Advances in Management of Precious Corals to Address Unsustainable and Destructive Harvest Techniques

46

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Abstract

Precious corals have been used in jewelry, decorative arts, religious artifacts, and for medicinal purposes for over 5,000 years. Traditional harvest of precious corals involves the use of non-selective coral dredges and trawls. In many fisheries, these destructive fishing gears are still legally used due to the logistical challenges and high costs associated with extraction of these sessile organisms from great depths. The high value of these resources have triggered exploitation patterns that are similar to strip mining. This has resulted in unstable yields and frequent population collapses, and fishers have been forced to search for new stocks as local areas were depleted. Tangle net dredges have been slowly eliminated from some fisheries, beginning in the 1980s, with harvest undertaken using conventional and mixed-gas SCUBA, ROVs and submersibles. These newer techniques have allowed fishermen to harvest black coral, Mediterranean red coral and certain Pacific species of red coral more selectively and efficiently. While SCUBA fisheries cause less damage to the habitat, targeted species are being extracted from refuges that were previously inaccessible to traditional coral dredges and trawls. This practice has helped maintain landings at artificially high levels, providing a false sense that the fishery is sustainable. Nevertheless, in the same manner as non-selective trawl fisheries, SCUBA fishers have been forced to expand their search into new areas and deeper waters as shallow coral beds are depleted, contributing to further decline of precious coral stocks.

The majority of the research conducted worldwide has concluded that most historically harvested precious coral beds in the Mediterranean and Pacific are depleted, and populations that are being targeted today are experiencing rapid declines. Although several countries have taken steps to conserve precious coral resources, effective management of precious coral stocks is lacking in many countries and poaching is increasing. Measures to restrict international trade have been proposed, yet a select few of these have been implemented. Recent management interventions are certainly a step forward, but they fail to achieve the intended goals of sustainable fisheries because (1) management has traditionally focused on single species instead of a more holistic ecosystem management approach; (2) the biology and life history of these species are not adequately considered; (3) known coral beds continue to be intensively fished and new areas are exploited without first acquiring scientific knowledge of the status of the resource and levels of harvest they can support; and (4) the escalating value and demand for precious corals in concert with short-term economic gains is driving unsustainable exploitation and increased poaching.

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46.1 Introduction

Precious corals have been collected for over 5,000 years for use as jewelry, homeopathic medicines, religious and cultural artifacts, and ornamentation using a variety of selective and non-selective fishing methods and destructive fishing gear. These corals remain highly vulnerable to depletion because of their biology and life history, combined with a boom and bust strategy of most commercial fisheries that is characterized by the removal of all accumulated standing stock from one bed before fishermen move on to explore new areas and exploit new stocks. In addition to their slow growth, late reproductive maturity, low rates of natural mortality and other k-selective strategies, these sessile corals exhibit a patchy and limited distribution. Precious coral fisheries have followed a historic tradition centered on an artisanal industry specializing in highly ornate carvings and extensive trade routes. Throughout the history of this industry, the value of raw materials have fluctuated based on the supply, quality and demand. An increasing consumption and demand for coral products since 2009 has caused prices to escalate to such high levels that some species are now more valuable than gold, fueling excessive exploitation and illegal poaching (Tsounis et al. 2010, 2013; Chang 2015). Globally, most precious coral stocks are overharvested and the industry faces a growing threat of localized depletion and even economic extinction, sparking debates about the adequacy of management measures and enforcement. This review summarizes biological attributes of precious corals and how this affects their potential for sustainable harvest. A historical overview of the industry is presented, focusing on the socioeconomic patterns of use, historical and present day fisheries and the supply chain, and traditional approaches to manage these resources. Recent efforts undertaken to improve the management and conservation of these species are discussed, along with some of the limitations of these approaches. By analyzing all data, the review illustrates how modern day fishing practices along with newly emerging technology, a paucity of suitable management interventions, limited enforcement capacity, and escalating poaching continue to drive an unsustainable fishery, to the extent that these resources are quickly becoming commercially extinct. The chapter concludes with a discussion of the need for a holistic ecosystem-based approach to avoid the eventual collapse of the industry and to achieve a sustainable fishery.

46.1.1 Biology and Ecology of Precious Corals

Precious corals belong to three taxonomically distinct orders of cnidarians in the class *Anthozoa*: Zoanthidae, Antipatharia, and Gorgonacea. The most valuable of these are the pink and red corals in the family Corallidae (order Gorgonacea), with 2 genera (*Corallium* and *Paracorallium*) and 33 described species, 8 of which are commercially harvested: Mediterranean red coral (*Corallium rubrum)* and 7 Pacific species [*Paracorallium japonicum*, *C. elatius*, *C. konojoi*, *C. secundum, C. lauuense (C. regale), C. sulcatum* and *Corallium* sp. nov.] (Bayer and Cairns 2003; Simpson and Watling 2011; Tu et al. 2012). Next in importance are the black corals in the order Antipatharia, which includes seven families (Antipathidae, Aphanipathidea, Cladopathidae, Leiopathidae, Myriopathidae, Schizopathidae and Stylopathidae) and over 200 known species, with at least 13 species in 11 genera used in the jewelry trade (Opresko 2001; WCMC 2008). Other precious corals fabricated into jewelry include two types of gold corals, zoanthids in the family Gerardidae (*Gerardia* spp,) and gorgonians in the family

Table 46.1 Precious and semi-precious corals that are commercially harvested

Order	Family	Genus most common in commerce	Common name	Total # taxa	# Harvested taxa
Gorgonacea	*Corallidae*	*Corallium*, *Paracorallium*	Pink and red corals	33 species	8
Gorgonacea	*Isididae*	*Keratoisis, Acanella, Lepidisis*	Bamboo Coral	38 genera, 138 species	4
	Antipathidae	*Antipathes, Cirrhipathes, Leiopathes*	Black coral	200+ species	11 genera, 13 species
Zoanthidae	*Gerardidae*	*Gerardia*	Gold Coral	3 species	1
Gorgonacea	*Primnoidae*	*Primnoa, Narella, Callogorgia*	Gold Coral	>200 species	3
Gorgonacea	*Melithaeidae*	*Melithaea*	Sponge coral	5 genera	3+
Gorgonacea	*Helioporacea* and gorgonians in the family	*Heliopora*	Blue coral	1 species	1
Gorgonacea	*Tubiporidae*	*Tubipora*	Organ pipe coral	1 species	1

Primnoidae (*Primnoa*, *Narella* and *Callogorgia*), and bamboo corals (family Isididae: *Acanella*, *Keratoisis*, and *Lepidisis*) (Table 46.1).

Semi-precious species, including several hydrozoan corals, blue coral (*Heliopora coerolea*), organ pipe coral (*Tubipora musica*), numerous scleractinian corals, and gorgonians in the family Melithaeidae (sponge or apple corals) are used primarily for curios and in aquarium displays, while some (blue coral and sponge coral) are also made into jewelry (Wells 1981, 1983). Sponge corals have a porous skeleton, full of holes and irregular surfaces. The most notable feature of the skeleton is that it is segmented, consisting of a series of nodes that contain sclerites embedded in a gorgonian matrix and internodes formed from sclerites infused with calcite. They are found in shallow, tropical and subtropical waters and tend to be relatively short-lived compared to precious corals. They include hundreds of species with a variety of colors, but *Melithaea ochracea* is the only species reported to be currently used for jewelry. *Melithaea* forms fan-shaped colonies with a skeleton that is red with yellow-orange-brown streaks. Most of the harvest occurs in the South China Sea, from Taiwan to Indonesia. It is typically infiltrated with resin to harden and stabilize the skeleton. Blue coral (*Heliopora coerulea*) forms branching, submassive and erect plate-like colonies on shallow tropical reefs throughout much of the Indo-Pacific. Its common name stems from the coral's ability to extract iron from seawater that it forms into a blue salt which is incorporated into its skeleton, turning it a sky blue color. Like red sponge coral, the skeleton is stabilized with resin when used for jewelry.

Precious corals are widely distributed but most populations tend to be small. They occur from the temperate waters of New Zealand, through the tropical Indo-Pacific, the Red Sea, the Caribbean, tropical and temperate Atlantic Ocean, the Mediterranean and the north Pacific. Precious corals are most abundant below 100 m depth, but some can be found within SCUBA diving depths. Antipatharians inhabit the shallowest depths, typically occurring from 10 to 100 m depth, with large populations in the New Zealand fjords, the temperate and tropical Pacific, the Caribbean, and the Mediterranean; commercial fisheries for these species are primarily in the tropical Pacific, Caribbean, Red Sea and Mediterranean. Species in the family Corallidae inhabit tropical, subtropical and temperate oceans, but only two areas historically had large populations and are commercially exploited: the Mediterranean Sea and the northern Pacific Ocean. The Mediterranean red coral, *Corallium rubrum* is distributed throughout the Mediterranean and neighboring Atlantic coasts, with commercial beds known from Sardinia, Corsica, Elba, southern Italy, Croatia, the Greek islands, Turkey, Mallorca, Alboran Sea, Costa Brava, southern France and the northern African coast (Fig. 46.1). Small colonies of red coral can be found in dimly lit submarine caves and under ledges from 3 to 10 m depths (Tescione 1973; Tsounis et al. 2006b), while larger, commercially valuable colonies occur on banks, boulders and other hard substrates to 800 m depth (Costanti et al. 2010), being most abundant from 30 to 200 m (Rossi et al. 2008). Other species in the family Corallidae occur below the euphotic zone. Pacific red and pink corals are mostly found within two

Fig. 46.1 Known range of *Corallium rubrum*. The coral occurs along the central and western basin of the Mediterranean and the neighboring eastern Atlantic along the coast of Africa and the Canary Islands, southern Portugal and Cape Verde. It occurs in shallow water (<10 m) in dimly lit caves and can be found on deeper banks at 800 m depth, being most abundant from 30 to 200 m

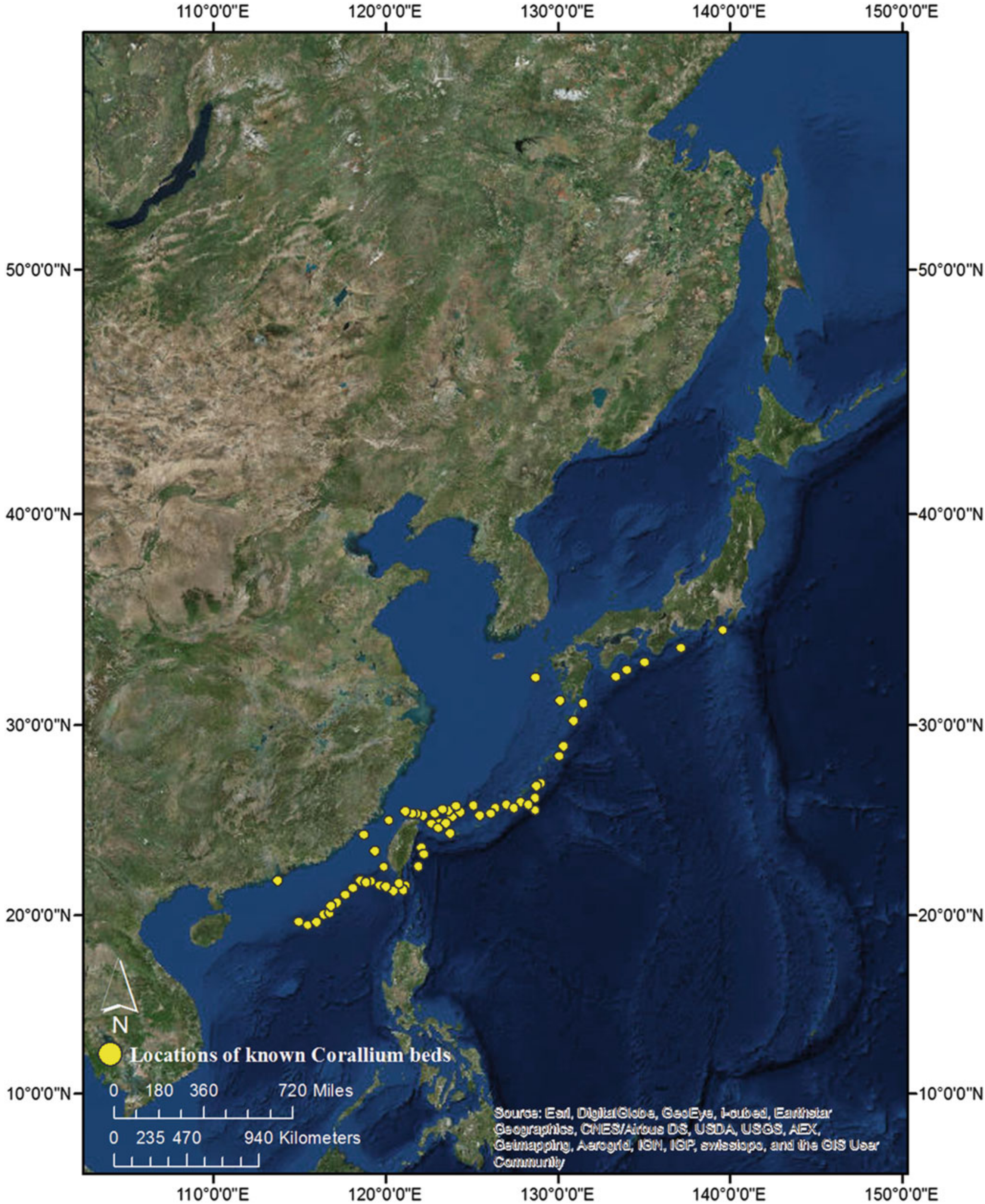

Fig. 46.2 Location of inshore North Pacific coral beds. Red coral *Paracorallium japonicum*, pink coral is found around Japan, Okinawa and Bonin Islands from 80 to 300 m. *Corallium elatius* is reported from the northern Philippines to Japan, around the island of Taiwan, and Mauritius and Palau from 150 to 330 m. White coral *C. konojoi* occurs from Japan to northern Philippines, around Palau and the Chinese islands of Hainan from 50 to 200 m. A fourth coral, *Corallium sulcatum* is reported to have been intensively harvested around Japan and Taiwan between the 1970s–1990s (Tu et al. 2012), but this is not reported in the FAO dataset and is likely pooled with other species

depth zones, 50–400 m and 1,000–1,500 m. Three commercially valuable species inhabit waters around Japan, the Philippines and Taiwan: *C. konojoi* is found from 50 to 150 m and *Paracorallium japonicum* and *Corallium elatius* occur from 75 to 330 m (Fig. 46.2). *Corallium* sp. nov. is found on the Emperor Seamounts at depths of 1,000–1,500 m, while *C. secundum* is found on the Emperor seamounts and also throughout the Hawaiian archipelago, in shallower water (350–475 m). Hawaiian gold coral (*Gerardia*), bamboo coral (*Lepidisis olapa*) and angel skin coral (*Corallium secundum*) coexist in the same depth zone (350–600 m) and habitat, with the largest known populations found in Makapu'u bed off Oahu and smaller populations identified in at least 16 other locations (Fig. 46.3; Grigg 1984; Baco 2007; Parrish and Baco 2007). Bamboo corals are also found in the Gulf of Mexico, Southeast USA, the northeast Pacific and Indo-Pacific, with most harvest currently occurring in waters surrounding Indonesia (Fabricious and Aldersdale 2001; Etnoyer and Morgan 2003). The primnoid gold corals have one of the broadest bathymetric ranges of all precious corals, occupying depths of 25–2,600 m, while the commercially valuable *P. resedaeformis* is found in Alaska between 91 and 548 m (Cairns and Bayer 2005) (Table 46.2). Ecological requirements of precious corals include the presence of a hard substratum, strong bottom currents, and an absence of significant sources of sediment.

All precious corals are ahermatypic species – meaning they lack symbiotic algae and do not form reefs. They have a hard axial skeleton composed of a complex of proteins and/or calcium carbonate and typically exhibit an arborescent (branched, bushy or fan-like) or an unbranched whip-shape, or spiral growth form. These sessile invertebrates are considered habitat engineering species because they provide structural complexity that fish and mobile invertebrates use as feeding, spawning, and resting grounds, and colonies provide valuable habitat for other sessile invertebrates by protecting them from strong currents and predators (Fig. 46.4; Gili and Coma 1998; Husebo et al. 2002). Precious corals create some of the most complex communities in the deep ocean through their trophic activity and biogenic structure, hosting a wide variety of suspension feeders and a high species richness and functional diversity of motile invertebrates, fishes, turtles, and marine mammals (Parrish 2006a). Furthermore, due to their slow growth and long life spans, the skeletons of precious corals and other deep corals provide geochemical and isotopic data that can serve as a proxy for reconstructing past changes in ocean climate and oceanographic conditions (Smith et al. 2002; Adkins et al. 1998; Weinbauer et al. 2000; Risk et al. 2002; Frank et al. 2004; Thresher et al. 2004; Williams et al. 2009).

Because of their sessile life history and k-selected biological traits, precious corals are particularly vulnerable to physical damage from fishing gear such as bottom trawls and long lines. Furthermore, populations under pressure from harvest often exhibit dramatic shifts in age and size structure, and recovery may require decades (Andrews et al. 2002).

