Effects of Fishing Gear on Deep-Sea Corals and Sponges in U.S. Waters

Chapter 4 in The State of Deep-Sea Coral and Sponge Ecosystems of the United States Report

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Large red tree coral caught as bycatch in a bottom trawl survey off Alaska.

EFFECTS OF FISHING GEAR ON DEEP-SEA CORALS AND SPONGES IN U.S. WATERS

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I. Introduction

Since the 1996 amendment of the Magnuson-Stevens Fishery Conservation and Management Act (MSA), there have been extensive efforts to identify and protect essential fish habitat (EFH). The 2007 MSA reauthorization further provided discretionary authority to protect areas containing deep-sea corals, recognizing these corals in their own right. Beginning around 2005-2007, management authorities in some regions of the U.S. acted to protect deep-sea corals and sponges. These species are slow-growing (Leys and Lauzon 1998, Stone and Wing 2001, Andrews et al. 2002, Prouty et al., this volume), comprise habitat for other species, and may take a long time to recover from damage (Gutt and Piepenburg 2003, Rooper et al. 2011). They are often damaged by mobile bottom-contact fishing gears, such as bottom-trawls (Chuenpagdee et al. 2003), and to a lesser extent by fixed-location gears, e.g. bottom longlines and bottom-set nets (Lumsden et al. 2007, Fuller et al. 2008). The 2007 report on the State of the Deep Coral Ecosystems of the United States notes that use of bottom-tending gears, especially bottom-trawls, is the largest threat to deep-sea coral communities (Hourigan et al. 2007). The report advocates further research on the effects of fishing on deep-sea corals to inform management decisions. This research priority was extended to sponges in NOAA's Strategic Plan for Deep-Sea Coral and Sponge Ecosystems (NOAA 2010). Here, we briefly summarize the known interactions between fishing gear and deep-sea corals and sponges in U.S. waters.

II. Recent Developments in Research and Management

The effects of fishing gear on deep-sea corals and sponges are of considerable interest to fishermen, scientists, managers, environmental groups, and the general public. Since the 2007 report on the State of the Deep Coral Ecosystems of the United States, there have been efforts to:

1) Study the effects of mobile and fixed-location fishing gears on deep-sea corals and sponges;

2) Close areas where fishing may impact deep-sea corals and sponges; and

3) Modify fishing gears and practices to protect deep-sea corals and sponges.

Identifying areas where fishing overlaps the presence of deep-sea corals and sponges requires knowledge of fishing locations and deep-sea coral occurrences. Fishing locations are obtained from vessel monitoring systems (e.g., SAFMC 2010, 2013), logbooks or on-board observers. Coral and sponge occurrences are from observations and bycatch data for sponges and corals collected by the National Marine Fisheries Service (NMFS) observers (NMFS 2011, 2013) and bottom-trawl surveys (Clarke et al., this volume, Stone and Rooper, this volume). However, not all fisheries include observers, and not all observers collect bycatch data on corals and sponges (e.g. Packer et al., this volume). Yet bycatch data, anecdotal observations, and the spatial and depth overlap of fishing operations show that in all U.S. regions, some fishing is conducted in areas with deep-sea corals and sponges (Hourigan et al. 2007, NMFS 2011, NMFS 2013).

Based on these types of bycatch data, models have been developed that predict the distribution of deep sea corals and sponges (Bryan and Metaxas 2007, Sigler et al. 2015, Guinotte et al., this volume, Packer et al., this volume). These models can help identify areas of overlap of sensitive invertebrates with fishing activity. However, many of these models are for small areas, have coarse spatial and taxonomic resolutions, and are insufficiently informed by observation data.

II.1. Mobile Bottom-Contact Fishing Gear

In U.S. waters, bottom-trawls are used on the continental shelf and upper slope, typically shallower than 500 m depth. In other regions of the world, bottom trawls are also used in deeper continental slope waters (Roberts 2002, Norse et al. 2012, Clark et al. 2016).

The effects of mobile bottom-contact fishing gear on deep-sea corals are well documented (reviewed by Clark and Koslow 2007, Hourigan et al. 2007, Clark et al. 2015), but less so for their effects on sponges (Van Dolah et al. 1987, Freese 2001, Wassenberg et al. 2002, Austin et al. 2007, Hogg et al. 2010). Impacts include damage and removal of the organisms (Freese 2001, Hall-Spencer et al. 2002, NRC 2002, Reed et al. 2007), changes in community composition and productivity (Hiddink et al. 2006, Hixon and Tissot 2007), and broad-scale modification of geology (Puig et al. 2012). For example, in the Aleutian Islands, damage to corals increased with fishing intensity (Heifetz et al. 2009), with the highest damage to antipatharians (15%), hydrocorals (9%) and gorgonians (6%) (Stone 2014). Additionally, coral removal by bottom-trawls accounted for over 92% of observed coral bycatch in west coast fisheries (Whitmire and Clarke 2007).

In the Gulf of Alaska, a single pass of a bottom-trawl removed 1,000 kg of *Primnoa*

coral and detached 27% of the colonies (Krieger 2001). Cumulative removals of coral by bottom-trawling in Alaska, from 1997 to 1999, were estimated at 81.5 metric tons (mt) per year, totaling about 250 mt (NMFS 2004). More recently, the bycatch of corals (including sea pens and whips), bryozoans, and hydroids were reportedly 54 mt from 2003-2005 (NMFS 2011) and 35.6 mt in 2010 (NMFS 2013). Comparable figures for Alaskan sponge bycatch were 238 mt in 2003-2005 and 271 mt in 2010 (NMFS 2011, 2013).

NOAA has determined that year-round closures to mobile bottom-tending gear are particularly effective at protecting biogenic habitats comprised of deep-sea corals and sponges (NOAA 2010, Hourigan 2014). The world's first bottom-trawl fishing closure, specifically designed to protect deep-sea corals, occurred in 1984 at Oculina Bank, a Habitat Area of Particular Concern (HAPC) off eastern Florida. In 1986, the entire Exclusive Economic Zone (EEZ) surrounding the U.S. Pacific Islands was closed to bottom-trawls and bottom-set nets and longlines. The Western Pacific Fishery Management Council had previously identified bottom-trawling by foreign fishing fleets as a threat to the region's precious coral beds (Hourigan 2014).

Most other bottom-trawl closures have been enacted since 2005, primarily to protect EFH (Hourigan 2009, Hourigan 2014, Fig. 1). This includes bottom-trawl closures between 700 and 1,750 ftm (1,280-3,200 m) on the west coast of the continental U.S., as well as 34 additional areas including biogenic habitats, banks, ridges, and canyons in March 2006. This management action protected 336,698 km² (130,000 mi²) of marine habitat in Washington, Oregon, and California of EFH for groundfish.

In the Southeast U.S., five new areas containing *Lophelia pertusa* coral were closed to bottom-contact fishing in 2010, and these were expanded in 2015 to include newly identified coral areas. In the same year, the Mid-Atlantic Fishery Management Council became the first council to use the discretionary provision of Magnuson-Stevens Act to propose establishment of a deep-sea coral protection area encompassing more than 38,000 mi². The Deep Sea Coral Amendment[1] includes measures to restrict trawls, dredges, bottom longlines, and traps within the bounds of the protection area. Areas of the Aleutian Islands in Alaska were closed to mobile bottom-contact fishing gear in 2006 (NMFS 2010). This decreased the bycatch of corals and sponges under steady or decreasing fishing effort, until 2011 (NPFMC 2012). However, data collected through 2013 indicated an increase in bycatch of coral and sponges in the Aleutian Islands, possibly due to increased fishing effort for rockfish in the region.

The cumulative effect of these management actions between 2005 and 2010 was a six-fold increase in the total area of seafloor that restricts bottom contact fishing gear within the U.S. continental EEZ (Fig. 1). The majority of the area closures in the U.S. occurred in the Pacific and North Pacific Fishery Management Council regions, and comprised more than 1.35 million km² (530,000 mi²) of the U.S. EEZ. The cumulative area of these closures represents 22% of the continental US EEZ (2,401,232 mi²). For the most part, these closures have not been monitored to determine whether protections are effective in recovering, maintaining or increasing deep-sea coral diversity and abundance.

