

# STATE OF DEEP CORAL ECOSYSTEMS IN THE U.S. PACIFIC ISLANDS REGION: HAWAII AND THE U.S. PACIFIC TERRITORIES

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## I. INTRODUCTION

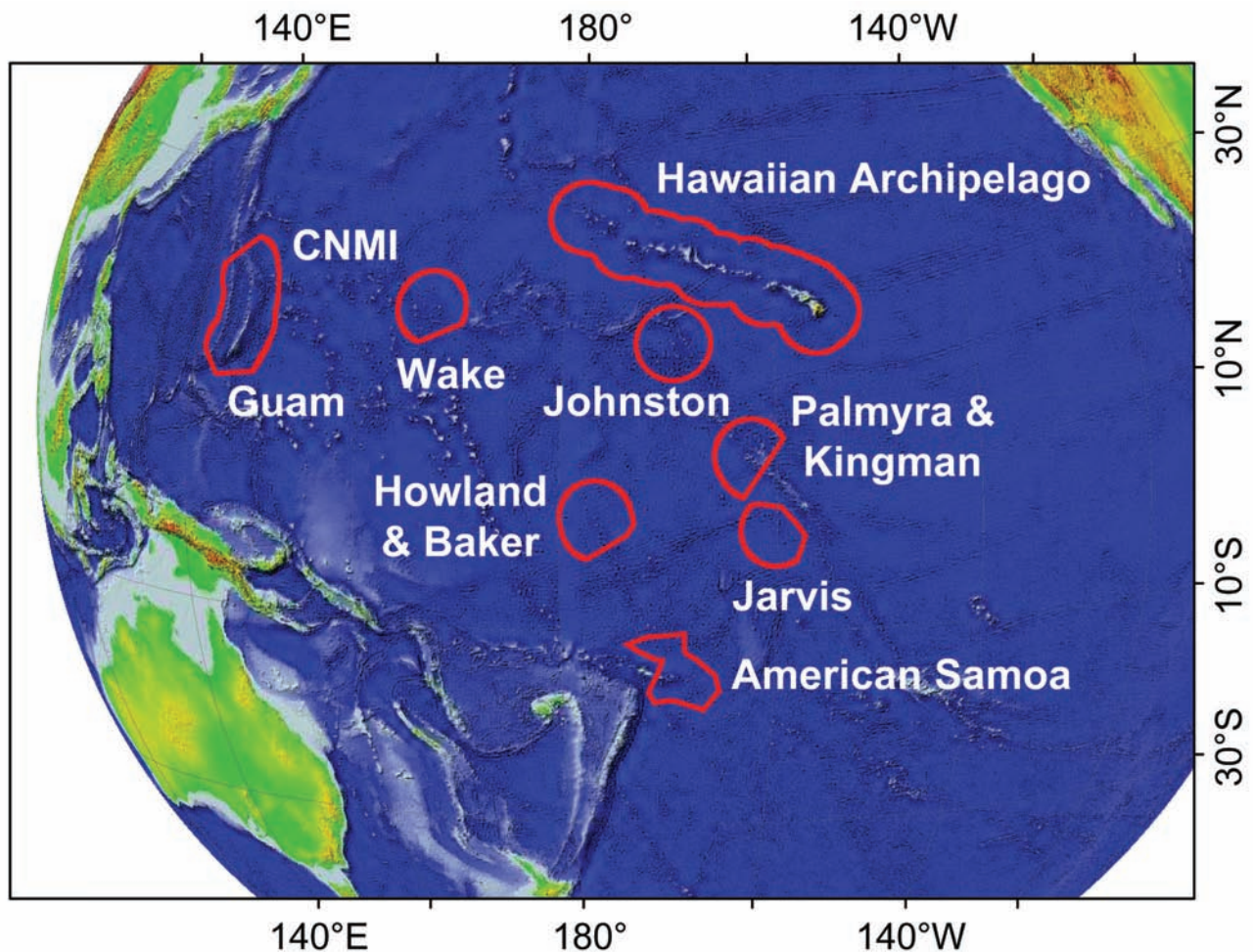
The U.S. Pacific Islands Region consists of more than 50 oceanic islands, including two archipelagos (Hawaii and Mariana Islands), parts of four other archipelagos (Samoa, Line Islands, Phoenix Islands, and Marshall Islands), and numerous seamounts in proximity to each of these groups. These islands include the State of Hawaii, the Commonwealth of the Northern Mariana Islands (CNMI), and the territories of Guam and American Samoa, as well as nine sovereign Federal territories—Midway Atoll, Johnston Atoll, Kingman Reef, Palmyra Atoll, Jarvis Island, Howland Island, Baker Island, Rose Atoll, and Wake Island). This area also encompasses the Pacific Island States in free association with the United States (former U.S. trust territories also known as the Freely Associated States) including the Republic of Palau, the Federated States of Micronesia (Chuuk, Pohnpei, Kosrae, and Yap), and the Republic of the Marshall Islands. This region includes some of the most remote, unpopulated islands in the Pacific, as well as many densely populated islands, and it extends from the South Pacific (e.g., American Samoa; 14° S latitude) to the North Pacific (Kure Atoll 28° N latitude) (Figure 4.1). The punctuated habitat of the Pacific Region distinguishes deepwater coral communities biogeographically and ecologically from other areas in the United States. Because of the isolated nature of these islands (especially Hawaii and the Northwestern Hawaiian Islands), they possess some of the highest levels of marine endemism recorded anywhere on earth.

While trace coral samples from anecdotal dredging and bycatch suggest a wide distribution of deep corals throughout the Pacific, the only detailed assessment of deep corals within the U.S. waters of the Pacific has been in the Hawaiian Archipelago. Antipatharians were first reported from Hawaiian waters more than 75 years ago (Verrill 1928). The earliest descriptions of deep octocorals in Hawaii are recorded by Dana (1846), with Nutting (1908) reporting 68 species. Other significant contributions to the species lists of this region include Muzik (1979) and Grigg and Bayer (1976) for octocorals, as well as Vaughan (1907) and Cairns (1984, 2006) for scleractinians. Wells (1954) provides data on the Marshall Islands. Pacific deep coral research has expanded greatly over the last four decades, primarily as a result of the establishment of commercial fisheries for black, pink, and gold coral off the main Hawaiian Islands, and subsequent development of fishery management plans for these resources by the State of Hawaii and the Western Pacific Fishery Management Council. Deep corals are harvested as raw material for the jewelry trade. The coral supports a portion of a \$70 million Hawaii-based industry that employs roughly 650 people in its manufacturing facility and 50 retail stores (Carl Marsh—Maui Divers pers. comm.)

Commercial beds of black coral were first discovered at a depth of 30-75 m off Lahaina, Maui in 1958. Some of the earliest ecological work on black corals was carried out in the 1960s in the channel waters off Maui using SCUBA (Grigg 1965). The Maui black coral bed has remained the focus of coral harvesters throughout the fishery's history and has been periodically resurveyed over the last 40 years. These studies have provided the longest data sets available worldwide on the status and trends of black coral populations and the effects of the commercial fishery and other natural and anthropogenic stressors. In the mid 1960s, isolated patches of pink (*Corallium* spp.), gold (*Gerardia* sp.) and bamboo (*Lepidisis* sp., *Acanella* sp.) corals

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**Figure 4.1.** Map of the Pacific Basin showing U.S. islands and their Exclusive Economic Zone that comprise the Pacific Islands Region for the National Marine Fisheries Service.

were identified at 300–500 m depths north of Midway Island (Milwaukee Banks) and off Oahu (Makapuu Bed) (Grigg 1993). A long-term deep coral research program focused on precious corals began at the University of Hawaii in 1970. Many of the earliest surveys of precious coral beds used tangle net dredges and other nonselective gear. A key advancement in Hawaii's deep coral research infrastructure was access to the two-person submersible *Deep Star 2* from General Dynamics. Aside from periodic research (Grigg 1993) the sub was leased to commercially harvest coral for the fishery between 1974 and 1979. In 1980 the submersible was renamed the *Makalii* and became the centerpiece of the newly formed Hawaii Undersea Research Laboratory (HURL), an established node of NOAA's Undersea Research Program (NURP). The facility has since expanded, replacing the *Makalii* with two, deep-diving 3-person submersibles (*Pisces IV* and *Pisces V*) and a dedicated support vessel equipped with a multibeam bottom mapper and

a remotely operated vehicle (*RCV-150*) (Chave and Malahoff 1998). This new infrastructure expanded the focus of coral research and increased participation by more researchers.

This chapter provides a summary of what is known about deep corals within the Pacific Islands Region. In keeping with the intent of this national report, the chapter will mostly focus on corals deeper than 50 m. However, shallower black corals will be included. Most of the information available on black corals, precious corals, and other deep corals are from the Hawaiian Archipelago, where most of the surveys have been conducted. Studies have focused on the taxonomic and genetic composition of the region's coral community, ecological relationships between corals and other organisms, and on the distribution and dynamics of deep corals. Much of this work is focused on the coral taxa that are targets for the commercial fishery. Also discussed are the measures that have been employed to

protect deep coral ecosystems and to manage the commercial fishery.

## II. GEOLOGICAL SETTING

The U.S. Pacific Islands lack the shelf area that typically defines the deep-sea benthic habitats of the continental United States. Instead, the submerged slopes of volcanic pinnacles that rise steeply from abyssal depths of 4–7 km provide the hard substratum that deep corals colonize. The region has endured a long history of plate drift, subsidence, and sea level rise, and many of the volcanic islands have drowned creating numerous submerged banks and seamounts. A striking feature of the Pacific Basin is the linear nature of the island chains and seamounts. They are aligned in a north-northwesterly direction, a consequence of the northwesterly drift of the Pacific plate over stationary volcanic hotspots (Kennett 1982). The resulting islands and seamounts are progressively older in proportion to distance from a hotspot. For example, the island of Hawaii lies above the mantle plume and is the only island in the Hawaiian Archipelago that is volcanically active. To the northwest, volcanism on Oahu ceased about three million years ago; Kauai about five million years ago; and Midway Island about 27 million years ago (Grigg 1988a). This geologic process defines the Pacific plate and, as a result, the Pacific Islands region has some of the youngest (main Hawaiian Islands) and oldest (Line Islands) volcanic archipelagos in the world.

## III. OCEANOGRAPHIC SETTING

The Pacific is composed of two large gyres, the northern and southern central gyres. In the South Pacific, southeast trade winds drive the South Equatorial Current westerly between 15° S and 3° N latitude. Within the South Equatorial Current is the Cromwell Current, or Pacific Equatorial Undercurrent. This current exists at depths of 70–200 m, and is approximately 450 km wide and flows with velocities of up to 5 km h<sup>-1</sup> for a distance of up to 13,000 km in the opposite direction of the South Equatorial Current (Tchernia 1980; Thurman 1981). In the North Pacific, the North Equatorial Current flows westward at 1 km h<sup>-1</sup> between 8° and 20° N latitude. The Equatorial Counter Current is located between the North

Equatorial Current and the South Equatorial Current and travels eastward at slightly more than 2 km h<sup>-1</sup> (Thurman 1981). The boundaries of these water masses overlap and contribute to long-distance dispersal of pelagic larvae, particularly in the western Pacific. The northern Hawaiian seamounts fall in the northern portions of the north gyre; Hawaii, Wake and Johnston are in the center of the North Pacific gyre; Kingman and Palmyra are in the equatorial/eastern Pacific; Jarvis, Howland, and Baker are in the equatorial system; American Samoa is in the equatorial portion of the southern gyre; and the Mariana Islands are affected by the north central gyre, the equatorial systems, and the Kuroshio current from Asia.

While deep water masses originate from surface currents, no deep water masses form in the Pacific Basin. Deep water migrates in from the Atlantic via the southern hemisphere with a uniform temperature and salinity below about 2000 m (Knauss 1996). The deep water flows northward at depths below 2500 m and southward above 2500 m. Seamounts, pinnacles, and other structures obstruct current flow and can generate eddies of varying intensity, depending on the current velocity, depth or height of the seamount, slope of the side, and strength of the seawater stratification. Both cold and warm water eddies are formed as a result of a seamount obstructing current flow in the deep ocean. Typically, anticyclonic (cold water) eddies are formed above the seamount and remain tightly associated with the top of the seamount, while the cyclonic (warm water) eddy is formed downstream behind the seamount (Kamenkovich et al. 1986). Deep corals are thought to benefit from the flow acceleration, larval retention, and high nutrient waters from deep upwelling caused by the presence of the seamount and the generated eddies (Genin et al. 1986; Mullineaux and Mills 1997; Coutis and Middleton 2002).

Oxygen in the deep water of the Pacific has been depleted to very low levels as a result of the length of time it takes for water to move into and across the Pacific Basin. Having aged thousands of years, oxygen averages 0.5–4.5 ml l<sup>-1</sup> versus the significantly higher Atlantic average of 3.0–6.5 ml l<sup>-1</sup> (Thurman 1981). The effect of low oxygen levels on deep corals is poorly documented; however, Wishner et al. (1990) attributed patterns in the abundance and distribution of sponges,



sea pens, and other benthic organisms to depth-specific patterns in oxygen levels.

#### IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

Most of the major deep coral groups are known to exist in the U.S. Pacific region. However, most species have been identified only around the Hawaiian Archipelago largely because deep waters around other U.S Pacific Islands have not yet been explored. Published records of deep

corals from the Hawaiian Archipelago include more than 137 species of gorgonian octocorals and 63 species of azooxanthellate scleractinians, with 21% of the scleractinians thought to be endemic to Hawaii (Cairns 2006, See chapter appendix). A 2003 cruise in the Northwestern Hawaiian Islands (A. Baco, unpublished data) identified eight new species of octocorals, two new genera and several new species of antipatharians, three new stylasterid species (Cairns 2005), and 1 new zoanthid species. In addition, a 2004 main Hawaiian Islands cruise collected at least three new species of octocorals, two new species of

**Table 4.1** Structure-forming attributes of deep corals in Hawaii.

Taxa	Reef-Building	Abundance	Maximum Colony Size	Morphology	Associations with Other Structure-Forming Invertebrates	Colony Spatial Dispersion	Overall Rating of Structural Importance
<i>Enallopsammia rostrata</i>	No	Medium	Medium	Branching	Many	Clumped	Medium
Other scleractinians	No	Low	Small	Non-Branching	Many	Solitary	Low
<i>Gerardia</i> sp.	No	High	Large	Branching	Many	Clumped	High
Shallower antipatharians	No	Low	Large	Branching	Few	Clumped	High
Other octocorals and antipatharians in deeper water	No	High	Med	Branching	Many	Clumped	High
Other octocorals and antipatharians in precious coral beds	No	Medium	Medium-Low	Branching	Many	Clumped	High
<i>Corallium secundum</i>	No	High	Medium	Branching	Many	Clumped	Medium
<i>Corallium laauense</i>	No	High	Medium	Branching	Many	Clumped	Medium
Isidids in deeper water	No	High	Med	Branching	Many	Clumped	Medium

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

antipatharians, and provided range extensions for several genera and species of corals that were not previously known from Hawaii. Thus, although an extensive species list exists for the Hawaiian Archipelago, the high rate of discovery of new species and new records implies the Archipelago is also largely undersampled.

