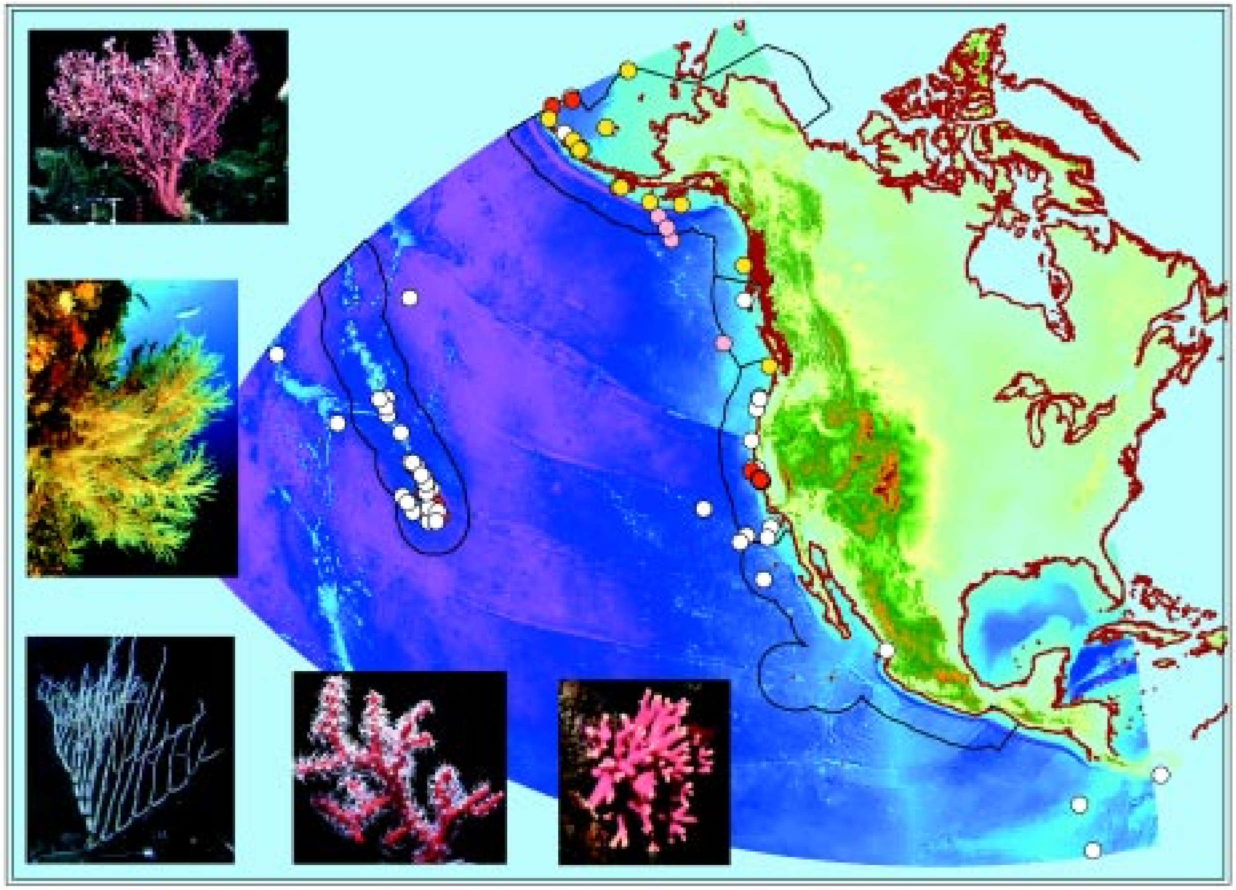

Occurrences of Habitat-forming Deep Sea Corals in the Northeast Pacific Ocean

A Report to NOAA's Office of Habitat Conservation

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MCBI MARINE CONSERVATION BIOLOGY Institute

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Occurrences of Habitat-forming Deep Sea Corals in the Northeast Pacific Ocean

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Abstract

Mid-nineteenth century naturalists once considered the abyssal seafloor a barren, lifeless plain akin to terrestrial deserts. However, in 1872, the H.M.S. Challenger began a four year expedition of the oceans, collecting specimens and revealing for the first time the extensive marine life found below 200 meters. Subsequent deep-sea exploration has discovered that life extends to the hadal depths of the oceans (greater than 10,000m), and that these profound waters are home to a diverse assemblage uniquely adapted to their extreme environment. Few people know of the vast extent of dep sea corals in temperate waters of the US when, in fact, these corals extend over a much greater area of the US exclusive economic zone than the much more familiar tropical coral reefs.

Habitat-forming deep-sea corals, octocorals, hexacorals, and hydrocorals in the Phylum Cnidaria, are defined as those families with a majority of species exhibiting a complex branching morphology and sufficient size to provide substrate or refuge to associated species. We gathered a total of 2,649 records (name, geoposition, depth, and data quality) from 10 institutions on 8 habitat-forming deep-sea coral families, including octocorals in the families Corallidae, Isididae, Paragorgiidae and Primnoidae, hexacorals in the families Antipathidae, Oculinidae and Caryophylliidae, and hydrocorals in the family Stylasteriidae. We use these records to investigate the range and distribution of these families in the Northeast Pacific Ocean and Bering Sea.

Acknowledgements

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Photo Credits:

Lophelia	Dr. Andre Friewald
Antipathes	F. Cardigo copyright ImgDOP
Corallidae	Glasgow University Zoology Museum
Isididae	Monterey Bay Aquarium Research Institute
Paragorgiidae	NOAA Office of Ocean Exploration , GOASEX
Primnoidae	F.E. Moen
Stylaster (2)	Phillip Colla Photography, Oceanlight, Carlsbad, CA
Lingcod/hydrocoral	V. O’Connell ADF&G

Background on Deep-Sea Corals

The term “coral” refers to a vast array of organisms that are found throughout the world’s seas from freezing polar regions to equatorial reefs, and at all depths from the intertidal zone to the bottoms of the deepest hadal trenches. The word “coral” is derived from the ancient Greek word “korallion,” which referred to the precious red coral of theMediterranean, known today as *Corallium rubrum* (Linaeus 1758). Coral is a loosely defined paraphyletic assemblage of organisms belonging to the phylum Cnidaria. All corals are cnidarians, but some are more closely related to other coelenterates than to other “corals”. For example, hydrocorals are more closely related to hydroids than they are to other corals, while hexacorals include sea anemones and stony-corals.

In this report, we use the term deep-sea coral to refer to the families of hexacorals, octocorals, and hydrocorals we know to exist beyond the traditional tropical boundaries commonly attributed to zooxanthellate shallow water tropical scleractinian corals. Cold water corals are also commonly referred to as deep-sea corals, even though some of these species are found in waters shallower than 200 meters. Similarly, deep-sea corals can be found in tropical waters, and this term is intended to reflect their latitudinal range rather than their habitat requirements.

Corals have a long fossil record dating back 450-500 million years to the Ordovician Period of the Paleozoic Era. Three groups of early corals- the heterocorals, the tabulate corals, and the rugose corals- were extinct by the end of the Paleozoic. Three other groups of corals, which developed during the Mesozoic and Cenozoic Eras, survive to the present day; the hydrocorals, hexacorals, and octocorals. All three of these types inhabit the Northeastern Pacific Ocean, and are documented in this report.

Following is a brief summary of those families of hexacorals, octocorals and hydrocorals considered to form complex bottom habitat for associated species in the Northeast Pacific Ocean. This appendix borrows form and content from a report on North Atlantic deep-sea corals by H. Breeze and M. Butler of the Ecology Action Center, and D. S. Davis of the Nova Scotia Museum of Natural History, but the list has been updated with facts relevant to the North Pacific.

Class Anthozoa

Members of the class Anthozoa (corals and sea anemones) are exclusively polypoid, having lost the medusoid stage, while most hydrozoans retain both polypoid and medusoid stages in their life cycles.

Subclass Zoantharia = Hexacorallia

Order Scleractinia "stony or hard corals"

These are the stony or hard corals and the species most often associated with the living coral reef. Hard corals have massive calcium carbonate skeletons with relatively large polyps (> 5mm in diameter), each containing internal radiating ribs called septa. Two families are known as deep-water structure-forming taxa in the Northeastern Pacific, the Caryophylliidae, represented by the genera *Lophelia*, and the Oculinidae, represented by the genera *Madrepora*, but there are many other non-structure forming scleractinians in the Northeastern Pacific.

Family Caryophylliidae

Lophelia pertusa (Linnaeus 1758) occurs throughout the North Atlantic, and has been well mapped by the British Geological Survey, in response to threats from bottom trawling. This is a highly branched, massive coral that occurs in large colonies on flat bottoms. These colonies are called bioherms. Bioherms are recorded with heights over 2m covering an area greater than 1500m (5000 ft) (Wilson 1979). The species occurs at suitable depths throughout the North Atlantic, and in the southern hemisphere, with very few records in the Northeast Pacific.

Family Oculinidae

This is a small family with only one genus *Madrepora* known from the Northeastern Pacific. At certain places along the Atlantic coast of North America, unique banks of *Oculina* are found that occur nowhere else on Earth. Two species of *Oculina* exist along the Atlantic coast and each inhabits a very restricted range. *Oculina arbuscula* is found off of Cape Hatteras in North Carolina while the ivory tree coral, *Oculina varicosa* (Lesueur 1821) is found on offshore banks and can form pinnacles of up to 30 m (100 ft) tall, growing below the Gulf Stream at depths of 60-90 m (200 to 300 ft). Like their shallow coral reef cousins, the reefs are critical habitat for a wide diversity of fish and invertebrates. Several species of snapper and grouper live and spawn on these reefs.

Order Antipatharia

Family Antipathidae

Antipatharians, or "black corals" are tree-like or stick-like cnidarians with a solid dark brown skeleton decorated with small spines or knobs. Colonies occur along current-swept drop-offs and under ledges. Live colonies may be rusty brown, orange, yellow, green, or white due to color of the polyps. They may also fluoresce. Several species are listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Appendix II (i.e., not threatened with extinction, but may become so without trade restrictions).

