Deep-Sea Coral Research and Technology Program: Alaska Deep-Sea Coral and Sponge Initiative Final Report

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U.S. Department of Commerce
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Executive Summary

Deep-sea coral and sponge ecosystems are widespread throughout most of Alaska's marine waters. In some places, such as the central and western Aleutian Islands, deep-sea coral and sponge resources can be extremely diverse and may rank among the most abundant deep-sea coral and sponge communities in the world. Many different species of fishes and invertebrates are associated with deep-sea coral and sponge communities in Alaska. Because of their biology, these benthic invertebrates are potentially impacted by climate change and ocean acidification. Deep-sea coral and sponge ecosystems are also vulnerable to the effects of commercial fishing activities. Because of the size and scope of Alaska's continental shelf and slope, the vast majority of the area has not been visually surveyed for deep-sea corals and sponges. NOAA's Deep Sea Coral Research and Technology Program (DSCRTP) sponsored a field research program in the Alaska region between 2012–2015, referred to hereafter as the Alaska Initiative. The priorities for Alaska were derived from ongoing data needs and objectives identified by the DSCRTP, the North Pacific Fishery Management Council (NPFMC), and Essential Fish Habitat-Environmental Impact Statement (EFH-EIS) process.

This report presents the results of 15 projects conducted using DSCRTP funds from 2012-2015. Three of the projects conducted as part of the Alaska deep-sea coral and sponge initiative included dedicated at-sea cruises and fieldwork spread across multiple years. These projects were the eastern Gulf of Alaska *Primnoa pacifica* study, the Aleutian Islands mapping study, and the Gulf of Alaska fish productivity study. In all, there were nine separate research cruises carried out with a total of 109 at-sea days conducting research. The remaining projects either used data and samples collected by the three major fieldwork projects or were piggy-backed onto existing research programs at the Alaska Fisheries Science Center (AFSC).

The suite of projects that examined *P. pacifica* habitats and associated species in the eastern Gulf of Alaska were important and provided significant new information about these communities. The multibeam mapping project extended coverage in the region by an additional ~167 square nautical miles to depths of 1300 m in areas of known or suspected *P. pacifica* habitat. The study confirmed that *P. pacifica* habitat extends significantly beyond the areas currently closed to fishing as part of the Habitat Areas of Particular Concern (HAPCs) in the region. At a number of the unprotected sites there was evidence of damage to *P. pacifica* from longline fishing activity. Colony sizes were related to depth, with the largest colonies exceeding 2 m in height and found at the deeper depths (> 200 m). These large colonies (> 2 m) also formed a significant portion of the population, comprising 10% of the total colonies. Overall, almost 70% of the colonies were > 1 m in height and the recovery time for the largest colonies was estimated at > 100 years and 50-60 years for the average size colonies. The samples collected during this study using a remotely operated vehicle (ROV) were used to examine reproductive ecology, feeding ecology, and genetic connectivity of *P. pacifica*. As a group, these studies confirmed the gonochorism and multiple developing cohorts of oocytes that have been previously observed in shallow-water populations. However, the study also found evidence for reduced fecundity in the deeper water populations. Recruitment substrates were also deployed in the *P. pacifica* thickets and the absence of new *P. pacifica* recruits after 22 months confirmed the episodic and rare nature of successful recruitment for this species. However, the observed recruitment of another octocoral (*Calcigorgia spiculifera*) was unique and indicated the potential for the success of the experimental design. The settlement plates were redeployed for future retrieval. The feeding ecology study indicated that *P. pacifica* is likely feeding on both particulate organic matter (POM) and zooplankton, findings similar for other species in other regions of the deep-sea.

An important accomplishment of the Alaska Initiative was the production of maps of predicted occurrence of corals and sponges on a 1 ha scale for each of the three major regions of Alaska. These maps and models were confirmed (with the exception of the wider Gulf of Alaska) with field studies and indicated that coral and sponge ecosystems occur at predictable locations where hard bottom substrate is present. During the course of the project three previously unexplored locations were also examined using field observations, Bowers Bank and Ridge and the eastern and western Aleutian Islands. These explorations found that dense coral and sponge communities are found throughout the western Aleutians, on the shallowest depths of Bowers Bank, and in the area from Sequam Pass to Unalaska Island. Areas without coral and sponge communities were also identified, especially on the shelf south of Unalaska Island, in the deeper areas of Bowers Ridge, and between Aggatu and Attu Islands. One of the important variables to come out of this modeling was the effect of current speed (either tidal currents or mean oceanographic currents) on the distribution of corals and sponges. The highest densities tended to be in areas where currents could be moderate to high (> 50 cm/s). Depth was also an important factor across regions controlling benthic invertebrate distribution. An important component of the data from this fieldwork was height and density information for corals and sponges in the Aleutian Islands. These new data and models will be used in the future to inform management decisions on where fishing closures can be most effective in protecting the oldest, most diverse, and densest coral and sponge communities.

One of the foundations of the distribution maps for deep-sea corals and sponges is maps based on sediment and bathymetry that were developed from the Alaska Initiative. New bathymetry and sediment maps for the Aleutian Islands and parts of the Gulf of Alaska were completed during this project. These maps mined the NOS charting data as far back as the late 1900s and new multibeam bathymetry data from study sites all over Alaska into a single product that was used to derive distribution models for deep-sea corals and sponges. Future work will expand geological interpretation of these maps and data to provide substrate-based classifications for regions where enough supporting data exist.

During the Alaska Initiative, we also tried to document the differences in fisheries productivity using a number of measures in different types of habitats (hard substrate with coral, hard substrate with no coral, and bare sand habitat). Densities of rockfish, especially juveniles and smaller species, was higher in coral habitat than the other types of habitat, which has previously been shown in other areas by other studies. However, other measures of productivity, such as gonosomatic index, relative fecundity, energetic content, and reproductive failure were also measured in the different types of habitats, and highest productivity using these measures tended to be in the coral habitat. Preliminary results indicate that for rockfish, there may be benefits to coral habitat in terms of fish productivity that exceed the benefits of the same type of substrate without coral. Further data and results are forthcoming from this project as samples continue to be analyzed.

Because climate change and ocean acidification are expected to have large impacts on high latitude systems, such as those found in Alaska, some monitoring programs were set up that used existing facilities within the AFSC to collect data. An oceanographic monitoring array was tested in Tracy Arm Fjord, Southeast Alaska, and a permanent real-time data delivery station will be established at Little Port Walter in Southeast Alaska that will be connected to other oceanographic monitoring programs (NESDIS and AOOS). The AFSC bottom trawl surveys also have been collecting oceanographic data using equipment purchased by the Alaska Initiative. So far, these data have shown distinct breaks and patterns in O_2 concentrations in the Gulf of Alaska especially. Prior to these collections, no synoptic data sets for summer oceanographic conditions throughout Alaska ecosystems were being collected, with the exception of temperature data. Both these data sets will continue to be monitored and provided to scientists and managers to support ecosystem management not only for deep-sea corals and sponges, but for other purposes as well.

Samples collected during the fieldwork for the Alaska Initiative resulted in the description of 23 new species of demosponges. Collected samples were also critical to the revision of at least one family of demosponge as well as providing geographical range extensions for many species. Biochemical analyses and products also have resulted in important and potentially medically useful alkaloids. As samples continue to be analyzed, further species and taxonomic revisions are likely. These findings highlight the fact that there is still much to be learned about the taxonomy of deep-sea corals and sponges in Alaska, but that significant progress has been made partly because of the Alaska Initiative.

In all, the 3-year Initiative provided important new information that addressed both immediate management needs for coral and sponge ecosystems (such as the distribution mapping and modeling that has already been used by the NPFMC to inform fisheries management), as well as longer term goals (such as setting up long-term monitoring stations in Little Port Walter and on bottom trawl surveys that will measure the effects of climate change on the ecosystem). Equally as important, the Alaska Initiative has raised new questions but provided new techniques that can be used to inform future research in Alaska.

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The Alaska Deep Sea Coral Research Team members are Chris Rooper (AFSC RACE Division), Robert Stone (AFSC Auke Bay Laboratories), Peter Etnoyer (NCCOS, Center for Coastal Environmental Heath and Biomolecular Research), Jennifer Reynolds (University of Alaska Fairbanks), John Olson (NMFS Alaska Regional Office), and John Tomczuk (NOS). We would like to thank Kresimir Williams and Rick Towler provided the stereo cameras used in this projects, as well as the software used to analyze the stereo camera images. Rachel Wilborn and Pam Goddard conducted image analysis for the Aleutian Islands and fish productivity studies. Mark Zimmermann, Megan Prescott, Jane Reid and Nadine Golden worked on the bathymetry and sediment compilations for the Aleutian Islands and central Gulf of Alaska. Additional funding for this project was provided by the Alaska Fisheries Science Center, North Pacific Research Board and the Alaska Regional Office.

We thank Captain Jim deLaBruere and the crew of the ADF&G RV *Medeia* for their assistance during the 2013 cruise in the eastern GOA and the 2014 cruise to Holkham Bay to collect genetic samples. We thank Julie Nielsen (University of Alaska Fairbanks) for loaning us the acoustic release system used during the 2013 cruise. We thank Captain Lou Laferriere and the crew of the FV *Alaska Provider*, Ed Cassano of Ocean Science Service, and the crew at Deep Ocean Exploration and Research for their assistance during the 2013 ROV cruise. We thank Ed Cassano of Pelagic Research Services and the captain and crew of the RV *Dorado Discovery* for their assistance during the 2015 ROV cruise. We thank Captain Dan Foley and the crew of the FV *Steller* for their assistance during the 2014 dive cruise to Holkham Bay to deploy equipment for the long-term oceanographic study.

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1. Introduction

The Deep Sea Coral Research and Technology Program (DSCRTP) was established under the authority of Section 408 of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) as reauthorized in 2007 to identify, monitor, and provide information to protect deep-sea coral areas. The DSCRTP has supported exploration, research, and management activities critical to understanding and managing deep-sea corals and sponges. The objectives of NOAA's Deep-Sea Coral and Sponge Exploration and Research Strategy (NOAA 2010) are to 1) locate and characterize deep-sea coral and sponge ecosystems, 2) understand the biology and ecology of deep-sea corals and sponges, 3) understand the biodiversity and ecology of deep-sea coral and sponge ecosystems, 4) understand the extent and degree of impact to deep-sea coral and sponge ecosystems caused by fishing and other human activities, and to 5) understand past oceanic conditions and predict the impacts of climate change using deep-sea corals. Research activities in each of the six NMFS management regions have been supported by the DSCRTP through a series of 3-year funding initiatives.

Deep-sea coral and sponge ecosystems are widespread throughout most of Alaska's marine waters. In some places, such as the central and western Aleutian Islands, these may be among the most diverse and abundant deep-sea coral and sponge communities in the world. Deep-sea coral and sponge communities are associated with many different species of fishes and invertebrates in Alaska. Because of their biology, these benthic invertebrates are potentially impacted by climate change and ocean acidification. Deep-sea coral and sponge ecosystems are also vulnerable to the effects of commercial fishing activities. The challenges facing management of deep-sea coral and sponge in Alaska begin with the lack of knowledge of where these organisms occur in high abundance and diversity. Because of the size and scope of Alaska's continental shelf and slope, the vast majority of the area has not been surveyed for deep-sea coral and sponge abundance. Since the spatial distribution of these communities is not known in Alaska, it is difficult to predict the locations and types of human activities and climate impacts that may affect deep-sea coral and sponge ecosystems. From 2012-2015, the NOAA Deep Sea Coral Research and Technology Program (DSCRTP) sponsored a field research program in the Alaska region. The priorities for Alaska were derived from ongoing data needs and objectives identified by the DSCRTP, the North Pacific Fishery Management Council and Essential Fish Habitat-Environmental Impact Statement (EFH-EIS) process. The objectives of funded research projects were:

- to identify areas of high abundance of Primnoa corals in the Gulf of Alaska,
- to determine the distribution and areas of high abundance and diversity of sponges and corals in the Gulf of Alaska and Aleutian Islands,
- to estimate the recovery rates and sustainable impact rates for Primnoa corals in the Gulf of Alaska,
- to determine the productivity increases in terms of fish abundance and condition in areas with and without corals and sponges,
- to estimate the potential effects of long-line fishing on coral and sponge communities in Alaska,
- to estimate the connectivity of populations of Primnoa in the Gulf of Alaska, British Columbia, and the west coast of the U.S. through genetic studies,
- to collect long-term data sets of O_2 and pH from summer bottom trawl surveys,

- to set up long-term monitoring of nearshore and unique populations of coral and sponge in SE Alaska fjords,
- to improve the taxonomy of sponges and corals through special collections of unidentified specimens and collect data and specimens for paleoclimatological, microbial, and marine natural product studies, and
- to compile a geologically-based substrate map for the Gulf of Alaska and Aleutian Islands.

The research was carried out by AFSC scientists from the Auke Bay Laboratories and the Resource Assessment and Conservation Engineering Division, the Alaska Regional Office, as well as partners at the University of Alaska Fairbanks, the US Geological Survey, NCCOS, the Tombolo Institute, the University of Maine, and the Alaska Department of Fish & Game. Supplemental funding was provided by the AFSC and the North Pacific Research Board.

2. Major Field Research Projects

Three of the projects conducted as part of the Alaska deep-sea coral and sponge initiative included dedicated at-sea cruises and fieldwork spread across multiple years. These projects were the southeast Alaska *Primnoa* study, the Aleutian Islands mapping study and the Gulf of Alaska fish productivity study (Figure 1). In all, there were nine separate research cruises carried out with a total of 109 at-sea days (Table 1).

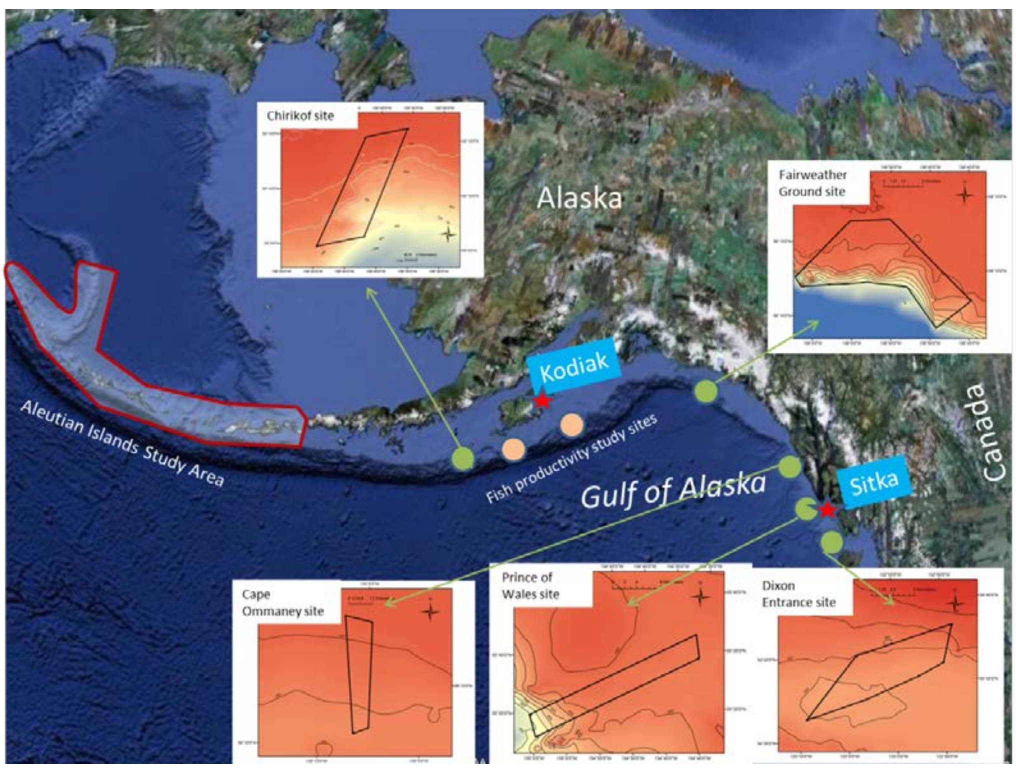

Figure 1. Locations of research cruises funded in FY12-15 by the Deep-Sea Coral Research and Technology Program. The Aleutian Islands mapping project was conducted in the area outlined by the red border, the fish productivity project was conducted at the two sites indicated by orange circles, and the Alaska Primnoa study was conducted at the four of the five sites (Cape Ommaney, Prince of Wales, Dixon Entrance and Fairweather Ground) in the eastern Gulf of Alaska indicated by green circles.

Table 1. List of cruises by project for the Alaska Coral and Sponge Initiative (FY12-15).

Project	Study sites	Cruise dates	Vessel	Survey tools	Purpose	Participating scientists
Southeast Alaska Primnoa study[1]	Dixon Entrance, Shutter Ridge, Prince of Wales, Chirikof Island	June 1-13, 2012	R/V *Pacific Star*	Multibeam sounder	Map study areas using multibeam sounder	J. Reynolds
	Dixon Entrance, Shutter Ridge, Prince of Wales, Fairweather Ground	August 7-21, 2013	F/V *Alaska Provider*	ROV	Survey transects, collect specimens for analysis	R. Stone, J. Reynolds, G. Greene, P. Etnoyer, C. Morrison, A. Turner
	Shutter Ridge, Fairweather Ground	August 13-18, 2013	R/V *Medeia*	Towed camera	Deploy settlement plates, survey transects	C. Rooper
	Dixon Entrance, Shutter Ridge, Fairweather Ground, Edgecumbe Pinnacle	June 1-11, 2015	R/V *Dorado Discovery*	ROV	Survey transects, collect specimens for analysis, collect settlement plates	R. Stone, J. Reynolds, C. Morrison, R. Salgado, R. McGuinn, K. Feehan
Aleutian Islands mapping study	Eastern and central Aleutian Islands, Bowers Bank and Ridge	August 14-29, 2012	F/V *Sea Storm*	Towed camera	Occupy random stratified survey transects	C. Rooper, R. Stone
	Central and western Aleutian Islands	April 20-May 14, 2014	F/V *Alaska Endeavor*	Towed camera	Occupy random stratified survey transects	C. Rooper, J. Olson
Gulf of Alaska fish productivity study[1,2]	Forty-nine fathom pinnacle	August 15-21, 2012	F/V *Pacific Storm*	Towed camera, trawl	Collect fish samples, survey transects	C. Conrath, B. Knoth, M-S Yang, D. Benjamin
	Forty-nine fathom pinnacle and Snakehead Bank	May 10-17, 2014	F/V *Gold Rush*	Towed camera, trawl	Collect fish samples, survey transects	C. Conrath, B. Knoth
	Forty-nine fathom pinnacle and Snakehead Bank	December 10-18, 2014	F/V *Gold Rush*	Towed camera, trawl	Collect fish samples, survey transects	C. Conrath, A. Vigjen

[1] Partially funded by Alaska Fisheries Science Center
[2] Funded by North Pacific Research Board

2.1 Red tree coral (*Primnoa pacifica*) thicket habitats in the eastern Gulf of Alaska

Background and Objectives: This research examined the biology and ecology of red tree corals (*P. pacifica*) at five study areas in the eastern Gulf of Alaska (GOA; Figure 2). Red tree corals are large gorgonians or sea fans that are the dominant structure forming coral species on the outer continental shelf and upper slope between the Alaska Peninsula and the Olympic Coast Marine Sanctuary off Washington State. Red tree corals form dense thickets in some areas of the North Pacific Ocean but their precise location is largely unknown and can often only be inferred from spatially imprecise sources such as fisheries bycatch data. Observations have confirmed the presence of thickets at several locations between the Fairweather Ground in the northeastern GOA and Bowie Seamount in northern British Columbia. The importance and vulnerability of red tree coral thickets has been recognized by the North Pacific Fishery Management Council (NPFMC) and some protection has been afforded to known thickets in the region through the establishment of five small Habitat Areas of Particular Concern (HAPCs). The HAPCs where all fishing activities are prohibited were established in 2007.

Colonies tend to be located on moderate relief bedrock and large boulders (glacial drop stones) which are also areas where bottom-contact fishing gear, principally set gear such as longlines, are used. Red tree corals are common bycatch in fisheries for demersal species and in stock assessment surveys. Colonies are easily damaged or dislodged from the seafloor by natural forces, such as landslides and low-level predation and unnatural forces, such as bottom fishing activities. Manned submersible observations in the GOA clearly indicate that some thickets have been disturbed by past fishing activities (Stone et al. 2014). Derelict longline gear has been observed entangled in coral colonies at several sites in the eastern GOA and some thickets have colony damage rates exceeding 16% (Stone et al. 2014). Owing to their large size, arborescent growth pattern, and reported slow growth rates, red tree corals are highly susceptible to disturbance from fishing activities and are likely slow to recover from such disturbance. Red tree corals have specifically been identified as important habitat for fishes and invertebrates in the Gulf of Alaska.

Previous research in eastern GOA thickets indicates that red tree corals are found on bedrock where the seafloor is rough and sloped (Masuda and Stone 2015). Otherwise we know little about the habitat requirements or the specific geological features that may control the establishment of thickets. This lack of basic knowledge inhibits effective management of red tree coral habitats in the face of anthropogenic disturbances and the potential effects of climate change and ocean acidification. Data collected during this study will provide important insights regarding the most appropriate tools available to resource managers to protect sensitive coral habitats and the ecosystem services they provide.

The objective of this research was to study the ecology and geology of seafloor habitats at several sites known to or suspected of supporting red tree coral thickets in the eastern GOA. We produced high-resolution bathymetry and seafloor habitat maps to identify targets of high interest and then used remotely operated vehicles (ROVs) to ground-truth and explore those targets for coral and sponge habitats. Results of this research will be provided to the NPFMC to modify the boundaries of the existing HAPCs and establish new HAPCs in the region if warranted.

Approach: We conducted a research cruise aboard the R/V *Pacific Star* between 4–15 June and 11–12 July 2012 to collect multi-beam and backscatter data at four sites in the Gulf of Alaska (Sites 1, 2, 4, and 6; Figure 2). Sites 3 and 5 had been mapped during previous research projects. Fugro-

Pelagos, Inc. was contracted to collect and process the seafloor imagery data. Each site was mapped (100 percent coverage) to ~800 m depth with a Reson Seabat7111 multi-beam sonar operating at 110 kHz. Bathymetry and backscatter maps for each of the study areas were produced in August 2012. In total, 522.8 linear nautical miles were mapped over an area of 167.2 square nautical miles. Mapped areas ranged in depth from approximately 100 to 1287 m.

Seafloor maps were used to identify hard, rough substrates that were potential targets for the presence of red tree coral thickets. Maps were also used to plan ROV dives to explore various geographical features for the presence of corals. In August 2013 we used the Deep Ocean Exploration and Research H2000 ROV to conduct dive operations at three sites (Sites 1, 2, and 3) in the eastern GOA. In June 2015 we used the Pelagic Research Services and Odyssey Marine ROV *Zeus II* to conduct dive operations at four sites in the eastern GOA (Figure 3). Dive Site 6 in the western GOA was not explored during either year of this study due to budgetary constraints. The ROVs were used to collect video footage of the seafloor along strip transects chosen at random locations within the high priority areas that comprised suitable substrate for red tree corals. Transects covered a broad depth range spanning 1000 to 80 m at each site. Video footage of the seafloor was collected with at least two cameras. The primary camera was mounted with the imaging plane directed nearly perpendicular to the seafloor so as to provide a fixed-width (~120 cm) image area from which counts of biota were made. The width of the image area was be delineated by two parallel lasers (wavelength = 532 nm) mounted on the "brow bar" of the ROV. A secondary camera with pan, tilt, and zoom functions was mounted forward and controlled by the science team to provide close-up imagery of the transect and collected specimens. In addition, all video cameras recorded two parallel laser marks (wavelength = 670 nm) 10 cm apart projected onto the seafloor to provide calibration for measurements of the dimensions of the image area (i.e. transect width and length), and size of fauna. The ROV was equipped with a SeaBird CTD or other oceanographic sensors used to collect depth, temperature, and salinity profiles along the entire ROV dive track at regular (e.g., 2 second) intervals. All imagery, oceanographic, and navigational data was cross-referenced and synchronized with time stamping set to the ROV tracking system onboard the support vessel.