In general, the deep corals in the Pacific Islands do not form the extensive reef structures observed in the Atlantic and South Pacific. Instead, corals grow attached directly to the exposed fossil carbonate, basalt or manganese substratum. Octocorals and antipatharians have been found to grow in high densities at numerous sites, particularly on summit areas of seamounts or other topographic highs, where they often form extensive coral gardens or “beds” with abundant associated invertebrates. The coral taxa listed in this chapter are those that present a conspicuous relief profile that could serve as a source of habitat (Table 4.1). At death, these taxa decay from physical and bioerosion forces until they detach from the substratum and are swept away. Cemented reefs from accumulated dead material have not been observed.

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

*Enallopsammia rostrata* is an arborescent scleractinian coral in the Family Dendrophyllidae. The full depth range for this species is listed as 229–2165 m in Cairns (1984), but it has been observed in Hawaii primarily at depths of 500–600 m. In some areas it forms bushy colonies, with dead coral accumulating near the base of the colony much like that observed among *Lophelia* reefs in the Atlantic. Further exploration and characterization of this species is needed to determine its abundance throughout the region and its potential role in forming habitat.

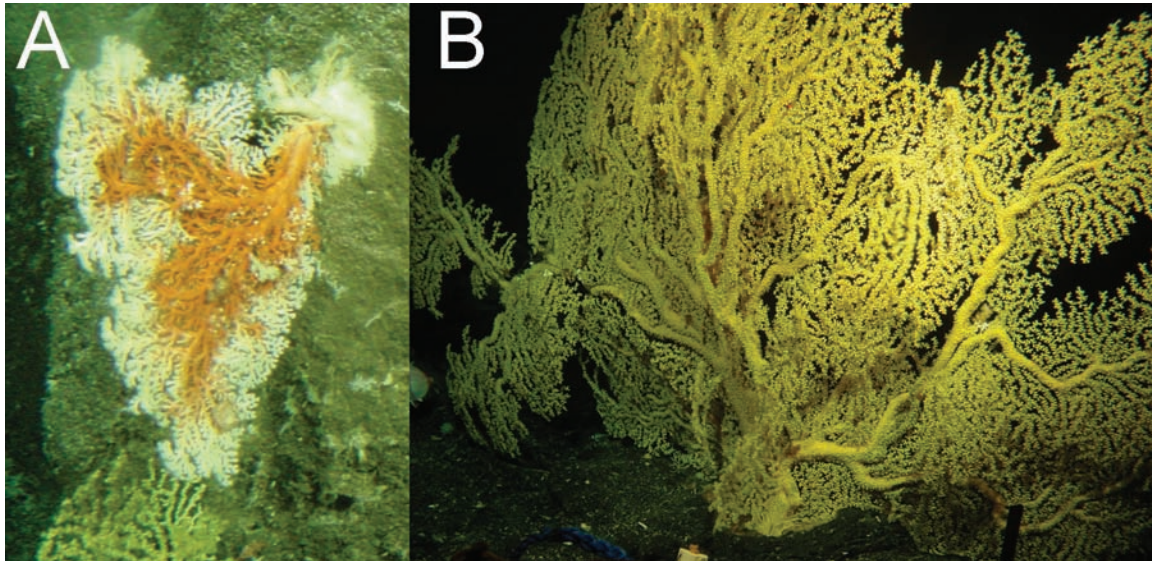
*Madrepora kauaiensis* and *M. oculata* also occur in Hawaii and have the potential to form reef structures, however, little is known of their abundance or distribution in the Archipelago. Besides these examples, scleractinians that have been observed are primarily solitary cup corals. They can occur in abundance, e.g., on Cross Seamount (A. Baco pers. obs), but many species are small and not observable with a submersible, preventing a true determination of their distribution. A complete species list (to date)

for Hawaii can be found in Cairns (2006) and is also included in the Appendix to this chapter.

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

Fourteen genera of black corals are reported from the Hawaii-Pacific region with species found in both shallow and deep habitats. The shallowest genera (*Cirripathes* spp. and *Antipathes* spp.) prefer shaded or low light areas and can occur underneath ledges and in caves in shallow water (e.g., *Cirripathes anguina* can occur in 4 m depth) where surge is minimal, or in the open on steep walls at deeper depths. *Antipathes* spp. appears to settle predominantly in depressions, cracks or other rugged features along steep ledges, with few colonies found on smooth basaltic substratum (Grigg 1965). Shallower antipatharians in Hawaii also appear to prefer substrates that are encrusted with calcium carbonate from coralline algae, bryozoans, and corals. The highest densities are found on hard sloping substratum, in areas with 0.5–2 knot currents (Grigg 1965). The best studied black corals are the commercially harvested species *Antipathes dichotoma* and *Antipathes grandis*. Recent taxonomic work (D. Opresko pers. comm.) on the Hawaiian *A. dichotoma* suggests it is a new species and is currently being referred to as *Antipathes* cf. *curvata*. The *A. cf. curvata* and *A. grandis* exhibit similar growth rates (6.42 cm yr<sup>-1</sup> and 6.12 cm yr<sup>-1</sup>, respectively) and reach reproductive maturity at ages 12–13. Fertilization takes place externally in the water column, and light and temperature influence larval settlement patterns. The larvae of *A. cf. curvata* and *A. grandis* are negatively phototactic, and the lower depth limit coincides with the top of the thermocline (~ 100 m) in the main Hawaiian Islands (Grigg 1993).

Much less is known about deeper genera of black corals. They have similar morphologies to the shallower corals, including colonies shaped as whip-like filaments (*Stichopathes* spp.) and as branching, sometimes “feathery” colonies (*Myriopathes*, *Bathypathes* spp., *Stauropathes* and *Leiopathes*). However, the life history of these deeper genera is likely to be much different than their shallower relatives. Radiometric dating of *A. cf. curvata* and *Leiopathes* indicates the deeper *Leiopathes* genera grow 10 to 70 times slower than the shallower *A. cf. curvata* (Roark et al. 2006).



**Figure 4.2.** Photos of the two primary Genera that comprise the Hawaiian precious coral fishery A—*Corallium* sp. and B—*Gerardia* sp. Photo credit F. Parrish, NOAA Fisheries.

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

No species of zoanthid has yet been described from deep water in Hawaii although taxonomically, at least six species have been observed and collected (Baco, unpublished data). The gold coral, *Gerardia* sp., is probably the most common and certainly the largest of these species. It has an arborescent morphology similar to gorgonians, and colonies have been observed as tall as 2–3 m in height (Figure 4.2 B). *Gerardia* sp. is widely distributed throughout the Hawaiian Archipelago and into the Emperor Seamount Chain at depths of 350–600 m.

Zoanthids in Hawaii have been observed to colonize other living coral species as well as hard bottoms. In the case of *Gerardia* sp., the zoanthids may eventually replace the host colony completely. It is not known if *Gerardia* sp. can outcompete the living tissue of the host or if it opportunistically colonizes and spreads after a portion of the host coral has been decorticated by predatory urchins or some other cause. The life span of *Gerardia* sp. is uncertain. Counts of growth bands assumed to be annual in periodicity have provided an estimated lifespan of around 40 years (Grigg 2002). Recent radiometric work on the Hawaiian species has estimated the life span of gold coral samples between 450 and 2700 years (Roark et al. 2006), which is consistent with findings from radiometric aging on *Gerardia* sp. in the Atlantic (Druffel et al. 1995).

Gold coral was one of the few corals seen during the 2005 Line Island surveys and it was present at Jarvis, Palmyra, and Kingman. However, the colonies were sparse, with no patches large enough to be called a “bed.” All colonies were infested with other unidentified zoanthids. Surveys at the base of the cliffs below the spot where the individual gold colonies were attached found no accumulation of fallen colonies, suggesting gold coral has always been in low abundance in the region (Frank Parrish pers. obs.).

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

Gorgonian octocorals are by far the most abundant and diverse corals in the Hawaiian Archipelago. Two species, *Corallium laauense* (red coral; formerly identified as *Corallium regale*) and *Corallium secundum* (pink coral) are known to occur at depths of 350–600 m on islands and seamounts throughout the Hawaiian Archipelago (Grigg 1974, 1993; Baco, unpublished data) and into the Emperor Seamount Chain (Bayer 1956). Growing to more than 30 cm in height the *Corallium* spp. occur in a variety of red/pink color shades, and the height and shape of the colony’s “fan” can vary considerably (Figure 4.2 A). They are often found in large beds and usually support a high diversity of invertebrates with an abundance of other octocorals, zoanthids, and sometimes scleractinians co-occurring in the beds. *C. secundum* and *C. laauense* are gonochoristic (Grigg 1993; Waller and Baco in press) and are estimated to reach reproductive



maturity at 12–13 years (Grigg 1993). These species are relatively long lived, with some of the oldest colonies observed within Makapuu Bed about 0.7 m in height and approximately 80 years old (Grigg 1988b, Roark 2006). Populations of *C. secundum* appear to be recruitment limited, although in favorable environments (e.g., Makapuu Bed) populations are relatively stable, suggesting that recruitment and mortality are in a steady state (Grigg 1993).

More than 130 other species of octocorals are known from the Archipelago and they represent a diverse array of families and genera. Most abundant are the Families Coralliidae, Isididae, Primnoidae, Plexauridae, Chrysogorgiidae and Acanthogorgiidae. To our knowledge, besides the species discussed above, there isn't any information on the biology and ecology of these groups in this region. Further discussion of their depth distributions are in the following sections and a complete species list (to date) is included in the Appendix to this chapter.

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

The Alcyonacea are represented in this region by only 12 species in three families. Of these, the genus *Anthomastus* is the most widely distributed. It is often observed in precious coral beds in patches with large number of small individuals surrounding a larger individual (A. Baco pers. obs.). The bright purple *Clavularia grandiflora* has been observed growing on *Gerardia* at a number of sites throughout the Archipelago (A. Baco pers. obs.)

Like the gorgonians, little else is known about the biology and ecology of these species in this region. A complete species list (to date) is included in the Appendix to this chapter.

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

Pennatulaceans seen in Hawaii tend to be more abundant in areas high in sediment, although *Kophobelemnon* sp. has occasionally been observed on adjacent hard bottoms near the Cross Seamount deep coral bed. Near the Keahole deep coral bed on the island of Hawaii, a single species (as yet unidentified) occurs in high abundance in patches of sediment at depths of about 400 m (A. Baco pers. obs.). Again, little else is known about the biology and ecology of

these species in this region. A complete species list (to date) is included in the Appendix to this chapter.

g. *Stylasterids* (Class Hydrozoa, Order Anthoathecatae)

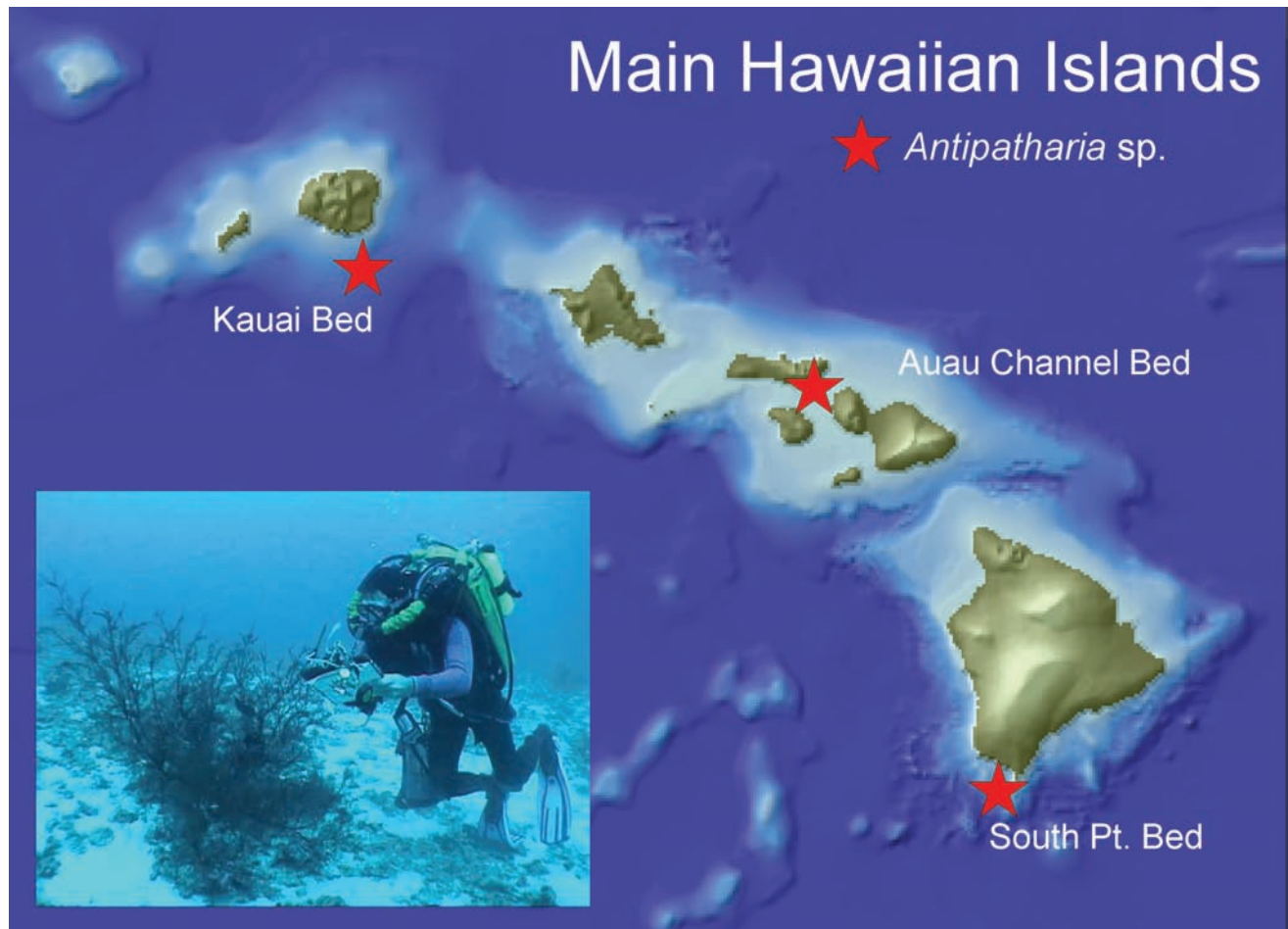
Four species of stylasterids are present in Hawaii, but they are distributed very patchily throughout the Archipelago. An extreme example is *Disticophora anceps*. It has a very wide depth range but has only been found on the northwest slope of Laysan Island in densities of several colonies per square meter in some areas (Cairns 2005; A. Baco unpublished data). Again, little else is known about the biology and ecology of this group in this region.

