Incidence of disturbance and damage to deep-sea corals and sponges in areas of high trawl bycatch near the California and Oregon border

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Abstract

We evaluated disturbance and damage to deep-sea corals and sponges (DSCS) in areas of longtime (>65 years) bottom trawling off southern Oregon and northern California. The incidence of disturbance was quantified from video and still images collected along strip transects conducted with underwater vehicles operating at depths of 600-2,100 m. All DSCS were identified, counted, and measured, condition (healthy, unhealthy, or dead) was determined, and associated seafloor substratum types were designated. Physical disturbance and damage were classified as DSCS with broken or missing parts, overturned, or detached from the seafloor. Overall frequency of disturbance to DSCS throughout the study area was 2% of the total number observed; most of these were coral colonies while sponges were rarely damaged. There was notable disturbance to corals, particularly to bamboo corals of the family Isididae (45% of 873 colonies were impacted), at depths of 1100-1150 m in our most northern study site off southern Oregon and the southern site off Cape Mendocino, California. Nearly 20% (n=78) of disturbed bamboo corals were sheared off at the base, leaving only small stumps to be counted. Height of intact undisturbed bamboo coral colonies ranged from 5 to 185 cm. The Mendocino Ridge area had the highest incidence of coral bycatch in research bottom trawls conducted between 2001 and 2015. Using visual survey tools, we now have a better understanding of the extent of damage and disturbance to DSCS. Conservation areas have been implemented off the U.S. West Coast to protect seafloor habitats, but DSCS in our study site remain vulnerable to impacts from bottom-contact fishing gears.

1. Introduction

Deep-sea corals and sponges (DSCS), as well as other megafaunal invertebrate taxa, add complexity and structure to seafloor habitats. With the notable exception of sea pens, DSCS mostly are located on rocky substrata and co-occur with many managed groundfish species (e.g., rockfishes, *Sebastes* spp.) on the U.S. West Coast (Tissot et al. 2006). DSCS are slow growing and vulnerable to disturbance by those bottom-tending mobile and fixed fishing gears that generally target groundfish species (e.g., trawl, trap, longline). Damage to corals and associated seafloor habitats from trawling, in particular, can be widespread and long lasting (Heifetz et al. 2009; Rooper et al. 2011), and can result in changes to the structure of deep-sea ecosystems (Auster et al. 1996; Collie et al. 1997; Rooper et al. 2016).

Commercial fishing with bottom trawls has occurred on the continental shelf and slope of the U.S. West Coast for more than 65 years (Love 2006). Much of our early understanding of the taxonomy, distribution, and abundance of DSCS came from chance collections of these organisms (often just broken pieces) as bycatch in historical research dredge and trawl surveys dating to the late 1800's, and more recently in fishery dependent and independent bottom trawls (Clarke et al. 2015). However, the ecological function of DSCS in benthic communities cannot be evaluated using bycatch collections, and critical information on intact size and species compositions of DSCS prior to fishing simply will never be available.

Direct observations of DSCS using underwater camera systems have become more commonplace over the past two decades, which is resulting in an improved understanding of these organisms as members of the benthic ecosystem. Such visual surveys usually are directed to rocky habitats that are suspected to support coral and sponge communities. For example, discrete sites of particularly high numbers of bamboo (family Isididae) and black (order Antipatharia) corals have been identified in bycatch from bottom trawl catch records off northern California (Clarke et al. 2015). This region of the coast has sustained high levels of fishing pressure from the west coast groundfish trawl fleet for many decades (Mason et al. 2012). It was only recently that some of these sites were explored using telepresence technologies, such as remotely operated vehicles (ROV), autonomous underwater vehicles (AUV), and towed camera system (TCS), to begin to assess the extent of these coral colonies for the first time (Yoklavich et al. 2016; Merle and Embley 2016[1]). In our present study, we quantify the extent of disturbance and damage to DSCS observed during these visual surveys in areas of high coral bycatch in trawl tows off southern Oregon and northern California.

2. Material and Methods

We focused visual surveys in areas of high trawl bycatch of deep-sea corals (excluding sea pens) off the U.S. West Coast between Cape Mendocino and the Oregon-California border (Figure 1). Bycatch records were compiled from research tows conducted as part of the National Marine Fisheries Service (NMFS) West Coast Groundfish Bottom Trawl Survey (WCGBTS). This annual survey collects about 750 independent samples of fish and invertebrates from randomly selected locations nominally between 32.0 and 48.5° N (i.e., from the U.S.-Mexico border to Cape Flattery, WA; Keller et al. 2017). Eighty percent of the samples are collected north of Point Conception, allocated by depth at 55-183 m (32% of all samples), 184-549 m (24%),

[1] *Merle*, S. and R. Embley. 2016. NA072-Seeps and ecosystems of the Cascadia Margin, June 1-20, 2016, Victoria BC, Canada to San Francisco CA, USA. 276 pp.

and 550-1,280 m (24%). Duration of research tows is relatively short (i.e., 15 min) compared to commercial fishing tows (hrs) such that the uncertainty of location of corals along each research tow is minimized. All invertebrates in WCGBTS tows are identified to lowest possible taxonomic level and weighed by taxon. In order to discern concentrations of corals, we summarized the total amount of standardized catch-per-unit effort (CPUE) of corals for all research tows conducted from 2001 to 2015. Dive sites subsequently were selected based on location of high bycatch of corals. Specific dive locations also were informed by maps of bathymetry at various levels of spatial resolution, which were developed in advance of the surveys[2]. Dives were located on rocky ridge tops and sedimentary ridge flanks, and in a submarine canyon.