In August 2013 we chartered the Alaska Department of Fish & Game (ADF&G) RV *Medeia* to place settlement arrays on the seafloor at Site 3 (Shutter Ridge) and Site 4 (Fairweather Ground). During that cruise we also collected video imagery of the seafloor at both sites along select transects using a stereo-video drop camera system deployed from an oceanographic winch. The camera system was towed at slow speed along a pre-determined bearing just above the seafloor and recorded still images once per second. At Site 3, images were collected along two transects, one south and one north of existing surveys to determine if red tree coral thickets extended to regions beyond the Shutter Ridge proper. At Site 4, images were collected along several transects along the continental slope and shelf previously not explored.

Preliminary analysis of video footage occurred onboard the support vessel, but the bulk of the analysis has and will occur in the videographic laboratories at the Auke Bay Labs and NOS Center for Coastal Environmental Health and Biomolecular Research (NOS/CCEHBR). In the laboratory, all corals, sponges, fish and large invertebrates (including the predatory seastar *Hippasteria phrygiana*) within the strip transect video will be enumerated. Corals and sponges will be classified as damaged if they have missing or broken branches, are detached from the seafloor, or are attached but overturned and lying in contact with the seafloor. Evidence for the nature of the disturbance, e.g., natural disturbance by slumps, landslides, or earthquake events, anthropogenic disturbance by fishing gear, or predation will be noted. Mobile fauna (fish and crabs) will be enumerated if they are observed within the bounds of the strip transect and their presence on the transect does not appear to be in response to the ROV (Figure 4). Habitat variables will be recorded using established criteria for the region (Stone et al. 2014) and will include depth, substrate, slope, roughness, and slope aspect. All data will be archived and made available at NOAA's National Database for Deep-Sea Corals and Sponges.

Significant Results to Date: The August 2013 cruise with the ADF&G RV *Medeia* produced two stereo-video transects at Site 3 (Shutter Ridge) that confirmed the presence of red tree corals beyond the existing HAPC to the south and extended the known distribution of red tree coral thickets to the north, beyond the Shutter Ridge proper. These data will be a valuable consideration should the existing boundaries of the HAPC be re-evaluated by the NPFMC in the future. Data collected on two stereo-video transects on the deep slope (740–300 m depth) at Site 4 (Fairweather Ground) provided valuable information to ground-truth the multi-beam and backscatter data previously collected. The video data also revealed that these sites on the continental slope were relatively devoid of red tree corals in this region but do contain small numbers of black corals (*Chrysopathes* spp., *Bathypathes* sp., and *Dendrobathypathes boutillieri*), hydrocorals (*Stylaster* spp.), bamboo corals (*Isidella tentaculum* and *Keratoisis* sp.), and other octocorals *Paragorgia* sp., *Psammogorgia simplex*, *Swiftia pacifica*, *Halipteris* sp., and soft corals (*Heteropolypus* sp.).

ROV dives at Site 1 (Dixon Entrance) in 2013 and 2015 focused on two areas; the deep (~350 m depth) basin in soft-sediment habitats with scattered glacial drop-stones and several hard-bottom areas along the upper slope and outer shelf of the basin (~165 m depth). The deeper area was the site of prior submersible exploration by AFSC scientists in the 1990s (Krieger 2001, Krieger and Wing 2002) and 2005 (R. Stone, unpublished data). An important observation during this study was that the condition of the red tree corals has markedly degraded since the earlier observations with the majority of colonies partially or completely skeletonized. Many colonies had signs of damage, likely from longline fishing gear (Figure 5), and predation by the three predators of red tree corals documented in the region (Stone et al. 2014). Analysis of all video footage is planned in the future to document the apparent demise of the deep corals and investigate possible mechanisms that might include ocean warming, ocean acidification, increased fishing activity, and shifts in community structure. Observations made during exploration of the two shallow sites revealed previously undocumented red tree coral thickets with large numbers of associated rockfish (*Sebastes* spp.) on bedrock outcrop features (Figure 6).

Five ROV dives were made at Site 2 (Prince of Wales) in 2013 to investigate areas where red tree coral bycatch in AFSC longline surveys had previously been documented and to explore interesting geological features revealed on the multi-beam and backscatter data. A single dive was made in deep water (600–500 m) on the continental slope and revealed mixed-substrate habitats with only a few black corals (*Bathypathes* sp.) and pennatulaceans (*Halipteris* sp.). Four ROV dives were made on the shelf (~250 m depth) and revealed that the interesting "pock marks" observed on the seafloor imagery were depressions and mounds, with rims of carbonate crusts, and possibly relic cold seeps. The carbonate crusts provided some hard substrate for sponges but otherwise the shelf regions were relatively devoid of corals.

ROV dives at Site 3 (Shutter Ridge) in 2013 and 2015 were used to support other aspects of this project only. Since the entire ridge had previously been explored (Stone et al. 2014, Masuda and Stone 2015) additional reconnaissance dives were not warranted with the ROV.

ROV dives at Site 4 (Fairweather Ground) were limited to 2015 as inclement weather and high seas prevented ROV operations in 2013. A total of six reconnaissance dives were made in 2015 and included four dives on volcanic and other bedrock features on the shelf (190–140 m depth) and two dives on the slope including submarine canyons (625–320 m depth). The deeper dives revealed that the slope in the region is principally composed of unconsolidated sediments. A few areas of siltstone and bedrock outcrop provide suitable substrate for black corals (*Chrysopathes* spp., *Bathypathes* sp., and *Dendrobathypathes boutillieri*), hydrocorals (*Stylaster* spp.), bamboo corals (*Isidella tentaculum* and *Keratoisis* sp.), and other octocorals *Paragorgia* sp., *Psammogorgia simplex*, *Swiftia pacifica*, *Halipteris* sp., and soft corals (*Heteropolypus* sp.). We did find a few red tree corals growing at depths of 398 m but no thicket habitat. We found new red tree coral thickets on the four ROV dives made on the shelf habitats. These were newly explored areas, not within the four existing HAPCs at this site, so will provide valuable data for consideration should the existing boundaries of the HAPC be re-evaluated by the NPFMC in the future.

A single ROV dive at Site 5 (Edgecumbe Pinnacle) in 2015 explored a volcanic cone (183–153 m depth) discovered in the early 1990s with the submersible Delta during ADF&G groundfish stock assessment surveys. The volcanic feature is located off the SW end of Kruzof Island at 57° 05.621' N, 136° 07.356' W. We video documented the geological and biological features of the cone by conducting a transect from the base of the feature to the summit. First, we circumvented the feature in a counterclockwise fashion beginning on the eastern side until we encountered a debris field containing shells of the giant barnacle (*Chirona evermanni*) where they were collected. The calcareous plates or "mouthparts" of the barnacles, the terga and scuta, will be aged and used as a proxy to reconstruct the volcanic timeline of the feature. Additionally, scattered red tree corals were found on pillow basalt from the bottom to the top of the cone.

Funding: DSCRTP funds ($324,352) were used in FY2012 to support the multi-beam mapping contract. DSCRTP funds ($498,500) were used in FY2013 to support the ROV and vessel charter, the RV *Medeia* charter, and other project costs. DSCRTP funds ($455,666) were used in FY2014 and FY2015 to support the ROV and vessel charter and other project costs. Additionally, the AFSC provided supplemental funding ($231,717) in FY2015 to make this project whole. Travel, salary and benefits costs for the principal investigators and all science team members were in-kind contributions by their supporting agencies.

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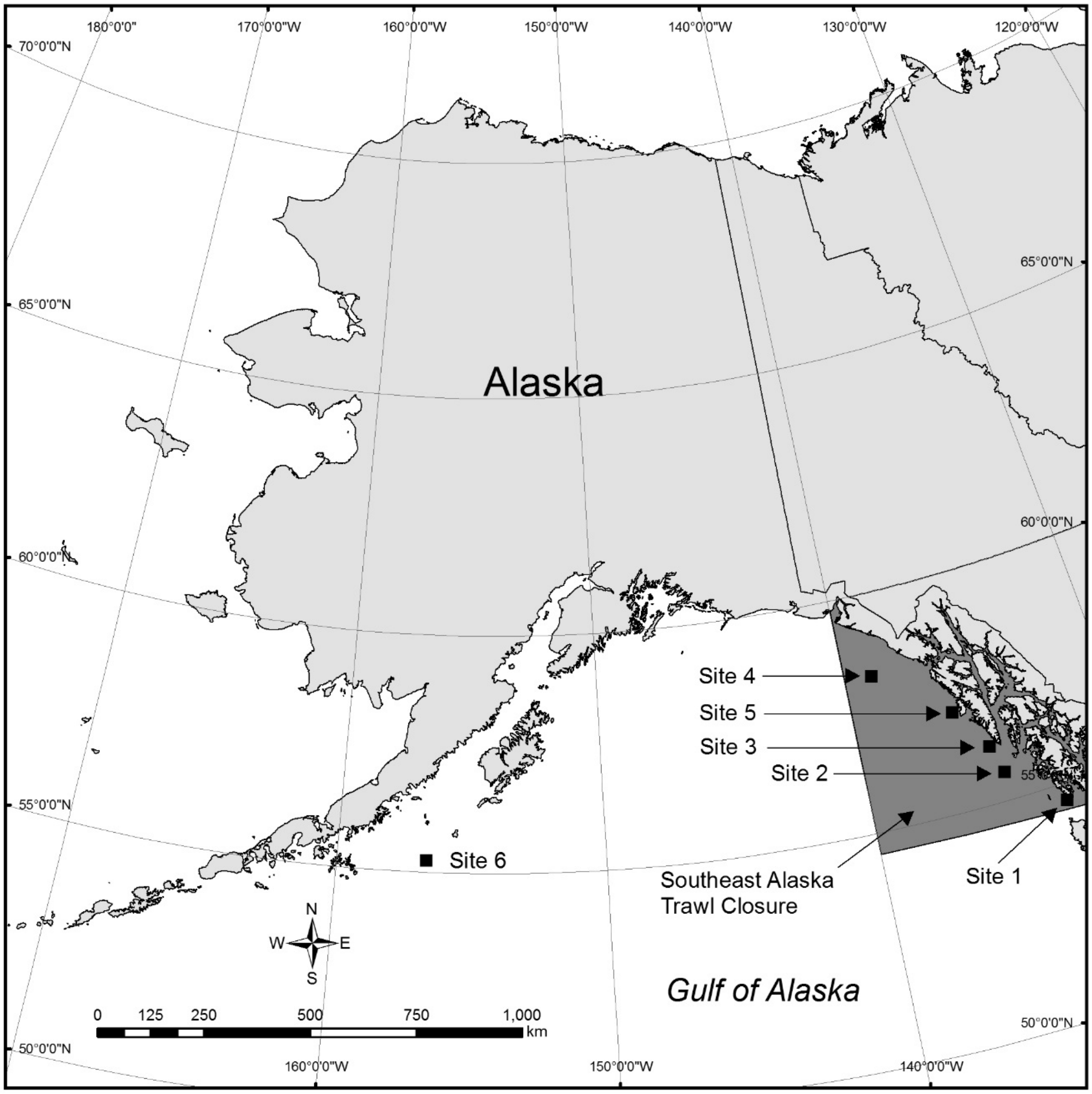

Figure 2. Map of Alaska showing the six study sites. Sites 1–5 (Dixon Entrance, Prince of Wales, Shutter Ridge, Fairweather Ground and Edgecumbe Pinnacle) were surveyed with remotely operated vehicles in the eastern Gulf of Alaska in 2013 and 2015. Site 6 (Chirikof) was not surveyed using remotely operated vehicles.

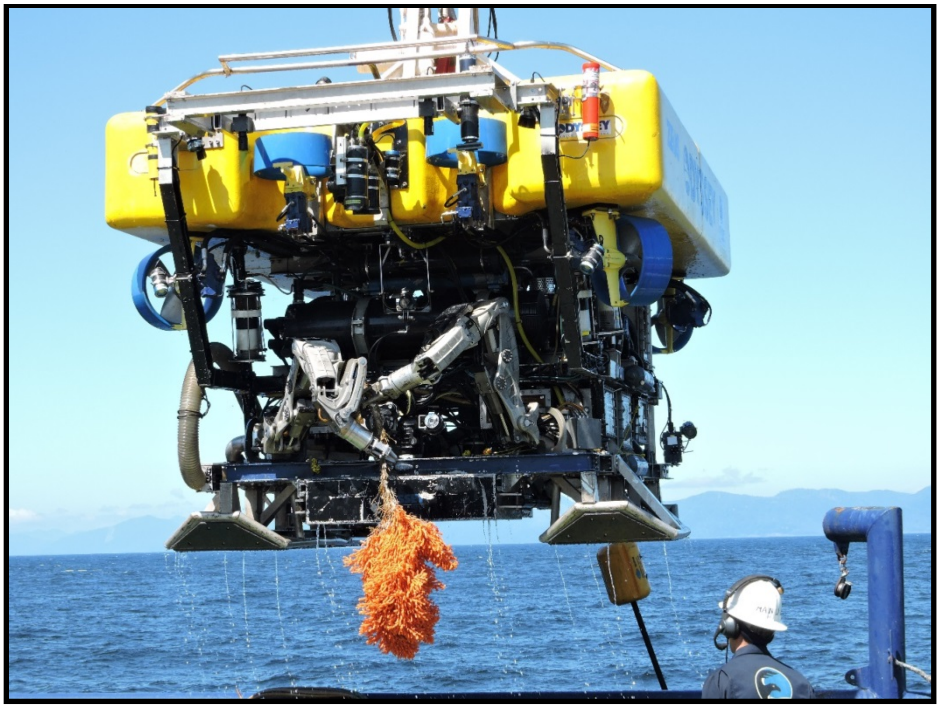

Figure 3. The ROV Zeus II, used during the 2015 expedition, is recovered after a dive at the Fairweather Ground (Site 4) where it collected a large red tree coral colony for age and paleo-climatological analyses.

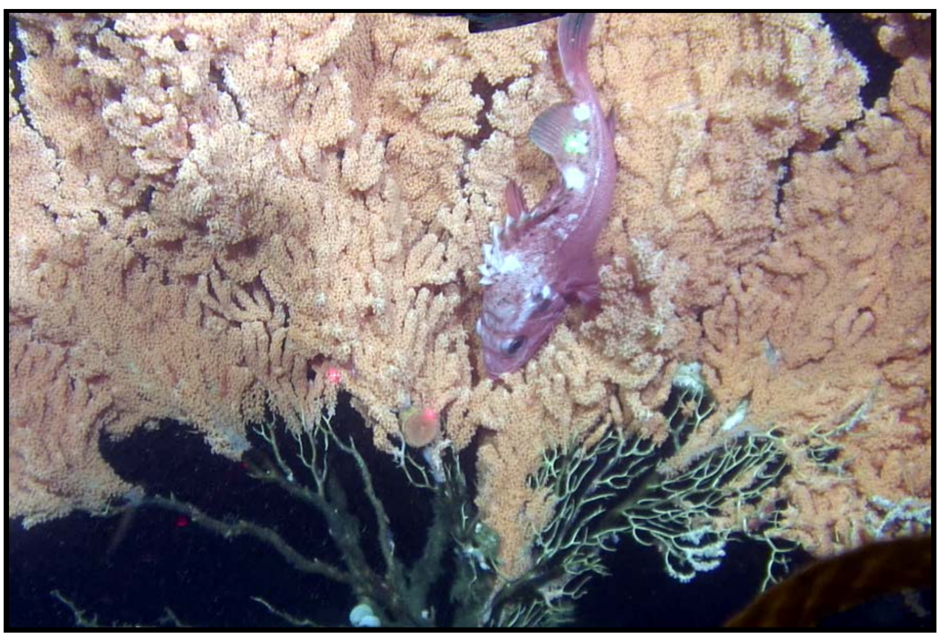

Figure 4. A large rougheye rockfish (Sebastes aleutianus) in a red tree coral colony at a depth of 347 m in the Dixon Entrance basin (Site 1). The coral is attached to a large glacial drop-stone and is being preyed upon by calliostomatid snails (Otukaia sp.).

Figure 5. Longline damage to a large red tree coral at a depth of 193 m at the Shutter Ridge (Site 3).

Figure 6. Redbanded rockfish (Sebastes babcocki) are common residents in red tree coral thickets, this one at 207 m at the Shutter Ridge (Site 3). The large glass sponge (Farrea occa) is also common in red tree coral thickets and grow to more than 3 m in diameter.

2.2. Mapping and modeling coral and sponge distribution in the Aleutian Islands site

Background and Objectives: Effective management of deep coral and sponge ecosystems in Alaska requires knowledge of where these organisms occur and patterns in diversity and abundance. Because of the size of Alaska's marine environment it is not possible to assess the distribution of coral and sponge at every location in Alaska, so a systematic and statistically rigorous methodology was necessary to determine likely coral and sponge habitat throughout Alaska. Spatial distribution models based on bottom trawl survey were developed for all regions of Alaska where coral are known to occur (Rooper et al. 2014, Sigler et al. 2015, Rooper et al. in review, see section 3.3), however, testing of the modeled distribution was necessary to see if bottom trawl catches truly were able to capture the distribution of corals and sponges in Alaska. The objectives of this fieldwork were to collect density and size estimates for corals and sponges at randomly selected sites in the Aleutian Islands and document species associations with fish and invertebrates.

Approach: We used a survey design that was depth stratified and incorporated randomly selected stations in the Aleutian Islands from Unimak Pass to Stalemate Bank (and including Bowers Ridge and Bank). Depths ranged from ~30 to ~900 m. At each station we deployed a stereo camera system and collected 15 minutes of on bottom imagery. Images were analyzed by identifying and measuring (using stereoscopy) benthic invertebrates and fishes. Substrate type was also recorded.

Significant Results to Date: The groundtruthing observations supported the bottom trawl survey models for corals, accurately predicting presence or absence in ~80% of cases (AUC ~ 0.59-0.81). Predicted and observed coral densities were significantly correlated in all cases ($p < 0.001$), however, the proportion of variance explained was relatively minor (17-30%). For sponges, the groundtruthing data provided less support for the modeling, with only about 55% of the observations predicted accurately (AUC = 0.59). Sponges were observed at 178 of 216 camera stations, corals (including hydrocorals and octocorals) were observed at 139 stations and pennatulaceans (sea whips and pens) were observed at 81 stations. Observed sponge densities were significantly correlated with predicted sponge densities ($p = 0.001$) however. This was an interesting result in that sponges were observed at 82% of camera stations, a higher number than the bottom trawl survey data used in the modeling (Rooper et al. 2014). The model used only "upright" sponge morphologies estimated from trawl catches, while all morphologies were counted from the image data. This may account for both the higher prevalence of sponge in the image data and the relatively poor fit for the observations versus models (Rooper et al. in review).

Corals from the family Primnoidae dominated the species observed in the Aleutians, and these corals were found in high densities roughly from Seguam Pass to Tahoma Reef (Figure 7). Sponges were widely distributed in high densities across the region, while sea pens and sea whips were not as dense as other benthic invertebrates (Wilborn et al. in review). Mean height across all taxa was between 20 and 40 cm, except sea whips (Figure 8). Corals were observed almost exclusively on hard-bottom substrates (Figure 9)

Funding: DSCRTP funds ($192,783) were used in FY2012 to support a 12 day vessel charter in the Aleutian Islands and other project costs. DSCRTP funds ($163,072) were used in FY2013 to support a 12 day vessel charter in the Aleutian Islands and other project costs. DSCRTP funds ($205,697) were used in FY2014 to support a 14 day vessel charter in the Aleutian Islands and other project costs. Travel, salary and benefits for science team members were contributed by the AFSC.

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Site Characterization Report: http://www.afsc.noaa.gov/techmemos/nmfs-afsc-313.htm

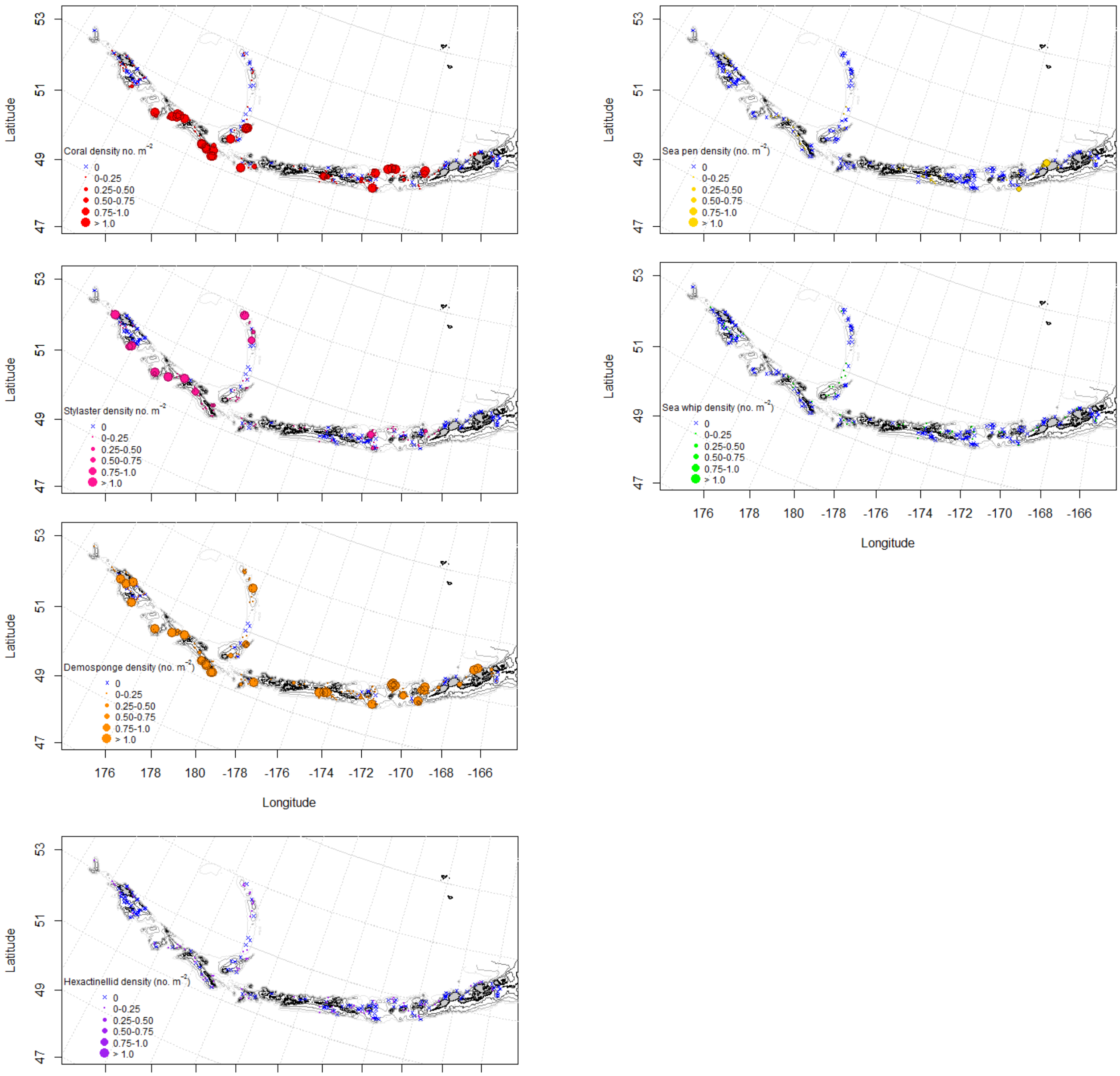

Figure 7. Densities of various benthic invertebrates from the towed camera fieldwork conducted in the Aleutian Islands in 2012 and 2014.