Hawaiian stylasterids are discussed in Cairns (2005) and a complete species list (to date) is included in the Appendix to this chapter.

## V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITAT

### *General distribution*

Our knowledge of the spatial distribution of deep corals in the U.S. Insular Pacific is limited to Hawaii. Even in Hawaii, very little of the deep sea has been explored and every research expedition is yielding large numbers of new species. Until 2003, the majority of studies in Hawaii came from sparse trawl data or had concentrated on the harvested black, gold, and pink corals. Often referred to as “precious corals,” these are the primary deep coral taxa harvested for the jewelry trade. Most of these are found between depths of 300 and 500 m and have been collected by dredge or submersible. Often, black coral (*Antipathes* spp.) is distinguished from the rest of the precious corals because the *Antipathes* taxa that are used for jewelry occur much shallower (<100 m) and are harvested by scuba divers. Beside precious corals, many other taxa of deep corals have not been studied because they were not one of the management unit species of the precious coral fishery. In 2003 and 2004, the *Pisces* submersibles were used for the first studies of non-precious corals, thus extending the exploration of corals well below previously surveyed depths. In 2005, the first surveys conducted outside of Hawaii using the *Pisces* submersibles were at Rose Atoll and the U.S Line Islands (Jarvis, Palmyra, and Kingman).



**Figure 4.3.** Topographic map of the main Hawaiian Islands with the three known black coral beds marked. Inset shows a diver conducting a coral survey. Map credit: F. Parrish, NOAA Fisheries.

The distribution of deep corals in the rest of the U.S. Pacific is unknown.

Depth clearly influences the distribution of different coral taxa and certainly there is patchiness associated with the presence of premium substrate and environmental conditions (flow, particulate load, etc.). The environmental suitability for colonization and growth is likely to differ among coral taxa. For example, *Corallium secundum* appears to grow in large numbers in areas of high flow over carbonate pavement; *Corallium laauense* grows in an intermediate relief of outcrops; and *Gerardia* sp. grows in high relief areas on pinnacles, walls, and cliffs (Parrish in press). These habitat differences may reflect preferred flow regimes for the different corals (e.g., laminar flow for *C. secundum*, alternating flow for *Gerardia* sp.).

#### *Black coral beds*

Black coral beds are found off the main Hawaiian Islands at depths of about 30–110 m. The largest

bed covers an estimated area of 1.7 km<sup>2</sup> and lies in the middle of the Auau Channel, between Maui and Lanai, encrusting a drowned land bridge between the two islands at depths of 30–90 m (Grigg et al. 2002). A smaller black coral bed (0.4 km<sup>2</sup>) is located off Kauai and another at the southern end of the island of Hawaii (Figure 4.3). The dominant species found in these locations are *Antipathes* cf. *curvata* (95% of the population) followed by *Antipathes grandis*. Grigg (1976) estimated a total standing crop of *A. cf. curvata* for the Auau Channel area, between 40 and 70 m, to be 166,000 kg or 84,000 colonies, while the bed at Kauai contained 40,000 kg. *Myriopathes ulex* is found in deeper locations (110–565 m) off the main Hawaiian Islands, along with other species of antipatharians absent from shallower depths (Devaney and Eldridge 1977) (see chapter appendix). Little commercially important black coral has been found in the Northwestern Hawaiian Islands (Grigg 1974), perhaps due to the shoaling of the thermocline towards the northwest end of the chain. Other species of black corals



occur in the Northwestern Hawaiian Islands and include taxa such as *Cirripathes*, *Stichopathes*, *Stauropathes*, *Bathypathes*, *Myriopathes ulex*, *Trissopathes*, *Umbellopathes*, *Dendropathes*, and *Leiopathes*.

#### Between Black and Precious Coral Beds

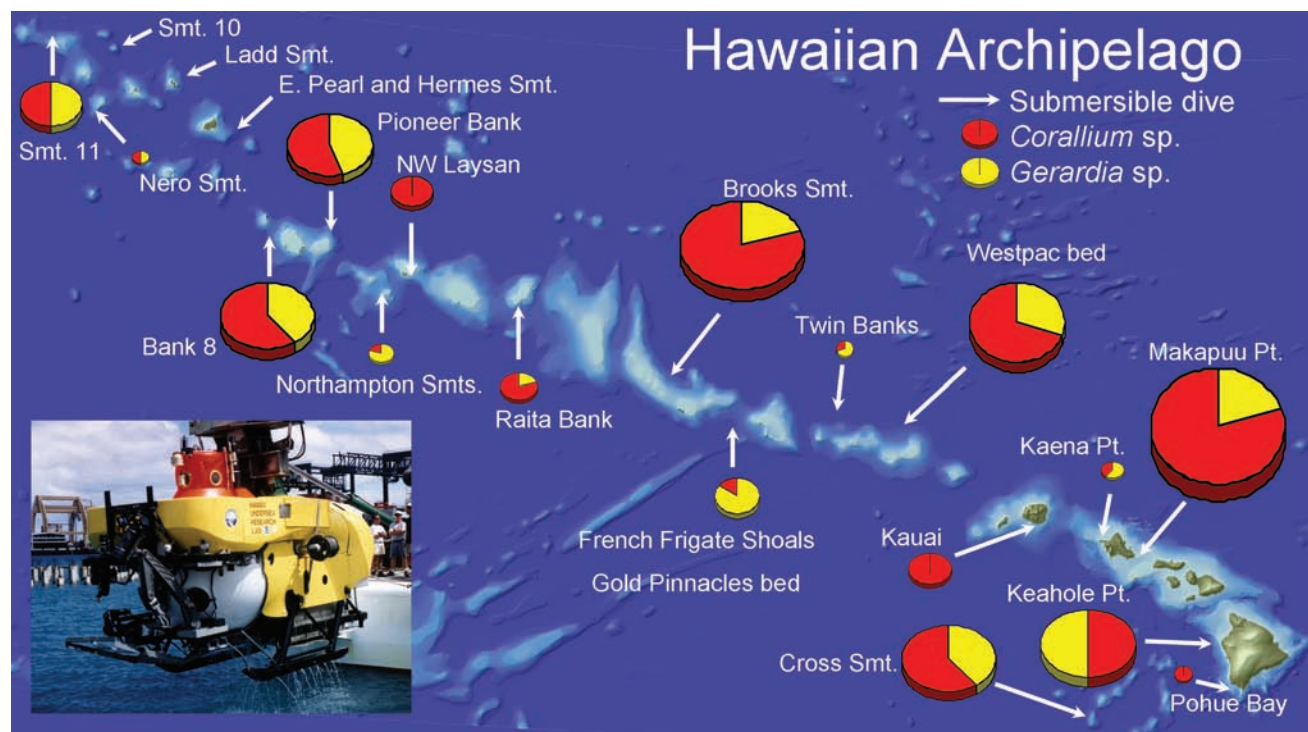
The depth zone between the black coral beds and the precious coral beds has had less study. Corals have been observed in this zone; for example, an abundance of octocorals occur at the Makapuu coral bed on the island of Oahu, shallower than the precious corals, but they have not been sufficiently sampled to comment on diversity or species composition.

#### Precious coral beds

Probably the most abundant of Hawaii's known deep corals are the precious corals, including octocorals *Corallium laauense* (red coral) and *Corallium secundum* (pink coral), and the zoanthid *Gerardia* sp. (gold coral). These species are known to occur in significant abundance in at least 16 locations in the Hawaiian Archipelago at depths of 350–600 m (Grigg 1974, 1993; Baco, unpublished data) and into the Emperor Seamount Chain (Bayer 1956). Within a given coral bed, the two primary genera (*Corallium*

and *Gerardia*) are usually found, but the ratio of abundance can vary greatly (Parrish in press)(Figure 4.4). It is difficult to estimate the size of coral beds, so only relative differences in bed size (based on impressions of coral density and the area covered by the submersible track) were shown in Figure 4.4 to determine the size of pie diagrams. Most precious coral sites also have a number of other noncommercial taxa; these include various octocorals (e.g., *Callogorgia*, *Paracalyptophora*, *Acanthogorgia*, *Lepidisis*, *Keratoisis*, *Isidella*, *Kereoides*, *Paragorgia*, and various paramuriceids) and antipatharians (e.g. *Leiopathes*, *Trissopathes*, and *Bathypathes*) (A. Baco, unpublished data).

Of the known coral beds, the Makapuu coral bed is the best studied and most diverse. It is located between 375 and 450 m depth in the channel between the islands of Oahu and Molokai. The bed comprises an area of about 3.6 km<sup>2</sup>, with the most abundant coral *C. secundum*, at a mean density of 0.22 colonies per square meter between 365 and 400 m (Grigg 1988b). Other corals found at Makapuu include bamboo coral (*Lepidisis olapa*, 0.041 colonies m<sup>-2</sup>; *Acanella* spp., 0.001 colonies m<sup>-2</sup>), gold coral (*Gerardia* sp., 0.0005 m<sup>-2</sup>), as well as three genera of gorgonians



**Figure 4.4.** Topographic map of the Northwestern Hawaiian Islands with coral survey dive sites of the submersible Pisces V (inset). Pie charts represent the relative amount of coral among sites and the within-site fraction of the two primary precious coral genera. 3D map and Pisces photo credit: Hawaii Undersea Research Laboratory.

(*Narella* sp., *Psuedothesea* sp and *Callorgorgia gilberti*), a sea pen (*Stylatula* sp.), and black coral (*Leiopathes* n. sp.). Many taxa of no commercial interest are also present in or adjacent to the bed including *Enallopsammia rostrata*, *Thouarella hilgendorfi*, acanthogorgiids, *Paragorgia* sp., Paramuriceidae, *Trissopathes pseudotristicha* (antipatharian) and a number of undescribed octocorals.

#### *Beyond Precious Coral Beds*

Explorations have been conducted at only a few sites below precious coral depths; Pioneer Ridge, the small seamount southeast of Laysan Island, an unnamed seamount east of Necker Island, Cross Seamount, and Keahole Point. At these deeper depths in high current areas such as ridges and pinnacles, a fair amount of overlap appears to occur in species composition of both corals and sponges between sites. Although the number of observations is very limited, there appears to be a transition in species below about 600 m, from *Corallium*- and *Gerardia*-dominated communities, to a different suite of species. Many species of chrysogorgiids, primnoids, isidids, coralliids, and antipatharians begin to appear around this depth (A. Baco, unpublished data). Among the more common octocoral genera observed are: *Chrysogorgia*, *Metallogorgia*, *Iridigorgia*, *Narella*, *Calyptrophora*, *Candidella*, *Keratoisis*, *Isidella*, *Acanella*, *Corallium*, and *Paragorgia*, as well as the antipatharian genus *Bathypathes*. The depth distribution of many,

but not all, of these species appears to continue below 1800 m (Baco, unpublished data).

## V. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

The harvesting of deep corals has prompted a number of studies focused on the species associations with deep coral communities. Nationally, most effects to coral-associated species come from trawling and dredging, which are banned in U.S. Pacific waters. The harvesting of precious corals is allowed using selective methodologies such as hand collection by scuba divers or using the manipulator of a submersible. Take of deep corals as a fishery target is a direct effect to the bottom habitat with uncertain ecological consequences. Studies have been conducted to address the NOAA mandate of essential fish habitat, protected species, and ecosystem concerns. These have historically been focused on fish and only recently have been expanded to include invertebrates.

#### *Commercial fishery species*

With the exception of the fishery that harvests precious corals, there is little evidence of a direct association between precious corals and other fishery targets. However, these evaluations have been limited to comparing the overlap in depth ranges and making infrequent underwater observations. Even less is known about the deep sea corals not targeted in the precious coral fishery, or any indirect ecological effects that any of these corals may contribute to commercial fishery stocks. Some of the shallow coral reef fish targeted by recreational fishers and the aquarium trade range into depths where black corals (antipatharians) can be found (30–100 m) (Moffitt et al. 1989; Parrish and Boland 2004; Boland and Parrish 2005). One of the commercially sought bottom fish *Aprion virescens* (grey snapper), also lives in this depth range but most of the commercial bottom



**Figure 4.5.** Two species of black coral trees *Antipathes grandis* (left) and *Antipathes*. cf. *curvata* (right). Photo credit F. Parrish, NOAA Fisheries.



