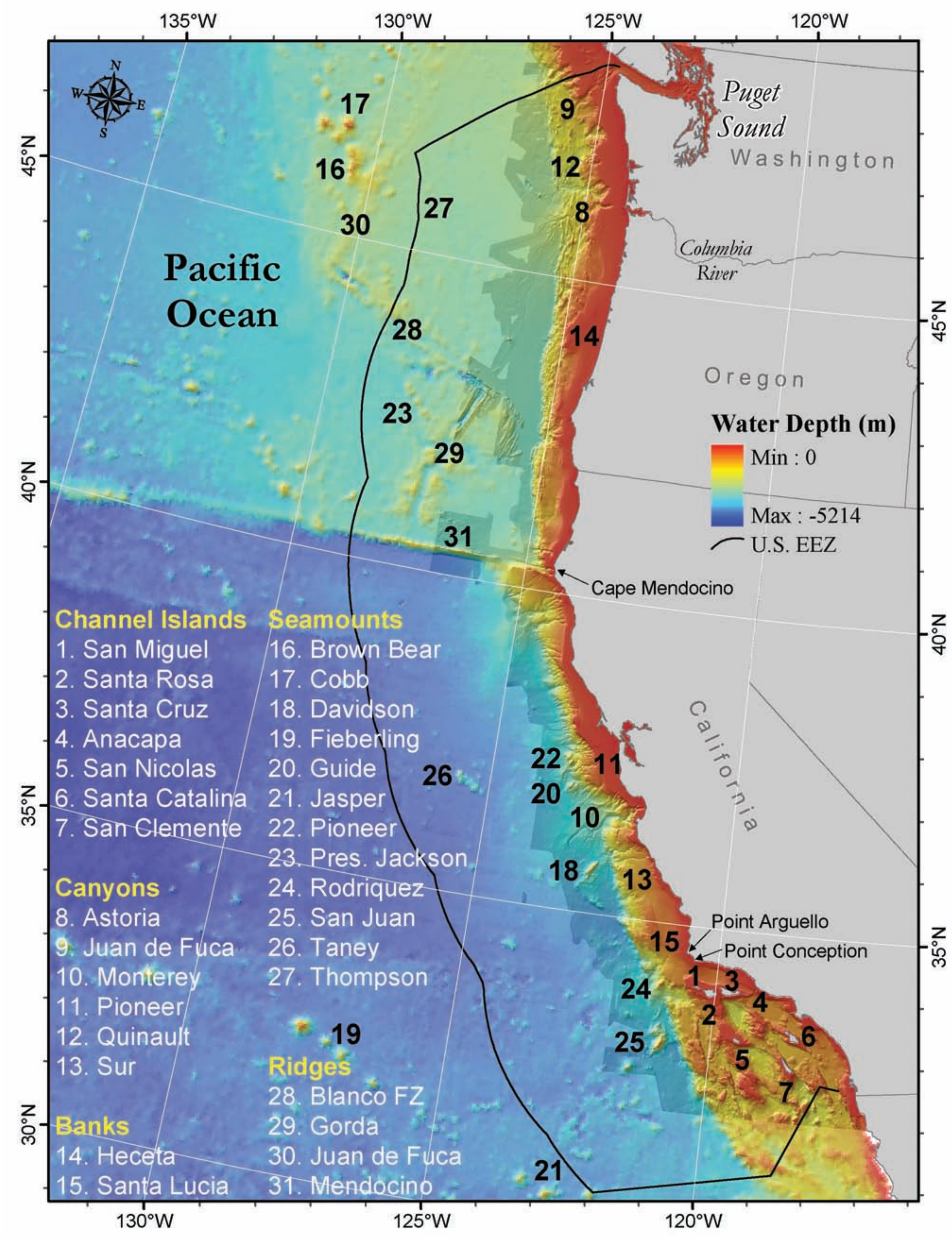

Figure 3.2. Bathymetric map of the U.S. Pacific coast region. Major topographic features that are mentioned in this chapter are labeled.

in the region include the surface-flowing California Current, the Inshore Countercurrent (Davidson Current) and the Southern California Countercurrent, and the subsurface-flowing California Undercurrent. The California Current forms the eastern boundary of a large clockwise circulation pattern in the North Pacific. The California Current is a year-round flow that transports cold, nutrient-rich subarctic water equatorward (Hickey 1998). It extends from the shelf break to about 1000 km offshore with peak speeds at the surface during spring and summer yet significant flows down to 500 meters (Hickey 1998). South of Point Conception, the California Current splits, with its core continuing farther offshore while a smaller portion turns shoreward both north and south of the Channel Islands (Figure 3.3). Near San Diego, part of the core flow turns northward to form the Southern California Countercurrent, an inshore poleward flow off Southern California. During some years, the Southern California Countercurrent forms a counterclockwise circulation pattern known as the Southern California Eddy (Figure 3.3). During other years, the Southern California Countercurrent rounds Point Conception and combines with the Inshore Countercurrent, a poleward flow inshore of the equatorward California Current (Hickey 1979, Figure 3.3). Below these surface currents lies a narrow, high speed flow known as the California Undercurrent, which brings warmer, nutrient-poor waters poleward along the slope from the eastern equatorial Pacific (Pierce et al. 2000). A major feature of the eastern North Pacific and the California Current is a layer where oxygen concentrations are low within a depth zone along the upper continental slope, extending to depths greater than 1000 m. This feature lies beneath the California Undercurrent and is called the oxygen minimum zone (dissolved oxygen <0.5 ml l^{-1} (22 mM kg^{-1}) (Deuser 1975).

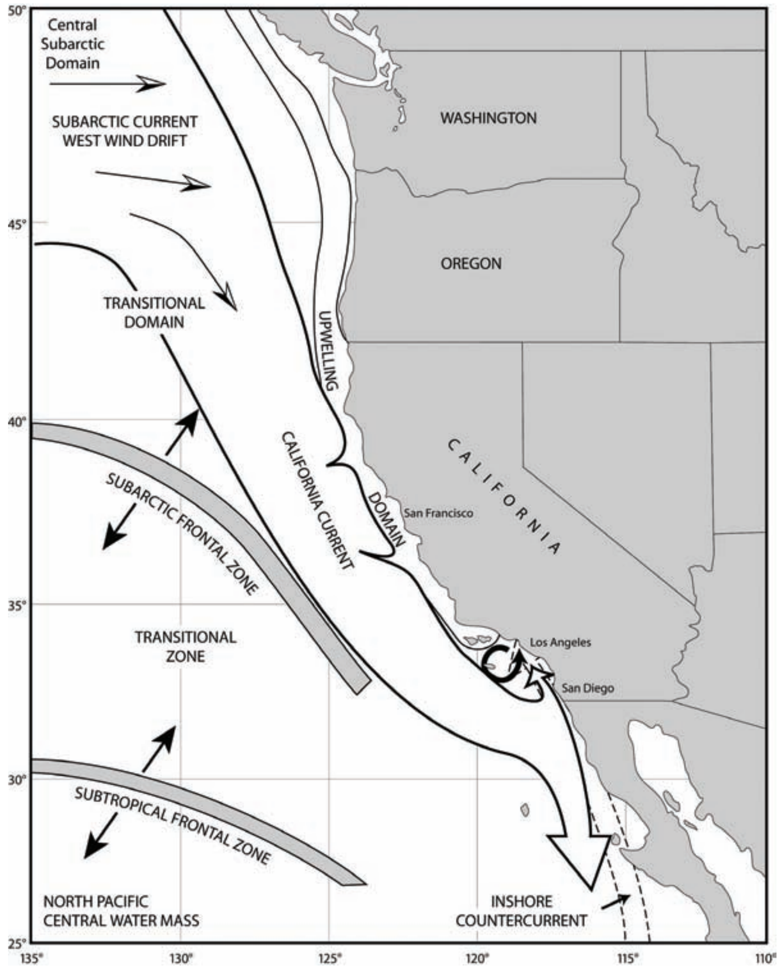

Figure 3.3. Map of portion of the Pacific coast of North America showing major oceanographic currents. Image source: NMFS 2007, in prep.

Circulation in the region is driven by the intensity and duration of prevailing seasonal winds and storms. Spring and summer northwesterly winds drive an upwelling system that replenishes nutrients to the photic zone, which in turn stimulate biological productivity (Batchelder et al. 2002). A shift in wind direction in the winter north of Santa Cruz, CA creates favorable downwelling conditions, while upwelling conditions persist year-round south of Santa Cruz due to modest storm activity (Strub and James 2000). Upwelling plumes also occur at coastal headlands, particularly where the California Current and Inshore Countercurrent intersect off Pt. Conception.

Another important hydrographic feature in the northern part of the region is the Columbia River plume, contributing as much as 90% of the freshwater input between the Strait of Juan de Fuca and San Francisco Bay (NMFS 2007 in prep). The position of the plume is highly seasonal, generally extending equatorward and offshore in the spring and summer, and poleward along the coast in the fall and winter (Thomas and Weatherbee 2006).

According to Briggs (1974), the temperate northeastern Pacific includes three coastal zoogeographic provinces, two of which include waters off Washington, Oregon and California. The San Diego Province, in the warm-temperate region, extends from Point Conception, CA south to Magdalena Bay, Baja California Sur, Mexico. The Oregon Province is the lower boreal province in the cold temperate region and extends from Point Conception north to the Dixon Entrance, the maritime boundary between Alaska and British Columbia. Another review of Pacific Ocean zoogeography by McGowan (1971) placed the northern boundary of the Oregon (or "Oregonian") Province at the Strait of Juan de Fuca.

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

Several coral taxa in the region are designated as "structure-forming", meaning they are known to provide vertical structure above the sea floor that can be utilized by other invertebrates or fish. Attributes contributing to structure include morphology (i.e., branching vs. non-branching), whether or not the taxa is known to form reefs, relative abundance, maximum colony size, manner of colony spatial dispersion (i.e., solitary vs. clumped) and the relative number of associations with other organisms (Table 3.2). With the exception of maximum colony size, structure-forming attributes are specific to records of corals in the region. Likewise, discussions of structure-forming taxa that follow are limited to current information in this region. Taxa that are considered structure-forming in other regions may not be designated as so in this region due to lack of specific information on structural attributes.

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

Stony corals off the Pacific coast include 18 species from seven families (Appendix 3.1). Most of the records of stony coral are of solitary, non-branching cup corals (e.g., *Balanophyllia elegans)*. However, at least seven branching species are known to occur in the region, including *Lophelia pertusa*, *Oculina profunda*, *Madrepora oculata*, *Dendrophyllia oldroydae*, *Astrangia haimei*, *Labyrinthocyathus quaylei* and *Coenocyathus bowersi*. *L. pertusa* is widely distributed off southern California (Hardin et al. 1994; Mary Elaine Helix, MMS, pers. comm.) and has been collected at four sites in the Olympic Coast National Marine Sanctuary (Hyland et al. 2004; Brancato et al. 2007). One site in the Olympic Coast NMS may support the largest aggregation of *L. pertusa* reported in the northeast Pacific. Because of this discovery and the fact that *L. pertusa* is relatively abundant off southern California, it was given a high rating of structural importance (Table 3.2). Other structure-forming stony corals are *Dendrophyllia oldroydae* and *Oculina profunda* (Stephen Cairns, Smithsonian Institution, pers. comm.; Table 3.2).

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

Antipatharians are very abundant off the Pacific coast but not very speciose with only seven species from three families, Antipathidae, Cladopathidae and Schizopathidae (Opresko 2005, 2003, 2002, Appendix 3.1). *Antipathes* sp. and *Bathypathes* sp. exhibit coast wide distributions, while *Lillipathes* sp. and *Umbellapathes* sp. have only been collected at Davidson Seamount (Erica Burton, Monterey Bay NMS, pers. comm.). *Antipathes* sp. and *Bathypathes* sp. are branching, can reach heights >30 cm, and occur in high abundance. *A. dendrochristos* (Opresko 2005), a newly described species ranging in height from 10 to 250 cm, has been observed via submersible on several deepwater banks off southern California at water depths between 90 and 360 meters (Love et al. 2007; Tissot et al. 2006; Yoklavich and Love 2005). Many of these specimens showed epifaunal associations with other invertebrates including crinoids, amphipods, brittle stars, anemones, sponges and crabs. One large (2.1 m high) dead colony, which was heavily colonized by over 2500 invertebrate individuals, was recently aged to 140 years (Love et al. 2007). For these reasons, *Antipathes* spp. was given a high rating of structural importance (Table 3.2).

c. *Gold corals* (Class Anthozoa, Order Zoanthidea)

Gold corals are very rare in the region, with only one unconfirmed record from Davidson Seamount (DeVogelaere et al. 2005).

d. *Gorgonians* (Class Anthozoa, Order Gorgonacea)

Gorgonians are the most speciose group of corals off the Pacific coast with 36 species from 10 families (Appendix 3.1). *Paragorgia arborea* is found in high abundance (including extensive

Table 3.2. Structure-forming attributes of some deep coral taxa off the U.S. Pacific coast. Relative abundance data was compiled from taxonomic records, *in situ* photographic surveys, and to a lesser extent bottom trawl surveys. Numbers of species associations were quantified from *in situ* photographic surveys. Size, morphology and other colony attributes were informed by taxonomic descriptions. '?' means insufficient data available in the region to comment.

	Attributes Contributing To Structure						
Taxa	**Reef-Building**	**Relative Abundance**	**Maximum Colony Size**	**Morphology**	**Associations with Other Species**	**Colony Spatial Dispersion**	**Overall Rating of Structural Importance**
Lophelia pertusa	No	High	Large	Branching	Many	Clumped	High
Oculina profunda	No	Low	?	Branching	?	?	Low
Dendrophyllia oldroydae	No	Medium	Medium	Branching	?	Clumped	Medium
Antipathes dendrochristos	No	High	Large	Branching	Many	Solitary	High
Bathypathes sp.	No	High	Medium	Branching	?	Solitary	Medium
Isidella sp.	No	High	Medium	Branching	?	Solitary	Medium
Keratoisis sp.	No	High	Medium	Branching	?	Solitary	Medium
Paragorgia arborea	No	High	Large	Branching	Many	Solitary	High
Primnoa pacifica	No	Low	Large	Branching	Many	Solitary	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

"forests" observed along several ridges on Davidson Seamount [DeVogelaere et al. 2005]), can reach heights >1 m and has shown epifaunal relationships with numerous other structure-forming invertebrates. *P. arborea* is therefore given a high rating of structural importance (Table 3.2). *Isidella* spp. and *Keratoisis* spp. are found coast wide mostly on the continental slope. Although both genera can reach heights greater than 30 cm, other gorgonians (e.g., *P. arborea* and *Primnoa pacifica*) in the region can reach heights exceeding 1 meter. Therefore, *Isidella* and *Keratoisis* were given a medium rating of structural importance (Table 3.2). ROV surveys in the Olympic Coast NMS have resulted in numerous observations of gorgonians including large colonies of *P. pacifica*, numerous colonies of *Plumarella longispina* and smaller colonies of *Leptogorgia chilensis, Swiftia pacifica,* and *Swiftia beringi* at several sites. Colonies of *P. pacifica* obtained off La Jolla, CA (north of San Diego) at 205-234 meters are the southernmost record of the species in the Pacific (Cairns and Barnard 2005). Specimens of *Keratoisis* and *Corallium* from Davidson Seamount have been aged to over 200 and 115 years, respectively (Andrews et al. 2005).

e. *True soft corals* (Class Anthozoa, Order Alcyonacea)

Only eight species of true soft corals from three families occur off the Pacific coast (Appendix 3.1). *Anthomastus* sp. is abundant and exhibits coast wide distributions, while *Gersemia* sp. has been caught primarily on the northern Oregon slope during trawl surveys. *Alcyonium rudyi* and *Cryptophyton goddarti* were described recently (1992 and 2000, respectively) off the Oregon coast (Cairns et al. 2002). Other than *C. goddarti*, references to *Clavularia* and *Telesto* off southern California (SCAMIT 2001), and *Telestula ambigua* in deep water off central California (Austin 1985), there are no other data on stoloniferans in the region. Because of their small stature, none of the true soft corals in the region are considered to be structure-forming.

f. *Pennatulaceans* (Class Anthozoa, Order Pennatulacea)

Pennatulaceans are the most abundant coral taxon in the region and have been observed from submersibles and ROVs either alone or in groves of numerous individuals similar to aggregations observed off Alaska (Stone et al. 2005; Brodeur 2001). They are also the most common coral taxon recorded from trawl surveys (Table 3.1). To date, 27 species from eleven families are known to occur off the Pacific coast (Appendix 3.1). *Stylatula* sp., *Anthoptilum grandiflorum* and *Umbellula* sp. are the most common taxa, all of which are found coast wide. Although groves of pennatulaceans have been shown to support higher densities of some fish species than adjacent areas (e.g., Brodeur 2001), they are not considered to be structure forming as defined by this report.

g. *Stylasterid corals* (Class Hydrozoa, Order Anthoathecatae, Suborder Filifera)

Lace corals or stylasterid corals off the Pacific coast have been observed colonizing moderate to high-relief rocky habitats from the intertidal down to shelf water depths. Only five species from three genera are known to occur in the region (Fisher 1938; Cairns 1983; Alberto Lindner, pers. comm., Appendix 3.1). *Stylaster californicus* is the only species known from the San Diego Province while *S. venustus* is found throughout the Oregon Province. Other species that exhibit narrower distributions in the Oregon Province include *Errinopora pourtalesii*, *Stylantheca porphyra* and *S. petrograpta* (Fisher 1938; Cairns 1983). The two *Stylaster* species and *E. pourtalesii* are flabellate (i.e., fan-shaped) while *Stylantheca* is encrusting (Cairns 1983). Because most specimens in the region rarely exceed 30 cm in height or width, they are not considered to be structure-forming. Stylasterid corals have rarely been identified in trawl survey catches (Table 3.1), most likely because bottom trawls do not target the high-relief habitats and shallow depths at which stylasterids are typically found.