Underwater visual surveys of corals, sponges, and seafloor substratum types were conducted using three vehicles: the Ocean Exploration Trust's ROV '*Hercules'* in June 2016, the NMFS Alaska Fisheries Science Center (AFSC) TCS in September 2014, and NMFS Pacific Islands and Northwest Fisheries Science Centers' SeaBED-class AUV in September 2014 (Figure 2). The TCS was equipped with two standard definition (SD) stereo cameras, one color and one black and white, both directed forward. Four still images were collected per second simultaneously from both cameras, yielding a continuous real-time view of the seafloor (only 1 image per second was saved for post-survey analyses). The TCS was towed 0.5 m above the seafloor at 0.25 m/s (0.5 kt) for 1 hour per dive. The AUV was equipped with high dynamic range, digital, color, 5 MP photographic cameras arranged in a stereo pair directed downward and perpendicular to the seafloor, and a third high dynamic range, digital, color, 11 MP photographic

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camera directed forward at approximately 35°. The AUV was programmed before each dive to follow a specified path. AUV surveys were conducted 3 m above the seafloor at a forward speed of 0.25 m/s (0.5 kt) for 4-6 hours per dive. Still images were collected at a rate of 1 image per 6 - 7.5 seconds. The ROV had 1 high definition (HD) color video camera directed forward to capture images during the surveys and two paired scaling lasers mounted 10 cm apart in association with the HD camera. ROV surveys were conducted an average height of 2 m above the seafloor at an average speed of 0.2 m/s (0.4 kt). The duration of an ROV dive varied from 5.8 to 12.5 hrs. All vehicles had depth sensors. Live video and audio during the ROV dives were transmitted around the world, which allowed shore-side researchers to contribute to the project in terms of identification of organisms and specific survey routes.

Navigation data for the TCS were collected from the ship’s GPS and smoothed and plotted in ArcGIS to determine the distance traveled for each dive. The AUV and ROV were tracked using a combination of inertial navigation that pairs a Doppler velocity log and fiber optic gyrocompass to provide precise speed and heading over the seafloor, and ultra-short baseline navigation that provides position of the vehicle relative to the support vessel. Resultant navigation data were processed along with the vessel’s GPS data to determine the length and location of the track lines.

Following field surveys, varying numbers of 10-min strip transects were delineated from digital images of each dive. During these transects, the survey vehicles moved forward at relatively consistent speed and height off the seafloor. Cameras were fixed at wide angle on all vehicles during the transects. Transects were located a minimum distance of 100 meters apart. All DSCS were identified to the lowest possible taxonomic level and enumerated from expert examination of digital video and still images collected along each transect. Some sponges were classified by general morphology (e.g., barrel, shelf, vase, mound) when taxonomic identification was difficult. Physical disturbance and damage to DSCS, such as organisms with broken or missing parts, or overturned, displaced, or detached from the seafloor, were quantified. Condition of each DSCS was determined from expert examination of the images to be healthy (<10% of organism is dead), unhealthy (10-50% is dead), or dead (>50% of organism dead). Height of corals and sponges were estimated using *Sebastes* image-analysis software[3] for images from the TCS stereo cameras and using the scaling lasers in video from the ROV. Not all organisms could be measured in ROV and TCS surveys, and no organisms were measured in AUV surveys.

Seafloor habitats were classified by type of substratum along each transect: hard complex rock (e.g., rock ridge, boulder, cobble, flat rock), mixed (hard substrata combined with mud), and soft mud sediment. Length of each patch of habitat type along each transect was determined from the geographic position at the beginning and end of each patch. Field of view was estimated using the *Sebastes* software for TCS, the paired scaling lasers for ROV, and camera optics and height above seafloor for AUV images. Area surveyed on each transect was estimated as the product of average width of field of view and length of each transect. Densities of corals and sponges were estimated by dividing total number of each taxon by the area surveyed.

3. Results

[3] Williams, K., R. Towler, P. Goddard, R. Wilborn, and C. Rooper. 2016. *Sebastes* stereo image analysis software. AFSC Processed Rep. 2016-03, 42 p. Alaska Fish. Sci. Center, NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Forty visual strip transects were conducted along a total of 6,815 m (26,705 m^2) of the seafloor using the TCS (24 transects), AUV (5 transects), and ROV (11 transects) (Table 1). All TCS dives and one ROV dive (ROV-H1523) were conducted on the tops of rocky ridges at average depths ranging from 600 to 750 m, while deeper ridge flanks having more soft mud and mixed sediments were surveyed by the AUV (1,100 - 1,150 m average depth) and ROV (1,150 - 2,100 m average depth).

A total of 22,567 corals comprising at least 12 families were observed throughout the study area (Table 2). Bamboo (n=873; height=5-185 cm) and other gorgonian corals (n=9,937; height 5-65 cm) were the most abundant groups in our surveys, along with black corals (n=2,011; height=5-90 cm) and smaller soft corals (n=9,661; height = 5-20 cm). Corals were observed on all transects, and were most abundant during TCS dives on relatively shallow rocky ridge tops where density ranged from 138 to 9,545 colonies/1,000 m^2 (Table 1).

Sponges, representing at least 13 different taxa, were far less abundant (n = 1,721) than corals throughout the study area (Table 2). Unidentified barrel sponges 5- 50 cm in height comprised 67% of all sponges and occurred at an average depth of 703 m on rocky ridges surveyed with the TCS. Glass sponges *Farrea* spp. (5-50 cm in height; 13%), *Heterochone calyx* (5-20 cm in height; 9%), and *Asbestopluma* spp. (10-30 cm in height; 4%) also were relatively abundant. Sponges were observed at low densities relative to coral colonies (0-435 sponge/1,000 m^2; Table 1). Sponge densities were lowest (0-118/1,000 m^2) in deep water (>= 1,000 m) surveyed by the ROV and AUV.

Damage or disturbance to most taxa was rare, with an average of 4% of corals and 0.2% of sponges evaluated during this study either damaged or disturbed (Table 1). The highest percentage of disturbed/damaged corals (up to 34%) occurred at depths 1,100-1,150 m on transects of the two AUV dives (AUV-3 and AUV-8) off Cape Mendocino and one ROV dive (ROV-H1522) at our most northern study site off southern Oregon (Figure 1; Table 1). Bottom habitat on these transects was composed largely of mixed rock substrata (60% of area surveyed on 9 transects) and soft sediment (39%; Table 1). Only 0-5.3% of corals observed during the TCS transects on relatively shallow rocky ridges were disturbed/damaged. Next to no damage was noted to corals surveyed on the deepest dive (ROV-H1524) conducted with the ROV at depths 1,950-2,200 m largely on soft sediment (71% of total area surveyed on 3 transects) in Trinidad Canyon.