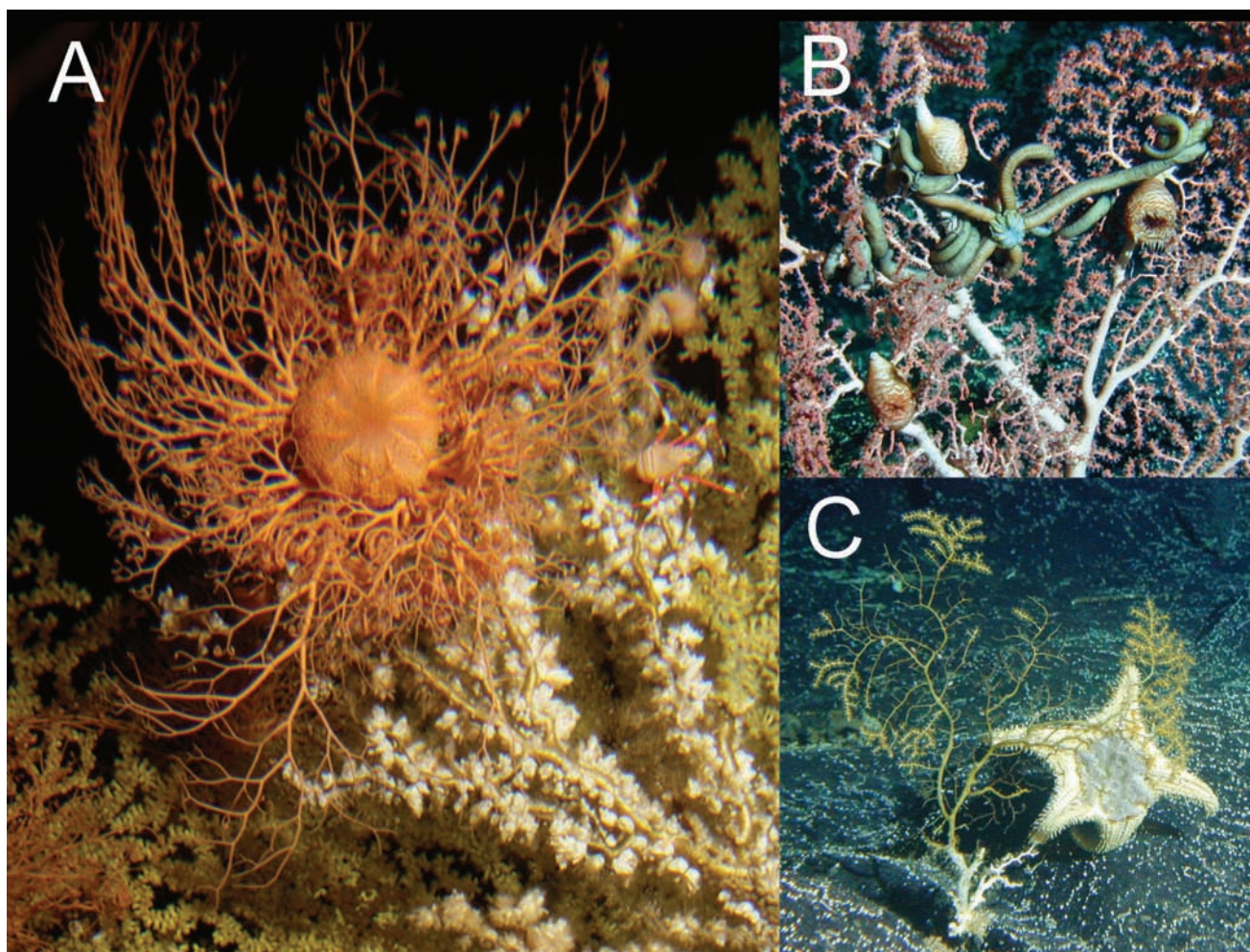
fish reside at depths below antipatharians and above the precious corals (<300 m) (Uchida and Tagami 1984). The shallowest members of this group, such as *Pristipomoides filamentosus* (pink snapper), *Pristipomoides zonatus* (oblique-banded snapper), and *Epinephelus quernus* (Hawaiian grouper), have been seen in the vicinity of deeper black coral trees (Moffitt et al. 1989). Similarly, the deeper members including *Etelis carbunculus* (ruby snapper) and *Etelis coruscans* (flame snapper) have been seen among the shallower precious corals (Kelley et al. 2006). The groundfish, *Pseudopentaceros wheeleri* (armorhead) and *Beryx* sp. (alfonsino) occur throughout this depth range (250–350) but are more common on the seamounts at the northern end of the Hawaiian Archipelago (Uchida and Tagami 1984). There is no information on the degree of overlap of these fish with deep sea corals. *Heterocarpus* sp. (deep-water shrimp) has been seen among the precious corals but at densities consistent with other bottom relief types.

*Heterocarpus* sp. is the focus of an intermittent main Hawaiian Island trap fishery that targets depths of 500 to 900 m (Moffitt and Parrish 1992) overlapping the lower limit of precious coral depths, but in the depth range of many other deep coral species.

### **Noncommercial species**

#### *Fish*

Studies of fish associations with deep corals have focused almost exclusively on the inventory of fish taxa and appraisal of the obligate or facultative roles corals play in fish assemblages. The fish community of the Auau Channel black coral bed was recently surveyed (Boland and Parrish 2005) and 95% of the fish found in and around the black corals were known to commonly occur on shallower reefs where black corals do not grow. *Oxycirrhites typus* (the longnose hawkfish), was found exclusively within the black coral trees. Behavioral data indicated that although most of the reef fish routinely passed through the coral



**Figure 4.6.** Examples of invertebrates found associated with deep corals (A-basket star, B-ophiuroid, C-asteroid. Photo credit A.Baco, WHOI.



branches, only four species reliably used the corals for cover when evading a threat (Figure 4.5). Although there is little or no known obligate relationship between fish and black coral, the coral colonies contribute to the fish community by enhancing the vertical aspects of the deep reef and perhaps improving the corridors for fish movement.

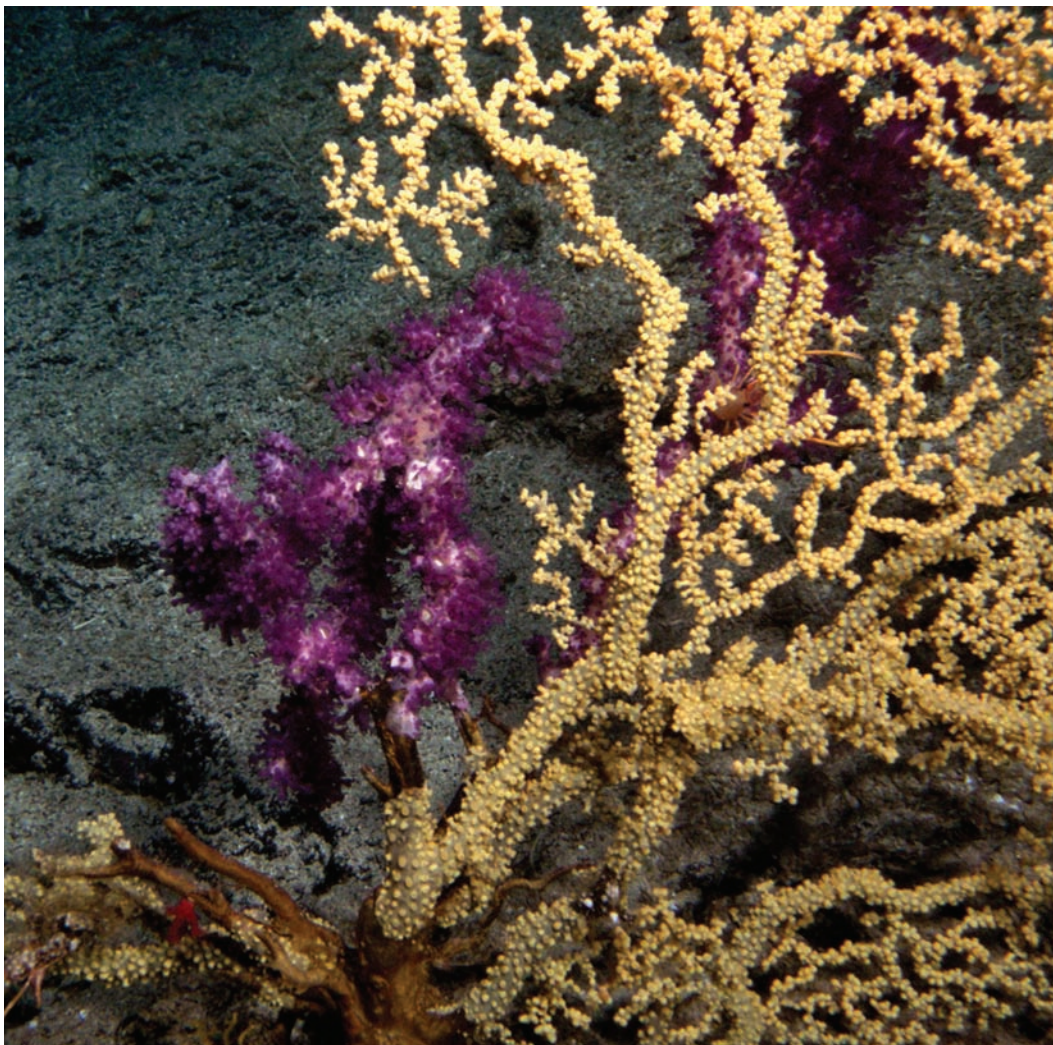
Most of the fish of the deep slope and subphotic depths are noncommercial species (Chave and Mundy 1994). The surveys of fish communities at deeper subphotic depths indicated few fish associations with precious corals (Parrish 2006). Many of the 42 fish taxa observed were seen to use *Gerardia* and *Corallium* spp. as shelter interchangeably with abiotic relief sources. Species richness of fish was not observed to differ between areas with corals and those without. Most fish taxa were observed in low numbers with only a couple of dominant species. Areas with corals often supported greater fish density, but statistical evaluations suggested that this

was based on co-occurrence of fish and coral in areas of relief and high flow and not based on a dependency of fish on corals. Also, differences were not seen in the mean size of fish in or outside of the coral beds. Of the three commercial coral species, fish oriented mostly around *Gerardia* sp. probably because it is significantly taller than the two *Corallium* species. Classifying the fish into functional groups revealed “benthic hoverers” as the segment of the fish community that most frequently used *Gerardia* sp. as shelter.

Although use of corals by the fish appeared incidental, it is important to consider these studies were conducted in summer, during the day and focused exclusively on adult fish. It is unknown if the corals play some seasonal or diurnal role in the fish ecology or if juvenile stages rely on the coral colonies.

#### *Invertebrates*

There is a wide array of invertebrate species associated with deep corals. Black corals are



**Figure 4.7.** The purple octocoral *Clavularia grandiflora* growing on a *Gerardia* sp. colony. Photo credit A. Baco, WHOI.

known to be colonized by oysters, bryozoans, and shrimp (Hoover 1998). The most common invertebrates associated with the deeper precious corals include zoanths, anemones, galathaeoid crabs, sponges, ophiuroids, and basket stars (Figure 4.6). *Gerardia* sp. is perhaps the best known coral that overgrows the skeletons of other coral species. Examination of *Gerardia* sp. skeletons and many submersible observations suggests it has an obligate need to start its colony over the skeleton of other corals. Bamboo corals seem to be the most frequent target, particularly *Isidella trichotoma*, but *Gerardia* has been observed growing on quite a number of species. Several other species of unidentified zoanths also appear to prefer to grow on other corals, including *Gerardia* sp. At least one of these zoanths was observed growing on basalt substrate as well as encrusting other corals (A. Baco pers. obs.). Octocorals also can grow on the skeletons of other coral species. The bright purple *Clavularia grandiflora* has been observed growing on *Gerardia* at a number of sites throughout the Archipelago (Figure 4.7). In all of these cases, it is not clear whether the overgrowing corals are actually killing or injuring the coral whose skeleton they are growing on, or if they have simply colonized a dead area of the skeleton.

Many coral colonies have a number of commensal invertebrates such as galathaeoid crabs, barnacles, sponges, anemones, polychaetes, crinoids, ophiuroids, and basket stars (Chave and Malahoff 1998; A. Baco and Shirley, unpublished data). Casual observations suggest some of these commensals may be specific to their host while others are more generalized. The relationships between the coral and the commensal, e.g., symbiotic, parasitic, obligate, facultative, etc., have not been determined in most cases and many of the commensal species have yet to be identified. One of the more notable commensal relationships is the general association of polychaetes with species in the genus *Corallium*. Each *Corallium* species appears to have its own species of polynoid polychaete. In *Corallium secundum* and *Corallium laauense*, these polychaetes can reach fairly high densities. The polychaetes live in tunnels under the coral soft tissue with the skeleton often growing over the polychaete tunnels. This relationship has also been observed in other corals such as *Candidella helminthophora*.

A more generalized commensal is the unbranched basket star, *Asteroschema*. *Asteroschema* sp. has been observed in a number of different species of octocorals at a number of sites, but not on the surrounding substratum. Dead coral skeletons also appear to provide good recruitment habitat for many invertebrate species. Many types of sessile fauna have been observed as well as several types of young corals. In particular, young colonies of the red coral, *Corallium laauense* have been observed growing on dead skeletons of *Gerardia* sp.

Besides the galathaeoid crabs that inhabit the branches of coral colonies, a number of larger crabs are routinely encountered patrolling the bottom around deep corals (e.g., crabs in the families Homolidae, Parapaguridae).

Predation on deep corals by resident invertebrates also occurs. Seastars feed on coral colonies by everting their gut, leaving behind patches of bare coral skeleton. Cidarid urchins are also known to feed on deep corals and these urchins have been observed on deep corals in Hawaii. However, an absence of bare coral skeleton around the urchin's location suggests it is unlikely they are consuming the coral tissues (A. Baco, unpublished data). A single species of orange crinoid was observed in 2004 in very high densities at the Makapuu coral bed (A. Baco, unpublished data). Grigg 2002 comments on an abundant crinoid observed during night dives at this site. The crinoids now cover many octocoral colonies and anything else that sticks up more than a few millimeters off the bottom (A. Baco, unpublished data), suggesting their abundance has increased over Grigg's observations. Their origin and the reason for their recent increase in population density, as well as their potential for competing with corals for food, are unknown.

#### *Monk seals*

In the lower Northwestern Hawaiian Islands, the endangered Hawaiian monk seal has been documented to routinely visit deep corals as part of its foraging activities. However, there have been no reported interactions between monk seals and the precious coral harvesting in the main Hawaiian Islands. Telemetry and scatological analysis indicate seals prey on bottom-dwelling fish (Goodman-Lowe 1998; Parrish and Abernathy 2006; Longnecker et al. 2006). Video cameras fitted to seals in the



**Table 4.2** Potential effects of fishing gears on deep coral habitat in Hawaii. Ratings detailed in table key. Tuna/Swordfish includes: Albacore, Bigeye tuna, Yellowfin Tuna, Skipjack Tuna, Swordfish, Striped Marlin, Pacific Blue Marlin, Black Marlin Sailfish, Shortbill spearfish, Wahoo, Dolphinfish, Opah, Pomfret, sharks. Deepwater shrimp include: two species of *Heterocarpus*, Snappers and Groupers include: Pink snapper, Flower snapper, Squirrelfish snapper, Hawaiian Grouper, Ruby-colored snapper, Blue-green snapperfish.

Gear Type	Current Fishery Use in Region	Potential Severity of Impact	Potential Extent of Impact from Fishing Gear	Current Geographic Extent of Use in Region	Overlap of use with coral habitat	Overall Rating of Gear Impact
Bottom Trawl	N/A	High	High	N/A	N/A	N/A
Mid-water Trawl	N/A	Low	Low	N/A	N/A	N/A
Dredge	N/A	High	Low	N/A	N/A	N/A
Bottom-set Longline	N/A	Med	Low	Low	N/A	N/A
Bottom-set Gillnet	N/A	Med	Med	N/A	N/A	N/A
Pelagic longline	Tuna/swordfish	Low	Med	Med	Low	Low
Traps	Deepwater Shrimp	Med	Med	Low	Low	Low
Hook and line	Snappers/groupers	Low	Low	High	Low	Low

Northwestern Hawaiian Islands have recorded seals commuting to beds of *Cirripathes* sp. whip corals (100 m) where they feed on eels. Satellite tags attached to seals indicated certain seals spent weeks of their foraging focused at specific subphotic locations where surveys with submarines have revealed red and gold corals (Parrish et al. 2002). More recent satellite tagging of seals at the northern extent of the Northwestern Hawaiian Islands shows similar feeding patterns to subphotic depths (Stewart et al. 2006). Monk seals have also been observed from the Pisces V submersible at more than 500 m while scientists were conducting coral surveys (A. Baco pers. obs.). The video of the encounter shows the seals briefly looking over the submersible and then using the light field from the sub to look into holes and cracks of the bottom.