V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITATS

Much of the information on general zoogeography of corals in the region originates from taxonomic records and bottom trawl surveys conducted by the National Marine Fisheries Service (NMFS) (Appendix 3.1). The Alaska Fisheries Science Center (AFSC) conducted regional trawl surveys off the Pacific coast from 1971-2001, and the Northwest Fisheries Science Center (NWFSC) began ongoing surveys in 1998. Identification of invertebrates was initially very limited; therefore this report focuses on catch records from 1980-2005. Cumulatively, both surveys covered much of the continental shelf and upper slope (10-1600 m water depth); however, survey effort has been spatially and temporally variable. Prior to 2002, there was limited trawl survey effort south of Pt. Conception (34.5ºN). Also, the number of trawls conducted during each survey varied from year to year. A total of 7252 AFSC and 3274 NWFSC trawl catch records were queried for coral occurrences. Pennatulaceans were recorded in 16% of survey trawls, while all other coral taxa occurred in only 5% of trawls (Table 3.1, Figure 3.4). In addition to NMFS, the Southern California Coastal Water Resource Project (SCCWRP) conducted bottom trawls during three different continental shelf surveys off southern California from 1994 to 2003 (Allen et al. 1998; Allen et al. 2002). Catch records from 304 of 957 (32%) SCCWRP trawls include 316 records of pennatulaceans encompassing thirteen species from six families, and 225 records of other corals encompassing fifteen species from six families.

In addition to trawl surveys, Etnoyer and Morgan (2003) compiled records of observations and collections of structure-forming corals off the Pacific coast by the California Academy of Sciences (CAS), the Monterey Bay Aquarium Research Institute (MBARI), the Smithsonian's National Museum of Natural History (NMNH), and Scripps Institution of Oceanography (SIO). Taxonomists have confirmed the identities of some of these records, but many records are limited to higher taxa (e.g., genus and family). Records off Washington, Oregon and California include representatives from two families of stony corals (Oculinidae and Caryophyllidae), one family of black corals (Antipathidae), four families of gorgonians (Corallidae, Isididae, Paragorgiidae and Primnoidae) and stylasterid corals (Family

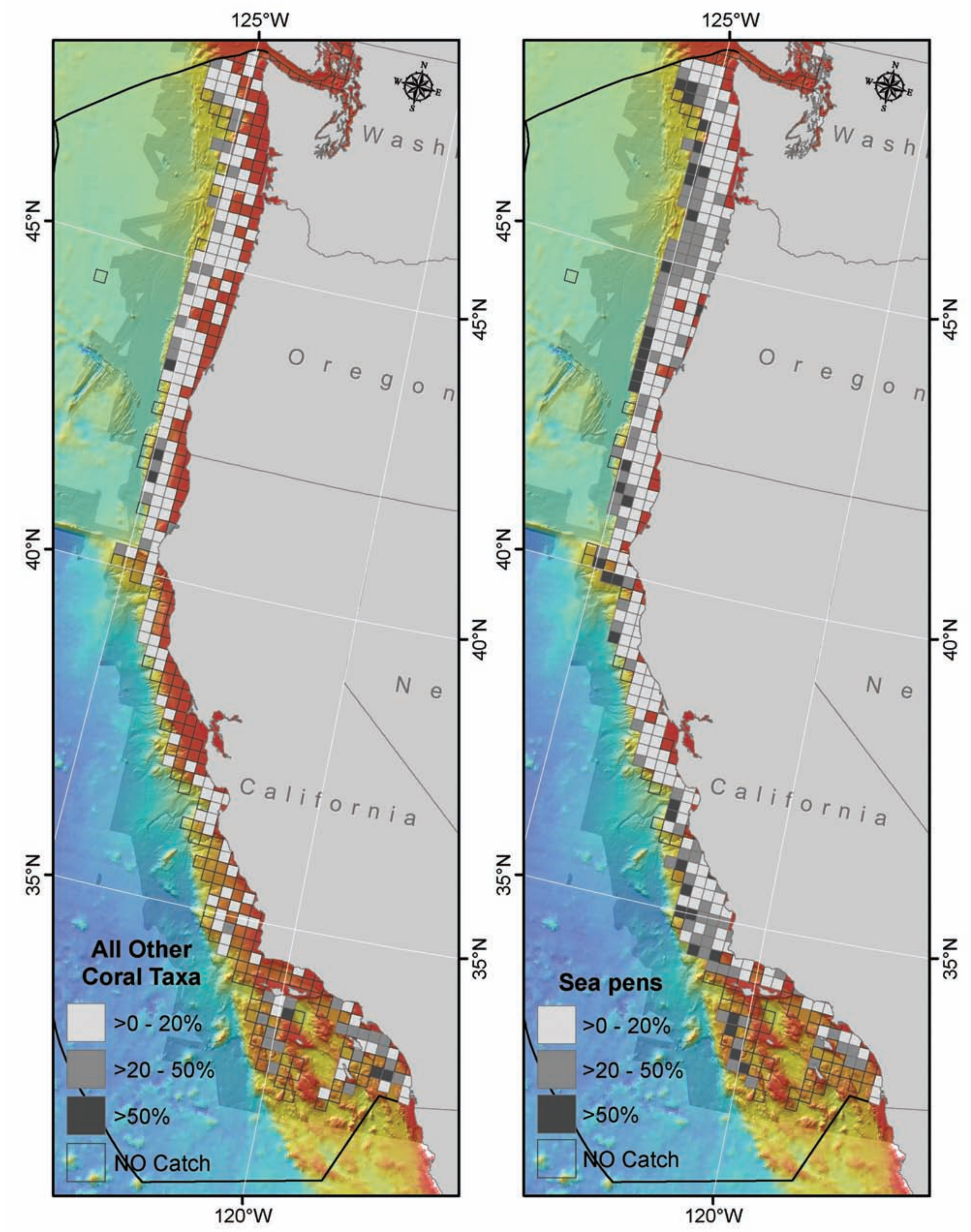

Figure 3.4. Maps of frequency of occurrence for two groups of deep coral taxa sampled during NMFS bottom trawl surveys (1980-2005). Frequency defined as number of trawls with corals identified in the catch sample divided by total number of trawls within each 20x20 km cell. Frequency was categorized into three classes: >0-20%, >20-50%, and >50%. Cells where survey trawls occurred but where no corals were identified in the catch sample are labeled as "NO Catch" and are symbolized with an empty box where the underlying bathymetry shading is visible. Pennatulaceans were singled out because they inhabit different habitat types and were caught much more frequently than other coral taxa. See Table 3.1 for frequency information.

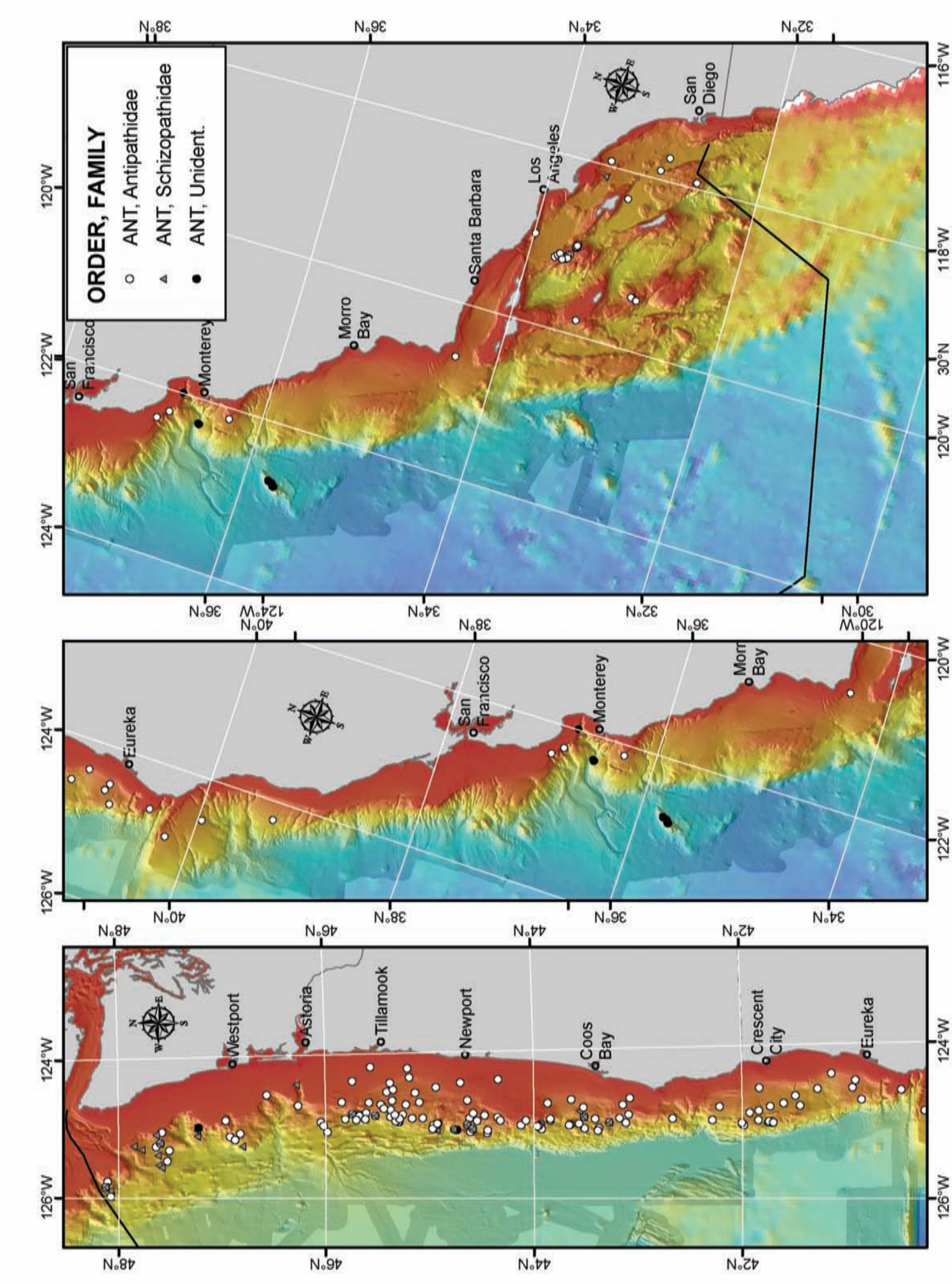

Figure 3.5. Map showing locations of black corals (Order Antipatharia) from NWFSC, AFSC, and SCCWRP trawl surveys, Etnoyer and Morgan (2003) and Tissot et al. (2006). Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

Stylasteridae). A total of 389 records of corals span much of the EEZ off the U.S. Pacific coast. This information contributes to the general zoogeography of coral taxa in the region, many of which are highlighted in the following sections pertaining to the two zoogeographic provinces.

More detailed information on coral habitats in the region is provided by *in situ* photographic surveys. When possible, the data sources and brief descriptions of these surveys are provided.

San Diego Province

The U.S. portion of the San Diego Province extends from the Mexican border, north to Point Conception, CA, and includes the geologically

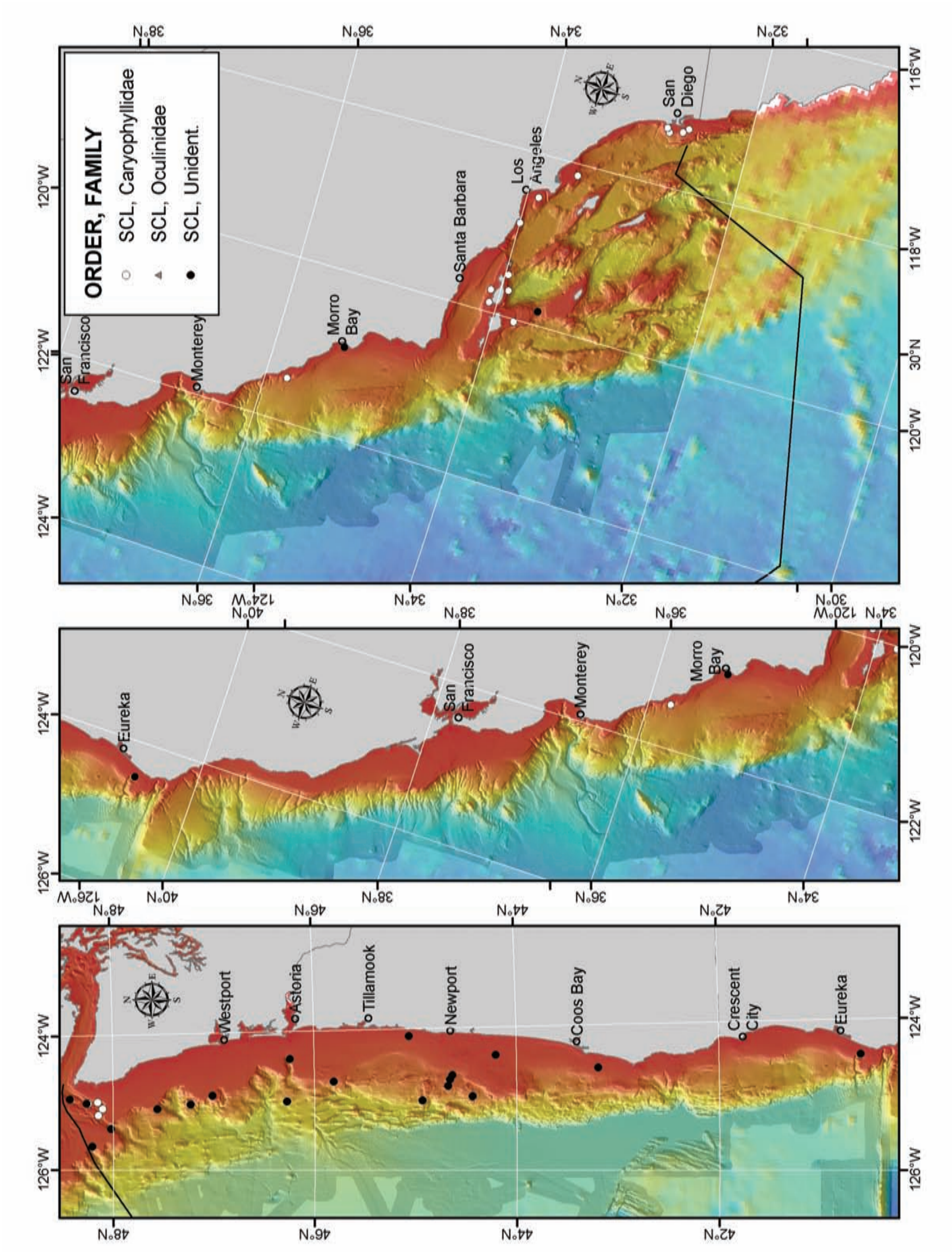

Figure 3.6. Map showing locations of stony corals (Order Scleractinia) from NWFSC, AFSC, and SCCWRP trawl surveys, Etnoyer and Morgan (2003) and Brancato et al. (in review). Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

complex borderlands (Figure 3.2). A number of species found in this region, such as the newly described black coral, *Antipathes dendrochristos* (Opresko 2005) have not been described further north. These black corals have been observed via submersible on numerous rocky outcrops in the province at water depths ranging from 90 to 360 m (Love et al. 2007; Tissot et al. 2006; Yoklavich and Love 2005, Figure 3.5). *Lophelia pertusa* and *Desmophyllum dianthus* have been observed on numerous high-relief, hard-bottom features below 120 meters near oil platforms surveyed in the late 1980s off Pt. Conception, CA (Steinhauer and Imamura 1990; Hardin et al. 1994). Near one platform, *D. dianthus* and *L. pertusa* were among the most abundant taxa observed in high-

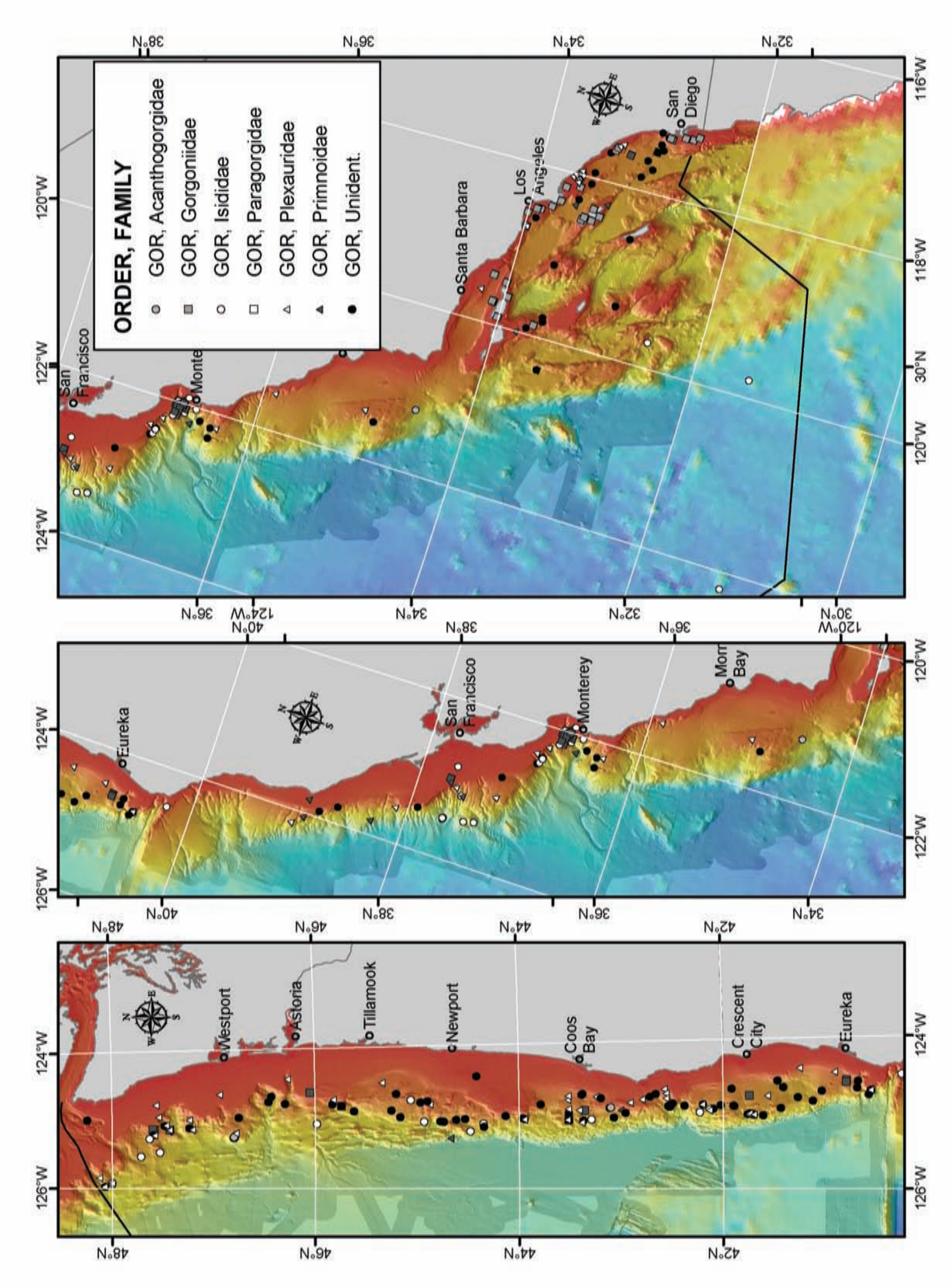

Figure 3.7. Map showing locations of gorgonians (Order Gorgonacea) from NWFSC, AFSC, and SCCWRP trawl surveys, Etnoyer and Morgan (2003) and Tissot et al. (2006). Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

relief habitats at water depths ranging from 160-212 meters. Another scleractinian, *Caryophyllia arnoldi*, is known to occur throughout the province especially around the Channel Islands (Cairns 1994). The cup coral, *Paracyathus stearnsii*, is also common around the Channel Islands including 25 specimens deposited at SIO (Cairns 1994). *Coenocyathus bowersi* has been collected from the nearshore off the coasts of mainland California, around the Channel Islands and down to 80 meters off Pt. Conception (Cairns 1994). One record of the colonial scleractinian, *Madrepora oculata,* collected at 84 meters water depth near Anacapa Island, is only one of two records known from the northeast Pacific (Cairns 1994, Figure 3.6).