Modifications to mobile bottom-contact fishing gear to reduce bycatch (e.g., turtle and marine

[1] http://www.mafmc.org/actions/msb-am16
[2] https://en.wikipedia.org/wiki/Exclusive_economic_zone

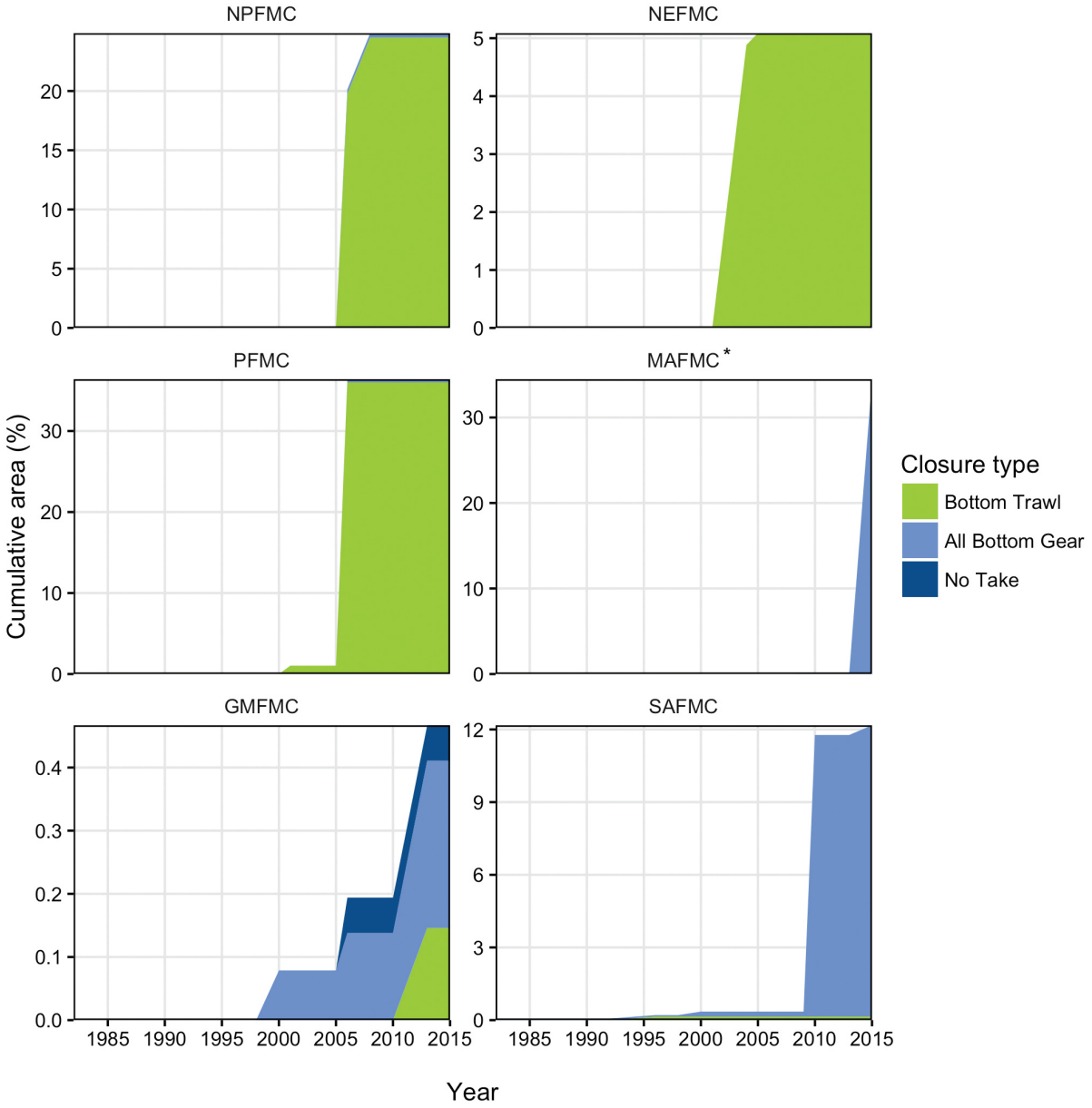

Figure 1. *Cumulative areal extent of bottom closures by Fishery Management Council (FMC) region between 1982 to 2015 as a percent of EEZ in each region. Colors designate the closure type. US Regional FMCs are: GMFMC = Gulf of Mexico; SAFMC = South Atlantic; MAFMC = Mid-Atlantic; NEFMC = New England; NPFMC = North Pacific; PFMC = Pacific. The MAFMC closure (*) represents the deep-sea coral protection zones proposed in June 2015, covering 28,864 n mi². The Western Pacific Council (WPFMC) and Caribbean Council (CFMC) are not shown. The WPFMC protected the entire EEZ (1,499,972 nm²) under its jurisdiction from trawling and certain other bottom-contact fishing gears in 1983. Bottom-trawling does not occur in the CFMC region. The figure includes closures specifically designed to protect deep-sea corals and those using Essential Fish Habitat (EFH) authorities (NOAA 2011, Sutter et al. 2014). There are additional closures in place to reduce gear conflicts and other purposes, which may also protect deep-sea corals and sponges in such areas. Asterisk (*) indicates closures were proposed in 2015 and approved in 2016.*

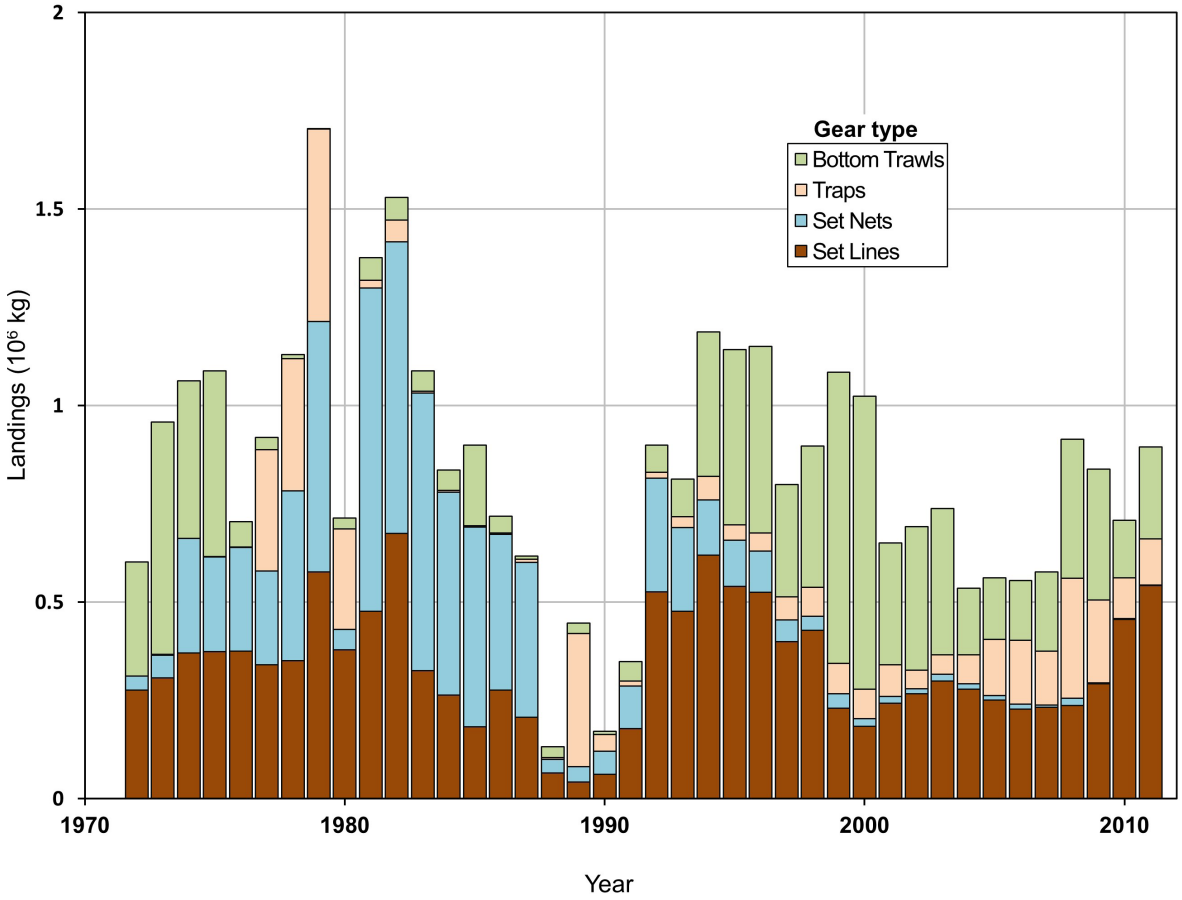

Figure 2. *Commercial landings (millions of kg) of deep demersal species (> 50 m) in the Southern California Bight by gear type. Data are from California Department of Fish and Wildlife landings tickets (Perry et al. 2010; Perry et al. unpublished data) for select deep-water species codes during the time period 1972-2011.*