## VI. STRESSORS ON DEEP CORAL COMMUNITIES

Deep coral communities within the Pacific region may be affected by a number of natural and anthropogenic stressors. Natural mortality has

been attributed to smothering by sediments and by bioerosion of the substrata at the attachment site, which leads to toppling of colonies (Grigg 1993). Detached colonies are rarely able to reattach.

The life history attributes of deep corals makes them highly vulnerable to habitat damage associated with fishing gear and overexploitation in unmanaged coral fisheries (Table 4.2). Many year classes are exposed to effects at the same time. During intensive periods of indiscriminate fishing using bottom damaging gear, decades of accumulated coral growth can be lost (Grigg 1993).

### **Fishing effects**

#### *Bottom Trawling*

Mobile bottom-tending gear (e.g., trawls, dredges) are banned in the U.S. Pacific Islands Region. From 1967 to 1975, Soviet and Japanese trawlers fished the seamounts at the south end of the Emperor Chain (e.g., Coco Seamount, Milwaukee Seamount, Colahan Seamount) and some of the seamounts at the north end of the Hawaiian



Archipelago, including seamounts that were later designated as part of the U.S. exclusive economic zone (e.g., Hancock Seamount, Seamount 10, Seamount 11, Ladd Seamount) (Uchida and Tagami 1984). The primary fishing target was *Pseudopentaceros wheeleri* (armorhead) and *Beryx* spp. (alfonsinos) (Uchida and Tagami 1984). In 2003, submersible dives at Seamount 11 found a large area with coral stumps and no new colonization (A. Baco pers. obs). The destruction was confined to a large swath within a fairly large precious coral bed (previously unknown). It could not be determined if this affected area was the result of mobile bottom-tending gear used in the early 1970s but if so, recovery clearly requires decades.

#### *Longline fishing*

Bottom longlining is not permitted in the Pacific Islands Region. Pelagic longlining for tuna and swordfish is permitted and is the region's largest fishery. Longlines must be set at least 25 miles, and in most cases 50–75 miles from emergent parts of the Hawaiian Archipelago (WPFMC 1991). This regulation was adopted to prevent conflicts with the coastal trolling fishery but it also reduces the possibility that the gear will affect deep corals on the slopes and seamounts of the Hawaiian Ridge. One exception is Cross Seamount located ~ 100 miles south of Oahu. A popular fishing site for monofilament handline fishing and some longline activity, it has accumulated numerous large fragments of monofilament line draped over the summit (F. Parrish pers. obs). Some of these line fragments have been seen entangled in *Gerardia* sp. colonies (A. Baco pers. obs.) and other coral trees appear to have been damaged. As this is the only location that impacts to deep coral from monofilament fishing have been documented the assigned impact rating is "Low."

#### *Traps*

Bottom-set traps have been used to catch lobster and shrimp in the Hawaiian Archipelago. The Northwestern Hawaiian Islands trap fishery for *Panulirus marginatus* (Hawaiian spiny lobster) and *Scyllarides squammosus* (slipper lobster) is now closed, but had always operated in waters shallower than deep coral habitat (Polovina 1994, Dinardo and Moffitt 2007). Trap fishing for the deepwater shrimp *Heterocarpus laevigatus* and *Heterocarpus ensifer* is a small-scale pulse fishery limited to the main Hawaiian Islands that

has landed 680 metric tons since the fishery's inception in 1984 (PIFSC IR-06-010). The shrimp trapping overlaps the depth range of deep corals (Ralston and Tagami 1992; Moffitt and Parrish 1992), but actual impacts to deep corals have not been documented. Shrimp have been observed associated with hard bottom features (Moffitt and Parrish 1992) and if fishers seek hard bottom to set their traps, there is potential for damage to deep corals. In Table 4.2, the overall gear impact rating of shrimp trapping was classified "Low" because of the small size and localized nature of the fishery. However if the fishery expands the potential impacts to deep corals would be an important consideration. There are no other recognized trap fisheries operating in the U.S. Western Pacific Islands and if any recreational or artesanal trapping is happening, it is at a very small scale and in shallow depths.

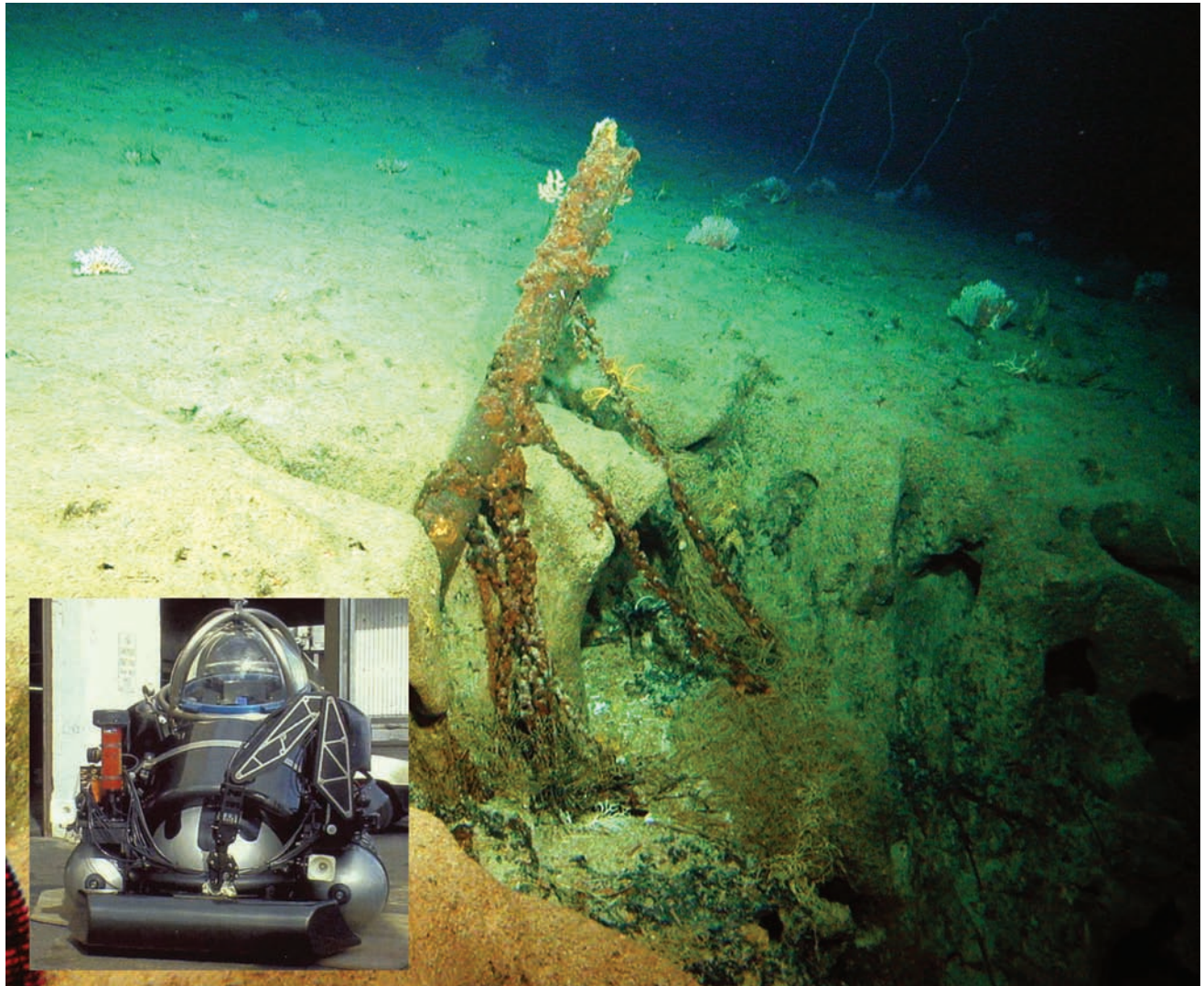
#### *Other*

Fishing for reef species and bottom fish typically rely on spearing and hook and line fishing. Spearfishing is largely constrained to the shallowest depths and is unlikely to have an effect on deep corals. Corals might be damaged by the 3-kg bottom weight used to lower handlines for bottom fishing or might be snagged by the attached hooks. However, visual surveys from submersibles have inspected popular bottom fishing sites in the main and Northwestern Hawaiian Islands for fishing impacts and have found little or no derelict gear (Kelley et al. 2006), and there are no reports of coral bycatch (WPFMC 2005).

#### ***Effects of other human activities***

##### *Coral Harvesting*

The commercial harvest of coral is the best documented effect to black corals and precious corals (pink, red, and gold) within the Hawaiian Archipelago. Coral harvesting has been subject to management under both federal and state regulations since the 1980s. Commercial harvest of black coral has always been selective, collected by scuba divers using hand tools. The deeper precious coral beds were fished initially using nonselective tangle net dredges, but regulations now require the use of selective methodologies such as a submersible (Figure 4.8). Commercial harvesting of black and precious corals has not been reported elsewhere in the U.S. Pacific outside of the Hawaiian Archipelago.



**Figure 4.8.** A derelict coral dredge lost during the earliest days of the fishery (Dredge photo credit: A. Baco, WHOI). Inset is the Deepworker submersible which was the most recent harvesting tool employed. Photo credit: American Deepwater Engineering.

Maui Divers, Inc. established the small black coral industry in 1960 and has kept the fishery operating at varying levels continuously to the present. Limited commercial harvest of black coral also occurred in two other beds off Hawaii and Kauai. State records indicate a mean annual harvest of black coral at  $1014 \text{ kg yr}^{-1}$  from 1981 to 1997 (Grigg 2001). Between 1999 and 2002 there was an increase in demand accompanied by an increase in harvesting (Grigg 2004). This fishery often operates with fewer than three fishers so confidentiality prevents disclosure of annual data. Aggregating data into 7-year bins showed landings increased from 1985 to 2005 with the 1999-2005 7-year bin at 22 mt which is more than double the prior 7-year bins (WPRFMC 2006). Much of this increase has been attributed to improved efficiency in fishing due to the availability of detailed bathymetric maps

and adoption of GPS positioning. Although 11 genera of antipatharians have been reported in international trade, only three species (*Antipathes* cf. *curvata* {formerly *Antipathes dichotoma*} *Antipathes grandis* and *Myriopathes ulex*) have been commercially harvested in Hawaiian waters, with >90% of the harvested coral consisting of *A. c.f. curvata*. Other black coral species known to exist in this region are found in deeper waters and are not considered to be of commercial grade (Grigg 1993).

In 1965, a bed of commercial grade pink coral was discovered at about 400 m depth on the Milwaukee Banks in the Emperor Seamount Chain. In 1966, *Corallium secundum* was also discovered in the Makapuu Bed off Oahu, and a small group of fishermen dredged the bed using tangle nets (Grigg 1993). Maui Divers of Hawaii



began using a manned submersible to selectively harvest pink, gold, and bamboo coral from this bed. They removed a total of 8227 kg of pink coral and 2097 kg of gold coral between 1973 and 1978 and then discontinued fishing as a result of high operating costs (Grigg 1993). Pink corals were also harvested in 1988 from Hancock Seamount using nonselective gear, although only 450 kg of *C. secundum* were obtained, most of which were considered poor quality (Grigg 1993). In 1978, an undescribed species of *Corallium* was discovered at Midway Grounds (Emperor Seamounts) at depths of 900–1500 m. This resulted in a “coral rush,” with more than 100 boats from Japan and Taiwan operating in this area. Total yield exceeded 300 metric tons from 1979 to 1984 and then dropped off because of resource depletion (Grigg 1993).

In 1999, a Hawaii-based marine salvage and engineering company bought two deep-worker submersibles and began commercial harvesting of deep corals at the Makapuu and Keahole coral beds. Operations targeted pink, red, and gold corals. Harvesting ended in 2001, when their first coral auction indicated the price of the coral was too low to make submersible operations cost effective, and potential harvesting grounds in the Northwestern Hawaiian Islands were eliminated as a result of Presidential Executive Order 13196, which formed the Coral Reef Ecosystem Reserve

in the Northwestern Hawaiian Islands (Grigg 2002). Because the fishery is made up of a single company, confidentiality prevents reporting of landings data. However the permitted quota was not filled at either of the two beds where corals were harvested. Grigg (2002), working closely with the industry, reported removal of 60% of the allowed coral quota (1,216 kg) at the Makapuu Bed and 20% (211 kg) at the Keahole Bed. The precious coral fishery remains dormant today.

#### *Illegal coral dredging*

Currently, the threat of illegal coral dredging is thought to be remote. It is included here because foreign fishing vessels were documented illegally coral dredging in the remote Northwestern Hawaiian Islands in the early 1970s (Grigg 1993). Currently, there is no evidence or even rumors of such illegal activity. However, much of the Pacific region is remote and unpopulated and any such activity could go undetected. Given the slow growth of deep corals and low recruitment rates, even brief periods of illegal dredging could have lasting effects.

#### *Invasive species*

In 1972, the alien soft coral *Carijoa riisei* (Family Clavulariidae) was found in the fouling community of Pearl Harbor (Englund 2002). Originally thought to have colonized from the tropical Atlantic, recent genetic work (Samuel Kahng pers. comm.) suggests it arrived from elsewhere. It has and continues to spread to other suitable areas in Hawaii with high flow and low light (Figure 4.9). In 2001 deepwater surveys of the Auau Channel black coral beds using submarines revealed that more than 50% of the black coral, particularly the deeper, large reproductive colonies, were overgrown and killed by *Carijoa* (Kahng and Grigg 2005). However, *Carijoa* was rare on black coral trees in waters shallower than 75 m (Boland and Parrish 2005). Light levels are thought to be too high for *Carijoa* to colonize the shallower black coral trees. This invasive coral has been identified as a risk to the black coral fishery. Historically, black coral trees that were too deep to be harvested by divers were thought to serve as a de facto reserve for the fishery. With the recent discovery that many of the deep colonies have been killed by *Carijoa*, current management practices are being reviewed (Grigg 2004). Preliminary surveys of black



**Figure 4.9.** The invasive gorgonian octocoral *Carijoa riisei*, that infests the deeper black corals of the Auau Channel beds. Photo credit: F. Parrish, NOAA Fisheries.



coral beds on Kauai and the island of Hawaii have not found an infestation of *Carijoa*. The occurrence of *Carijoa* or other invasive species on deep corals elsewhere in the Pacific has not been reported.