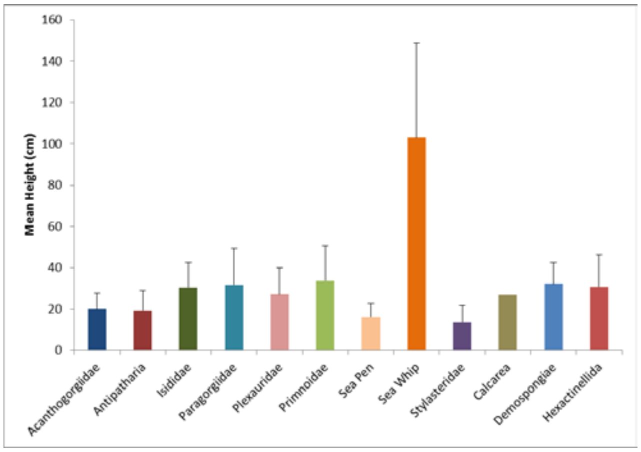

Figure 8. Mean height (and standard error) of coral and sponge observed in the Aleutian Islands.

Figure 9. Example images from the Aleutian Islands.

2.3 Productivity of FMP species in coral and sponge habitats in the Alaska region.

Background and Objectives: Associations of rockfish and other species with coral and sponge communities is well established in Alaska (Heifetz et al. 2002, Malecha et al. 2005, Rooper and Boldt 2005, Rooper et al. 2007, Stone 2014, Laman et al. 2015). The contribution of coral and sponge habitat to fish productivity as compared to other non-biotic complex structure (e.g., boulders) for the productivity of rockfish and other FMP species remains unknown. These complex habitats likely provide enhanced food resources, protection from predators, and a refuge from strong ocean currents. The vulnerability of these habitats to fishing gear (Heifetz et al. 2009, Stone 2014) is of concern and further emphasizes the need to better understand these ecosystems. The overarching goal of this study is to examine the productivity of FMP species within coral and sponge habitats in the Gulf of Alaska.

Approach: Two areas within the central Gulf of Alaska were sampled during three seasons (Figure 10). During each sampling cruise a variety of platforms were used to collect physical and biological data from coral, boulder, and bare habitats. A comparative approach was used to examine differences in community structure, diet, prey availability, energetic content, growth, and reproductive productivity of FMP species within these habitats.

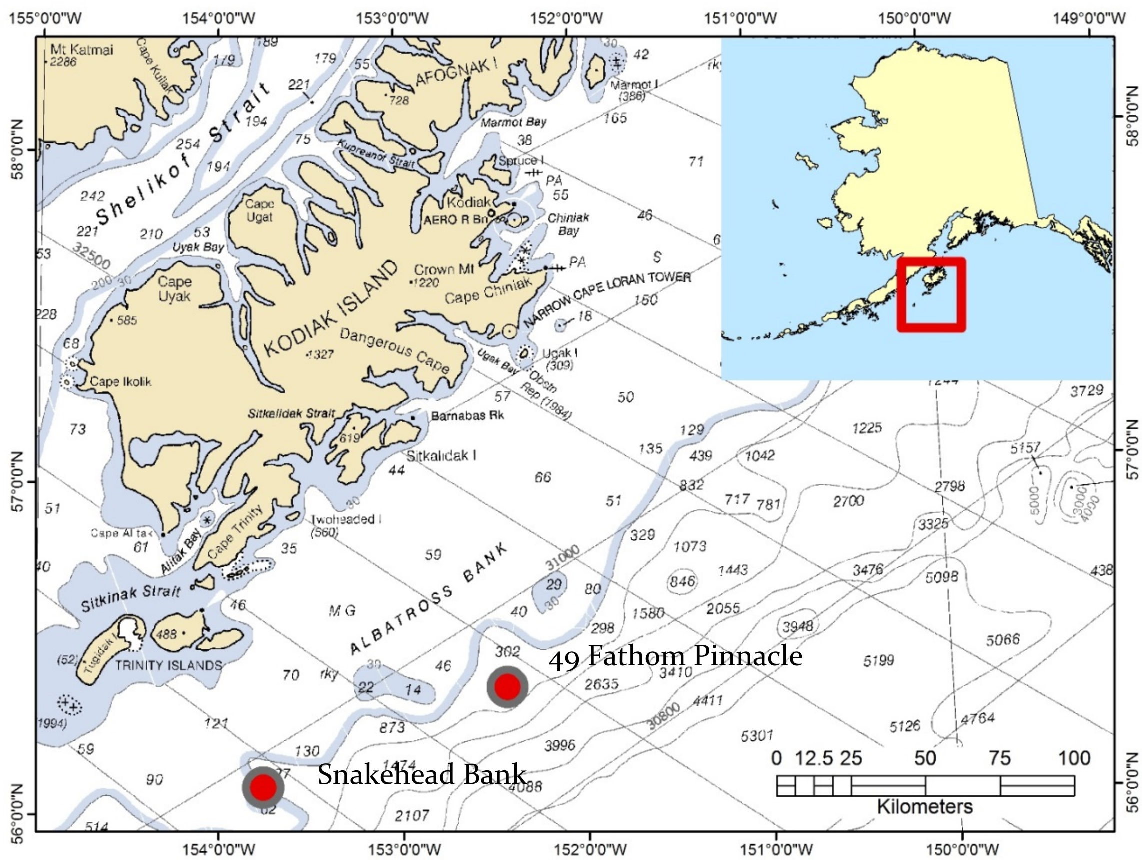

Figure 10. Location of study sites for FMP production study in the Gulf of Alaska.

Significant Results to Date: Preliminary results indicate that the coral habitat at the 49 Fathom Pinnacle site was dominated by *Stylaster* hydrocorals. Hexactinellid sponges were also frequently observed. In contrast, preliminary results indicate the coral habitat at the Snakehead site was dominated by the gorgonian corals, including *Fanellia frasieri, Plumarella* spp. and Plexauridae. Densities of gorgonian corals and sponges from the coral present sites averaged 0.050 and 0.052 colonies*m^{-2} respectively. Preliminary CPUE estimates of rockfish density from the SDC video drops indicate significant differences in rockfish density among habitats, with highest densities in the boulder and coral habitats at both sampling sites.

Trawl catches at the 49 Fathom Pinnacle site consisted predominately of adult dusky and northern rockfish throughout this sampling area though Pacific ocean perch (POP) occur along the deeper edges of this site. Preliminary data from the second sampling site (Snakehead) indicate that this area has a much higher abundance of small rockfish including juvenile POP, juvenile northern rockfish, juvenile redstripe rockfish, and juvenile and small adult species including harlequin and pygmy rockfish.

Preliminary energetic and reproductive results of dusky and northern rockfish reveal differences in productivity of these species across the three habitats. In the low relief habitat, energy content was the highest in the winter for both northern and dusky rockfish, while in the high relief coral habitat, the energy content in the winter for the same species was the lowest. Energy content of all three species in the high relief rocky/boulder and high relief coral/sponge habitats were similar, with the northern rockfish having the higher energy content of the two species in both habitats. Differences in the gonadosomatic index and relative fecundity varied between the two sampling sites and the three habitats within each sampling site with the highest productivity measures occurring in the coral habitat for both northern and dusky rockfish (Figure 11). A portion of both dusky and northern rockfish sampled for this project had evidence of partial or total reproductive failure due to either skip spawning or fertilization failure. Reproductive failure was consistent across habitats for northern rockfish but for dusky rockfish was lower in coral habitats (Figure 11).

Funding: In FY12, $150,340 in DSCRTP funds were used to support vessel charters, sample processing contracts and other project costs. In FY13 funding was received from both the DSCRTP ($116,020) and a successful proposal to the AFSC Habitat and Ecological Processes Research Program (HEPR; $31,800) to support fieldwork. In FY14 only $38,180 was received from the DSCRTP to support sample processing for this project. Additional fieldwork on this project in FY13 and FY14 was supported by a funded proposal to the North Pacific Research Board ($272,321). Travel, salary and benefits for science team members were contributed by the AFSC.

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Site characterization report: Available at https://www.afsc.noaa.gov/Publications/ProcRpt/PR2017-06.pdf.

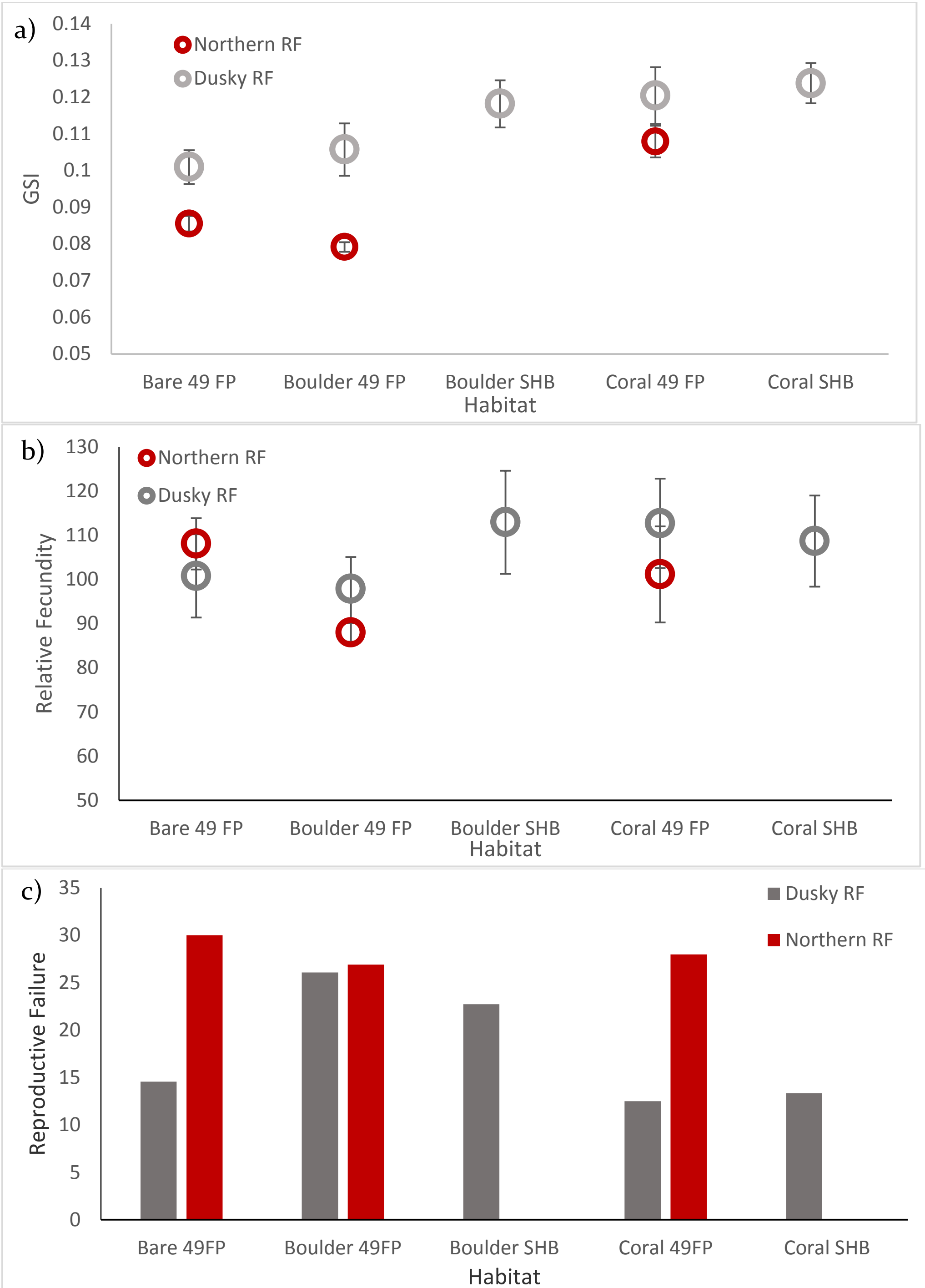

Figure 11. Preliminary reproductive productivity of northern and dusky rockfish during the month of May 2014, measured as a) gonadosomatic index, b) relative fecundity, and c) reproductive failure, separated by habitat and site. 49 FP = the 49 Fathom Pinnacle site, and SHB = the Snakehead Bank site.

3. Associated studies

In addition to the three major field research projects, a number of other studies were undertaken during the Alaska Coral and Sponge Initiative. Some of these projects involved fieldwork or field collection of data, but these projects were piggy-backed onto existing cruises or existing activities at the Alaska Fisheries Science Center.

3.1. Recruitment of red tree coral (*Primnoa pacifica*) in thicket habitats in the eastern Gulf of Alaska

Background and Objectives: Recruitment of sedentary fauna is a critical component of seafloor habitat recovery. Very little is known about the mechanisms and periodicity of recruitment by corals but observations in the Gulf of Alaska indicate that it is episodic and occurs infrequently (Stone et al. 2014, Stone et al. 2017). Understanding the dynamics and habitat requirements of coral recruitment will provide important information for the management of fisheries habitat. The objectives of this study were to determine the periodicity of recruitment for red tree corals and examine the dynamics of larval dispersal.

Approach: In August 2013 we chartered the Alaska Department of Fish & Game (ADF&G) RV *Medeia* to place four settlement arrays on the seafloor in two areas of high red tree coral abundance (Site 3 - Shutter Ridge, and Site 4 - Fairweather Ground). Arrays were slowly lowered to the seafloor with an oceanographic winch. The exact position and depth of each array deployment was recorded. The deployment array consisted of an Ixsea Oceano shallow water acoustic release system and a stereo camera system. Each array measured 100 cm X 100 cm X 5 cm and consisted of four blocks of the same type of rock found at the study sites (granodiorite, greenstone, and greywacke). Each array had a stainless-steel lifting point and a location marker consisting of a 3-m polypropylene line attached to a small trawl float. A Star-Oddi DST centi-T recorder was attached to each polypropylene line and programmed to record temperature and depth every six hours for the life of the deployment (up to 4 years).

In June 2015 we charted the RV *Dorado* and using the ROV *Zeus* retrieved two settlement arrays at Site 4 and one array at Site 3 (Figure 12). We additionally located but did not retrieve a second array at Site 3 and collected detailed video footage of the array. Before each retrieval we video-documented each array and the surrounding habitat (Figure 13). Samples were collected from each adult coral colony (> 40-cm height) within a 10-m radius of each array. From each sample we will examine genetics, gender, and reproductive parameters. On deck, all organisms that recruited to the blocks were collected. The blocks were thoroughly cleaned, temperature recorders were replaced, and the arrays were then redeployed with the ROV in the same approximate location and in immediate proximity to adult coral colonies (Figure 14).

In the laboratory, recruited organisms were examined with a stereo microscope (Leica S8 APo) and photographed with a Moticam 5 camera attachment used to grab images (Figure 15). The length of each recruit was determined from each photograph. Samples from each recruit were collected for genetics to determine if nearby adults are potentially the parents of the recruits, thereby providing us with important larval dispersal distance information.

Significant Results to Date: Three settling arrays were retrieved at two study sites (one at Site 3 and two at Site 4) in June 2015 using the ROV *Zeus*. Despite the fact that the three sampling arrays had been deployed for about 22 months and in close proximity to large, mature red tree coral colonies we found no new red tree coral recruits. We observed several known predators of red tree corals (Stone et al. 2014) on and near the settling plates so it is possible that predation is a major limiting factor to recruitment as previously noted for the Atlantic congener of *P. pacifica* in the Atlantic (Lacharité and Metaxas 2013). The settling array retrieved at Site 3 did however have numerous small recruits of the holaxonian *Calcigorgia spiculifera* on both the settling blocks and the marker buoy line (Figure 15). This was surprising since we observed no potential parent colonies in the immediate area of the settling plates, although *C. spiculifera* is locally abundant further upslope on the rocky pinnacles that form the ridge. The settling arrays were cleaned and redeployed in the same general areas with the intent to retrieve all arrays during the next opportunity.

The three temperature probes retrieved at the two study sites provided valuable data on the current thermal regime experienced by red tree corals. Of particular relevance was the high temperatures (10°C) experienced by corals during November 2014; temperatures known to be well within the lethal range for red tree corals held in the laboratory (R. Stone, unpublished data). The annual mean temperature at a depth of 197 m (Site 3) was 0.36°C warmer in 2014 (6.23°C) than in 2013 (5.87°C) and the annual mean temperature at a depth of 143 m (Site 4) was 0.90°C warmer in 2014 (7.33°C) than in 2013 (6.43°C). These observations indicate that the "warm blob" experienced in the North Pacific Ocean in 2014-2015 reached to depths occupied by red tree corals, possibly putting them under severe thermal stress.

Funding: Deployment of the settlement arrays in 2013 from the ADF&G RV *Medeia* and recovery of two arrays in 2015 with the ROV *Zeus* were supported with DSCRTP (Alaska 3-year Initiative) funds as part of Project 1. DSCRTP (Alaska 3-year Initiative) funds ($5,000) were used in FY2012 for the construction and purchase of supplies and materials for the settlement arrays and oceanographic equipment.

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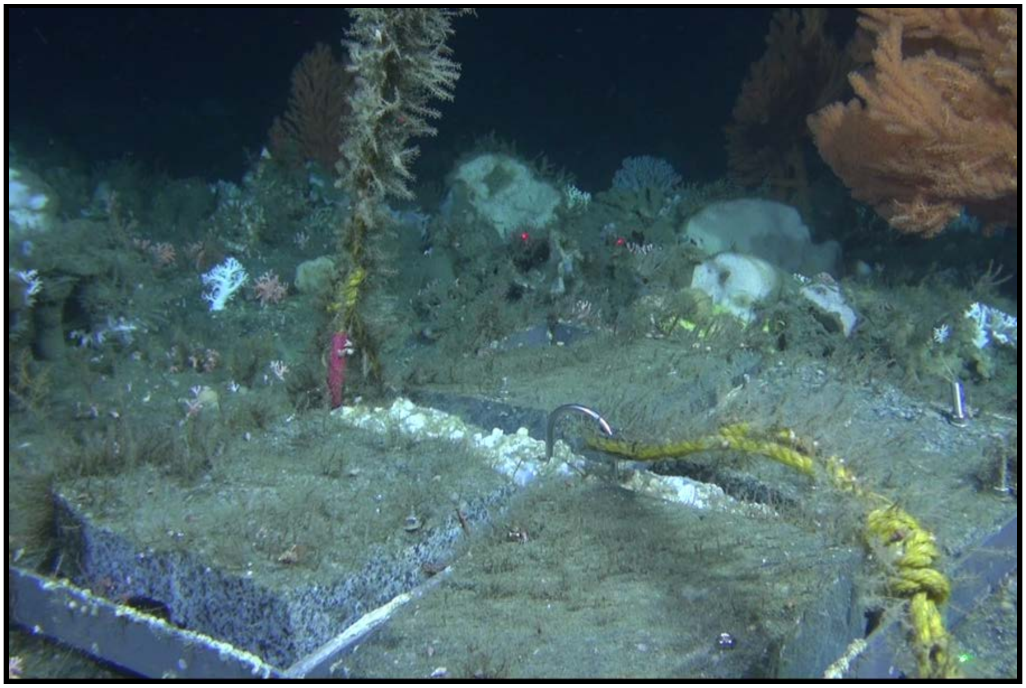

Figure 12. Retrieval of array # 8 at Site 4 (Fairweather Ground) at a depth of 140 m.

Figure 13. Retrieval of array # 8 at Site 4 (Fairweather Ground) showing heavy growth of hydroids after a 22-month deployment.

Figure 14. Re-deployment of array #5 at Site # 4 (Fairweather Ground) at a depth of 143 m.

Figure 15. A new recruit (2-polyp stage) Calcigorgia spiculifera collected on one of the settling arrays at Site 3 (Shutter Ridge) in June 2015.

3.2 Reproductive ecology of red tree coral (*Primnoa pacifica*) in thicket habitats in the eastern Gulf of Alaska

Background and Objectives: Understanding the reproductive ecology of red tree corals, the largest and often most abundant coral species in the northeast Pacific Ocean, is important to help gauge how this species and other cold-water corals may respond to disturbance and their capability to recover from seafloor perturbation. Studies of this kind are very difficult to conduct given the remote and deep-water environments that most corals inhabit and the large number of samples necessary. Fortunately we had year-round access to an emerged population or red tree corals in Tracy Arm, Holkham Bay, Southeast Alaska. We conducted a study there on reproductive ecology (e.g., reproductive mode, seasonality and fecundity) of red tree corals with the intent to use the information as a proxy for the deep-water populations that are subjected periodically to fishing disturbance (Waller et al. 2014).

Females within the population developed asynchronously, although males showed trends of synchronicity, with production of immature spermatocysts heightened in December/January and maturation of gametes in the fall months. Seasonality of individuals varied from a single year reproductive event to more than the 16 months and multiple stages of gametes occurred in polyps of the same colony during most sampling periods. Mean oocyte size ranged from 50 to 200 μm in any season and maximum oocyte size (802 μm) suggest a lecithotrophic larvae. No brooding larvae were found during the study, although unfertilized oocytes were found adhered to the outside of polyps, where they are presumably fertilized. This species has size-dependent reproduction, with gametes first forming in colonies over 42-cm in height (an approximate age of 23 years), and steady oocyte sizes being achieved after reaching 80-cm in length. The average fecundity of this species is 86 (±12) total oocytes per polyp, and 17 (±12) potential per polyp fecundity. Sub-lethal injury by removing 21–40% of colony tissue had no significant reproductive response in males or females over the course of this study, except for a corresponding loss in overall colony fecundity. The reproductive patterns and long gamete generation times observed indicate that recruitment events are likely to be highly sporadic increasing its vulnerability to anthropogenic disturbances.

Approach: Sub-samples of red tree corals were collected at Study Sites 1, 3, and 4 with the goal of sampling at least 15 female and male colonies at each site. Samples were used to determine the gender, fecundity (females only) and stage of development for both male and female colonies. These data will be used to validate the recent findings from the shallow-water population in Tracy Arm regarding seasonality, reproductive schedule, and the relationships of environmental variables with development and colony size with fecundity. Data on the reproductive timing and larval dynamics, especially the mode of larval dispersal, of deep-water octocorals fills a major void in our knowledge of the relationships among the major anthozoan groups.

Significant Results to Date: All samples collected from the three study sites in the Gulf of Alaska have been processed in the laboratory and examination of processed samples for reproductive parameters is underway. At Site 1, 16 females and 7 males have been examined. At Site 3, 20 females and 23 males have been examined. And at Site 4, 13 females and 9 males have been examined. Additional samples at Sites 1 and 4 are being examined so that we have a minimum sample size consisting of 15 colonies of each gender.

Preliminary observations indicate that the deep-water populations have similar reproductive strategies (i.e. gonochorism and multiple developing cohorts of oocytes) to the shallow-water population. The deep-water populations, however, appear to have greatly reduced fecundity as is often observed in populations of the same species residing in deeper water. We will also compare all reproductive parameters between sites that will allow us to determine differences associated with latitude and depth.