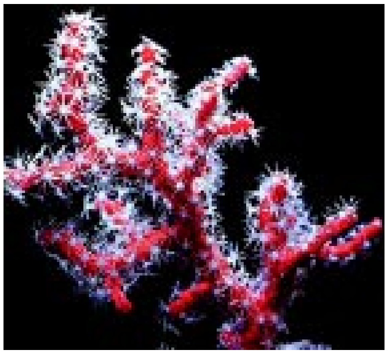
Two species of precious black coral are found at scuba diving depths in Hawaii. The largest of such trees in Hawaii reach about 6 feet tall, averaging 2 inches of growth per year. Both were collected extensively for the jewelry trade; a few large colonies may be still found in remote locations. Both are very similar to the untrained observer. *Antipathes dichotoma* (Pallas 1766) is more common, found as shallow as 4 m (15 feet). The stiff, vertically pointing branches may be as little as 0.6mm in diameter. *Antipathes grandis* (Verrill) was harvested extensively for the jewelry trade and is rare today. It normally occurs in water deeper than 45 m (150 feet). It has flexible branches as thin as 0.3mm in diameter, and 12 polyps per cm. Some rare fishes are associated with *Antipathes,* including the longnose hawkfish (G. Stender 2003).

Subclass Alcyonaria = Octocorallia

This group is comprised of the gorgonians and relatives, the soft corals, sea fans, sea whips and sea pens. All octocorals are easily identified by the eight feather–like (pinnate) tentacles that surround the mouth of each polyp. Soft corals are important members of deep Pacific benthic communities; their abundance, diversity and biomass rivals or exceeds that of the hard corals in some regions. Octocoral skeletons don't form reef structures like some stony corals, although octocorals can have calcareous internal skeletons (sclerites). In addition to sclerites, the gorgonians also have internal axes composed of horn and/or calcium carbonate. The axis is always smooth, never horny as in black corals. The flexible internal skeleton of sea fans and sea whips allow them to bend and sway in the currents and bottom surges like the branches of a tree in gusty winds.

Order Gorgonacea "Gorgonians"

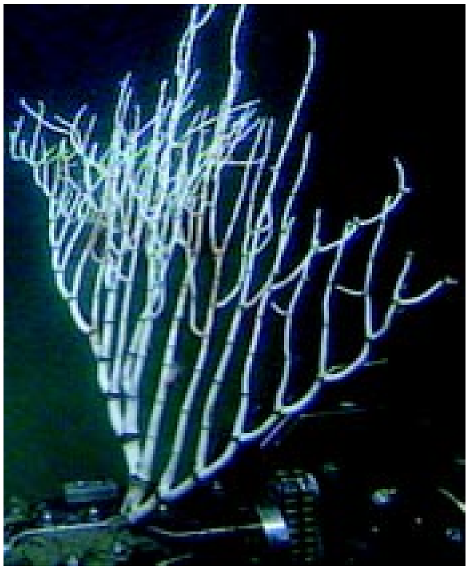
Family Corallidae



Also known as red coral or pink coral. These colonies are generally less than 0.3 m (12 in) with a loosely spaced, rigid branching morphology. In the Gulf of Alaska colonies of *Corallium* were found attached to small rocks of low relief.

These corals are prized in Japan for their decorative quality, and known to herbalists for their medicinal qualities. In Japanese traditional medicine, *Corallium rubrum* is thought to alleviate symptoms of bronchitis, tuberculosis, and gonorrhea.

Family Isididae



The bamboo corals are a species rich family within the octocorals. They have eight pinnate tentacles on each polyp that can be either retractile or non-retractile. The bony calcareous structures (internodes) are interspersed with proteinaceous gorgonin (nodes). This structure gives the skeletal remains of the organism an eerie fingerlike appearance.

Lepidisis colonies are unbranched, like sea whips, but they have an axis of proteinaceous nodes and calcareous internodes. *Lepidisis* is the only documented unbranched genus in the family Keratoisidinae. The are three unbranched genera. In *Keratoisis,* the branches arise from the nodes. In *Isidella,* the branches arise from the internodes, and the colonies are flat and spreading like candelabra. In *Acanella,* the branches also arise from the internodes, but the colonies are bushy, and branch in whorls.

Family Paragorgiidae

Paragorgia arborea (Linnaeus 1758) is a large and well known species that occurs in the North Atlantic and the North Pacific as well as the Southern Hemisphere. It is found off Greenland and in parts of the southern Grand Banks, Newfoundland. *Paragorgia* is found in submarine canyons off George's Bank between 200 and 900 meters and on seamounts in the Gulf of Alaska at similar depths. Large specimens exceeding 2.5 m (8 ft) have been reported. The GOASEX expedition recorded a specimen with a base of ~8cm harboring large numbers of individual galatheid crabs (pinchbugs), basket stars, and shrimps.

Family Primnoidae

Primnoa resedaeformis (Gunnerus 1763). This species occurs in the North Pacific and the North Atlantic. *Primnoa* is also well known to fishermen and trawlers from the Gulf of Maine. Dr. David Honeyman presented specimens of this and *Paragorgia arborea* to the Nova Scotian Institute of Science in 1880. Colonies are calcified and robust, and can grow to a height of one meter. They are often found attached to boulders between 100 and 500 m (330-1650 ft) (Deichmann, 1936).

Class Hydrozoa

Hydrocorals belong to the Class Hydrozoa. All other corals are anthozoans. Hydrocorals include both the stylasterine and milleporine corals. Stylasterine or lace corals include delicate colorful species belonging to the genera *Stylaster* and *Allopora*, both commonly found in the Pacific. All hydrocorals are characterized by a massive and relatively brittle calcium carbonate skeleton with numerous pinpoint - sized pores from which emanate two kinds of hydroid - like polyps, which are often finger-shaped with knob-like tentacles. The two kinds of polyps have a defensive function (dactylozoids) or a feeding function (gastrozooids).

Family Stylasteriidae

Stylasteriids are calcified and highly modified hydroids, occurring worldwide over a wide range of depth. Some stylasteriids resemble bryozoans and others colonial scleractinians, convergences that have caused confusion in recent and ancient faunas, and may also have limited our knowledge of their geological record. *Stylaster californicus* is an indicator of the strong currents. This species has low relief, but supports a number of associated species. It is common throughout the Channel Islands in California. Its presence in the deep-sea (depths >200m - 660ft) is documented in only a few cases.

Introduction

Deep-sea corals are a poorly known and poorly documented group of species that are becoming an increasing conservation concern because they are important habitat for commercially important fishes, as well as a wide variety of marine life. On the East Coast of the United States deep-sea corals occur from north of Georges Bank (*Paragorgia arborea)* to the mid-latitudes off of Florida (*Oculina*) (George 2002). Deep-sea coral records in Alaska and California date to the late 19th century (Dall 1884), but contemporary concerns about commercial fishery sustainability and the benthic impacts of commercial fishing gear have renewed interest in habitat forming deep-sea corals and areas of occurrence. In 1996, the United States Congress revised the Magnuson-Stevens Fishery Conservation and Management Act to include new habitat conservation provisions for U.S. marine fisheries. One candidate for a habitat area of particular concern (HAPC) under these provisions is "coral". The *Oculina* Banks off Florida were destroyed by trawling over 25 years ago and are now designated as a Habitat Area of Particular Concern. These banks are important habitats and spawning areas for commercially important snappers and groupers. Proposals for similar HAPC designations are being developed for corals in the north Pacific.

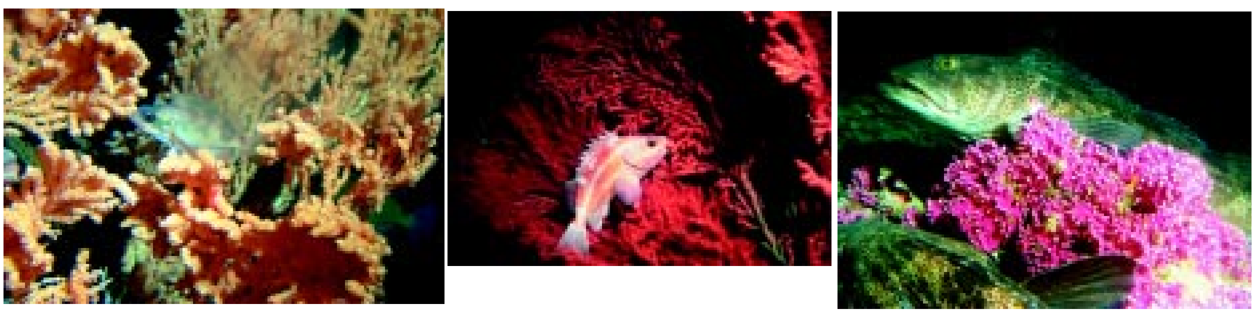


Figure 1. Juvenile rockfish in red-tree corals (*Primnoa* sp.) off southeast Alaska. Lingcod associated with hydrocal (*Stylaster* sp.). Photo credit V. O'Connell ADF&G.

In the tropics, reef fish species richness is less associated with coral species richness than it is with "rugosity", a measure of three dimensional complexity (Connell and Jones 1991, Friedlander 1998). Complex habitats, such as seagrass beds and branching corals, are known to provide more refuge to prey species than less rugose habitats (Figure 1). Risk (1972) stated for tropical coral reefs, "there exists a striking positive correlation between fish species diversity and degree of substrate topographic complexity." Complex habitats also provide more vertical relief, more surface area for settlement, and more microhabitat variability than simpler habitats. It is likely that the complex morphology of deep-sea corals similarly influence benthic communities in colder, deeper waters. Greater evidence of this relationship should result from increased exploration of these environments.

Deep-sea corals are known to occur on rocky habitats in deepwater (>200m) with strong water currents, similar to shallow-water gorgonians. These currents may facilitate settlement onto clean swept surfaces, or increase food availability and, therefore, growth rate and survivorship. Deepwater hard bottom biological communities of the California coast are commonly distinguished based on localized differences in relief height, although large-scale patterns are strongly influenced by depth and current regimes that influence productivity and sediment transport (e.g., Lissner and Benech 1993). Relief has been recognized for decades as a factor that influences the types of communities, although the origin of a relatively standardized definition appears to stem from early studies conducted for the Department of the Interior, Minerals Management Service (e.g., SAIC 1986). Changes in the species composition of seafloor communities are observed between areas with relief greater than 1m (3 ft) as compared to areas with less than 1 m relief. This distinction is not "razor" sharp, but 1m relief is a useful definition for habitat-forming species that has been applied to studies along the coast (e.g., Lissner 1989, Steinhauer and Imamura 1990, SAIC and MEC 1995).