mammal excluder devices) and negative impacts on the seabed (e.g., reducing footrope or roller size on bottom-trawls) have been an active area of research within NMFS. Some of the gear modifications and restrictions have the potential to reduce impacts on deep-sea corals and sponges. For example, in Alaska, NMFS scientists have been working with flatfish bottom-trawl fisheries since 2002 to reduce bycatch and mortality of crab and other benthic invertebrates in soft substrates without negatively affecting catches of target species (Rose et al. 2010a, Rose et al. 2010b, Rose et al. 2013). In those studies, the sweeps of bottom-trawls were raised off the seafloor using disk clusters spaced at 9-m intervals along the trawl sweeps. This gear modification reduced crab mortality, since the modified sweeps passed over many of the crabs it encountered, but had no significant effect on flatfish catch. Additionally, these gear modifications reduced, by almost half, the damage to sea pens under the path of the trawl gear (Rose et al. 2010a). Working closely with the fishing industry and the North Pacific Fishery Management Council, new regulations were implemented in 2011 that required bottom-trawl sweep modifications in the eastern Bering Sea flatfish fishery. On the U.S. west coast, where footrope size restrictions were instituted to reduce catches of rockfish species (*Sebastes* spp.), trawl fishing effort has

shifted away from rugose habitats known to support corals and other sensitive benthic invertebrates (Bellman et al. 2005).

II.2. Fixed Bottom-Contact Fishing Gear

In addition to mobile fishing gear, there are many types of fixed gear used in commercial fishing, including traps or pots, bottom-set nets, and longlines. Fixed gears are typically deployed in a wide range of depths, including depths > 1,000 m. Most of these gears are in contact with the seafloor when fishing, and are often used in areas, such as rocky reefs. These areas may be most important for deep-sea corals and sponges that rely on rocky substrates for attachment.

In some areas, fixed-gears account for considerably more landings than mobile gears. For example, according to California Department of Fish and Wildlife (CDFW; formerly California Department of Fish and Game) annual landings reports (Perry et al. 2010), the total landings by traps, set lines, and set nets in southern California can outweigh landings by bottom-trawls, especially in recent years (Fig. 2). Nearly 64% of recent (2007-2011) deep-water demersal landings from Southern California are from fixed gears (longlines and pots) for sablefish, thornyhead, hagfish, and spot prawn. The remaining 35% from mobile gear were predominantly soft sediment fisheries for sea cucumber and sole (Perry et al. 2010, Etnoyer et al. 2013). Fishing with fixed-gear (Fig. 3A) is often conducted further offshore, over a wider portion of the continental shelf and slope than mobile gear (Fig. 3B), yet probably covers a smaller cumulative area (e.g., NMFS 2005).

Off southern California, and likely elsewhere, fixed-gear fisheries that target deep-water demersal species operate within the depth ranges of deep-water corals and sponges with the potential for negative interactions where overlap occurs. Fixed fishing gears can interact with corals in several ways. Pots and traps can be dropped directly on top of colonies, or dragged on the bottom during deployment and recovery. Nets can snag on rocks, or be cut loose during storms. Longlines may become entangled during recovery, or when hooked fish struggle. Incidentally, museum specimens of the precious *Corallium* coral were retrieved by longline fisheries surveys off the Azores in 2005 (Sampaio et al. 2009). In the U.S. Pacific Northwest, *Paragorgia arborea* was toppled and wrapped in longlines in the Olympic Coast National Marine Sanctuary (Brancato et al. 2007) (Fig. 4A). Derelict fishing gear has also been caught on coral in other areas, such as Southern California (Fig. 4B-D), Gulf of Mexico mesophotic reefs (Etnoyer et al. 2015), Nova Scotia, Canada (Mortensen et al. 2005), and in parts of the northeast Atlantic Ocean (Sampaio et al. 2012).

There are, however, few peer-reviewed studies that rigorously examine the effects of fixed-gear fisheries on deep corals and sponges. A recent study of small-scale, shallow (< 25 m) artisanal fisheries in Mexico found that bycatch rates were negligible for traps and gillnets – less than 0.5 kg (0.12 kg of gorgonians and 0.37 kg for sponges) for each $1,000 of revenue generated by the fishery catch – while bycatch rates of habitat-forming invertebrates (as a percentage of total catch) were ~20% for set gillnets and close to zero for traps (Shester and Micheli 2011). Damage and removal of 17% of shallow-water gorgonian corals within a meter of a set net was observed, while damage was minimal and removals were zero for traps. Although the impacted areas were relatively small for these gear types, the cumulative impact may

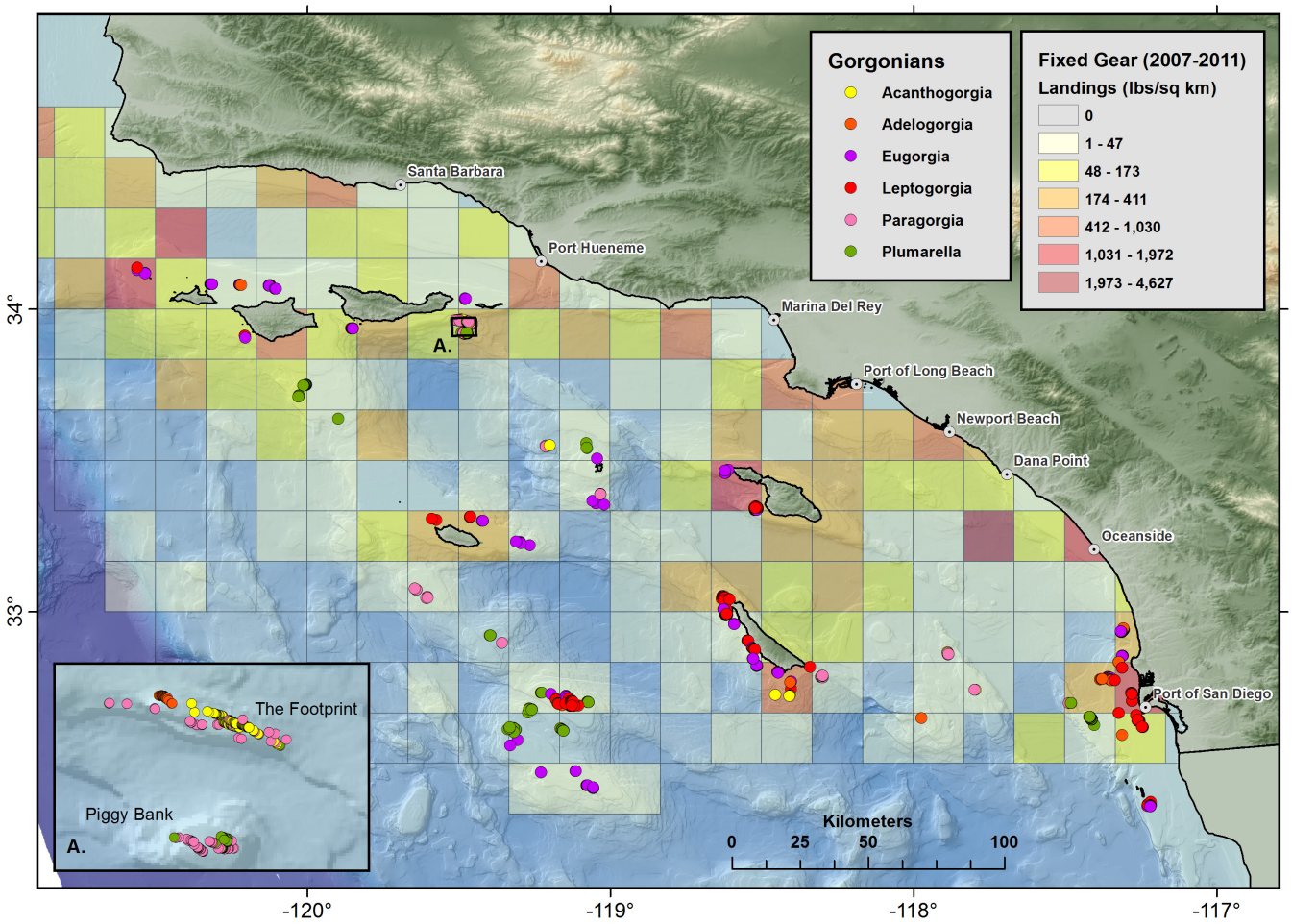

Figure 3A. *Distribution of demersal landings between 2007 and 2011 for deep-water fixed gear fisheries from California Department of Fish and Wildlife catch blocks in the southern California Bight (Perry et al. 2010; Perry et al. unpublished data). Also shown are the locations of gorgonian octocorals observed during remotely operated vehicle surveys since 2006 (NOAA 2015).*