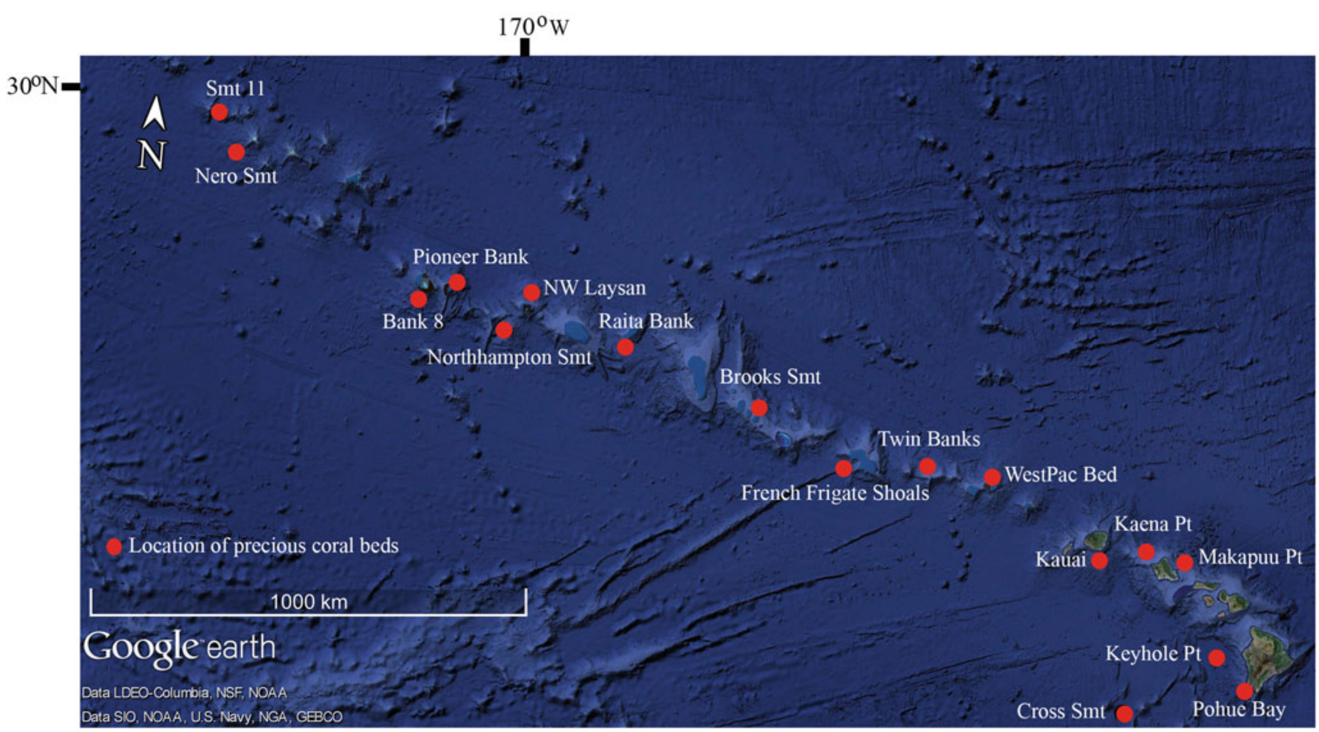

Fig. 46.3 Known locations of precious coral beds (*Corallium* and *Gerardia*) along the Hawaiian Archipelago to the Emperor Seamount chain. Coral is found at depths of 350–600 m

Table 46.2 Distribution of commercially valuable species of precious corals

Species	Common name	Distribution	Depth (m)	Reference
Corallium rubrum	Red coral, chichuukai sango, kowatari sango, Sciacca coral	Mediterranean Sea, primarily coasts of Sardinia, Corsica, southern Italy, Sicily and northern Tunisia	7.5–800; most from 30 to 200	Tsounis et al. (2007) and Costanti et al. (2010)
Corallium secundum	Angel skin coral, pelle d'ange, boke, mittdo sango, Midway coral	Hawaiian archipelago to the Milwaukee Banks; (20–36° N)	350–475	Grigg (1974b)
Corallium sp. nov.	Midway deep-sea coral	Midway Island to Emperor Seamounts, 28–36° N	1,000–1,500	Grigg (1982)
Paracorallium japonicum	Deep red coral, Aka-sango, tiaka	Ishigaki Islands, Sagami Bay on Japan's Pacific coast, between the Ogasawara Islands and Taiwan, and near the Goto Islands, Nagasaki (24–36° N)	76–310	Kitahara (1904), Grigg (1982), Nonaka and Musik (2009), Iwasaki and Suzuki (2010)
Corallium konojoi	White coral, Siro sango	Southern Kagoshima region of Ryukyu Archipelago, Japan to northern Philippines, 19–36° N	50–250	Kitahara (1904), Grigg (1982), Nonaka and Musik (2009)
Corallium elatius	Pink coral, Momoiro sango, momo	Pacific coast near Wakayama, from the Ogasawara islands to the northern China Sea, off the Goto Islands and Northern Philippines to Japan, 19–36° N	100–330	Kitahara (1904), Grigg (1982), Iwasaki and Suzuki (2010)
Corallium lauuense (C. regale)	Garnet coral	Hawaii to north of Midway Island, 20–32° N	400–700	Grigg (1974b)
Corallium sulcatum	Miss coral, Pink coral	Japan (Boso peninsula) and Taiwan	180–550	Tu et al. (2012)
Primnoa resedaeformis, Primnoa willeyi	Alaskan gold coral	Southeastern Alaska (Dixon Entrance) to Amchitaka, Aleutian Islands	10–800	Cairns and Bayer (2005)
Gerardia sp.	Hawaiian gold coral	Hawaiian archipelago & Emperor seamounts	300–400	Grigg (1974b)
Antipathes griggi (dichotoma)	black coral	Main Hawaiian Islands, Indo-West Pacific region	30–110	Grigg (1976)
Antipathes grandis	black coral, pine or umimatsu	Main Hawaiian Islands (Hawaii to Niihau)	45–146	Grigg (1976)
Antipathes spp.	Black coral	Caribbean Sea, Hawaii,		
Antipathes ulex	Fern black coral	Hawaii	40–100	Grigg (1993)
Cirrhipathes anguina	Wire coral	Taiwan, Philippine Sea	10–100	Wells (1983) and Bruckner et al. (2008)
Leiopathes glaberimma	Black coral	Mediterranean, Malta	500–600	Deidun et al. (2010)
Lepidisis olapa	Unbranched bamboo coral	Hawaiian Archipelago	375–400	Grigg (1984) and Tsounis et al. (2010)
Acanella spp.	Branched bamboo coral	Hawaiian Archipelago to Indo West Pacific	375–450	Grigg (1984) and Tsounis et al. (2010)
Isis hippuris	Jointed coral	Australia, India, Indonesia, Japan, Palau, Papua New Guinea, Philippines, Taiwan	1–40	Cooper et al. (2011)

First, all species are long-lived, reaching an age from upwards of a century to several millennia, depending on the taxa (Roark et al. 2006). Second, they tend to achieve a very large size if undisturbed, yet their growth is extremely slow. Most precious corals are characterized by low fecundity and low rates of recruitment, and first reproduction is reached at an age of more than a decade. *Corallium rubrum* is unusual in that shallow populations exhibit high recruitment and a small size and early age at first reproduction. Yet, comparable to other precious corals, *C. rubrum* is gonochoric with discrete annual reproduction, a low fecundity, slow growth rate and a long life span (Santangelo et al. 2003, 2012; Tsounis et al. 2006a; Bramanti et al. 2007; Torrents and Garrabou 2011). In all precious corals, including *C. rubrum*, fecundity is positively related to both colony size and age, with smaller colonies being less fecund and damaged or

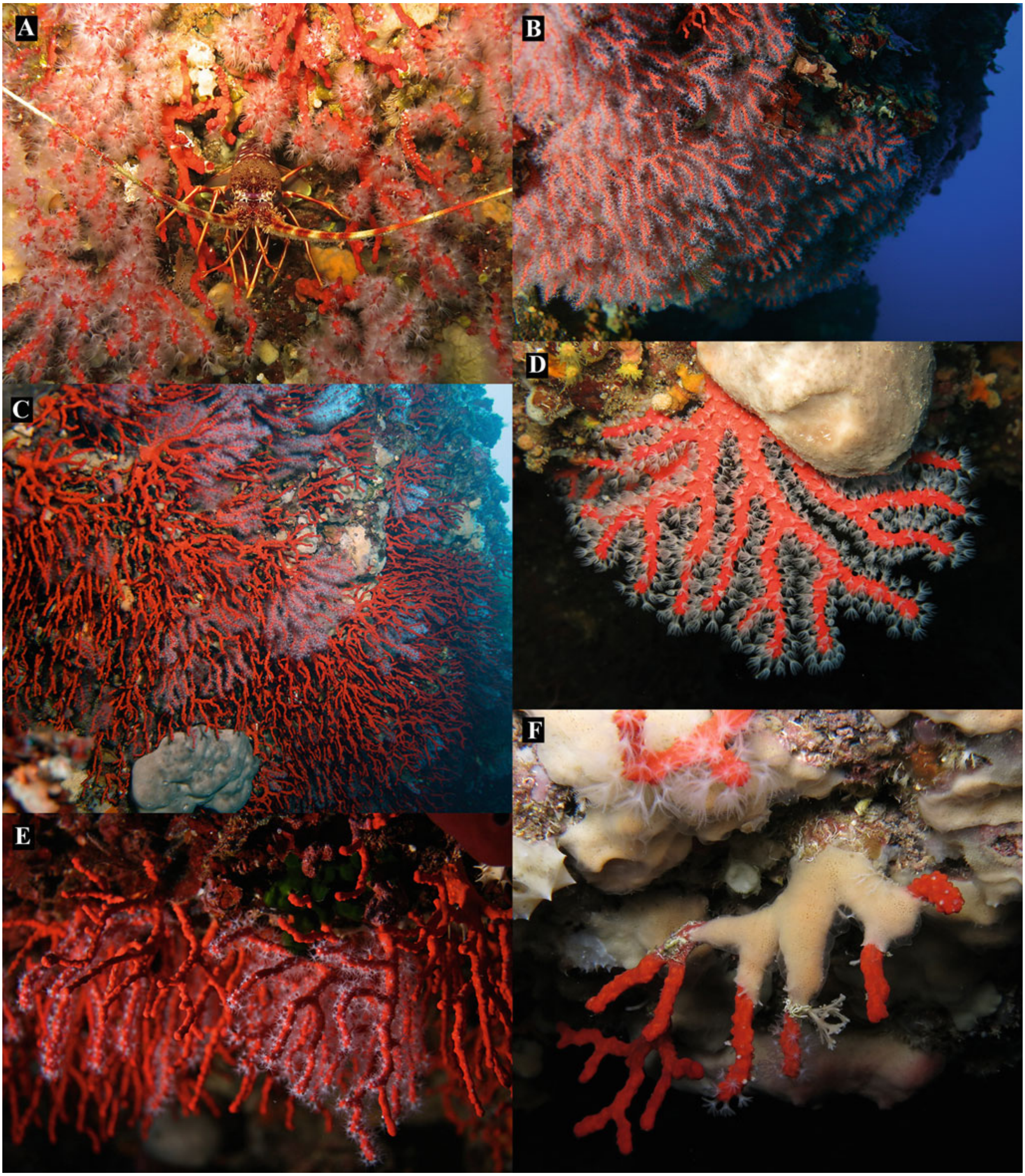

Fig. 46.4 Living colonies of *Corallium rubrum*. (**a**) A Mediterranean lobster hiding in a bed of *C. rubrum*. (**b**) A dense population of *C. rubrum* in shallow water under a ledge. Most colonies have their polyps extended. (**c**) In dimly lit shallow water habitats, *C. rubrum* can form dense assemblages, but most colonies tend to be small (<5 cm) and have few primary and secondary branches. (**d**) Larger colonies tend to occur at very low densities primarily at mid depths (below 30 m) and in deep water. (**e**) A close-up of several colonies of *C. rubrum*, some with polyps retracted and others with expanded polyps. (**f**) Because of the sessile nature of *C. rubrum* and high competition for space, colonies are often overgrown by other encrusting organisms such as sponges (Photos by Betta Nelblu)

injured colonies showing reduced or no reproduction (Abbiati et al. 1991; Weinbauer and Velimirov 1996; Grigg 1974a, 1976).

Precious corals tend to grow much more slowly than shallow water gorgonian and scleractinian corals, and generally have lower rates of recruitment and longer lifespans. The largest precious coral is *Primnoa*, which can reach a height of 7 m (Krieger 2001); nonetheless, annual growth rates of *Primnoa resedaeformis* are only 1.6–2.32 cm in height and 0.36 mm in diameter (Andrews et al. 2002). Both antipatharian black corals and gold coral (*Gerardia*) form dendritic colonies with heights of up to 4 m or more, and trunks that are 1–15 cm diameter. Antipatharians exhibit a diametric increase that ranges from 0.26 to 2.28 mm per year, and linear growth rates of up to 6.4 mm per year (Grigg 1976), while gold coral (*Gerardia*) has the slowest growth of all precious corals (0.03 mm per year) and colonies can live for thousands of years (Roark et al. 2006). Growth rates of bamboo coral is equally slow: *Lepidisis sp*. colonies from New Zealand increase in diameter only 0.05–0.117 mm per year and colonies are estimated to live from 40 to 150 years (Roark et al. 2005; Tracy et al. 2007).

Precious corals in the family Corallidae will form large bushes when undisturbed for long periods, and all species exhibit slow growth. *Corallium elatius* is one the largest species in the family, achieving a maximum size of 1.1 m in height and 1.7 m in width and a weight of 67 kg (Iwasaki and Suzuki 2010). *Corallium konojoi* is one of the smallest commercially harvested coral in this family, with a maximum height of only about 30 cm. *Corallium rubrum* historically formed bushes up to about 75 cm height with a basal diameter of 1–5 cm, while shallow-water populations (<50 m depth) today consist predominantly of 2–5 cm tall, unbranched colonies (Fig. 46.4; Santangelo et al. 2007; Rossi et al. 2008; Tsounis et al. 2006b). *Corallium secundum* was estimated to increase in height 9 mm per year using growth ring analysis (Grigg 1976), whereas more accurate radiometric studies of Roark et al. (2006) have demonstrated much slower growth rates (0.11 mm per year). Linear growth rates of Japanese red coral ranges from 2.22 to 6.66 mm per year (Luan et al. 2013). Growth of *C. rubrum* is slower (0.2–1.83 mm per year), with growth rates declining with age. The average increase in diameter of *Corallium* ranges from 0.19 mm per year (*C. elatius)* to 0.58 mm per year (*C. konojoi*) for Pacific species (Luan et al. 2013), and 0.20–0.62 mm per year for *C. rubrum* (Bramanti et al. 2005; Garrabou and Harmelin 2002).

Due to their sessile nature, precious corals are very sensitive to perturbations. Precious corals are vulnerable to smothering by movement of sand along the bottom, toppling caused by organisms that bore into their skeletons and weaken the site of basal attachment, and encrustation and overgrowth by other invertebrates including invasive species (Fig. 46.4; Grigg 2004; Corriero et al. 1997; Calcinai et al. 2008; Tsounis et al. 2010). These corals are also affected by diseases and several corallivores, such as predatory gastropods (Omi 2007; Priori et al. 2015). Climate change is an emerging threat, especially for shallow species such as *C. rubrum*, as this coral is particularly vulnerable to temperature shifts, and possibly acidification of the oceans as pH decreases and the global-mean depth of calcite and aragonite saturation horizon changes (Cerrano et al. 2013). Mass mortalities of *C. rubrum* have already been reported during abnormally warm summers (Cerrano et al. 2000; Garrabou et al. 2001; Bramanti et al. 2005, 2007). Direct human impacts associated with bottom trawling, long lines and other types of bottom fishing are extremely harmful to sessile precious corals, as these gear types scour the bottom, alter bottom features, re-suspend sediment, dislodge and entangle corals, and cause incidental damage to corals through removal as bycatch.

For most commercially valuable precious corals, unsustainable harvest is the primary threat, as it has triggered large shifts in population dynamics and abundance. Dredges are the most widely used gear for harvest, whereby the coral is entangled in nets and pulled to the surface. This practice is a destructive and wasteful process that breaks and dislodges coral, with 60–90 % detached and lost during collection, much of which consequently dies (GFCM 1984; CITES 2007). Dredging operations dislodge and remove non-target sessile invertebrates, including undersized precious corals of low value that are subsequently discarded. Dredges also destabilize the bottom, reducing availability of hard substrates for future settlement of larvae. The use of dredges to harvest *Corallium* is known to have caused extensive habitat impacts to the coralligenous zone in the Mediterranean (Chessa and Cudoni 1988). Furthermore, the combined use of coral dredges and intensive harvest on SCUBA has degraded the three-dimensional “forest-like” structure created by large, highly branched *C. rubrum* colonies to a “grass-plain-like” structure dominated by unbranched colonies 10–50 mm in height (Garcia-Rodríguez and Massò 1986; Tsounis et al. 2006a, b; Rossi et al. 2008).

46.2 Value as a Raw Material

The skeletons of precious corals provide the raw materials used in jewelry, sculptures, figurines, amulets, clothing ornamentation, and a variety of art objects, and are also reported to have medicinal and mystical powers. Red and pink corals have very hard, magnesium-rich calcitic skeletons, instead of aragonitic skeleton found in scleractinian corals (Dauphin 2006). Antipatharians have a skeleton made of a horn-like protein called gorgonin that is typically dark brown to black and of a consistence resembling hard wood. Gold corals of the genus *Gerardia* secrete a golden keratin protein, but lack calcium carbonate found in other precious corals. Gorgonin is also an important component of the skeletons of *Primnoa* gold corals, but the protein is infused with calcite ($CaCO_3$) spicules. Skeletons of bamboo corals are constructed of alternating sections of calcium carbonate and protein.

The value of precious corals varies depending on the color, luster and hardness, condition, and size of the skeleton (Torntore 2002). The color tends to differ among species and locality where collected, and the popularity of colors and value follows fashion trends. Of all the precious corals, *Corallium* skeletons have the widest spectrum of colors, ranging from pure white through shades of pink, salmon, and orange to a very dark blood red, and less commonly a bluish, violet or yellow. These colors, originally attributed to the incorporation of iron oxide (Ranson and Durivault 1937), were later confirmed to be due to a specific carotenoid pigment, canthaxanthin (Cvejic et al. 2007). Individual colonies often lack a uniform coloration throughout the skeleton, and presence of striations of different colors may lower the value. For example, many of the Pacific species of *Corallium* are pink to red with a white core, white spots, or veins of different shades of red and pink. Red coral is composed primarily of calcium carbonate (82–87 %) and magnesium carbonate (7 %), and has a hardness of about 3.5–3. 75 on Mohs' scale, which means the skeleton is easily broken but hard enough to be polished (Liverino 1989; Webster 1975). Black coral can also be polished to an onyx-like luster. Because of its horn-like protein skeleton, it can also be bent and molded while being heated. Natural bamboo coral is a creamy white to grey in color, with a discernible dark core, however it is often dyed pink or red to imitate Mediterranean coral. Small coral branches (less than 7 mm in diameter) used to be discarded due to their low value. The introduction of composite coral manufacture, where small branches and fragments are ground into powder and formed into larger blocks and beads with plastic epoxy, has changed this component of the industry (Tsounis et al. 2010). Specimens of *Gerardia* and *Primnoa* exhibit growth rings and have a similar texture and consistency. However, *Gerardia* skeletons are more golden in color and have a smooth surface texture that is finely dimpled, rather than the striated surface of the skeleton of *Primnoa.* The condition of the skeleton refers to the state of the precious coral when it was collected, and the extent of bioerosion. Japanese fishermen distinguish four conditions: colonies harvested when attached and living (seiki), dead but still attached (ichi-kari), dead and toppled (ni-kari), and long-dead unattached colonies that are bioeroded by worms and other invertebrates (san-kari) (Grigg 1971; Cooper et al. 2011; Fig. 46.5). One additional consideration for black, gold, and bamboo corals is the degree to which dead portions of the skeleton are encrusted by *Parazoanthus* and other invertebrates (Grigg 1971, 2004).

46.2.1 *Corallium* and *Paracorallium*

46.2.1.1 Historical Significance

Red coral has been used for rituals, ornaments, talismans, medicines, aphrodisiacs and currency since Paleolithic times. Some of the earliest remains are perforated beads of *Corallium rubrum* uncovered in Germany from the Aurignacian Period (Tescione 1965) and in the Chamblandes settlement on Lake Lemano in Switzerland, dating from roughly 30,000 years ago (Ascione 1993). In the alpine region of Italy and around the island of Sardinia, beads, pendants and suspended ornaments from the Neolithic and Copper Age (4200–3400 B.C.) were found among human remains (Skeates 1993). One of the oldest pieces of engraved red coral, believed to be a talisman, was found in Neolithic tombs of Grotta dei Piccioni in Bolognano, Italy, providing some of the earliest evidence that magical powers have been attributed to red corals since ancient times.