Most of the damage or disturbance occurred to coral colonies, while sponges rarely were impacted (Table 2). In particular, 87% of disturbed corals were bamboo corals (family Isididae; Figure 3) all of which were living on rock substratum. Nearly half of the 873 bamboo colonies observed during the visual surveys were classified as disturbed or damaged. Seventy-eight (20%) of these disturbed bamboo corals were sheared off at the base, leaving only small stumps to be counted among scattered dead coral fragments (Figure 3B). In addition, we observed large linear swaths (estimated to be at least 8 m in width) of broken, dead, prostrate bamboo corals (Figure 3C) some with bases still attached to overturned rocks. One relatively narrow (estimated 1-m wide) cut or track from an unknown source was observed in 3 continuous images of mud substratum during 1 transect on dive AUV-8. Height of intact undisturbed bamboo coral colonies ranged from 5 to 185 cm, with relatively more damage occurring to those colonies 20-80 cm tall (Figure 4). In addition to bamboo corals, gorgonians (e.g., *Paragorgia* spp.), sea pens, and black coral (Antipatharia) sustained damage to a much lesser extent (Table 2).

Most DSCS were healthy, with <3% of all corals and <1% of all sponges classified as either unhealthy or dead. Bamboo corals were found to be in the poorest condition, with only 50% (439 out of 873 corals) considered to be healthy. Virtually all of the dead or unhealthy bamboo corals (393 of 434 corals) were broken, knocked over, or severed at the base. Only 1% of upright, intact corals were classified as dead or unhealthy, including 1 black coral and bamboo, plexaurid, and other gorgonians. A few of these colonies had invertebrate predators climbing among the branches (n = 4 nudibranchs, *Tritonia* spp., and n = 3 sea stars). *Farrea* spp. was the only sponge taxa observed to be dead or unhealthy (6% of 218 *Farrea*); most of these were upright and intact.

Coral bycatch in the WCGBTS was relatively high in three of four of our general study areas, with the highest incidence off Cape Mendocino (Figure 1). Corals (excluding sea pens) were recorded in 8% of 9,052 research trawl hauls between 2001 and 2015 across the entire geographical extent of the WCGBTS; mean coral catch rate (CPUE) coastwide was 29 kg/km^2. At depths >= 600 m in our study area, however, corals were encountered as bycatch more frequently (20% of 366 research trawl hauls) and at higher CPUE (mean = 145 kg/km^2). The three largest catches of corals were all >2,184 kg/km^2; all other hauls were under 1,000 kg/km^2. The three largest hauls were made at depths of 787 - 1,061 m, with the deep portion of this range coinciding with the highest incidence of damage and disturbance observed during our visual surveys. In hauls at depths of 600 - 1,000 m throughout our study area, 92% of coral bycatch (by weight) was represented by black corals (order Antipatharia); at depths >1,000 m, bycatch was dominated by bamboo corals (family Isididae; 86% by weight) followed by bubblegum corals (family Paragorgiidae; 8%).

In contrast to corals, coastwide sponge bycatch in the WCGBTS between 2001 and 2015 occurred much more frequently (26% of the hauls) and at higher CPUE (mean = 666 kg/km^2). Sponges were encountered in 37% of the research hauls at depths >= 600 m in our study area, and mean catch rate was 479 kg/km^2. Eighty-seven percent of sponge bycatch (1,149 kg) was from depths of 600 - 1,000 m; only 165 kg of sponges occurred in deep water (>1,000 m) hauls. These results correspond to those from our visual surveys, wherein density of sponges was higher on rocky ridge tops at 650-750 m depth relative to sponge density at depths >1,000 m (Table 1). In hauls at depths >600 m within our study area, 32% of sponge bycatch (by weight) was recorded as unidentified (phylum Porifera) and 66% was identified as glass sponge (class Hexactinellida).

4. Discussion

It is clear from our visual surveys that notable damage and disturbance was sustained by DSCS, particularly bamboo corals, in some areas of the continental slope off southern Oregon and northern California. Although it is less clear as to the cause of this damage, indirect evidence suggests bottom trawling as a likely source. Bottom trawls are used on the U.S. West Coast by the commercial fishery to target a suite of groundfish and shrimp species living on or near the seafloor, and also by NMFS during annual regional surveys to inform groundfish stock assessments. Bottom trawling, in areas where it is used, has been considered the greatest threat to DSCS communities, as fishing gear is dragged across the seafloor resulting in broken, crushed, and the complete removal of these organisms (NRC 2002; Hourigan 2009). Damage and disturbance to DSCS, similar to that in our study, were observed more frequently during visual surveys conducted in heavily trawled areas off the Aleutian Islands of Alaska than in areas with little or no bottom trawling (Heifetz et al. 2009). In that study, up to 49% of all corals in high-intensity trawled areas sustained damage such as broken skeletons, detachment from the seafloor, or overturned while remaining attached to small rocks. From visual surveys off northern British Columbia, Du Preez and Tunnicliffe (2011) reported that large corals and sponges were rare and that the red tree coral (*Primnoa pacifica*) in particular were 13 times less abundant in areas having experienced high levels of trawling compared to adjacent areas of similar substrata that were not trawled. Damage from experimental bottom trawling in cobble and boulder fields in the Gulf of Alaska was assessed by visual surveys conducted from a human occupied submersible and included overturned, broken, detached, and removed corals and displaced rock boulders up to 2 meters in diameter (Krieger 2001).

Commercial trawling for groundfishes has been one of California's largest fisheries since at least the mid twentieth century (Love 2006). In addition to U.S. trawlers, foreign fleets exerted significant fishing pressure on groundfishes and seafloor habitats on the continental margin off the West Coast from the early 1960's through 1976 (Rogers 2003). In recent years, the highest trawl effort in California has occurred in the vicinity of our study site from Cape Mendocino to the Oregon border in depths >365 m (Mason et al. 2012). This area includes the major fishing ports of Eureka and Crescent City in northern California and Brookings, Bandon, and Coos Bay in southern Oregon. From records of fishing effort (1990-94) and trawl marks in sidescan sonar imagery collected in 1995-96, Friedlander et al. (1999) reported that much of the outer continental shelf and slope off Eureka, CA (to depths >880 m) had been trawled an average of 1.5 times annually. For context, significant damage, disturbance, and removal of sponges and corals and displacement of boulders >0.75 m in diameter resulted from a single pass of trawl gear during experimental studies in the Gulf of Alaska (Freese et al. 1999; Krieger 2001).