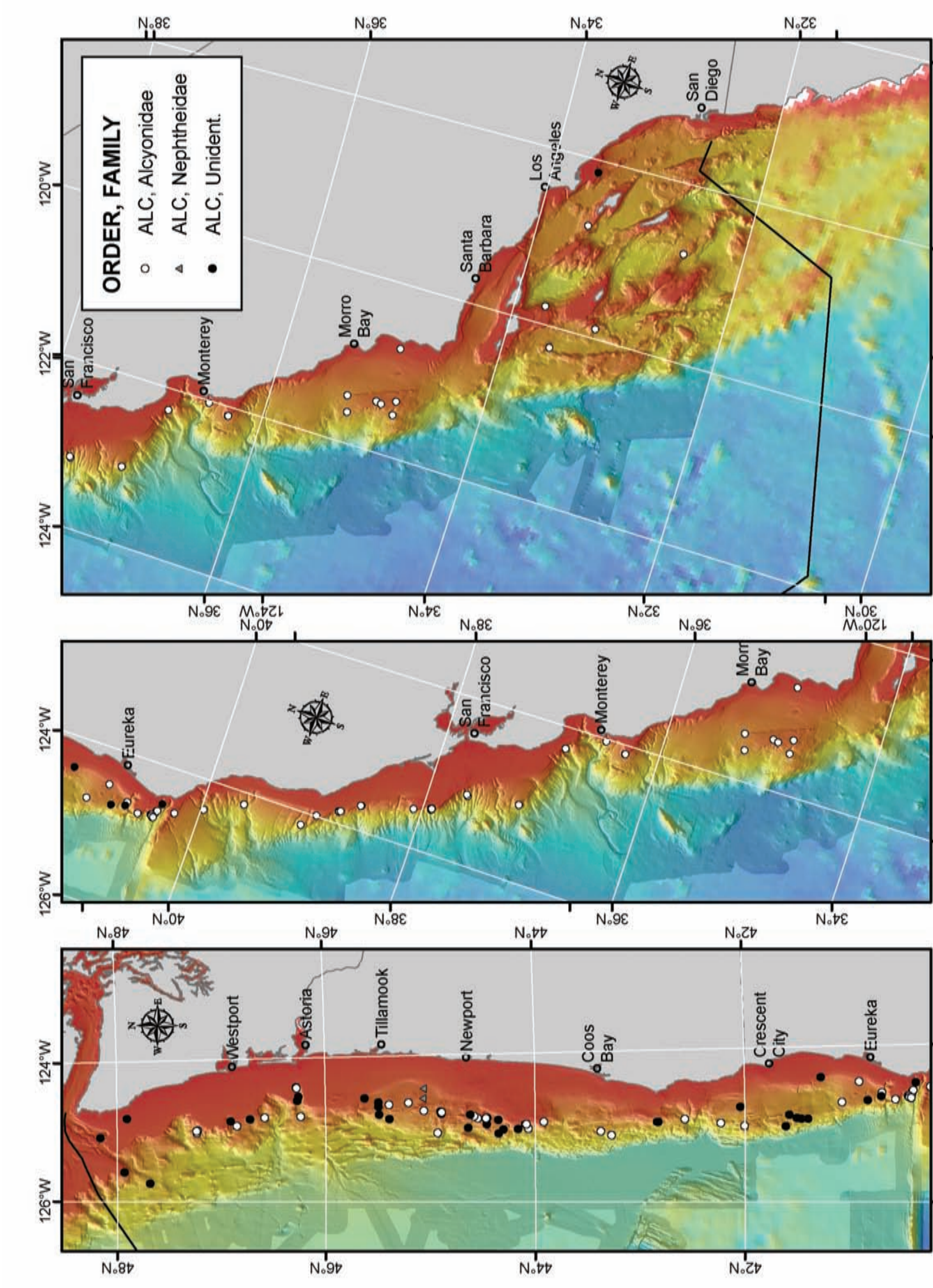

Figure 3.8. Map showing locations of true soft corals (Order Alcyonacea) from NWFSC, AFSC, and SCCWRP trawl surveys and Etnoyer and Morgan (2003). Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

Gorgonians are not as prevalent as they are in the Oregon Province (Figure 3.7); however, this may be due to sampling bias. Tissot et al. (2006) observed 27 specimens from four different habitat types at 144-163 m. Other records in the province include *Lepidisis* sp. at 950 m and *Keratoisis* sp. far offshore San Diego at 3180 and 3880 m (Etnoyer and Morgan 2003). Gorgonian catches from trawl surveys range in water depths from 77-1400 meters. Pennatulaceans (mostly members of suborder Subselliflorae) have been observed from underwater vehicles in the sedimented flanks of numerous rocky outcrops in the province (9726 specimens from Tissot et al. 2006) and are caught more often than other coral taxa in bottom trawls at water depths ranging from 44 to over 1500 meters. The only stylasterid coral known to occur in the province is *Stylaster californicus*, which has been recorded in rocky habitats down to 90 meters water depth.

Oregon Province

The Oregon Province, which extends from Pt. Conception, CA north to the maritime boundary between Alaska and British Columbia, and includes one of the more recent discoveries of structure-forming stony coral off the U.S. Pacific coast – *Lophelia pertusa* at the Olympic Coast NMS. During ROV surveys, *L. pertusa* was observed on a rock ledge in 271 meters of water in 2004 (Hyland et al. 2004) and at three other sites in 2006, including a broad (tens of meters wide), low-lying mound (<1 meter high) at approximately 250 meters water depth (Brancato et al. 2007). Both dead and living colonies were observed. *Desmophyllum* sp. was also observed in association with *L. pertusa* (Brancato et al. 2007), which is consistent with observations of *Lophelia* elsewhere in the region and world (see Hardin et al. 1994; Cairns and Stanley 1982). Colonies of the stylasterid coral, *Stylaster venustus*, were observed in water depths of about 100 meters off Cape Flattery, WA (A. Lindner, pers. obs.).

Scleractinians and stylasterids are also found elsewhere in the province. *Labyrinthocyathus quaylei* is found on Cordell Bank and south to San Diego at water depths of 37-293 m (Cairns 1994). Stylasterids and solitary cup corals are common primarily in nearshore hard bottom habitats (Cairns 1983, 1994), including over 36,000 observations of *Balanophyllia elegans* at Cordell Bank (Pirtle 2005). During surveys of proposed submarine cable routes off Pt. Arguello, CA, epifaunal coverage of *Stylantheca porphyra,* two cup corals (*B. elegans* and *Paracyathus stearnsii*) and two species of anemones often reached 100 percent on moderate-relief hard-bottom habitats (Aspen 2006). *Caryophyllia arnoldi* is known from throughout the Oregon Province including inside waters of Washington state and British Columbia. *Paracyathus stearnsii* is common in Monterey Bay including 45 specimens deposited at CAS (Cairns 1994). The Farallone Islands (off San Francisco, CA) mark the northern and southern distributional extents of two stylasterid corals, *Stylaster californicus* and *S. venustus*, respectively. Other stylasterids include *Errinopora pourtalesii*, which is found off central California at shelf depths, and *Stylantheca petrograpta*, which is found only in the northern part of the province off the southern part of Vancouver Island and in Puget Sound (Fisher 1938; Alberto Lindner, pers. comm.).

Black corals in the Oregon Province are most prevalent north of Cape Mendocino with the largest reported catches from the northern Oregon slope (Figure 3.5). *Chrysopathes speciosa* and *Antipathes* sp. are the most common antipatharian taxa in the province and entire region. Gorgonians are common at all depths covered by regional trawl surveys but also more common north of Cape Mendocino (Figure 3.6). They have also been recorded from water depths over 2900 m off San Francisco, CA (Etnoyer and Morgan 2003). During submersible dives off the Oregon coast in the mid-1990s, high densities of gorgonians were observed at depths between 200 and 250 meters, where hard rocky substrate was covered with thick, hummocky sediments at the southern edges of submerged rocky banks (Strom 2006). Despite being the second-most abundant invertebrate taxa observed (21% of all organisms encountered), gorgonians observed at these sites did not exceed 30 cm in height. The soft coral, *Anthomastus* sp., has been caught over all latitudes but only on the slope (Figure 3.8). Pennatulaceans are ubiquitously distributed throughout the region both by latitude and depth (Figure 3.9). Most specimens are *Stylatula* sp., but *Anthoptilum grandiflorum*, *Ptilosarcus gurneyi* and *Umbellula* sp. are also abundant and widely distributed. As in the San Diego Province, they prefer sedimentary habitats and *Stylatula* has been observed in dense groves.

VI. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

Several studies both in the region and elsewhere in the north Pacific report fine-scale associations between demersal fishes, corals and other structure-forming invertebrates (e.g., Stone 2006; Krieger and Wing 2002; Brodeur 2001; Hardin et al. 1994; Hixon et al. 1991) and some studies have even investigated the nature of those relationships (e.g., Tissot et al. 2006; Auster 2005; Pirtle 2005; Parrish 2004; Syms and Jones 2001). In addition to *in situ* observations, corals have been collected with other invertebrates and fishes during bottom trawl surveys and commercial fishing operations. Unfortunately,

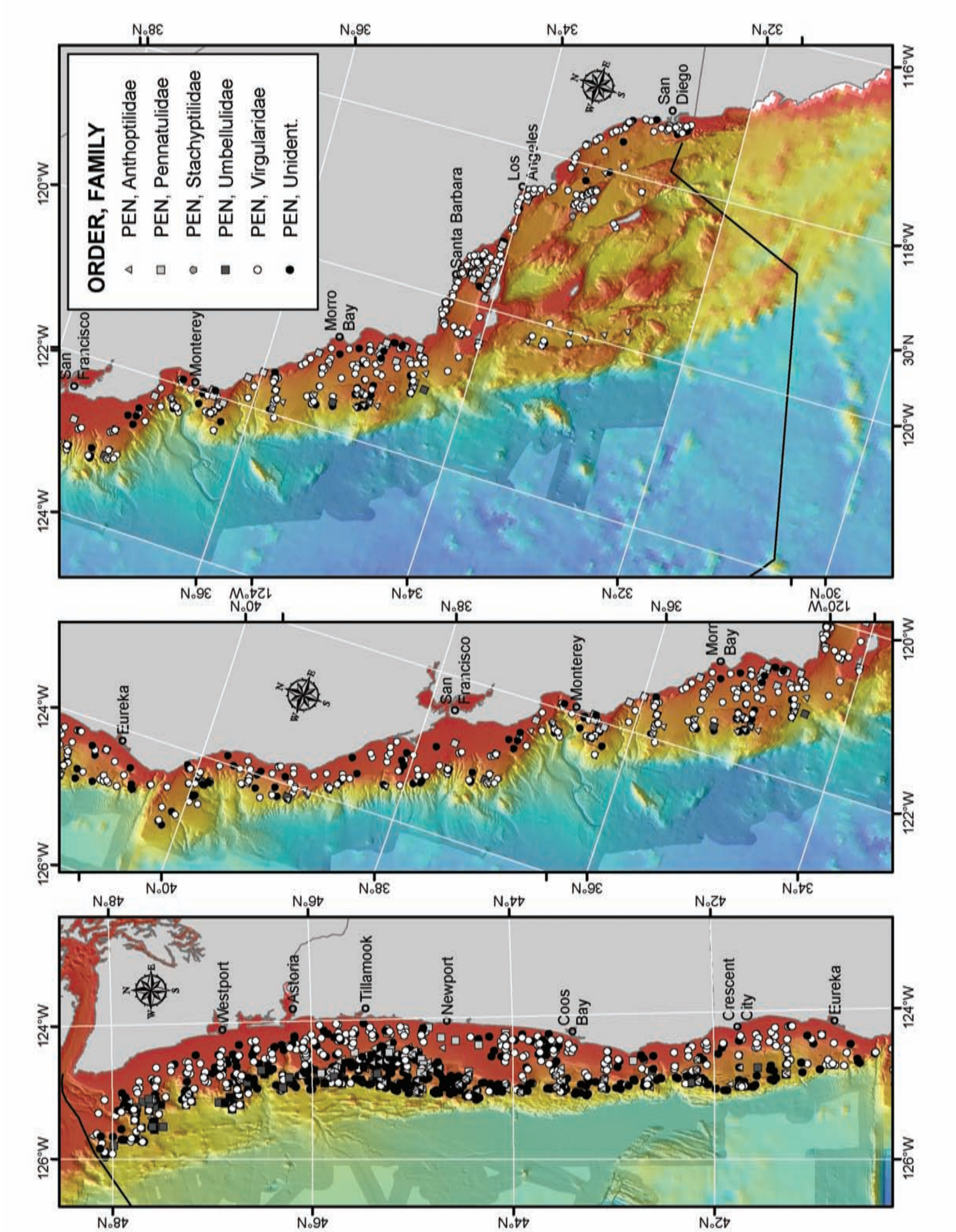

Figure 3.9. Map showing locations of pennatulaceans (Order Pennatulacea) from NWFSC, AFSC, and SCCWRP trawl surveys. Specific identities from trawl survey catch records are unconfirmed and primarily limited to genus or family level.

bottom trawls are of limited precision because they often extend over kilometers of seabed, traversing a variety of low-relief habitats. Furthermore, trawl gears are not designed to target sessile invertebrates. Therefore, catches of corals only represent presence data, and cannot be used to develop standardized indices of coral abundance. Lastly, catches of corals often consist of partial colonies or skeletal fragments, making it difficult to ascertain the size and overall health of the organism. Consequently, the best source of data on species associations comes from direct observations via submersibles or other *in situ* photographic methods (e.g., ROVs). Three studies in particular have examined the nature of relationships between deep corals and other fauna in the region (Tissot et al. 2006; Pirtle 2005; Hardin et al. 1994), though other recent video surveys (e.g., Brancato et al. 2007; Tissot et al. in prep) are currently being analyzed in this context.

San Diego Province

Data analysis of submersible observations from 11 rocky banks off southern California (Tissot et al. 2006) includes the most comprehensive study of fish-invertebrate relationships to date in the province. Densities of gorgonians and black corals were highest in low relief, mixed rock areas including boulders, cobbles, pebbles and sand. Approximately 15% of the 135 black corals observed had other organisms lying on or attached to them and epifauna were mostly crinoids (6.8%) followed by sponges (3.1%). Only 1.3% of all black coral associations involved fishes. None of the 27 observations of gorgonians showed evidence of epifaunal associations. Fish species exhibiting higher frequencies of occurrence near large corals and sponges than elsewhere along transects included cowcod (*Sebastes levis*; median distance = 5.5 m), bank rockfish (*S. rufus*; 1.0 m), swordspine rockfish (*S. ensifer*; 1.3 m), shortbelly rockfish (*S. jordani*; 1.5 m), pinkrose rockfish (*S. simulator*; 1.7 m) and other members of the rockfish subgenus *Sebastomus* (1.4 m). Most of these species including cowcod, bank rockfish and several members of the subgenus, *Sebastomus*, have been targeted commercially. Although these six fish species and large invertebrates co-occurred in similar habitats, the authors questioned the existence of functional relationships because the median distances between them were not small (1.0-5.5 m). In addition to fishes, black corals (*Antipathes* sp.) were observed in association with crinoids, sponges, crabs, basketstars, brittlestars, anemones, algae and salps.

Hardin et al. (1994) examined the spatial distributions of epifauna on both low- and high-relief hard bottom features off Pt. Conception. The second-strongest positive correlation reported between two taxa was that of the cup coral, *Desmophyllum dianthus* and the colonial scleractinian, *Lophelia pertusa*. Moderately positive correlations existed between two other cup corals – *Paracyathus stearnsii* and *Caryophyllia* sp. Other associations with *D. dianthus* included galatheid crabs and anemones (e.g., *Amphianthus californica*). The authors suggest that these correlations, while statistically significant, are most likely due to common affinities to the physical attributes of their habitat (depth, relief, orientation to currents), and not indicative of any functional relationships among taxa.