Funding: Collection of the samples was supported with DSCRTP (Alaska 3-year Initiative) funds as part of Project 1 in 2013 and 2015. Funding for field work assistance and laboratory analyses by the University of Maine was provided by the AFSC ($60,326) through a successful proposal to the HEPR program.

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3.3 Food-web ecology and trophic ecology of red tree corals (*Primnoa pacifica*) in the eastern Gulf of Alaska

Background and Objectives: In general, the deep sea is a food-limited environment because only a small percentage of organic carbon produced in surface waters settles to the seafloor. In contrast, relative to more quiescent slope environments, deep-sea corals such as the red tree coral (*P. pacifica*), often occur in environments that experience dynamic current flow and turbulence that influence the supply and quality of organic matter to these habitats and enhancing trophic complexity (Cartes and Sorbe 1999). Stable isotope analysis (SIA) is a useful method for discerning complex food webs, particularly in remote environments where red tree corals occur. Stable carbon isotopes ($\delta^{13}C$) closely reflect a consumer's food source (Peterson and Fry 1987), while stable nitrogen isotopes have been used to estimate trophic level, because $\delta^{15}N$ values typically increase 2–5 ‰ with each trophic level (Minagawa and Wada 1984, Post 2002, McCutchan et al. 2003). Primary producers exhibit distinct isotopic compositions due to the types of nutrients fixed and the associated photosynthetic pathways (Peterson and Fry 1987) and isotopes integrate over an extended time frame, recording the assimilated diet of the consumer of long time scales. SIA have been used to understand transfer of carbon through systems, including tracing its vertical transport from the sea surface to the seafloor. In addition, SIA can help estimate food-chain length, trophic level, providing temporally and spatially integrated trophic estimates used to understand and define trophic linkages among species and communities (Davenport and Bax 2002, Harvey et al. 2002). Our objective was to use stable carbon and nitrogen isotope analysis to discern primary carbon sources and estimate the trophic level for suspension feeding red tree corals.

Approach: Sub-samples of red tree corals collected in 2013 and 2015 with ROVs for the genetics and reproduction studies were used to study food-web dynamics and trophic ecology. Stable carbon and nitrogen isotope analysis was used to track the trophic transfer of energy from the primary producers to the corals which reside at intermediate trophic levels. These data will allow us to track changes in upstream nutrient conditions and productivity through examining the corals occurring downstream (deep sea) fueled by raining surface production on a regional level. We will also perform compound specific stable isotope analysis to further define and identify the food resources for these corals and whether they feed on primary producers that may be affected by ocean acidification.

Significant Results to Date: Red tree coral tissue and associated water samples were collected from three study sites (Site 1 – Dixon Entrance, Site 3 – Shutter Ridge, and Site 4 – Fairweather Ground). Estimated trophic levels for all coral samples at Site 3 (2013) are approximately 1.5 to 3 trophic levels above the measured particulate organic matter (POM) suggesting potential mixotrophy (i.e. both autotrophic and heterotrophic; Figure 16). These data indicate that the corals could be consuming both POM and zooplankton, which in general is consistent with the published literature. Interestingly, the POM collected in water samples directly above the corals was well depleted in ^{13}C relative to the corals, so it is also possible that there is some seasonality in the POM source, which can lead to isotopic differences between present POM and past (what the corals consumed).

Funding: Collection of the samples was supported with DSCRTP (Alaska 3-year Initiative) funds as part of Project 1 in 2013 and 2015. Salary and benefits costs of the principal investigator (A. Demopoulos) and laboratory support were an in-kind contribution by the USGS (Wetland & Aquatic Research Center).

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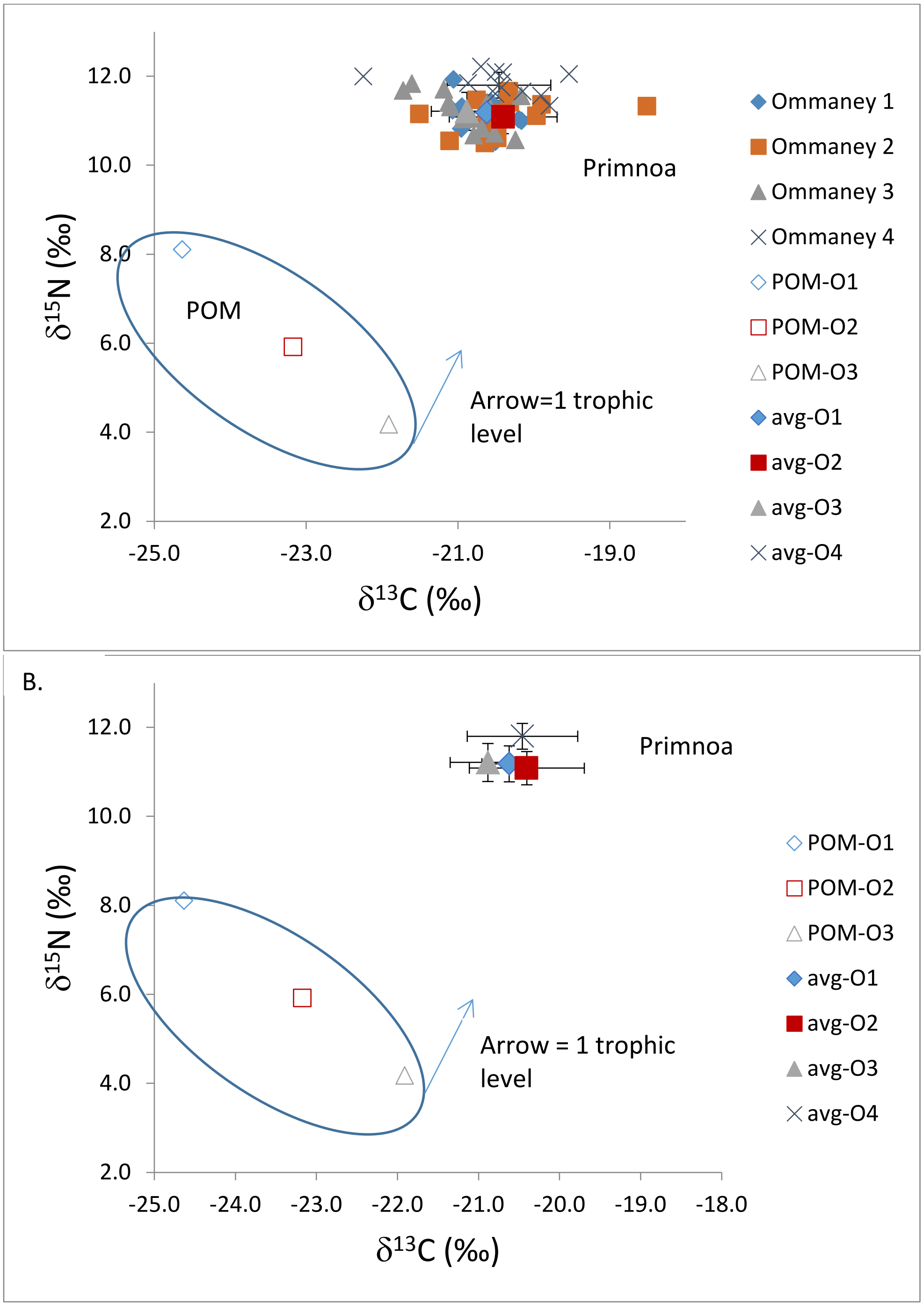

Figure 16. Relationship of δ^{13}N and δ^{13}C raw data (A) and average values (B) for red tree corals collected at Site 3 (Shutter Ridge) in the eastern Gulf of Alaska in 2013 and the particulate organic matter (POM) collected at the same collection sites. O1-O4 are coral tissue samples and POM01-POM03 are the POM samples. The estimated trophic level arrow indicates that all coral samples are approximately 1.5 to 3 trophic levels above the measured POM.

3.4. Geological substrate mapping and bathymetry and sediment compilations

Background and Objectives: Five disparate sites in The Gulf of Alaska were selected for the assessment of sponge and corals in regard to substrate types. These sites were located near Chirikof Island, on Fairweather Ground, on Shutter Ridge, near Prince of Wales Island, and near Dixon Entrance (Figure 2). One of the primary informational tools for identifying potential locations of deep-sea coral and sponge ecosystems is seafloor substrate maps. In some parts of Alaska and in other regions these maps have been constructed using newly available multibeam echosounder (MBES) backscatter and bathymetry, as well as NOS bathymetry and sediment data from historical charting activities. The objective of this phase of work was to interpret the geology from the MBES data and select the most promising hard substrate locations for observation and sampling of deep-sea coral and sponges.

A second objective of this project was to fund research to acquire existing bathymetry and sediment data available from NOS smooth sheets, digitize, correct the spatial projections and compile these into contiguous maps of the seafloor for the central Gulf of Alaska and Aleutian Islands.

Approach: Using habitat maps constructed for the Alaska Department of Fish and Game for Albatross Bank, Portlock Bank, Fairweather Ground, Cape Ommaney, Cape Felix, and Learmonth Bank extended the substrate types from these sites into the five sites selected for sampling based on backscatter and bathymetry of newly collected and previously uninterpreted MBES and NOAA compiled data sets. Hard substrate locations at each of the five sites were selected for examination and sampling using a remotely operated vehicle (ROV).

The approach for bathymetry and sediment data compilation is outlined in Zimmermann and Benson (2013). Briefly, existing charting data was downloaded from NGDS and other sources. Data were digitized and overlapping bathymetries hand checked for errors and agreement. Data were compiled to a common projection. The sediment data was compiled using the same approach.

Significant Results to Date:

Interpretation of newly collected MBES and compiled NOAA data sets provided targets for ROV dives in locations where hard or mixed soft over hard substrate appeared to be present. Several locations were picked at each of the five sites as explained below:
Chirikof – five locations where hard or mixed substrate appeared to be present were selected and consist of possible bedrock or hard mud bottom in interfluve (ridges separating slope gullies, "1" in Figure 17) and boulders associated with drop stones at the front of a former ice front ("2" in Figure 17). This site is located seaward of a past glacial front and contains extensive glacial sediment. **Fairweather Ground** – six locations where hard substrate appeared to be present, four in locations where high relief, rugged bedrock crops out on the continental shelf floor and along the ridge of an interflu on the continental slope ("1" in Figure 18), and two along the upper walls of submarine canyons or gullies ("2" in Figure 18) on the upper continental slope. This site is not glaciated but consists of local areas of glacial deposition. **Cape Ommaney** – two potential hard substrate locations were selected for sampling and are denoted in dark green polygons along the western edge of Figure 19, a potential marine benthic habitat map. The primary site known as "Shutter Ridge" consist of hard fractured and jointed plutonic (granite) basement rock outcrop on the continental shelf and shown as a N-S elongated green polygon along the SW edge of Figure 19.

This is an area that has been locally affected by glaciation. **Prince of Wales** – eight potential hard to soft to hard substrate locations were selected for sampling and consist of possibly five hard bedrock outcrops in gully walls and a fault scarp on the upper continental slope and mixed soft covered isolated large boulders or bedrock outcrops on the continental shelf ("1" in Figure 20). Two linear subtle scarps with rugged (possibly boulders) relief near the distal edge of the continental shelf and one isolated boulder or sediment covered bedrock outcrop ("2" in Figure 20) were selected for sampling. This is a heavily glaciated area with moraines and an extensive drop stone field. **Dixon Entrance** – seven locations that appear to consist of hard or soft over hard substrate were selected for sampling. Two locations where hard substrate appears to be present along a fault scarp and rock outcrops or large boulders exist in high relief on the continental shelf were selected for sampling ("1" in Figure 21). Three locations consisting of soft over hard substrate types, one in a small boulder field on the continental shelf and two on the upper slope were selected for sampling ("2" in Figure 21). Two other locations were selected in deeper water and consist of poorly defined relatively high relief features ("3" in Figure 21) in a generally subtle hummocky to flat seafloor. The site represents a glaciated area on the continental shelf with extensive deposition of glacial material over the continental slope.

Funding from the DSCRTP partially supported the efforts of AFSC scientists as they proofed, corrected, and digitized 1.75 million lead-line and single-beam echosounder soundings from 225 National Ocean Service (NOS) hydrographic surveys represented as smooth sheets in the central Gulf of Alaska. This bathymetry compilation ranged geographically from the Trinity Islands in the west to Cape Ommaney in the east, covering an arc of about 1,400 km of shelf. The bathymetry maps were compiled for an area of the central Gulf of Alaska near Prince William Sound. In the Aleutian Islands, AFSC scientists also digitized 25,000 verbal surficial sediment descriptions from 234 of the smooth sheets, providing the largest single source of sediment information. Scientists from the USGS proofed and digitized ~117K verbal surficial sediment descriptions from the 225 NOS hydrographic surveys represented as smooth sheets in the central Gulf of Alaska (Golden et al. 2016). These bathymetry and sediment layers were a critical data set for coral and sponge distribution modeling (Rooper et al. in review).

Funding: Geological substrate verification for this project was completed during the Primnoa thickets study in the eastern Gulf of Alaska. Grants and contracts to UAF and UC Davis for geological substrate interpretation, fieldwork and coordination ($91,355) were funded in FY12-14. Funding to support technicians for sediment and bathymetry compilation ($67,160) was also used in FY12-14.

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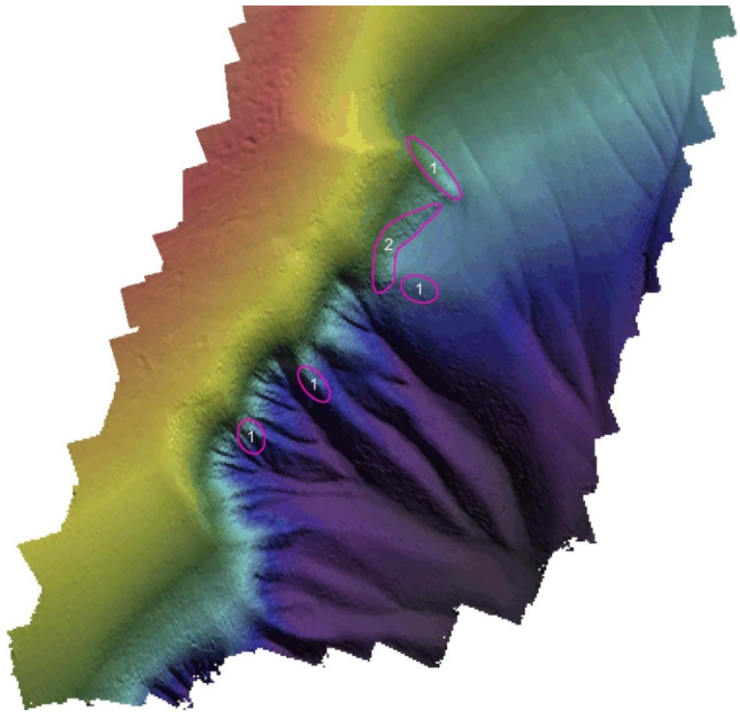

Figure 17. Multibeam bathymetric images of the Chirikof dive site selected for ROV examination and sampling of deep-water corals and sponges. Red outlines indicate interesting geological features identified for further exploration with underwater cameras or remote operated vehicles.

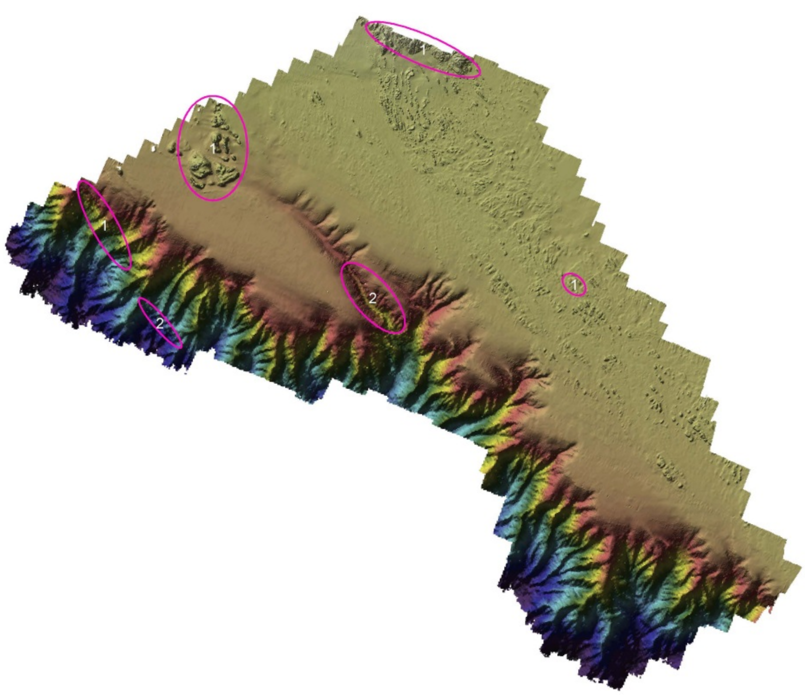

Figure 18. Multibeam bathymetric images of the Fairweather Ground dive site selected for ROV examination and sampling of deep-water corals and sponges. Red outlines indicate interesting geological features identified for further exploration with underwater cameras or remote operated vehicles.

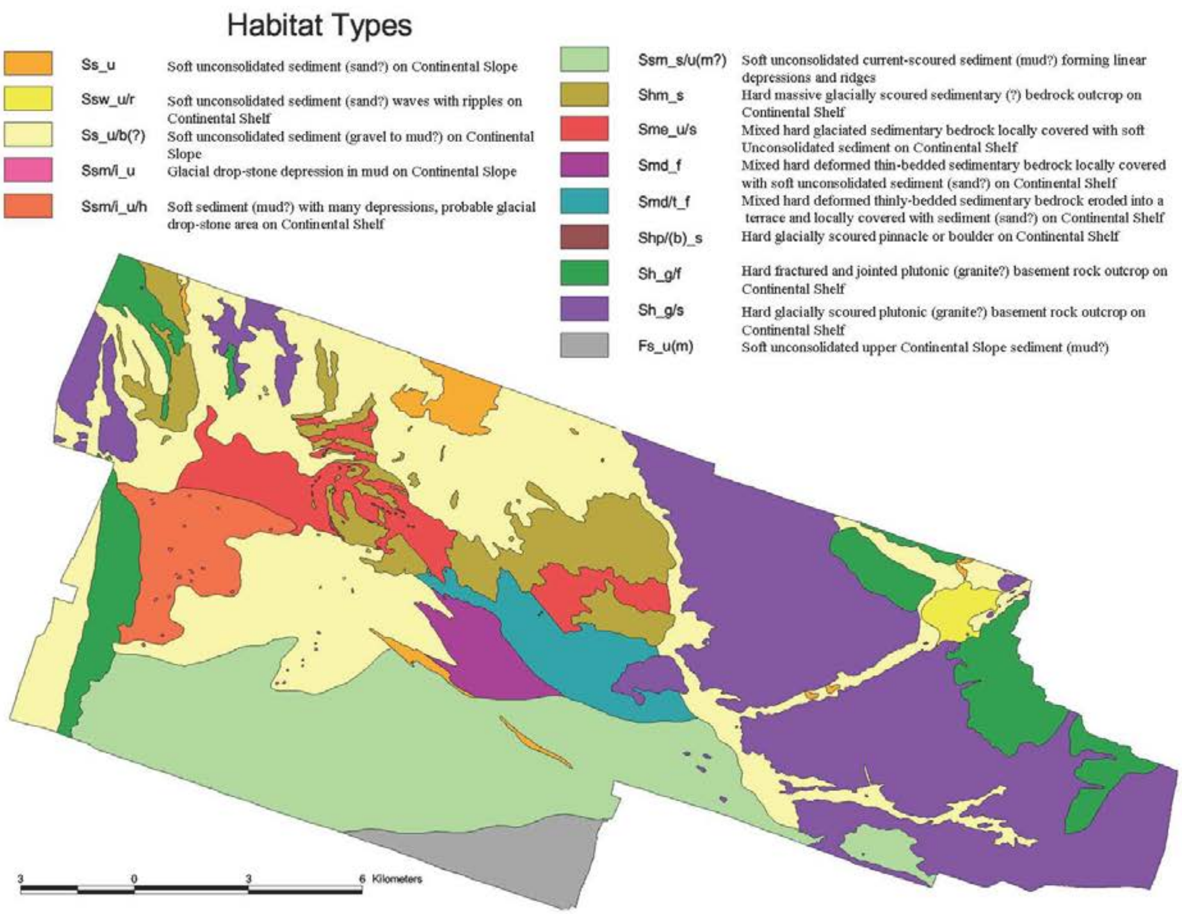

Figure 19. Marine benthic habitat map of the Cape Ommaney dive site selected for ROV examination and sampling of deep-water corals and sponges.

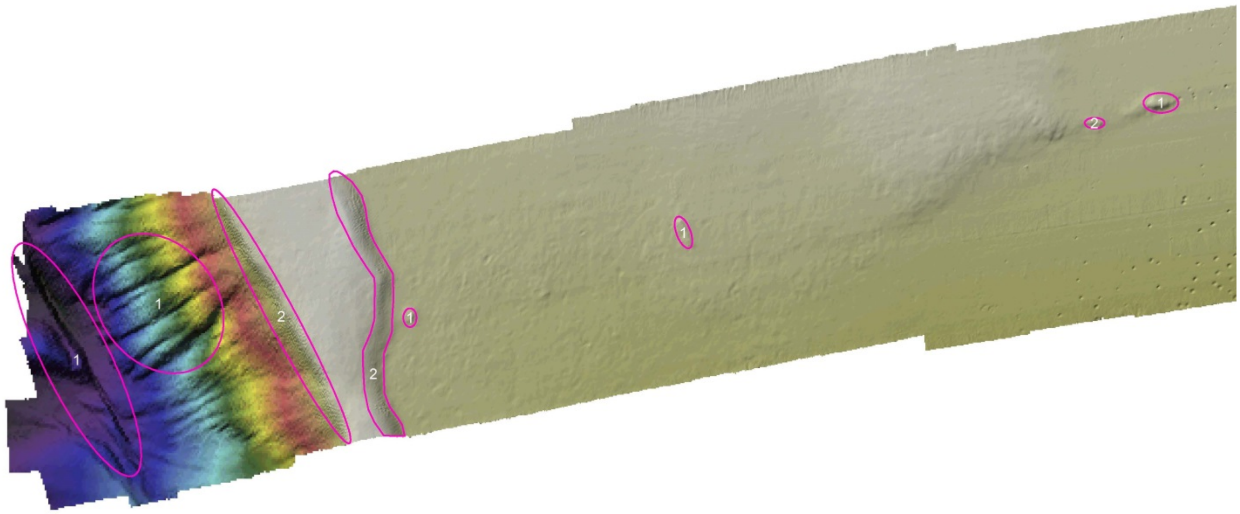

Figure 20. Multibeam bathymetric images of the Prince of Wales dive site selected for ROV examination and sampling of deep-water corals and sponges. Red outlines indicate interesting geological features identified for further exploration with underwater cameras or remote operated vehicles.