Rockfish Conservation Areas (RCA) were established on the outer shelf of the West Coast in 2002, with large areas closed to bottom trawling based on depth in order to reduce incidental catch of overfished groundfish species. Following RCA implementation off northern California, trawling effort was displaced offshore to areas that remained open to fishing for deep-water species at depths >365 m (Mason et al. 2012). Such redistribution of fishing effort in this area could have resulted in some of the impacts on DSCS that we have documented at depths to 1,150 m. Likewise, the NMFS WCGBTS, which is conducted annually in this area between 55 and 1,280 m water depth (Keller et al. 2017), also is a potential source of the observed coral damage. Indeed, fishing effort by the NMFS WCGBTS is proportionally greater with increasing depth relative to effort associated with commercial bottom trawl fishing[4], which decreases considerably below 1,000 m. Aside from bottom trawling, fixed gears (e.g., hook-and-line and pots for sablefish) are commonly used in our study area. However, fishing effort and catches are considerably smaller with these gears[4], as is the expected damage or disturbance to corals (Chuenpagdee et al. 2003; Heifetz et al. 2009).

Despite our focus on areas of historical trawl bycatch, and notwithstanding the

[4] Somers, K. A., Y.-W. Lee, J.E. Jannot, C.E. Whitmire, V.J. Tuttle, and J.T. McVeigh. 2017. Fishing Effort in the 2002-2015 U.S. Pacific Coast Groundfish Fisheries. West Coast Groundfish Observer Program. National Marine Fisheries Service, NWFSC, 2725 Montlake Blvd E., Seattle, WA 98112.

disturbance to bamboo corals and some other gorgonians, we found a diverse and healthy assemblage of DSCS throughout much of our study area. Most of the abundant undisturbed DSCS were relatively short in height. The soft coral *Heteropolypus ritteri* was the most abundant coral in our study, ranging in height from 5-20 cm; all were healthy and undamaged. This coral occurred in high numbers on rocky ridge tops off Cape Mendocino (site TCS-60). In a study on reproduction and growth of this coral off California, Cordes et al. (2001) found that *H. ritteri* has continuous gametogenesis, high fecundity, and large larvae resulting in a long competency period relative to other deep-sea corals. These life history characteristics increase the probability that some larvae will be transported to suitable rocky habitats for successful settlement and maintenance of the population. Other small individuals of DSCS also were found in relatively high numbers in this area (e.g., *Swiftia pacifica*, 5-50 cm in height). Du Preez and Tunnicliffe (2011) reported 90% of the red tree coral, *Primnoa pacifica,* in trawled areas were short (10-30 cm in height) compared to only 20% small colonies on untrawled transects. They speculated that this uniformly small size composition could be the result of recent re-colonization of these corals following trawl disturbance, as was observed by Krieger (2001) in the Gulf of Alaska. This seems plausible for at least some abundant, healthy, short colonies of corals observed in the area of highest bycatch in our study site off Cape Mendocino.

Our study was the first time DSCS have been observed in situ in this relatively remote, long-time fished area of the west coast. Because there is no information on intact DSCS assemblages prior to fishing in this area, it is impossible to fully understand the magnitude of damage and disturbance that has been sustained over the past many decades. In addition, we have no means to discern the specific source, frequency, or time of occurrence of damage to corals observed in our study. We therefore consider visual surveys, such as those conducted in our study, to yield a new baseline from which to evaluate recovery of these DSCS populations and thereby assess restoration of the community structure and associated services (e.g., nursery, shelter, prey enhancement functions) provided by DSCS to the benthic ecosystem. Long-term restriction on the use of the most damaging bottom-contact fishing gears is an appropriate management measure to protect vulnerable DSCS from continued physical damage (Hourigan 2009). Protecting the remaining stands of DSCS in our study area, as well as elsewhere on the West Coast, could require additional no-take fishery closures, such as the essential fish habitat conservation areas currently under review by the Pacific Fisheries Management Council. Understanding the functional roles that DSCS have in benthic communities and the future potential impacts from offshore activities (e.g., wind energy development, installation of telecommunication cables) will require routine monitoring of these diverse assemblages at spatial scales relevant to their occurrence in rocky habitats across the continental shelf and slope of the West Coast.

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References

Auster, P.J., Malatesta, R.J., Langton, R.W., Watling, L., Valentine, P.C., Donaldson, C.L.S., Langton, E.W., Shepard, A.N., Babb, I.G., 1996. The impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (northeast Atlantic): implications for conservation of fish populations. Rev. Fish. Sci. 4,185–202.

Chuenpagdee, R., Morgan, L.E., Maxwell, S.M., Norse, E.A., Pauly, D., 2003. Shifting gears: assessing collateral impacts of fishing methods in US waters. Front. Ecol. Environ. 1, 517-424.

Clarke, M.E., Whitmire, C.E., Yoklavich, M.M., 2015. State of deep-sea coral and sponge ecosystems of the U.S. west coast: 2015. in: Hourigan, T.F., Etnoyer, P.J., Cairns, S.D. (Eds.), The State of Deep-Sea Coral and Sponge Ecosystems of the United States: 2015. NOAA Tech. Memo. XX. NOAA, Silver Spring, MD, pp. 5-1 – 5-42.

Collie, J.S., Escanero, G.A., Valentine, P.C., 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. Mar. Ecol. Prog. Ser. 155,159–172.

Cordes, E.E., Nybakken, J.W., VanDykhuisen, G., 2001. Reproduction and growth of *Anthomastus ritteri* (Octocorallia: Alcyonacea) from Monterey Bay, California, USA. Mar. Biol. 138, 491-501.

Du Preez, C., Tunnicliffe, V., 2011. Shortspine thornyhead and rockfish (Scorpaenidae) distribution in response to substratum, biogenic structures and trawling. Mar. Ecol. Prog. Ser. 425,217–231. doi:10.3354/meps09005.

Freese, L., Auster, P.J., Heifetz, J., Wing, B.L., 1999. Effects of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska. Mar. Ecol. Prog. Ser. 182,119–126.

Friedlander, A.M., Boehlert, G.W., Field, M.E., Mason, J.E., Gardner, J.V., Dartnell, P.,1999. Sidescan-sonar mapping of benthic trawl marks on the shelf and slope off Eureka, California. Fish. Bull. 97,786–801.

Heifetz, J., Stone, R.P., Shotwell, S.K., 2009. Damage and disturbance to coral and sponge habitat of the Aleutian Archipelago. Mar. Ecol. Prog. Ser. 397,295–303.

Hourigan, T.F., 2009. Managing fishery impacts on deep-water coral ecosystems of the USA: emerging best practices. Mar. Ecol. Prog. Ser. 397,333-340. doi:10.3354/meps08278.

Keller, A.A., Wallace, J.R., Methot, R.D., 2017. The Northwest Fisheries Science Center's West Coast Groundfish Bottom Trawl Survey: history, design, and description. NOAA Tech. Memo. NMFS-NWFSC-123, pp. 1 – 37.