Oregon Province

At Cordell Bank, Pirtle (2005) examined relationships between structure-forming megafaunal invertebrates and demersal fishes. During submersible dives at water depths from 55 to 250 meters, gorgonians were observed in mixed rock habitats of varying relief while pennatulaceans (*Ptilosarcus* sp. and members of suborder Subselliflorae) occurred in low-relief habitats of mud and bedrock. Widow (*S. entomelas*), rosy (*S. rosaceus*) and unknown juvenile rockfish, adult *Sebastomus*, black-eyed gobies and combfishes were observed more often near gorgonians than expected by chance in habitats where they occurred. In sand- and mud-dominated habitats, flatfish, poachers, combfishes and greenspotted rockfish (*S. chlorostictus*) were observed near pennatulaceans (*Ptilosarcus* sp.). Greater than half of all associations between gorgonians and fishes were within a distance of 1 m; however, none involved direct physical contact.

Davidson Seamount, in contrast to Cordell Bank, is a much deeper submarine environment. Davidson rises from the surrounding seafloor at 3600 meters water depth to its crest at 1250 meters. Corals were observed here primarily on ridges and often oriented to maximize surface area towards the current (DeVogelaere et al. 2005). Rattails (*Coryphaenoides* sp.) and thornyheads (*Sebastolobus* sp.) were observed adjacent to corals, along with sponges, other corals, sea stars, clams, sea cucumbers and octopi (*Graneldone* sp.). Coral epifauna included polychaete worms, isopods, shrimps, crabs, basket stars, crinoids, brittle stars and anemones.

With the exception of Pirtle (2005), DeVogelaere et al. (2005) and Tissot et al. (in prep), much of the data from underwater surveys in the Oregon Province have yet to be analyzed for species associations with deep corals. Recent *in situ* studies at Davidson Seamount, Monterey Canyon and in the Olympic Coast NMS may elucidate additional species associations. For example, the recent ROV survey of deep-sea

Table 3.3. Ratings of potential fishing gear impacts to deep corals off the U.S. Pacific coast. Each measure of impact is rated as High (H), Moderate (M), or Low (L).

Gear Type	Measure of Impact			
	Severity of Impact	**Extent of Impact**	**Geographic Extent of Use in Region**	**Overall Rating of Gear Impact**
Bottom trawls	H	H	H	H
Midwater trawls	L	L	H	L
Demersal seines	L	M	L	L
Bottom longlines & gillnets	M	M	M	M
Pots & Traps	M	L	L	L
Other hook and line	L	L	L	L

coral assemblages at the OCNMS (Brancato et al. 2007) revealed many species of fishes and large invertebrates (e.g. shrimp, brittle stars, crabs) nestled among the coral structures (see also. However, the degree to which corals might contribute to the feeding, growth and reproduction of demersal fishes or provide biogenic structure for other megafaunal invertebrates is largely unknown for most of the Oregon Province.

VII. STRESSORS ON DEEP CORAL COMMUNITIES

Compared to other regions in the U.S., the Pacific coast from California to Oregon has a narrow continental shelf, which may result in coral communities here being more susceptible to coastal activities. Some activities that may adversely effect corals include oil and gas development, deployment of gas pipelines and communication cables, and marine pollution. However, fishing operations, particularly bottom trawling, pose the most immediate and widespread threats to deep coral communities.

Effects of fishing

The temperate, nutrient-rich waters of the California Current support lucrative commercial, tribal and recreational fisheries. Fishing operations in the region are very diverse. A limited-entry trawl fishery operates from the Canadian border south to Morro Bay, CA targeting numerous demersal species both on the shelf and upper slope. Vessel sizes range from 35 to 95 feet and average 65 feet (NWFSC 2006). Off California and Oregon, an open-access fishery targeting nearshore species is comprised of vessels from 10 to 50 feet in length (NWFSC 2007). Charter boats also operate out of numerous coastal ports and target a variety of pelagic and demersal species. Gear types used in the region include bottom trawls, midwater trawls, demersal seines, pots, bottom-set gillnets, bottom longlines and other hook-and-line gear, but bottom trawls are the most widely used and potentially harmful to corals. The degree of impact to corals from fishing operations depends on the physical attributes of their habitat (e.g., sediment type, relief), attributes of the gear (e.g., configuration, mode of operation, footprint) and its geographic extent of use (Table 3.3). These attributes will be detailed in relation to each gear type used in the region.

Bottom trawls

Bottom trawls are the most widely used fishing gear off the Pacific coast. They are used off Oregon and in federal waters off Washington and California to target numerous species of demersal fishes, shrimp, prawns, sea cucumbers and sea urchins. Bottom trawls also have the greatest severity ranking of all gear types used in the region (Morgan and Chuendpagdee 2003). Gear components that contact the seafloor include the doors, bridles, footrope (except in shrimp trawls) and occasionally the netting (PFMC 2005). Gear configurations depend on target species and operating depths, with door separation distances ranging from 34-50 m for shelf trawls and 50-200 m for slope trawls (PFMC 2005). Footrope lengths commonly range from 15-34 m for shelf fisheries. Due to their weight and speed (1.5-2.5 knots) over the seafloor, all trawl components that contact the seafloor have the potential to snare, undercut or topple emergent structures, including deep corals. The Pacific Council Groundfish Essential Fish Habitat (EFH) Environmental Impact Statement (EIS) identified sensitivity of coral habitats to trawl gear as relatively high

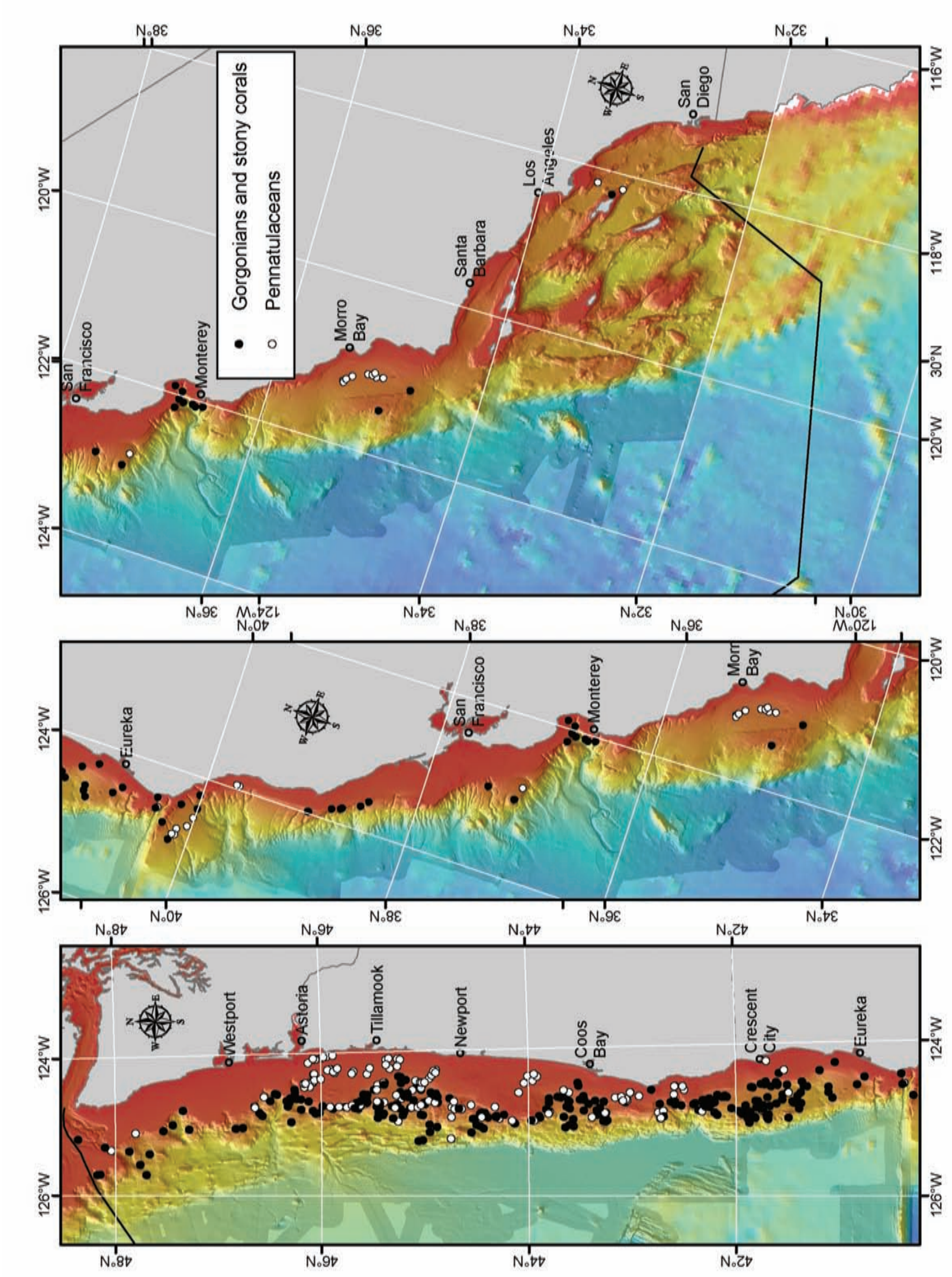

Figure 3.10. Map showing locations of deep coral bycatch recorded by fishery observers in the West Coast Groundfish Observer Program. All observed trips and gear types from August 2001 – August 2004 were queried. Due to limitations of specific identifications, coral bycatch was grouped into two classes: 1) gorgonians and stony corals, and 2) pennatulaceans. Point symbols represent start locations of bottom trawls or longline and pot sets.

(2-3) on a scale of 0-3 with three defined as “major changes in bottom structure, such as re-arranged boulders; large losses of many organisms with differences between impact and control sites greater than 50% in most measured metrics.” Furthermore, bottom trawls accounted for over 92% of observed coral bycatch in the region between August 2001 and August 2004 (Figure 3.10). Because bottom trawls are used extensively throughout the region and deep coral habitats are particularly sensitive to these gears, they were given a high rating of impact (Table 3.3).

Midwater trawls

Midwater trawls are used extensively in the

Oregon Province to target Pacific hake (*Merluccius productus*). Hake is a schooling, pelagic species and therefore vessels using midwater trawls try to avoid contact with the seafloor. As evidenced by no records of coral bycatch from this gear type between August 2001 and August 2004 and their very low rating of habitat impact (Morgan and Chuendpagdee 2003), midwater trawls have low impacts to deep coral communities in the region (Table 3.3).

Demersal seines

Demersal seines, also known as Scottish seines, are used in nearshore and shelf areas to catch flatfish (e.g., sand dabs, Petrale sole, English sole) and chillipepper rockfish (PFMC 2005). Demersal seines use a large net attached to long (hundreds of meters) ropes to herd fish on the seafloor. In contrast to trawl gear, their lighter weight and slower movement over the seafloor cause little disturbance (PFMC 2005). Corals most likely to be impacted by this gear are pennatulaceans, because demersal seines are used in areas of unconsolidated sediments where pennatulaceans inhabit. Due to their limited use in the region; however, demersal seines were given a low rating of impact (Table 3.3). Furthermore, there are no records of deep coral bycatch from this gear type.

Scallop dredges

Although dredges were once used to target weathervane scallops, they are now prohibited in the region.

Bottom longlines and gillnets

Bottom-set gillnets are prohibited offshore Washington and Oregon and in California state waters. In federal waters off California, gillnets are used to catch white seabass, bonito, flying fish, white croaker, angel shark, California halibut, lingcod, mullet and perch (PFMC 2005). Bottom longlines, on the other hand, are used throughout the region to target sablefish, rockfish, Pacific halibut, cabezon, lingcod or dogfish. Bottom longlines are composed of weights, hooks and a mainline that contact the seafloor. Gillnets are anchored by weights and leadlines, which weigh about 100 pounds per 100 fathoms of line (PFMC 2005). These gears can travel significant distances over the seafloor, particularly during retrieval when the vessel is not directly over the gear, snaring or undercutting emergent structures (e.g., corals). According to Morgan and Chuendpagdee (2003), bottom longlines and gillnets have a medium to low impact on the physical and biological components of habitat. Furthermore, from August 2001 through August 2004, gillnets and longlines accounted for less than 4% of all observed coral bycatch. However, this low percentage may reflect a sampling bias to mobile gears or that corals damaged by these gears do not reach the surface. Lost longline gear has been observed on the seafloor at several sites within the Olympic Coast NMS (Hyland et al. 2004; Brancato et al. 2007). Nevertheless, sensitivity of coral habitats to hook and line gear (e.g., longlines) was classified as low to moderate (0.3-1.3) on a scale of 0-3 (PFMC 2005). Due to this low to moderate sensitivity rating, medium to low habitat impact rating, and their moderate use in the region, bottom longlines and gillnets were given a medium rating of overall impact (Table 3.3).

Other fishing gears

Throughout the region, pots (also called traps) are used to catch sablefish, Dungeness and other species of crab, spot prawns, spiny lobster and other finfish. Pots can be single (e.g., Dungeness crab) or in a series of up to 50 attached to a groundline (e.g., sablefish) (PFMC 2005). The effect of pots on the seabed depends on their weight, shape and lateral movement during retrieval. If the vessel is not directly above the pot being retrieved, significant contact with the bottom can occur; however, this movement is typically minimized so as not to put excessive strain on the line and other equipment (PFMC 2005). Severity of impact to coral habitats by pots and traps was ranked as low to moderate (PFMC 2005; Morgan and Chuendpagdee 2003). Factoring in their limited use in the region, pots were given a low overall rating of impact (Table 3.3).

In addition to longlines, other types of hook and line gear (e.g., stick gear, rod and reel, jig gears and vertical longlines) are used in the region, but their impacts to deep corals are most likely minimal. Sinkers, hooks and lines can snare and damage corals, but the area of seafloor contacted is small relative to trawls and dredges. Consequently, these hook and line gears were given a low rating of impact (Table 3.3).

Effects of other human activities

In addition to fishing operations, sedimentation caused by oil and gas development has been shown to be detrimental to corals in the region. Other human activities that may adversely impact corals include the deployment of gas pipelines and communication cables and pollution. Unfortunately, little is known about these potential stressors but they are likely to have only localized impacts, if any. In the future, global climate change has the potential to adversely impact corals throughout the Pacific Ocean and in other parts of the world.

Oil and Gas Exploration and Extraction
Since 1958, production of oil and gas has occurred from offshore platforms in southern California. A total of 26 platforms (23 in federal waters, 3 in state waters) are currently sited off Pt. Arguello, San Pedro and in the Santa Barbara Channel at water depths ranging from 11 to 363 m (Love et al. 2003, Figures. 3.11-3.13). A permanent moratorium is currently in place on new oil and gas leases in California state waters, and a moratorium on new leases in federal waters is in affect until 2012 (John Romero, MMS, pers. comm.). No restrictions are in place for existing lease sites, although no platforms have been erected since 1989 (Nevarez et al. 1998). As of 1 May 2006, 1290 total wells had been drilled at the 23 platforms in federal waters. In 2005, 43 of 79 active leases were producing and 23 development wells were spudded (MMS 2006). One potential threat to corals and other filter-feeding organisms from offshore oil and gas operations is through the introduction of suspended or re-suspended materials (Cimberg et al. 1981; Raimondi et al. 1997; NOAA 2004). During drilling, a mixture of water, clay, and barite is pumped down the well hole primarily to cool the equipment and dislodge any rocks. Hyland et al. (1994) documented the abundance of hard-bottom epifauna before, during and after drilling began at three platforms. They found a decrease in the density of four invertebrate taxa, including *Caryophyllia* sp., after drilling began.

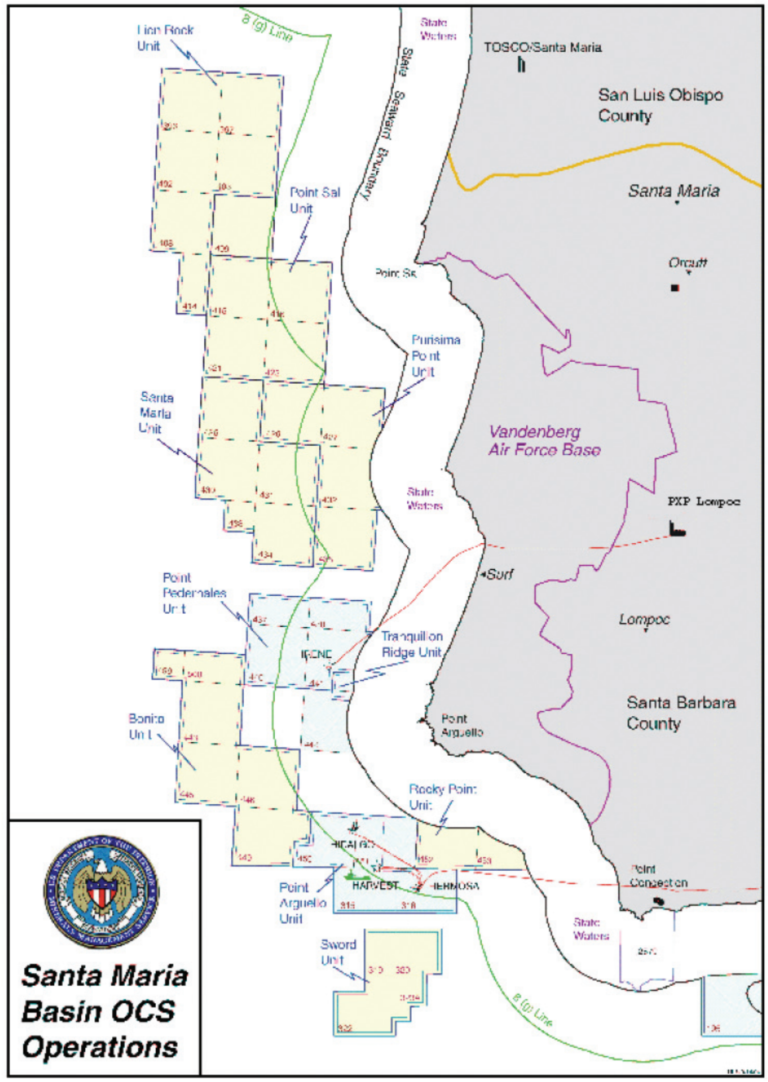

Figure 3.11. Map showing locations of oil and gas leases, platforms and associated pipelines in the Santa Maria Basin off Pt. Arguello, California. Image source: MMS Pacific OCS Region.