Red coral formed an important component of trade routes throughout Africa, Asia and Europe since pre-Christian times. The presence of red coral in ancient Mesopotamia was linked with the fortunes of the empires and the city-states along the Tigres-Euphrates river system, corresponding to modern day Iraq, Kuwait, Palestine, Turkey and Iran (Ascione 1993). During the Bronze Age, ornate gold cups, helmets, crowns, bracelets, and other artifacts were inlaid with precious stones and red coral by Sumerian craftsmen. Precious corals became one of the most sought after exchange products on the oriental markets of the Phoenicians and Egyptians up to fifteenth century B.C., following the shipping routes used to transport incense across the Mediterranean and into Asia (Liverino 1989). The Phoenicians obtained large quantities of coral from Spain, Sardinia, Sicily and North Africa which they used to make highly ornate jewelry and amulets (Ascione 1993).

In the Middle Ages, coral products could be found in most Mediterranean countries and red coral became an important commodity in the great Eurasian caravan routes. In the tenth and eleventh century, Marsa'el Karez on the northern African coast became the largest coral port and trade center. During the Classical Period, Rome, India, Persia, and China carried on an extensive international trade in coral and other luxury goods, with much of the trade conducted by water via the Mediterranean and the Indian Ocean (Warmington 1974; Francis 1989). One of the main areas of coral fishing at this time was the Greek Islands (the Hellenic regions of the Cyclades between Europe and Asia Minor), with the main center of production of coral goods centered around Izmar, Turkey (Ascione 1993). Trade routes also expanded across

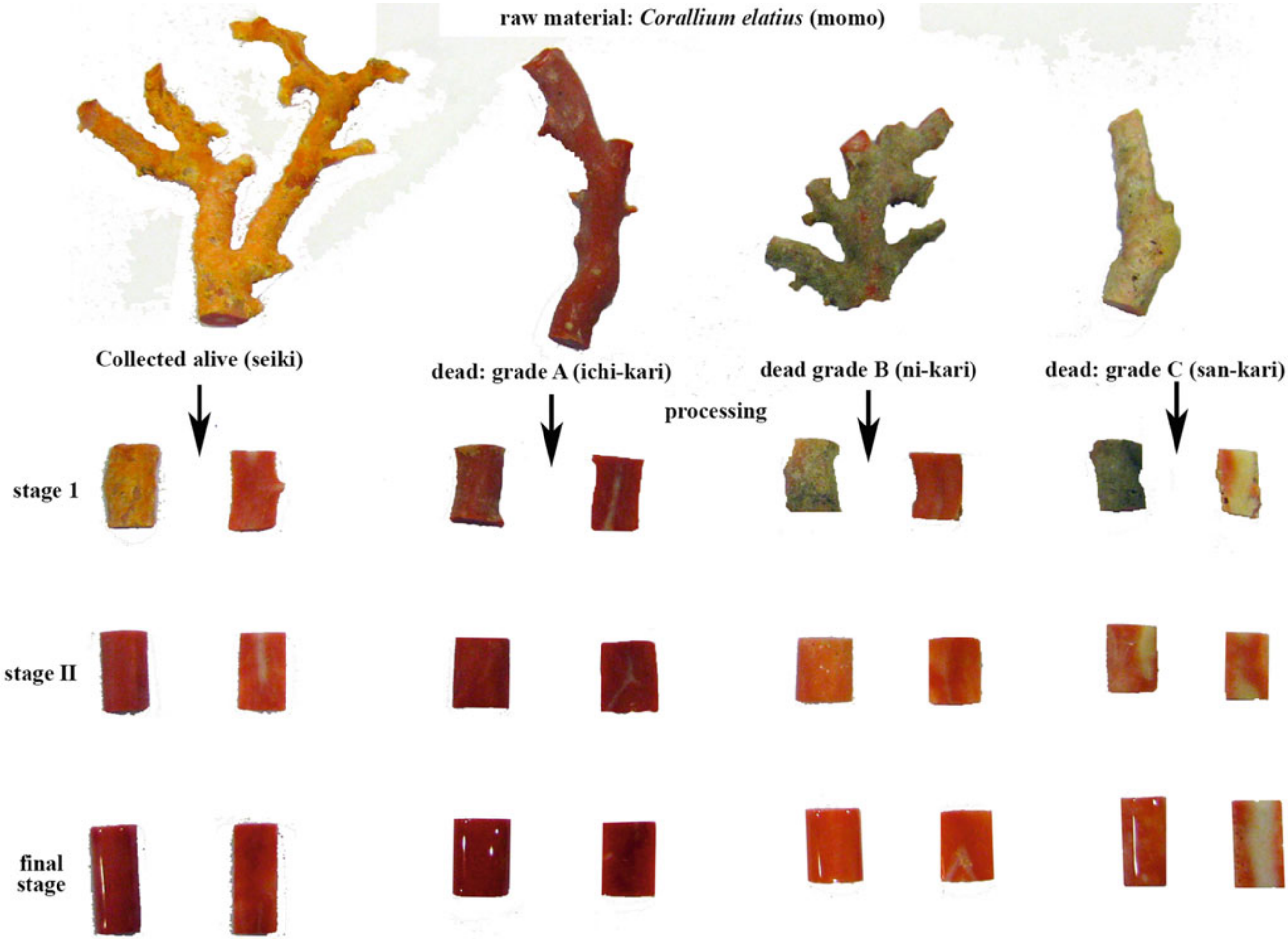

Fig. 46.5 A comparison of pink coral (*Corallium elatius*, momo coral) specimens graded following the Japanese system of classification: (**a**) collected live (grade A; seiki). (**b**) Harvested dead but still standing in growth position with minimal deterioration (grade B; ichi-kari). (**c**) Harvested dead after falling to the ocean floor (grade C; ni-kari). (**d**) Harvested dead with advanced bioerosion and deterioration (grade D; san-kari). Specimens are shown after collection and three subsequent stages of polishing

the Red Sea into the southern end of the Arabian Peninsula and into southern coast of India. The peoples of Arabia, Turkey, Turkmenistan, Uzbekistan, Tibet, Mongolia and India all became captivated by the beauty and allure of red coral. Coral was worn as jewelry by women in Morocco and Arabia. In Turkey, both men and women wore coral jewelry, and inlays of coral were used to create ornate knife handles, mural decorations, ornamentation of pipes and weapons, and harnesses for horses (Liverino 1989). The largest demand for red coral at this time was in India, where it was worn as bracelets, necklaces, anklets, used for prayer beads and amulets, and buried or burned with the dead under the presumption that it had the power of preventing evil spirits (Busuttil 1971). African kingdoms became important importers and consumers of coral beginning around the seventh century (Schick 1995). East Africa was connected to India and the Arabian Peninsula through the Indian Ocean merchant trade, and North Africa was connected through Mediterranean ports in Egypt and Tunisia. Red coral was also known from the far corners of Asia, where they were it was used in jewelry, ornaments, and depicted as a symbol of wealth and treasure (Tescione 1973). The use of red coral as a decoration in Chinese clothes dates back several thousand years (Knuth 1999). In Japan, coral beads were used to ornament Kimono belts, a tradition that survived into modern times (Liverino 1983). *Corallium rubrum* was first introduced to the New World by the Spaniards some 300 years ago, and it still is commonplace in Native American jewelry today.

Ancient writings on the mythology, origins, and magical properties of corals appeared in Greece in fourth century B.C. and during the first century A.D. in Italy. Theoprastus wrote a monograph titled *Concerning Stones* (Greece, 315 B.C.) where he described coral as a stone, red in color, which grows in the sea and is rounded like a root (Caley and Richards 1956). Pliny (79 A.D.), in his treatise *Naturalis Historia*, presented the first account of known areas of coral fishing, types of harvested coral, and trade with India. The origin of red coral and its mystical powers are also explained in Greek mythology by the story of Perseus and the Gorgon Medusa. According to legend, Perseus used the head of Medusa to petrify Cetus, the sea monster threatening Andromeda. Wanting to wash his hands of the sea monster's blood, Perseus placed the Medusa's head on a bed of leaves and seaweed on a riverbank. When he picked the head back up, he saw that the touch of the severed head of Medusa had petrified the seaweed and stained it red by its blood. The legend also states that Perseus gave Medusa's head to the goddess Athena, who used it as a shield against her enemies, possibly explaining why red coral talismans were used for protection (Tsounis et al. 2010). The Greek word for coral, "Gorgeia", originated from this legend, as Medusa was one of the three Gorgons.

Throughout its history, red coral has served as a symbol of life, good health and fortune, a protectorate, and remedy for a host of maladies. The Romans used powdered *Corallium* skeleton in liquid tonics, granules and pills as an antidote for poisons, and also as an antacid, astringent, emmenagogue, nervine tonic, laxative, diuretic, emetic and antibilious agent (Wells 1981). It was used to treat snake bites and insect and scorpion stings. Red coral was believed to have many other healing powers, such as comfort for fainting spirits, to counteract fascinations, to purify the blood, to ward off epilepsy, to cure imbecility of the soul, melancholy, mania, and to eliminate hatred from the home (Busuttil 1971). *Corallium* was thought to protect against Satan in Christian cultures and was worn as a protector against the evil eye and other misfortunes in other religions (Wells 1983; Tescione 1973). The writings of Pliny first described the superstitious belief in coral's alleged power against the evil eye and its ability to protect children from diseases. According to Pliny, red coral was used to predict the onset of illness and it was also a cure for kidney stones, ulcers, and hemorrhages. Belief of its magical and protective powers were commonplace in Italy and parts of Northern Europe throughout the Middle Ages, and it also had a number of other religious and cultural uses. Because of its luster and blood red color, it symbolized Christ's blood shed to redeem humankind, and its hardness and tree-like shape made it a symbol of life (e.g. tree of life), rebirth and immortality. When mixed with grains of corn during planting, red coral was believed to protect crops from drought. In Iranian beliefs, amulets and ornaments made of red coral served to defend ships and homes against lightning and storms. In Buddhism, precious corals were relished as treasures from paradise and used to decorate Buddha statues (Kosuge 1993).

Red coral has continued to play an important role in religious art, jewelry, sculptures, ornaments and other artifacts into the modern age, although market saturation, political and economic pressures, and changes in demand have affected the style, quality, and levels of production (Fig. 46.6; Ascione 1993). Beginning in the fourteenth century, coral necklaces and coral branches appeared in works of spiritual and religious art by Renaissance artists, such as the paintings of the Madonna and Child by Piero della Francesca and Andrea Mantegna (Ascione 1993). In Italy, the art of working coral was introduced in the 1400s by Jewish craftsmen. Jewelry production started in Trapani, a tuna and coral fishing village on the northwest coast of Sicily and then spread to Naples, Liverno, Genoa and Torre de Greco (Fig. 46.7). Much of the jewelry from the early 1800s consisted of uncarved beads (Fig. 46.8), often faceted into large pieces, while the Renaissance-style corals involved new designs that included allegoric and mythological compositions, cherubs and racemes, and many pieces had a "flower and leaves" style (Ascione 1993). With the introduction of Pacific *Corallium* in the early twentieth century, larger sculptures, inlays and statues were created, due to the larger sizes and different colors of these species (Fig. 46.6). Newly emerging fisheries and discoveries of unusually large precious coral beds in the 1960s–1980s inundated markets with Pacific *Corallium*; new production centers emerged, and the coral trade sky rocketed. Periodic gluts of coral, as well as an abundance of low-quality raw material caused prices to tumult, and fishing effort temporarily declined, but these trends were short lived. Since 2008, the value and demand for precious coral has achieved new record levels, leading to excessive exploitation and illegal poaching (Chang 2015). Coral artisans from Torre del Greco continue to produce some of the most intricate and valuable designs, but international markets are flooded with pink and red coral jewelry, sculptures and other decorations from India, Taiwan and Japan, Native American tribes of Arizona (Ascione 1993) and new markets have emerged in China (Chang 2015).

46.2.1.2 Mediterranean *Corallium* Fisheries

Mediterranean red coral was first collected in the form of fragments and large branches that washed up on the shore after storms, possibly as early as the Aurigacian Period, Late Paleolithic (Tescione 1973). The first recorded evidence of fisheries for *Corallium* date from about 5,000 years ago, with skin divers removing colonies from shallow caves (Grigg 1984). Harvesting of coral in ancient times is assumed to have been undertaken by free divers, initially without goggles, while at a later stage breath-hold divers were equipped with Japanese goggles. These early coral free-divers were likely quite proficient at breath-holding, as demonstrated in other free-diving fisheries in the region (Tsounis et al. 2010). Greek sponge divers capable of free diving to over 80 m depth fabricated iron hooks called "kouralio" and other primitive tools to dislodge the corals (Mayol 2000). These

Fig. 46.6 Examples of carvings, inlays and sculptures made from *Corallium* and *Paracorallium*

Fig. 46.7 Processing of *Corallium* in Torro de Greco, Italy. Common lapidary techniques are used to cut, grind and polish precious corals. In some cases the carves pieces and beads are soaked in a solution of hot water with hydrogen peroxide and muriatic acid and then buffed to obtain a high gloss finish

Fig. 46.8 The principle products made from pink and red corals are beads which are strung into necklaces, bracelets and earings. (**a**–**f**) Several different sizes and shapes of beads. (**g**) The production process involves at least 12 different stages including washing, cutting, shaping, cleansing, polishing and finally stringing of red coral colonies. (**h**) Typical necklace, bracelet and earings made from beads of *Corallium rubrum*

tools were first used between first and fourth century B.C. by Greek divers and by Roman divers into the first century A.D.

During the Neolithic, a larger-scale boat-based fishery was established following the development of nets used to drag for the coral (Grigg 1974b). The Greeks are credited with inventing the first dredging devices capable of being towed behind small row boats between the fourth and third century B.C. (the Hellenistic, Roman-Carthaginian, and late Etruscan ages) (Galasso 1998, 2000; Galili and Rosen 2008). Dredges of a similar style, varying mainly in size, weight and shape of materials used as ballast, and number of attached nets, gradually spread throughout the region. When Arab fishermen began harvesting coral in the tenth century, they developed a wooden dredge which became known as the "ingegno", or "Saint Andrews Cross". The ingegno consisted of a wooden cross with a central ballast of stone or lead and nets attached along the beams that was towed by a boat and dragged along the bottom, detaching and entangling red coral. These early dredges were used by Spanish, Sardinian, and Catalonian fishers into the Middle Ages, eventually being replaced with a larger and heavier metal dredge, the "barra italiana" during the industrial age (Galasso 2000). The barra italiana was made of a heavy iron bar (>1 t) with chains and nets attached along its length. Although the barra italiana could be dragged in deeper water and was considerably larger, it still was not very efficient: it is estimated that only about 40 % of the coral broken off the substrate was entangled and retrieved (GFCM 1984).

The coral fishery in the Mediterranean has fluctuated between periods of prosperity and decline, depending on supply (new discovery of *Corallium* beds) and demand, political regime changes, wars, restrictions on fishing, and various political struggles for supremacy over the fishing grounds. Introduction of large wooden and metal dredges allowed the fishery to shift from one based on individual divers and small row boats to industrial-scale operations, as fleets of boats could be deployed and multiple dredges used simultaneously. With the emergence of industrial fisheries, securing of the right to the coral fisheries off the African coasts became the object of considerable rivalry among the Mediterranean communities of Europe, and processing centers and fisheries moved around the region. For example, in the twelfth and thirteenth century most of the exploited coral banks were located in Tunisia and Algeria with fishermen from Catalonia, Genoa and Marseille (Tescione 1973). In the mid-1500s, one coral harvesting company in Marseille had a monopoly of fishing along a 250 km stretch of the Northern African coast, and also collected coral off Corsica, Sardinia, Tunisia and Karpathos (a Greek Island in the south Aegean Sea). During the sixteenth and seventeenth centuries, most coral fishing boats were based out of Genoa and Naples, with harvest occurring off the North African Coast. By the late seventeenth century, the majority of the coral fishermen were based out of Lisbon and Marseille, while Livorno and Torre del Greco emerged in the eighteenth century as the major production centers (Francis 1994; Tescione 1973; GFCM 1989). For a short period, Tunisian fisheries were secured by Charles V for Spain. The monopoly soon fell into the hands of the French, who held the right to the fishery until the end of the French Revolution when it shifted from Marseille to Naples, Rome and Genoa.

In 1806, the British government controlled the fisheries, but this quickly returned to the French and Italians. The Italian fishery achieved an extended period of prosperity in the mid to late 1800s, with thousands of small sail and rowboats, tens of thousands of workers, and dozens of processing centers. In 1862, there were 347 registered coral fishing boats. By 1865 this increased to 1,200 vessels, with 24 Italian factories processing coral, employing about 17,000 fishermen and jewelers (Tescione 1965, 1973). Most coral fishing in Italy had shifted to Torre del Greco by 1870, with smaller fisheries based out of Livorno, Genoa and Corsica (Torntore 2002). Almost 250 vessels were dredging for coral off Algeria in the late 1870s, with landings off the east coast of approximately 250–300 metric tons per vessel each year. In the 1880s, following discoveries of three large beds of dead, subfossil red coral on Sciacca banks, between Sicily (Italy) and Tunis (Tunisia), a coral rush began. At its peak, over 2,000 boats worked these banks, levels of harvest quadrupled, and numbers of processing factories increased from 40 to over 80. Intense fishing quickly depleted these grounds, and they were abandoned around 1915, but the glut of low quality coral simultaneously lowered prices and reduced fishing in other areas (Geronimo et al. 1993; Tsounis et al. 2010). Ironically, Sciacca coral is some of the most valuable found in the market today.

Coral fishing in the Mediterranean stopped completely between 1914 and 1918. At about the same time, imports of Japanese pink and red coral started to reduce demand of Mediterranean red coral (Tescione 1973). The Italian coral industry adapted to market demand and crafted large coral pieces of the popular pale pink coral, but coral artisans struggled to survive. Demand for Mediterranean coral increased once again in the 1930s, followed by another decline during the early 1940s. In 1941, there were only 5 active coral fishing boats; this increased to 31 in 1947 and industrial scale exploitation began once again (Liverino 1983).

Shortly after the invention of the Cousteau/Gagnan Aqualung, SCUBA diving emerged as a new, highly profitable method for the harvest of red coral, as it allowed divers to selectively remove large corals in protected crevices that were previously inaccessible to dredges. Leonardo Fusco is credited as being the pioneer SCUBA red coral fisher, harvesting 250 kg in his first season (Liverino 1983). Several other professional divers from Italy also began harvesting coral off banks in Sardinia, Elba and Corsica in the mid-1950s

(Roghi 1966). In 1956, divers were harvesting coral from a cavern off Sardinia 30–35 m depth, but these resources were quickly depleted. To continue finding coral, divers had to descend to 40–45 m by 1958, followed by 70–90 m in the mid-1960s, and 100 m in the early 1970s as shallow water resources became scarce (Liverino 1983). Similar trends for the dive fishery, with divers working in shallow water and descending into progressively deeper water, were documented from other coral beds in Italy, France and Spain (Liverino 1983; Galasso 2000; Tsounis et al. 2010). Helium-based mixed gas diving technologies began to be used by coral divers in 1974, permitting them to work between 80 and 150 m for longer periods (Liverino 1983). Discovery of large resources along the 14 mile Scherchi Channel (located between Sicily and Tunisia) led to a short-lived coral rush beginning in 1978, with 80 divers from Italy, France and Spain working these beds. The divers initially harvested coral from 60 m depth, and gradually worked their way down to 130 m, with 366 boats and 150 divers extracting coral from Scherchi beds by 1979 (Liverino 1983).