Krieger, K.J., 2001. Coral (*Primnoa*) impacted by fishing gear in the Gulf of Alaska, in: Willison, J.H.M., Hall, J., Gass, S.E., Kenchington, E.L.R., Butler, M., Doherty, P. (Eds.), Proceedings 1st International Symposium on Deep-sea Corals, Halifax, Nova Scotia, 30 July – 2 August 2000. Ecology Action Centre, Dalhousie University and Nova Scotia Museum, Halifax, pp. 106–116.

Love, M.S., 2006. Subsistence, commercial, and recreational fisheries, in: Allen, L.G., Pondella, D.J., Horn, M.H. (Eds.), The Ecology of Marine Fishes: California and Adjacent Waters. University California Press, Berkeley, pp. 253–266.

Mason, J., Kosaka, R., Mamula, A., Speir, C., 2012. Effort changes around a marine reserve: the case of the California rockfish conservation area. Mar. Policy 36,1054 – 1063. doi:10.1016/j.marpol.2012.03.002.

National Research Council (NRC), 2002. Effects of trawling and dredging on seafloor habitat. Natl. Acad. Press, Washington DC, pp. 1 – 136. doi: https://doi.org/10.17226/10323.

Rogers, J.B., 2003. Species allocation of *Sebastes* and *Sebastolobus* sp. caught by foreign countries from 1965 through 1976 off Washington, Oregon, and California, USA. NOAA Tech. Memo. NMFS-NWFSC-57, pp. 1-117.

Rooper, C.N., Wilkins, M.E., Rose, C.S., Coon, C., 2011. Modeling the impacts of bottom trawls and the subsequent recovery rates of sponges and corals in the Aleutian Islands, Alaska. Cont. Shelf Res. 31,1827–1834.

Rooper, C.N., Etnoyer, P.J., Stierhoff, K.L., Olson, J.V., 2016. Effects of fishing gear on deep-sea corals and sponges in U.S. waters, in: Hourigan, T.F., Etnoyer, P.J., Cairns, S.D. (Eds.), Chapter 4 State of Deep-sea Coral and Sponge Ecosystems of the United States. NOAA Tech. Memo. XX, Silver Spring, MD, pp. 4-1 – 4-19.

Tissot, B.N., Yoklavich, M.M., Love, M.S., York, K., Amend, M., 2006. Benthic invertebrates that form habitat on deep banks off southern California, with special reference to deep sea coral. Fish. Bull. 104,167–181.

Yoklavich, M., Clarke, M.E., Laidig, T., Fruh, E., Krigsman, L., Anderson, J., Taylor, J., Romsos, C., 2016. A characterization of deep-sea coral and sponge communities in areas of high bycatch in bottom trawls off northern California. NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-556, pp. 1–39.

Table 1. Amount of area, type of substratum (percent of area), average depth, density of corals and sponges, and density (and percentage) of damaged corals and sponges surveyed during quantitative transects on dives conducted with a towed camera system (TCS), autonomous underwater vehicle (AUV), and remotely operated vehicle (ROV) off southern Oregon and northern California in 2014 and 2016.

Dive-Transect	Area (m^2)	Habitat % Soft	% Mixed	%Rock	Average Depth (m)	Density Coral (1,000 m^{-2})	Density Damaged Coral (1,000 m^{-2})	% Damaged Coral	Density Sponge (1,000 m^{-2})	Density Damaged Sponge (1,000 m^{-2})	% Damaged Sponge
TCS-52-1	474	0	0	100	650	648	0	0.0	0	0	-
TCS-52-2	911	2	32	66	700	523	1	0.2	8	0	0.0
TCS-52-3	724	18	65	17	700	628	6	0.9	64	0	0.0
TCS-52-4	862	0	69	31	700	880	2	0.3	56	2	4.2
TCS-53-1	688	0	0	100	600	2,923	0	0.0	6	0	0.0
TCS-53-2	707	0	0	100	600	569	0	0.0	23	0	0.0
TCS-53-3	631	0	0	100	650	1,893	3	0.2	46	0	0.0
TCS-55-1	815	13	87	0	700	335	1	0.4	87	1	1.4
TCS-55-2	706	57	40	3	750	1,269	0	0.0	21	0	0.0
TCS-56-1	676	0	100	0	750	251	4	1.8	107	0	0.0
TCS-56-2	610	0	32	68	750	838	0	0.0	102	0	0.0
TCS-56-3	573	0	95	5	700	1,467	0	0.0	44	0	0.0
TCS-57-1	587	0	100	0	750	1,770	5	0.3	31	0	0.0
TCS-57-2	510	0	35	65	750	2,804	8	0.3	84	0	0.0
TCS-57-3	594	0	36	64	700	2,318	0	0.0	27	0	0.0
TCS-58-1	873	0	44	56	700	384	3	0.9	315	2	0.7
TCS-58-2	724	0	0	100	650	485	3	0.6	319	3	0.9
TCS-58-3	859	0	75	25	650	314	7	2.2	435	5	1.1
TCS-59-1	587	0	99	1	600	220	2	0.8	3	0	0.0
TCS-59-2	590	0	0	100	600	327	8	2.6	17	0	0.0
TCS-59-3	682	2	27	71	600	138	7	5.3	0	0	-
TCS-60-1	311	0	0	100	750	9,545	6	0.1	328	0	0.0
TCS-60-2	461	0	0	100	650	2,807	2	0.1	15	0	0.0
TCS-60-3	441	0	1	99	650	349	0	0.0	200	0	0.0
ROV-H1522-1	637	20	80	0	1,150	537	116	21.6	2	0	0.0
ROV-H1522-2	711	6	94	0	1,150	361	124	34.2	0	0	-

ROV-H1522-3	1,700	74	26	0	1,150	142	39	27.8	7	0	0.0
ROV-H1522-4	1,308	23	77	0	1,150	228	46	20.1	31	0	0.0
ROV-H1523-1	658	0	100	0	750	406	2	0.4	0	0	-
ROV-H1523-2	708	0	18	82	750	1,267	0	0.0	0	0	-
ROV-H1523-3	865	0	37	63	750	329	1	0.4	1	0	0.0
ROV-H1523-4	921	0	0	100	750	596	1	0.2	5	0	0.0
ROV-H1524-1	408	44	56	0	2,100	81	0	0.0	118	0	0.0
ROV-H1524-2	551	72	28	0	2,100	35	0	0.0	74	0	0.0
ROV-H1524-3	634	96	4	0	1,950	32	0	0.0	0	0	-
AUV-3-1	365	69	31	0	1,150	652	16	2.5	5	0	0.0
AUV-3-2	356	3	89	8	1,100	955	121	12.6	8	0	0.0
AUV-3-3	378	26	74	0	1,100	1,378	119	8.6	8	0	0.0
AUV-8-1	455	69	31	0	1,100	382	20	5.2	7	0	0.0
AUV-8-2	458	62	38	0	1,100	358	24	6.7	0	0	-

Table 2. Total number, size range (height, cm), depth range, and number and percent disturbed or damaged of deep-sea coral and sponge taxa observed during visual surveys conducted off southern Oregon and northern California. Not all individuals were measured.