Deployment of Gas Pipelines and Communication Cables
Numerous gas pipelines connect offshore production platforms to shore side facilities in southern California (Figures. 3.11-3.13). In addition, cable routes transect many parts of the continental margin off all three west coast states. Recent cable installations include the Alaska United Fiber System – West, which extends from Warrenton, Oregon west-southwest over the shelf and is buried down to 1500 meters water depth. A reinstallation of a communication cable that connects the U.S. and Japan via the northeastern portion of the Olympic Coast NMS was completed in September 2006 (Mary Sue Brancato, Olympic Coast NMS, pers. comm.). Future cable laying operations include the NEPTUNE cable system – a regional cabled ocean observatory in the

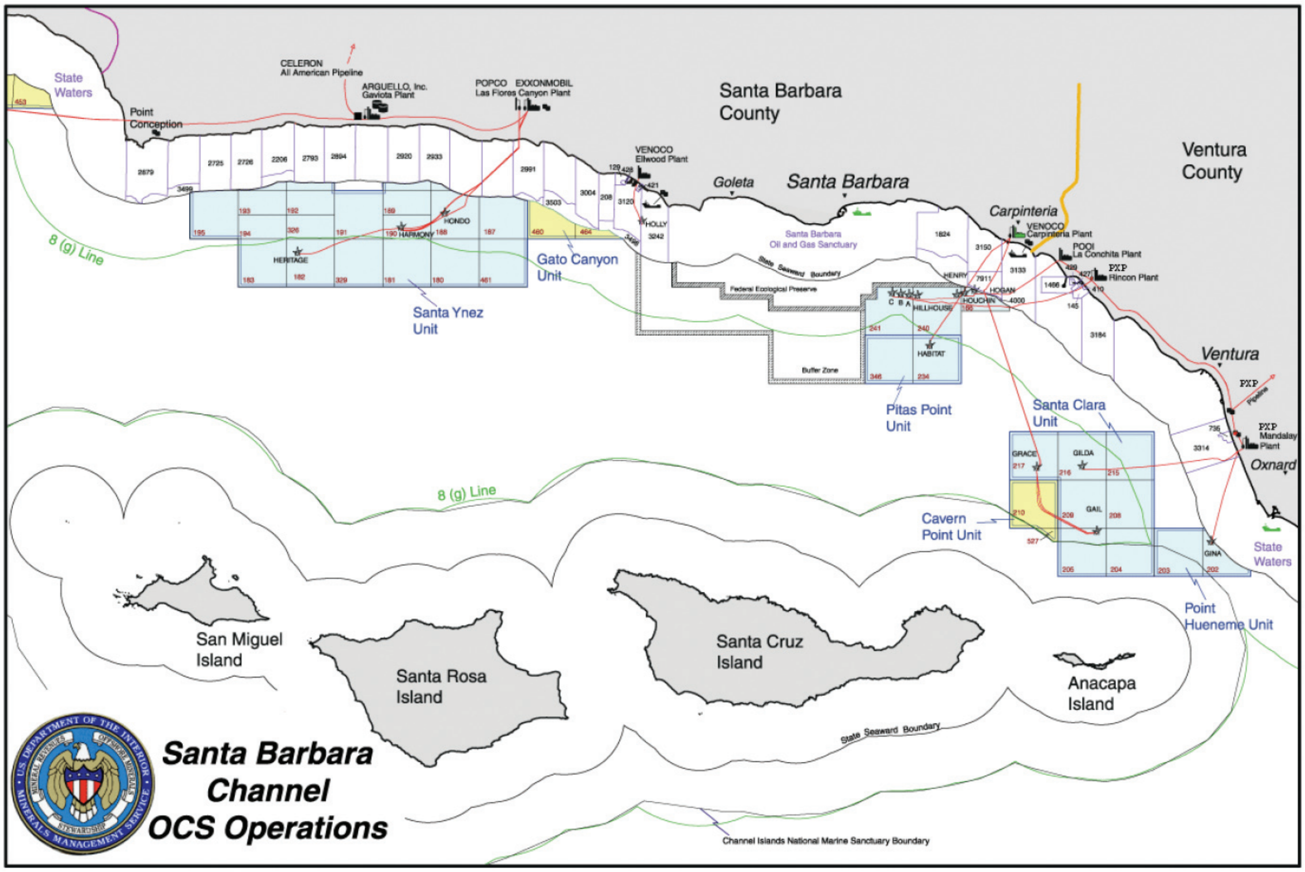

Figure 3.12. Map showing locations of oil and gas leases, platforms and associated pipelines in the Santa Barbara Channel off southern California. Image source: MMS Pacific OCS Region.

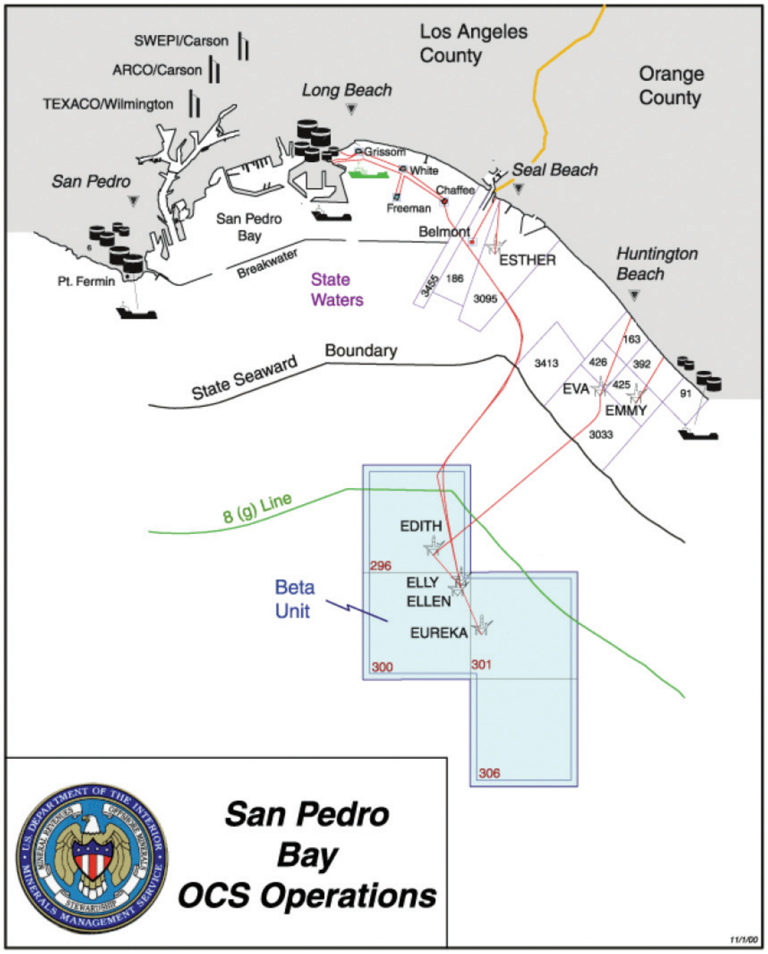

Figure 3.13. Map showing locations of oil and gas leases, platforms and associated pipelines off San Pedro, California. Image source: MMS Pacific OCS Region.

northeast Pacific Ocean. NEPTUNE will consist of a 3000-km network of fiber-optic cables with about 20 instrumented nodes located along the route (Figure 3.14). Portions of the cable network off Vancouver Island, BC are under construction, with the U.S. portion to be installed later.

There have been no reports in the region of communication cables or gas pipelines transecting areas of known coral habitat. However, this may be due to a lack of effort on this topic. Where feasible, cables and pipelines are buried down to deep-water depths (usually 1500 m) to avoid interactions with commercial fishing operations. If corals were located nearby, they could be buried or smothered by resuspended sediments. Where cables and pipelines transect hard-bottom seabed, they cannot be buried and therefore may cause severe impacts to corals if present in the area. Damage can occur along the cable or pipeline itself or over larger swaths by the heavy anchors often used during placement or repair (Freiwald et al. 2004).

Sedimentation

Studies throughout the world report negative effects of sedimentation on corals (Dodge et al. 1974; Dodge and Vaisnys 1977; Dodge and Lang 1983; Hardin et al. 1994); however, some taxa are more vulnerable than others. For example, two experiments have shown that scleractinians have the ability to actively remove sediment from their polyps (Reigl 1995; Shelton 1980), while alcyonaceans rely solely on water motion and gravity (Reigl 1995). Despite this ability by some taxa, sedimentation is still a major threat to the health of coral communities throughout the world (Norse 1993). The U.S. Pacific coast is no exception. At hard-bottom sites off Pt. Conception, CA, Hardin et al. (1994) examined the spatial distribution of epifaunal assemblages in relation to suspended sediment flux. The authors discovered a negative correlation between sediment flux within 2 m of the seafloor and the coverage of filter-feeding organisms that include two stony corals – *Lophelia pertusa* and *Desmophyllum dianthus*.

Natural sources of sediments to the continental margin include coastal rivers – the Columbia being the largest in the region. Studies of sediment deposition and accumulation rates have been conducted at sites off Oregon (Kulm et al. 1975), northern California (Wheatcroft et al. 1997) and central California (Lewis et al. 2002; Eittreim et al. 2002). Although these studies did not specifically address impacts to corals or others filter feeders, they did provide average annual deposition rates over broad ranges of depth and latitude.

Other causes of sediment resuspension include bottom trawling, slumps, storms and turbidity currents (triggered by earthquakes). Bottom trawling may pose the highest risk because of its documented interactions with corals (mostly pennatulaceans and gorgonians in the form of bycatch) and its widespread use in the region. Unfortunately, there is little specific information in the region on the effects of any of these potential causes.

Pollution

The authors are aware of only one study in the region that specifically addressed the effects of pollutants on deep coral communities. Hyland et al. (1994) examined the effects of chemical contaminants from drilling discharges on the benthos off Pt. Arguello, CA. The authors found that concentrations were below toxic levels, suggesting that any biological changes to epifauna were due to increased particulate loading. Because of the lack of information in the region and throughout the world, the effects of pollution on deep corals remain uncertain.

Coral Harvest

Because it retains its pigment after death, *Stylaster californicus* is popular among recreational collectors and has also been harvested commercially for sale in shell shops (NMSP 2005). However, commercial harvest of Stylasterids is now prohibited off California.

Mineral Mining

Compared to oil and gas development, mineral mining has the potential to adversely impact larger areas of seafloor habitat (Carney 2001). Two mining operations have been proposed off the U.S. Pacific coast, but neither has been initiated. Manganese nodules are ores containing minerals including manganese, cobalt, nickel and copper. They were originally discovered during the *HMS Challenger* voyage, although later discoveries of dense aggregations in the central north Pacific provoked economic interest during the Cold War (Carney 2001). Because of the distance and operating depths involved and continued availability of key minerals from

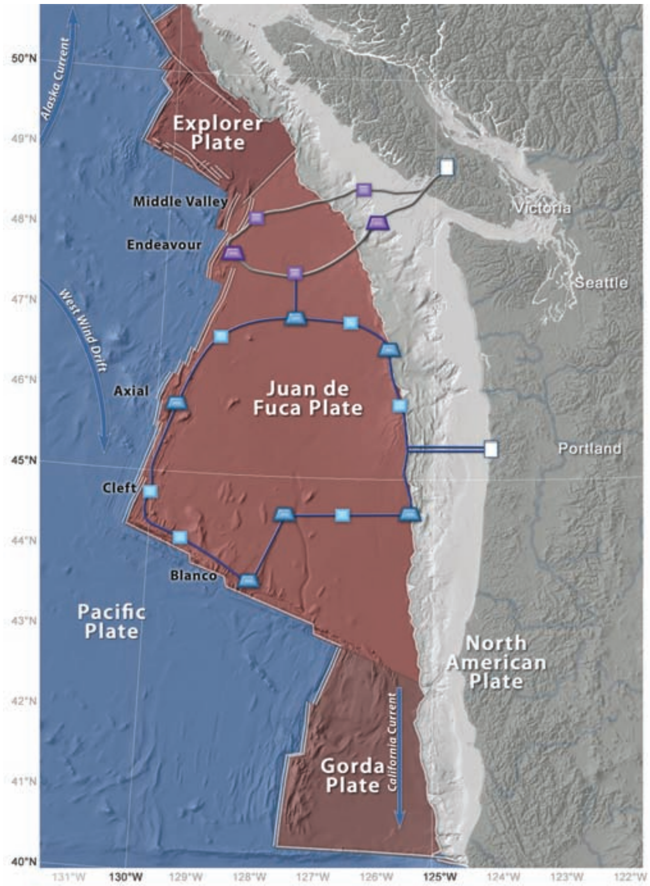

Figure 3.14. Map showing locations of proposed cable routes and node locations for the NEPTUNE project. Image credit:: Debbie Kelley, Univ. of Washington, Center for Environmental Visualization.

terrestrial sources, mining of the nodules was never initiated. These dense aggregations occur outside the EEZ, however, so potential mining operations would not impact U.S. coral resources. The second proposed offshore mining operation was for polymetallic sulfides. In 1983, the U.S. Minerals Management Service issued a draft environmental impact statement for a proposed lease sale of a portion of the seabed on the Gorda Ridge (see Figure 3.2). Despite initial studies as to the impact of mining in the vicinity, there was lack of industry interest. Although it is not known whether corals occur on Gorda Ridge, a photographic study of the proposed lease site in 1986 revealed the presence of other suspension feeders (Carney 2001).

Climate Change

Although oceans are moderating climate change by assimilating anthropogenic CO_2 emissions, it is not without consequence to ocean chemistry. Uptake of atmospheric CO_2 is causing declining pH in ocean surface waters (already 0.1 units lower than preindustrial values) and is predicted to decrease carbonate concentrations in the deep ocean (Orr et al. 2005). Corals use carbonate ions to form skeletal components. Two forms of calcium carbonate are common in the oceans: 1) aragonite, used by scleractinians and most stylasterids, and 2) calcite, used by octocorals and about 10% of stylasterids (Cairns and Mcintyre 1992). Aragonite is more soluble than calcite; therefore its depth of saturation (i.e., aragonite saturation horizon (ASH)) is shallower than that of calcite. Furthermore, the ASH in the north Pacific occurs at shallower water depths than the north Atlantic, resulting in dissolution rates twice as high in the upper 1000 m (Feely et al. 2004). Guinotte et al. (2006) hypothesize that the paucity of deep-sea, bioherm-building scleractinians in the north Pacific is a result of this relatively shallow (50-600 m) ASH. The authors also suggested that stony corals in the north Pacific are already living in marginal aragonite saturation states. Off the U.S. Pacific coast, stony corals are known to occur at water depths down to 578 meters (Cairns 1994). One of the largest accumulations of colonial scleractinian observed thus far in the region (i.e., an extensive low-lying mound of *Lophelia pertusa* at the Olympic Coast NMS) was at a water depth of approximately 250 m (Brancato et al. 2007). Guinotte et al. (2006) predicted that the ASH off the entire U.S. Pacific coast would be shallower than 200 m by 2060, while changes in the calcite saturation horizon will be less pronounced (Orr et al. 2005). If those predictions are correct, the distributions of scleractinians in the region could be severely impacted. Stylasterids would most likely be less affected by changing ASH because they occur at shallower water depths (<183 m).

Evidence suggests that global climate change may pose other threats to corals. Corals are sessile filter feeders, most likely feeding on suspended organic matter that rains down from the surface or is transported by currents (Kiriakoulakis et al. 2005). Because many of the organisms that comprise this source of organic material (e.g., coccolithophores, foraminiferans, pteropods) use carbonate to form protective shells, reduced carbonate concentrations may impact nutrient availability for corals. In addition, rising atmospheric CO_2 is increasing deep-sea water temperatures (Barnett et al. 2005) and altering salinities (Curry et al. 2003), which may in turn cause changes in thermohaline circulation

(Joos et al. 1999). Because corals have evolved in steady-state, nutrient-rich environments, they may be particularly susceptible to such changes in environmental conditions (Guinotte et al. 2006).

Invasive Species
NOAA continues to search for information on the effects invasive species might have on deep corals in the region. Thus far, no specific studies or adverse interactions have been identified.

VII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

The Pacific Fisheries Management Council (the Council) and the National Marine Fisheries Service (NMFS) are responsible for the management of fishery resources in federal waters off the U.S. Pacific Coast from California to Washington. Fisheries that occur solely within state waters (e.g., pink shrimp in Oregon) are regulated by the individual states, along with other activities that may have impacts to intertidal and subtidal habitats. Other activities occurring within five national marine sanctuaries and on the outer continental shelf are regulated by the NOAA's National Marine Sanctuary Program and the Department of Interior's Minerals Management Service (MMS), respectively. Although specific protections of corals have only been implemented recently, a number of measures adopted by these federal and state agencies have had the indirect effect of coral habitat conservation. These measures will be highlighted below after a brief synopsis of research and mapping programs in the region.

Mapping and Research
A multitude of seabed information exists for the Pacific coast region including swath bathymetric data and sidescan sonar imagery collected during large-scale mapping programs and during targeted geologic investigations, an extensive database of sediment samples collected by the oil industry and during submersible surveys, seismic reflection profiles collected by the oil industry and academic institutions, structural geologic maps created by the state of California, the United States Geological Survey (USGS) and Oregon State University, and photographic and video imagery collected during numerous submersible and ROV surveys. This information was recently used in the creation of a regional map of benthic habitats for the entire continental margin (i.e., intertidal out to ca. 3000 meters water depth) off the Pacific coast (Figure 3.15). Two complimentary projects were commissioned to inform the recent Groundfish EFH environmental impact statement. The Center for Habitat Studies at Moss Landing Marine Laboratories created the map for California (Greene and Bizzarro 2005), while the Active Tectonics and Seafloor Mapping Lab at Oregon State University produced the maps for Oregon and Washington (Goldfinger et al. 2005). The maps show habitat polygons delineating physiographic structures (e.g., shelf, slope and canyons) and surficial lithology (e.g., mud, sand and rock) at horizontal scales ranging from tens of meters to a kilometer. Habitat types were coded based on a modified version of a deep-water habitat characterization scheme developed by Greene et al. (1999). A unique feature of these maps is an associated layer of data quality that quantifies data density and ranks data sources for their utility to habitat mapping (Romsos et al. in press). From these habitat maps, rocky habitats are estimated to comprise approximately 9% (21,000 km^2) of the seafloor area out to ca. 3000 meters water depth.