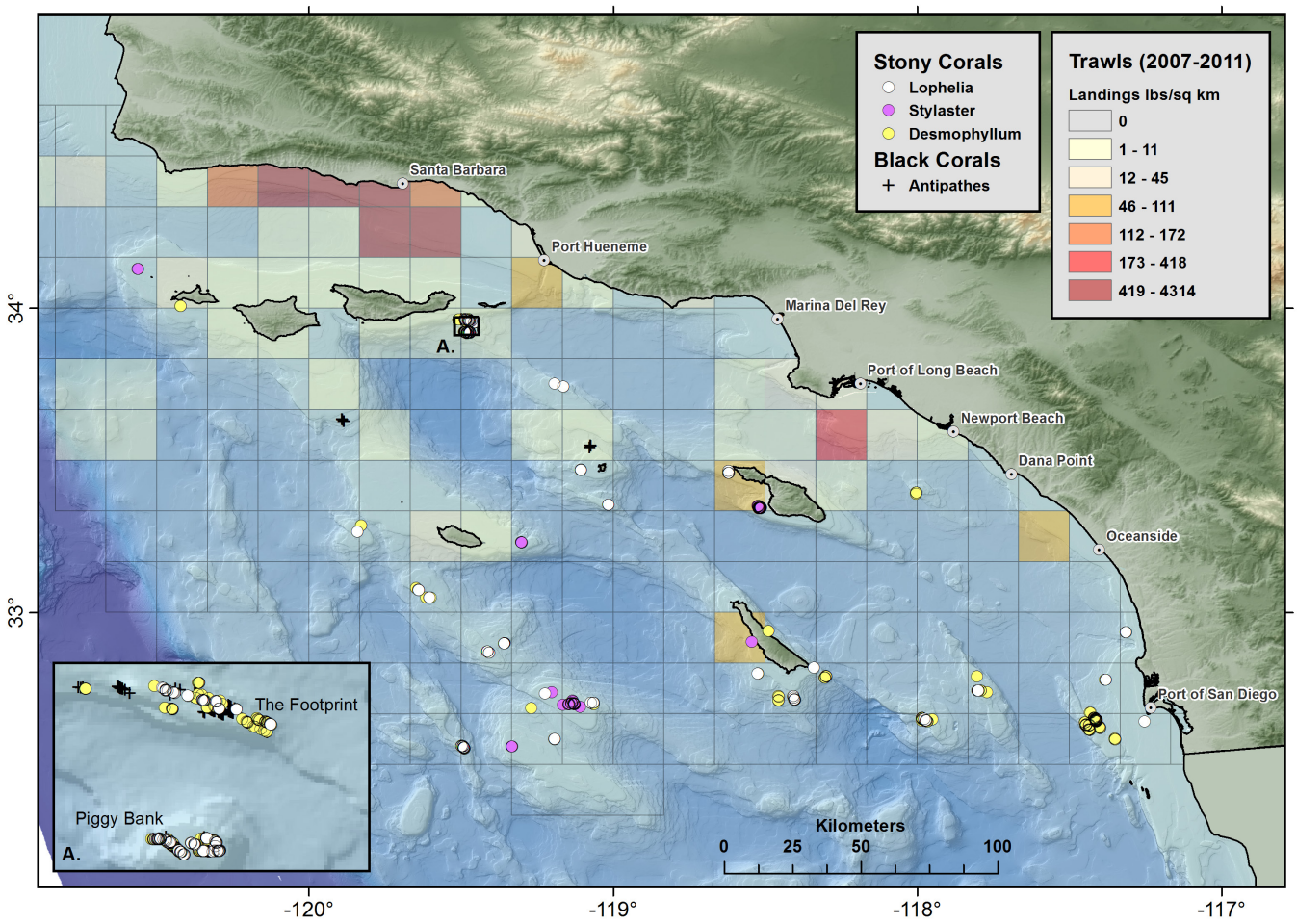

Figure 3B. *Distribution of demersal landings between 2007 and 2011 for deep-water bottom-trawls from California Department of Fish and Wildlife catch blocks in the southern California Bight (Perry et al. 2010; Perry et al. unpublished data). Also shown are the locations of stony corals from surveys since 2006 (NOAA 2015).*

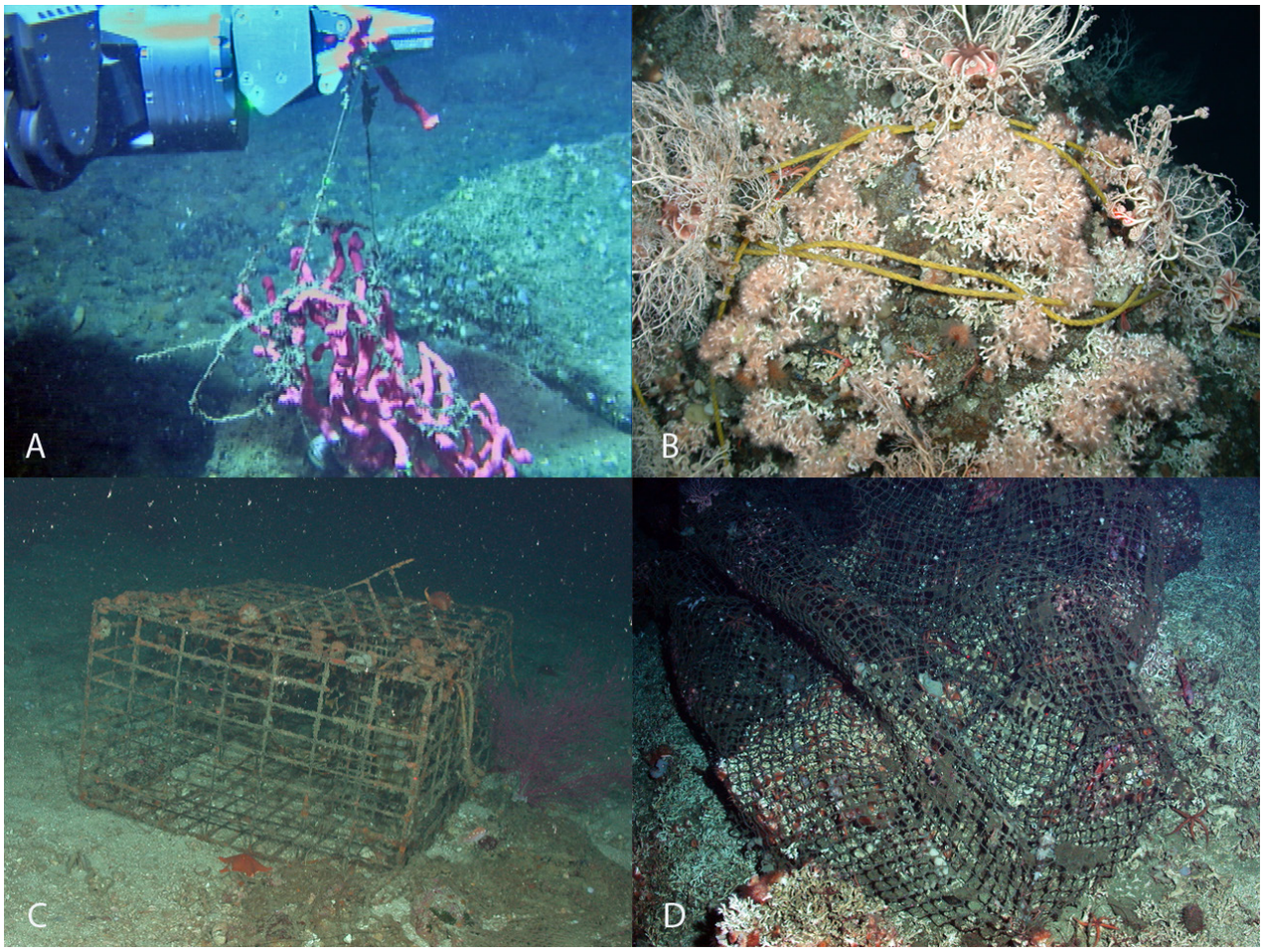

Figure 4. *Images of longline and trap gear from remotely operated vehicle surveys on the US West Coast: A) Bubblegum coral (*Paragorgia arborea*) entangled in longline gear at ~200 m depth in Olympic Coast National Marine Sanctuary (OCNMS; Brancato et al. 2007); B) Scleractinian coral (*Lophelia pertusa*) colonies with yellow polypropylene line, possibly from an anchor line, or a buoy line on fixed gear; C) trap gear (center) and netting (lower right) adjacent to a purple sea fan (*Eugorgia rubens*); and D) a section of mesh from a trawl net wrapped around* Lophelia pertusa *rubble. Photo A is courtesy of NOAA OCNMS. Photos B-D are courtesy of NMFS, Southwest Fisheries Science Center.*

be substantial given the large number of participants in the fisheries. In the Atlantic Ocean off Canada, a review of observer data indicated that the rate of coral occurrence in longline sets (13%) was higher than that of either gillnets (7%), trawls (4%), or crab pots (0%) (Edinger et al. 2007).