## VII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

The Pacific Islands Region has a 25-year history of managing deep corals associated with its Precious Coral Fishery Management Plan. The plan was the first fishery management plan approved by NMFS when the Western Pacific Fishery Management Council was established as part of the national network of fishery councils (WPFMC 1980). The plan was implemented in September 1983 (48 FR 39229).

### *Management of fishery resources and habitats*

Historically, research has been focused on taxonomy (Grigg and Bayer 1976), coral assessments and estimates of age and growth to support the information needs to manage the fishery (Grigg 1965, 1974, 1988b, 1993, 2001). In recent years, management research has expanded to include work assessing the connectivity of coral taxa across the Hawaiian Archipelago (Baco and Shank 2005; Baco et al. 2006; Baco in prep.) and potential ecological associations between corals and other fauna (Parrish et al. 2002; Boland and Parrish 2005; Parrish 2006; Baco and Shirley in prep.). Studies are now focusing on the threat *Carijoa riisei* presents to the black coral stock (Grigg 2002; Kahng and Grigg 2002). Replanting corals has been discussed as a means to mitigate impacts to the black coral stock from *Carijoa* and coral harvesting. Some preliminary “replanting” research has been conducted with Hawaiian black coral (Montgomery 2002), and coral harvesters have expressed interest in continuing the work. The expeditions that supported all this research established study sites, deployed thermographs, and marked colonies for future remeasurement to validate growth and monitor the deep coral ecosystem.

### *Mapping Research*

Future coral research will have the benefit of recent multibeam sonar mapping efforts. Supplementing earlier sidescan sonar (GLORIA system) and single beam sonar mapping efforts, multibeam

products, including detailed bathymetry and backscatter imagery, have been made for the Hawaiian archipelago and other portions of the U.S. Pacific (Products by John Smith at HURL; Miller et al. 2003; Parke and Wang 2005). These efforts will provide a fundamental bathymetric context that future coral surveys will be able to use to infer the likelihood of deep corals. Efforts are currently underway to test laser-line scan survey technology on the black coral beds of the main Hawaiian Islands as a more promising means of directly surveying the colony abundance of deep corals.

### *Fisheries Management Council*

The Western Pacific Fishery Management Council (WPFMC) has responsibility for preparing fishery management plans (FMPs) for the fisheries in the U.S. exclusive economic zone (EEZ) of the Pacific Islands Region. Because of the steep relief of many Pacific Islands, deep corals also occur within state and territory waters, and fisheries can also be governed by state and territory laws and regulations. The Freely Associated States are sovereign countries and management of fisheries within their EEZs is governed by their own laws and regulations. WPFMC, an early leader in managing habitat impacts of fishing gears, prohibited demersal fish trawls, bottom-set longlines, and bottom-set gillnets throughout the U.S. Pacific Island EEZ in 1983. The State and territorial laws of Hawaii, Guam, CNMI, and American Samoa all prohibit the use of demersal fish trawls within their waters. The sovereign territories of Kingman Reef, Palmyra Atoll, Jarvis Island, Howland Island, Baker Island, Midway Island, and Rose Atoll are National Wildlife Refuges administered by the U.S. Fish and Wildlife Service, while Wake Island and Johnston Atoll are managed by the Department of Defense. Commercial fishing is not allowed within the Fish and Wildlife Refuges. Thus, throughout the region, both shallow and deep corals have been largely spared impacts from trawling, at least within the last 25 years.

### *Directed Harvest*

The Precious Coral FMP and its regulations classify known coral beds within the western Pacific region and designate the harvesting method and amount of corals that can be harvested from each bed. All the known coral beds are in the Hawaiian Archipelago but the FMP includes provisions for exploratory fishing

in other areas of the U.S. Pacific. The beds are classified as: 1) Established Beds, 2) Conditional Beds, 3) Refugia Beds, and 4) Exploratory Permit Areas. Established beds have a history of harvest for which maximum sustainable yield (MSY) has been determined. Makapuu is the only designated Established Bed although the Auau black coral bed is in the process of being designated as established. Conditional beds have MSYs estimated based on their perceived size relative to established beds. There are four conditional beds: Keahole Point, Kaena Point, Brooks Banks and 180 Fathom Bank. The WESTPAC Bed is designated as a refugia bed, where no harvest is permitted. Exploratory permit areas include four unexplored portions of the EEZ around Hawaii, Guam and CNMI, American Samoa, and all remaining U.S. Island Possessions. The FMP, as amended in 2002, prohibits the use of nonselective gear (e.g., tangle nets, dredges) throughout the management area. Black coral is primarily found in State waters and the State and the WPFMC jointly manage the resource. Quotas and minimum size limits are monitored through mandatory reporting to NMFS and the Hawaii State Division of Aquatic Resources using coral landing logs and buyer reports.

Currently, two precious coral issues are progressing through the WPFMC process. The first is reconciling coral lifespan estimates derived from radiometry studies (Roark et al. 2006) with prior estimates made from the size structure distribution of coral colonies and ring counts from basal stem cross sections. Of the three commercial corals, the black coral (*Antipathes cf. curvata*) radiometric estimates were consistent with growth rates estimated from size structure data (Grigg and Bayer 1976). The radiometric life span of pink coral was twice prior estimates, and gold coral (*Gerardia* sp.) was estimated at more than an order magnitude longer lived than prior growth estimates (Grigg 2002). This has prompted the WPFMC to put a 5-year moratorium on the fishing of gold coral until the conflicting lifespan data can be resolved. The second issue is concern that the Maui black coral bed may be experiencing reduced recruitment (Tony Montgomery, State of Hawaii, unpublished data; WPFMC 2006). This uncertainty combined with the loss of a portion of the stock to *Carijoa riisei* leaves today's biomass at least 25% lower than assessments in 1976 (Grigg 2004).

#### *Closed areas*

As noted above, all U.S. State and Federal waters in the Pacific Islands are closed to trawling and dredging—the fishing techniques most destructive to deep corals. Additional restrictions on fishing and other potentially harmful activities are in place in the National Wildlife Refuges, Papahānaumokuākea Marine National Monument, and in marine protected areas within state or territory waters.

The only area that was specifically closed to protect deep corals was WESTPAC Bank (located N.W. of Nihoa) in the Northwestern Hawaiian Islands. It was set aside by the precious coral FMP as a refuge from coral harvesting. Despite some interest, domestic precious coral fishing has never occurred in the Northwestern Hawaiian Islands. On determining that monk seals were visiting precious coral beds, the WPFMC proposed expanding the refuge to include areas where seals were visiting. Superseding this move, the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve was established in 2001 by Executive Order (No. 13178 and No. 13196) and prohibited most commercial fishing, including all harvesting of deep corals in the Reserve. In 2006, while the Northwestern Hawaiian Islands Reserve was undergoing the designation process to become a national marine sanctuary, it was proclaimed a national monument by Presidential Order under the Antiquity Act of 1906 and renamed Papahānaumokuākea Marine National Monument. Within the main Hawaiian Islands and elsewhere in the Pacific, marine protected areas have not been established specifically for the purpose of protecting deep coral communities. However, there is interest from managers and coral harvesters to establish a closed area off Maui specifically for black coral to serve as a reproductive reserve and a biological reference site.

#### *Minerals Management Service*

Oil or gas exploration does not occur in the Pacific Islands Region. Historically, some research has focused on the prospect of mining manganese nodules that are formed at abyssal depths. Recently, interest in cobalt-rich manganese mining has resurged and large areas of the Pacific seabed, some of which include U.S. Pacific Islands and seamounts, are part of the potential mining areas (International Seabed Authority [www.isa.org.jm/en/seabedarea/default](http://www.isa.org.jm/en/seabedarea/default)).



asp). Further studies of these cobalt-rich regions to determine deep-coral abundance and potential mining impacts should be considered a high priority.

### VIII. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

The priorities for future work can be divided into the following: 1) mapping and species inventory of deep corals, and 2) determining the important physiological and ecological components of deep coral ecosystems. The inherently fragile and patchy nature of deep corals means that determining where they are found is a primary goal. Good success has been achieved using available mapping, remotely operated vehicles (ROV), and submersible infrastructure. This should continue and extend out to the more remote areas of the U.S. Pacific Islands Region. Also, research is needed to validate promising new tools to assess coral stocks with an initial focus of using such gear at sites previously surveyed using visual methods.

#### 1) Highest mapping and assessment priorities

- Assessments in the remote Pacific—Historically, most research has occurred in and around the Hawaiian Archipelago, leaving American Samoa, Guam, CNMI, and the rest of the western Pacific unstudied. Baseline assessments are needed for these other areas, particularly those that may be affected by cobalt-manganese mining or fishery activities. Documenting areas with extensive coral resources will permit more focused enforcement and conservation effort. These assessments will also provide the DNA material for connectivity work, provide samples to improve taxonomy and systematics of deep corals, and provide an invaluable test to current theories on deep coral biogeography.
- Deeper surveys—Although the Hawaiian Archipelago has had some studies, few baseline assessments of deep corals have occurred outside of precious corals depth and none below 1800 m. There is a need to survey deeper habitats to better determine the species ranges, biodiversity, and abundance of deep corals.

- Taxonomy—Critical to all of the assessment and ecology studies will be a dedicated effort to improve the taxonomy and systematics of deep corals, and to increase the number of people trained to identify these corals. There are very few deep coral experts in the world and there are currently more groups of deep corals needing revision and new species needing description than these taxonomists can complete in their lifetimes.
- Coral recovery studies—Beds that have been commercially harvested or impacted by fishing gear and coral harvesting should be periodically reassessed to determine whether or not the coral taxa are recovering. The seamounts that were subjected to bottom trawling or illegal harvesting more than 30 years ago should be surveyed for signs of coral recovery.

#### 2) Physiological and ecological components of the deep coral ecosystem

- Environmental parameters for deep corals—The patchy nature of deep corals, even in areas with similar substrate, relief, and depth implies that their distribution is influenced by other biological or environmental factors. Understanding the oceanographic factors that influence coral distributions will be fundamental to evaluating deep corals as a climate record as well as predicting where they might occur in unexplored areas.
- Life history, population connectivity, and biogeography—There is a need to understand more about the life history, reproduction, recruitment, growth, and dispersal abilities of deep corals; how the populations are connected within island/seamount chains and between them, and how the islands and seamounts of the U.S. Pacific are connected genetically and biogeographically to other parts of the Pacific.
- Species associations—The ecological contribution of corals to their associated community needs greater attention, particularly the invertebrates, which are more likely to be dependent on the coral colonies. Subphotic fish communities are likely to be different in the remote regions of the Pacific and may be more tightly associated with deep corals.
- The ecological impact of *Carijoa riisei*—*Carijoa riisei* represents the most clear and present threat to the stock of black coral and

has important implications to the black coral fishery. Research is needed to identify and understand possible ecological changes to the community and develop means to limit the spread of *Carijoa riisei* to other black coral habitats. Some research should be conducted to determine the feasibility of remediation efforts for black coral through replanting programs.

## IX. CONCLUSIONS

- Deep corals occur throughout the U.S. Pacific but only the Hawaiian Archipelago and Line Islands have been the subject of any surveys. Coral habitat is patchy, suggesting at least a basic need for suitable bottom type and conditions of rapid flow. The gradients in dissolved oxygen, temperature, suspended particulates, etc., are less understood and are a priority for future work. Available surveys indicate coral beds dense with colonies that cover large areas are the exception. Given the region has little history of trawling and mobile bottom-tending gear, it is reasonable to assume this is the natural condition.
- Hawaiian fish are known to opportunistically use the corals as shelter and to some degree they co-occur with corals in high flow habitats. It is not known how the fish behave with deep corals in the other parts of the Pacific. Invertebrates are largely unstudied and the degree of their association with deep corals is unknown but likely to be greater.
- Currently, the greatest threat to corals is the potential for spread of the invasive species *Carijoa riisei* from the Auau channel to other black coral beds on Kauai and Hawaii. Following that, the harvesting in the 3 beds where the coral fishery operates needs to be closely monitored. For the black coral bed in the Auau channel, attention is needed because of the unanticipated loss of black coral to *Carijoa riisei*. At Makapuu, the regrowth of pink coral has been documented once and should be checked for continued resilience. The Keahole bed was targeted for red and gold coral, and its prospects for resilience are as yet unproven. Finally,

the impacts to deep corals from derelict handlines/longlines at Cross Seamount and shrimp trapping in the main Hawaiian Islands should be assessed.

- Many of the new coral beds that have been identified in the Northwestern Hawaiian Islands are protected as part of the Papahānaumokuākea Marine National Monument. Being remote from the anthropogenic influences of the main Hawaiian Islands make them important biological reference sites for future research.



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**Appendix 4.1.** List of known species of deep corals from the U.S. Pacific Islands. All species listed are found in Hawaii except one octocoral, *Keroeides koreni* and several antipatharians as noted. List for octocorals and scleractinians in Hawaii based primarily on unpublished list compiled by Dr. Stephen Cairns, Smithsonian Institution, with additions from recent Pisces cruises led by A. Baco and additions for non-Hawaiian islands based on cited literature. List for antipatharians from Hawaii and Guam unpublished list compiled by and courtesy of Dr. Dennis Opreško.