A principal factor that appears to influence low- versus high-relief community differences is near-bottom sedimentation and particle loads. Many low-relief habitats can be subject to sediment encroachment and burial due to natural processes of sediment transport, and/or high near-bottom particle loads that can result in clogging and/or less effective filter/suspension feeding by many sessile species such as cnidarians and sponges (Lissner et al. 1991). In contrast, high-relief communities are relatively insulated from these factors and are often characterized by greater abundance, diversity, and size of many filter/suspension feeding organisms. Thus, low-relief habitats represent comparatively marginal habitat for some species as episodic events bury or uncover the substrate and associated organisms.

As summarized by Lissner and Benech (1993), high relief habitats are typified by suspension feeders including sponges, a variety of anemones (e.g., *Metridium*, *Amphianthus*, *Actinostola*, and *Stomphia*) and zooanthids, corals (e.g., *Lophelia*, *Paracyathus*, *Desmophyllum*, and *Caryophyllia*), crinoids (*Florometra*), basket stars (*Gorgonocephalus*), and bryozoans. Many of these species, especially sponges, are also larger in size since higher relief is a generally more stable habitat allowing longer term survival and growth than many lower relief habitats that are subject to sediment encroachment and high particle loads. In contrast, low-relief habitats are usually characterized by relatively short-lived, smaller organisms including many hydroids, bryozoans, cup corals, and other opportunistic "turf" species, representing a complex low-growing matt of numerous invertebrate phyla. Other distinctions are evident based on depth, often with larger sponges observed at greater depths, perhaps influenced by reduced sediment transport in lower current regimes.

The strong currents that deep sea corals prefer can make survival particularly difficult for smaller marine life, such as juvenile fish. Coral outcrops and "forests" are also important habitat for adult fishes, crustaceans, sea stars, sea anemones and sponges because they provide protection from these currents and from predators. Clusters of biodiversity around deep sea corals were recently documented by submersible craft in missions to the Gulf of Alaska and the Gulf of Maine. A wide variety of fishes rely on coral areas for food, protection, and a place to lay their eggs (e.g. Fig. 2). *In situ* evidence of habitat functions for deep-sea corals is currently limited to video and photographic observations (e.g. a egg case attached to a *Paragorgia*, crabs perched atop *Isidella*, snail fish resting in the polyps of *Isidella*).With current research expanding into the deep-sea more quantifiable results are forthcoming.

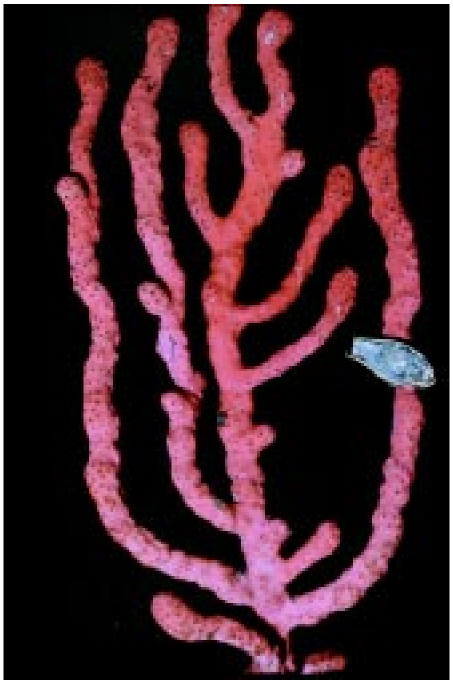


Fig 2. *Paragorgia* with an egg case attached, evidence of habitat function. Photo Credit: CAS.

Others findings suggest some commercially important fish species are found in association with these reefs, such as Atka mackerel, *Pleurogrammus monopterygius,* and shortspine thornyhead, *Sebastolobus alascanus,* in Alaska (Heifetz 2002). Krieger and Wing (2002) reported rockfish associated with *Primnoa* corals in the Gulf of Alaska. Fossa (2002) presented results at the *First International Symposium on Deep Sea Corals* indicating dense aggregation of *Sebastes sp.* associated with *Lophelia* corals off the coast of Norway. Elsewhere, Husebo et al. (2002) found that fish in coral habitats tended to be larger than in non-coral habitat.

Plans to commercially exploit precious coral beds in the Northwestern Hawaiian Islands recently raised concern about harmful impacts to endangered resident monk seal populations. In 1998, surveys withHawaii Undersea Research Laboratory (HURL) submersibles found coral beds at sites where seals fitted with satellite tags and dive recorders had repeatedly foraged in deep waters. One hypothesis is that colonies of deep sea corals tend to aggregate fish, and foraging monk seals may exploit this by frequently revisiting coral beds to improve their access to prey. This hypothesis is now being tested (Parrish 2001).

The most obvious threat to these complex habitats is the impact of commercial fishing activities. Bottom trawling is considered to be the most ecologically damaging method of fishing (Morgan and Chuenpagdee 2003), and is expanding globally especially to vulnerable seamounts (Roberts 2002). More than 5000 km^2 of the Northeast Pacific seabed is trawled more than once annually for Atka mackerel and other species (NRC 2002). Trawl nets and longline gear frequently remove coral trees from the rocks and boulders they grow upon. The benthic impacts of this mobile fishing gear is similar to clearcutting techniques in old growth forests (Watling and Norse 1998). Other anthropogenic activities, such as ocean dumping and seafloor mining also threaten deep-sea corals (Rogers 1999).

Based on limited knowledge of deep-sea corals and their growing conservation significance, the National Oceanic and Atmospheric Administration's, Office of Protected Resources commissioned Marine Conservation Biology Institute to document the known occurrences of habitat-forming deep-sea corals for the Northeast Pacific and the adjacent Bering Sea.

Methods

The goals of this project were to map occurrences of selected deep-sea corals suspected of being important formers of biogenic habitat, as well as to construct a database of the accumulated records that informed these maps. Our definition of deep-sea, habitat-forming coral includes hexacorallian, octocorallian, and hydrocorallian families with complex branching morphologies that grow large enough to provide substrate and/or shelter for associated species of fish and invertebrates. This definition excludes deep-sea scleractinian cup corals.

Our initial data gathering efforts focused on records of few well-documented species, e.g. *Paragorgia arborea and Primnoa resedaeformis,* in the Northeast Pacific. However, record reviews of database outputs from participating museums revealed that species-specific searching often resulted in record loss due to species name changes and spelling changes over time spans sometimes exceeding 100 years. For example, records from the Smithsonian Institution for the family Isididae revealed that the name *Ceratoisis* has been revised to *Keratoisis*. A database search for a single species name inevitably inadvertently excluded alternate spellings.

After consultation with Drs. Frederick Bayer and Stephen Cairns of the Smithsonian Institution, (leading taxonomic authorities on octocorals and deep-sea scleractinian corals respectively), it was suggested that searches should be conducted by family name rather than species name. This alleviated issues related to misspelling and synonymy, but also speeded search time, limited institutional effort, incorporated lesser-known species names with similar morphology and minimized the impacts of taxonomic misidentification at the species level. Drs. Bayer and Cairns identified 8 families as habitat-formers in the Northeast Pacific Ocean: hexacorals in the families Antipathidae, Oculinidae and Caryophylliidae; octocorals in the families Corallidae, Isididae, Paragorgiidae and Primnoidae; and hydrocorals in the family Stylasteriidae.

Based upon this list of families, we contacted all known deep-sea coral researchers through a series of networked contacts that resulted from the *First International Symposium on Deep-Sea Corals* held in Halifax, Canada, July 30- August 3, 2000. Of these contacts, a limited number maintained deep sea coral records, and of those, a further reduced number maintained geo-positional records and were willing or able to distribute these records due to staffing constraints or other institutional limitations. A total of 10 different organizations and institutions ultimately supplied range and distribution records, including the California Academy of Sciences (CAS), Canadian Museum of Nature and Department of Fisheries and Oceans (CMN-DFO), the Monterey Bay Aquarium Research Institute (MBARI), the National Museum of Natural History at the Smithsonian Institution (NMNH), National Oceanic and Atmospheric Administration (NOAA) Office of Ocean Exploration (NOAA-OE), the National Marine Fisheries Service RACEBASE (RACE), the Santa Barbara Museum of Natural History (SBMNH), the REEF Foundation (REEF), the Scripps Institution of Oceanography (SIO) and a study performed by the late Dr. Robert Cimberg for VTN Oregon (Cimberg). Contact lists are provided in appendices at the end of this report.

The record selection methodology varied only slightly between institutions. Generally, we selected only those records that included a field for taxonomic identification. RACE includes many records identified as "coral", but these were not included in this effort. Records from NOAA-OE do not represent the extent of that office's documentation of cold water corals. NOAA-OE records represent the results of a single expedition to the Gulf of Alaska.

Each database maintained different information, so all database records were subset to their common fields: latitude ("lat"), longitude ("lon"), family ("family"), species name ("sp_name"), and depth in meters ("depth"). Additional fields were added to these records in order to facilitate potential researcher follow up. These fields include an institution name ("inst") as abbreviated above, an institution specific identification number ("inst_id"), a coordinate's code ("coord_code"), and a rank ("rank").

"Coord_code" is a measure of accuracy for the latitude and longitude information. If a given record included coordinate information, it was assigned a value of 1, if that record included a place name only it was assigned the value of 2, and we assigned approximate coordinates to that place name. If a record lacked either of these qualities, or if the place name was too general (e.g. Alaska) it was dropped from the database. Most often these records were duplicated by other more specific records (e.g. Alaska, Aleutian Islands, Unimak Pass).

"Rank" is a relative measure of record quality based upon two factors: 1) whether a physical sample is associated with that record and 2) the identifiers level of expertise.

The ranking system is as such:

1 = sample collected, expert identification
2 = sample collected, non-expert identification
3 = no sample collected, expert identification
4 = no sample collected, non-expert identification

This ranking system is consistent with ongoing efforts at HURL, where a fleet of manned submersibles makes frequent deep water dives, but takes few samples, relying instead on video and photo identification. This ranking is also consistent with a need to conserve slow growing cold water coral resources, and to limit the impact of scientific collections to sustainable levels.

Results

The table below summarizes those records made available to this analysis. A total of 2649 records on 8 habitat-forming deep-sea coral families were gathered from 10 participating organizations in the United States and Canada. The National Marine Fisheries Service's RACEbase was the largest contributor with 1540 records on 5 families, followed by the Smithsonian Institution, the most comprehensive contributor, with 423 records in 7 of the 8 families. The Smithsonian is believed to have additional records in the family Stylasteriidae (unavailable at the time of this writing).