Common Name	Scientific Name	Height (cm)	Depth (m) Range	Depth (m) Average	Total Number	Number Disturbed	Percent Disturbed
Black Coral	Antipatharia	5 - 50	660-1,148	748	1,999	1	0
	Bathypathes spp.	15 - 35	740-2,139	1,226	8	0	0
	Lillipathes spp.	40 - 90	1,148-1,148	1,148	4	0	0
Soft Coral	*Clavularia* spp.	15	590-780	692	39	0	0
	Gersemia spp.	5 - 20	600-790	704	946	0	0
	Heteropolypus ritteri	5 - 20	580-1,148	702	8,676	0	0
Gorgonians							
Bamboo Coral	*Isidella tentaculum*	25 - 185	650-1,148	1,117	190	51	27
	Isididae	5 - 160	650-1,148	1,127	612	325	53
	Keratoisis spp.	110 - 120	1,100-1,148	1,104	71	14	20
Holaxonia	Holaxonia	5	680-750	710	4	0	0
	Plexauridae	5 - 60	580-1,148	776	1,957	12	1
	Swiftia pacifica	5 - 50	580-2,141	882	4,931	8	0
Other	Alcyonacea	N/A	1,100-1,100	1,100	13	0	0
	Paragorgia arborea	15	680-790	756	5	0	0
	Paragorgia spp.	5 - 65	580-1,100	693	2,795	36	1
	Parastenella ramosa	5 - 35	580-1,140	792	232	1	0
Sea Pen	*Anthoptilum grandiflorum*	10 - 45	1,148-1,148	1,148	7	0	0
	Funiculina spp.	5 - 50	700-1,148	878	19	1	5
	Pennatulacea	10 - 30	730-1,974	1,159	32	1	3
	Umbellula lindahli	20	1,100-1,148	1,124	2	0	0
Zoanthid	Zoantharia	N/A	1,100-1,100	1,100	2	0	0
Unidentified Coral	Hexacorallia/Octocorallia	15 - 25	680-1,140	1,069	23	1	4
Total Corals					22,567	451	2
Sponges	*Asbestopluma* spp.	10 - 30	1,148-2,184	1,357	77	0	0
	Farrea spp.	5 - 50	580-2,153	822	218	2	1
	Heterochone calyx	5 - 20	660-790	709	147	0	0
Lightbulb	*Hexactinella* spp.	5 - 25	650-1,100	704	21	0	0
	Poecillastra spp.	20	730-730	730	1	0	0
Barrel	Porifera	5 - 50	590-2,126	703	1,151	9	1
Mound	Porifera	5 - 10	1,100-2,141	1,730	13	0	0
Puffball Mound	Porifera	5	640-640	640	2	0	0
Shelf	Porifera	20 - 25	730-790	760	2	0	0
Vase	Porifera	5 - 40	650-2,153	1,686	44	0	0
	Rhabdocalyptus dawsoni	25 - 30	730-730	730	2	0	0
Picasso	*Staurocalyptus* spp.	35	690-690	690	1	0	0
White	*Staurocalyptus* spp.	15 - 90	670-770	733	31	0	0
Other	Porifera	10 - 40	600-2,120	954	11	0	0
Total Sponges					1,721	11	0.6