\* = depth range known from full range for species, including outside chapter region

\*\* = depth range known from 2 or more specimens from Hawaii, Christmas, Line Islands, etc

\*\*\* = depth from a single individual from Hawaii, usually the holotype

Higher Taxon	Species	Distribution	Depth Range (m)	References
Phylum Cnidaria				
Class Anthozoa				
Subclass HEXacorallia (Zoantharia)				
Order Scleractinia				
Family Anthemiphylliidae	<i>Anthemiphyllia macrolobata</i>	HI Islands	369***	Cairns, 1999
	<i>Anthemiphyllia pacifica</i>	HI Islands & Bikini Atoll, RMI	205-296**	Vaughan, 1907, Cairns, 1984
Family Caryophylliidae	<i>Anomocora</i> sp. cf. <i>A. fecunda</i>	HI Islands	201-271**	Pourtales, 1871, Cairns, 1984
	<i>Bourneotrochus stellulatus</i>	HI Islands	274-336**	Cairns, 1984
	<i>Caryophyllia atlantica</i>	HI Islands	1602**	Duncan, 1873, Cairns, 1984
	<i>Caryophyllia hawaiiensis</i>	HI Islands	44-388**	Vaughan, 1907, Cairns, 1984
	<i>Caryophyllia marmorea</i>	HI Islands	331-337**	Cairns, 1984
	<i>Caryophyllia octopali</i>	HI Islands	457-627**	Vaughan, 1907, Cairns, 1984
	<i>Caryophyllia rugosa</i>	HI Islands	137-439**	Moseley, 1881, Cairns, 1984
	<i>Caryophyllia</i> sp. cf. <i>C. ambrosia</i>	HI Islands	56-206**	Alcock, 1898, Cairns, 1984
	" <i>Ceratotrochus</i> " <i>laxus</i>	HI Islands	583-678**	Vaughan, 1907
	<i>Coenosmilia inordinata</i>	HI Islands	244-322**	Cairns, 1984
	<i>Conotrochus funiculumna</i>	HI Islands	165-600**	Alcock, 1902, Cairns, 1984
	<i>Crispatotrochus rubescens</i>	HI Islands & Christmas Island, Line Islands	197-634**	Moseley, 1881, Cairns, 1984
	<i>Deltocyathus</i> sp. cf. <i>D. andamanicus</i>	HI Islands	274-518**	Alcock, 1898, Cairns, 1984

Higher Taxon	Species	Distribution	Depth Range (m)	References
	<i>Desmophyllum dianthus</i>	HI Islands		Esper, 1794
	<i>Paracyathus molokensis</i>	HI Islands	161-260**	Vaughan, 1907
	<i>Trochocyathus aithoseptatus</i>	HI Islands	371-454**	Cairns, 1984
	<i>Trochocyathus burchae</i>	HI Islands	64***	Cairns, 1984
	<i>Trochocyathus gardineri</i>	HI Islands	274-470**	Vaughan, 1907, Cairns, 1984
	<i>Trochocyathus mauiensis</i>	HI Islands	174-278**	Vaughan, 1907
	<i>Trochocyathus oahensis</i>	HI Islands	75-571**	Vaughan, 1907, Cairns, 1984
	<i>Trochocyathus patelliformis</i>	HI Islands	1020***	Cairns, 1999
	<i>Trochocyathus rhombocolumna</i>	HI Islands	110-530*	Alcock, 1902
<b>Family Dendrophylliidae</b>	<i>Balanophyllia desmophyllioides</i>	HI Islands	143-406**	Vaughan, 1907
	<i>Balanophyllia diomedea</i>	HI Islands	110-307**	Vaughan, 1907, Cairns, 1984
	<i>Balanophyllia gigas</i>	HI Islands	90-640*	Moseley, 1881
	<i>Balanophyllia laysanensis</i>	HI Islands	238-271**	Vaughan, 1907
	<i>Cladopsammia echinata</i>	HI Islands	295-470**	Cairns, 1984
	<i>Cladopsammia eguchii</i>	HI Islands		Wells, 1982
	<i>Eguchipsammia gaditana</i>	HI Islands	244-470**	Duncan, 1873, Cairns 1984
	<i>Eguchipsammia fistula</i>	HI Islands		Alcock, 1902
	<i>Eguchipsammia serpentina</i>	HI Islands	269-362**	Vaughan, 1907
	<i>Enallopsammia rostrata</i>	HI Islands	362-583**	Pourtales, 1878, Cairns, 1984
	<i>Endopachys grayi</i>	HI Islands	37-274**	Milne-Edwards & Haime, 1848a & b, Cairns, 1984
<b>Family Flabellidae</b>	<i>Flabellum marcus</i>	HI Islands & NW of Wake Island	1261-1602**	Keller, 1974, Cairns, 1984
	<i>Flabellum pavoninum</i>	HI Islands	183-517**	Lesson, 1831, Cairns, 1984
	<i>Flabellum vaughani</i>	HI Islands	232-369**	Cairns, 1984
	<i>Javania exserta</i>	HI Islands	400***	Cairns, 2006
	<i>Javania fuscus</i>	HI Islands	13-271**	Vaughan, 1907
	<i>Javania insignis</i>	HI Islands & Christmas Island, Line Islands	52-825**	Duncan, 1876, Cairns, 1984

Higher Taxon	Species	Distribution	Depth Range (m)	References
	<i>Javania lamprotichum</i>	HI Islands & Johnston Atoll	244-322**	Moseley, 1880, Cairns, 1984
	<i>Placotrochides minuta</i>	HI Islands	119-291***	Feinstein and Cairns, 1998, Cairns 2006
	<i>Polymyces wellsi</i>	HI Islands	440-858**	Cairns, 2006
<b>Family Fungiacyathidae</b>	<i>Fungiacyathus fissilis</i>	HI Islands	212-503**	Cairns, 1984
	<i>Fungiacyathus fragilis</i>	HI Islands	1762-2056**	Sars, 1872, Cairns, 1984
<b>Family Gardineriidae</b>	<i>Gardineria hawaiiensis</i>	HI Islands	369-541**	Vaughan, 1907, Cairns, 1984, 2006
<b>Family Guyniidae</b>	<i>Guynia annulata</i>	HI Islands	64-384**	Duncan, 1872, Cairns, 1984
<b>Family Micrabaciidae</b>	<i>Letpsammia formosissima</i>	HI Islands	109-470**	Moseley, 1876, Cairns, 1984
<b>Family Pocilloporidae</b>	<i>Madracis kauaiensis</i>	HI Islands	362-538**	Vaughan 1907, Cairns 2006
<b>Family Oculinidae</b>	<i>Madrepora kauaiensis</i>	HI Islands	362-538**	Vaughan, 1907, Cairns, 1984
	<i>Madrepora oculata</i>	HI Islands	627-750**	Cairns, 1984
<b>Family Turbinoliidae</b>	<i>Deltocyathoides orientalis</i>	HI Islands	439-494**	Duncan, 1876, Cairns 1984, Cairns 2006
<b>Family Stenocyathidae</b>	<i>Stenocyathus vermiformis</i>	HI Islands & S. Pacific Seamounts	439**	Pourtales, 1868, Cairns, 1982, Cairns, 1984
<b>Order Antipatharia</b>				
<b>Family Antipathidae</b>	<i>Antipathes grandis</i>	HI Islands		Verrill, 1928
	<i>Antipathes</i> sp., cf. <i>A. curvata</i>	HI Islands		van Pesch, 1914
	<i>Antipathes</i> n. sp., cf. <i>A. dichotoma</i>	HI Islands		Pallas, 1766
	<i>Antipathes</i> sp. cf. <i>A. flabellum</i>	Guam		Pallas, 1766
	<i>Antipathes</i> sp., cf. <i>A. spinulosa</i>	Guam		Schultze, 1896
	<i>Antipathes intermedia</i>	HI Islands	347-366***	Brook, 1889, Grigg and Opreko, 1977
	<i>Cirripathes anguina</i>	HI Islands	25-40***	Dana, 1846, Grigg and Opreko, 1977
	<i>Cirripathes contorta</i>	Guam		
	<i>Cirripathes propinqua</i>	Guam		
	<i>Cirripathes spiralis</i>	HI Islands		Linnaeus, 1758, Grigg and Eldridge, 1975



## PACIFIC ISLANDS

Higher Taxon	Species	Distribution	Depth Range (m)	References
	<i>Stichopathes echinulata</i>	HI Islands	305-565***	Brook, 1889, Grigg and Opreko, 1977
<b>Family Aphanipathidae</b>	<i>Aphanipathes sarothamnoides</i>	Guam		Brook, 1889
	<i>Acanthopathes undulata</i>	HI Islands	110-490**	van Pesch, 1914, Grigg and Opreko, 1977
<b>Family Cladopathidae</b>	<i>Trissopathes pseudotristicha</i>	HI Islands & Channel Islands	326-4539**	Opreko, 2003
	<i>Trissopathes tetracrada</i>	HI Islands	375-425**	Opreko, 2003
<b>Family Leiopathidae</b>	<i>Leiopathes glaberrima</i>	HI Islands		Esper, 1792, Opreko, 1974
	<i>Leiopathes</i> n. sp.	HI Islands	403-471**	Prelim. ID by Opreko, Pisces Cruise 2003 & 2004
<b>Family Myriopathidae</b>	<i>Myriopathes ulex</i>	HI Islands & Guam		Ellis and Solander, 1786, Grigg and Eldridge, 1975
	<i>Myriopathes</i> sp., cf. <i>M. japonica</i>	HI Islands		Brook, 1889
	<i>Cupressopathes abies</i>	Guam		Linnaeus, 1758
	<i>Antipathella</i> sp., cf. <i>A. subpinnata</i>	HI Islands	455-460***	Ellis and Solander, 1786, Grigg and Opreko, 1977
<b>Family Schizopathidae</b>	<i>Bathypathes alternata</i>	HI Islands	1195-1744**	Brook, 1889, Pisces Cruise 2003
	<i>Bathypathes conferta</i>	HI Islands	380***	Brook, 1889, Grigg and Opreko, 1977
	<i>Bathypathes patula</i>	HI Islands		Brook, 1889, Unpubl record at USNM
	<i>Stauropathes staurocrada</i>	HI Islands & Johnston Atoll	220-441, 1400-1700**	Opreko, 2002
	<i>Stauropathes</i> sp.	HI Islands	604***	Prelim. ID by Opreko, Pisces Cruise 2003
	<i>Umbellapathes helioanthes</i>	HI Islands	1205-1383**	Opreko 2005
	<i>Umbellapathes</i> , new species B	HI Islands	742-744***	Prelim. ID by Opreko, Pisces cruise 2004
	<i>Dendropathes bacotaylorae</i>	HI Islands	408***	Opreko 2005
<b>Order Zoanthidea</b>				
	Zoanthid blue	HI Islands	352-415**	Chave and Malahoff, 1998

Higher Taxon	Species	Distribution	Depth Range (m)	References
	Zoanthid tan	HI Islands	500-1910**	Chave and Malahoff, 1998
	<i>Gerardia</i> sp.	HI Islands	343-577**	Ryland and Baco in prep., Chave and Malahoff, 1998
	<i>Parazoanthus</i> sp. 1	HI Islands	343-460**	Chave and Malahoff, 1998
	<i>Parazoanthus</i> sp. 2	HI Islands	332-1025**	Chave and Malahoff, 1998
<b>Subclass Octocorallia</b>				
<b>Order Alcyonacea</b>				
<b>Family Alcyoniidae</b>				
	<i>Anthomastus fisheri</i>	HI Islands	356-462**	Bayer, 1952, Chave and Malahoff, 1998
	<i>Anthomastus (Bathyalcyon) robustus</i>	HI Islands		Versluys, 1906, fide Williams
	<i>Anthomastus granulatus</i>	HI Islands	20-201**	Kukenthal 1910, Bayer, 1952
	<i>Inflatocalyx</i> sp.	HI Islands		fide Williams
<b>Family Clavulariidae</b>				
	<i>Carijoa riisei</i>	Invasive, HI Islands		Duch. And Mich., 1860
	<i>Clavularia grandiflora</i>	HI Islands	966*	Nutting, 1908, Bayer, 1952
	<i>Telestula corrugata</i>	HI Islands	914*	Nutting, 1908, Bayer, 1952
	<i>Telestula spiculicola</i>	HI Islands	518-616*	Nutting, 1908, Bayer, 1952
	<i>Telestula spiculicola robusta</i>	HI Islands		Bayer, 1952
<b>Family Nidaliidae</b>				
	<i>Nidalia</i> sp.	HI Islands		fide Williams
	<i>Siphonogorgia alexanderi</i>	HI Islands	223-283*	Nutting, 1908, Bayer, 1952
	<i>Siphonogorgia collaris</i>	HI Islands	144*	Nutting, 1908, Bayer, 1952
<b>Order Gorgonacea</b>				
<b>Family Acanthogorgiidae</b>				
	<i>Acanthogorgia</i> sp. cf. <i>A. striata</i> Nutting, 1911	HI Islands	215-564**	Grigg and Bayer, 1976
	<i>Acanthogorgia</i> n. sp.	HI Islands		Muzik, 1979
	<i>Acanthogorgia</i> sp. cf. <i>A. paramuricata</i>	HI Islands	350-396**	Stiasny, 1947, Grigg and Bayer, 1976
	<i>Acanthogorgia</i> sp.	HI Islands	1295***	Bernitson et al., 2001
	<i>Cyclomuricea flabellata</i>	HI Islands	71-396**	Nutting, 1908, Grigg and Bayer, 1976
	<i>Muricella tenera</i>	HI Islands	237-2533*	Ridley, 1884, Nutting, 1908
<b>Family Anthothelidae</b>				
	<i>Anthothela nuttingi</i>	HI Islands	340-465, 1387-1820**	Bayer, 1956, Grigg and Bayer, 1976

Higher Taxon	Species	Distribution	Depth Range (m)	References
	<i>Anthothela</i> n. sp. 1	HI Islands	1319***	Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Anthothela</i> n. sp. 2	HI Islands	1804***	Prelim. ID by Cairns, Pisces Cruise 2003
<b>Family Chrysogorgiidae</b>	<i>Chrysogorgia arborescens</i>	HI Islands	722-914*	Nutting, 1908
	<i>Chrysogorgia chryseis</i>	HI Islands	732***	Bayer and Stefani, 1988, Bertson et al., 2001
	<i>Chrysogorgia delicata</i>	HI Islands	536-1463*	Nutting, 1908
	<i>Chrysogorgia elegans</i>	HI Islands	433-634*	Verrill, 1883, Nutting, 1908
	<i>Chrysogorgia flavescens</i>	HI Islands	1688-1977*	Nutting, 1908
	<i>Chrysogorgia geniculata</i>	HI Islands	146-616*	Wright & Studer, 1889, Nutting, 1908
	<i>Chrysogorgia</i> sp. cf. <i>C. japonica</i>	HI Islands	750-1050**	Wright & Studer, 1889, Grigg and Bayer, 1976
	<i>Chrysogorgia paillosa</i>	HI Islands	704-1858*	Kinoshita, 1913, Grigg and Bayer, 1976, Nutting, 1908
	<i>Chrysogorgia scintillans</i>	HI Islands	580-2050**	Bayer and Stefani, 1988, Chave and Malahoff, 1998
	<i>Chrysogorgia stellata</i>	HI Islands	649-678*	Nutting, 1908
	<i>Chrysogorgia</i> sp. cf. <i>C. stellata</i>	HI Islands	646-675, 830-922*	Nutting, 1908, Grigg and Bayer, 1976, Bayer and Stefani 1988
	<i>Chrysogorgia</i> n. sp. (1/3R)	HI Islands	1204***	Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Chrysogorgia</i> n. sp. (2/5L)	HI Islands	691-742**	Prelim. ID by Cairns, Pisces Cruise 2004
	<i>Iridogorgia superba</i>	HI Islands	704-914*	Nutting, 1908, Grigg and Bayer, 1976
	<i>Iridogorgia bella</i>	HI Islands	750-1925**	Nutting, 1908, Chave and Malahoff, 1998
	<i>Iridogorgia</i> n. sp.	HI Islands	1443***	Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Metallogorgia melanotrichos</i>	HI Islands	183-1385*	Wright and Studer, 1889, Nutting, 1908
	<i>Metallogorgia</i> n. sp.	HI Islands	1805***	Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Pleurogorgia militaris</i>	HI Islands	2142*	Nutting, 1908
	<i>Radicipes spiralis</i>	HI Islands	258**	Nutting, 1908, Grigg and Bayer, 1976