Several federal and state agencies and academic institutions have conducted additional targeted seafloor mapping projects off the Pacific coast to provide base maps for a variety of benthic habitat investigations. Study areas that have incorporated underwater observational platforms (e.g., camera sleds, submersibles, ROVs) with remote geophysical mapping techniques (e.g., sidescan and multibeam sonar, seismic profiling, laser line scan) include several rocky banks and outcrops off southern California, the Big Sur coast, Davidson Seamount, Monterey Canyon, Cordell Bank, rocky banks on the outer shelf and reefs along the Oregon coast, Astoria Canyon, and hard bottom seafloor features in the Olympic Coast NMS (Figure 3.16). Olympic Coast NMS is also continuing its deep sea habitat mapping program (Intelmann 2006) to guide future ROV survey efforts to document deep coral communities. Many of these investigations have resulted in the discoveries of deep coral communities that were highlighted earlier in this chapter.

To date, there has been no regular monitoring of deep coral habitats in the region. In 2004 and 2006, the Olympic Coast NMS conducted assessments

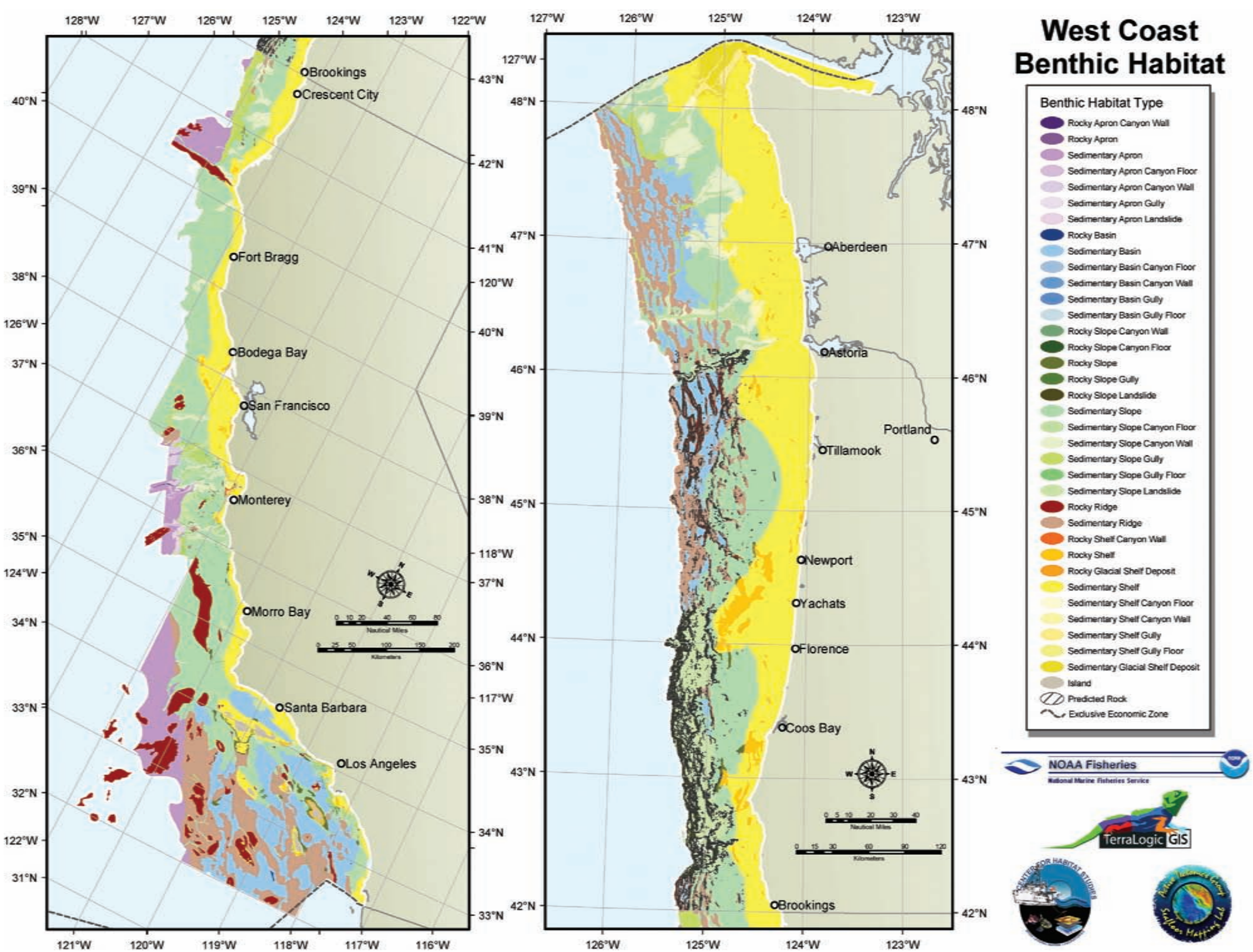

Figure 3.15. Map of Pacific coast of the U.S., showing benthic habitats from the coastline out to approximately 3000 meters water depth. Benthic habitat characterization was modified after Greene et al. (1999) and incorporates information on seafloor lithology (e.g., sedimentary or rocky) and physiography (e.g., shelf, slope, basin, canyon wall). Maps of Washington and Oregon habitats were created the Active Tectonics and Seafloor Mapping Lab at Oregon State University. Map of California habitats was created by the Center for Habitat Studies at Moss Landing Marine Laboratories.

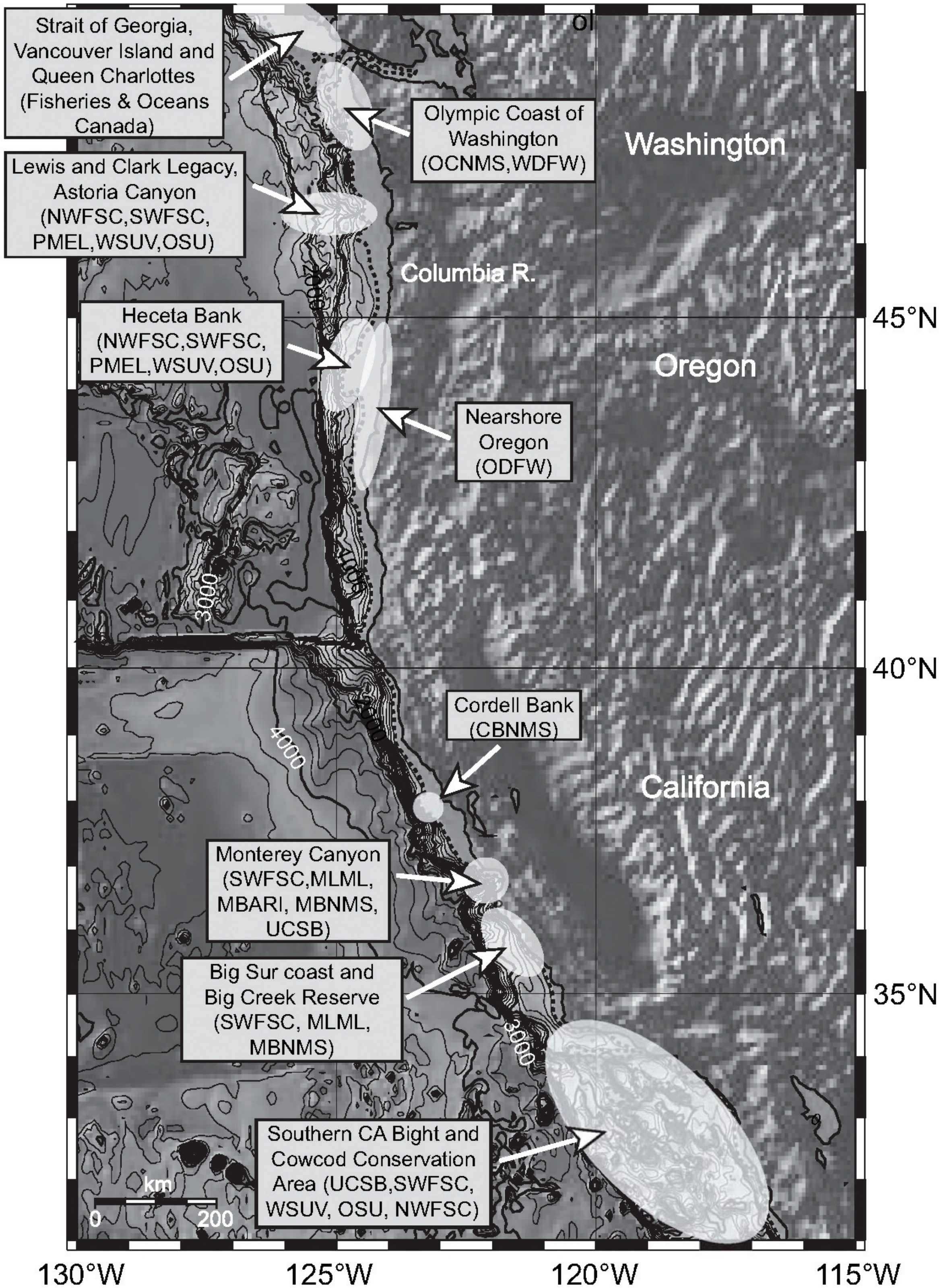

Figure 3.16. Map of the Pacific coast of the U.S., highlighting growing network of study areas and some of the participating organizations conducting interdisciplinary studies of fish habitat (WDFW, Washington Department of Fish and Wildlife; OCNMS, Olympic Coast National Marine Sanctuary; NWFSC, Northwest Fisheries Science Center; SWFSC, Southwest Fisheries Science Center; PMEL, Pacific Marine Environmental Laboratory; WSUV, Washington State University, Vancouver; OSU, Oregon State University; ODFW, Oregon Department of Fish and Wildlife; CBNMS, Cordell Bank National Marine Sanctuary; MLML, Moss Landing Marine Laboratories; MBNMS, Monterey Bay National Marine Sanctuary; and UCSB, University of California, Santa Barbara). Image source: Wakefield et al. 2005, Figure 3.

of deep coral and sponge communities, but it is unclear how future fiscal environments will affect regular monitoring efforts. The Southwest Fisheries Science Center (SWFSC) often conducts submersible surveys of hard-bottom habitats off California. Although the primary focus of these surveys is groundfish habitats, they often occur in areas where corals are located and have therefore resulted in important discoveries, including that of the newly described black coral, *Antipathes dendrochristos*. Other surveys by the Northwest Fisheries Science Center (NWFSC) such as those utilizing AUVs are just being developed as a routine method for groundfish and may provide more routine monitoring of deep coral habitats coastwide.

Directed Harvest

Presently, there is no directed harvest of corals in the region.

Minerals Management Service

The United States Minerals Management Service (MMS) is responsible for the regulation of development and extraction of offshore energy resources, and they regularly conduct research in the Pacific outer continental shelf region. Mitigation of potential impacts to the nearby marine environment from oil and gas development has been a priority of MMS since oil production began of southern California in 1958. Because of the potential risks from offshore oil and gas operations, MMS developed anchoring guidelines to minimize impacts to hard-bottom communities. These guidelines were crafted as a result of numerous studies conducted before and after drilling projects (Mary Elaine Helix, MMS, pers. comm.). In addition, a long-term monitoring program was conducted in the late 1980s to evaluate environmental impacts of oil and gas development on marine and coastal resources (Steinhauer and Imamura 1990). It was these studies that provided some of the first *in situ* observations of stony corals in the region including *Lophelia pertusa*, *Desmophyllum dianthus* and *Paracyathus stearnsii*.

Fishery Management Councils

The Pacific Fishery Management Council, in cooperation with NMFS, has implemented a comprehensive plan to protect EFH for groundfish (see PFMC 2005, 2006). The plan was developed in collaboration with NGOs, the fishing industry, and the National Marine Sanctuary Program to focus largely on pristine or untrawled habitat and biogenic habitats such as corals that are vulnerable to impact from human activities. The plan is considered comprehensive because it addresses impacts from the full range of human activities (fishing and non-fishing), and includes procedures for adaptation as new information becomes available.

Management measures to minimize adverse impacts from fishing include marine protected areas, reductions in fishing effort, and gear restrictions as recommended by the National Research Council (NRC 2002). Over 130,000 mi^2 (336,700 km^2) are now marine protected areas (MPAs) and fully protected from impacts from bottom trawls, with selected vulnerable habitats protected from all fishing gears that contact the bottom (Figure 3.17). The MPAs are distributed the length of the coast and include both federal and state waters. The MPAs work in concert with other spatial management actions taken by the Council such as the Rockfish Conservation Areas and Cowcod Conservation Areas (Figure 3.18) that have significantly reduced fishing effort in habitats important to the adult life-stage of some overfished species. Some of these habitats are hard-bottom areas that may include deep corals. Fishing effort has also been significantly reduced off the central California coast through a collaboration of the fishing industry and the Nature Conservancy. A feature of this collaboration is the private purchase of trawl fishing permits by the Nature Conservancy. Finally, gear restrictions implemented by the Council include coast wide prohibitions on gear types known to have a high impact on benthic habitats. Prohibited gears include dredge gear, beam trawl and large footrope bottom trawl.

Impacts from non-fishing activities were addressed by the Council through the establishment of Habitat Areas of Particular Concern (HAPC) and publication of recommended conservation measures (PFMC 2005). NMFS is now using the HAPC to focus their conservation efforts related to non-fishing activities through the EFH consultation process.

The Council and NMFS recognized that the plan to protect groundfish habitat is, in large part, based on precautionary management principles due to important gaps in available information. To accommodate the likelihood that new information

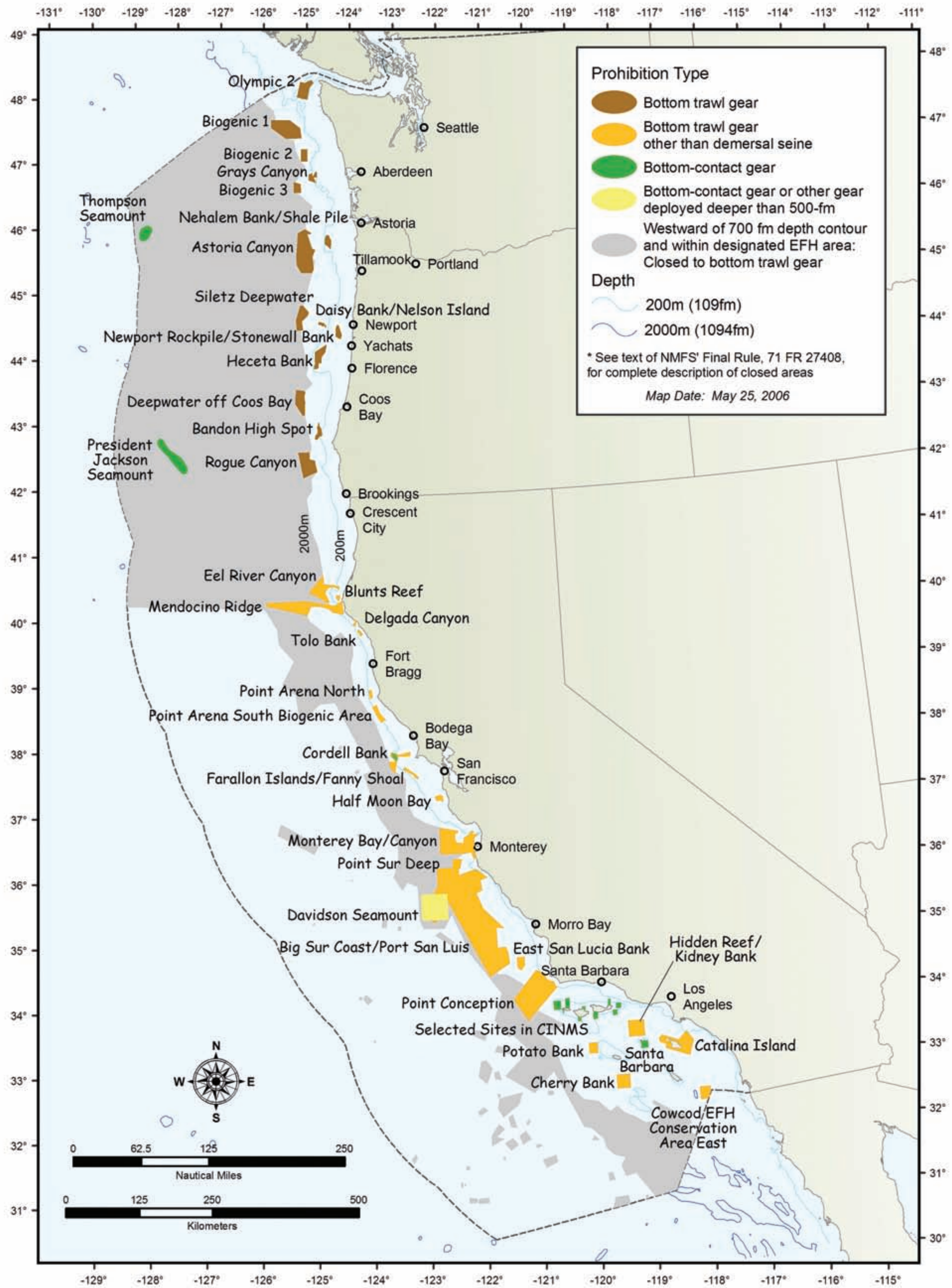

Figure 3.17. Map showing locations of conservation areas specified in Amendment 19 to the Pacific coast Groundfish fishery management plan. Conservation areas were developed in the Pacific Coast Groundfish Essential Fish Habitat EIS as part of the preferred alternative to minimize adverse impacts to EFH. Image source: PFMC 2006.