From the advent of SCUBA fisheries and continuing until the mid-1980s, coral dredges continued to play a major role in the Mediterranean fishery, as they could be used to drag for coral in deeper areas that could not be exploited by divers. Small boats were replaced by larger motorized vessels capable of dragging immense (7 m long, 800 kg) metal dredges at much greater depths (180 m) in the 1970s (GFCM 1989). Tunisia allowed Italian dredging boats and French divers until it developed its own dredge and dive fishery in 1974. Both dive and dredge fisheries continued to expand throughout the region; by 1982, there were 150 factories, employing 4,000 workers and 1,600 fishermen (Tsounis et al. 2010).

As research began to expand in Mediterranean waters, scientists began to document immense damage to the coralligenous habitat in the Mediterranean caused by the coral dredge (Thrush and Dayton 2002). As a protective measure, Algeria was the first country to ban its use in 1977, followed by Morocco, Spain, Tunisia and Croatia in the mid-1980s. By 1994, the barra italiana and other types of coral dredges were completely phased out throughout European Union waters. SCUBA diving remains the dominant method of exploitation today, with traditional diving from 30 to 80 m depth and technical (mixed-gas) SCUBA used between 80 and 150 m depth. There are an estimated 350 licensed SCUBA divers collecting coral from the Mediterranean, and numerous more that are reported to be fishing illegally (Tsounis et al. 2010). In some areas fishermen have begun to rely on remote operated vehicles (ROV) to locate colonies, but the use of manipulator arms to remove the corals is currently illegal throughout the region, and some countries even prohibit its use for exploration. The use of rebreather technology is being considered in some areas, as most of the shallow traditional SCUBA-accessible beds are overexploited, and regulations have been implemented in some countries to close fisheries above 60 m depth (Tsounis et al. 2013). There is a single area off the Spanish coast (Islan de Alboran) where submarines have been used to collect corals (Paracuellos et al. 2006). There were two authorized submarines, but only one was ever used. It began operating in 1989 and worked until 1997 harvesting corals from 120 to 180 m depth. Landings were approximately 500 kg/year, which was substantially less than the 1500 kg quota.

46.2.1.3 Pacific *Corallium* Fisheries

The first record of precious coral harvest in Japan was in 1812, when a fisherman found a precious coral entangled in his net off Muroto, Kochi Prefecture (Suzuki 1999). For the next several decades, coral fishing was very limited because coral dredging was prohibited under Tokugawa Shogunate law, and the local rulers (Tosa Clan) did not permit the collection and trading in coral that was collected by other fisheries within their domain (Kosuge 1993). Furthermore, any coral that was landed could not be sold on the open market, but was required to be given to the regional rulers (the Shoguns). A document published in 1838 stated that anyone harvesting precious coral was prohibited from selling the coral freely, but they could offer it to the government (Kosuge 2010). In 1868, during the Meiji Reform, the Tokugawa feudal system was abolished and along with it the Tosa Clan laws banning coral fisheries. By 1871, precious coral fisheries began operating in the Muroto region of Tosa Bay (Kosuge 2010). The fisheries quickly expanded into western and southern Japan (Okinawa and the Bonin Islands), with about 100 boats gathering coral from 100 to 400 m depth (Kitahara 1904). Initially, rectangular nets attached to bamboo sticks were dragged across the bottom, but in 1890 this was modified by Konojoi Ebisuya to include additional netting at the rear of the dredge, thereby increased the efficiency of harvest (Kosuge 1993). Landings in coastal waters were sporadic, with several pulses as new beds were discovered and quickly exploited, and abandonment of most beds after a few years of intense fishing (Table 46.3). During World War II, fishing effort dropped by about 80% (Grigg 1971a; Kosuge 2010). After World War II, Japanese coral fisheries began to spread to more distant locations. From 1950 to 1951 most of the harvest by Japanese fishermen consisted red coral *Paracorallium japonicum* and pink coral *Corallium elatius* from Hachijo (150 miles off Tokyo). Shortly thereafter, fishermen began harvesting coral from inshore areas near Arnani, Shikoku, Kyushu, and Goto islands and Tosa Bay. These areas supported unusually large populations of *P. japonicum* and *C. elatius* and a third species, white coral *C. konojoi* was discovered (Liverino 1983). By 1960, the fishery had expanded to more distant Ryu-Kiu Islands, south of Kagoshima (Okinawa, Amani, Miyado), and southeast of

Table 46.3 Changes in the fishing ground for precious coral and duration of fisheries in Japan. Only two areas are currently active (Liverino 1983; Kosuge 2010)

Location	Period of activity
Tosa Bay	1800s–present day
Hachijo (150 miles off Tokyo)	1950–1951
Goto and Danjyo Islands	1900–1936, 1952–1995
Amani and Goto Islands	1952–1953
Nomozaki, Nagasaki Prefecture	1911–1915, 1935–1938
Koshiki Islands	1886
Okinawa Islands	1926, 1960
Sumizu, off Okinawa and Hachijo	1961–1963
Izu Islands	1939–1960
Bonin Islands	1918–1955
Southern Kagoshima Islands	1954–present day
Miyako Island	1959–1973
South China Sea	1965

Osaka and Yokohama (Ogosawara, Hachijo, Sumisu) (Ogi 2010). In 1965, fishermen began targeting beds in the South China Sea, with harvest of *C. elatius* and a new species, *C. secundum* (Liverino 1983).

In inshore areas of Japan, most coral fishing vessels were small (5 t). To accommodate the greater distance to fishing grounds, 2–5 month fishing trips became common, with larger vessels (150–180 t), more crew (25–30 men) and up to 18 mini-dredges used simultaneously (Liverino 1983). These dredges consisted of a round, 10 kg stone with five attached nets, allowing harvest by individual boats of up to 80 kg of coral per day. Japanese fisheries and subsequent commerce were locally managed by the three fishery associations: All Japan Sango Fishing Association, the Sukomo Kyodo Kumiai, and the Goto Sango Kogei Kyodo Kumiai (Iwasaki et al. 2012).

Taiwanese coral fisheries commenced in 1924 in offshore regions of Taiwan and south of Japan, shortly after discovery of precious coral by Japanese shark and porgy longline fisheries (Chang et al. 2013). The precious coral fishery in Taiwan prospered during the Japanese Colonial Period between 1930 and 1940, with up to 180 vessels fishing at one time for coral (Huang and Ou 2010). During this first phase of the fishery, landings peaked at 10–20 t per year. Each peak corresponded to the discovery of new fishing grounds and a dramatic, rapid increase in the number of fishing vessels shortly thereafter. These rich periods were followed by sharp declines within a few years, because the coral beds were small and easily overexploited. In 1934, the Penghu government supported research on coral beds, and placed limits on the number of coral fishing boats (20–40 vessels) in attempt to promote sustainable harvest (Liverino 1983). Nevertheless, "boom and bust" trends repeated four to five times until World War II, when the fishery went dormant (Huang and Ou 2010). Coral fishing was briefly revived for one season in 1954. AT this time, the Taiwanese Fisheries Research Institute and the Taiwanese Coral Industry cooperated in efforts to assess the economic feasibility of coral dredging. During these surveys only 19 % of the dredge hauls were successful and costs greatly exceeded the value of landings. As a result, it was recommended that new grounds be searched for coral, but the fishery was not revived until 1962 (Huang and Ou 2010).

Since the inception of the precious coral fishery in Taiwan, Taiwanese fishermen have used non-selective fishing gear that is similar to the gear used by the Japanese, and they continue to use this type of gear today (Fig. 46.9). Their coral tangle net dredges are comprised of a cobblestone weighing approximately 30 kg tied with steel wire in a crisscross fashion, with four to five nets attached to the steel wire around the cobblestone. Individual boats may deploy several dozen of these dredges simultaneously, depending on the number of winches and the size of the boat. Precious corals harvested in Taiwanese waters include four species, *P. japonicum, C. konojoi, C. secundum* and *C. elatius* (Lai 2006), although most of what is landed today is *C. elatius*.

Beginning in the 1960s, Japanese and Taiwanese fishermen expanded their search for precious coral into international waters, as most beds in their own waters were no longer productive. Taiwanese fishermen discovered coral banks off Hong Kong in 1962 in 70–100 m depth, in 1963 on the Oza Banks, 100 miles south of Okinawa, and then in 1968 off the Pratas Islands (Liverino 1983). In 1965, an unusually large population of *Corallium secundum* was found at Koko Seamount in the Milwaukee Banks, on Mellish Bank, and in surrounding seamounts in the Emperor Seamount Chain, all of which were located in international waters near the Hawaiian Archipelago (Grigg 1974b). The coral occurred much deeper than most of the coral harvested from inshore waters (375–450 m), and it required much larger fishing boats.

Over the next 20 years, most of the world's harvest of *Corallium* came from the Milwaukee Bank and the surrounding Emperor Seamounts. About 200 vessels from Taiwan and Japan made up to seven trips per year during the first peak, with 150 tons landed in 1969 (CITES 2007). After a few years stocks became depleted, and yield remained low until discovery of new beds in at depths of 900–1,500 m 5 years later. These beds were dominated by an undescribed deep water species (Midway coral, *Corallium sp. nov.*). This discovery led to another coral rush, with over 100 boats from Japan and Taiwan involved in the harvesting. Landings increased substantially between 1978 and 1981, declined briefly, and then reached a second peak in 1985. This was short-lived, with virtually no coral landed from these beds after 1989.

Three separate groups of coral fishermen have operated out of Japan: the All Japan Coral Fisheries Association

Fig. 46.9 Taiwanese fisheries. (**a**) Tangle nets are still the only fishing tackle used to collected precious corals in Taiwan. Each tangle nets is composed of one big stone (**e**) used to sink the net and up to seven pieces of net. Windlasses are used to release and manipulate tangle nets. (**b**) Precious coral fishing vessel. Most of the fishing vessels are smaller than 50 tons, but vessels of up to 100 tons can be used for coral fishing. All vessels must be equipped with VMS (Fishing Vessels Monitoring System). (**c**) Each fishing vessel has four workers, one captain, and one chief mate. All tangle nets are equipped in the head of the vessel. The tail of the vessel is living space. The fishing vessel usually spend 2–3 weeks at a time collecting precious corals. (**d**) Fisherman works on the raw material on boat, cutting off and disposing of the thin branches at sea because each vessel is only allowed a total harvest of 200 kg. Most harvest are corals that have been for a long time and covered by sediments. (**e**) The cobblestone used to sink the net is about 30 kg tied with steel wire and attached to four to five nets (Images by Professor Tzu-Hsuan Tu)

(JCFA) operating out of Kochi City, Kochi Prefecture; coastal fishermen using tangle net dredges; and submarine and robot harvesters. The JCFA was comprised of "Midway Deep Sea Coral" fishermen who operated 17 vessels in 1981, but due to the collapse of the resource no vessels operated in 1987 and 1988, and 1 vessel fished these offshore beds in 1989; JCFA also harvested *Corallium* near the Bonin Islands off Tokyo (Grigg 2003). The coastal and shallow-sea coral fishermen operated out of Sukumo City, Kochi Prefecture with 100 small vessels (3–10 tons) in 1981, but this declined to 60 vessels in 1989. Each was manned by one fisherman for day-fishing off Tosa City, Kochi Prefecture (eastern Shikoku). Four species were harvested: *Paracorallium japonicum* (200–300 m depths); *C. elatius* (250–400 m); *C. nobile* (150–300 m); and *C. konojo* (100–200 m) using dredges consisting of 20 kg concrete weights with embedded rings attached to netting and hauling lines. Coral fisheries around the Amami Islands started in 1910 and continued intermittently until the late 1970s using tangle nets (Ogi 2010). Dredges were replaced by a small two-man submarine and a robot from Tokyo 1978, and then in 1987 by ROVs (Iwasaki et al. 2012).

Although Japan continued to harvest *Corallium* during the 1980s and 1990s, many of the historic fishing grounds were depleted and landings remained at historic low levels. Areas that were no longer productive included: (1) the Peng-hu Islands near Taiwan; (2) continental slope areas near the southern tip of Taiwan; (3) Oza bank near Miyako Island; (4) the Danjo Islands near Kyushu; (5) Japan Banks of Tosu; and (6) Shikoku, Smith Bank, Tourishima Island and Sofu Island located between Japan and the Bonin Islands (Grigg 1971). Japanese fishermen also abandoned coral beds around the Emperor Seamounts in the late 1980s, and many inshore fisheries began to focus more on food fishes due to the higher value of food fishes, with coral harvest occurring secondarily (Chen 2012; Chang et al. 2013).

As the value of precious corals rebounded, harvest resumed and continues to the present day in two regions of Japan: the Kochi Prefecture and Kagoshima and Okinawa Prefectures. Of 24 areas that were traditionally harvested only three are open. In Kochi, two areas are fished using traditional stone-weighted non-selective tangle nets. The number of vessels that are active in these areas ranges from 120 to 230, with each fishing for approximately 2 weeks per year. In Kagoshima and Okinawa coral is selectively harvested using manned and unmanned submersibles (Iwasaki and Suzuki 2010).

During the coral boom in the Midway Islands, the number of Taiwanese fishing vessels was greater than the Japanese vessels, and they continued to target these grounds for a longer duration (until 1992). The larger fishery was partially attributed to government fishery enhancement programs and bank loans designed to promote and modernize the precious coral fisheries industry. Initially, inshore fisheries expanded, but numerous longline vessels were remodeled to allow coral fishing in more distant locations. The project was terminated in 1979, and regulations were subsequently implemented to reduce the number of vessels in the coral fishery because the government realized that the coral fishing grounds were not large enough to support the expanded fishing fleet and coral fishermen had started to illegally enter and fish the EEZ of Japan and the USA (Chen 2012; Chang 2015). To address these concerns, Taiwan first began requiring licenses for small (less than 50 tons) coral fishing vessels, expanding the licensing program to all vessels in 1983, and also implementing a maximum number of allowable vessels (150). The combined impact of the new regulations, along with a substantial drop in the value of *Corallium* (partially attributed to a glut of coral and the low quality of the harvested material), caused a sharp decline in landings and effort during 1982. Shortly thereafter there was a renewed influx of fishing effort that lasted until 1985, followed by a rapid collapse of the Midway coral fishing grounds and abandonment of the fishing grounds beginning in 1989.

Contrary to the expected impacts of the collapse of the Emperor Seamount fisheries, Taiwanese coral fisheries continued to survive. Many of the longline vessels were subsequently abandoned or re-outfitted for dolphinfish fisheries, while smaller vessels focused their effort in inshore waters for *C. elatius* and *P. japonicum*, the dominant species reported in landings since 1991 (Chang 2015). The fishery continued to operate through illegal, unregulated and unreported (IUU) fishing with an estimated 50 vessels in the Nan-Fan-Ao area of Yilan County and an increase to close to 100 vessels following discovery of *C. secundum* south of Lanyu Island in 2001 (Huang and Ou 2010). Although only three coral fishing boats were licensed in 2007, an investigation carried out by Taiwan Fisheries Agency identified 96 unregulated vessels equipped with coral fishing gear that were illegally fishing and not reporting their catch (Huang and Ou 2010). To address IUU fishing, the government issued new management standard for Taiwan's precious coral fisheries. This included a maximum of 60 licensed fishing boats and five designated fishing grounds (Huang and Ou 2010; Chen 2012; Fig. 46.10).

46.2.1.4 Hawaii *Corallium* Fisheries

Collections containing *Corallium* were first made during the Albatross Expedition of 1900, but it was not until 1966 that a small fishery was initiated, following discovery of a large bed (Makapu'u) of *C. secundum* approximately 9 km off Oahu in the Molokai Channel (Grigg 1974b). Using heavy stone or iron bars with attached netting (tangle net dredges), approximately 1,800 kg of *Corallium* was harvested from this bed between 1966 and 1969. Maui Divers of Hawaii, Inc., the leading manufacturer and retailer of precious coral

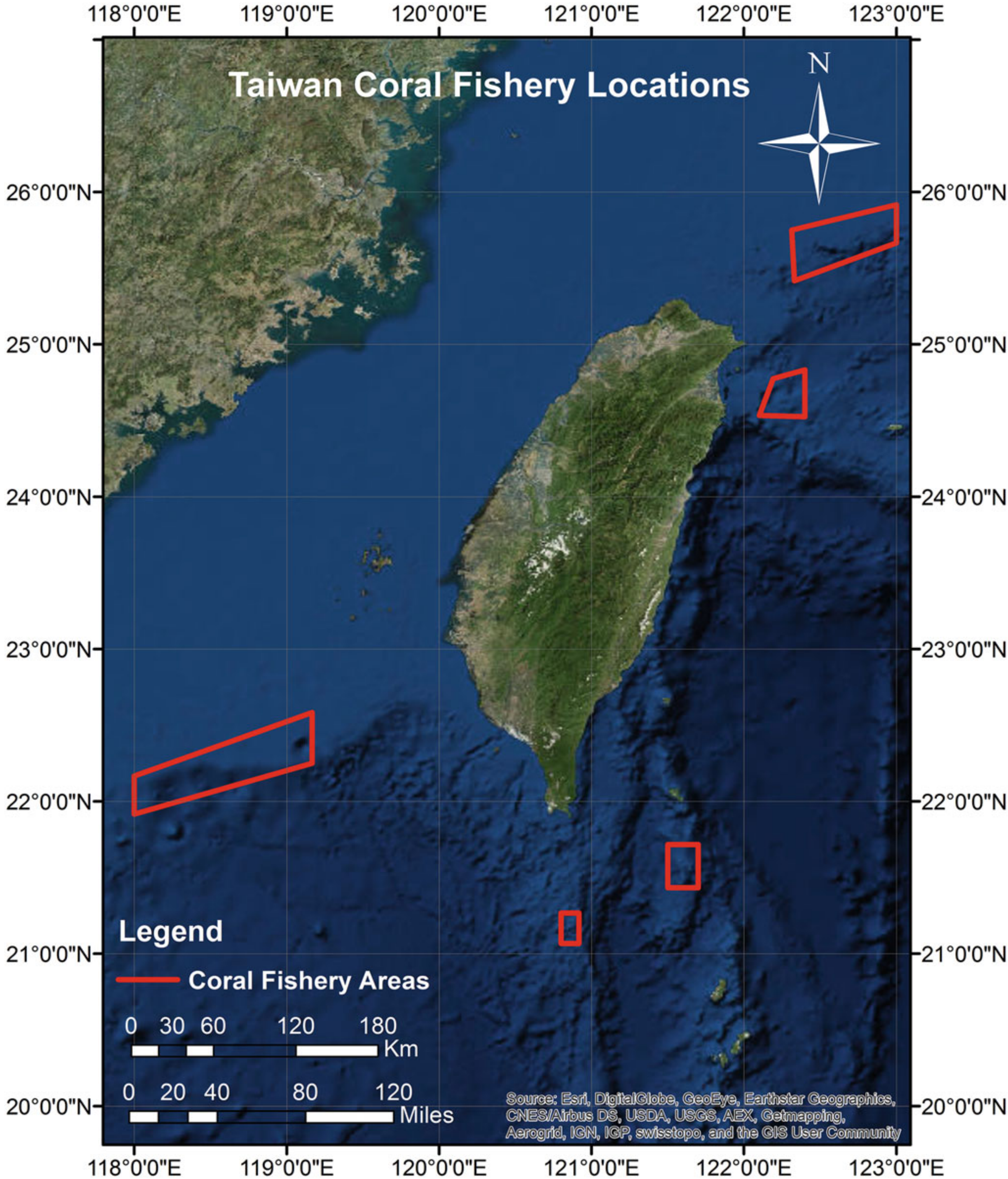

Fig. 46.10 Location of the boundaries of the five legal coral fishing areas off Taiwan (*red polygons*)

jewelry in Hawaii, harvested an additional 6,400 kg of coral from Makapu'u between 1972 and 1978 using a manned submersible (Grigg 2010). Harvest was discontinued in 1978 due to high operating costs and a diving accident (Grigg 2002). In 1988, the domestic fishing vessel Kilauea used a tangle-net dredge to harvest precious coral at Hancock

Seamount, landing approximately 500 kg of coral. Because of the high costs and landings that consisted mostly of dead or low-quality pink coral, the operation was discontinued. A *Corallium* fishery was revived briefly by American Deepwater Engineering between 1999 and 2001, using a one-person submersible. A total of 1,216 kg *C. secundum* was collected from the Makapu'u Bed, along with 61 kg of *C. lauuense* (*C. regale)* from exploratory areas off Kailua, Kona (Grigg 2002). No harvest of *Corallium* has occurred since 2002.