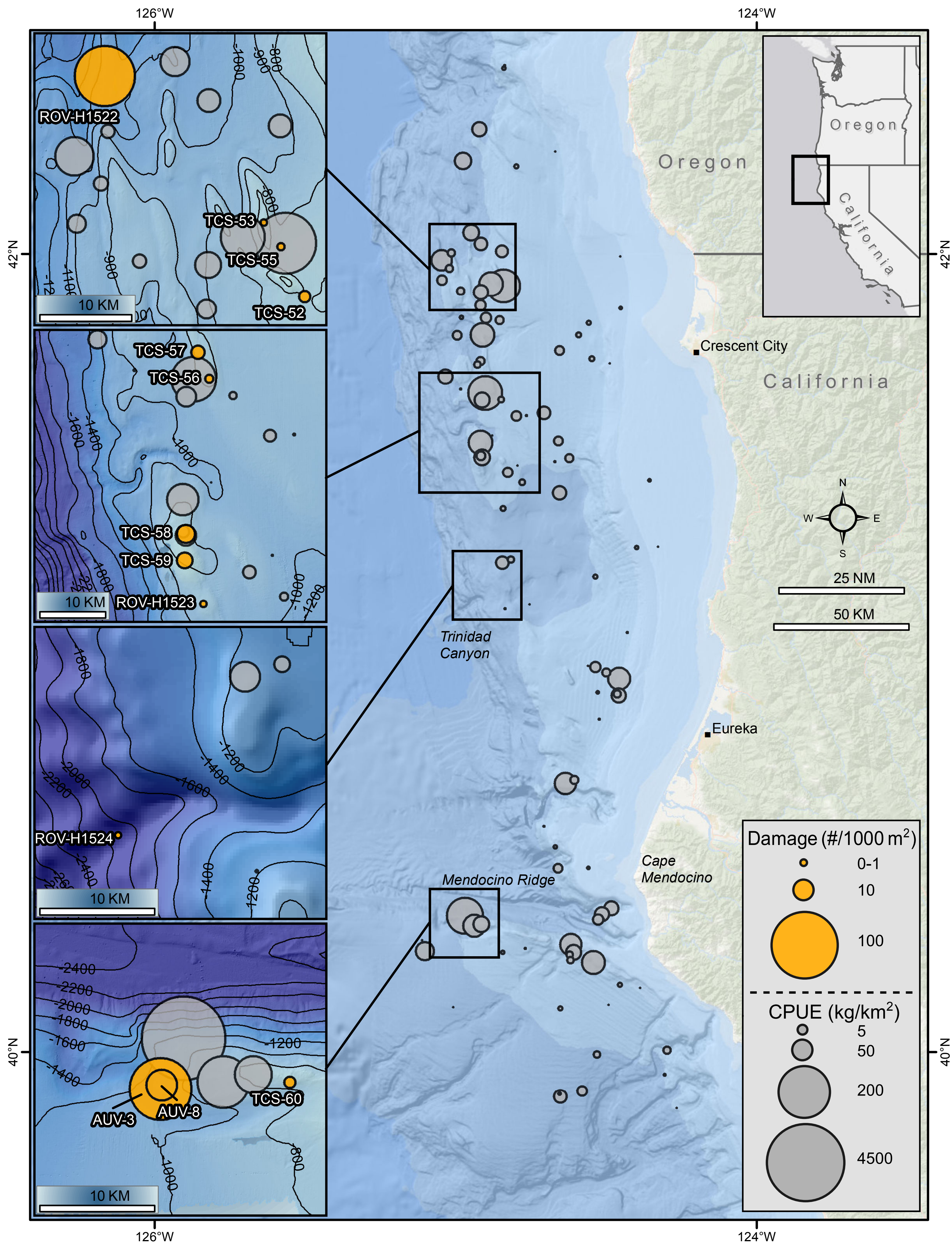
Figure Legends

Figure 1. Study site off southern Oregon and northern California. Size of orange circles (located at centroid of each dive) is proportional to average density of disturbed or damaged deep-sea corals and sponges observed during transects on dives conducted with a towed camera system (TCS), autonomous underwater vehicle (AUV), and remotely operated vehicle (ROV). Size of gray circles is proportional to catch per unit effort (CPUE) of corals as bycatch in NMFS NWFSC West Coast Groundfish Bottom Trawl Survey (2001-2015).

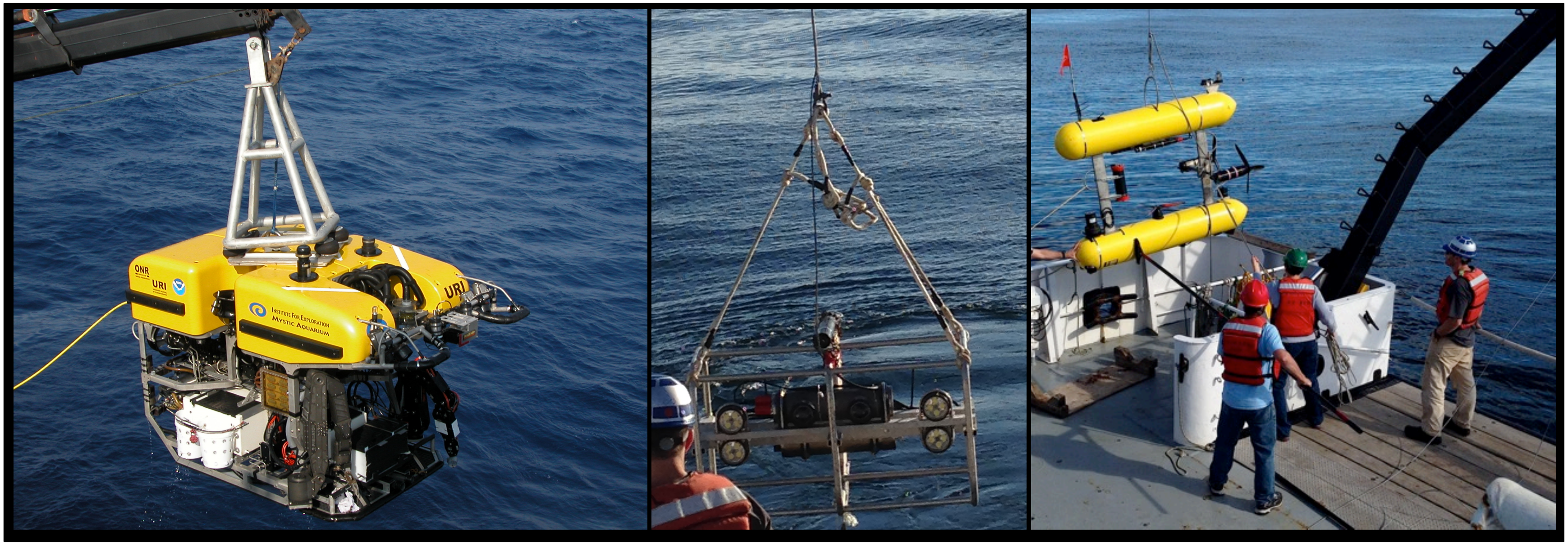
Figure 2. Visual survey tools used to survey deep-sea corals and sponges off southern Oregon and northern California. From left to right, the '*Hercules'* remotely operated vehicle, towed camera system, and SeaBED-class autonomous underwater vehicle.