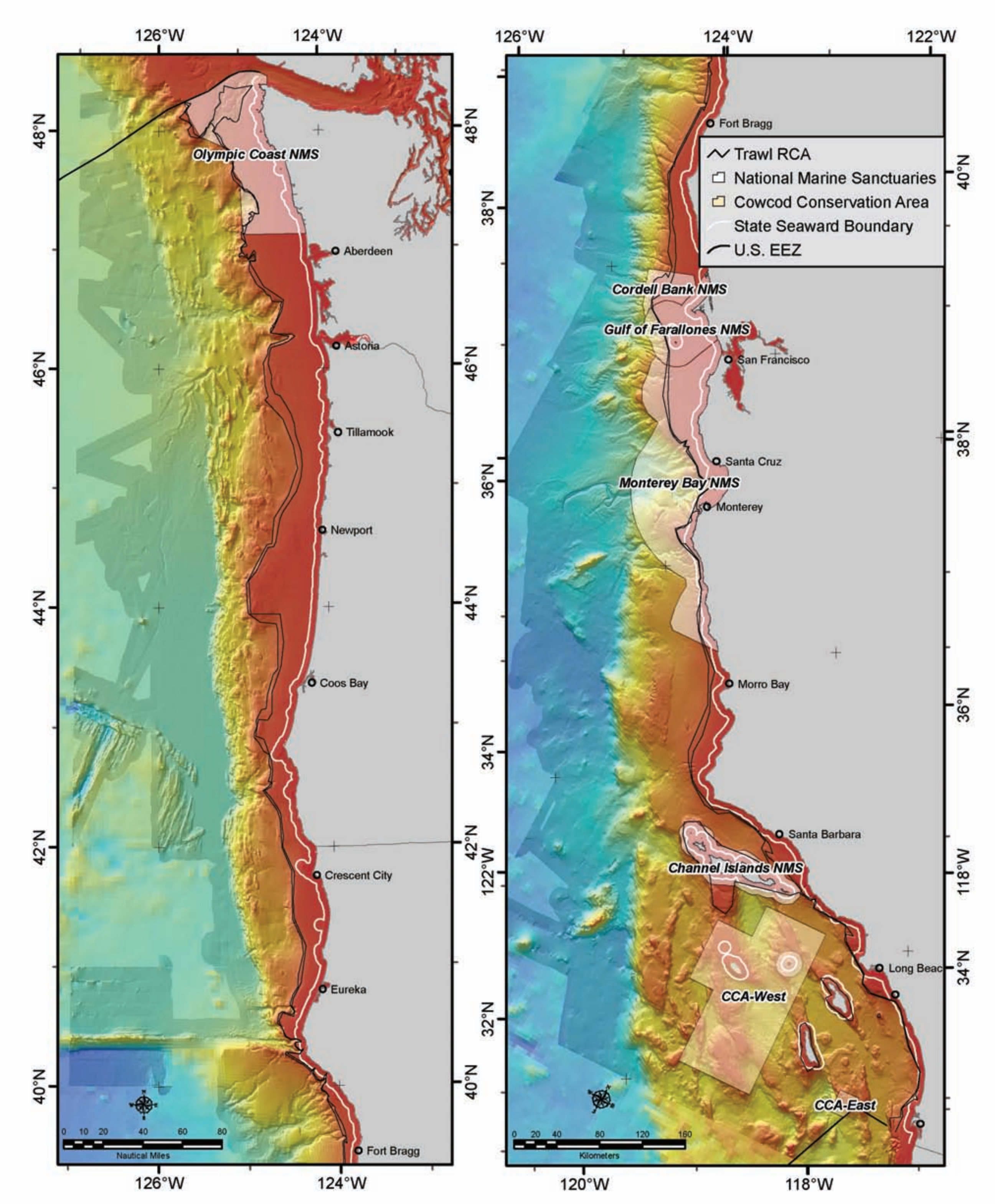

Figure 3.18. Map showing locations of some federal marine managed areas off the U.S. Pacific Coast, including national marine sanctuaries, the Cowcod Conservation Areas (CCA) and the trawl Rockfish Conservation Areas (RCA). The boundaries of the trawl RCA are adjusted on two-month management cycles in response to bycatch information on overfished species. Shoreward boundaries can be as shallow as the shoreline while seaward boundaries can be as deep as 250 fathoms. An area between the lines approximating the 100- and 150-fathom isobaths (shown on map) has been permanently closed to bottom trawling since inception of the trawl RCA in 2002.

will become available through research, the Council established a streamlined process to adapt habitat protection measures.

In the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 (P.L. 109-479), Congress directed NOAA to implement a Deep Sea Coral Research and Technology Program and allowed the designation of deep coral zones. The Deep Sea Coral Research and Technology Program will identify, locate and map locations of deep sea corals, monitor activity in locations where deep sea corals are known or likely to occur, conduct research and develop technologies to assist fishing industry participants in reducing interactions between fishing gear and deep sea corals. The Councils have discretionary authority to designate zones for the protection of deep sea corals in areas where deep sea corals have been identified by the Deep Sea Coral Research and Technology Program.

National Marine Sanctuaries

In the Pacific region there exist five national marine sanctuaries. The Olympic Coast NMS is located off northern Washington, while the other four sanctuaries, Cordell Bank, Gulf of the Farallones, Monterey Bay, and Channel Islands are located off central and southern California (Figure 3.18). Except in designated marine reserves or conservation areas, the sanctuaries do not regulate fishing including the use of bottom contact gears. All sanctuaries, however, prohibit other activities that may be harmful to corals, including but not limited to 1) new oil, gas or mineral exploration, development and production, 2) discharge of materials or substances except fish parts, bait, water or other biodegradable effluents, and 3) alteration of the seabed except for normal fishing activities and anchoring. In addition, the Cordell Bank NMS prohibits the removal or injury of benthic organisms in waters above 50 fathoms (91 m), except during normal fishing operations outside of designated conservation areas.

In May 2007, the National Marine Sanctuary Program established a network of marine reserves and one conservation area within the Channel Islands NMS (Figure 3.19) to complement an existing network of state reserves implemented in April 2003 by the state of California (Figure 3.19). After implementation in July 2007, the new federal reserves and conservation area will total 110.5 nmi^2 and 1.7 nmi^2, respectively. The state of California is expected to extend the boundaries of it's existing reserves to the three mile state-federal waters boundary, thereby increasing to total area of reserves and conservation areas to 232 nmi^2 and 8.6 nmi^2, respectively. Like existing state reserves, all extractive activities will be prohibited while certain fishing for lobster and recreational take of pelagic fishes will be allowed in conservation areas (15 FR 29208). Proposed

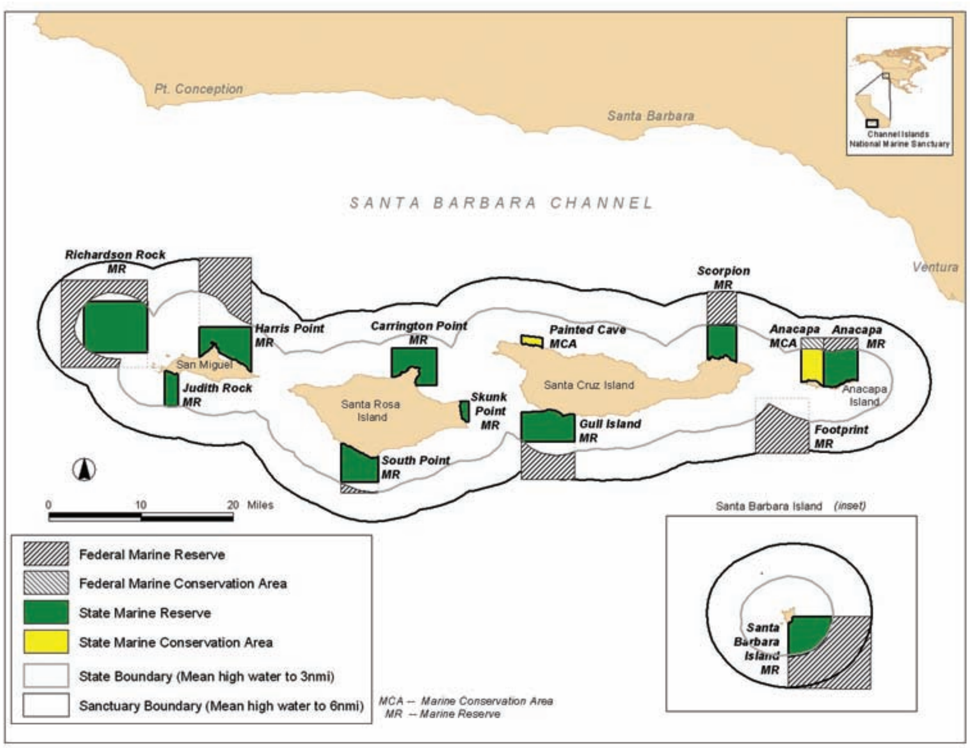

Figure 3.19. Map showing location of the Channel Islands National Marine Sanctuary (CINMS) and its network of marine protected areas. State MPAs were implemented in April 2003 while federal MPAs will be implemented in July 2007. Image source: Channel Islands NMS.

rules for marine zoning in the Monterey Bay and Cordell Bank NMS are expected in the near future.

State activities

The state of California in recent years has enacted a series of laws to direct the management of state marine resources, including the Marine Life Management Act (Stats. 1998, ch. 1052), the Marine Life Protection Act (MLPA, Stats. 1999, ch. 1015), and the Marine Managed Areas Improvement Act (Stats. 2000, ch. 385). In particular, a key mandate of the MLPA is to design and manage a network of MPAs to protect marine life, habitats, ecosystems, and natural heritage while providing recreational, educational and study opportunities. In addition to the marine protected areas implemented in 2003, the state, in April 2007 adopted a network of 29 MPAs for their Central Coast Study Region, which encompasses state waters between Pt. Conception and Pigeon Point (Figure 3.20). These include new and expansions of existing MPAs that cover approximately 204 mi^2 (528 km^2) or 18% of state waters in the central coast region, including 97 mi^2 (251 km^2) of no-take reserves (Office of Administrative Law Notice File Number Z06-1031-05). While corals (specifically hydrocorals) are listed as "benefit species" for only three of the MPAs, the protection of both shallow and deep hard bottom habitats is an objective for this network of MPAs. Planning and scoping of additional MPAs began in early 2007 for the next study region, the North Central Coast, which encompasses state waters from Pigeon Point north to about Pt. Arena.

To date, only about a third of the seafloor in California state waters has been mapped at any appreciable scale (Rikk Kvitek, CSUMB, pers. comm.). The Seafloor Mapping Lab of California State University Monterey Bay (CSUMB) and its partners are currently engaged in the North Central Coast Mapping Project, which will produce multibeam base maps for state waters seaward of the 20-meter isobath from Año Nuevo north to Pt. Arena. Another project mapping the coastal area in the Santa Barbara Channel involves the Seafloor Mapping Lab, USGS and the California Ocean Protection Council. Over the next 5-6 years, the California Coastal Conservancy and Ocean Protection Council hope to complete comprehensive mapping for the remaining 66% of state waters (Rikk Kvitek, CSUMB, pers. comm.). The time frame for completion will depend on available funds.

Oregon also suffers from lack of seabed information in state waters. To date, less than 5% of Oregon's ca. 950 nm^2 (3263 km^2) territorial sea is mapped. In March 2006, a consensus statement, signed by 20 Oregon marine scientists, called for support and funds to map the seafloor within Oregon's territorial sea. Projected costs are under $6 million. Stated reasons for this mapping plan include management of hazards posed by tsunami events, describing nearshore habitats on which nearshore fisheries and marine resources depend, and scientific support of two gubernatorial proposals – establishment of a limited network of marine reserves in state waters, and a national marine sanctuary to be sited off Oregon. In response to the scientific consensus statement, the Territorial Sea Mapping Bill (HB 2924), which would appropriate funds for seafloor mapping, was introduced in February 2007. Passage of HB 2924 along with the establishment of reserves and a national marine sanctuary are still pending.

In September 2006, the three west coast governors signed a joint agreement to collaborate on critical ocean and coastal protection and management issues. Short-term priorities for this collaboration include increased funding for mitigation of nonpoint source pollution, opposition to oil and gas leasing, exploration and development, and a regional research plan to support ocean observing programs and seafloor and habitat mapping.

VIII. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

Given the limitations of existing information off the U.S. Pacific coast, it is clear that more targeted data collections and mapping efforts are needed. Because many collections are made from long trawls that can traverse several habitats, it is impossible to determine specifically the habitat from which these species were collected. Therefore, to date, it is difficult to map corals at a regional scale showing the appropriate habitat associations. Furthermore, coral specimens are continuously collected during *in situ* photographic surveys, regional trawl surveys and by fisheries observers. Rapid identification of these samples is

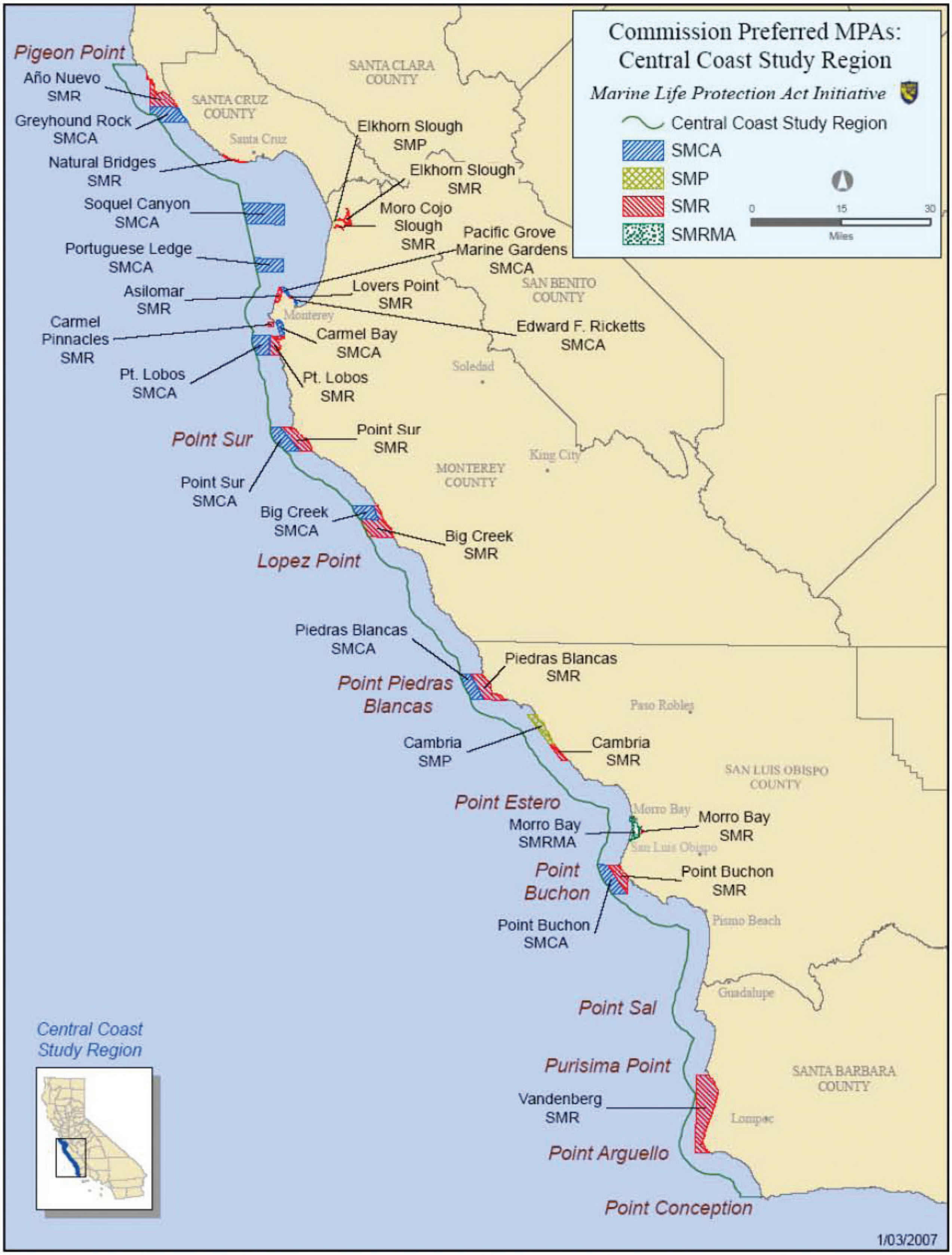

Figure 3.20. Map showing locations of marine protected areas in the Central Coast study region for the state of California, including state marine conservation areas (SMCA), marine parks (SMP), marine reserves (SMR) and marine recreational management areas (SMRMA). Image source: California Department of Fish and Game.

needed to mitigate further impacts to deep corals and their habitats. Finally, the establishment of a network of conservation areas in the region provides an unprecedented opportunity to monitor coast wide recovery of benthic habitats (including those that support coral communities) from fishing impacts.

Mapping

Because little is known about the nature of relationships between corals, other invertebrates and demersal fishes off the Pacific coast, the highest mapping priority is to quantify those relationships. To date, few studies (see Tissot et al. 2006; Pirtle 2005; Hardin et al. 1994) in the region have examined the nature of relationships between corals, other structure-forming invertebrates and fishes, though analysis of recent surveys is ongoing (see Brancato et al. 2007). In order to evaluate the importance of corals to their benthic communities, future *in situ* surveys will need to incorporate a more holistic investigation of species relationships and habitat characteristics.

Surveys are needed that specifically monitor the abundance and distribution of corals in representative habitat types so that accurate and comprehensive maps of their distribution and abundance can be made. Targeted surveys on representative habitats using underwater platforms (e.g., submersibles, ROVs, AUVs) in conjunction with optical survey systems (e.g., video, laser line scan) are needed. Survey areas can be selected using maps of surficial geologic habitats that were developed for the Pacific coast Groundfish EFH EIS (see Figure 3.15) or higher resolution maps of specific areas. In addition, areas of repeated coral bycatch identified during mapping of existing observer and trawl survey data, should be intensively mapped to establish the extent of these "hot spots."