In the U.S., much of the data on bycatch rates for fixed gears comes from fishery-independent surveys. For example, the catch rates for gorgonian corals in the Alaska longline survey that operates annually at stations on the slope of the eastern Bering Sea suggest very low rates of bycatch for corals and sponges (~2-4 coral colonies or sponges per station occupied by the survey, Fig. 5).

Although some anecdotal evidence exists, there is generally less data available from U.S. fisheries to compare damage rates to coral and sponge habitat by fixed and mobile fishing gear. The most comprehensive study to date looked at damage rates in areas of

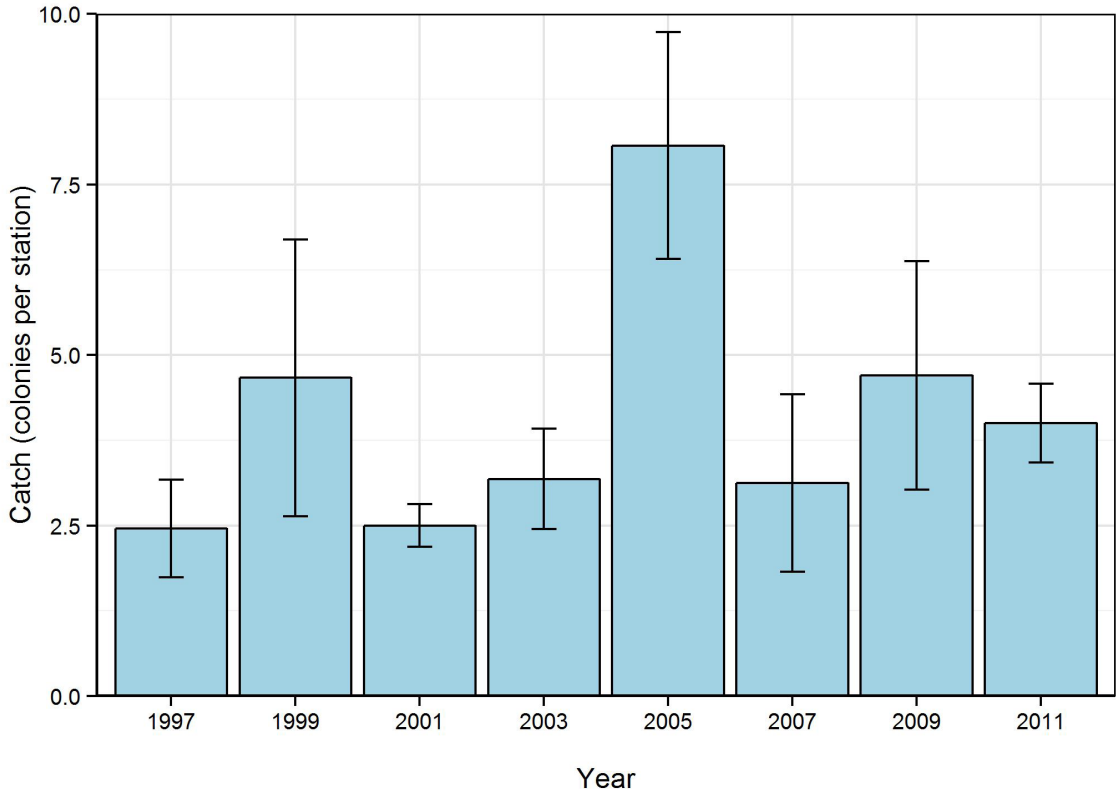

Figure 5. *Catch (mean number of colonies ± SE) of coral and sponge taxa in the Alaska Fisheries Science Center biennual longline survey of the eastern Bering Sea continental slope from 1997-2011. Data are available from the Alaska Fisheries Information Network (AKFIN, www.akfin.org).*

the central Aleutian Islands that were only fished with fixed gear (pots and longlines) and found damage rates to be higher, but not significantly higher than damage rates in unfished areas (Heifetz et al. 2009). Removals of corals and sponges in Alaska by longline fisheries between 2003 and 2005 were estimated at 14 mt and 6 mt respectively, but these values constituted a minor fraction of the target species catch (NMFS 2011). Removals by pot fishing accounted for a negligible amount of coral bycatch and only 1 mt of sponge removal during the same time period.

Removals of corals and sponges by fixed gears occur in other regions as well, but some of the evidence is anecdotal. For example, bamboo corals (*Isidella* sp.) have been reported in sablefish pots off California (S. Risherman, Marine Applied Research and Exploration, pers. comm.). *Paragorgia* bubblegum corals have been observed decorating the ceilings of salmon shacks in Neah Bay, Washington (P. Etnoyer, pers. obs.). Large black corals have been retrieved from trawl nets in Alaska, then polished and carved into decorative artifacts or jewelry (P. Etnoyer, pers. comm.).

In some places, derelict fishing gear may also damage deep-sea corals and sponges. During a rockfish study in the Aleutian Islands in 2004, a juvenile rockfish was observed residing in a tangle of derelict longline gear (Rooper et al. 2007). During that study, 4.29 ha of seafloor was observed with an underwater video camera and three separate observations of derelict longline gear were observed among corals and sponges.

Observations from remotely operated vehicles (ROVs) of derelict fixed gear in areas with deep-sea corals and sponges have also been documented in the northern Gulf of Mexico, where injuries to gorgonian octocorals were attributed to the snapper and grouper fisheries that comprise the reef-fish fishery (Etnoyer et al. 2015).

In the U.S., many areas have been closed to fishing to reduce the impacts of fixed gears on seabed habitats. For example, fifteen seamounts off the U.S. west coast and Alaska have been closed to all bottom-contact fishing gears since 2006, and a total of 7,020 m^2 were restricted. Other examples include "Piggy Bank" and "The Footprint" essential fish habitat area in the Channel Islands National Marine Sanctuary, which harbors abundant coral and sponge species (Yoklavich et al. 2011, 2013), that are now protected from bottom fishing of all types. Still, enforcement of these restrictions remains a challenge (C. Mobley, NOAA pers. comm.).

In a review of the impacts of gear on sensitive seabed habitats in the Southeast U.S., Barnett (2001) recommended excluding the use of bottom longlines in the vicinity of coral reefs due to their potential for entanglement. In this region, the use of bottom longlines, pots, and traps, as well as mobile gears is not allowed in the Oculina Banks HAPC, as well as in the larger deep-water Coral HAPCs, except in Golden Crab Allowable Fishing Areas or Shrimp Fishery Access Areas. We are not aware of any efforts to modify fixed bottom-contact gear to reduce their impacts.

III. Rationale for Closures

It is important to recognize that most, if not all of the management actions and research on the interactions between fisheries and sensitive fauna have aimed to protect corals and sponges while maintaining or enhancing existing fisheries. In some cases, such as with Oculina Banks and the *Lophelia* reefs in the southeast U.S., the reef-like structure provided by a single coral species has been the impetus for protection measures. In others, such as the "coral gardens" in Alaska, management actions have focused on groups of taxa (such as groups of corals and sponges separately) rather than trying to protect an area for a particular species. Corals and sponges have also benefitted from research and management actions that were driven by management issues for other species. For example, trawl modifications to reduce bycatch of overfished species (as in the west coast footrope restrictions example above) or non-target species (as in the Alaska crab example above).

In the Gulf of Mexico, *Lophelia* reefs provide habitat for golden crab (*Chaceon fenneri*), which is fished using traps strung together and recovered from the seafloor by grappling hook. The deep-sea red crab (*Chaceon quinquedens*) can aggregate in large colonies of *Madrepora oculata* as deep as 1,000 m in the Gulf of Mexico (Boland et al., this volume). The fisheries for these species are not well developed in the Gulf of Mexico, but they do represent an emerging concern. The South Atlantic Fishery Management Council designated allowable fishing areas for golden crab pot fisheries during the establishment of Deepwater Coral HAPCs.