MBARI was a substantial contributor for a very specific locale, namely Monterey Bay, where "easy" access to deep water and remotely operated vehicles (ROVs) facilitates almost daily expeditions to the Monterey Canyon. Video archivists at MBARI meticulously document most of those species familiar to them. CAS also worked closely with this study to accommodate numerous data requests, and their high quality, very comprehensive information based on Gary Williams' identification was an important supplement to this study. Records from NOAA-OE are derived from the 2002 Gulf of Alaska Seamount expedition aboard the R/V Atlantis with the Alvin submersible. Though the NOAA-OE contribution was small in number, this remote expedition to seamounts in the Gulf documented several habitat-forming corals where none were known before, extending the known range of Isididae and Corallidae into the Gulf of Alaska.

Table 1. A total of 2649 records from 10 institutions on 8 habitat-forming deep-sea coral families contributed to the results from this report.

FamilyName	CAS	NMNH	SIO	SBMNH	NOAA-OE	CMN-DFO	MBARI	Cimberg	REEF	RACE	**Total**
Antipathidae	8	29			3		101			102	243
Oculinidae		2									2
Caryophylliidae		8	1	1							10
Corallidae		128			2						130
Isididae	17	60	5		4		237	2		19	344
Paragorgiidae	12	38			2	11	51	9		143	266
Primnoidae	53	158			5	15		73		1012	1316
Stylasteriidae	58								16	264	338
Total	148	423	6	1	16	26	389	84	16	1540	2649
Data rank	1			2		3			4		

Accessing institutional databases by family name resulted in a 13% increase in data records for Isididae across all institutions. For Paragorgiidae, searching by family increased CAS records from 6 to 18, and NMNH records from 16 to 39. *Primnoa* records increased from 1 record for *Primnoa willeyi* to 53 records for *Primnoa sp.*

A review of the taxonomic methods practiced by each of the participating institutions indicated that CAS, NMNH and SIO records ranked "1". CMN-DFO, NOAA-OE, and SBMNH ranked "2". Each of these institutions maintains physical samples associated with their records. MBARI and Cimberg's Report ranked "3", while REEF and RACE ranked "4", as these records failed to maintain a physical sample. RACE represents data gathered by fisheries observers with minimal training in taxonomic identification, and REEF records are gathered by volunteer scuba divers with a similar cursory training and background. As an example, in order to the identify octocorals to the species level, one often requires a scanning electron microscope (SEM) to identify sclerites in the preserved tissue. Thus, even a physical sample of a calcium carbonate skeleton may be insufficient to satisfy the highest level criterion.

The database documents 105 habitat forming deep sea coral species in the Northeast pacific. The species names associated with each family are detailed in Appendix 1. The family Primnoidae contains the greatest number of species in the Northeast Pacific according to the database, with 63 species names assigned to that family, compared to 14 species names for Isididae, 10 for Corallidae, 9 for Stylasteriidae, 4 for Paragorgiidae, 3 for Antipathidae, and one each for Caryophylliidae and Oculinidae. Maps are presented by family in Appendix 2, color coded by data rank. Database users may symbolize these records by species name, or any other field, using Geographic Information System (GIS) software.

Depth ranges for the families of interest are detailed in Table 2. Bamboo corals in the family Isididae have the deepest documented specimen from Scripps Institution at 3880 m (12,800 ft). Cimberg (1981) documents a specimen of *Keratoisis profunda* at 3532 m (11,650 ft) in the Aleutian Islands. Specimens of Primnoidae and Antipathidae are also documented at depth nearing 3000 m (10,000 ft). Paragorgiidae and Primnoidae have maximum depths of approximately 2000 m (6,600 ft). Each of these families is also represented by species records shallower than 220 m (660 ft), suggesting a wide vertical distribution. Alvin pilots and researchers aboard the GOASEX expedition consistently documented greater densities of deep sea corals at depths shallower than 700 m (2,300 ft), though there were exceptions to this rule, particularly for the Primnoidae (Etnoyer, *pers obs*.).

Table 2. Deep-sea coral families exhibit a range of species diversity and depth distributions. Bamboo corals (Isididae) are documented at the greatest depths. (In order of max depth recorded.)

	Species richness	Mean Depth	Min Depth	Max Depth
Isididae	**21**	-1262	-107	-3880
Antipathidae	**3**	-924	-9	-2957
Primnoidae	**63**	-324	-25.5	-2600
Corallidae	**8**	-539	-215	-2116
Paragorgiidae	**4**	-406	-19	-1925
Stylasteridae	**11**	-265	-79	-823
Oculinidae	**2**	-278	-40	-556
Caryophylliidae	**1**	-301	-115	-486

Discussion

The families Isididae, Paragorgiidae and Primnoidae all have ranges that encompass the greatest portion of Northeast Pacific from the Bering Sea south to the Equator and west to the Hawaiian Islands. Antipathidae appears equally ubiquitous, but is documented only as far south as Baja California. Families Corallidae, Caryophylliidae, and Stylasteriidae are not documented north of the Aleutian Islands chain. Upon review, the family list used in this study is likely a subset of those that satisfy the habitat forming criteria at this basin scale. Some genera in the families Zooanthidae, Gorgonidae, and Plexauridae should be considered for future study.

All families have records on one or more seamounts in the Gulf of Alaska, except Stylasteriidae which is best documented along the continental shelf, and Oculinidae and Caryophyllidae which are well documented in the Atlantic but poorly documented here. The depth ranges of these families include the shallowest maximum depths. *Stylaster californicus* of the family Stylasteriidae has a maximum recorded depth of 823m (2700 ft) (CAS). Several northeast Pacific seamounts reach above that depth, and may provide habitat for stylasteriids. Alternatively, stylasteriids may actually be restricted to the nearshore. They are widely distributed in nearshore habitats of California (Morgan, *pers. obs.)*, and most of the records reported here are from SCUBA surveys (REEF).

The southern extent of records along the mainland of North America for the family Stylasteriidae is the northern tip of Baja California. However since this family is present at lower latitudes in the Hawaiian Islands, its southern range limit along the North America margin might be an artifact of the geographic extent of our national databases. Similarly, the distribution map for Antipathidae suggests that any apparent geographic limit for deep-sea corals is most likely an artifact of sampling effort and expertise. *Antipathes sp.* is best documented in the islands of Hawaii, partly due to collaborations between scientists there and a manned submersible fishery (Grigg 1981). *Antipathes sp.* is likely to be present in seamounts off western Mexico at latitudes similar to those from Hawaii. Isididae, Paragorgiidae, and Primnoidae occur north and south of Pacific Mexico with an absence of records in Mexico, and west of Baja California.

Future data gathering might concentrate on building collaborations with Mexican benthic ecologists to test these southern range limits. This data gap could result from either a real lack of deep sea corals or, more likely, a lack of exploration and/or connections to researchers performing studies in these regions. Future submersible research might focus on the Islas Revillagigedo and the Mathematician Seamounts off the coast of western Mexico to better understand the southern extent of these deep-sea coral species in the Northeast Pacific. The volcanic origin of the Islas Revillagigedo and their proximity to the highly productive Gulf of California make these impressive seamounts prime candidates for thick coral forests.

In 2002, the R/V Atlantis and Alvin submersible conducted multi-beam bathymetric surveys of 7 seamounts in the Gulf of Alaska: Patton, Murray, Chirikof, Marchand, Campbell, Scott and Warwick Seamount (Fig. 3). The Alvin obtained physical samples of each of these deep-sea coral families from one or more of those seamounts, and those few data points represent a dramatic expansion of the known ranges of some of these families. GOASEX also documented the first occurrence of Corallidae north of the Hawaiian Islands.

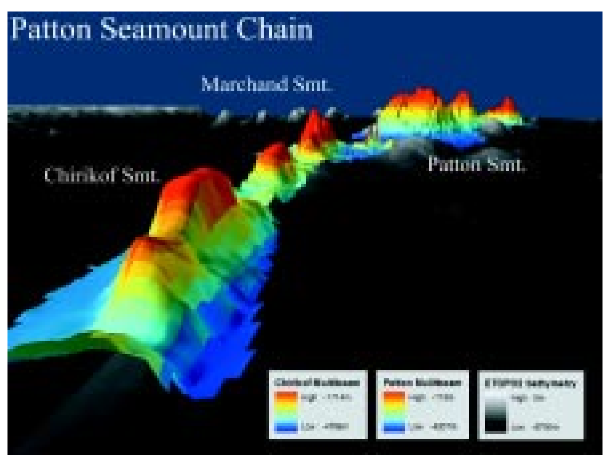


Fig. 3. Seamount "chains" consist of several peaks along a volcanic ridge, these seamounts are "home" to deep-sea corals.

It is important to note that this data ranking exercise is a relative one, and that a low data rank does not necessarily indicate poor quality. A low data rank in this case indicates that the researcher failed to preserve an intact sample, and that the researcher lacks scientific expertise in systematics. Neither of these conditions is surprising or rare. Research vessels may have limited human resources available, with few specialists dedicated to benthic invertebrates, limited quantities of ethanol preservative, and/or limited storage facilities. Also, the global number of researchers that can claim systematic expertise with deep-sea stony corals and gorgonians is less than a dozen (S. Cairns, *pers. comm*.). The number of researchers that may claim this expertise in the Northeast Pacific accounts for less than half that number.

The data ranking exercise suggests that the waters around Hawaii and Southern California have the largest numbers of high quality records. This is most likely due to the efforts of particular researchers in those regions to collect samples and submit them to the proper authorities for species level identification. However, Alaskan waters exhibit the greatest number of data points. This can be largely attributed to the RACEbase program, as evidenced by Table 1. The RACEbase program is the best candidate for data quality improvement in the near future. Capacity-building training in deep-sea coral systematics for these observers and record keepers should be a high priority.

Relatively little research has looked at deep-sea corals from a biogeographic standpoint. The 2002 seamount expedition by NOAA-Ocean Exploration to seamounts in the Gulf of Alaska (GOASEX) established additional Gulf of Alaska records for Isididae, extending the known range of the family there by 700 km. NOAA-OE records of Corallidae extended the known range of that family by more than 4000km to the north, a substantial increase in range from previous NMNH records.