Research

Coral information can be collected ancillary to other survey and monitoring activities, however it is difficult for non-specialists on these surveys to provide specific identifications. Collaborations with systematics experts at museums through a pilot project in the NWFSC's Genetics and Evolution Program to develop molecular methods for the rapid identification of Pacific coast corals are already in place. The development of this capability will provide for species-level identification of corals and potentially other difficult to identify structure-forming invertebrates from the region's ongoing trawl surveys and observer program and will provide validations of identifications during targeted deep coral surveys.

Deep corals are vulnerable to a variety of activities including oil and gas exploration and fishing; however, little is known about the potential recovery rates of these species. There are a variety of ways to monitor recovery. For instance, age and growth information can be obtained through a combination of biochemical studies, ^{14}C and other radiometric dating, stable oxygen isotope data from the corals themselves and other biochemical analyses. In addition to basic age information, it should be possible to associate growth stages of corals to environmental change. Working with biochemists at collaborating academic institutions, the physiological potential for recovery of deep corals via geochemical and biochemical analyses of age and growth as well as growth potential can be investigated.

Other gaps in information result from the fact that few targeted surveys have been conducted in the region. Nearly thirty species of stylasterid corals have been observed in waters off Alaska including the Aleutian Islands coral gardens and parts of the Bering Sea and Gulf of Alaska (Stone and Shotwell, Chapter 2). In contrast, only five species of stylasterids have been observed in the Oregon Province with an additional two species found off British Columbia (Appendix 3.1, Jamieson et al. 2006). This may be a result of sampling bias; nonetheless, more focus needs to be given to the shallower depths where these taxa are commonly found. Also, reef-building scleractinians (e.g., *Lophelia pertusa*) while common in the San Diego Province do not form expansive reefs like those in the north Atlantic. While ocean chemistry may be a factor (see Guinotte et al. 2006; Orr et al. 2005), it's clear, especially with the recent discovery of a *Lophelia* mound in the Olympic Coast NMS that more attention needs to be given to these taxa.

Although more research on deep coral communities is needed, data mining opportunities do exist. Since the late 1980s, underwater vehicles and camera sleds have been used to survey the benthic environment off the Pacific coast. A product of these surveys is hours upon hours of video data. Review of these videos, while time-consuming, may provide additional observations of deep corals and insights into their ecology (see Strom 2006). A great example of rescuing existing data from past visual surveys of deep corals and other structure-forming invertebrates is a longterm and productive collaboration among fishery biologists at the SWFSC and invertebrate ecologists at Washington State University. This collaboration has resulted in a georeferenced database on the distribution and abundance of deep corals and associated fishes and habitats off California, as well as providing the informational basis for evaluating deep corals as EFH for demersal fishes.

Summary of research priorities:

- Quantify and describe the nature of associations of deep corals with other structure-forming invertebrates and demersal fishes.
- Timely identification of coral specimens collected during region trawl surveys and by fisheries observers.
- Investigate recovery rates of corals and their habitats from a variety of stressors, particularly fishing.
- Focus more survey effort in shallow rocky habitats where corals may be more susceptible to coastal activities.
- Data mining of video records from numerous submersible and ROV surveys of rocky features throughout the region to identify deep corals and any significant habitat and species associations.

IX. CONCLUSION

The Pacific coast from California to Washington hosts a considerable amount of deep coral habitat. Significant coral communities have been discovered at Davidson Seamount (DeVogelaere 2005), in Monterey Canyon, at Cordell Bank (Pirtle 2005), in the Olympic Coast NMS (Brancato et al. 2007) and on numerous rocky banks off southern California (Love et al. 2007; Tissot et al. 2006; Yoklavich and Love 2005), including the recently discovered Christmas tree coral, *Antipathes dendrochristos* (Opresko 2005). Pennatulaceans, black corals and gorgonians have also been recorded coast wide in the catch of bottom trawl surveys and by fishery observers. For the most part, corals in the region do not build reefs with observations of only two reef-building stony corals - *Lophelia pertusa* and *Madrepora oculata* in the San Diego Province and *L. pertusa* in the Olympic Coast NMS. Although associations of corals with other invertebrates and fishes have been reported, there is no direct evidence that any of these represent obligate relationships between taxa. More targeted studies are needed to further investigate and quantify these relationships.

Much of the recent information on the regional zoogeography of higher-level coral taxa was collected during bottom trawl surveys. Some of these surveys are ongoing and will provide continued mapping information within the limitations of the collection methods on these species. More detailed information, but in a limited geographic scope, has been collected using submersibles, remotely operated vehicles (ROVs) and more recently, autonomous underwater vehicles (AUVs); however, these surveys most often focus on demersal fishes, though usually in areas where deep corals are found. Unlike trawl surveys, these *in situ* photographic surveys can provide information on the relationships between deep corals, other invertebrates and demersal fishes. *In situ* photographic surveys provide localized mapping of deep coral habitats but are seldom conducted on a repeated basis, and therefore do not provide routine monitoring of these sites. Additional information on the distribution of corals as well as monitoring fishing impacts can be gleaned from information collected by fisheries observers. Observers currently collect this information on an ongoing basis.

Unique attributes of the region that may influence coral distributions include a narrow continental shelf, coastal upwelling and a large latitudinal extent encompassing two distinct zoogeographic provinces. Unlike the eastern coast of the U.S., the Pacific coast is part of an active continental margin, with both prolonged (e.g., subduction) and episodic (e.g., turbidity currents) events that both shape and impact deep coral habitats. However, the most significant and immediate threat to coral habitats in the region is commercial fishing, namely widespread use of bottom trawls to target demersal fishes. Direct evidence of fishing impacts to corals has been reported by fishery observers. Additional evidence of fishery interactions with the seafloor (e.g., trawl marks in sediments, derelict gear) in the vicinity of corals also is provided from *in situ* photographic surveys, such as those conducted recently in the Olympic Coast NMS (Hyland et al. 2004; Brancato et al. 2007). With recent fishery management measures (e.g., area closures, gear restrictions), however, the risk posed by bottom trawling has been significantly reduced. Although conservation areas encompass many known coral habitats coastwide, recent discoveries of diverse coral communities outside of conservation areas (e.g., in the Olympic Coast NMS) warrant further consideration of protection.

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Appendix 3.1. Taxonomic list of known species of deep corals off the U.S. Pacific Coast, California to Washington. List includes both confirmed taxonomic records and some unconfirmed records of genera identified from surveys using bottom trawls and underwater vehicles. These unconfirmed records are denoted by the genus name followed by the word "species" (abbreviated as "sp"). Occurrence in two zoogeographic provinces (San Diego and Oregon) is noted. Known depth distributions are noted and originate from taxonomic records, published papers, and National Marine Fisheries Service (NMFS) bottom trawl surveys. Other abbreviations include the Olympic Coast (OCNMS) and Monterey Bay (MBNMS) National Marine Sanctuaries.

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
Phylum Cnidaria					
Class Anthozoa					
Subclass Hexacorallia					
Order Scleractinia					
Family Fungiacyathidae	*Fungiacyathus marenzelleri* Vaughan, 1906	x	x		Cairns (1994)
Family Micrabaciidae	*Leptopenus discus* Moseley, 1881		x		Cairns (1994)
Family Rhizangiidae	*Astrangia haimei* Verrill, 1866	x	x	1-53	Cairns (1994)
Family Oculinidae	*Oculina profunda* Cairns, 1991		x	119 -578	Cairns (1994)
	Madrepora oculata Linnaeus, 1758	x		84	Cairns (1994), Etnoyer and Morgan (2003)
Family Caryophylliidae	*Caryophyllia arnoldi* Vaughan, 1900	x	x	183 - 505	Cairns (1994)
	Labyrinthocyathus quaylei Durham, 1947	x	x	37 - 293	Cairns (1994)
	Crispatotrochus foxi Durham and Barnard, 1952	x		82	Cairns (1994)
	Paracyathus stearnsii Verrill, 1869	x	x		Cairns (1994)
	Paracyathus montereyensis Durham, 1947		x	75 - 146	Cairns (1994)
	Coenocyathus bowersi Vaughan, 1906	x	x	9 - 302	Cairns (1994), NMFS
	Nomlandia californica Durham and Barnard, 1952	x		82	Cairns (1994)
	Desmophyllum dianthus (Esper, 1794)	x	x		Cairns (1994)
	Lophelia pertusa (Linnaeus, 1758)	x	x		Cairns (1994), Etnoyer and Morgan (2003), OCNMS, unpublished data
Family Flabellidae	*Javania californica* Cairns, 1994		x	62 - 170	Cairns (1994)
	Polymyces montereyensis (Durham, 1947)	x	x	69 - 212	Cairns (1994), NMFS
Family Dendrophylliidae	*Balanophyllia elegans* Verrill, 1864	x	x		Cairns (1994), Pirtle (2005)
	Dendrophyllia oldroydae Oldroyd, 1924	x		99 - 366	Cairns (1994)

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
Order Antipatharia					
Family Antipathidae	*Antipathes dendrochristos* Opresko, 2005	x		90 - 360	Tissot et al. (2006)
	Antipathes sp.	x	x	82 - 1162	NMFS, Etnoyer and Morgan (2003), MBNMS, unpublished data
Family Cladopathidae	*Chrysopathes formosa* Opresko, 2003	x			Opresko (2003)
	Chrysopathes speciosa Opresko, 2003		x	296 - 1400	Opresko (2003), NMFS
	Trissopathes pseudotristicha Opresko, 2003	x	x		Opresko (2003), MBNMS, unpublished data
Family Schizopathidae	*Bathypathes* sp.	x	x	136 - 1243	NMFS, Etnoyer and Morgan (2003), MBNMS, unpublished data
	Lillipathes sp.		x	531 - 1243	NMFS, MBNMS, unpublished data
	Umbellapathes sp.		x		MBNMS, unpublished data
Subclass Octocorallia					
Order Gorgonacea					
Family Acanthogorgidae	*Acanthogorgia* sp.		x		MBNMS, unpublished data
	Calcigorgia spiculifera Broch, 1935		x	1127 - 1159	NMFS
Family Anthothelidae	*Anthothela pacifica* (Kukenthal, 1913)	x	x		Austin (1985)
Family Chrysogorgiidae	*Chrysogorgia* sp.		x		MBNMS, unpublished data
	Radiceps sp.		x		Austin (1985)
Family Coralliidae	*Corallium* sp.		x	1357 - 2447	MBNMS, unpublished data, OCNMS, unpublished data
Family Gorgoniidae	*Adelogorgia phyllosclera* Bayer, 1958	x	x		Montagne and Cadien (2001)
	Eugorgia rubens Verrill, 1868	x			Montagne and Cadien (2001)
	Heterogorgia tortuosa Verrill, 1868	x			Montagne and Cadien (2001)
	Leptogorgia caryi Verrill, 1868	x	x	129 - 1200	Cairns et al. (2002), NMFS
	Leptogorgia chilensis Verrill, 1868	x	x	86 - 710	Cairns et al. (2002), NMFS, OCNMS
	Stenogorgia kofoidi Nutting, 1909		x		Austin (1985)
Family Isididae	*Acanella* sp.		x		MBNMS, unpublished data
	Isidella sp.	x	x	808 - 1165	NMFS, Etnoyer and Morgan (2003), MBNMS, unpublished data

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
	Keratoisis flabellum Nutting, 1908		x		Etnoyer and Morgan (2003)
	Keratoisis philippinensis Wright and Studer, 1910		x		Etnoyer and Morgan (2003)
	Keratoisis sp.	x	x	516 - 1707	NMFS, Etnoyer and Morgan (2003), MBNMS, unpublished data
	Lepidisis sp.	x			Etnoyer and Morgan (2003), MBNMS, unpublished data
Family Muriceidae	*Muricea californica* Aurivillius, 1931	x			Grigg (1970)
	Muricea fruticosa Verrill, 1869	x			Grigg (1970)
	Thesea sp. A	x			Ljubenkov (1986), Montagne and Cadien (2001)
	Thesea sp. B	x			Ljubenkov (1986), Montagne and Cadien (2001)
Family Paragorgiidae	*Paragorgia arborea* (Linnaeus, 1758)		x	185 - 1743	Etnoyer and Morgan (2003), MBNMS, unpublished data, OCNMS, unpublished data
	Paragorgia sp.	x	x		Etnoyer and Morgan (2003)
Family Plexauridae	*Swiftia spauldingi* (Nutting, 1909)	x	x		Austin (1985)
	Swiftia beringi Nutting, 1912		x		OCNMS, unpublished data
	Swiftia kofoidi (Nutting, 1909)	x	x		Austin (1985)
	Swiftia pacifica (Nutting, 1912)		x	78 - 1186	NMFS, OCNMS, unpublished data
	Swiftia simplex (Nutting, 1909)	x	x	62 - 1075	Austin (1985), NMFS
	Swiftia torreyi (Nutting, 1909)	x	x		Austin (1985)
Family Primnoidae	*Amphilaphis* sp.	x		114 - 114	NMFS
	Callogorgia kinoshitae Kukenthal, 1913	x	x	127 - 464	NMFS, Etnoyer and Morgan (2003)
	Calyptrophora sp.		x		Carey et al. (1990)
	Narella sp. cf. *bowersi* Nutting, 1908		x		Carey et al. (1990)
	Parastenella doederleini Wright and Studer, 1889	x	x		Etnoyer and Morgan (2003)
	Parastenella sp.		x		Etnoyer and Morgan (2003)
	Plumarella longispina Kinoshita, 1908		x		Etnoyer and Morgan (2003)
	Primnoa pacifica Kinoshita, 1907	x	x		OCNMS, unpublished data

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
	Thouarella sp.		x		Etnoyer and Morgan (2003)
Order Alcyonacea					
Family Alcyoniidae	*Alcyonium rudyi* Verseveldt and van Ofwegen, 1992		x		Cairns et al. (2002)
	Anthomastus ritteri Nutting, 1909	x	x	293 - 972	NMFS
Family Clavulariidae	*Cryptophyton goddarti* Williams, 2000		x		Cairns et al. (2002)
	Clavularia sp. A		x		Austin (1985)
	Clavularia sp. H	x			Hochberg (1978), Montagne and Cadien (2001)
	Telestula ambigua Nutting, 1909		x		Austin (1985)
	Telesto sp.	x			Montagne and Cadien (2001)
Family Nephtheidae	*Gersemia rubiformis* (Ehrenberg, 1834)		x		Austin (1985)
Order Pennatulacea					
Suborder Sessiliflorae					
Family Renillidae	*Renilla koellikeri* Pfeffer, 1886	x			Montagne and Cadien (2001)
	Renilla reniformis (Pallas, 1766)	x		intertidal	Berntson et al. (2001)
Family Kophobelemnidae	*Kophobelemnon affine* Studer, 1894		x		Hochberg and Ljubenkov (1998)
	Kophobelemnon biflorum Pasternak, 1960		x		Austin (1985)
	Kophobelemnon hispidum Nutting, 1912		x		Austin (1985)
Family Anthoptilidae	*Anthoptilum grandiflorum* (Verrill, 1879)	x	x	103 - 1543	Hochberg and Ljubenkov (1998), NMFS
	Anthoptilum murrayi Kolliker, 1880	x	x	516 - 1083	NMFS
Family Funiculinidae	*Funiculina parkeri* Kukenthal, 1913	x	x		Hochberg and Ljubenkov (1998)
Family Protoptilidae	*Distichoptilum gracile* Verrill, 1882		x		Hochberg and Ljubenkov (1998)
	Helicoptilum rigidum Nutting, 1912		x		Austin (1985)
Family Stachyptilidae	*Stachyptilum superbum* Studer, 1894	x	x		Montagne and Cadien (2001)
Family Scleroptilidae	*Scleroptilum* sp.		x		Austin (1985)
Family Umbellulidae	*Umbellula lindahli* Kolliker, 1874	x			Austin (1985)
	Umbellula magniflora		x		Hochberg and Ljubenkov (1998)
Family Halipteridae	*Halipteris californica* Moroff, 1902	x			Hochberg and Ljubenkov (1998)

Higher Taxon	Coral Taxa	San Diego	Oregon	Depth (m)	Source
	Halipteris sp.		x		
Suborder Subselliflorae					
Family Virgularidae	*Acanthoptilum album* Nutting, 1909	x	x		Hochberg and Ljubenkov (1998)
	Acanthoptilum gracile (Gabb, 1863)		x		Hochberg and Ljubenkov (1998)
	Stylatula elongata (Gabb, 1862)	x	x		Hochberg and Ljubenkov (1998)
	Stylatula gracilis Verrill, 1864	x	x	64 - 1243	Hochberg and Ljubenkov (1998), NMFS
	Stylatula sp. A	x			Ljubenkov (1991), Montagne and Cadien (2001)
	Virgularia agassizii Studer, 1894	x			Montagne and Cadien (2001)
	Virgularia californica Pfeffer, 1886	x			Montagne and Cadien (2001)
	Virgularia cystiferum (Nutting, 1909)	x	x		Austin (1985)
	Virgularia sp. cf *glacialis* Kolliker, 1870		x		Austin (1985)
Family Pennatulidae	*Pennatula californica* Kukenthal, 1913	x	x	465 - 991	Hochberg and Ljubenkov (1998), NMFS
	Ptilosarcus gurneyi (Gray, 1860)	x	x	11 - 922	Hochberg and Ljubenkov (1998), NMFS
	Ptilosarcus undulatus Verrill, 1865		x		Cairns et al. (2002)
Class Hydrozoa					
Order Anthoathecatae					
Suborder Filifera					
Family Stylasteridae	*Errinopora pourtalesii* (Dall, 1884)		x	49-183	Fisher (1938), Alberto Lindner, pers. comm.
	Stylantheca petrograpta (Fisher, 1938)		x	intertidal	Fisher (1938), Alberto Lindner, pers. comm.
	Stylantheca porphyra Fisher, 1931		x	intertidal	Fisher (1938), Alberto Lindner, pers. comm., Etnoyer and Morgan (2003)
	Stylaster californicus (Verrill, 1866)	x	x	35-90	Fisher (1938), Alberto Lindner, pers. comm., Etnoyer and Morgan (2003)
	Stylaster venustus (Verrill, 1868)		x	49-84	Fisher (1938), Alberto Lindner, pers. comm., Etnoyer and Morgan (2003)