46.2.1.5 Landings of *Corallium*

By piecing together available *Corallium* literature and official catch records compiled by FAO available since the late 1970s a consistent boom and bust cycle becomes apparent. Throughout the history of coral fisheries, both effort and landings increased dramatically following the discovery of a precious coral bed, with sharp declines occurring within a few years, as the resource is depleted (Grigg 2010; Tsounis et al. 2010; Bruckner 2014). Precious coral fisheries are similar to strip mining and clear cutting of forests, as the sessile nature of the corals makes them vulnerable to depletion, and use of destructive fishing gear (trawls and dredges) dislodges and removes all corals from the fished area while simultaneously destroying the habitat (Bruckner 2009).

In addition to the depletion of the resource, economics have contributed to the observed changes in landings for both Mediterranean and Pacific fisheries. In situations where harvest levels were so high that the volume exceeded demand and/or the market was flooded with low quality coral, the resulting surfeit of coral has caused a drop in market value. The wholesale value of the coral in some instances fell to such low levels that the operating costs of the vessels exceeded the value of the commodity, and fishing boats were abandoned or re-outfitted for food fisheries. One of the best examples of this is from the Mediterranean following the discovery of large coral beds off Sciacca (southwest coast of Sicily). The exploitation of the Sciacca's coral cays had two fundamental repercussions on the coral market. First, the surge in fishing effort led to overproduction of low-quality raw coral, followed by a surplus of *Corallium* and a steady fall in price. The drop in prices, compounded by the emergence of new sources of Pacific coral from Japan caused a serious crisis that led to a reduction in fishing effort and landings, with repercussions felt by Italy's coral artisans. A second example is the overharvest of Pacific *Corallium* around Emperor Seamounts between the 1960s and 1980s. Over this period there were several sharp increases in landings and rapid declines, and eventual abandonment of the fishing grounds in the late 1980s. These dramatic cycles can be attributed to the discovery of new beds followed by an influx of coral fishing boats, with a subsequent reduction in fishing fleet due to the commercial extinction of individual coral beds, elimination of government subsidies and bank loans to Taiwanese fishers, and most importantly, declines in market value due to market gluts and increased landings of low quality, dead coral (Bruckner 2009, 2014; Chang 2012).

46.2.1.6 Mediterranean Landings of *Corallium*

In the Mediterranean, 12 countries have reported landings (yield) data to FAO since 1978 (FAO 2015; Fig. 46.11). These data were highest during the first years of reporting, and show a sharp decline in over 20 years, from a maximum of 98 tons in 1978 to 18.9 tons in 1998. The largest declines over this period were reported by Italy and Tunisia, while yield from African countries (Morocco and Algeria) increased substantially in the mid-1980s. The declines observed in the 1980s can be partially attributed to a phase-out of the use of non-selective dredges, as well as a reduction overall in effort and a change in management schemes. However, these changes are not the only reason for the decline. SCUBA fisheries were first introduced in the 1950s, while the use of the coral dredge was not banned until 1989 (in Sardinia only) or 1994 (throughout the rest of European waters). Landings were already less than 50 % of 1978 levels (42 tons) in 1984, and they remained at these low levels (32–48 tons) for the next 5 years, all prior to the ban on dredging. Even in Italy, where the coral dredge was banned 5 years earlier than in other locations, landings had already declined from a peak of over 72 tons in 1978 to 40 tons in 1980 and 19.3 tons in 1985, with less than 10 tons landed each year up to 1988. Landings from Italian fisheries declined further following the ban by close to 50 %, yet this reduction is minimal when compared to changes observed during years when the ingegno was still legally used (Fig. 46.11).

Despite a dramatic change in fishing techniques with the introduction of SCUBA diving, and the enhanced efficiency and specialization of the fishery, landings increased but never returned to levels reported in the 1970s. Mediterranean-wide landings have steadily increased over the last 20 years, reaching a second peak of 54.11 tons in 2010, but have since begun to decline slightly (Bruckner 2014). Furthermore, landings reported by individual countries show sharp swings in quantity since inception of SCUBA fishing, which are suggestive of the discovery of large aggregations of coral in a particular area, followed by rapid overexploitation of these populations.

An examination of catch data by country reveals relatively stable landings in some countries, while others show a slow but progressive increase, giving a false impression that the fishery has been sustainable. Part of this increase is due to the expansion of fisheries outside the European Mediterranean to the North African countries, the Atlantic coastline, Turkey, and the Eastern Adriatic Sea. Simultaneously, as shallow beds (30–50 m) have been progressively overfished, divers in the European Mediterranean

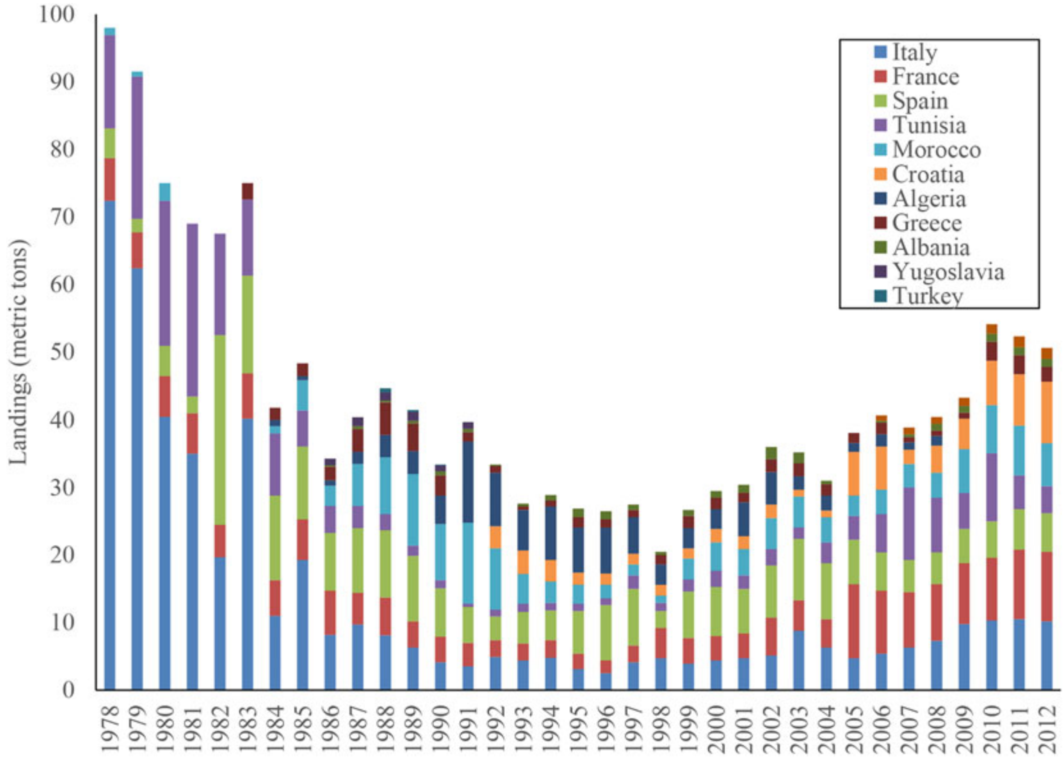

Fig. 46.11 Global catch data for the Mediterranean between 1963 and 2012 broken down by individual country

have begun to exploit unfished areas in deeper water (80–130 m). Individual peaks in landings during a single year reflect a pulse mode of fishing associated with SCUBA fisheries, whereby all of the large colonies are cleared from an individual bed, and then divers move on to new areas. Furthermore, in some countries there are reports that SCUBA divers are harvesting higher numbers of smaller corals in areas where the large size classes have been depleted (Tsounis et al. 2010). The recent use of ROVs to search for colonies, and in some cases illegally harvest corals, is an important factor in the ever increasing landings being reported from some countries (Tsounis et al. 2010, 2013). Proposals to list corals in CITES, as well as new measures being developed and implemented through FAO, may have pushed divers to harvest as much coral as possible before new regulations on trade and harvest are implemented (Tsounis et al. 2013). This is especially true around Sardinia, where landings of red coral doubled from 4.7 tons in 2005 to 10 tons per year since 2009. France also shows large increases in landings between 2004 and 2010 and landings from Croatia and Morocco both increased since 2009. Data from Tunisia shows substantial increases from 2006 to 2010 but landings have since begun to decline (Fig. 46.11).

46.2.1.7 Pacific Landings of *Corallium*

In the North Pacific, precious corals has been harvested at low levels since the 1870s, primarily from inshore waters around Japan and Taiwan (Fig. 46.2). The annual Japanese catch from the inception of the fishery until several decades after World War II has varied from about 2–20 metric tons (Wells 1981; Grigg 2010). Production records Japanese fishermen operating near Okinawa in the 1960s were similar, reaching a peak of 14.78 tons in 1963 and dropping to less than 1 ton by 1969 as the resource was entirely wiped out (Grigg 1971). In Taiwan, during the early days of the fishery (1925–1940), catch ranged from 10 to 20 tons per year during peak periods with declines to 3–5 tons in low periods (Fig. 46.12).

Pacific landings greatly expanded following discovery of a large bed of *C. secundum* in Midway Islands in 1965, and again in the mid-1970s when a second (undescribed) species was found around Emperor Seamounts. Reconstructed FAO Global Capture Production data (FAO 2015) show five major peaks over this period (Fig. 46.13), followed by a progressive decline between 1984 and 1989. Landings reported by Japan exceeded 300 tons per year between 1965 and 1967, sharply declined to 52 tons by 1968, and reached a second peak of 113 tons in 1969 before declining once more to less than 50 tons until 1975 (Fujioka 2008). Annual yield from Japan was the greatest from 1965 to 1969 and 1975–1980 (63–103 t/year), with 70–90 % of the harvest in later years consisting of Midway deep-sea coral (*Corallium* sp. nov.). Landings from these beds reported by Taiwan were similar to Japan between 1968 and 1970, but they then dropped off

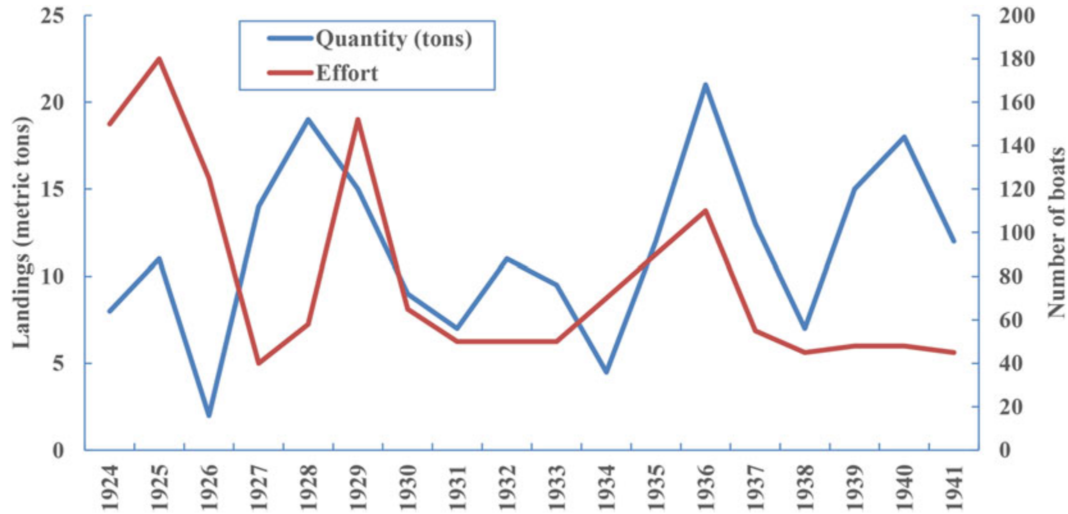

Fig. 46.12 Reported landings of precious coral (*C. konojoi, C. elatius* and *P. japonicum* are pooled) from inshore waters of Taiwan and approximate number of boats fishing for coral between 1924 and 1940 (Data extrapolated from Grigg 1971)

until 1976 when they climbed to values that were two to three times greater than that reported by Japan (Fig. 46.13a) with peaks in landings of *C. secundum* in 1969 (112 tons), 1976 (102 tons), 1981 (270 tons) and 1984 (226 tons), and even higher amounts of *Corallium* sp. nov. from 1983 to 1986 (564 t), most of which was harvested off Midway Island (Bruckner 2014).

The cause of the decline of the Emperor Seamount fisheries has been widely debated. Several reports from Japan and Taiwan indicate the precipitous declines are due solely to a decrease in effort but not the depletion of the resource (Iwasaki and Suzuki 2010; Chang et al. 2013). Firstly, excessive harvest in the 1970s resulted in a glut in the market which caused the wholesale value to drop below harvest costs. Secondly, the fishery was reported to have taken off shortly after discovery of these resources primarily because of incentives provided by the government to promote the fishery, which were terminated in 1979. A limit on the total number of coral fishing vessels in the 1980s led to the pulling out of Japanese fishing vessels, and later Taiwanese fishing vessels (Iwasaki and Suzuki 2010). To date, a coral fishery never resumed in these areas, largely because (1) these corals are less valuable than other species; (2) there are reports of remaining stockpiles; and (3) the costs of fuel and operations associated with offshore fisheries exceeds the value of the coral (Chang et al. 2013).

While economics and government incentives certainly affected landings around Emperor Seamounts, it is reasonable to assume the fishery caused the depletion of most of the coral from these depths relatively quickly, based on the biological attributes of these corals and the large scale nature of this fishery in comparison to the overall amount of accessible coral habitat (Bruckner 2009). With such a large number of fishing vessels, individual areas would have been dragged repeatedly; fishers are also likely to have continuously spread into new fishing grounds in search of new stocks, as indicated by reports of illegal poaching outside of international waters, especially in US waters around Hawaii (Grigg 1993). The presence of a large proportion dead, poor quality corals in landings is further evidence that live colonies were severely depleted, and much of what was landed in later years was coral that had been broken off by dredges during earlier efforts. Although few biological data exist from these areas, submersible surveys conducted by Japan in 2008 on Emperor Seamounts included areas targeted by coral draggers in the 1960s–1980s. These surveys identified isolated live colonies and dead and broken colonies, but they failed to identify a single large patch of *Corallium* (Fisheries Agency of Japan 2008). This further suggests the resource was overexploited beyond limits of recovery, and even in absence of fishing for more than 20 years populations have not rebounded.

Since the late 1980s, following the reduction and eventual termination of coral fisheries on the Emperor Seamounts, only a fraction of the historic harvest has been landed. The JCFA estimates that the total Japanese harvest of precious corals decreased from over 55 metric tons (t) in 1982 to only 3 t in 1988 and have remained at levels that are 10–20 % of that reported in the late 1980s (Carleton and Philipson 1987; Grigg 1989). Reported landings (compiled by FAO) of all species from inshore waters around Japan have varied from 7 to 8 tons/year in the early 1980s, dropping to 1–3 tons in the 1990s and stabilizing at about 5 tons/year over the last decade (Fig. 46.14). The coral consists predominantly of *C. elatius* (mean = 1.97 tons/year) and *P. japonicum* (1.2 tons/year), with minimal amounts of *C. konojoi* and *Corallium* sp. nov. (0.15 tons/year) reported in the catch statistics (Fig. 46.14a). Interestingly, vessels using non-selective tangle net dredgesPacific coral was in the

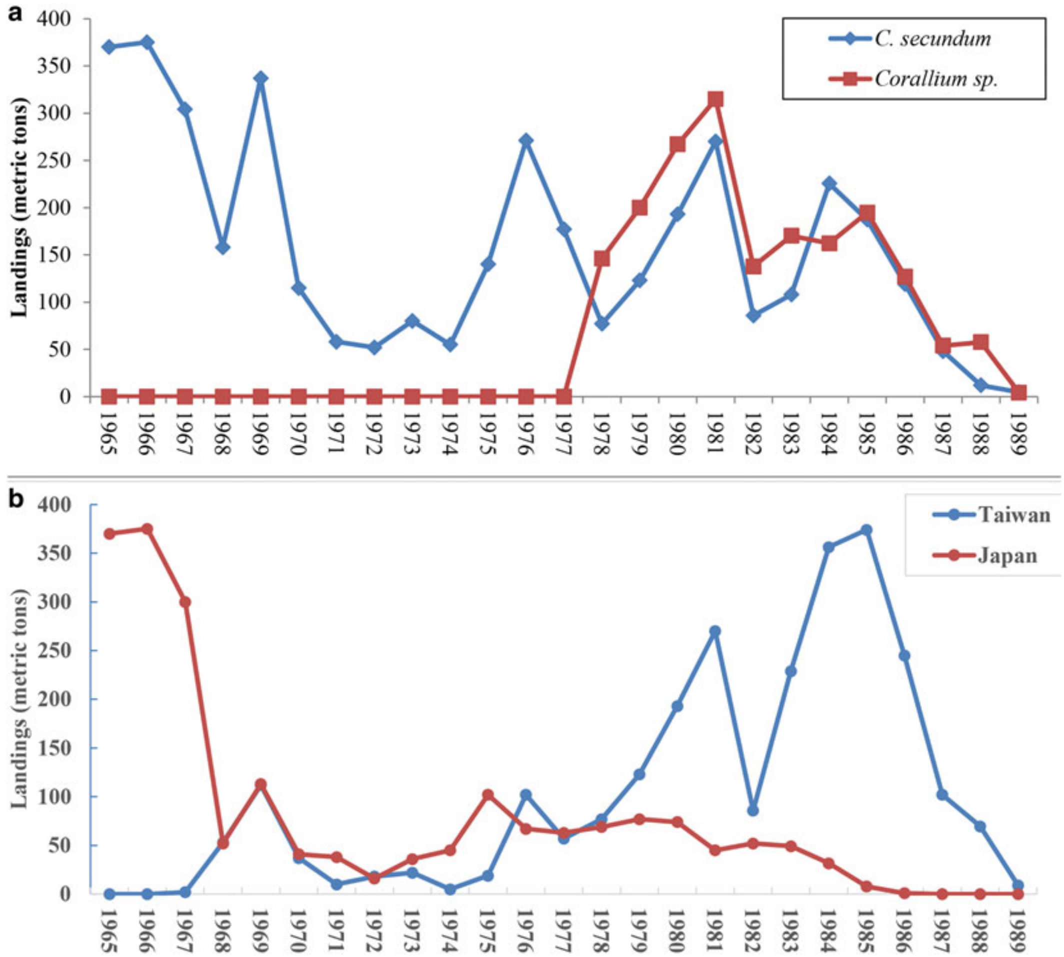

Fig. 46.13 Global capture production for precious corals harvested off Midway Islands and Seamounts extrapolated from FAO Fishery and Aquaculture Global Statistics (FAO 2015). (**a**) Landings of angel skin (*C. secundum*) and Midway deep sea coral (*Corallium* sp.) pooled for both countries. (**b**) Landings for all species for Taiwan (*blue*) and Japan (*red*). *Corallium secundum* was the only species harvested between 1965-approx. 1978, while Midway deep sea coral was first discovered around 1978 and harvested until 1989

Kochi Prefecture operate for only about 2 weeks per year, with each of the 120–230 boats landing approximately 12 kg per year (Tsounis et al. 2010).