The occurrences of the habitat-forming deep-sea coral families presented here suggest they have a large depth range throughout the Northeast Pacific. Dr. Bayer (*pers. comm.*) supports the conclusion that these families are widespread throughout their depth range (200-2000m) along the Pacific Rim. Too few data points and too little effort have been focused on seamounts in the Gulf of Alaska. Species occurrence appears directly related to sampling effort. Sampling effort in the Gulf of Alaska and the Bering Sea, however, is unfortunately defined as “bycatch” to the commercial bottom trawl industry. While some of these records represent first occurrences, most of these records are dated, and may represent deep sea coral forests that are no longer. With the expansion of trawl fleets into deeper waters and seamounts, deep-sea corals will be at greater risk in the future (Roberts 2002).

Studies suggesting deep-sea coral reefs may be decades to hundreds of years old further highlight the need for conservation. Retrospective analysis and isotope dating techniques for *Primnoa resdaeformis* suggest that a 5 cm diameter sample may be as old as 500 years (Risk et al. 1998). In another recent study conducted by Moss Landing Marine Laboratories, age and growth characteristics of *Primnoa resedeaformis* were described by counting growth rings in cross-sections of the coral skeleton. These estimates were validated using a radiometric aging technique. Andrews (2002) estimated growth rates of 1.74 cm per year in height, suggesting the largest limb studied took approximately 112 yrs to grow from its initial settlement to a total height of 197.5 cm (Andrews 2002).

At present there appears to be a great deal of variability in age estimates that likely reflects differences in the biology and ecology of the different corals, or laboratory methodologies. *In situ* measurements of corals belonging to 2 different orders, *Antipathes dichotoma* (Order: Antipatharia) and *Corallium secundum* (Order: Alcyonacea) yielded growth rates of 6.42 cm/yr and 0.9cm/yr, respectively (Grigg 1976), a 6 fold difference in growth rates under similar laboratory conditions. Andrew's (2002) study of *Primnoa resedeaformis* , 1.74 cm/yr, (Order: Alcyonacea) is more similar to the other Alcyonacea (*Corallium*) from Grigg's study (1976), suggesting variation in growth rate measurements might be due, in part, to different life histories.

Despite difficulties in documenting the age of deep-sea corals the importance of conserving coral communities cannot be overstressed. They are some of the world's most diverse deep-sea marine communities, representing banks of biological diversity and unique adaptations to life in extreme environments. Deep-sea corals are historical record keepers, and indicators of environmental stress such as pollution, sedimentation, and sea temperature fluctuations (Smith et al. 1997). Deep-sea corals are also sources of pharmaceutically important compounds such as prostaglandins and anti-cancer agents. Regardless of their research potential, however, these organisms perform important habitat functions for numerous associated species, and must be protected from fishing gears which destroy seafloor habitat (Watling and Norse 1998, Rogers 1999).

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Appendix 1: Scientific names associated with each family in this report.

CLASS HYDROZOA

ORDER STYLASTERINA

Family Stylasteriidae
Allopora
Allopora campyleca Fisher, 1938
Allopora petrograpta Fisher, 1938
Allopora porphyra Fisher, 1931
Distichopora
Errinopora pourtalesii Dall, 1885
Stylantheca porphyra Fisher, 1931
Stylaster
Stylaster californicus Verrill, 1866
Stylaster cancellatus Fisher, 1938
Stylaster venustus Verrill, 1868

CLASS ANTHOZOA

SUBCLASS HEXACORALLIA
ORDER ANTIPATHARIA

Family Antipathidae
Antipathes
Bathypathes
Parantipathes

SUBCLASS OCTOCORALLIA
ORDER GORGONACEA

Family Corallidae
Corallium regale
Corallium abyssale
Corallium ducale
Corallium imperiale
Corallium kishinouyei
Corallium laauense
Corallium niveum
Corallium regale
Corallium secundum
Corallium tortuosum

ORDER SCLERACTINIA

Family Caryophylliidae
Lophelia pertusa (*L. prolifera*)
Family Oculinidae
Madrepora oculata

SUBCLASS OCTOCORALLIA
ORDER GORGONACEA

Family Isididae
Acanella eburnea Pourtales
Acanella dispar Bayer, 1990
Ceratoisis flabellum Nutting, 1908
Isidella sp. 5
Keratoisis cf. *flabellum* Nutting
Keratoisis paucispinosa Wright & Studer
Keratoisis philippinensis Wright & Studer
Ceratoisis grandis Nutting, 1908
Isidella trichotoma Bayer, 1990
Isidella sp. 3
Keratoisis sp.
Lepidisis evelinaea Bayer, 1986
Lepidisis longiflora Verrill
Lepidisis olapa Muzik, 1978
Lepidisis sp.
Keratoisis profunda Wright