IV. Knowledge Gaps and Future Challenges

In most regions of the U.S., methods have been developed and employed to study the effects or anticipated effects of mobile bottom-tending fishing gear. Most of this

knowledge has been gained in response to the EFH management mandate under the 1996 amendment of the MSA, which emphasizes an ecosystem approach to management. In the last five years, the NMFS, in partnership with the fishing industry, has better characterized where fishing with bottom-tending gears is likely to occur. The extent that fishing overlaps with deep-sea coral and sponges is determined by the distribution of these organisms and fishing effort. For fisheries with observer programs, additional information on the locations and amounts of bycatch can provide some indication of the extent of interactions between fishing gear and these organisms. There is little information, however, on the relationship between bycatch observed on the vessel and the actual impact or encounter rates with corals and sponges on the seafloor. These impacts will vary among gear types, species assemblages, and seabed types. However, the effects of fixed gear on corals and sponges are poorly studied in most regions.

A better understanding of the effects of fixed fishing gear on deep corals and sponges will come as more available data on the spatial extent contacted by this gear during fishing is revealed. With this information, the footprints of the various fixed gear types, and thus the area of the impacted seafloor can be calculated. There are also estimates of the bycatch of deep-sea corals and sponges from fishing gears from mandatory observer programs in Alaska (NMFS 2011). Still unknown is the performance of the gear during setting, fishing, and retrieval, and the amount of derelict gear that remains on the seafloor. We need to better understand the interactions between deep demersal target species, the gear types being used to fish them, and the types of corals and sponges occurring in fishing areas before we can develop optimal measures to protect these sensitive ecosystems while maintaining sustainable fisheries.

A second unknown is the degree to which the closed areas aid the recovery of damaged deep corals and sponges. Few studies quantify the densities, diversities, and distributions of deep-sea corals and sponges before and after areas are closed. Althaus et al. (2009) studied stony coral habitats and associated megabenthic invertebrate assemblages on seamounts off Tasmania and found no clear signal of recovery after five years for habitats damaged by bottom-trawling; invertebrate communities remained impoverished, comprising fewer species at reduced densities than untrawled areas. Similarly, Williams et al. (2010) found no evidence of recovery in trawled seamount areas 5-10 years after protection in Australian and New Zealand. They concluded that the resilience of seamount ecosystems, dominated by corals, is low compared to most other marine systems disturbed by bottom-trawling. Studies to determine how quickly damaged ecosystems on the continental shelf and slope of the U.S. recover after a closure could inform optimal strategies for protecting areas and monitoring recoveries.

V. Future Research and Technology

Studies are needed that research pot and longline gear dynamics during deployment, fishing, and retrieval operations. These studies should be based on direct observation, remote sensing, or both. A number of new technologies may provide direct observations. Cameras on ROVs have been used to observe longline gear during fishing activities, but not during deployment or retrieval (K. L. Yamanaka, Department of Fisheries and Oceans, Canada, pers. comm.). Advances in camera technologies have also facilitated

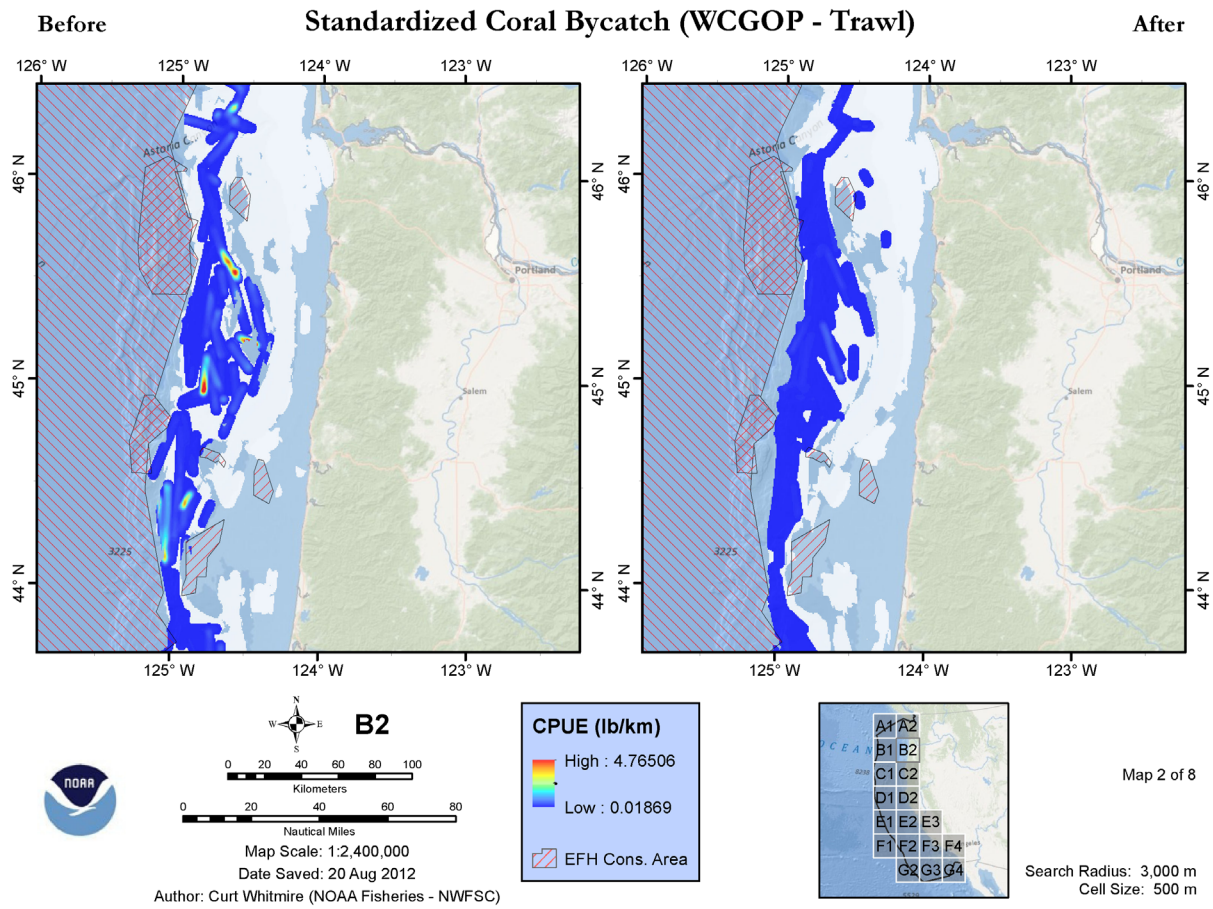

Figure 6. Coral bycatch (lb./km fished) from west coast trawl fisheries offshore Oregon state before (1 Jan 2002 - 11 Jun 2006) and after (12 Jun 2006 - 31 Dec 2010) essential fish habitat closures (PFMC 2012).

observations. For example, researchers in the Australian Antarctic Division developed a camera system to collect video images periodically during longline deployments and retrievals (Kilpatrick et al. 2011). A modified version of the camera system is being developed at the Alaska Fisheries Science Center to deploy on commercial longline and pot gear. The intention is to collect stereoscopic images to measure objects and fish, and estimate the area that is contacted by the fishing gear during setting, deployment, and retrieval.

Multiple studies examined changes in coral and sponge communities in closed areas where trawling previously occurred (e.g. Freese 2001, Heifetz et al. 2009). In the Gulf of Alaska, there was no indication of sponge recovery after experimental trawling when the damaged sites were revisited a year later. These sites should be sampled on appropriate time and space scales to evaluate the recovery processes and periods. Following area closures off Oregon, the bycatch of coral appears to have declined for some fisheries (Fig. 6). However, it is unclear if bycatch reductions are due to area closures, gear restrictions, changes in abundances and distributions of coral and target species, or other factors that may influence fishing behavior (PFMC 2012). Few studies have examined differences in

the community structure of deep-sea corals and sponges "before and after" area closures, or demonstrated how long and how many of these closures are needed to maintain the ecosystem services that deep-sea coral and sponge ecosystems provide.

VI. Conclusion

Since publication of the report on the State of Deep Coral Ecosystems of the United States in 2007, there have been a limited number of studies of the effects of fishing activity on deep-sea corals and sponges. In the U.S., most studies have focused on the effects of mobile fishing gear. However, studies are also needed on the likely, but perhaps lesser, effects of fixed-gears. Information from observer programs and scientific surveys have been instrumental in the identification of areas where high coral and sponge bycatch is occurring and for designating closed areas. Bycatch of non-target species has driven the development of fishing gear modifications, which has reduced their impacts on deep-sea corals and sponges.