Landings by Taiwanese coral fisheries have shown much more fluctuation. Landings between 1990 and 2008 were higher than Japan (mean = 7.1 ton/year), but they are still a fraction of the coral harvested in the 1970s and 1980s. The highest landings occurred in 1996 (12.6 ton), 2002–2004 (35 ton), and 2008 (11.95 ton); most of this was *C. elatius* harvested from 300 to 500 m between Taiwan and the Philippines. Since 2009, when Taiwan introduced new regulations, landings have been considerably less (2.9–4.8 ton/year), and appear to show a downward trend. A surge in Pacific coral was reported in FAO statistics in 2012 (21 ton) consisting mostly of *C. konojoi* harvested by Chinese fishing vessels operating illegally in waters around the Diaoyu islands and Miyako islands and off Taiwan (Chang 2015; Fig. 46.14b).

46.2.2 Black Coral

46.2.2.1 Historical Significance

Like *Corallium*, similar mystical powers and medicinal properties have been attributed to black coral. The skeleton of the larger black coral species has been used for jewelry and religious articles from at least the time of the ancient Greeks. In Indonesia, black coral branches are boiled in oil and when softened are bent to form arm bangles. Indonesian folklore suggests that a black coral bracelet worn on the right arm increases virility, while one worn on the left arm cures rheumatism (Wells 1981). In the Red Sea, black coral was used as an aphrodisiac and to cure eye diseases (Castorena and Metaca 1979). The name “*Antipathes*” translated from Latin means “against disease or suffering”. It is thought to have originated in North Africa, where black coral was prized because it “neutralized” the magic of the dreaded “evil eye” (Hansen 1981). Black coral branches are also

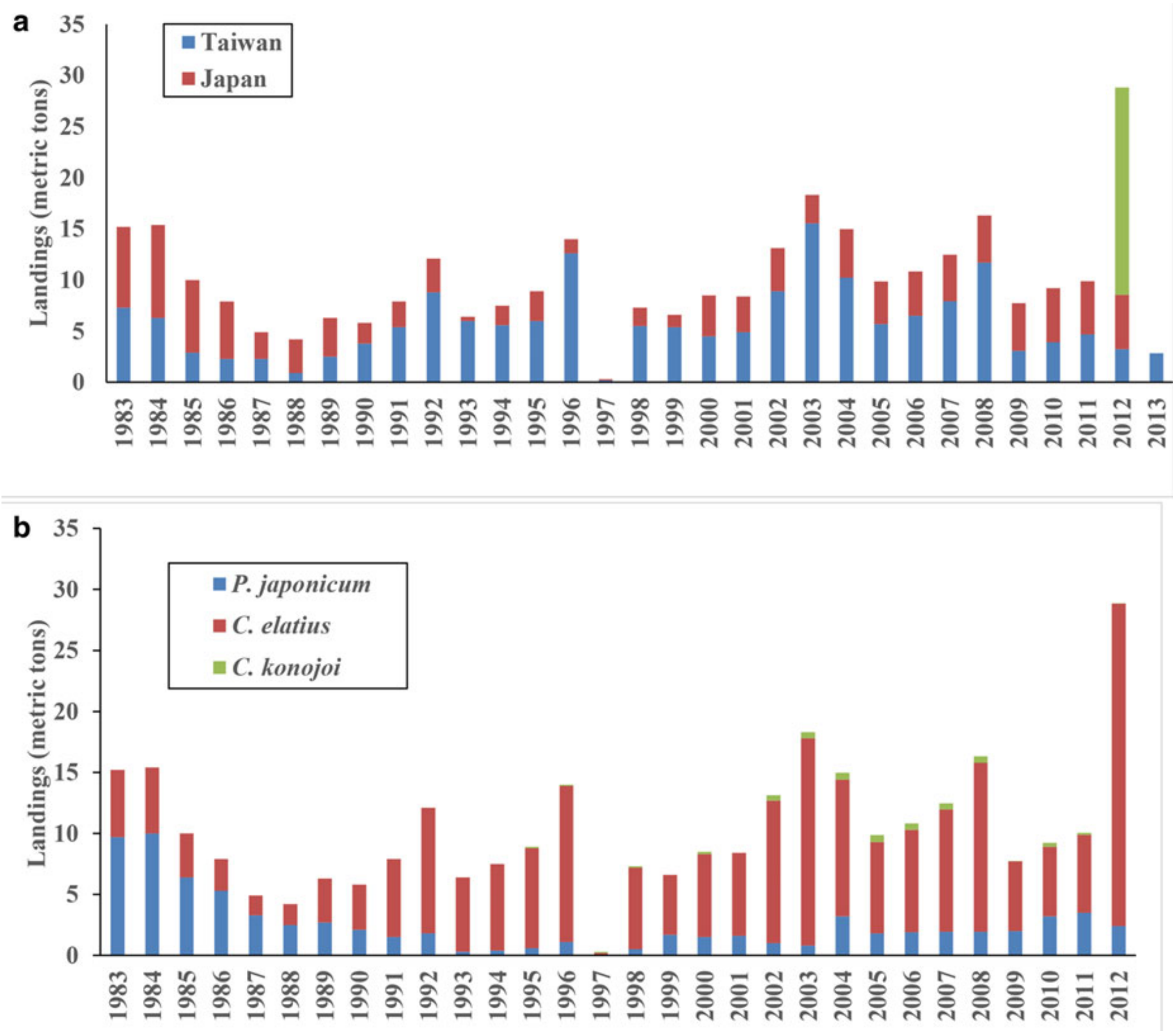

Fig. 46.14 Global production statistics for inshore precious coral fisheries of Japan, Taiwan and China between 1983 and 2013. (**a**) Landings pooled for all species by country. China first reported landings of *Corallium* in 2012 (green bar). Landings data for 2013 were only available from Taiwan. (**b**) Landings data pooled for the three countries for each species. *P. japonicum* made up the bulk of the landings in the early 1980s, while most coral landed since 1990 consists of *C. elatius*. The large spike reported for 2012 are due to landings of *C. elatius* from China

ground into a medicinal powder and used in Chinese traditional medicine; black corals are said to relieve pain, reduce fever, stop bleeding, and soften hard masses (Qi et al. 2009). In ancient Greco-Roman culture, black coral powder was applied to wounds before and after cranial surgery (Mariani-Costantini et al. 2000). In Hawaiian culture, black coral powder was mixed with other natural ingredients and used to treat mouth sores and lung diseases (Nagata 1971; Chun 1994). The high cultural importance of black coral is still apparent today, as it is the official state gemstone of the State of Hawaii (USA). In many tropical nations, especially Hawaii and the Cayman Islands, high end jewelry and carvings of black coral are commonplace.

46.2.2.2 Black Coral Fisheries

The earliest known fisheries for black coral were in the Red Sea. One of the largest fisheries in this time was based out of Jeddah, Saudi Arabia, where corals were harvested along a 100 mile stretch of coastline. Much of the coral from Saudi Arabia was carved into beads and mouthpieces for cigar holders (Tressler and Lemon 1951). Black coral was also marketed in the Far East for use as scepters, divining rods and amulets. Black coral (*Antipathes ternatensis* and *Cirrhipathes* spp.) has also been extensively harvested off the Vietnamese coast and Sumatra Malaysia region, while *A. arborea* and *Isidis plecarus* were historically harvested off Sri Lanka.

Commercial beds of black coral were discovered in 1958 in two locations off Hawaii (Auau channel off Maui and the southwestern coast of Kauai) at 30–90 m depth and have been fished almost continuously for over 50 years (Grigg 2001). Maui Divers first established a small black coral jewelry industry in 1960, employing 10–12 divers who removed corals with axes, hammers and saws (Grigg 1993). Between 1963 and 1970, these divers harvested over 23,000 kg from the two locations, most of which was *Antipathes dichotoma* (90 %) with lesser amounts of *A. grandis* (10 %) and *A. ulex* (1 %) (Grigg 1971; NOAA 2002; Bruckner et al. 2008). During the 1970s and 1980s, consumer demand for black coral was greatly reduced, and the market shifted to *Corallium* and *Gerardia* (Grigg 1993, 2001), although landings still remained quite high. Grigg (2010) estimated that approximately 8,000 kg was harvested annually from the Maui Bed and 4,000 kg from the Kauai bed over this period. Technological advances in coral processing in Hawaii in the 1980s led to a dramatic decrease of the amount of coral needed to produce the same value of finished product, and many of the items are smaller in size and of a higher quality (Grigg 1993). The import of cut and polished black coral from Taiwan further affected the volume of harvest of coral by Hawaiian coral fishers, as the industry consumed less than 2 tons per year on average during the 1980s (Oishi 1990). Hawaii also imported roughly 70 t of *Cirrhipathes anguina* (whip coral) that had been harvested in the Philippines and processed in Taiwan into beads, rings, bracelets and necklaces (Carleton 1987). Lesser amounts of black coral were imported from Tonga (Harper 1988).

Since 1980, virtually all black coral harvested in the Hawaiian Islands has been taken from the Au'Au Channel Bed (total size of about 1.7 km^2) with a lesser harvest from the smaller (0.4 km^2) Kauai Bed. Black coral landings in Hawaii increased considerably during the 1990s and early 2000s (WPRFMC 2006). From 1981 to 1990 the state of Hawaii reported that landings of black coral amounted to 6,200 kg, with an annual take of 72–1,977 kg (Oishi 1990). The total black coral landings increased to over 9,000 kg over the next 7 years (1992–1998) and they continued to increase between 1999 and 2005, comprising 58 % of the total harvest since 1985 (Parrish 2006b). Currently, only about five coral divers are active in this region.

Although black coral was fished commercially from the 1960s to the 1980s in many other Pacific locations, such as Ecuador, Indonesia, and Palau, the quantities taken were generally small, and landings were rarely reported (Wells 1983; Grigg 1993). For example, black corals were intensively collected around the Galapagos and Ecuador in the 1980s, and these species have completely disappeared from several sites (Martinez and Robinson 1983).

In the Caribbean, most of the harvest has been *A. pennacea*, *A. dichotoma*, *Leiopathes glaberrima*, and *Cirrhipathes lutkeni*, primarily for use in the tourist jewelry trade and not for export. In general, most Caribbean fisheries were short-lived and collection was sporadic as the resource was patchy and shallow water populations were easily overexploited. By the early 1980s, depletion of local populations as a result of unsustainable harvest had been reported in St. Lucia, Barbados, Netherlands Antilles, Bahamas, and British Virgin Islands (Anon 1979a, b; Wells 1981). Much like the red coral fishery, divers depleted resources from shallow water and progressively expanded their search into deeper water. Following adoption of international regulations on trade through CITES, legislation curtailing or prohibiting collection and trade was implemented in Antigua, Belize, Trinidad and Tobago, the Bahamas, the Netherlands Antilles, the US Virgin Islands, and British Virgin Islands (Wells 1981).

Large populations of black coral (*Antipathes caribbeana*) were first discovered in Cuba in the 1960s and collection began in the 1970s. The fishery expanded substantially in the mid-1980s in the Cazones Gulf, with 1,355 kg of black coral harvested between 1987 and 1993. Black coral was also extracted from Pinar del Rio, with a maximum of 301 kg taken in 1992 (Guitart et al. 1997). The fishery was unregulated until 1990, when recently minimum size limits and on boat inspections began. The most recent landings data for Cuba are from 1998, when 1,468.6 kg of coral were landed from depths of 20–55 m by four enterprises (Alcolado et al. 2003).

In 1984, a government-owned company, the Mediterranean Coral Fishing Company, began to conduct surveys to identify and harvest precious corals in Maltese waters. These fisheries relied on SCUBA divers using helium-based breathing gas mixtures, an ROV, and a manned submersible. In addition to *Corallium*, 250 tons of black coral were harvested from 500 to 600 m between 1984 and 1987. The black coral fishery in the Maltese Islands eventually came to the attention of the International Union for the Conservation of Nature (IUCN) which, in 1987, solicited the Maltese government to sustainably manage and regulate these slow-growing species. They based their concerns on scientific studies, highlighting the fact that this was the only known black coral fishery in the Mediterranean (Deidun et al. 2010).

Southeast Asia and the South Pacific islands continue to be an important source of black coral for international markets, however very limited information is available on the status of the industry or the amount of harvest. In the 1980s, an estimated 60–100 tons of black coral were harvested from the Philippines each year, with most of the remainder (about 8 % of all world harvest) collected from South Pacific countries, principally Tonga, Fiji and Papua New Guinea (JP Parish SPC/Inshore Fish. Res./WP.2). According to the CITES database, a total of 72 metric tons and 7,400,000 pieces of black coral were recorded as being traded between 1982 and 1998, with most exported from Taiwan, the Philippines, and the Dominican Republic.

46.2.3 Other Precious Corals

Other types of precious corals, including gold corals and bamboo corals have made up a small fraction of the industry and very few data are available on locations of fisheries and landings. It is likely that most fisheries have been active for short periods in more of an exploratory manner, and quickly terminated due to the scarcity of these resources. This presumption is further supported by the limited amount of bamboo coral and gold coral jewelry that has appeared in the marketplace. During the 1970s, small quantities of four species of bamboo corals, *Acanella eburnea, Keratoisis flexibilis, K.ornata* and *Lepidisis caryophyllia* were collected commercially from the Gulf of Mexico and used to produce beads (Wells 1981). Bamboo coral harvest in Bone Bay, Sulawesi (Indonesia), appears to have increased significantly in recent years with exports of more than 100 tons reported in 2005 (Department of Fishery and Marine Affairs [Dinas Perikanan dan Kelautan Bone sudah tercatat]).

Hawaiian Gold Coral was first discovered in Makapu'u Bed in 1971 and later found in small quantities in 16 other locations throughout the Hawaiian Archipelago (Fig. 46.3). It was first introduced to the jewelry industry in 1974, and quickly gained popularity due to its interesting color patterns. Unlike other precious corals, its color ranged from a sandy beige to almost black. It has a special characteristic called "Chatoyance," from the French word for "cats eye," which describes a mysterious moving inner light. The only commercial fishery established to date is in Hawaii, with selective harvest using a small submersible from approximately 400 m depth. The initial landings from Makapu'u Bed in 1974 amounted to 734 kg (Grigg 1993). *Gerardia* was harvested from the same beds between 1975 and June 1978, with reported landings of 621 kg in 1975, decreasing each year to 363, 329 and 50 kg respectively, after which the operation was discontinued. Hawaii placed a 5-year moratorium on gold coral harvest in 2008 and this was recently extended for another 5 years. A limited harvest of *Gerardia* spp. was reported from waters surrounding Turkey (Deudin et al. 2010).

Primnoa gold corals from Australia were never commercially harvested, but they did appear as bycatch of halibut fisheries in the 1980s. These were sold to jewelers for approx. US $20–$25/lb (Cairns and Bayer 2005). Cimberg et al. (1981) reported two species of *Primnoa* in trade in the 1970s: *P. resedaeformis* and *P. willeyi*. Between 1997 and 2002, less than 200 kg of *Primnoa* was harvested per year for the jewelry trade (Krieger and Wing 2002).

46.2.4 Management of Precious Coral Fisheries

Throughout the history of precious coral fisheries, there have been numerous attempts to sustainably manage the harvest. The most common measures applied to these fisheries have focused on licensing schemes, limited entry, quotas and minimum sizes, gear restrictions, area closures, and rotation of harvest, as well as proposed restrictions on international trade through the Convention on the Trade in Endangered Species (CITES). Some of the earliest measures date from the tenth century when Arabs rotated fishing effort within *Corallium rubrum* beds located off Tunis. The French controlled the trade in the eighteenth century and also recommended rotation of fishing grounds, advising the Algerians to fish their coral beds only once every 5 years (Mcintosh 1910; Douglas 1947; WPFMC 1980). Historic measures applied to Pacific fishery resources by Japan and Taiwan have also focused on limiting effort through licensing schemes, limited entry, allowable sizes of fishing vessels, quotas, and area closures. For instance, the Penghu government attempted to promote longevity for the emerging fishery in Taiwan by limiting the fishery to 20–40 vessels (Liverno 1983).

The success of these measures has been extremely limited and efforts continue to be plagued with problems including frequent incursions by foreign fishermen into the territorial limits of other countries, lack of oversight, and inadequate enforcement (Grigg 2010). Besides a growing need to address poaching, successful management requires a better scientific understanding of the biology and ecology of these species, more thorough stock assessments, and application of sustainable yield methods similar to those applied to fisheries of other long-lived species (Grigg 2010). In the past, this would have been virtually impossible to achieve due to the type of fishing gear most commonly employed (destructive tangle nets) and the damage it causes to the habitat, combined with the sessile nature of these organisms that exposes all size classes to harvesting at the same time. Furthermore, the difficulty of conducting scientific research at these depths has limited our understanding of the locations and sizes of coral beds, the size/age structure of colonies within those beds, and other biological attributes such as natural mortality and rates of replenishment.

46.2.4.1 Management of Mediterranean Fisheries

Since the earliest days of the red coral fishery, harvest has followed a practice similar to strip mining, where one coral bed was depleted before fishermen began exploring and harvesting coral in new areas (Tsounis et al. 2010). Several centuries of this type of intense commercial harvest led to sharp declines in landings, causing scientists and conservation groups to question the sustainability of the fishery and adequacy of management measures. Scientific data collected over four decades provided further evidence of the depleted states of these resources, and debates about the potential commercial extinction of these species have steadily increased (Tsounis et al. 2013; Bruckner 2014; FAO 2015).