Higher Taxon	Species	Distribution	Depth Range (m)	References
Family Coralliidae	<i>Corallium abyssale</i>	HI Islands	1829-2403***	Bayer, 1956, Bayer unpubl ms
	<i>Corallium ducale</i>	HI Islands		Bayer, 1955, Bayer unpubl ms
	<i>Corallium kishinouyei</i>	HI Islands	1145***	Bayer, 1996, Bayer unpubl ms
	<i>Corallium laauense</i>	HI Islands	365-580**	Bayer, 1956, Grigg and Bayer, 1976
	<i>Corallium niveum</i>	HI Islands	232-282***	Bayer, 1956, Bayer unpubl ms
	<i>Corallium regale</i>	HI Islands	365-719**	Bayer, 1956, Grigg and Bayer, 1976
	<i>Corallium secundum</i>	HI Islands	231-576**	Dana, 1846, Bayer, 1956, Grigg and Bayer, 1976, Pisces Cruise 2003
	<i>Corallium imperiale</i>	HI Islands	1096***	Bayer, 1955, Pisces Cruise 2003
	<i>Corallium cf. secundum</i>	HI Islands		Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Corallium laauense x halmahera</i>	HI Islands		Prelim. ID by Cairns, Pisces Cruise 2003
Family Gorgoniidae	<i>Corallium n. sp.</i>	HI Islands		Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Paracorallium tortuosum</i>	HI Islands	167-408**	Bayer, 1956, Grigg and Bayer, 1976
	<i>Eunicella n. sp. A</i>	HI Islands	275-495**	Grigg and Bayer, 1976
	<i>Acanella dispar</i>	HI Islands	275-445**	Bayer, 1990
	<i>Acanella weberi</i>	HI Islands		Nutting, 1910
	<i>Isidella trichotoma</i>	HI Islands	1920***	Bayer, 1990
	<i>Isidella sp. "5"</i>	HI Islands		Muzik museum id
	<i>Isidella n. sp. (lyrate)</i>	HI Islands	1808***	Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Keratoisis flabellum</i>	HI Islands	346-465**	Nutting, 1908, Grigg and Bayer, 1976
	<i>Keratoisis grandis</i>	HI Islands	1344-1582*	Nutting, 1908
Family Isididae	<i>Keratoisis n. sp.</i>	HI Islands	305-565**	Grigg and Bayer, 1976
	<i>Lepidisis nuda</i>	HI Islands		Wright and Studer, 1889, Grigg and Bayer 1976
	<i>Lepidisis olapa</i>	HI Islands	215-665**	Muzik, 1978
	<i>Lepidisis paucispinosa</i>	HI Islands	539-631**	Wright and Studer, 1889, Nutting 1908, Muzik, 1978
	<i>Lepidisis sp.</i>	HI Islands	1425***	Bemton et al., 2001

Higher Taxon	Species	Distribution	Depth Range (m)	References
Family Keroeidae	<i>Keroeides fallax</i>	HI Islands	238-245***	Bayer, 1956
	<i>Keroeides koreni</i>	Marshall Islands		Wright & Studer, 1889, Bayer, 1956
	<i>Keroeides mosaica</i>	HI Islands	167-465**	Bayer, 1956, Grigg and Bayer, 1976
	<i>Keroeides pallida</i>	HI Islands	146***	Hiles, 1899, Bayer, 1956
Family Paragorgiidae	<i>Paragorgia dendroides</i>	HI Islands	490-1910**	Bayer, 1956, Chave and Malahoff, 1998
	<i>Paragorgia</i> sp. cf. <i>P. regalis</i> Nutting, 1912	HI Islands	350-396**	Grigg and Bayer, 1976
	<i>Paragorgia</i> n. sp.	HI Islands	350-396**	Grigg and Bayer, 1976
Family Plexauridae	<i>Anthomuricea tenuispina</i>	HI Islands	428-531, 581-688**	Nutting, 1908, Grigg and Bayer, 1976
	<i>Anthomuricea</i> sp. cf. <i>A. divergens</i>	HI Islands	381-426**	Kükenthal, 1919, Grigg and Bayer, 1976
	<i>Anthomuricea</i> sp. cf. <i>A. reticulata</i>	HI Islands	362-421**	Nutting, 1910, Grigg and Bayer, 1976
	<i>Anthomuricea</i> n. sp. A	HI Islands		Muzik, 1979
	<i>Bebryce brunnea</i>	HI Islands	167-396**	Nutting, 1908, Grigg and Bayer, 1976
	<i>Bebryce</i> n. sp.	HI Islands		Muzik, 1979
	<i>Muriceides</i> sp. A	HI Islands		Muzik, 1979
	<i>Muriceides</i> sp. B	HI Islands		Muzik, 1979
	<i>Filigella</i> n. sp. <i>Thesea</i> n. sp.	HI Islands		Muzik, 1979
	<i>Muriceides tenuis</i>	HI Islands	232-362*	Nutting, 1908, Muzik, 1979
	<i>Muriceides</i> n. sp. A	HI Islands		Muzik, 1979
	<i>Muriceides</i> n. sp. B	HI Islands		Muzik, 1979
	New genus, n. sp.	HI Islands		Muzik, 1979
	<i>Paracis horrida</i>	HI Islands		Thomson & Henderson, 1906, Muzik, 1979
<i>Paracis miyajimai</i>	HI Islands	362-531**	Kinoshita, 1909, Grigg and Bayer, 1976	
<i>Paracis</i> n. sp. A	HI Islands		Muzik, 1979	
<i>Paracis spinifera</i>	HI Islands	350-396**	Nutting, 1912, Grigg and Bayer, 1976	
<i>Paramuricea HI Islandsensis</i>	HI Islands	350-396, 924-1241**	Nutting, 1908, Grigg and Bayer, 1976	

Higher Taxon	Species	Distribution	Depth Range (m)	References
	<i>Placogorgia</i> n. sp.	HI Islands		Bayer unpubl ms
	<i>Placogorgia</i> sp. n. A	HI Islands		Muzik, 1979
	<i>Placogorgia</i> n. sp. B	HI Islands		Muzik, 1979
	<i>Placogorgia</i> sp. cf. <i>P. dendritica</i>	HI Islands	350-396**	Nutting, 1910, Grigg and Bayer, 1976
	<i>Placogorgia</i> sp.	HI Islands	335-375**	Grigg and Bayer, 1976
	<i>Placogorgia</i> sp. cf. <i>Ps. placoderma</i>	HI Islands	73, 182**	Nutting, 1910, Grigg and Bayer, 1976
	<i>Pseudothesea</i> sp. cf. <i>Ps. orientalis</i>	HI Islands	147, 350-396**	Thom & Hend, 1906, Grigg and Bayer, 1976
	<i>Swiftia</i> n. sp. 1	HI Islands	340-365**	Grigg and Bayer, 1976
	<i>Swiftia</i> n. sp. 2	HI Islands	350-396**	Grigg and Bayer, 1976
	<i>Swiftia pacifica</i>	HI Islands		Muzik 1979
	<i>Thesea</i> sp. cf. <i>T. ramosa</i>	HI Islands	313-399**	Nutting, ??, Grigg and Bayer, 1976
	<i>Villogorgia arbuscula</i>	HI Islands	315-412**	Wright & Studer, 1889, Grigg and Bayer, 1976
	<i>Villogorgia</i> n. sp. 1	HI Islands	350-396**	Grigg and Bayer, 1976
	<i>Villogorgia</i> n. sp. 2	HI Islands	350-396**	Grigg and Bayer, 1976
	<i>Villogorgia</i> n. sp. A	HI Islands		Muzik, 1979
	<i>Villogorgia</i> n. sp. B	HI Islands		Muzik, 1979
	<i>Villogorgia</i> n. sp. C	HI Islands		Muzik, 1979
<b>Family Primnoidae</b>	<i>Callogorgia formosa</i>	HI Islands		Kukenthal, 1907, Bayer, 1982
	<i>Callogorgia gilberti</i>	HI Islands	215-960**	Nutting, 1908, Grigg and Bayer, 1976
	<i>Callogorgia</i> n. sp.	HI Islands	350-396**	Grigg and Bayer, 1976
	<i>Calyptrophora agassizii</i>	HI Islands	781-1145**	Studer, 1894, Grigg and Bayer, 1976
	<i>Calyptrophora angularis</i>	HI Islands	1207-3292*	Nutting, 1908, Grigg and Bayer, 1976
	<i>Calyptrophora clarki</i>	HI Islands	12-1275	Bayer, 1951
	<i>Calyptrophora japonica</i>	HI Islands	216-432**	Gray, 1866, Grigg and Bayer, 1976
	<i>Calyptrophora</i> n. sp.	HI Islands	344-454**	Grigg and Bayer, 1976



## PACIFIC ISLANDS

Higher Taxon	Species	Distribution	Depth Range (m)	References
	<i>Calyptrophora wyvillei</i>	HI Islands	744-823*	Wright, 1885, Nutting, 1908
	<i>Calyptrophora</i> n. sp. 1 (lyrate)	HI Islands	1078***	Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Calyptrophora</i> n. sp. 2	HI Islands	1807***	Prelim. ID by Cairns, Pisces Cruise 2003
	<i>Candidella gigantea</i>	HI Islands	1720-1815**	Wright & Studer, 1889, Pisces cruise 2003
	<i>Candidella helminthophora</i>	HI Islands	38-1820**	Nutting, 1908, Grigg and Bayer, 1976
	<i>Fanellia euthyeia</i>	HI Islands		Bayer and Stefani, 1989
	<i>Fanellia medialis</i>	HI Islands		Bayer and Stefani, 1989
	<i>Fanellia tuberculata</i>	HI Islands		Versluys, 1906, Bayer, 1982
	<i>Narella bowersi</i>	HI Islands	1344-1937*	Nutting, 1908, Berntson et al., 2001, Grigg and Bayer, 1976
	<i>Narella dichotoma</i>	HI Islands		Versluys, 1906, Bayer ms: 27
	<i>Narella</i> sp. cf. <i>N. megalepis</i>	HI Islands	215-564**	Kinoshita, 1908, Grigg and Bayer, 1976
	<i>Narella nuttingi</i>	HI Islands	1350***	Bayer, 1997, Berntson et al., 2001
	<i>Narella ornata</i>	HI Islands	748-1007***	Bayer, 1995
	<i>Narella studeri</i>	HI Islands		Versluys, 1906
	<i>Narella</i> n. sp. 1	HI Islands	350-396**	Grigg and Bayer, 1976
	<i>Narella</i> n. sp. 2	HI Islands	353-417**	Grigg and Bayer, 1976
	<i>Narella</i> n. sp. (unbranched)	HI Islands		Prelim. ID by Cairns Pisces Cruise 2003
	<i>Paracalyptrophora</i> n. sp.	HI Islands	367-398**	Prelim. ID by Cairns Pisces Cruise 2004
	<i>Parastenella</i> n. sp.	HI Islands	517***	Prelim. ID by Cairns Pisces Cruise 2004
	<i>Plumarella</i> n. sp.	HI Islands	384-432**	Grigg and Bayer, 1976
	<i>Thouarella (A.) biserialis</i>	HI Islands	439*	Nutting, 1908, Grigg and Bayer, 1976
	<i>Thouarella (A.) regularis</i>	HI Islands	183-722*	Wright and Studer, 1889, Nutting, 1908
	<i>Thouarella</i> sp. cf. <i>T. (T.) typica</i>	HI Islands	350-396**	Kinoshita, 1907, Grigg and Bayer, 1976

Higher Taxon	Species	Distribution	Depth Range (m)	References
Order Pennatulacea				
Family Anthoptiliidae	<i>Anthoptilum murrayi</i>	HI Islands	426-2286*	Kolliker, 1880, Nutting, 1908
Family Chunellidae	<i>Calibelemnon symmetricum</i>	HI Islands	196-1650**	Nutting, 1908, Chave and Malahoff, 1998
Family Echinoptiliidae	<i>Echinoptilum macintoshi</i>	HI Islands	225-232*	Hubrecht, 1885, Nutting, 1908
Family Funiculinidae	<i>Funiculina</i> sp.	HI Islands	254-1940**	Chave and Malahoff, 1998
Family Halipteridae	<i>Halipterus willemoesi</i>	HI Islands		vide Williams
Family Kophobelemnidae	<i>Kophobelemnon</i> sp. (short stemmed)	HI Islands		Prelim. ID by Cairns, Pisces Cruise 2003
Family Pennatulidae	<i>Pennatula flava</i>	HI Islands	223-316*	Nutting, 1908
	<i>Pennatula pallida</i>	HI Islands	402-530*	Nutting, 1908
	<i>Pennatula pearceyi</i>	HI Islands	1033*	Kolliker, 1880, Nutting, 1908
	<i>Pennatula sanguinea</i>	HI Islands	903-1033*	Nutting, 1908
Family Protoptiliidae	<i>Protoptilum wrighti</i>	HI Islands	523*	Nutting, 1908
	<i>Protoptilum attenuatum</i>	HI Islands	925*	Nutting, 1908
	<i>Protoptilum studeri</i>	HI Islands	97-421*	Nutting, 1908
Family Umbellulidae	<i>Umbellula carpenteri</i>	HI Islands	1046-2056*	Kolliker, 1880, Nutting 1908
	<i>Umbellula gilberti</i>	HI Islands	708-1951*	Nutting, 1908
	<i>Umbellula jordani</i>	HI Islands	704-2403*	Nutting, 1908
Family Virgulariidae	<i>Virgularia abies</i>	HI Islands	223*	Kolliker, 1870
	<i>Virgularia molle</i>	HI Islands	1265-1280*	Kolliker, 1880
Class Hydrozoa				
Order Stylasterina				
Family Stylasteridae	<i>Distichopora (Haplomerismos) anceps</i>	HI Islands	360-577**	Cairns, 1978, 2005
	<i>Distichopora asulcata</i>	HI Islands	293-377**	Cairns, 2005
	<i>Stylaster griggsi</i>	HI Islands	322-583**	Cairns, 2005
	<i>Stylaster infundibuliferus</i>	HI Islands	521-563**	Cairns, 2005