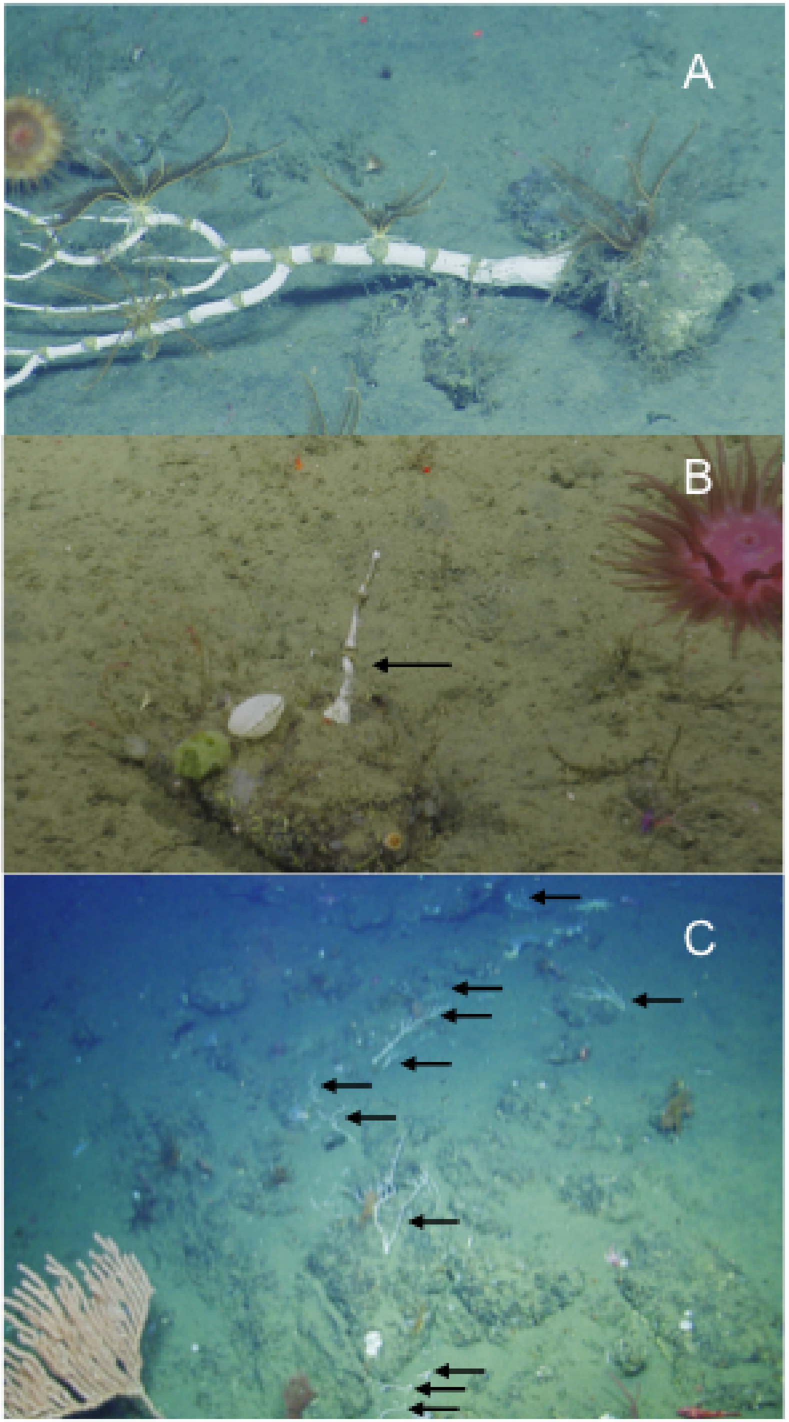
Figure 3. Examples of damaged or disturbed bamboo coral (family Isididae) in our study site off southern Oregon and northern California. (A) Dead coral attached to rock but overturned and lying on seafloor; (B) stump of dead coral (arrow) left upright on rock; and (C) path of dead bamboo corals lying on seafloor (arrows), with living upright pink bamboo coral colony in lower left corner.

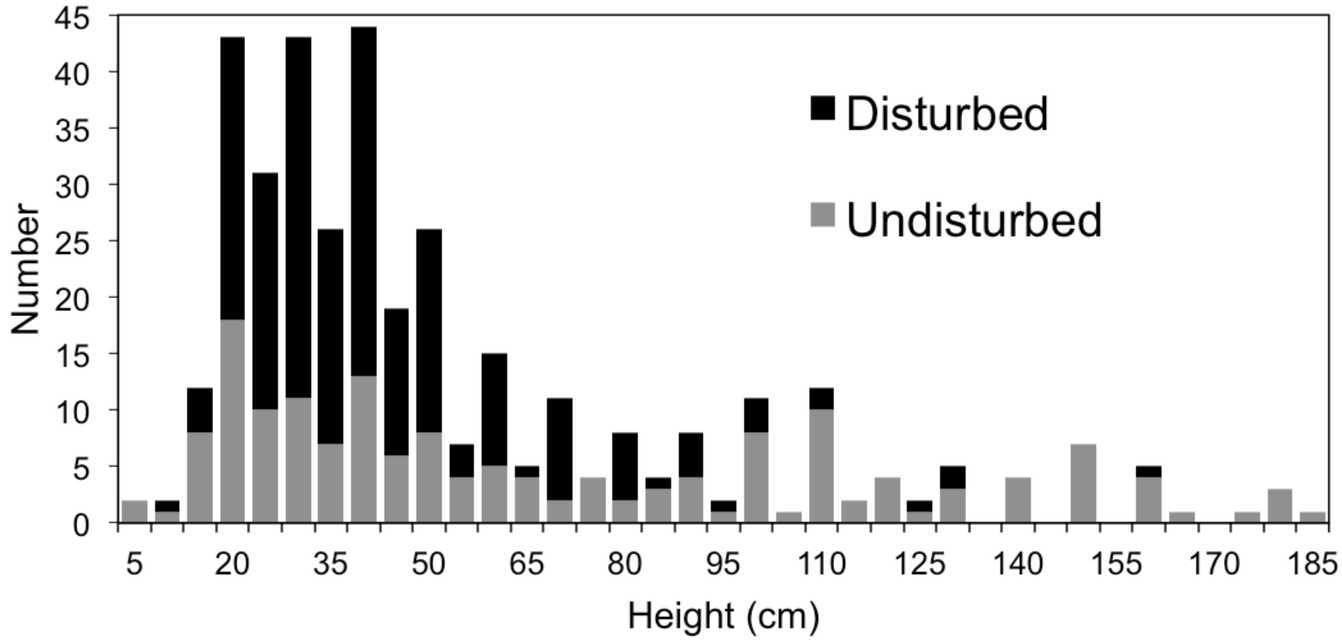
Figure 4. Size distribution of bamboo coral (family Isididae) classified as disturbed or undisturbed when observed during visual surveys conducted with a remotely operated vehicle (ROV) and towed camera system (TCS) off southern Oregon and northern California. This does not include size for those colonies sheared off at the base (leaving only a base that was <15 cm in height).



126°W
124°W
42°N
40°N
ROV-H1522
TCS-53
TCS-55
TCS-52
10 KM
TCS-57
TCS-56
TCS-58
TCS-59
ROV-H1523
ROV-H1524
AUV-3
AUV-8
TCS-60
Oregon
California
Crescent City
Eureka
Trinidad
Canyon
Mendocino Ridge
Cape
Mendocino
N
W
E
S
25 NM
50 KM
Damage (#/1000 m²)
0-1
10
100
CPUE (kg/km²)
5
50
200
4500


ONR
URI
Institute For Exploration
Mystic Aquarium
URI


A
B
C


Disturbed
Undisturbed
Number
45
40
35
30
25
20
15
10
5
0
5
20
35
50
65
80
95
110
125
140
155
170
185
Height (cm)