SUBCLASS OCTOCORALLIA

ORDER GORGONACEA

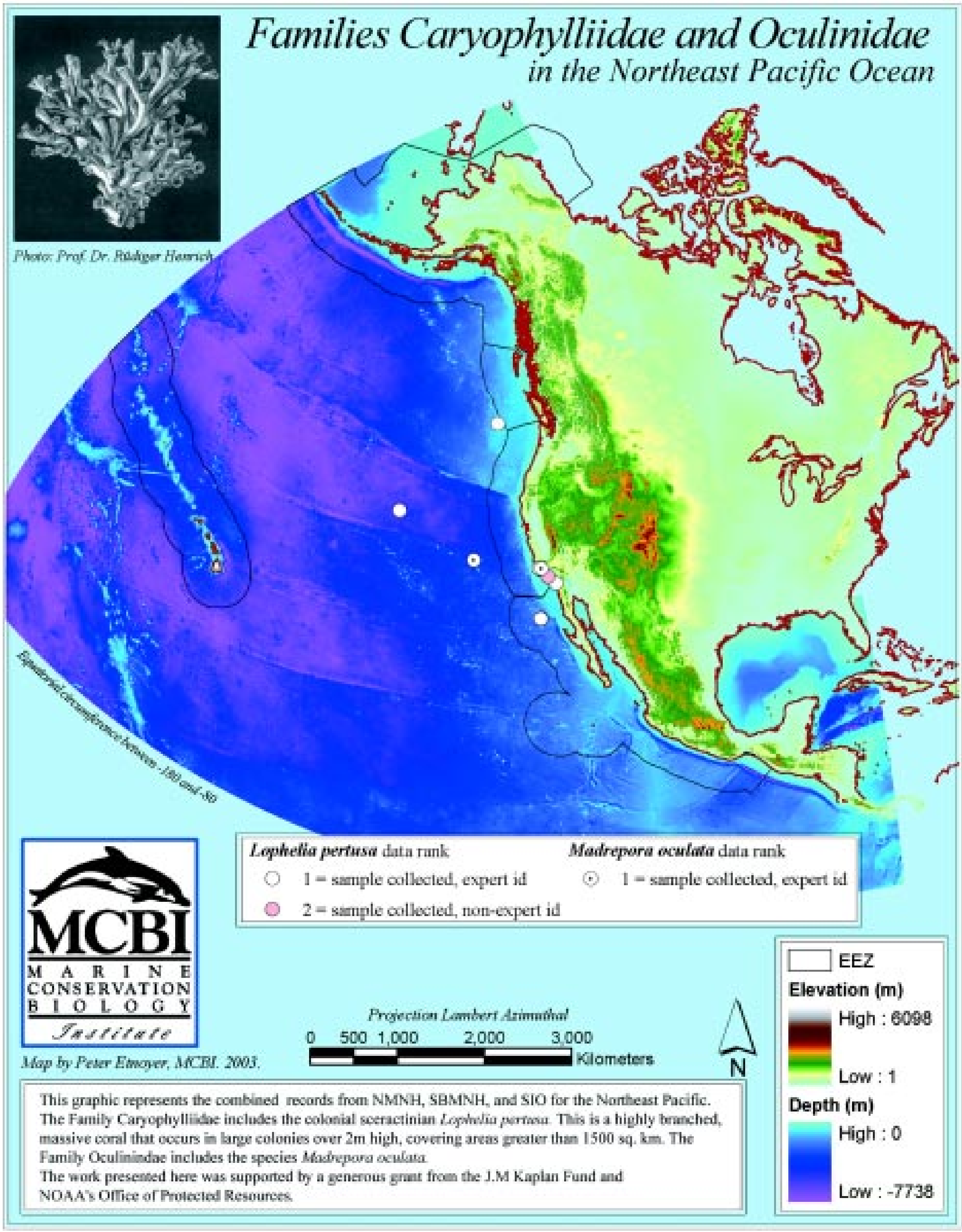
Family Paragorgiidae

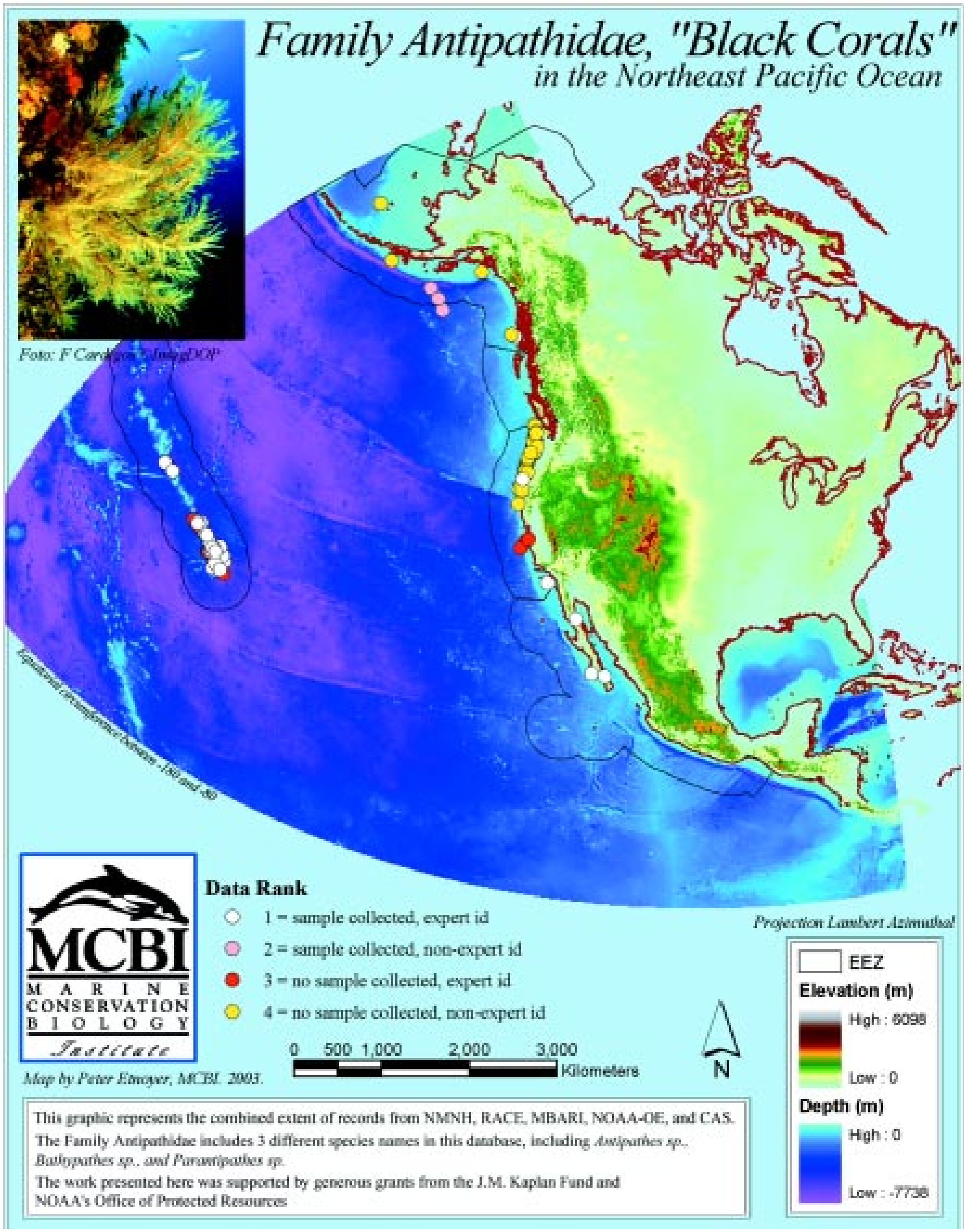
Paragorgia arborea Linnaeus, 1758
Paragorgia coralloides Bayer, 1993
Paragorgia dendroides Bayer, 1956
Paragorgia pacifica Verrill

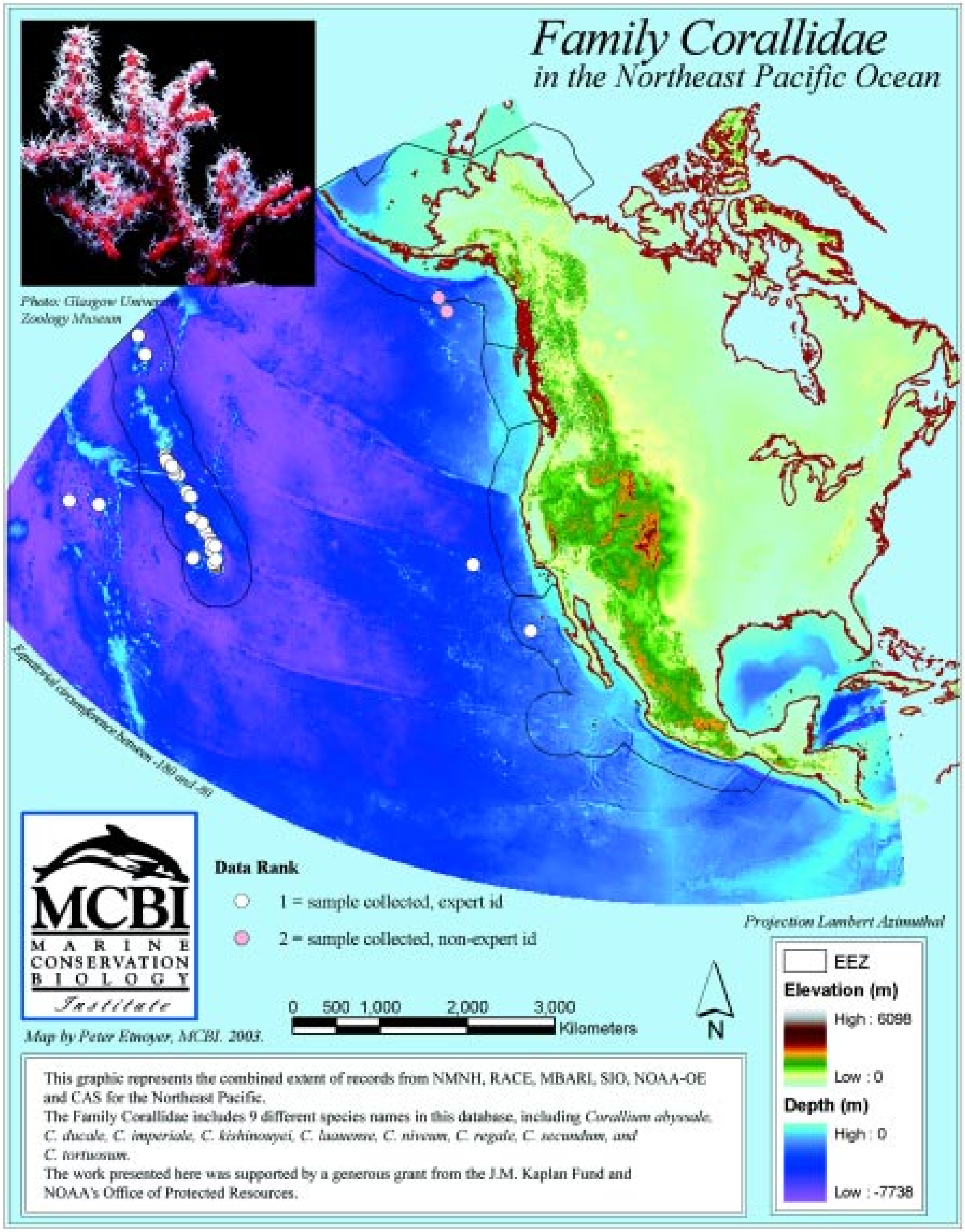
Family Primnoidae

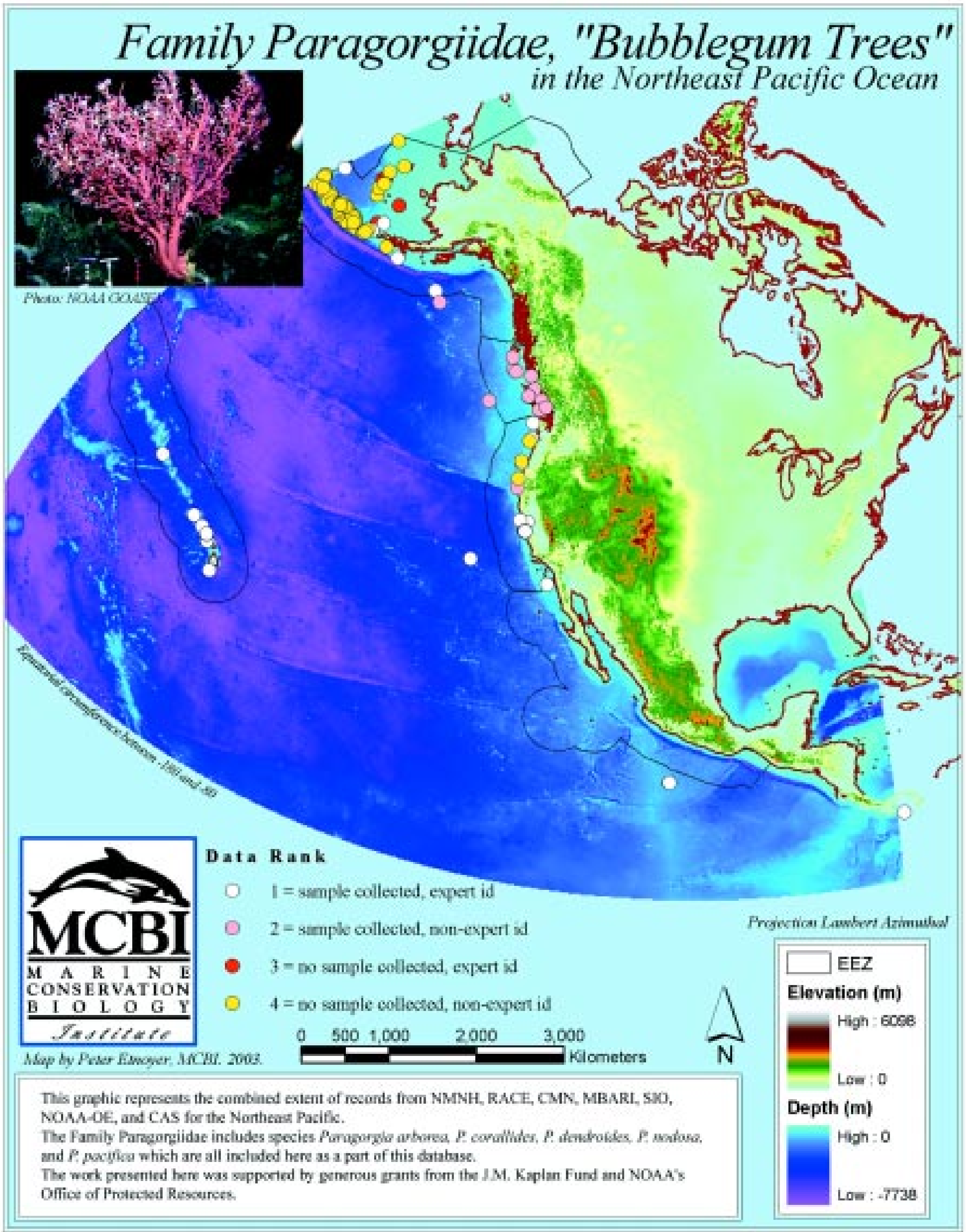
Amphilaphis biserialis
Amphilaphis
Amphilaphis sp. 1
Amphilaphis sp. 2
Amphilaphis sp. 3
Arthrogorgia sp.
Arthrogorgia utinomii
Caligorgia cristata
Caligorgia gilberti
Callogorgia
Callogorgia flabellum
Callogorgia formosa
Callogorgia gilberti
Callogorgia gracilis
Callogorgia kinoshitae
Calyptrophora angularis
Calyptrophora cf. versluysi
Calyptrophora versluyi
Calyptrophora wyvillei
Candidella
Candidella helminthophora
Fanellia compressa
Fanellia fraseri
Fanellia compressa
Fanellia euthyeia
Fanellia sp.
Fanellia tuberculata
Narella
Narella allmani
Narella ambigua
Narella bowersi
Narella dichotoma
Narella ornata
Narellai bayer
Paracalyptrophora
Paracalyptrophora kerberti
Parastenella
Parastenella doederleini
Plumarella
Plumarella flabellata
Plumarella longispina
Plumarella sp. 1
Primnoa
Primnoa reseda
Primnoa resedaeformis
Primnoa willeyi
Stachyodes bowersi
Stenella helminthophora
Thouarella
Parathouarella striata
Thouarella regularis