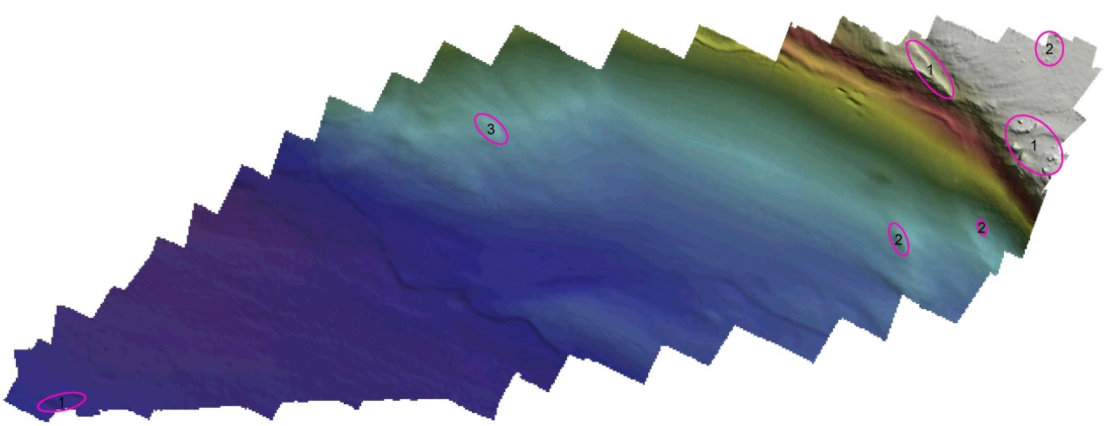

Figure 21. Multibeam bathymetric images of the Dixon Entrance dive site selected for ROV examination and sampling of deep-water corals and sponges. Red outlines indicate interesting geological features identified for further exploration with underwater cameras or remote operated vehicles.

3.5. Recovery, ages and growth rates of *Primnoa pacifica* in the Gulf of Alaska

Background and Objectives: Red tree corals (*Primnoa pacifica*) are common bycatch items in fisheries for demersal species and in stock assessment surveys in Alaska (Heifetz et al. 2005). *Primnoa* colonies have a large size and arborescent growth pattern that make them highly susceptible to disturbance from fishing activities (Stone et al. 2014). *Primnoa pacifica* populations are presumably slow to recover from such disturbance, because large corals are estimated 100+ years old (Andrews et al. 2002, Williams et al. 2007). The importance and vulnerability of red tree coral thickets has been recognized by the North Pacific Fishery Management Council and some protection has been afforded to known thickets in the region (Stone and Shotwell 2007). The Alaska Essential Fish Habitat Research Plan identifies recovery rate information for deep-sea corals as a high priority for research in Alaska (Sigler et al. 2012). The plan states that few recovery rate studies have been proposed, yet the information is critical for assessing the effects of fishing on vulnerable habitat.

A better understanding of population demographics in *P. pacifica* populations is needed in order to estimate recovery rates under various disturbance scenarios. Size class structure, rates of growth, rates of injury and mortality, size at maturity, and recruitment rates are all important parameters for understanding the vulnerability of populations and their potential for recovery. This study focuses on size-class structure as a non-invasive means of estimating colony age and maturity. The report is combined with another DSCRTP project funded through the National Undersea Research Program (NURP) "Ages, Growth Rates, and Climate Reconstructions from Deep-Sea Primnoidae Corals" (B. Williams and P. Etnoyer co-PIs).

Primnoa pacifica corals are good subjects of study because their age and growth rate can be determined using lead and radiocarbon dating of growth rings visible in cross-sections of the base of the colony (Andrews et al. 2002, Aranha et al. 2013). Assuming that age positively correlates to vertical and basal radial size, colony height, width, and basal diameter of the holdfast reflect population age-structure. Therefore, the age of deep-sea *Primnoa* corals can be estimated from scaled *in-situ* images. The objective in this study was to establish a baseline for the size class distribution on *P. pacifica* corals on Shutter Ridge and to correlate this with age to infer their age class structure.

Approach: Coral observations from three surveys of Shutter Ridge were included in this analysis: stereo drop-camera surveys in August 2013 (Table 2). HOV Delta submersible survey in August 2005 (Table 3, Stone et al. 2014); and remotely operated vehicle surveys during August 2013 (Table 4). Stereo-frame images were collected from a stereo drop-camera sled system towed or drifted continuously along linear transects at, or near the seafloor, collecting 17,461 stereo photo-frames (Table 2). Delta submersible surveys produced approximately 12 hours of benthic video footage within Shutter Ridge from 10 strip transects (Stone et al. 2014). The 2013 ROV survey of Shutter Ridge resulted in 15 hours of video footage.

Shutter Ridge is a deep-water geologic feature, in which elongated fault-line ridge rises dramatically on one side, but gently slopes on the opposite side (Greene et al. 2011). The base of the feature lies at 270 m depth, and it reaches 61 m at its highest summit. Several peaks near 150 m depth are notable within the 10 km long ridge (Figure 22), with many areas of exposed rock. The ridge lies ~26 km from Cape Ommaney and the southernmost point of Baranof Island in Southeastern Alaska's continental shelf.

Table 2. List of 2013 stereo drop camera hauls in Shutter Ridge feature.

Locality	Dive Type	Date	EventID	Haul	Duration	Start Latitude	Start Longitude	End Latitude	End Longitude	On Bottom Frames	Max Depth	Total Frames
Shutter Ridge	Drop Cam	8/14/2013	13-226D	1abc	1:21:00	56.1783	-135.1166	56.1798	-135.1151	170	222.1	1384
Shutter Ridge	Drop Cam	8/14/2013	na	2a	na	na	na	na	na	na	202.2	0
Shutter Ridge	Drop Cam	8/14/2013	13-226E	3a	0:08:00	56.1782	-135.1164	56.1788	-135.1198	122	222.9	459
Shutter Ridge	Drop Cam	8/14/2013	13-226F	4ab	0:44:00	56.1785	-135.1146	56.1798	-135.1208	238	224.1	1510
Shutter Ridge	Drop Cam	8/14/2013	13-226G	5a	0:45:00	56.1565	-135.1222	56.1595	-135.1187	239	246	2267
Shutter Ridge	Drop Cam	8/14/2013	13-226H	6a	0:29:00	56.1716	-135.1172	56.1669	-135.1193	112	225.8	1652
Shutter Ridge	Drop Cam	8/14/2013	13-226I	7a	1:27:00	56.2079	-135.1039	56.1959	-135.1082	102	172.2	4961

Table 3. List of ROV Dives in Eastern Gulf of Alaska shelf feature in 2013.

Locality	Dive Type	EventID	Dive Date	Start Time	End Time	Start Latitude	Start Longitude	End Latitude	End Longitude	Min Depth	Max Depth
Shutter Ridge	ROV	13-226A	8/14/2013	10:46:00	13:25:00	56.1725	-135.1360	56.1754	-135.1170	185	225
Shutter Ridge	ROV	13-226B	8/14/2013	16:18:00	18:51:00	56.1801	-135.1200	56.1777	-135.1180	196	218
Shutter Ridge	ROV	13-227A	8/15/2013	9:34:00	12:31:00	56.1972	-135.1011	56.1967	-135.1020	110	184
Shutter Ridge	ROV	13-227B	8/15/2013	16:15:00	19:31:00	56.1808	135.1194	56.1970	-135.1017	201	246
Shutter Ridge	ROV	13-228A	8/16/2013	9:14:00	12:35:00	56.1967	-135.1020	56.1979	-135.1020	71	114
Shutter Ridge	ROV	13-228B	8/16/2013	16:05:00	19:17:00	56.1783	-135.1184	56.1785	-135.1190	204	231

Table 4. List of dives in the Shutter Ridge feature by the Delta manned submersible.

Locality	Dive Type	Dive Date	EventID	Transects	Start Time	End Time	Start Latitude	Start Longitude	End Latitude	End Longitude	Min Depth	Max Depth
Shutter Ridge	Delta Sub	2005-08-20	05-232B	OM1; OM2	10:40:20	11:49:09	56.1707	-135.1056	56.6372	-135.0969	203	254
Shutter Ridge	Delta Sub	2005-08-19	05-231C	OM3; OM4	15:23:35	17:20:05	56.1702	-135.1088	56.1878	-135.1154	192	244
Shutter Ridge	Delta Sub	2005-08-20	05-232A	OM5	8:18:24	9:48:58	56.1878	-135.1154	56.1779	-135.1007	181	218
Shutter Ridge	Delta Sub	2005-08-17	05-229C	OM6	16:57:16	13:43:35	56.1880	-135.1176	56.1843	-135.1014	81	209
Shutter Ridge	Delta Sub	2005-08-19	05-231A	OM7	8:00:05	9:17:56	56.1893	-135.0938	56.1954	-135.1115	144	193
Shutter Ridge	Delta Sub	2005-08-17	05-229A	OM8	11:35:18	12:55:21	56.1949	-135.1084	56.1986	-135.0909	69	175
Shutter Ridge	Delta Sub	2005-08-17	05-229B	OM9	13:51:35	14:39:38	56.2005	-135.0944	56.2063	-135.1101	158	178
Shutter Ridge	Delta Sub	2005-08-19	05-231B	OM10	10:07:03	10:59:52	56.2133	-135.1065	56.2049	-135.0921	109	171

Stereo frames were enumerated and sized for coral observations using Sebastes 1.3 software (Williams et al. 2016). A screenshot of the size analysis method is shown in Figure 23.
Corals in submersible and ROV images were assessed using software Image-J with lasers to calibrate size. Colony counts and size estimates used downward-looking cameras with 20 cm lasers, and forward-looking cameras with 10 cm lasers. Data were binned into five size categories: 10-49 cm; 50-99 cm; 100-149 cm; 150- 199 cm; and 200 + cm. *Primnoa pacifica* colonies of indeterminate size were counted, but not used for size estimation

A total of fifteen whole colony biological samples of various sizes were collected by ROV during three surveys from 2013 to 2015 (Table 5). Each colony was measured for five morphometric variables (height, width, basal diameter, linear distance to first branch point and mass) wet weight, and dry weight. Three ~ 0.5 cm thick cross-sectional disks were removed from the base, middle, and top portion of specimens 1-3 (Table 5) for radiocarbon analysis.

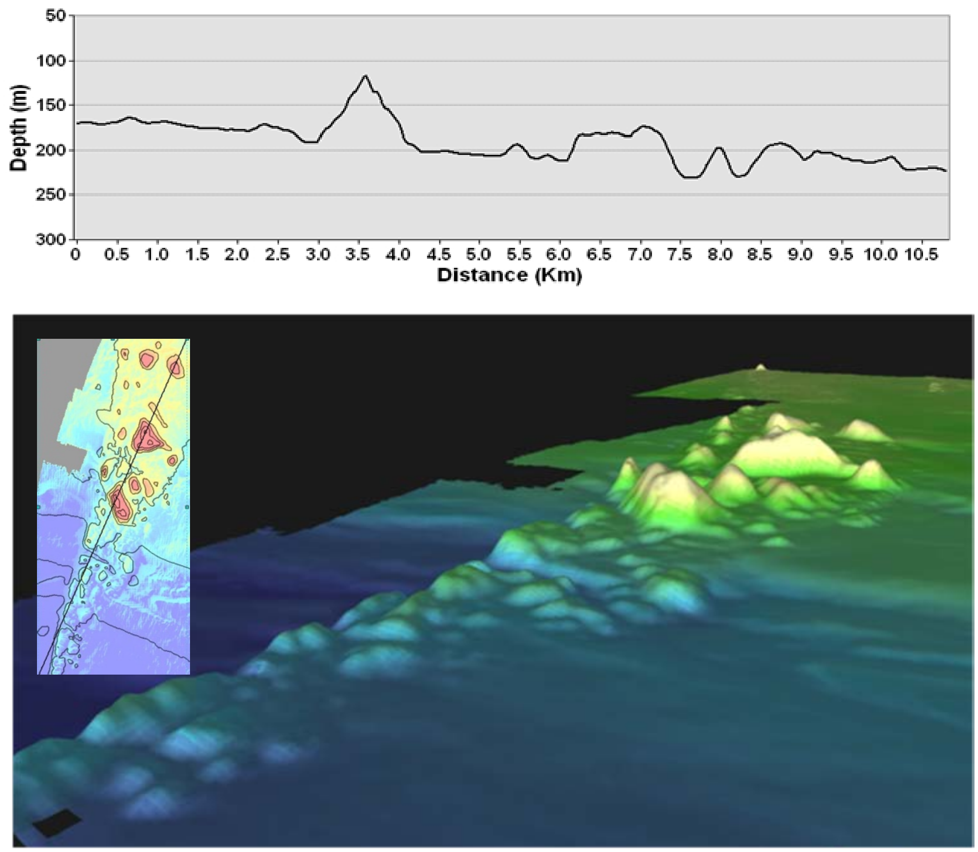

Figure 22. Depth-profile of Shutter Ridge (top, from NNE to SSW), plan view (inset left, red is shallow), and perspective view (bottom, yellow is shallow).

Figure 23. In situ stereo images showing the method for estimating <u>Primnoa pacifica</u> colony sizes using Sebastes 1.3 software (Williams et al. 2016). Euclidean triangulation is used to estimate distance based on the comparison between six measured values in two calibrated cameras mounted on a sled.

The disks were acidified in 5% HCl for one week with daily acid changes to ensure full dissolution of the calcite skeleton. Next, the samples were thoroughly washed with Milli-Q water and maintained wet in a Milli-Q bath. Under light microscope, growth rings were peeled away from each disk using forceps to work from the outside of the disk toward the inside. Growth rings from the center of each disk and the middle and outside of the basal disk (n = 5 per colony) were isolated, dried at room temperature overnight, and prepared for Accelerated Mass Spectrometer dating at the University of California Irvine.

Table 5. List of *Primnoa pacifica* *colony samples obtained during surveys from 2013 to 2015. Specimens were collected from the 2013 AFSC bottom trawl survey (AK Vessel 143), the 2013 ROV survey (AK Provider) or the 2015 ROV survey (Dorado Discovery). Specimens were measured for seven variables. Ring count measures are in progress across the basal cross-sections for all specimens, and initial radiocarbon values are available from three of the specimens.*

Sample	Collection Date	Vessel	Locality	Event	Latitude	Longitude	Depth (m)	Height (cm)	Width (cm)	BaseD (mm)	1st Branch dist. (cm)	Mass (Kg)	Dry Mass (Kg)
GOA 004	07/19/2013	FV Sea Storm	Nula Bay	Trawl Haul 224	59.3545	-150.5277	290	78	50	15.0	16.0	1.08	0.65
GOA 005	07/26/2013	FV Sea Storm	Middleton Ridge	Trawl Haul 252	59.6652	-143.2214	248	79	32	13.0	28.0	1.28	na
GOA 003	08/04/2013	FV Sea Storm	Dixon Entrance	Trawl Haul 290	54.5747	-132.9844	398	64	22	12.5	9.0	0.40	0.23
GOA 011	08/13/2013	FV AK Provider	Shutter Ridge	ROV Dive 10	56.1749	-135.1165	191	65	24	10.0	8.5	0.62	na
GOA 022	08/14/2013	FV AK Provider	Shutter Ridge	ROV Dive 11	56.1722	-135.1160	203	72	32	16.0	12.3	1.13	na
GOA 012	08/15/2013	FV AK Provider	Shutter Ridge	ROV Dive 12	56.1921	-135.1103	165	58	39	13.0	13.0	0.77	na
GOA 060	08/15/2013	FV AK Provider	Shutter Ridge	ROV Dive 13	56.1785	-135.1180	203	123	44	25.0	32.0	2.13	0.91
GOA 067	08/16/2013	FV AK Provider	Shutter Ridge	ROV Dive 15	56.1784	-135.1180	214	153	121	45.0	32.0	na	2.13
WPA 001	06/04/2015	Dorado Discovery	Fairweather Grd	ROV Dive 04	58.2457	-138.9045	141	123	67	32.5	7.0	2.24	0.96
WPA 002	06/04/2015	Dorado Discovery	Fairweather Grd	ROV Dive 04	58.2458	-138.9044	142	171	60	25.5	62.0	1.25	0.51
WPA 003	06/05/2015	Dorado Discovery	Fairweather Grd	ROV Dive 05	58.2377	-138.9894	147	110	70	24.0	30.0	na	na
WPA 004	06/06/2015	Dorado Discovery	Fairweather Grd	ROV Dive 08	58.2047	-138.8175	163	223	101	53.0	29.5	20.45	7.27
WPB 005	06/08/2015	Dorado Discovery	Dixon Entrance	ROV Dive 12	54.6252	-132.8828	335	160	98	49.0	29.0	16.60	na
WPB 006	06/08/2015	Dorado Discovery	Dixon Entrance	ROV Dive 13	54.6345	-132.8510	164	99	26	19.0	20.0	1.14	na
WPB 007	06/08/2015	Dorado Discovery	Dixon Entrance	ROV Dive 13	54.6345	-132.8510	164	87	23	15.0	17.0	0.64	na

Significant results to date: The total number of *P. pacifica* colonies observed on surveys of Shutter Ridge between 2005 and 2013 was n = 5,501. Colonies were observed with a depth range of 127 to 245 m. They were absent from the depth range 60-126 m. The mean depth for *Primnoa* observations on Shutter Ridge was 176 m, and the median 167 m. The mean depth for survey effort was 156 m. High densities of large colonies were observed (> 1 colony*m^{-2}).

In total, 1,020 *in situ* size estimates were made for *P. pacifica* colonies (Figure 24). Nearly 70% of colonies were larger than 1 m, and 10% were larger than 2 m (Figure 24). Colony size was correlated with depth. The largest colonies were deep and smallest ones were shallow (Figure 25). The largest *P. pacifica* colonies (> 2 m) were present near the base and surrounding perimeter of the Shutter Ridge at 200 m depth. Highest abundance of colonies was between 200 and 220 m depth. Most colonies were 0.5 to 1.5 m tall.

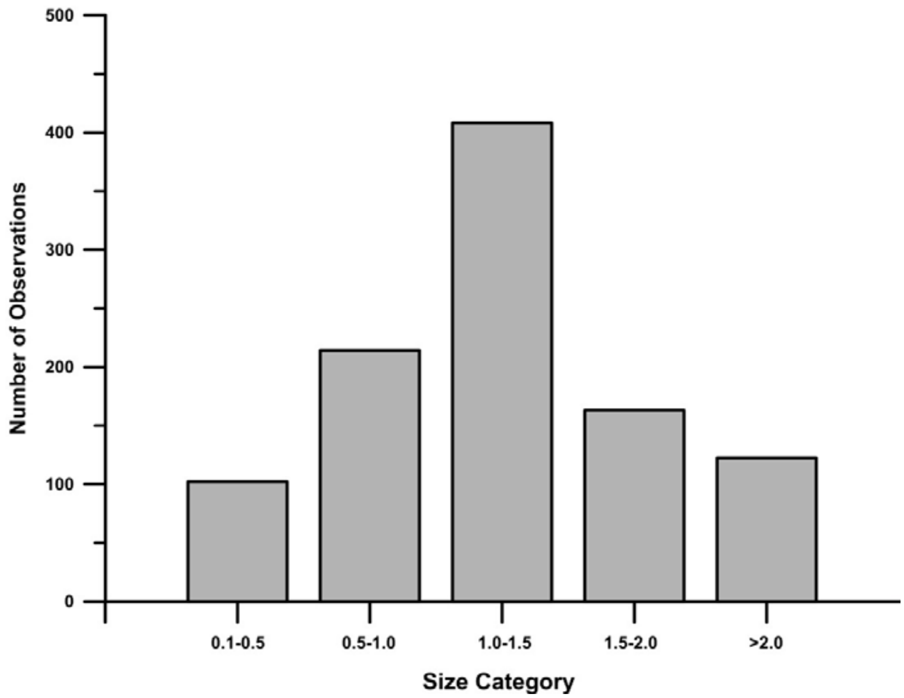

Figure 24. Size distribution (m size categories) of observed Primnoa pacifica colonies in Shutter Ridge. A total of 1,020 colonies were measured.

Radio-isotope aging of the colonies showed the radiocarbon content decreasing from the oldest part of the skeleton to the youngest part of the skeleton of all three colonies in both the radial and vertical directions. This suggests that coral growth could have started after thermonuclear bomb-testing peaked in the mid-1970s. Thus the corals are recording the decline in atmospheric concentrations of the "bomb" carbon. However, based on the sizes of the coral colonies and growth rates from *Primnoa* sp from other locations, it is likely that these corals exceed several decades in age. Thus, the declining radiocarbon content toward the present could also indicate increased contributions of old carbon, either via increased upwelling and/or increased contribution of terrestrial carbon.

Radiocarbon values (reported as Δ14C) ranged from -16.5 to 25.3 ‰ over the lifespan of the three corals (Figure 26). Particularly in specimens GOA 011 and GOA 0 22, the Δ14C indicate contributions of "old" 14C that dilutes the anthropogenic "bomb" carbon signature. This carbon could be carbon upwelled from below the surface mixed layer or terrestrial-derived carbon entering the ocean via rivers or glacial melt.

The majority of colonies measured in this study (900/1,020 = 88%) were of a mature height (> 42 cm, Waller et al. 2014). The population appears to be a viable, and potential source of larvae to other habitats. The estimated time to recovery is at least 100 years, give the size of the largest colonies. Radiocarbon and 210Pb data suggest that the largest colonies are over 100 years old but the average size colonies (0.5-1.5 m) tall may be closer to 50-60 years old.

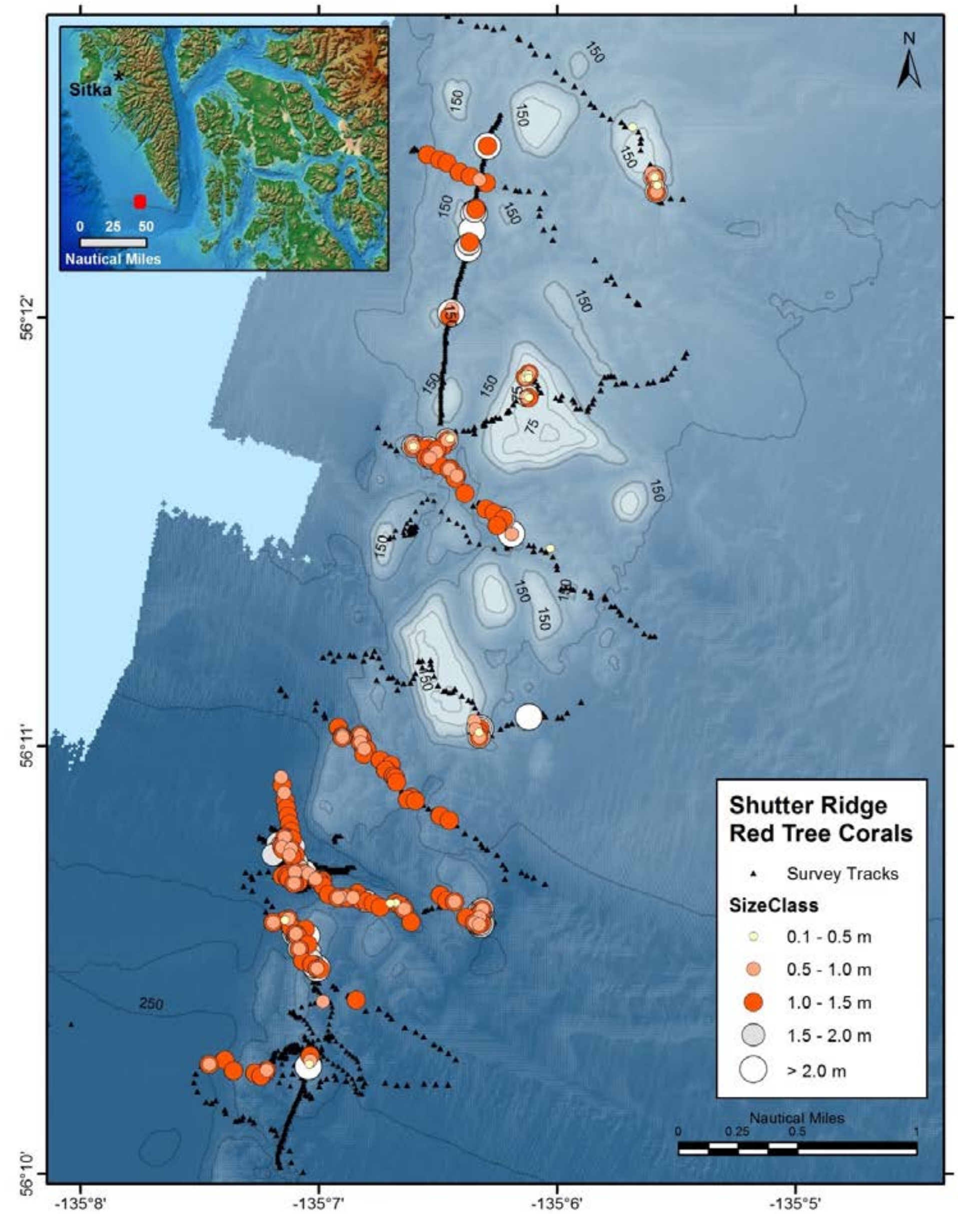

Figure 25. Distribution of <u>Primnoa pacifica</u> colony sizes. Black triangles represent survey tracks. The largest <u>Primnoa pacifica</u> colonies were generally observed in the deep rocky portion of the Shutter Ridge. They were absent from areas shallower than 100 m.