Management of red coral fisheries since the 1970s has included a variety of national measures within territorial waters (12 miles from the coast), EU-wide directives and international legal instruments. These range from broad directives to conserve the coral and protect the coralligenous habitat to very specific measures directed towards harvest in individual countries (Table 46.4). In the 1980s, the UN Food and Agriculture Organization (FAO) General Fisheries Commission for the Mediterranean (GFCM) convened a series of technical consultation meetings to develop a management framework for a sustainable coral fishery. The key recommendations from these consultations included (1) bans on the use of the coral dredge; (2) adoption of quotas; and (3) recommendations of a voluntary minimum size for harvest for SCUBA fishers of 7 mm (GFCM 1984, 1988; Council for the European Union 1994). Other actions that have been discussed and in some cases adopted include rotation of fishing grounds and area closures, as well as licensing and reporting requirements (Caddy 1993). Several of these measures have been incorporated into National Management Plans, along with a handful of other measures (Table 46.4).

The proposed listing of the family Corallidae in CITES in 2007 and 2009 (CITES-USA 2007; CITES-Sweden-USA 2010; see below) brought these corals back to the forefront. Although they were not listed, several ad hoc workshops held in response to these listing proposals, along with Scientific Advisory Committee meetings convened FAO GFCM has led to the development of an adaptive management plans for red coral fisheries in the Mediterranean (Bruckner and Roberts 2009; Bussoletti et al. 2010; FAO 2007, GFCM 2010, 2011, 2013). The current draft management plan for the Mediterranean region includes three key provisions: (1) a ban on harvest above 60 m depth; (2) a minimum size of 7 mm basal diameter; (3) allowable harvest using only SCUBA and hand tools and a ban on the use of ROVs with manipulator arms for collection.

46.2.4.2 Management of Japanese Inshore Fisheries

The harvest of precious coral in Japan is regulated by the prefectural governors (Kochi, Okinawa, Kagoshima, Nagasaki), according to the fishery rule for adjustment under the *Fishery Law and Conservation Policy for Marine Resource*. Both fishermen and vessels are licensed and three legal harvest zones are designated. No specific harvest season or quotas exist. New management measures were introduced in 2012, including gear restrictions (e.g. non-motorized tangle net dredges of a certain size or submersibles, depending on location), maximum total number of licenses, specific fishing grounds and depths, seasonal closures, maximum annual harvest (in some areas) and a minimum size.

From a biological perspective, the benefits of several of these measures are unclear. First, the 4 month closure (January, February, June and July) is unlikely to be a long enough duration to promote recovery of fished areas, given the slow growth rates of these species. There is also a requirement that undersized corals (<3 cm high or 7 mm in diameter) are "released", but these are unlikely to survive as they have been detached from the bottom.

A recent fishery-independent study comparing population structure inside and outside fished areas found alarming trends of decline in fished areas. Coral colonies in both areas had a similar density but dramatically different size structure: 10–20 year old colonies in fished areas and 20–60 year old colonies in no fished areas (Iwasaki et al. 2012). Since commercially collected species are ordinarily 30–40 years old and these are now rare in fished areas (Iwasaki et al. 2012), the resource must be reaching an overfished status. Furthermore, the finding of a similarly (very low) density in fished areas may result in reproductive failure of the populations. Firstly, because fertilization of broadcast spawners occurs externally, the number of gametes are greatly diluted because colonies are widely spaced; secondly, smaller sized corals are capable of producing fewer larvae (Beiring and Lasker 2000; Marschal et al. 2004; Bruckner 2009). Pacific corals are also characterized by much slower growth rates than *C. rubrum* (Iwasaki et al. 2012) and hence recovery may be significantly delayed.

46.2.4.3 Management of Taiwanese Inshore Fisheries

Fishing grounds from inshore areas around Taiwan have been historically managed through limits on the number of vessels, largely because of the tendency for newly discovered fishing grounds to be quickly inundated with fishing boats. Even with the licensing of vessels, one of the main issues in Taiwan has been illegal fishing and poaching. For instance, in 2007 there were three legally licensed vessels in Taiwan, yet investigations by the Taiwan Fishery Agency identified 90 vessels with coral fishing gear. Amended regulations adopted by Taiwan in 2009 include licensing of vessels (approximately 60 currently fish), an annual quota (200 kg *Corallium* and 120 g *Paracorallium* per vessel), five designated fishing grounds, and requirements of a Vessel Monitoring System (VMS), daily logbooks, designated landing ports, centralized auction markets, and an observer program (Huang and Ou 2010; Chen 2012).

These measures appear to have been effective in regulating the amount and spatial distribution of effort. Landing data are quite concerning, however, as they indicate the

Table 46.4 Summary of National Legislation for Mediterranean *Corallium rubrum* fisheries

Country	Gear types	Licenses	Closure	Quota	Size limit
Albania	Coral fishing is banned, yet landings reported	10 divers (estimated and unlicensed)			
Algeria	Dredge banned in 1977; no fishing from 1977 to 1982	1995: 8 areas divided among 100 divers	5 year harvest followed by 15 year closure; fishery closed in 2001	Max quota 850–1,200 kg/year per area, 8.9 tons total	8 mm min basal diameter, colony removed 3 cm from base
Croatia	Dredge banned in 1985	15 divers	Seasonal closure (Dec–March)	200 kg/year/diver, 3 tons total	No size restriction
France	No use of ROV (2012)	2011: 21 permits	No harvest above 50 m	50 kg/divers	8 mm min diameter
France, Corsica	1994	2006: 10 licenses	Voluntary min depth of 50 m	No limit	No size restriction
Greece	1994	Licensing introduced in 1987; 10 divers; no licenses granted in 2011	1994: Rotation of harvest over 5 areas, 50–110 m Harvest allowed for 5 years followed by a 20 year closure	No limit	No size restriction
Sardinia, Italy	Dredge banned in 1989 NO ROV, except for scientific observers	2012: 25 Regional permit issued annually; fines and confiscation of gear for harvest without permit and collection in prohibited areas	seasonal fishery (May-Nov); 7 MPAs 2008: All harvest must be below 80 m 7 protected areas	Max 2.5 kg/diver/day, 2 divers per boat, 13.5 tons total; Landings in 8 designated ports	2012: 10 mm minimal basal diameter (20 % tolerance)
Tuscany, Italy	Fishery closed July 2012-Dec 2013 No ROV allowed		2014: Harvest below 60 m		2014: 8 mm min diameter (5 % tolerance)
Malta	No exploitation allowed				
Monaco	*Corallium* habitat protected no exploitation allowed				
Montenegro	No data on regulations	Estimated 10 divers			
Morocco, Atlantic	Dredge Banned in the 1980s	10 boats/area, 3 divers/boat	2011: 40–80 m only from Larache to Cap Spartela	600 kg/boat, 6 tons total	No size limit
Morocco, Mediterranean	Dredge banned in the 1980s	Mediterranean: In 2006, Tofino (Al Hoceima) had a limit of 10 boats smaller than 50 t	Tofina area closed for 10 years in Aug. 2010	500 kg quota per boat; 6 tons total	No size limit

(continued)

Table 46.4 (continued)

Country	Gear types	Licenses	Closure	Quota	Size limit
Spain, external waters	Dredge banned 1983–1985; submarine allowed until 1997 off Isla de Alboran	47 authorized divers	5 areas: Catalonya, Illes Balears/Mallorca, Illes Balears/Menorca, Almería, South Atlantic Region from the border with Portugal to Punta Tarifa.	400 kg/fishermen/year, 10 % variance; quota of the submarine was 1,500 kg/year	7 mm diameter
Spain interior waters	Dredge banned 1983–1985	16 divers: Catalunya, 10; Balears, 6	4 MPAs, Cap de Creus, El Montgri, las Illes Medes, El Baix Ter	400 kg/diver	2012: 7 mm, 5 % tolerance
Tunisia	Dredge allowed below 100 m from 1982 to 1985; Banned in 1985	Divers licensed; estimated 30 divers	Closed areas off Bizerte, from Cap Blanc to Cap Zebit; fishing banned above 50 m at Cani Island	None	Catch weighed and reported
Turkey	Corallium harvest prohibited in 1990				

resource is at the limit of exploitation. The designated fishing grounds were fished intensively between 2009 and 2010, but most of the coral consists of long dead "fossilized" colonies and the proportion of live coral collected in the catch declined from 5 % to a low of 3 % over 2 years (Chen 2012).

46.2.4.4 Management of U.S. *Corallium* and *Gerardia* Fisheries

The Western Pacific Fishery Management Council's (WPFMC) Precious Corals Fisheries Management Plan (FMP) has regulated the harvest of precious corals since 1983 (NOAA 2002). The FMP imposes permit requirements valid for specific locations, harvest quotas for precious coral beds, a minimum size for pink coral, gear restrictions, area restrictions, and fishing seasons. The initial plan created four categories of coral beds: established beds, conditional beds, exploratory areas and refugia. At this time, a single bed, the Makapu'u Bed off Oahu Hawaii, was defined as an Established Bed for pink coral; four beds were established as Conditional Beds: Keahole Point, Kaena Point, Brooks Bank, and 180 Fathom Bank; and Westpac Bed was established as a refugium where coral harvest was not allowed (NOAA 2002; Grigg 2010). Specific quotas and size limits were established for precious coral beds in Hawaii based on the size of these beds, the standing stock and estimates of maximum sustainable yields and optimum yields. For Makapu'u bed, a 2-year harvest quota using selective gear was set at 2,000 kg for *C secundum*, 600 kg for *Gerardia* sp. and 500 kg for *L. olapa* and a minimum size (10 in. height) was set for *C. secundum*. The quotas for the conditional beds were directly related to their size, assuming the same optimal yield as Makapu'u. Because these beds are substantially smaller, the quotas for pink coral ranged from 67 to 444 kg and gold and bamboo corals were a fraction of these amounts (NOAA 2002). Because of the absence of data on the size of the bed and the population structure of corals within the EEZ exploratory areas, quotas of 1,000 kg were established for all species of precious coral combined, with the intent of modifying these based on future harvest records and research. Exploratory areas open to commercial coral harvesting at this time included the Main Hawaiian Islands, American Samoa, Guam, Rota, Tinian, and Saipan, while coral harvest was prohibited within the Northwest Hawaiian Islands (NWHI) National Monument.

The Fishery Management Plan has been amended eight times since its inception. These amendments reclassified eight of the exploratory areas as a single large area, defined overfishing of precious corals, established a framework to adjust management measures if necessary in the future, and designated the only established bed, Makapu'u, as a Habitat Area of Particular Concern because of its ecological function, rarity of the habitat and sensitivity to human perturbations. In late 2000, a Coral Reef Ecosystem Reserve was established in the Northwestern Hawaiian Islands (NWHI), protecting an estimated two thirds of the potential deep water habitat for precious corals from exploration and harvest (Grigg 2002). This measure placed a permanent zero-harvest cap on harvestable NWHI beds, including Brooks Banks and 180 Fathom Banks. Subsequent amendments to the fishery have included bans on the use of non-selective gear. In 2008, a 5 year moratorium was placed on the harvest of gold coral, which was extended indefinitely in 2014. Although earlier measures included new Experimental Fishing Permits to stimulate exploration, the *Corallium* fishery had only a brief revival between 1999 and 2001, and has remained dormant since 2002 (Grigg 2010).

46.2.4.5 Management of Black Coral Fisheries

Black coral beds in Hawaii are found in both Federal and state waters, with most of the fishing effort located in state waters, within 3 miles of islands. Similar to other precious coral fisheries in the U.S., regulations include specific provisions for harvest within designated known beds of precious corals, maximum sustainable yield (MSY), size restrictions and gear restrictions. State management involves a system of licensing and reporting requirements, as well as maximum sustainable yields, and minimum size limits. Black coral beds in Federal waters are classified as established beds, conditional beds, refugia beds and exploratory permit areas (Grigg 1994). The Makapu'u Bed and Au'Au channel bed are currently the only established beds. The established beds can only be harvested using selective gear. The state first established a minimum size requirement for black corals in 1998, limiting harvest to specimens with a minimum base diameter of 1.91 cm (0.75 in.). A minimum size of 122 cm (48 in.) height or 2.54 cm (1 in.) diameter became effective in Federal waters on April 17, 2002, but a grandfathering scheme was introduced, allowing veteran divers to harvest smaller size classes (Bruckner et al. 2008). This exemption was removed in 2007; current fishing regulations prohibit harvesting of colonies <90 cm in height in state waters, and colonies <120 cm in height in Federal waters.

Since inception of the Hawaii fishery, most of the harvest has occurred within the two major commercial beds, one situated off Maui (Au'au Channel) and the other off Kauai (Makawaena Point) (Grigg 1993). Black coral is selectively harvested by divers using SCUBA, which limits harvest to depths above 246 ft (Kahng 2006). Because there are significant amounts of black coral that are below the limit using standard SCUBA equipment, these colonies were thought to serve as a refuge for shallower populations. However, surveys from 2001 to 2004 on reefs below 70 m showed that over 50 % of the colonies were overgrown by a species of invasive coral, *Carijoa riisei* (Grigg 2003, 2004; Kahng 2006).

Biological surveys conducted between 2002 and 2004 illustrate a downward shift in the age structure of colonies as well as a reduction in biomass of about 25 %, and a decline in both recruitment and abundance of legal-sized black coral colonies (Grigg 2004). This was compounded by continued spread of the invasive coral (Kahng and Grigg 2005) and a large increase (25–50 %) in demand for black coral since 1998, leading to increased harvest pressure. Based on recommendations of a downward adjustment of MSY, state and federal authorities recently amended quotas for harvest within Au'au channel. The quota, previously set at 5,000 kg annually in Federal waters, was reduced to 5,000 kg biannually for both state and Federal waters (Bruckner et al. 2008).

While this fishery represents the first precious coral fishery that was managed using biological attributes of the coral along with detailed population surveys (Grigg 2001), it still requires further modification. In order to ensure that harvesting is sustainable and does not significantly limit recruitment, optimal harvest yields must be determined using measures of abundance, growth, natural mortality and recruitment, and not necessarily maximum profit. A minimum allowable size of harvest should provide sufficient time between age (size) at first reproduction and age (size) at first capture. The age at maximum yield per recruit for the dominant species in the Hawaiian black coral fishery (*A. dichotoma)* was estimated to be 22–40 years, corresponding to corals that measure 1.7 and 3.2 m in height. This is much less than the maximum size of these corals but much more than the minimum allowable size of harvest. The allowable minimum size has been developed based on presumed optimal yield whereby profit is maximized at disproportionately less effort (Tsounis et al. 2010).

Size limits have been applied to black corals in other countries, but in absence of other controls they appear to have been ineffective. For instance, Cuba established a minimum size of 1.2 m height and 2.5 cm diameter for *Antipathes caribbeana* in the 1990s. Nevertheless, black coral populations have been depleted along the Pinar del Rio Province, in Matanzas Bay (northeast Cuba), Puerto de Sagua (north-central Cuba) and Cazones Gulf (Alcolado et al. 2003).

46.3 International Regulations

Since the 1980s, several proposals have been submitted to include precious corals in Appendix II of the Convention on the International Trade in Endangered Species of Flora and Fauna (CITES). CITES, an agreement between 175 governments, was created in 1975 to ensure that international trade of wild animals does not threaten their survival. CITES actively controls trade in Appendix II listed species by requiring export permits from the country of origin for listed species. These permits are supposed to be issued if there is a finding that the harvest of a listed species does not affect the survival of that species in the wild or its role in the ecosystem. The determination of allowable harvest is supposed to be based on the biology of the species and status of the stocks. Stony corals, including Coenothecalia (blue corals), Tubiporidae (organ-pipe corals), Stylasteridae (lace coral) and Scleractinia (stony coral) have been listed for several decades mainly because of concerns of the curio trade (and more recently the aquarium trade).

Black corals were the first precious corals to be added to Appendix II of CITES, following a proposal at COP III (1981) by the United Kingdom on behalf of the Virgin Islands. Black coral began to be heavily collected in tropical countries in the 1970s for tourist souvenirs, and the Virgin Islands were concerned that Caribbean populations were being overexploited (Anon 1979b). At the time of listing, available data did not fulfill the criteria required to list a species today, mainly due to a lack of biological and population data, however concern about depletion of Caribbean stocks led to the international support for its listing (Wells and Bardzo 1991).

Following successful listings of stony corals and black corals, Spain proposed to include *Corallium rubrum* on Appendix II of CITES in 1986. The proposal was based on the conclusions that known coral beds in Spanish waters were overexploited – control of illegal collecting was necessary, and the use of non-selective dredges was causing considerable habitat damage. Spain also noted that there was uncontrollable poaching of *Corallium* by Sicilian fleets at Alboran. The proposal was overturned because of a suggested lack of data that demonstrated that these species were threatened due to unsustainable trade. After the proposal was rejected, GFCM convened three Technical Consultations on Red Coral (Spain 1983, Italy 1988 and Algeria 1989). These consultations were intended to provide helpful guidelines for a more effective management of the resource, but only a handful of the suggested measures were adopted (Table 46.5).

As new information on declines in yield, mounting evidence of overexploitation of coral beds, and additional supporting scientific information on the vulnerability of *Corallium* populations has accumulated, international conservation organizations began evaluating the need for new measures to protect these species. Since precious coral fisheries are largely driven by international demand, the U.S. proposed the genus *Corallium* for listing in Appendix II of the Convention on the Trade in Endangered Species (CITES) in 2007 (CITES-USA 2007). The 2007 proposal was adopted in Committee One and then subsequently overturned through a secret ballet during deliberations in Plenary on the final day. The main justification against a listing centered on concerns regarding the implementation of the listing (Table 46.5; Morell 2007). FAO, in a consulting role to CITES, reviewed the proposal and concluded that there were uncertainties whether the criterion of biomass decline was met for all species and noted that a deficiency of data was identified for several species (FAO 2007). Two ad hoc international workshops were held to clarify these issues and discuss whether a CITES listing could be effectively implemented (Bruckner and Roberts 2009; Bussoletti et al. 2010). The United States and Sweden submitted an updated proposal at the Conference of Parties 15 in 2010 (CITES-Sweden-USA 2010). While this clarified many of the CITES implementation issues and substantial new information was included on the extent of depletion of these species, the listing was not adopted.

The FAO review once again found that the data do not meet the decline criteria, highlighted some of the implementation concerns surrounding a CITES listing, and suggested revised local and regional management as a more effective mechanism to prevent unsustainable harvesting (FAO 2010). Furthermore, consensus from the second *ad hoc* workshop in Italy was that the FAO GFCM (General Fisheries Commission of the Mediterranean) was the appropriate organization to effectively manage *Corallium rubrum* (Bussoletti et al. 2010).