VII. Acknowledgements

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VIII. Literature Cited

Althaus F, Williams A, Schlacher TA, Kloser RJ, Green MA, Barker BA, Bax NJ, Brodie P, Hoenlinger-Schlacher MA (2009) Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting. Mar Ecol Prog Ser 397:279-294

Andrews AH, Cordes EE, Mahoney MM, Munk K, Koale KH, Cailliet GM, Heifetz J (2002) Age, growth and radiometric age validation of a deep-sea habitat-forming gorgonian (*Primnoa resedaeformis*) from the Gulf of Alaska Hydrobiologia 471:101-110

Austin WC, Conway KW, Barrie JV, Krautter M (2007) Growth and morphology of a reef-forming glass sponge, *Aphrocallistes vastus* (Hexactinellida), and implications for recovery from widespread trawl damage. In: Custódio MR, Lôbo-Hajdu G, Hajdu E, Muricy G (eds) Porifera Research: Biodiversity, Innovation and Sustainability - 2007, Série Livros 28. Museu Nacional, Rio de Janeiro

Barnett MC (2001) A review of the fishing gear utilized within the Southeast Region and their potential impacts on essential fish habitat. US Dep Commer, NOAA Tech Memo NMFS-SEFSC-449:62

Bellman MA, Heppell SA, Goldfinger C (2005) Evaluation of a US west coast groundfish habitat conservation regulation via analysis of spatial and temporal patterns of trawl fishing effort. Can J Fish Aquat Sci 62:2886-2900

Boland G, Etnoyer PJ, Fisher C, Hickerson E (this volume) State of Deep-Sea Coral and Sponge Ecosystems in the Gulf of Mexico Region: Texas to the Florida Straits. In: Hourigan TF, Etnoyer PJ, Cairns SD (eds.). State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD

Brancato MS, Bowlby E, Hyland J, Intelmann SS, Brenkman K (2007) Observations of Deep Coral and Sponge Assemblages in Olympic Coast National Marine Sanctuary, Washington. Cruise Report: NOAA Ship McArthur II Cruise AR06-06/07. Mar Sanctuaries Conserv Ser. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Sanctuary Program, Silver Spring, MD

Bryan TL, Metaxas A (2007) Predicting suitable habitat for deep-water gorgonian corals on the Atlantic and Pacific Continental Margins of North America. Mar Ecol Prog Ser 330:113-126

Chuenpagdee R, Morgan LE, Maxwell SM, Norse EA, Pauly D (2003) Shifting gears: assessing collateral impacts of fishing methods in US waters. Front Ecol Environ 1:517-524

Clark MR, Althaus F, Schlacher TA, Williams A, Bowden DA, Rowden AA (2015) The impacts of deep-sea fisheries on benthic communities: a review. ICES J Mar Sci: 19 pp

Clark MR, Koslow JA (2007) Impacts of Fisheries on Seamounts. In: Pitcher TJ, Morato T, Hart PJB, Clark MR, Haggan N, Santos R (eds) Seamounts: Ecology, Fisheries & Conservation. Blackwell Publishing Ltd

Clarke ME, Whitmire CE, Yoklavich MM (this volume) State of Deep-Sea Coral and Sponge Ecosystems of the U.S. West Coast. In: Hourigan TF, Etnoyer PJ, Cairns SD (eds.). State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD

Edinger E., Baker K., Devillers R., Wareham V. Canada: World Wildlife Fund; 2007a. Deep-water Corals Off Newfoundland and Labrador: Distribution and Fisheries Impacts; p. 49.

Etnoyer PJ, Stierhoff KL, Salgado EJ, Nehasil S (2013) Spatial overlap of commercial bottom-fishing activity with deep-water coral and sponge observations in the Southern California Bight: a report to NOAA's Deep-Sea Coral Research and Technology Program. Silver Spring, MD.

Etnoyer PJ, Wickes LN, Silva M, Dubick JD, Balthis L, Salgado EJ, MacDonald IR (2015) Decline in condition of gorgonian octocorals on mesophotic reefs in the northern Gulf of Mexico: before and after the Deepwater Horizon oil spill. Coral Reefs:1-14

Freese JL (2001) Trawl-induced Damage to Sponges Observed From a Research Submersible. Mar Fish Rev 63:7-13

Fuller SD, Picco C, Ford J, Tsao C-F, Morgan LE, Hangaard D, Chuenpagdee R (2008) How We Fish matters: Addressing the Ecological Impacts of Canadian Fishing Gear. 25 pp.

Guinotte JM, Georgian S, Kinlan BP, Poti M, Davies A (this volume) Predictive Habitat Modeling for Deep-Sea Corals in U.S. Waters. In: Hourigan TF, Etnoyer PJ, Cairns SD (eds.). State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD

Gutt J, Piepenburg D (2003) Scale-dependent impact on diversity of Antarctic benthos caused by grounding of icebergs. Mar Ecol Prog Ser 253:77-83

Hall-Spencer J, Allain V, Fossa JH (2002) Trawling damage to Northeast Atlantic ancient coral reefs. Proceedings Biological sciences / The Royal Society 269:507-511

Heifetz J, Stone RP, Shotwell SK (2009) Damage and disturbance to coral and sponge habitat of the Aleutian Archipelago. Mar Ecol Prog Ser 397:295-303

Hiddink JG, Jennings S, Kaiser MJ, Queirós AM, Duplisea DE, Piet GJ (2006) Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. Can J Fish Aquat Sci 63:721-736

Hixon MA, Tissot BN (2007) Comparison of trawled vs untrawled mud seafloor assemblages of fishes and macroinvertebrates at Coquille Bank, Oregon. J Exp Mar Biol Ecol 344:23-34

Hogg MM, Tendal OS, Conway KW, Pomponi SA, Van Soest RW, Gutt J, Krautter M, Roberts JM (2010) Deep-water sponge grounds: reservoirs of biodiversity. WCMC Biodivers Ser. UNEP-WCMC, Cambridge, U.K.

Hourigan TF (2009) Managing fishery impacts on deep-water coral ecosystems of the USA: emerging best practices. Mar Ecol Prog Ser 397:333-340

Hourigan TF (2014) A strategic approach to address fisheries impacts on deep-sea coral ecosystems. In: Bartone S (ed) Interrelationships Between Corals and Fisheries. CRC Press, Tampa, FL

Hourigan TF, Lumsden SE, Bruckner AW, Brooke S, Stone RP (2007) Deep coral ecosystems of the United States: introduction and national overview. In: Lumsden SE, Hourigan TF, Bruckner AW, Dorr G (eds) The State of Deep Coral Ecosystems of the United States. Department of Commerce, Silver Spring MD

Kilpatrick R, Ewing G, Lamb T, Welsford D, Constable A (2011) Autonomous video camera system for monitoring impacts to benthic habitats from demersal fishing gear, including longlines. Deep Sea Research Part I: Oceanographic Research Papers 58:486-491

Krieger KJ (2001) Coral (*Primnoa*) impacted by fishing gear in the Gulf of Alaska. In: Wilson JHM, Hall J, Gass SE, Kenchington E, Butler M, Doherty P (eds) Proceedings of the 1st International Symposium on Deep-Sea Corals. Ecology Action Center, Halifax

Leys SP, Lauzon NRJ (1998) Hexactinellid sponge ecology: growth rates and seasonality in deep water sponges. J Exp Mar Biol Ecol 230:111-129

Lumsden SE, Hourigan TF, Bruckner AW, Dorr G (2007) The State of Deep Coral Ecosystems of the United States. NOAA Technical Memorandum, Silver Spring MD

Mortensen PB, Buhl-Mortensen L, Gordon DCJ, Fader GBJ, MacKeown DM, Fenton DG (2005) Effects of fisheries on deepwater gorgonian corals in the Northeast Channel, Nova Scotia. Am Fish Soc Symp, Book 41

National Marine Fisheries Service (NMFS) (2004) Final programmatic supplemental groundfish environmental impact statement for Alaska groundfish fisheries. U.S. Department of Commerce, NOAA, NMFS, Alaska Region, Juneau, Alaska

National Marine Fisheries Service (NMFS) (2005) Final Environmental Impact Statement for Essential Fish Habitat Identification and Conservation in Alaska. Available at https://alaskafisheries.noaa.gov/habitat/efh-eis2005

National Marine Fisheries Service (NMFS) (2010) Alaska Essential Fish Habitat (EFH) 5-year Review for 2010

National Marine Fisheries Service (NMFS) (2011) U.S. National Bycatch Report. In: Karp WA, Desfosse LL, Brooke SG (eds) NOAA Tech Memo. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-F/SPO-117C, 508pp, http://www.nmfs.noaa.gov/by_catch/National_Bycatch_Report/2011/2011_National_Bycatch_Report.pdf

National Marine Fisheries Service (NMFS) (2013) U.S. National Bycatch Report First Edition Update 1. In: Benaka LR, Rilling C, Seney EE, Winarsoo H (eds). U.S. Department of Commerce., 57pp, http://www.nmfs.noaa.gov/sfa/fisheries_eco/bycatch/nationalreport.html

National Oceanic and Atmospheric Administration (NOAA) (2010) NOAA Strategic Plan for Deep-Sea Coral and Sponge Ecosystems: Research, Management and International Cooperation, 67pp, U.S. Dept. of Commerce. Silver Spring, MD

National Oceanic and Atmospheric Administration (NOAA) (2011) EFH Areas protected from fishing. Regional Fishery Management Council Datasheets from NOAA Office of Habitat Conservation, http://www.habitat.noaa.gov/protection/efh/

NOAA (2015) National Database for Deep-Sea Corals and Sponges (ver. 20150814-1). NOAA Deep Sea Coral Research & Technology Program, https://deepseacoraldata.noaa.gov/

National Research Council (NRC) (2002) Effects of Trawling and Dredging on Seafloor Habitat. National Academy Press, Washington D.C.