210Pb dating is in progress to verify the ages of the corals as to whether their lifespans pre-date peak "bomb" carbon concentrations. This information will either validate the radiocarbon growth estimates and the fast rates of growth of these corals or indicate that contributions of old carbon are confounding radiocarbon dating at this location. Regardless, the wide variability in radiocarbon recorded by the different corals in most recently formed skeleton suggests a heterogenic radiocarbon content of the water and organic matter. This supports the latter hypothesis of old carbon contributing to the radiocarbon signature at this location.

Radial ring counts are also in progress, which will be used with the 210Pb-derived dates to determine growth ring periodicity. Principal component analysis will determine components correlated to radial and linear growth and biomass.

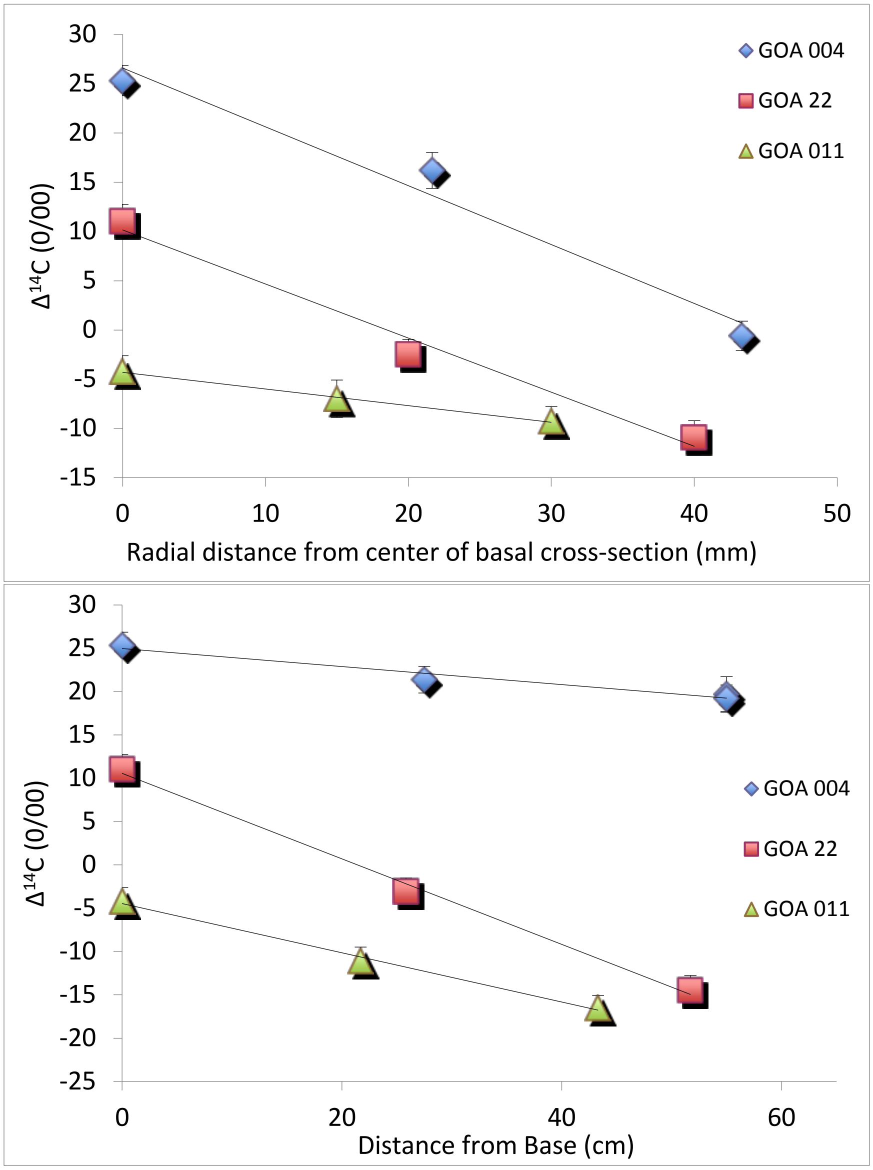

Figure 26. Radiocarbon results for three Primnoa pacifica colonies. Δ14C values were measured across a basal cross-section (top) and a linear transect (bottom) for each specimen.

Future surveys should recursively target small-scale features (200-500 m), in order to verify absence of *P. pacifica* from shallow depths and to gain understanding of *P. pacifica* patch-size and the fine-scale influence of aspect, bottom currents, turbulence, and resource availability. More information on settlement rates, gender ratio and fecundity of the population would help to quantify birth and immigration. More information on fishing intensity, fishing-induced mortality, and natural predation would be helpful to quantify death and emigration. The sum of this information would allow new types of population dynamic studies and state-and-transition models to define tipping points and thresholds in a changing deep ocean environment under pressure from commercial fisheries.

Funding: Collection of samples for this project was completed during the Primnoa thickets study in the eastern Gulf of Alaska. Funding for image analysis and travel to the fieldwork ($100K total) were provided by the Alaska Initiative. Additional funding for analysis of size structure data was provided by the AFSC HEPR program through a successful proposal ($52,500).

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3.6. Distribution models for eastern Bering Sea, Gulf of Alaska and Aleutian Islands deep-sea coral and sponge

Background and Objectives: Deep sea coral and sponge ecosystems are widespread throughout most of Alaska's marine waters. In some places, such as the western Aleutian Islands, these may be among the most abundant cold-water coral and sponge communities in the world. Because of the size and scope of Alaska's continental shelf and slope, the vast majority of the area has not been surveyed for the presence of coral and sponge communities. Since the spatial distribution of these communities is not known in Alaska, it is difficult to predict the locations and types of human activities that may be threats to the deep-sea coral and sponge ecosystems. The objectives of this project were to predict the distribution of coral and sponge ecosystems for the eastern Bering Sea, Gulf of Alaska and Aleutian Islands.

Approach: Historical bottom trawl surveys conducted by the RACE Division have collected data on the presence and abundance of corals and sponges in all areas of Alaska. We used data from 1996-2012 biennial bottom trawl surveys to examine the distribution and abundance of coral and sponge ecosystems. Generalized additive models based on the location (latitude and longitude), depth, slope, sediment, ocean current, bottom temperature and ocean color were used to predict the probability of presence of sponges corals and sea whips.

Significant results to date: In the eastern Bering Sea about 61% of coral habitat was predicted to occur in slope areas (39% was predicted to occur on the outer shelf of the eastern Bering Sea; Figure 27). Of the slope areas, the highest amount of coral habitat was predicted to occur in Pribilof Canyon (33% of the predicted coral habitat occurs here). Only 1% of coral habitat was predicted for Zhemchug Canyon and the rest occurred primarily in the Pribilof-Zhemchug inter-canyon area, in the Zhemchug-Pervenets inter-canyon area and in Navarin Canyon. This implies that about one third of the coral habitat predicted for the eastern Bering Sea occurs in Pribilof Canyon, an area that comprises only about 10% of the total slope area. In contrast, about two-thirds of sponge (64%) and most sea whip (91%) habitat was predicted to occur on the outer shelf, an area that comprises about 82% of the total area of the slope and shelf examined. These results and analyses were published in Sigler et al. (2015) and validated in Rooper et al. (2016).

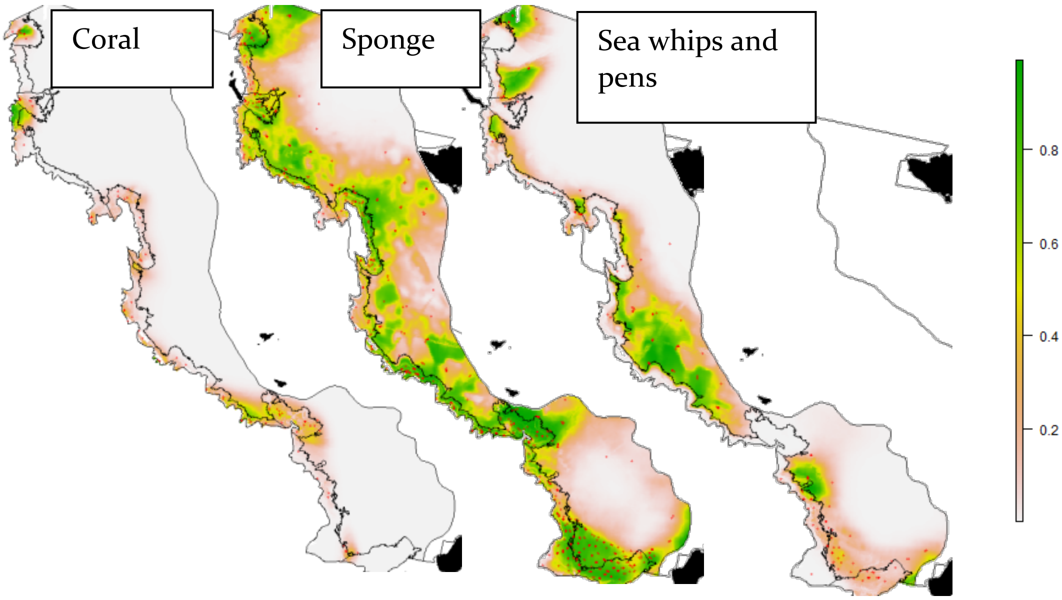

Figure 27. Predicted probability of presence or absence of coral, sponges and sea whips and sea pens from a generalized additive model (Sigler et al. 2015).

In the Aleutian Islands the most important factors in determining coral presence or absence and abundance were location, maximum tidal current and slope. For sponges the most important factors determining presence or absence and abundance were location, maximum tidal current and depth. Coral and sponge were predicted to occur in relatively high abundance throughout the Aleutian Islands, but particularly in the areas surrounding Seguam Pass, Petrel Bank, and the area just to the east of Kiska Island (Figure 28). In the Gulf of Alaska corals and sponges are predicted to occur primarily along the shelf break and in hard-bottom areas of the Gulf, while sea pens and whips occur in large areas of the continental shelf (Figure 28).

Funding: This project used existing data and required no funding from the DSCRTP. In kind contributions of time for the principal investigator was the only requirement.

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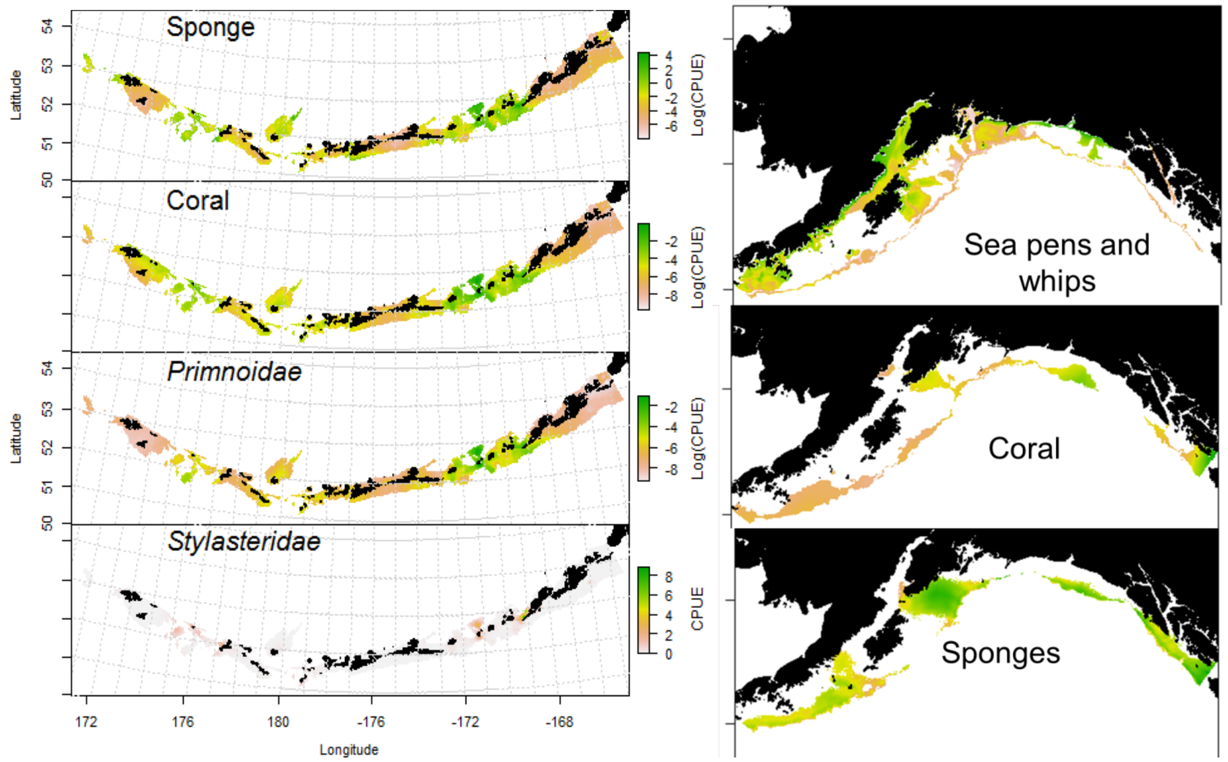

Figure 28. Predictions of the best-fitting generalized additive model for sponge, coral, Primnoidae, and Stylasteridae predicting the abundance (log-transformed catch-per-unit-of-effort (CPUE) or CPUE) in the Aleutian Islands (left) and pennatulaceans, corals and sponges in the Gulf of Alaska (right) bottom trawl surveys (Rooper et al. 2014, Rooper et al. in review).

3.7. Longline Impacts study

Background and Objectives: Disturbance from longline fishing to sensitive coral and sponge habitats has been documented in Alaska but the extent of and mechanisms of disturbance have not been well studied compared to bottom trawling. Observations in red tree coral thickets in the eastern Gulf of Alaska indicate that 17% and 20% of the "standing stock" of corals and sponges, respectively, have been damaged by longlines (Stone et al. 2014). Corals and sponges are common bycatch in both commercial fisheries and stock assessment surveys using longlines clearly indicating interactions between the gear and sensitive habitats. Bycatch of branching corals is generally higher than that of sponges, presumably due to differences in how easily they can become entangled in the gear. The goal of this project was to examine the behavior of longline gear *in situ* during all stages of fishing.

Approach: This pilot project used two tools to examine longline disturbance of benthic habitat. The first tool was a camera system was developed that took intermittent pictures of the seafloor during all stages of the set (deployment, on-bottom fishing and retrieval). The second tool was a series of accelerometers that were attached to the longline ground gear. Both tools were deployed on a longline survey vessel that was conducting stock assessment surveys in 2013 and 2014. The camera system was deployed in both years, while the accelerometers were deployed in 2014 only.

Significant results to date: Analyses of the images collected in 2013 did not indicate that the groundline of the longline moved along the seafloor during deployment. There were only two successful tests of the camera system that year, and in both cases the camera was stationary throughout the 6 hour set. Both deployments were conducted in sandy benthic habitat.

In 2014, 12 camera deployments were conducted. Image analyses for these deployments are still underway. The accelerometers were deployed on 12 longline sets in six locations along the longline in 2014. The accelerometer data are very noisy (Figure 29), and some Kalman filtering is necessary to analyze the data. For most cases, the data indicates minimal if any movement of the longline during setting, fishing and recovery. However, there were a few cases where there was some indication of increased acceleration during the set that could have indicated the longline was traveling across the seafloor. These results are very preliminary and analyses are still ongoing with this data.

Funding: Vessel time and personnel time were contributed in kind by the AFSC and the annual longline survey. The DSCRTP contributed ($18,125) for the purchase of underwater equipment and travel to and from the field locations in FY13 and FY14.

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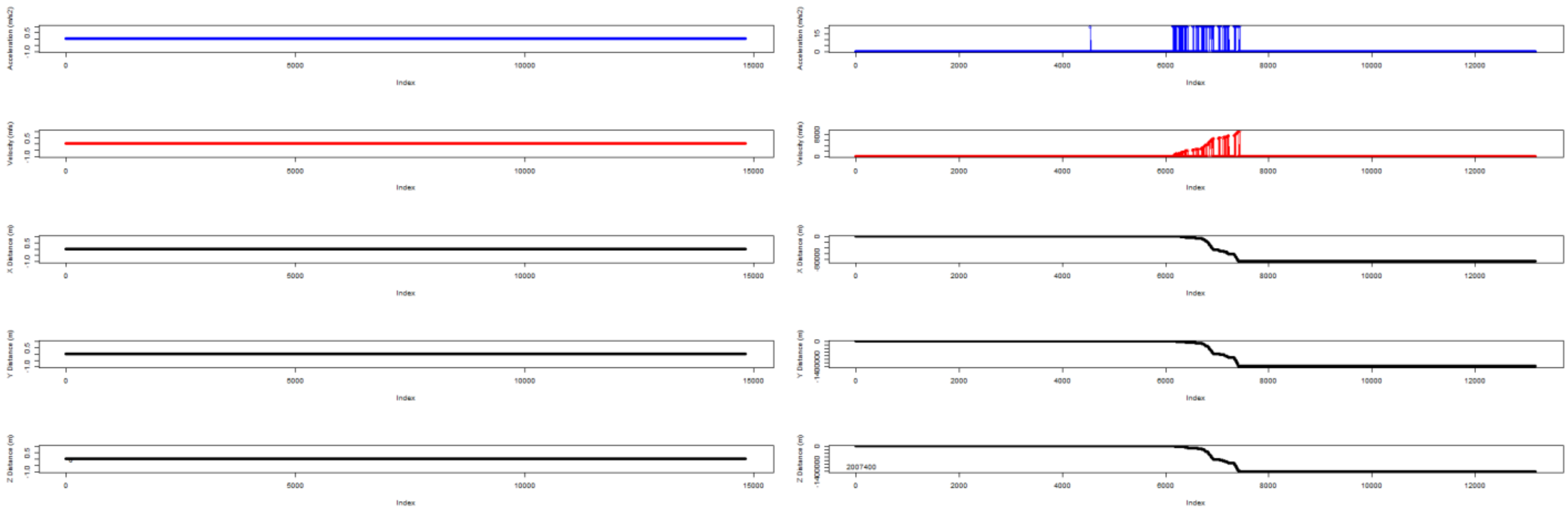

Figure 29. Example accelerometer data (acceleration, velocity, and distance in x, y and z directions) for two deployments on longline gear. The left hand deployment shows a probable movement of the longline gear during the middle of the deployment, while the right hand deployment shows a stationary deployment.

3.8. Genetic connectivity among offshore and emergent fjord-populations of red tree corals (*Primnoa pacifica*) in the Gulf of Alaska

Background and Objectives: Knowledge of the degree to which spatially discrete marine populations of sedentary fauna are connected through larval dispersal is important for effective resource management. Red tree corals (*P. pacifica*) are the dominant structure forming coral on the outer continental shelf and upper slope between the Alaska Peninsula and the Olympic Coast Marine Sanctuary off the Washington Coast yet little is known about their larval dispersal capability or population connectivity. Red tree corals provide important habitat for fishes and invertebrates and are long-lived animals highly susceptible to disturbance from human activities including interaction with fishing gear. Accordingly, some protection has been afforded to several offshore populations through the establishment of Habitat Areas of Particular Concern where all fishing activities are now prohibited. The closures were established however without any knowledge of how these populations may be connected genetically. Red tree corals are also a dominant component of emergent fjord communities in Southeast Alaska, occurring in depths as shallow as six meters. The complex combination of extreme tides, strong seasonal storms, freshwater discharge, and intricate passageways to the open ocean may restrict larval exchange between offshore and fjord populations, or conversely, fjord populations could become important larval sources should offshore populations become depleted.

The objective of this study was to examine the genetic connectivity of "distinct" red tree coral populations in the eastern Gulf of Alaska. This study builds on ongoing work using microsatellite DNA markers to generate data on the spatial scale and pattern of genetic connectivity across a large portion of the range of red tree corals in the North Pacific Ocean. These data will provide important insights regarding the most appropriate tools available to resource managers to protect sensitive coral habitats and the ecosystem services they provide. Using population genetic data for a North Pacific Ocean coral species for the first time, will provide important insights regarding population sensitivity and the capability of the region's ecologically most important coral species to recover from anthropogenic disturbance.

Approach: As part of an ongoing study on an emerged population of red tree corals in Tracy and Endicott Arms, Holkham Bay, Southeast Alaska we had completed much of the preliminary work developing microsatellite DNA markers for the species. We collected additional samples with a remotely operated vehicle (ROV) at Site 3 (Shutter Ridge) in 2013 (Figure 30, Figure 31) that provided for the successful develop of 12 microsatellite markers needed for this study (Morrison et al. 2015). Using an ROV in 2013 and 2015, we were able to collect samples from 46 colonies at Site 1 (Dixon Entrance), 52 colonies at Site 3 (Shutter Ridge), and 53 colonies at Site 4 (Fairweather Ground; Figure 30). In June 2014 we chartered the Alaska Department of Fish & Game (ADF&G) RV *Medeia* and using scuba and a small ROV (Phantom XTL) collected samples from 34 colonies in an emerged population (depths 14–50 m) in Endicott Arm, Holkham Bay, Southeast Alaska (Figure 30).

Significant Results to Date: Microsatellite markers were used to characterize the spatial scale and pattern of genetic connectivity across a large portion of the range of red tree corals in the eastern Gulf of Alaska. More than 240 discreet, geo-referenced samples were collected with ROVs and scuba from three offshore populations (Dixon Entrance, Shutter Ridge, and Fairweather Ground) and two emerged fjord populations (Tracy and Endicott Arms, Holkham Bay, Southeast

Alaska). A complex pattern of connectivity was recovered with offshore populations being more highly connected than fjord populations.

We also used next generation sequencing technology, specifically restriction site associated DNA (RAD), to identify and genotype 700 novel SNP (single nucleotide polymorphisms) markers for these same samples of red tree corals. These SNPs will allow for direct comparisons of connectivity patterns assessed from SNP versus the microsatellite markers.

Funding: Collection of the offshore GOA samples was supported with DSCRTP (Alaska 3-year Initiative) funds as part of Project 1 in 2013 and 2015. DSCRTP funds were used to support the 5-day cruise aboard the ADF&G RV *Medeia* in FY2014 ($20,000) and purchase laboratory supplies in FY2012 ($4,000), FY2013 ($3,200), and FY2014 ($3,000). An in-kind contribution by the Auke Bay Laboratory in FY2012 ($2,000) was used for the purchase of additional laboratory supplies. Travel, salary and benefits costs for the principal investigator (C. Morrison) and laboratory support were an in-kind contribution by the USGS (Leetown Science Center).