Appendix 2: Maps of range and distribution in the Northeast Pacific Ocean, by family




Family Antipathidae, "Black Corals"
in the Northeast Pacific Ocean
Data Rank
1 = sample collected, expert id
2 = sample collected, non-expert id
3 = no sample collected, expert id
4 = no sample collected, non-expert id
MCBI
MARINE CONSERVATION BIOLOGY Institute
Map by Peter Etnoyer, MCBI. 2003.
0 500 1,000 2,000 3,000
Kilometers
N
Projection Lambert Azimuthal
EEZ
Elevation (m)
High : 6098
Low : 0
Depth (m)
High : 0
Low : -7736
This graphic represents the combined extent of records from NMNH, RACE, MBARI, NOAA-OE, and CAS.
The Family Antipathidae includes 3 different species names in this database, including Antipathes sp., Bathypathes sp., and Parantipathes sp.
The work presented here was supported by generous grants from the J.M. Kaplan Fund and NOAA's Office of Protected Resources


Family Corallidae
in the Northeast Pacific Ocean
Photo: Glasgow University
Zoology Museum
Equatorial circumference between -180 and -90
Data Rank
1 = sample collected, expert id
2 = sample collected, non-expert id
MCBI
MARINE
CONSERVATION
BIOLOGY
Institute
Map by Peter Etnoyer, MCBI. 2003.
0 500 1,000 2,000 3,000
Kilometers
N
Projection Lambert Azimuthal
EEZ
Elevation (m)
High : 6098
Low : 0
Depth (m)
High : 0
Low : -7738
This graphic represents the combined extent of records from NMNH, RACE, MBARI, SIO, NOAA-OE and CAS for the Northeast Pacific.
The Family Corallidae includes 9 different species names in this database, including Corallium abyssale, C. ducale, C. imperiale, C. kishinouyei, C. lauuense, C. niveum, C. regale, C. secundum, and C. tortuosum.
The work presented here was supported by a generous grant from the J.M. Kaplan Fund and NOAA's Office of Protected Resources.


Family Paragorgiidae, "Bubblegum Trees"
in the Northeast Pacific Ocean
Data Rank
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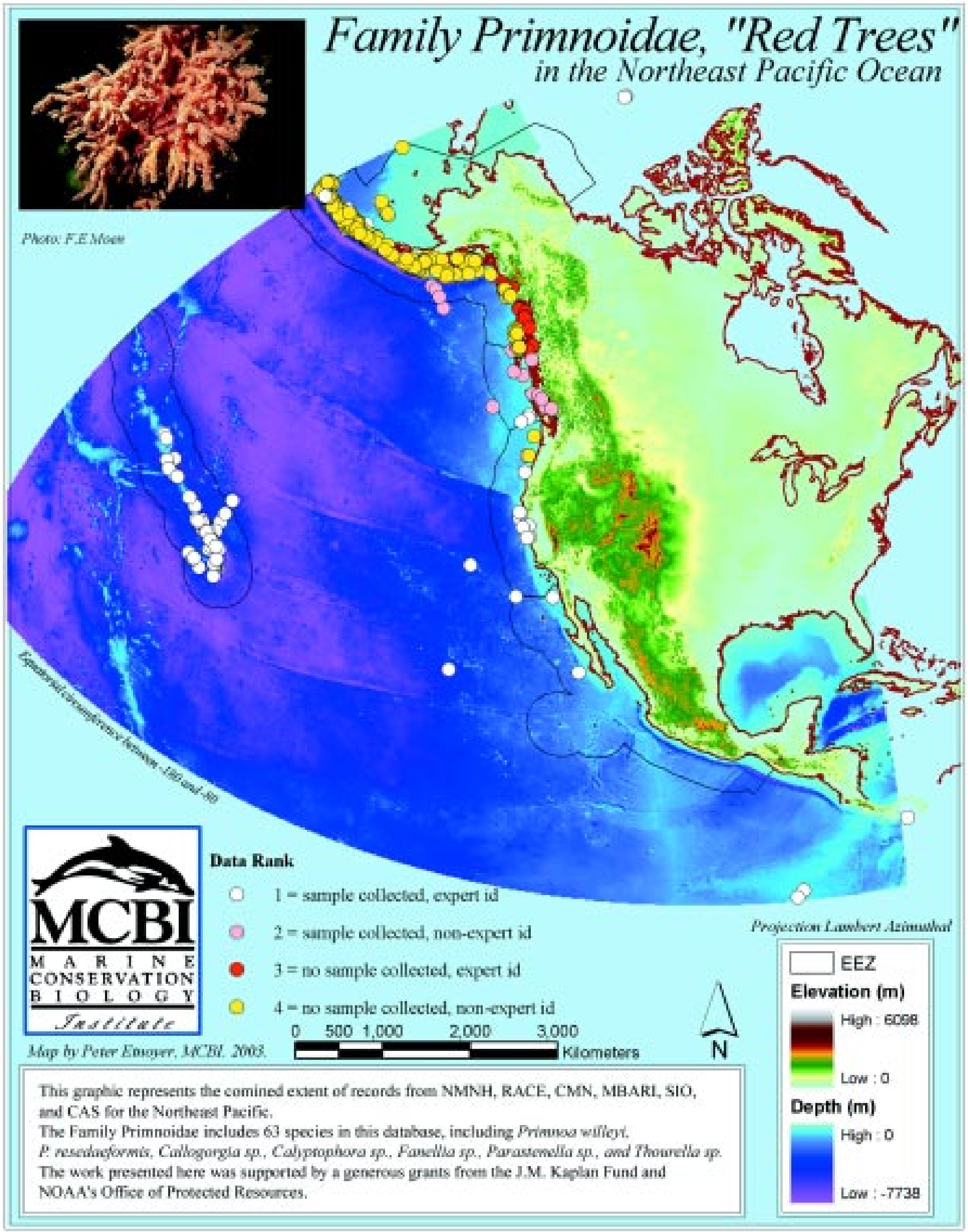
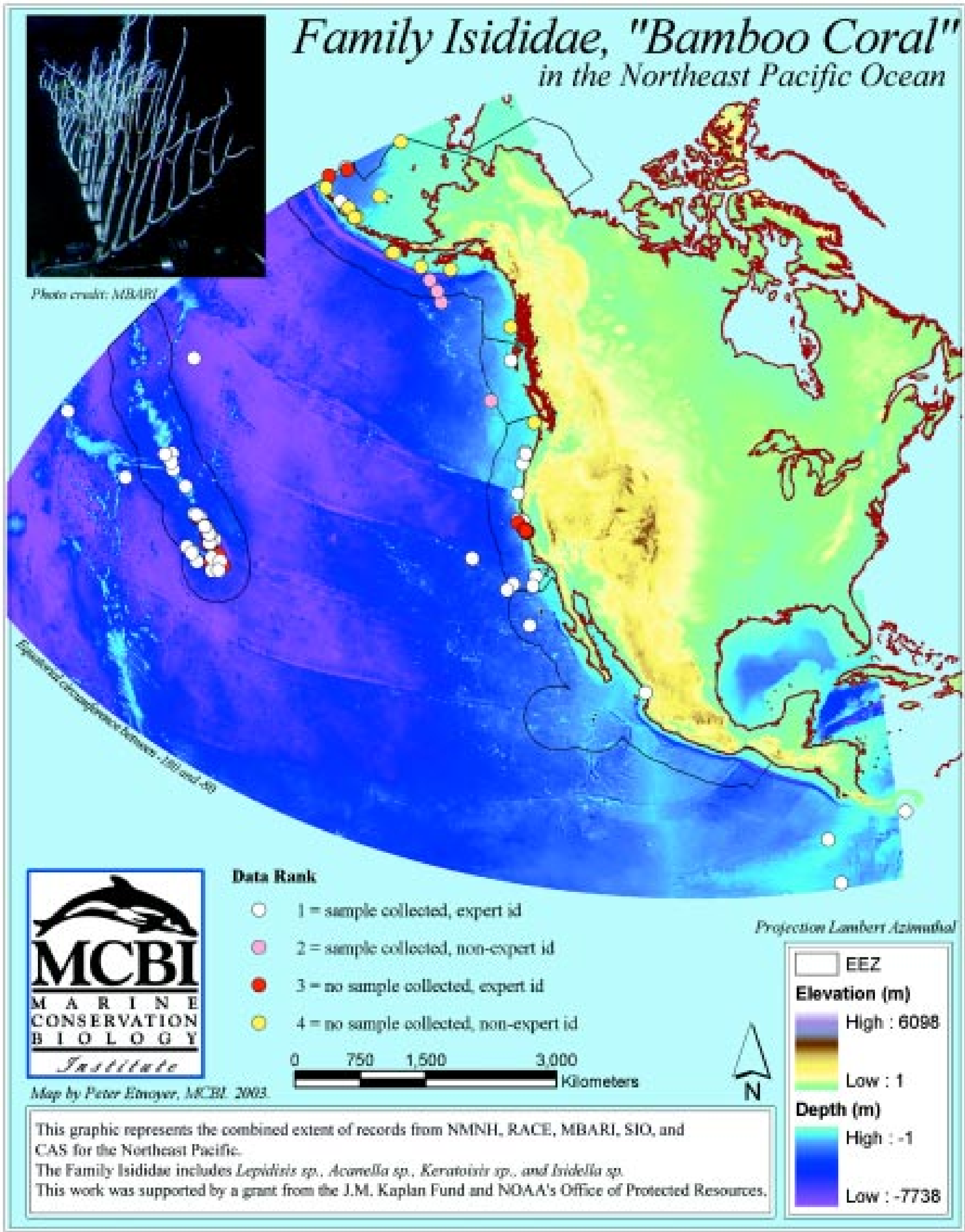
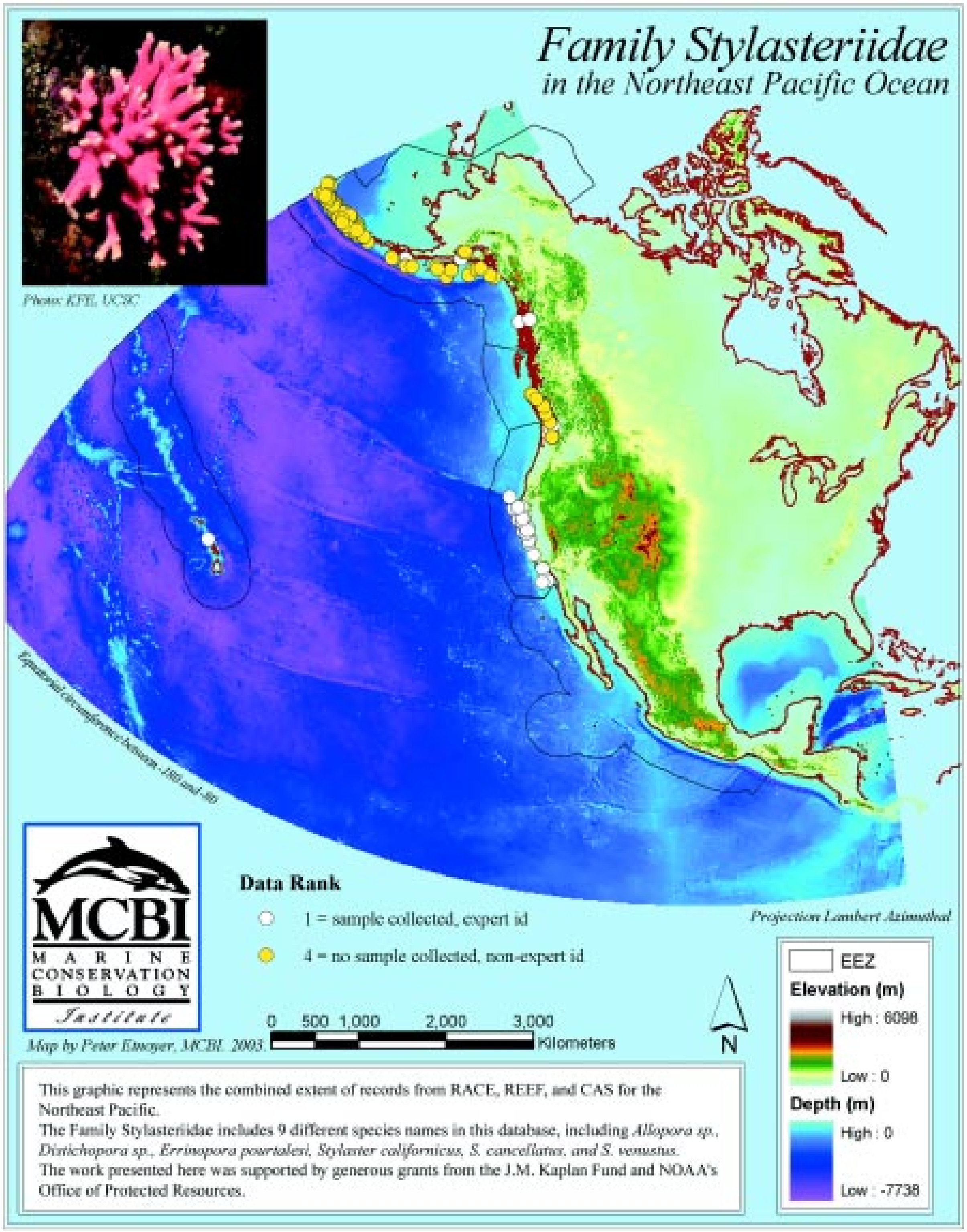
2 = sample collected, non-expert id
3 = no sample collected, expert id
4 = no sample collected, non-expert id
MCBI
MARINE CONSERVATION BIOLOGY Institute
0 500 1,000 2,000 3,000
Kilometers
N
Projection Lambert Azimuthal
EEZ
Elevation (m)
High : 6098
Low : 0
Depth (m)
High : 0
Low : -7738
Map by Peter Etnoyer, MCBI, 2003.
This graphic represents the combined extent of records from NMNH, RACE, CMN, MBARI, SIO, NOAA-OE, and CAS for the Northeast Pacific.
The Family Paragorgiidae includes species Paragorgia arborea, P. corallides, P. dendroides, P. nodosa, and P. pacifica which are all included here as a part of this database.
The work presented here was supported by generous grants from the J.M. Kaplan Fund and NOAA's Office of Protected Resources.