One of the main arguments against the CITES listing proposal is that declines in landings may not necessarily reflect biomass trends, unless effort is considered. A decrease in

Table 46.5 Implementation challenges associated with a CITES Appendix II listing for Corallidae

Issue	Concern	Solution and rationale
Identification of species in trade	Worked specimens (jewelry, carvings) of *Corallium* cannot be distinguished to species	Report only to family Corallidae. Some taxa of other listed corals are recorded on CITES documents to Genus
	Challenges in identifying raw coral to species	An identification manual for *Corallium* in trade was recently developed (Cooper et al. 2011)
Stockpiles of raw and semi-worked pieces of *Corallium*	Pre-existing corals that were collected prior to the listing could not be exported without permits	Delayed implementation would allow invoicing of stockpiles. Trade could occur under a CITES-preconvention certificate as done with other listed species
Legal acquisition findings	The high value of precious corals would encourage illegal harvest and trade	This is already a large problem; a listing would provide a mechanism for cooperation to eliminate poaching
Paperwork to track trade	Significant paperwork requirements and costs associated with international trade in listed species	CITES allows exemptions for personal use which would eliminate paperwork by tourists travelling abroad and can limit permitting requirements to commercial trade
Making non detriment findings	Countries lack the capacity and data to make a non-detriment finding, as required to export the coral	The listing would promote more research to determine the status and sustainable levels of harvest. Improvements to national and regional management plans could help ensure sustainable harvest

fishing intensity due to market forces that render fishing economically infeasible may result in declines in landings not necessarily due to a decline in the abundance of the resource. An overabundance of coral, and a glut of poor quality coral, drove prices to such low levels twice in the history of *Corallium* fisheries: (1) the discovery and excessive harvesting of poor quality fossilized Sciacca coral in the 1880s, and (2) the overharvesting of low quality Midway corals in 1982 (Tsounis et al. 2010). The declines in yield of Midway corals in the later years of the fishery as well as the declines in the Mediterranean landings prior to elimination of the dredge in the early 1980s reflect biomass declines – in both cases prices increased.

While countries have not adopted international trade restrictions through CITES for *Corallium* as of 2015, China listed four species of Coralliidae on Appendix-III of CITES *(P. japonicum, C. elatius, C. konojoi, C. secundum)* in 2008 due to concerns of illegal harvest and trade. This listing places a requirement on countries to identify worked and raw *Corallium* in trade (Cooper et al. 2011), thus they already have to deal with some of the implementation issues identified as a hindrance to the precious coral industry. Proponents of a CITES listing recognize that trade restrictions are not a substitute for local management, but existing efforts to manage these resources have failed to protect the resource largely because the necessary scientific information is unavailable. Because countries are required to assess the population status and the fisheries prior to the export of raw *Corallium* and *Corallium* products, a listing would stimulate the research and management necessary to make a non-detriment finding (Bruckner 2009). Furthermore, poaching has become one of the main problems plaguing the industry. A CITES listing may lead to more severe penalties for illegal fishing and export, thereby enhancing local management.

46.4 A Paradigm Shift for Precious Coral Fisheries

Management of precious coral fisheries has been hampered by complications associated with enforcement and jurisdiction, illegal and unregulated fisheries, and organized poaching that authorities are unable to control. Challenges are also due to the multinational character of the fishery and the presence of precious coral beds outside territorial limits in international waters. Because of the general nature of precious coral fisheries, fisheries are likely to continue to face growing problems as stocks are driven to commercial extinction. In all regions, throughout history of these fisheries, landings have shown large peaks shortly after the discovery of a coral bed followed by rapid and precipitous declines in yield within a few years, with continued expansion into new areas as known beds become overexploited (Tsounis et al. 2013; Bruckner 2014). Throughout the Mediterranean, large shifts in population structure are documented within fished areas, and all shallow *C. rubrum* beds (above 60 m) are now considered overexploited (Bussoletti et al. 2010). These areas have shown reductions in colony size from historic averages of 30–50 cm height (10–30 mm diameter) to populations dominated by small colonies (3–5 cm height and 5–7 mm diameter) (Garrabou and Harmelin 2002; Tsounis et al. 2006b, 2007). Defined areas where fishing is allowed is now established in both Japan and Taiwan, but landings from both regions consist predominantly of dead colonies (Kosuge 2010; Chen 2012). Even in Hawaii, which supports the only precious coral fishery in the world with defined quotas and size limits derived from models of maximum sustainable yield determined using information on the biology of the target species and detailed assessments of population size and structure, resources are in decline (Grigg 2001, 2003, 2004; WPFMC 2007). Over a decade ago, scientists observed a 25 % decline in biomass and shifts in the size structure of harvested black coral populations, which was attributed to a combination of fishing pressure and increased mortality associated with an invasive species (Grigg 2004, 2010). The precarious state of these precious coral fisheries suggests that existing management measures have not been adequate to conserve precious coral populations (Bruckner 2014).

46.4.1 Gear Types

The use of non-selective dredges in Mediterranean coral fisheries was first banned in Albania in 1977, in Sardinia and Spain in 1986, and finally Mediterranean-wide in 1994. In Hawaii and some areas of Japan, non-selective gear is also prohibited, with harvest being undertaken by SCUBA divers (Hawaii) or submersibles (Japan). The elimination of the tangle net dredge was a major step forward for conservation, as this gear type caused considerable damage to the habitat and it was non-selective and wasteful, with much of the detached coral remaining on the bottom. Nevertheless, it is still used in Taiwan and parts of Japan, mainly because the coral beds are too deep for harvest with SCUBA, currents are too strong for use of a submersible, and more advanced technologies are cost prohibitive (Kosuge 2010; Grigg 2010). Conventional and mixed gas SCUBA diving is one of the best options to ensure selective harvest, but there are potential problems with SCUBA fisheries (see below). Furthermore, SCUBA fisheries are only possible to depths of about 130 m. Submersibles have been used in Hawaii and in the Mediterranean, but they are currently used only in a single fishery in Japan, mainly due to the high cost of operations. Robotic harvesting using remote operated vehicles (ROVs) has been proposed in the Mediterranean, but these have the potential to cause habitat damage and they are likely to be less efficient than harvest on SCUBA. Furthermore, SCUBA divers are limited by time and maximum depth. The use of an ROV provides access to corals without depth restrictions, allowing harvest of deeper resources that currently serve as a refuge. If adopted, ROVs have the capability to exploit over 99 % of the world's *C. rubrum* populations, potentially harvesting the last remaining viable stocks (Tsounis et al. 2013).

46.4.2 Size Limits

One of the key strategies to help maintain precious coral populations is a minimum size of harvest. This approach has been applied to *Corallium* and black coral fisheries in Hawaii and to *C. rubrum* fisheries in certain parts of the Mediterranean, but this measure is only possible when the corals are selectively harvested. SCUBA fishing has the advantage of allowing a more selective harvest of only the largest colonies, leaving smaller colonies in place. There are reports, however, that divers operated in a pulse fishing mode, removing all colonies above a certain threshold size from individual patches, and returning to harvest smaller size classes once the larger colonies were depleted (Barletta et al. 1968; Santangelo and Abbiati 2001). To maintain similar levels of catch thereby necessitated collection of increasing numbers of colonies of a smaller size which has resulted in the progressive harvest of stocks down to very young age classes throughout depths accessible to SCUBA (Tsounis et al. 2010). Unless the sizes of individual colonies that are removed are verified, the removal of undersized specimens is unlikely to be noticed by management agencies since landings data are typically recorded by weight and not size.

Protection of precious corals from harvest until they reach a large size is likely the most important measures for conservation of coral resources, as fertility and reproductive success increases exponentially as colonies get larger and develop more branches (Bruckner 2009). Recognizing this life-history attribute, FAO first recommended a minimum basal diameter of 7 mm for red coral in 1983 (GFCM 1984), but this was not adopted through the region. As of 2013, only three countries (Spain, Italy and Algeria) have included a minimum size in their management plan. In an early demographic study of *C. rubrum*, García-Rodríguez and Massò (1986) documented the harvest of colonies that were 5–14 years in age which they concluded were well below MSY. Tsounis et al. (2007) estimated a MSY of 98 years, whereas the current practice of harvesting colonies once they achieve a 7 mm basal diameter (11 year old colonies) results in only 6 % of the potential yield. Based on recent age studies, *Corallium* colonies are two to four times older and growth rates are 2.6–4.5 times lower than previously thought (Marschal et al. 2004; Roark et al. 2006). For a modular organism like *C. rubrum* that characteristically forms highly complex, branched colonies, and can reach sizes of 30–50 cm, a mean height of 3–5 cm is equivalent to a loss of 80–90 % of the reproductive modules (polyps) of individual colonies, due to the absence of second, third and fourth order branches (Bruckner 2009). These small colonies can become sexually mature at a young age (2–3 cm height), although they don't achieve 100 % fertility until about 6 cm height and 10–20 years in age or older. The spawning potential in *C. rubrum* (and other gorgonians) increases exponentially with size, with larger arborescent colonies producing up to 90 % of the recruits. Given settlement rates of no more than 5 % of the total larval production, and continued removal of colonies by fisheries after they have reproduced no more than one or two times, typical shallow population today may produce 80–90 % fewer recruits than in the 1960s, and about half of that produced by populations that have been protected from fishing for 15–20 years and contain colonies twice as large.

Recognizing that colonies of *C. rubrum* achieve full sexual maturity only after approximately 10 years, but at least 20 years or more is needed to reach a size able to ensure a higher reproductive potential, scientists at recent international workshops have recommended that the proposed minimum size of 7 mm is not adequate and it should be increased to 10 mm (Bussoletti et al. 2010). To date, a 10 mm diameter has been implemented only in Sardinia, but collectors are allowed a 20 % variance (in effect, pushing the minimum size back to 8 mm), and in fact fisheries landings data show that a large proportion of the colonies (>50 %) are undersized (Chessa and Scardi 2010). Furthermore, contrary to scientific consensus, and recommendations at two GFCM workshops (GFCM 2010; 2013) the draft 2014 management plan developed by GFCM is recommending adoption of only the 7 mm minimum diameter (GFCM 2013), and the agreement to increase in the minimum size to 8 mm or 10 mm remains largely ignored (Bussoletti et al. 2010; Tsounis et al. 2013).

46.4.3 Biology, Life History and Population Status

For most precious coral fisheries around the world, exploitation of the resource has been undertaken without preexisting knowledge of the size or condition of a precious coral bed. One of the most critical steps in the development of a sustainable fishery is the completion of detailed baseline studies on population dynamics before a new area is open to fishing. Conservative estimates of landings from these areas should be adopted based on the size of the precious coral bed, and the biomass (abundance and size structure) of the resource, using a similar approach to that applied to food fisheries. Collection areas must be monitored to assess collection impacts and to modify measures as needed to prevent undesirable shifts in species assemblages. Furthermore, better reporting and monitoring of landings is necessary, including data on locations of harvest and numbers and sizes of colonies removed, and the condition of these colonies.

Using only colony abundance and density as an indication of population size and viability can be misleading, as the only precious coral known to occur in dense populations is *C. rubrum* colonies found in shallow water, and these tend to be dominated by small, reproductively immature colonies. For colonial organisms, change in population structure (size frequency distribution) is a more suitable measure of decline than changes in the absolute numbers of colonies (Bruckner 2009). Commercial extraction primarily eliminates the largest corals, followed by smaller colonies over time, but it is the largest, oldest colonies that contribute most to the replenishment of the population (Tsounis et al. 2006a). Furthermore, shifts in the size structure of populations due to fishing pressure can be directly compared, while density and abundance cannot. Even in the case of *C. rubrum*, colony density measured over the entire suitable habitat is likely to be much less than the density of small patches occupied by the coral within this habitat. In fact, a less-dense population is likely to represent an older, more stable and viable population as open substrates of suitable habitat can support high numbers of recruits, but these exhibit size-related survival that increases as the colonies get larger. Thus, populations with a high abundance and density, such as *C. rubrum* found in shallow water, are an indication of frequent and continuing perturbations responsible for rapid turnover of populations and a persistent state of early-stage recovery. This is similar to observations of other corals that brood their larvae; however, most corals that are brooders are considered early colonizing, "weedy" species, while *C. rubrum* is a long-lived species that may be attempting to adapt to increasing localized (direct human impacts) and global stressors (climate change). These types of populations are much less resilient to other stressors and are more likely to exhibit localized extirpations when compounded by fishing pressure than populations that contain a mix of small (10–50 mm tall), medium (60–140 mm), and large (150–500 mm) colonies, like that formerly observed in the Mediterranean and still present in some deep-water areas that have not been targeted by fisheries for several decades.

46.4.4 Protected Areas

Marine protected areas provide an efficient tool to maintain and manage fisheries and enhance biodiversity conservation. The success of an area closed to fishing depends on the size of the protected area, linkages with surrounding areas, and the duration of closure, with the life history of a species being a key determinant of these variables (Halpern 2003). Recovery of a target species within a MPA is also affected by the degree of exploitation and status of the species before the creation of the marine reserve. In the case of a long-lived, slow growing precious coral with limited capacity for dispersal, recovery of populations is likely to be slow, as coral harvest principally threatens the largest colonies.

Currently, less than 1 % of the coralligenous habitat in the Mediterranean is protected from harvest of red coral. The existing no take areas (protected areas) for *C. rubrum* are relatively small and it is unclear whether they are sited such that they would replenish fished areas, given the high degree of genetic structure and evidence that populations are self-seeding (Costantini et al. 2007). Within the protected areas colonies are substantially larger than in surrounding fished areas, yet still smaller than that observed at similar depths in the 1960s even after 22–30 years of protection (Garribou and Harmelin 2002; Linares et al. 2010). These observations illustrate the importance of MPAs, but they also emphasize the fact that full recovery from fishing can require many decades (Marschal et al. 2004; Torrents 2007).

An alternate approach to rebuild precious coral populations after intensive fishing involves a rotating harvest (Caddy 1993), which has been attempted and is currently used in parts of the Mediterranean and North Pacific (Table 46.4; Chen 2012; Iwasaki et al. 2012). One problem associated with this idea is the long recovery times due to slow growth rates and low recruitment success of these corals. If a minimum harvesting diameter of 7 mm for *C. rubrum* is considered, this would imply a recovery time of at least 30 or 40 years (Tsounis et al. 2006a, b). Time needed to reestablish populations to pre-harvest levels is probably considerably longer, largely because coral growth rates have been found to be much slower than previously estimated and some sites in the Mediterranean have not achieved the sizes observed in the 1960s, even after 30 years of protection (Caddy 1993; Francour et al. 2001; Tsounis et al. 2006a). The time for recovery may be further compounded in sites with non-selective fisheries, as tangle-net dredges remove all corals from an area. Unless adjacent upstream areas are left unfished, their recovery may be hampered because of lack of local sources of larvae. Thus, a rotating harvesting model would have to deal with long periods of closure for each area and also maintenance of neighboring unfished areas. This would restrict harvest into smaller defined areas, which is unlikely to sustain a profitable fishery as is becoming apparent in existing defined fishing grounds off Taiwan (Huang and Ou 2010).

One of the most important accomplishments in the conservation of Mediterranean red coral, was a recommended ban on shallow water fishing that was adopted in response to a proposed CITES listing. The consensus at one of the ad hoc workshops was the protection of corals shallower than 80 m depth to allow these populations to recover from past fishing impacts (Bussoletti et al. 2010). Unfortunately, this recommendation was ignored and the recent Mediterranean GFMC draft management recommends full protection for shallow resources, allowing harvest only below 60 m (GFCM 2013). In addition, proposals to limit collection to 60–130 m (mixed gas diving) appear to be short-sighted at this time because we know too little about these populations. This move to deeper water may be a reflection of the depleted nature of the resource – all acceptable (large) colonies have been removed from shallow water and collectors are now targeting areas that have not been fished for 20 years or more (e.g. since elimination of the dredge). First, genetic studies from the Mediterranean also suggest local recruitment, very limited dispersal of gametes and limited connectivity between deep populations (Costantini et al. 2007), which is where the bulk of the fisheries are now located. Secondly, the available information from these deeper areas indicates that populations occur at a lower density than in shallow water. Removal of colonies from these areas would further reduce density, possibly hampering potential for successful fertilization due to allee effects. Recent studies from Sardinia suggest deep water populations (60–150 m) are in better shape than shallow areas (Cannas et al. 2010), based on the indication that populations are dominated by larger sized corals. Nevertheless, this study acknowledges that colonies are much sparser and the data show that more than one third of all colonies examined in transects were still <5 cm and only 23 % are above 10 cm height. Even though there are larger colonies in deep water off Sardinia, it is unclear whether these are abundant enough to support a sustainable fishery, as biometrical analyses done by Chessa and Scardi (2010) showed that a very large percentage of the corals harvested by fishermen in deep water off Sardinia were well under the minimum allowable size of 10 mm (basal diameter).

46.5 Conclusion

Effective conservation of precious corals, with the intention of rebuilding of overexploited stocks and sustaining continued fisheries, will require stronger management measures, better enforcement and possible supplementary protection through trade restrictions in CITES. From a habitat protection standpoint, non-selective gear such as the tangle net dredges need to be completely eliminated from the fishery. From a biological perspective, the minimum size of allowable harvest must be further increased so that colonies can develop complex branching patterns to ensure a reproductive output that can compensate for fishing pressure. Rotation of fishing grounds is unlikely to be economically sustainable or effective as recovery of fished areas would require many decades due to the slow growth of precious corals and their limited recruitment. As an alternative to rotational harvest, the size and locations of marine protected areas that are completely closed to fishing need to be expanded, especially in shallow water where other stressors (e.g. climate change) are having compounding impacts. New approaches for the precious coral management should be based on current knowledge of the biology of the species and models considering maximum sustainable yield (MSY) must incorporate information on the size of the targeted coral bed and the abundance, density and size of the colonies within the bed, with fishing occurring only after the resource has been properly assessed. Further, these plans need to be adaptive, responding to changes associated with fishing and other natural and anthropogenic stressors.

While trade restrictions alone may be insufficient to fully protect these resources, they can complement local management by promoting stronger local measures, necessary research and data acquisition. China took an ambitious step to list four Pacific species of *Corallium* on Appendix III in 2008, but the protective measures need to extend to other countries and all species. Through a CITES Appendix II listing, commercial trade would still be allowed, provided that exporting countries demonstrate the established level of harvest and trade is not detrimental to the survival of the species. Thus a listing would give both exporters and consumers joint responsibility for management and enforcement, and it would require annual monitoring and reporting of fisheries and trade. A listing would also promote research on the status and trends of listed precious coral populations, the impacts of fisheries, and the development of sustainable harvest guidelines. A CITES listing could also reduce illegal trade and fishing, and promulgate stronger local and regional management and enforcement.

Precious coral fisheries are at a crossroads. The global rate of depletion of these resources and continued damage to habitats has made these long lived species particularly vulnerable to extirpation, seriously hampering their potential for recovery. Action must be taken now, if these fisheries are to survive into the future. It is possible to sustainably harvest precious coral resources, provided that management agencies completely eliminate the use of non-selective gear, new harvest guidelines are developed that fully consider the life history attributes of these species, and coral beds are not fished until a thorough assessment is undertaken to characterize the size of the bed, the abundance of the resource and the population structure of the corals. Areas that are off limits to fishing must be established, and these must be of adequate size and be connected to fished populations so they can serve as a refugia and seed stock to replenish fished areas. Furthermore, enforcement to eliminate poaching is critical. As stronger management measures are developed, considerations must be given to the local communities and fishers dependent on these resources. Through an expanded education program and involvement of the precious coral fishers and local communities in decision-making, it may be possible to halt the decline of these precious resources and work towards sustainable fisheries.

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