Points of Contact:

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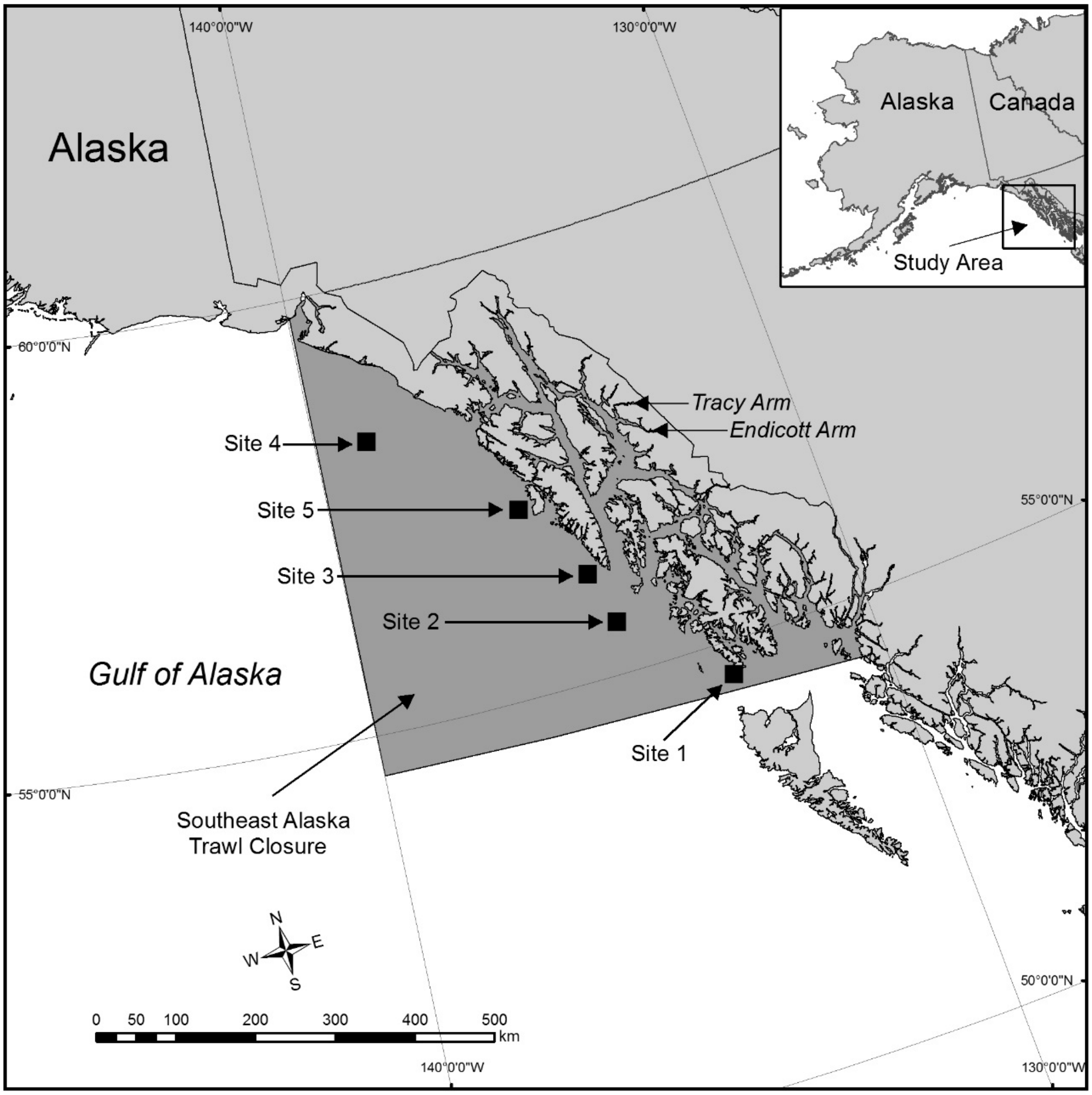

Figure 30. Map of the eastern Gulf of Alaska showing the five study sites (Site 1, Site 3, Site 4, Tracy Arm and Endicott Arm) where samples were collected from red tree corals to study genetic connectivity in 2013 and 2015.

Figure 31. Collecting red tree coral samples for genetics studies with the ROV Zeus II at Site 4 (Fairweather Ground) in June 2015.

3.9. Long-term monitoring of O_2 and pH in Alaska waters; a sentinel for global climate change and ocean acidification

Background and Objectives: The effects of global climate change and ocean acidification are expected to be more extreme at higher latitudes, such as in Alaska. Deep- coral and some sponge communities are especially susceptible to ocean acidification through reductions in calcification rates due to reduction in the available carbonate ions. Thus it is important to determine the rates of ocean acidification through monitoring pH and to determine shoaling and expansion of O_2 minimum zones in order to predict and understand the effects of climate change on deep coral and sponge ecosystems.

Approach: The AFSC RACE Division annually conducts stock assessment surveys in Alaska ecosystems aboard chartered fishing vessels. These platforms provide an opportunity for low cost monitoring by instrumenting the bottom trawl survey nets to collect additional environmental data. We purchased two Aanderra oceanographic units that have sensors that collect depth, temperature, salinity, turbidity, pH and O_2.

Significant Results to Date: Beginning in 2012, protocols for data collection were developed and the oceanographic equipment was deployed on bottom trawls in the eastern Bering Sea slope survey. Environmental variables were collected during 168 trawl hauls from Bering slope to the US-Russian border. In 2013, the environmental data was collected on 218 trawl hauls in the Gulf of Alaska and in 2014 data was collected on 300 trawl hauls in the Aleutian Islands.

Oxygen concentrations were higher in shallow areas of the eastern Bering Sea slope, but there were also some areas of low oxygen concentration in the middle of Pribilof and Zhemchug canyons (Figure 32). pH distribution followed oxygen very closely. Oxygen concentration in the Gulf of Alaska was highest in areas to the west of the Shumagin Islands the on the middle and inner shelf and was uniformly low in SE Alaska (Figure 32). pH was low in a band across the shelf near the Shumagin Islands and generally was low on the outer shelf elsewhere in the Gulf of Alaska (Figure 32). pH and oxygen varied spatially in the Aleutian Islands and also changed with depth. Both variables exhibited lower values on underwater banks (such as Petral Bank) and generally the two values appeared to be correlated. The highest concentrations of oxygen and the highest values of pH occurred in the central Aleutian Islands.

Environmental variables continued to be collected in 2015 and beyond. The on bottom environmental data is summarized annually and included in the Ecosystem Considerations Chapter of the Stock Assessment and Fisheries Evaluation documents provided to stock assessment authors and fisheries managers each year. In the future we plan to use these data to document changes in distribution of environmental conditions and model the effects on the distribution of deep-sea coral and sponge ecosystems.

Funding: Funding was provided by the DSCRTP to purchase two CTDs ($58,816) in FY12 and for calibration and modification in FY14 ($12,140).

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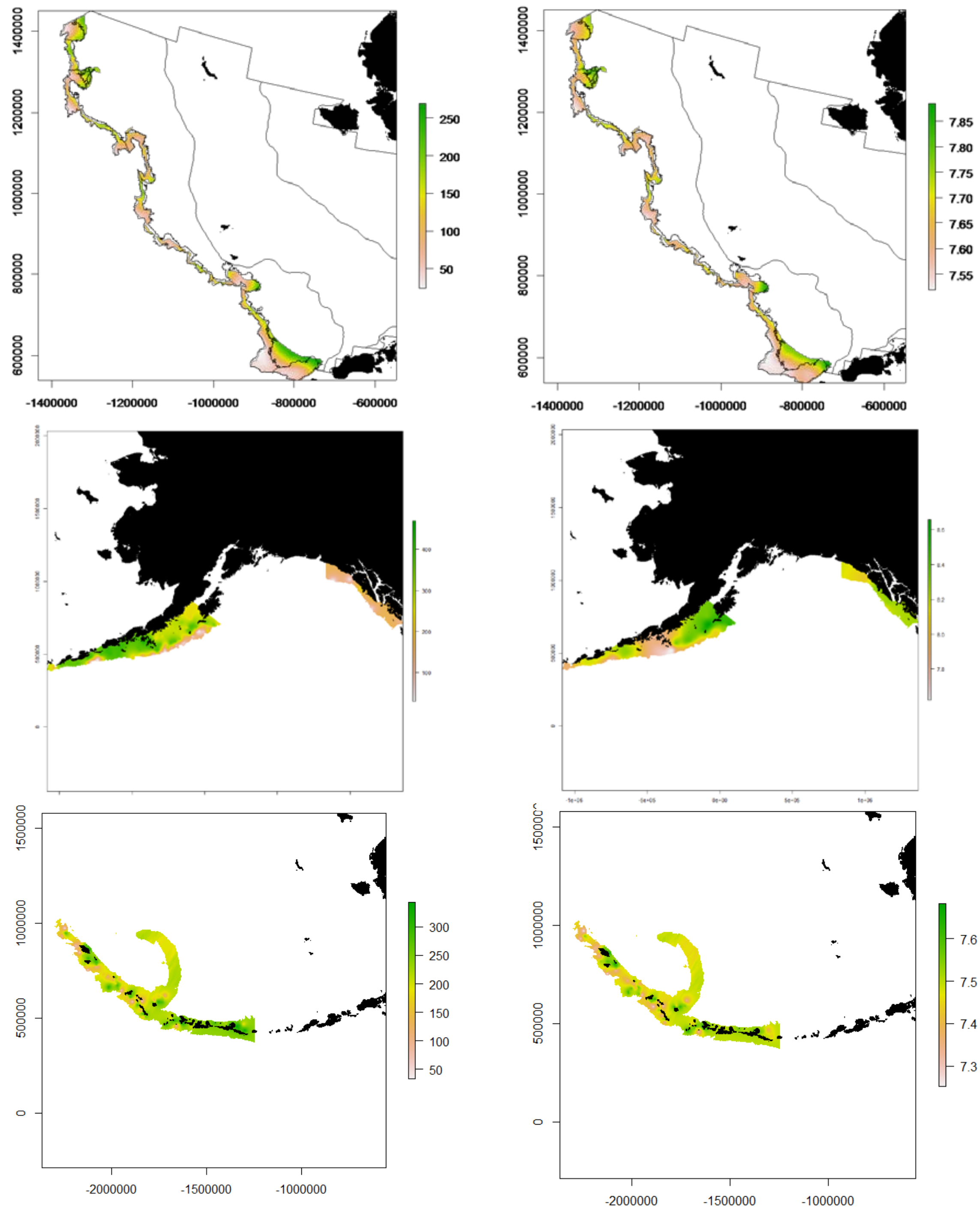

Figure 32. Maps of summer distribution of seafloor O2 (left panel) and pH (right panel) during trawl surveys of eastern Bering Sea slope (2012), Gulf of Alaska (2013), and Aleutian Islands (2014).

3.10. Long-term monitoring of oceanographic conditions in Southeast Alaska

Background and Objectives: There are few long-term oceanographic stations in the Gulf of Alaska and no sub-tidal stations in the eastern Gulf of Alaska where red tree corals (*P. pacifica*) form dense thickets on the continental shelf and in shallow waters of glacial fjords. Long-term oceanographic data are of paramount importance to study the pending effects of ocean warming and acidification on the coral resources of Alaska.

Access with scuba diving to red tree corals that have emerged into shallow water in several glacial fjords of Southeast Alaska have been studied year-round since 2004. These coral populations may prove to be sentinel populations for studies on the effects of global climate change and ocean acidification on marine processes in the North Pacific Ocean. This project was designed to establish a long-term oceanographic station in Tracy Arm, Holkham Bay, Southeast Alaska were studies on the biology and genetics of red tree corals have been ongoing since 2006.

Approach: In 2012 we purchased an oceanographic array from SAtlantic that included sensors depth, salinity, temperature, pH, and dissolved oxygen. The oceanographic array was deployed January 2013 at a depth of 17 m (MLLW) in Tracy Arm and then retrieved March 2014 (Figure 33). Total deployment time was 427 days.

Significant Results to Date: Unfortunately a series of firmware malfunctions during the deployment resulted in the collection of only some of the desired data. Some components in the purchased array were "prototypes", among the first deployed anywhere. The "bugs" were sorted out, faulty components replaced, all sensors serviced and rebatteried. One of the problems with the Tracy Arm deployment site was that it is very remote and routine maintenance is problematic. Accordingly, we have decided to deploy the array at the NOAA Little Port Walter marine station at a depth of 28 m (MLLW). This is the site of a previous coral study (Stone et al. in review). The data will be live fed to a land-based station, relayed to a GOES (geostationary operational environmental satellite) and made available via NOAA's Satellite and Information Service (NESDIS) and the Alaska Ocean Observing System (AOOS). The system is currently being field-tested and is scheduled for site deployment during the fall 2016 or spring 2017.

Funding: DSCRTP (Alaska Initiative) funds were used to purchase the oceanographic array ($28,000) and field supplies for the 2013 cruise ($3000). The costs of the field work (e. g. charter vessels, personnel support) were provided by the AFSC ($30,000). System upgrades and travel for training in 2016 were supported with AFSC funds ($8,000).

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Figure 33. Scuba divers deploy an oceanographic array in a red tree coral (Primnoa pacifica) thicket in Tracy Arm, Holkham Bay, Southeast Alaska.

3.11. Taxonomy of Alaska sponges and corals

Background and Objectives: We have made considerable progress with the taxonomy of both sponges and corals in Alaska during the past decade but some corals and quite a few sponges have not been collected or properly identified. Taxonomic studies are critical for accurate measures of biodiversity that are often used to gauge the importance of habitats. Proper taxonomic identifications are also important for constructing identification guides to be used in fisheries and surveys to record the location of coral and sponge bycatch. These data can be used by resource managers to identify the locations of high biodiversity and abundance that might indicate the location of vulnerable marine ecosystems. The objective of this study is to properly identify all specimens collected and appropriately preserved for all projects during the 3-year Alaska Initiative and to continue to support taxonomic cataloging of coral and sponge specimens collected during the annual AFSC RACE trawl surveys.

Approach: This project supported dedicated collections made as part of the Red Tree Coral Project (Section 3.1), opportunistic collections as part of the Mapping and Modeling Project (Section 3.2), dedicated collections as part of the FMP Project (Section 3.3), and in support of a special project requested by the NPFMC to study the taxonomy and species diversity of corals and sponges in the Bering Sea.

Dedicated collections of sponges and corals were made with an ROV during Project 1 in 2013 and 2015 in the eastern Gulf of Alaska. An opportunistic collection of several sponges was made during the Aleutian Island towed camera survey in 2012—a large cobble became entangled in the towed array. Several specimens collected from the central Gulf of Alaska as part of Project 5 in 2014 were collected to describe seafloor habitat. Sponge and coral specimens were also collected as part of the annual RACE groundfish stock assessment trawl surveys to support ongoing taxonomy projects. The first project was a general project to inventory the sponge and coral fauna in the Alaskan Region and consisted of collections in the Aleutian Islands in 2012 and the Gulf of Alaska and Bering Sea shelf in 2013. Special collections continued in 2014 and 2015 on the Bering Sea shelf and on the Bering Sea slope in 2016 as part of the NPFMC-requested project.

Significant Results to Date: Corals collected as part of Project 1 in 2013 and 2015 included the octocorals *P. pacifica*, *P. pacifica willeyi*, *Paragorgia* sp., *Isidella tentaculum*, *Calcigorgia spiculifera*, and *Halipteris* sp. A. Samples of the *Paragorgia* specimens contributed to an ongoing study to examine the taxonomy of Alaskan *Paragorgia* using DNA PCR-sequencing (Santiago Herrera, Centre for Environmental Epigenetics and Development, University of Toronto and Robert Stone). Antipatharians collected included *Chrysopathes* sp. and *Bathypathes* cf. *patula*. Several *Bathypathes* specimens contributed to an ongoing study to examine the taxonomy of that genus (Mercer Brugler, NYC College of Technology and Robert Stone). Hydrocoral collections included *Stylaster verrillii*, *S. brochi*, and *S. parageus columbienis*. The latter collection represented a northern range extension for the subspecies. A single scleractinian (*Caryophyllia arnoldi*) was collected.

Only two corals were collected as part of Project 5, the gorgonian *Fanellia fraseri* and the hydrocoral *Stylaster brochi*, both previously documented from the study region.

More than 100 sponge specimens were microscopically examined from the 3-year Alaska Initiative (2012–2014) collections and included the description of 23 new species and multiple range extensions from all three geographic regions. Twenty species of demosponges were described from the Aleutian Island RACE trawl survey collections: *Ancorina buldira*, *Geodia starki*, *Stelleta anthastra*, *S. makushina*, *Dysidea kenkriegeri*, *Cornulum globosum*, *Artemisina clavulata*, *A. flabellata*, *Coelosphaera kigushimkada*, *Stelodoryx mucosa*, *S. siphofuscus*, *Raspailia septentrionalis*, *Callyspongia mucosa*, *Megaciella lobata*, *M. pituitosa*, *M. triangulata*, *Cladocroce attu*, *C. infundibulum*, *C. kiska*, and *C. toxifera*. Two species of demosponges were described from Project 1 collections in 2015 (*Hamacantha cassanoi (*Figure 34*)* and *Prosuberites salgadoi*) and one species was described from the Gulf of Alaska RACE trawl survey collections (*Latrunculia lincfreesei*). The RACE trawl survey collections also provided specimens of *Latrunculia hamanni*, *L. oparinae*, and *L. velera* and contributed to a major revision of the family Latrunculiidae, as did specimens of *L. austini* collected as part of Project 1 in 2013 and 2015.

Funding: Collection of specimens for taxonomic studies was supported with DSCRTP (Alaska 3-year Initiative) funds as part of Project 1 in 2013 and 2015, Project 2 in 2012, and Project 5 in 2015. Special collections for the Bering Sea biodiversity study were supported by the AFSC in 2012–2016. Contracts for sponge taxonomy were issued each year during the 3-year Alaska Initiative (2012–2014) using AFSC funds ($60,250) and DSCRTP funds ($26,150). Follow-up contracts for sponge taxonomy were issued for the Bering Sea biodiversity study using AFSC funds in 2015 ($13,222) and DSCRTP funds (non-Alaska Initiative) in 2016 ($19,570).

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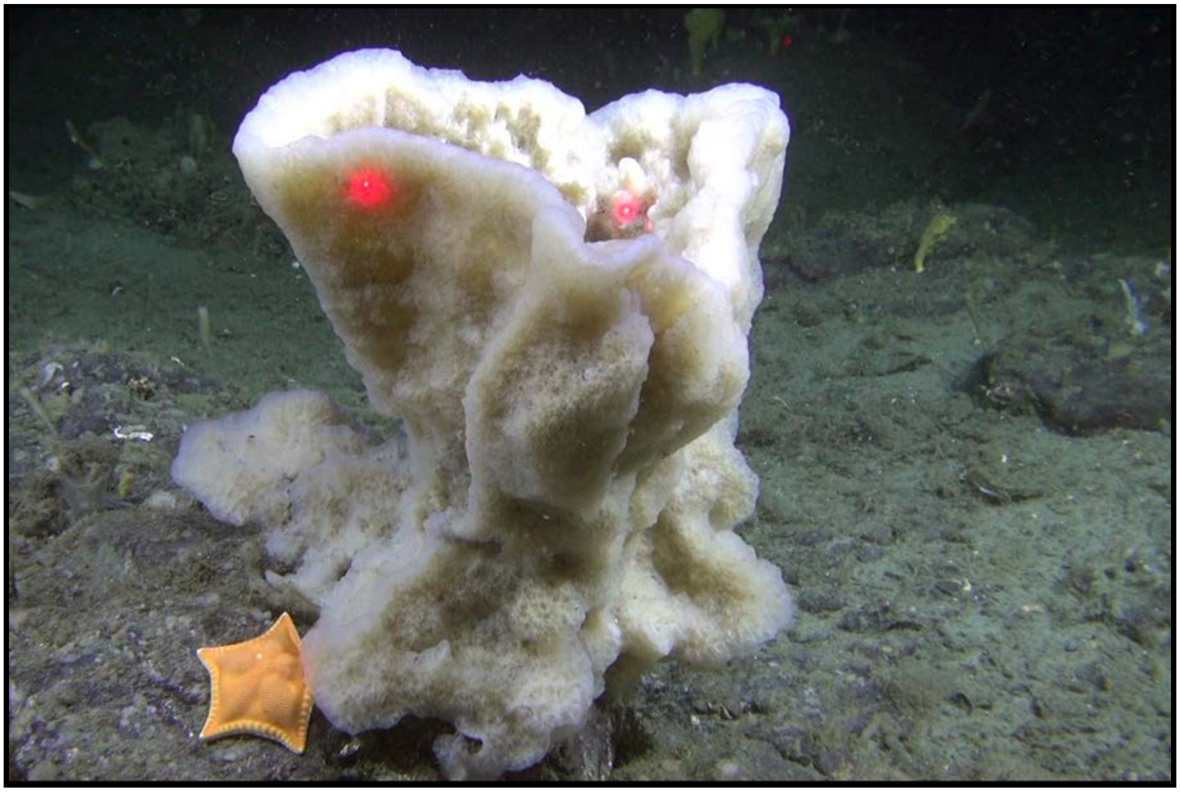

Figure 34. Hamancantha (Vomerula) cassanoi discovered at a depth of 174 at Site 4 (Fairweather Ground) during the 2015 eastern Gulf of Alaska expedition.

3.12. Marine natural products studies of Alaskan sponge fauna

Background and Objectives: Corals and particularly some sponges have evolved the ability to produce or accumulate from associated microorganisms a diversity of unique chemical compounds or secondary metabolites that they utilize in predator defense, competition for resources, and as physiological adaptations to living in extreme environments. Many of the compounds are currently in early clinical or late preclinical development for use as treatments for cancer, tuberculosis, HIV, asthma, and many other diseases and ailments. Deep-water sponges show particular promise in this emerging research area, and several species collected from the Aleutian Islands as part of a pilot program in 2004 exhibited near 100% inhibition during primary screening for *M. tuberculosis*. Only a handful of sponge species from the Aleutian Islands have been examined for the presence of secondary metabolites, but so far "hit rates" for biomedically active compounds are on the order of 10% rather than 1% which is typical for samples collected elsewhere.

Opportunistic collections from past expeditions in Alaska have provided samples for important studies of marine natural products associated with deep-sea sponges (Na et al. 2010, Kelly et al. 2016). Corals and particularly some sponges have evolved the ability to produce or accumulate from associated microorganisms a diversity of unique chemical compounds or secondary metabolites that they utilize in predator defense, competition for resources, and as physiological adaptations to living in extreme environments.

Approach: As part of Project 1 in 2013 and 2014 we collected specimens of the demosponge *Latrunculia austini* (Figure 35) with ROVs and specimens of the demosponge *Suberites montabildus* (Figure 36) from the 2014 Bering Sea shelf RACE trawl survey. Specimens were shipped frozen to the Department of Bio-Molecular Sciences laboratory at the University of Mississippi for processing and examination for the presence of biomedically active compounds.

Significant Results to Date: Preliminary work with *Latrunculia austini* collected from the eastern Gulf of Alaska in 2005 (Stone et al. 2014) isolated a new pyrroloiminoquinone alkaloid called atkamine. Atkamine has potent bioactivity towards various types of tumor cell lines and with the potential target of mammalian topo-isomerase II (Zou and Hamann 2013). Collections made as part of Project 1 provided sufficient material for phase II of that work—a total synthesis to further investigate the chemistry and effectively characterize the biological potential of this species.