Family Primnoidae, "Red Trees"
in the Northeast Pacific Ocean
Photo: F.E.Moan
Projection Lambert Azimuthal
Data Rank
1 = sample collected, expert id
2 = sample collected, non-expert id
3 = no sample collected, expert id
4 = no sample collected, non-expert id
0 500 1,000 2,000 3,000
Kilometers
N
MCBI
MARINE
CONSERVATION
BIOLOGY
Institute
Map by Peter Etnoyer, MCBI. 2003.
EEZ
Elevation (m)
High : 6098
Low : 0
Depth (m)
High : 0
Low : -7738
This graphic represents the comined extent of records from NMNH, RACE, CMN, MBARI, SIO, and CAS for the Northeast Pacific.
The Family Primnoidae includes 63 species in this database, including Primnoa willeyi, P. resedaeformis, Callogorgia sp., Calyptophora sp., Fanellia sp., Parastenella sp., and Thourella sp.
The work presented here was supported by a generous grants from the J.M. Kaplan Fund and NOAA's Office of Protected Resources.


Family Isididae, "Bamboo Coral"
in the Northeast Pacific Ocean
Photo credit: MBARI
Data Rank
1 = sample collected, expert id
2 = sample collected, non-expert id
3 = no sample collected, expert id
4 = no sample collected, non-expert id
0 750 1,500 3,000
Kilometers
N
Projection Lambert Azimuthal
EEZ
Elevation (m)
High : 6098
Low : 1
Depth (m)
High : -1
Low : -7738
MCBI
MARINE CONSERVATION BIOLOGY Institute
Map by Peter Etnoyer, MCBI. 2003.
This graphic represents the combined extent of records from NMNH, RACE, MBARI, SIO, and CAS for the Northeast Pacific.
The Family Isididae includes Lepidisis sp., Acanella sp., Keratoisis sp., and Isidella sp.
This work was supported by a grant from the J.M. Kaplan Fund and NOAA's Office of Protected Resources.


Family Stylasteriidae
in the Northeast Pacific Ocean
Photo: KFH, UCSC
MCBI
MARINE
CONSERVATION
BIOLOGY
Institute
Data Rank
1 = sample collected, expert id
4 = no sample collected, non-expert id
Projection Lambert Azimuthal
EEZ
Elevation (m)
High : 6098
Low : 0
Depth (m)
High : 0
Low : -7738
0 500 1,000 2,000 3,000
Kilometers
N
Map by Peter Etnoyer, MCBI. 2003.
This graphic represents the combined extent of records from RACE, REEF, and CAS for the Northeast Pacific.
The Family Stylasteriidae includes 9 different species names in this database, including *Allopora sp., Distichopora sp., Errinopora pourtalesi, Stylaster californicus, S. cancellatus, and S. venustus.*
The work presented here was supported by generous grants from the J.M. Kaplan Fund and NOAA's Office of Protected Resources.

Appendix 3: Contact List of Institutions Able to Provide Data

California Academy of Sciences
Data rank: 1
Robert Van Syoc
Department of Invertebrate Zoology and Geology, CAS
Golden Gate Park, San Francisco CA 94118
email: bvansyoc@calacademy.org

Smithsonian Institution
Data rank: 1
Stephen D. Cairns
P. O. Box 37012
National Museum of Natural History, W-329, MRC-0163
Washington DC 20013
email: cairns.stephen@nmnh.si.edu

Scripps Institution of Oceanography
Data rank: 1
Lawrence L. Lovell
Benthic Invertebrate Collection, SIO
9500 Gilman Drive, Mailcode 0244
La Jolla CA 92093
email: llovell@ucsd.edu

National Oceanic and Atmospheric Administration
Office of Ocean Exploration
Data rank: 2
Catalina Martinez
NOAA Office of Ocean Exploration
1315 East West Highway, Office #10226
Silver Spring MD 20910
email: Catalina.Martinez@noaa.gov

Santa Barbara Museum of Natural History
Data rank: 2
F.G. Eric Hochberg
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Canadian Museum of Nature
Data rank: 2
Noel Alfonso
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Canadian Museum of Nature
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Canada
email: nalfonso@mus-nature.ca

Hawaii Undersea Research Laboratory (data not included)
Data rank: 2
Edith H. Chave and Richard Grigg
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Monterey Bay Aquarium Research Institute
Data rank: 3
Judith L. Connor
Information and Technology Dissemination Division
Monterey Bay Aquarium Research Institute
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Resource Assessment and Conservation Engineering (RACE)
Division of the Alaska Fisheries Science Center
Data rank: 4
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Reef Environmental Education Foundation
Data rank: 4
Christy Pattengill-Semmens
Reef Environmental Education Foundation
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Key Largo FL 33037
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Appendix 4: Other potential data resources

American Museum of Natural History
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Division of Invertebrate Zoology, AMNH
Central Park West at 79th St
New York NY 10024 email: siddall@amnh.org

Lawrence Livermore National Laboratory
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UC/Lawrence Livermore National Lab L-397
7000 East Ave
Livermore CA 94550 email: tguilderson@llnl.gov

Minerals Management Service
Janice Hall
MMS Pacific OCS Region, Mail Stop 7001
770 Paseo Camarillo
Camarillo CA 93010 email: janice.hall@mms.gov

Moss Landing Marine Laboratories
Jonathan Geller
Moss Landing Marine Laboratories
8272 Moss Landing Rd
Moss Landing CA 95039 email: geller@mlml.calstate.edu

National Marine Fisheries Service, NOAA
Waldo Wakefield
Northwest Fisheries Science Center
Hatfield Marine Science Center
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Newport, OR 97365 email: waldo.wakefield@noaa.gov

Scientific Applications International Corporation
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Science Applications International Corporation
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University of Kansas
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