Norse EA, Brooke S, Cheung WWL, Clark MR, Ekeland I, Froese R, Gjerde KM, Haedrich RL, Heppell SS, Morato T, Morgan LE, Pauly D, Sumaila R, Watson R (2012) Sustainability of deep-sea fisheries. Mar Policy 36:307-320

North Pacific Fishery Management Council (NPFMC) (2012) Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. North Pacific Fishery Management Council, 605 West 4th Ave., Suite 306, Anchorage, AK 99501

Pacific Fishery Management Council (PFMC) (2012) Pacific Coast Groundfish 5-Year Review of Essential Fish Habitat Report to the Pacific Fishery Management Council. Phase 1: New Information.

Packer DB, Nizinski MS, Bachman MS, Drohan AF, Poti M, Kinlan BP (this volume) State of Deep-Sea Coral and Sponge Ecosystems of the Northeast United States. In: Hourigan TF, Etnoyer PJ, Cairns SD (eds.). State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD

Perry WM, Gustafson KB, Sanders GS, Takekawa JY (2010) Pacific Coast Fisheries GIS Resource Database. US Geological Survey, Western Ecological Research Center, Dixon and Vallejo, CA and Bureau of Ocean Energy Management, Regulation and Enforcement, Camarillo, CA BOEMRE study profile #2010-023 [CD-ROM]

Prouty NG, Roark EB, Andrews AH, Robinson LF, Hill T, Sherwood O, Williams B, Guilderson T, Fallon S (this volume) Age, Growth Rates, and Paleoclimate Studies in Deep-Sea Corals of the U.S. In: Hourigan TF, Etnoyer PJ, Cairns SD (eds.). State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD

Puig P, Canals M, Company JB, Martin J, Amblas D, Lastras G, Palanques A, Calafat AM (2012) Ploughing the deep sea floor. Nature 489:286-290

Reed JK, Koenig CC, Shepard AN (2007) Impacts of bottom trawling on a deep-water *Oculina* coral ecosystem off Florida. Bull Mar Sci 81:481-496

Roberts CM (2002) Deep impact: the rising toll of fishing in the deep sea. Trends in Ecology and Evolution 17:242-245

Rooper CN, Boldt JL, Zimmermann M (2007) An assessment of juvenile Pacific Ocean perch (*Sebastes alutus*) habitat use in a deepwater nursery. Estuarine, Coastal and Shelf Science 75:371-380

Rooper CN, Wilkins ME, Rose CS, Coon C (2011) Modeling the impacts of bottom trawling and the subsequent recovery rates of sponges and corals in the Aleutian Islands, Alaska. Continental Shelf Research 31:1827-1834

Rose C, Munk E, Hammond C, Stoner AW (2010a) Cooperative Research to Reduce the Effects of Bering Sea Flatfish Trawling on Seafloor Habitat and Crabs. AFSC Quarterly Report Feature:1-6

Rose CS, Gauvin JR, Hammond CF (2010b) Effective herding of flatfish by cables with minimal seafloor contact. Fish Bull 108:136-144

Rose CS, Hammond CF, Stoner AW, Munk JE, Gauvin JR (2013) Quantification and reduction of unobserved mortality rates for snow, southern Tanner, and red king crabs (*Chionoecetes opilio*, *C. bairdi*, and *Paralithodes camtschaticus*) after encounters with trawls on the seafloor. Fish Bull 111

Sampaio Í, Braga-Henriques A, Pham C, Ocaña O, de Matos V, Morato T, Porteiro FM (2012) Cold-water corals landed by bottom longline fisheries in the Azores (north-eastern Atlantic). J Mar Biol Assoc Uk 92:1547-1555

Sampaio Í, Ocaña O, Tempera F, Braga-Henriques A, Matos V, Porteiro F (2009) New occurrences of Corallium spp. (Octocorallia, Coralliidae) in the Central Northeast Atlantic. Arquipélago Life and Marine Sciences 26:73-78

Shester GG, Micheli F (2011) Conservation challenges for small-scale fisheries: Bycatch and habitat impacts of traps and gillnets. Biol Cons 144:1673-1681

Sigler MF, Rooper CN, Hoff GR, Stone RP, McConnaughey RA, Wilderbuer TK (2015) Faunal features of submarine canyons on the eastern Bering Sea slope. Mar Ecol Prog Ser 526:21-40

South Atlantic Fishery Management Council (SAFMC) (2010) Comprehensive Ecosystem-Based Amendment 1. In: Council SAFM (ed)

South Atlantic Fishery Management Council (SAFMC) (2013) Coral Amendment 8 to the Fishery Management Plan for Coral, Coral Reefs, and Live/Hardbottom Habitats of the South Atlantic Region: Modifications to Habitat Areas of Particular Concern and Transit Provisions. In: Council SAFM (ed)

Stone RP (2014) The ecology of deep-sea coral and sponge habitats of the central Aleutian Islands of Alaska. NOAA Prof Pap. U.S. Department of Commerce

Stone RP, Rooper CN (this volume) State of Deep-Sea Coral and Sponge Ecosystems in the Alaska Region. In: Hourigan TF, Etnoyer PJ, Cairns SD (eds.). State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD

Stone RP, Wing BL (2001) Growth and recruitment of an Alaskan shallow-water Gorgonian. In: Willison JHM, Hall J, Gass SE, Kenchington ELR, Butler M, Doherty P (eds) Proceedings of the First International Symposium on Deep-Sea Corals. Ecology Action Centre and Nova Scotia Museum, Halifax, Nova Scotia

Sutter B, Hourigan TF, Lederhaus T (2013) Integrating Habitat in Ecosystem-Based Fishery Management Proc Proceedings of Managing Our Nation's Fisheries 3: Advancing Sustainability Conference May 6-9, 2013. Pacific Fishery Management Council

Van Dolah RF, Wendt PH, Nicholson N (1987) Effects of a research trawl on a hard-bottom assemblage of sponges and corals. Fish Res 5:39-54

Wassenberg TJ, Dews G, Cook SD (2002) The impact of fish trawls on megabenthos (sponges) on the north-west shelf of Australia. Fish Res 58:141-151

Whitmire CE, Clarke ME (2007) State of Deep Coral Ecosystems of the U.S. Pacific Coast: California to Washington. In: Lumsden SE, Hourigan TF, Bruckner AW, Dorr G (eds) The State of Deep Coral Ecosystems of the United States NOAA Technical Memorandum CRCP-3, Silver Spring, MD

Williams A, Schlacher TA, Rowden AA, F, Clark MR, Bowden DA, Stewart R, Bax NJ, Consalvey M, Kloser RJ (2010) Seamount megabenthic assemblages fail to recover from trawling impacts. Mar Ecol 31:183-199

Woodby D, Carlile D, Hulbert L (2009) Predictive modeling of coral distribution in the Central Aleutian Islands, USA. Mar Ecol Prog Ser 397:227-240

Yoklavich M, Laidig T, Krigsman L, Taylor A, Watters D, Love M, Lundsten L, Negrete, B (2011) A characterization of the coral and sponge community on Piggy Bank seamount in southern California from a survey using a remotely operated vehicle. Report to the NOAA Deep-Sea Coral Research and Technology Program, Silver Spring, MD. 63pp

Yoklavich M, Laidig T, Taylor A, Watters D, Krigsman L, Love M (2013) A characterization of the Christmas tree black coral (*Antipathes dendrochristos*) community on three seamounts in the Southern California Bight from a survey using a manned submersible. Report to NOAA Deep-Sea Coral Research and Technology Program, Silver Spring, MD. 82pp