Laboratory work is scheduled to begin on the *Suberites montabildus* project in summer 2016. This species was selected for study since it was abundant enough to provide sufficient material for examination and had characteristics typical of sponges housing biomedically active compounds (e.g., dark color and odiferous).

Funding: Collection of samples was supported with DSCRTP (Alaska 3-year Initiative) funds as part of Project 1 in 2013 and 2015 and as an in-kind contribution by NOAA's AFSC as part of the annual RACE trawl surveys. Salary and benefits costs of the principal investigator (M. Hamann) and laboratory support were an in-kind contribution by the Department of Bio-Molecular Sciences, The University of Mississippi.

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Figure 35. The demosponge <u>Latrunculia austini</u> at a depth of 94 meters at Site 3 (Shutter Ridge).

Figure 36. The demosponge <u>Suberites montalbidus</u>, also known as the "stinky sponge", is very abundant in some areas of the southern Bering Sea. Pictured here is the catch of the stinky sponge from a bottom trawl survey haul in the eastern Bering Sea.

4. Conclusions

The suite of projects that examined *P. pacifica* and associated species in the eastern Gulf of Alaska provided significant new information about these communities. The multibeam mapping projects extended coverage in the region by an additional ~167 square nautical miles to depths of 1300 m in areas of known or suspected *P. pacifica* habitat. The study confirmed that *P. pacifica* habitat extends significantly beyond the areas currently closed as HAPCs. The research also documented other species of coral (especially black corals) on the surrounding continental shelf. Evidence of damage to *P. pacifica* potentially from longline fishing activity was documented beyond the boundaries of existing HAPCs. Colony sizes were related to depth, with the largest colonies exceeding 2 m in height and found at the deeper depths. These large colonies (> 2 m) also formed a significant portion of the population, comprising 10% of the total colonies. Overall, almost 70% of the colonies were > 1 m in height and the recovery time for the largest colonies was estimated at > 100 years and 50-60 years for the average size colonies. The samples collected during this study using a remotely operated vehicle (ROV) were used to examine reproductive ecology, trophic ecology, and genetic connectivity. We confirmed that deep-water *P. pacifica* are gonochoristic and have multiple developing cohorts of oocytes that were previously observed in shallow-water populations. However, the study also found evidence for reduced fecundity in the deeper water populations. Recruitment plates deployed in *P. pacifica* thickets found no *P. pacifica* recruits after 22 months confirming the episodic and rare nature of successful recruitment for this species. However, the observed recruitment of another octocoral (*Calcigorgia spiculifera*) indicated the potential for the success of the technique. The settlement plates were redeployed for future retrieval. The trophic ecology study indicated that *P. pacifica* is likely feeding on both POM and zooplankton confirming the findings found elsewhere for deep-water octocorals.

An important accomplishment of the Alaska Initiative was the production of maps of predicted occurrence of corals and sponges on a 1-ha scale for three of the four large marine ecosystems of Alaska. The accuracy of these maps and models were confirmed (with the exception of the wider Gulf of Alaska) with field studies and indicated that coral and sponge ecosystems occur at predictable locations where hard bottom substrate is present. During the course of the project three previously unexplored locations were also examined using field observations, Bowers Bank and Ridge and the eastern and western Aleutian Islands. These explorations found that dense coral and sponge communities can be found throughout the western Aleutians, on the shallowest depths of Bowers Bank, and in the area from Sequam Pass to Unimak Island. Areas without coral and sponge communities were also identified, especially on the shelf south of Unalaska Island, the deeper areas of Bowers Ridge, and between Aggatu and Attu Islands. One of the important variables to come out of this modeling was the effect of current speed (either tidal currents or mean oceanographic currents) on the distribution of corals and sponges. The highest densities tended to be in areas where currents could be moderate to high (> 50 cm/s). Depth was also an important factor across regions controlling benthic invertebrate distribution. An important component of the data from this fieldwork was height and density information for corals and sponges in the Aleutian Islands. These new data and models will be used in the future to inform management decisions on where fishing closures can be most effective in protecting the oldest, most diverse, and densest coral and sponge communities.

One of the foundations of the distribution maps for deep-sea corals and sponges is maps based on sediment and bathymetry that were developed during the Alaska Initiative. New bathymetry and sediment maps for the Aleutian Islands and parts of the Gulf of Alaska were completed during this project. Scientists mined the NOS (National Ocean Service) charting data as far back as the late 1900s and new multibeam bathymetry data from study sites all over Alaska into a single product that was used to derive distribution models for deep-sea corals and sponges. Future work will expand geological interpretation of these maps and data to provide substrate-based classifications for regions where enough supporting data exists.

During the Alaska Initiative, we also tried to document the differences in fisheries productivity using a number of measures in different types of habitats (hard substrate with coral, hard substrate with no coral, and bare sand habitat). Density of rockfish, especially juveniles and smaller species, was higher in coral habitat than the other types of habitat, which has previously been shown in other areas of Alaska and the U.S. West Coast. Other measures of productivity, such as gonosomatic index, relative fecundity, energetic content, and reproductive failure were also measured in the different types of habitats and highest productivity using these measures tended to be in the coral habitat. The preliminary results indicate that for rockfish, there may be benefits to coral habitat in terms of productivity that exceed the benefits of the same type of substrate without coral. Further data and results are forthcoming from this project as samples continue to be analyzed.

Because climate change and ocean acidification are expected to have large impacts on high latitude ecosystems, such as those found in Alaska, monitoring programs were set up that used existing facilities within the AFSC to collect data. An oceanographic monitoring station will be established at NOAA's Little Port Walter field station in Southeast Alaska that will interface with other oceanographic monitoring programs (NESDIS and AOOS). The AFSC bottom trawl surveys also have been collecting oceanographic data using equipment purchased through the Alaska Initiative. So far, these data have shown distinct breaks and patterns in O_2 concentrations particularly in the Gulf of Alaska. Prior to these collections, no synoptic data sets for summer oceanographic conditions throughout Alaska ecosystems were being collected, with the exception of temperature data. Both these data sets will continue to be monitored and provided to scientists and managers to support ecosystem management not only for deep-sea corals and sponges, but for other purposes as well.

Specimens collected during the fieldwork for the Alaska Initiative resulted in the description of 23 new species of demosponges. Collected specimens were also critical to a major revision of an important family of demosponges as well as providing geographical and depth range extensions for additional taxa. Biochemical analyses and products also have resulted in important and potentially medically useful alkaloids. As samples continue to be analyzed, further species and taxonomic revisions are likely. These findings highlight the fact that there is still much to be learned about the taxonomy of deep-sea corals and sponges in Alaska but significant progress has been made through the support of the Alaska Initiative.

In all, the 3-year AK Coral and Sponge Initiative has provided important new information that addressed both immediate management needs for coral and sponge ecosystems (such as the distribution mapping and modeling that has already been used by the NPFMC to inform fisheries management), as well as longer term goals (such as setting up long term monitoring stations in Little Port Walter and on bottom trawl surveys that will measure the effects of climate change on the ecosystem). Almost as important, the initiative has resulted in further questions and techniques that can be used to inform future research in Alaska.

5. Suggestions for future implementation/administration

Future research initiatives in Alaska would benefit from expanded consideration for logistical and financial challenges of working in an extremely remote location such as Alaska. The success of the 2012-2014 Alaska Deep-Sea Coral and Sponge Initiative would have been enhanced by greater availability of research vessels with appropriate capabilities and additional administrative and data analysis support.

Alaska has not received the NOAA vessel support that has been available for deep-sea coral projects in other NOAA regions. This lack of ship availability resulted in high costs for contract vessels (see Appendices for cost breakdown), particularly in terms of transit and fuel costs that heavily taxed the Initiative budget. We improvised by using commercial fishing vessels under contract for bottom trawl survey activities, but these contracted vessels were often not available during the short summer research season (when many vessels were busy fishing) or were not set up ideally for ROV work. The short field season and remote and difficult field conditions made it difficult to contract more capable vessels; several contracts solicited for vessel time received only single contract offer. For example, the 2014 Aleutian Islands camera survey was conducted in April (outside the optimal weather window), which resulted in about one-half of the total contract days being lost to bad weather. Similarly, we were unable to contract a vessel with a dynamic positioning system for the 2013 ROV cruise in the eastern Gulf of Alaska, which resulted in the loss of approximately 40% of available sea time. This problem will continue in the future without access to additional NOAA vessel time or an increased budget to offset these costs unique to the Alaska Region.

Administrative duties, such as contracting vessels and other research assets, took up a substantial amount of researchers' time. The amount of funding allocated to hire technicians to assist with data processing and logistical support was also inadequate, which further taxed the time of the few researchers dedicated to this Initiative. For future initiatives, hiring an assistant to help implement administrative tasks and ensuring additional technical support for logistics and data processing, even at the expense of conducting new research, would likely be beneficial.

Without the support of the AFSC and other organizations, many of the projects conducted during the Alaska Initiative would not have been completed. For some projects, financial and technical support was gathered from other places (Figure 37), including AFSC and NPRB providing financial support for additional fieldwork (such as the 2015 ROV survey and the May 2014 fish productivity survey). Substantial technical support for development of stereo camera technology and analysis software was also provided by programs within the AFSC (the MACE Program). These types of contributions were very useful in making the overall project a success, but we note that these contributions are not always available.

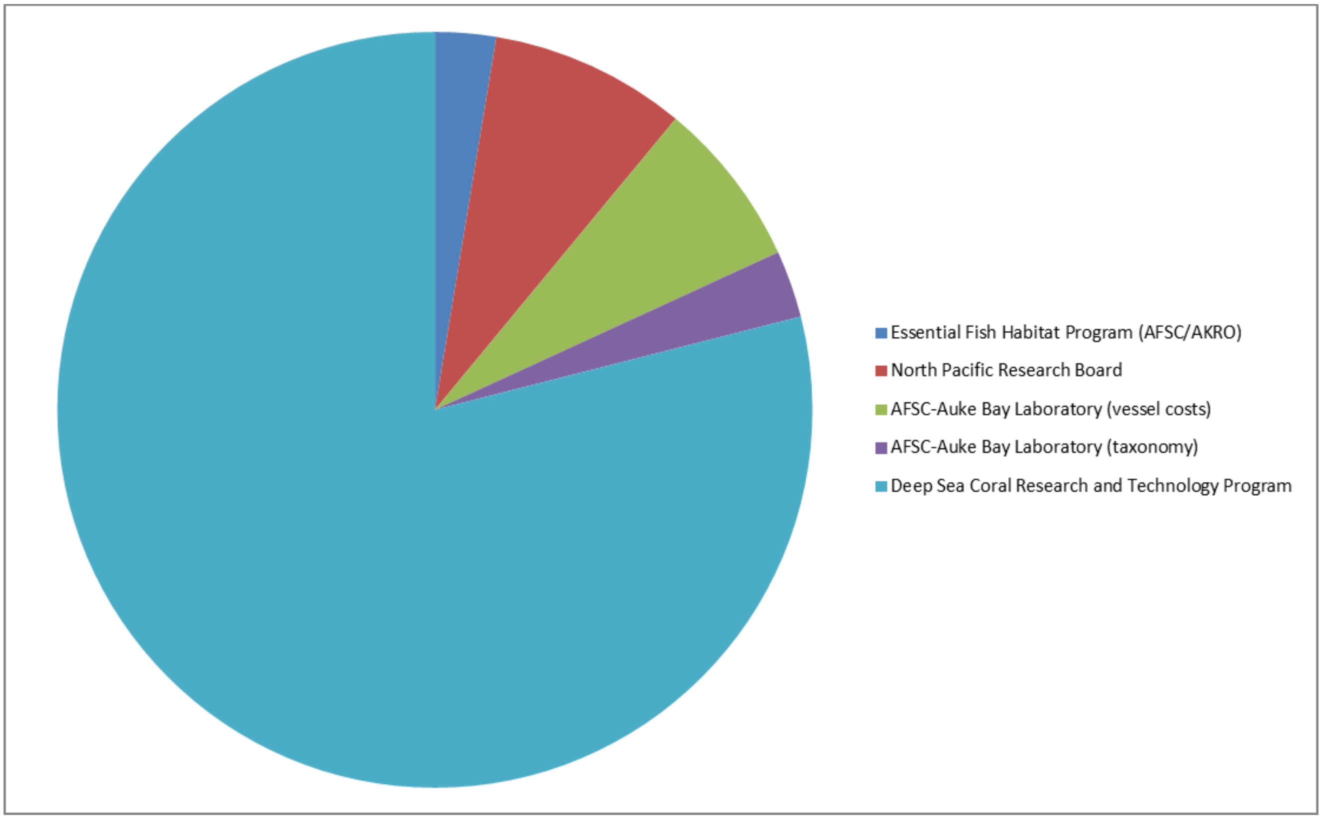

Figure 37. Proportion of expenditures by funding source ($3.17 million for FY12-15 combined) during the lifetime of the Alaska Coral and Sponge Initiative.

6. Priorities for future research

- Towed stereo camera survey based on stratified random sampling design in the Gulf of Alaska to validate coral and sponge distribution models based on bottom trawl survey data.
- Assessment of the effectiveness of current fishing closures and potential pathways forward with spatial management of coral and sponge ecosystems using a combination of spatial analysis tools (such as Zonation) and fieldwork that revisits previous sites to assess recovery from fishing impacts.
- Population assessment for major coral species in each region that integrates existing life history information and distribution information to estimate sustainable mortality rates (bycatch rates).
- Longline and pot gear impact rates for coral and sponge communities. Despite our pilot efforts in this area, impact rates for these gears are still unknown.
- Research into the benthos of Arctic regions of Alaska that are largely unsurveyed, as research on the east coast of Canada indicates that coral and sponge communities exist in the Arctic and could be widespread. Basic research to map the distribution and abundance of corals and sponges in Alaska's Arctic is recommended.

- Construction/revision of potential marine benthic habitat maps to represent the substrate types found with corals and sponges. This would entail sampling at coral and sponges collection sites, and modifying our habitat characterization to include in situ observations. There could also be a follow-up sampling program based on predictive models developed from this assessment.

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8. Appendices

8.1. Budget expenditures

In total the Alaska Coral and Sponge Initiative received $2,558,812 from FY12-FY15. In FY12, $900K was allocated, in FY13 $850K was allocated, in FY14, $800K was allocated and in FY15 we received $8,811. The major fieldwork project studying *P. pacifica* in the eastern Gulf of Alaska required about 49% of the total funds over the life of the project (Figure A1). It should be noted that this fieldwork supported collections and data from the Primnoa recovery and landscape ecology project, the Primnoa genetic connectivity, the geological substrate mapping project, the coral recruitment study and the taxonomic and other collections project. These projects were all successfully piggybacked onto the eastern Gulf of Alaska *P. pacifica* project. The other two major fieldwork projects required 22% (Aleutian Islands mapping project) and 12% (fish productivity study) of the total funds.

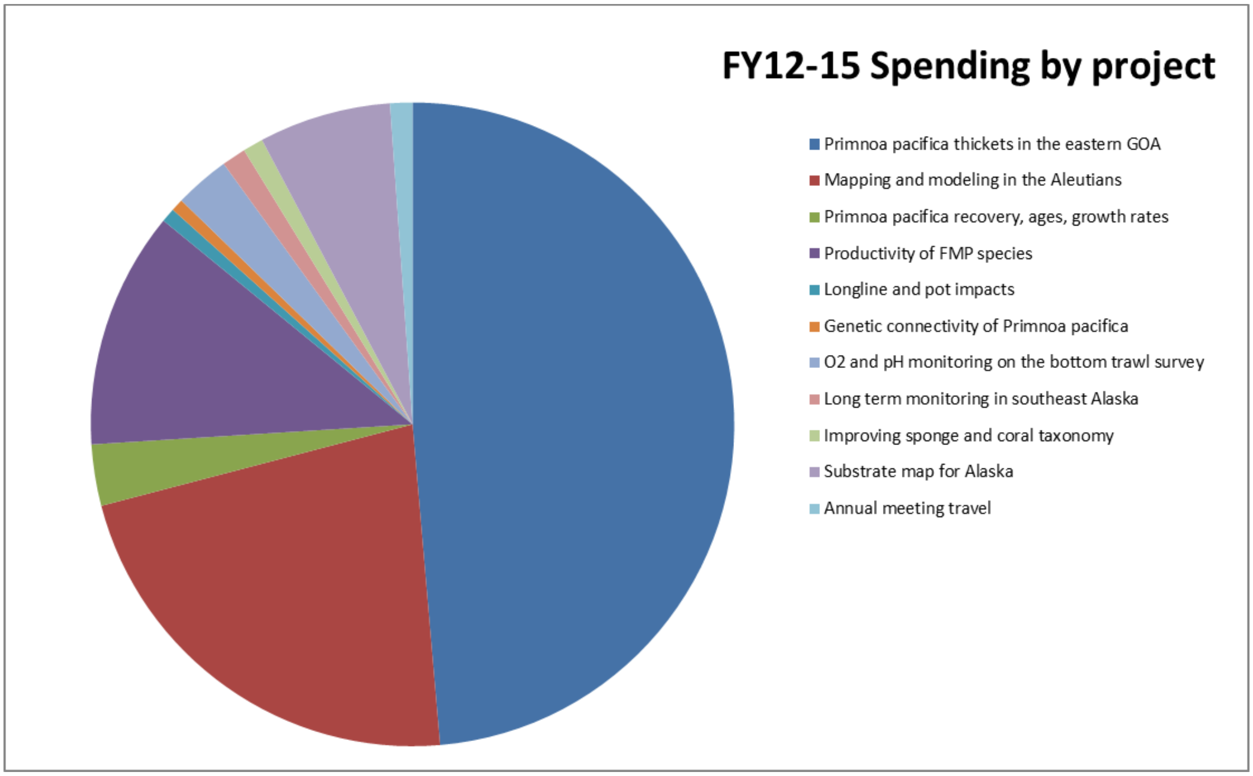

Figure A1. Expenditures by project for FY12-15 in the Alaska Coral and Sponge Initiative (DSCRTP contribution only).

It is also important to note that support from outside sources was also obtained over the course of these projects. In FY12-15 a funded proposal to the North Pacific Research Board paid for 47% (~$272K) of the fish productivity study by funding both a portion of the fieldwork and the associated laboratory analyses. In FY13 the Primnoa recovery project received $52.5K from a successful proposal to the AFSC/AKR HEPR Program. Also in FY13, the fish productivity project received $31.8K in additional funds from the AFSC/AKR HEPR Program to support laboratory analysis of rockfish fecundity. The sponge and coral taxonomy contracts received $93K from outside sources, the southeast Alaska monitoring project and Primnoa genetics projects received $38K and $2K respectively from the AFSC. The HEPR Program also provided funding ($60.3K) to study the reproductive ecology of Primnoa. Finally, the southeast Alaska ROV project received $231.7K in FY15 to support ROV activities and sample collection. In total (not including in-kind contributions of personnel time, salary and benefits), the AFSC and NPRB provided ~$612K of additional funding for the AKCSI or about 20% of the total cost of the program.

In terms of items were funding was spent, the largest cost for the project was for vessel charters for fieldwork and fuel for those charters (Figure A2). Together these two items accounted for 38% of the total funding. ROV contracts (20%) and the multibeam mapping conducted in southeast Alaska (13%) accounted for another large portion of the budget. Equipment and supplies accounted for 10% of the project cost. Contract personnel, grants to Universities made up 8% of the budget. Other contracts (4%), travel (4%), overtime for fieldwork (3%), and transportation of equipment (1%) made up the remainder of the budgets.

These values represent only the DSCRTP contribution ($2.55 million). Since much of the external funds were used to offset vessel and fuel costs, the percentage of the total budget consumed by these two components rises to 47% when the external funds are considered.

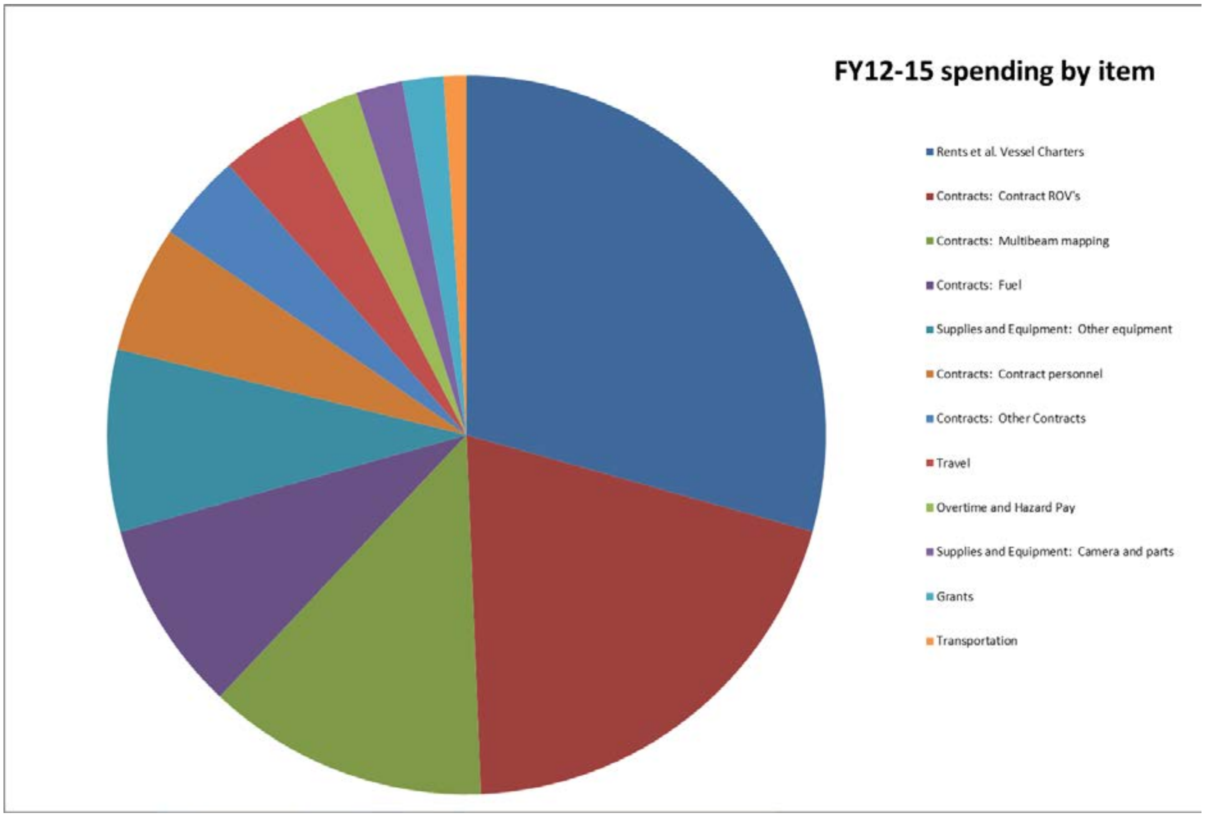

Figure A2. Expenditures by type for FY12-15 during the lifetime of the Alaska Coral and Sponge Initiative.

8.2. Publications to date

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8.3. Electronic resources:

Site Characterization Reports

- Aleutian Islands - https://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-351.pdf
- FMP species productivity sites - https://www.afsc.noaa.gov/Publications/ProcRpt/PR2017-06.pdf

Image gallery

- https://deepseacoraldata.noaa.gov/gallery

Sediment and bathymetry maps for EBS, GOA and AI

- http://www.afsc.noaa.gov/RACE/groundfish/Bathymetry/default.htm

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- http://docs.lib.noaa.gov/noaa_documents/CoRIS/Alaska_Deep-Sea_Coral_Workshop_Report_Final.pdf