Rockfish Recovery in the Salish Sea; Research and Management Priorities

A Workshop

Dan Tonnes, Editor

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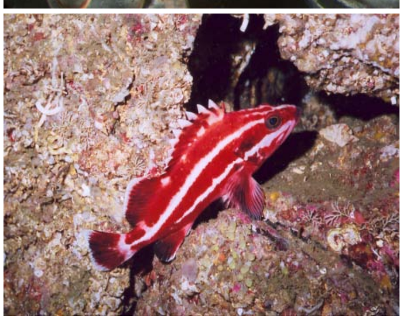

The yelloweye rockfish photo's are courtesy of Janna Nichols. The larval rockfish photo is courtesy of Mark Tagal.

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Rockfish Recovery in the Salish Sea: An Introduction to the Workshop

Dan Tonnes and Joe Gaydos

Rockfish comprise at least 28 of the over 200 species of fish within the Salish Sea. Because of their unique life-history, past over-exploitation, and currently degraded habitats, populations of many rockfish species in the Salish Sea have declined and some have been listed as Species of Concern by the State of Washington under the U.S. Federal Endangered Species Act and the Canadian Species at Risk Act. The Salish Sea comprises over 6,900 square miles of habitat used by rockfish and is managed under the various jurisdictions of the Government of Canada, the United States, and the State of Washington. This workshop convened scientists, managers, and industry professionals to focus on recent and on-going research and recovery efforts of rockfish and their habitats in the Salish Sea to enable further collaboration.

The first day of the workshop included sessions detailing recent research on the historical context of rockfish depletion, benthic habitat surveys and abundance estimates, stressors, ecosystem and species interactions, juvenile recruitment, and genetics.

The second day of the workshop focused on agency, tribal, and Canadian perspectives on rockfish recovery, and included concurrent sessions designed to list additional research priorities related to reserves and population biology. A final plenary session focused on collaborative planning and additional research needs. A survey was distributed at the end of the workshop regarding the regional recovery priorities and the relative amount of research needed to implement each measure.

Past rockfish workshops and symposiums have focused on the establishment of reserves (Yoklavich 1998), population biology, assessments, and management (Heifetz et al. 2005), and conservation of ecological genetics and stock structure (Berntson et al. 2007) along the North Pacific[1]. This workshop specifically focused on rockfish in the Salish Sea because of its unique and diverse habitats, and its complex socioeconomic dynamics that influence rockfish research and recovery measures.

Acknowledgements

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[1] Yoklavich, M. 1998. Marine harvest refugia for west coast rockfish of North America, A workshop summary. Environmental Conservation 25(3):273. Heifetz, J., J. Dicosimo, A.J. Gharrett, M.S. Love, V.M O'Connell, and R.D. Stanley (eds) 2007. Biology, assessment and management of North Pacific Rockfishes. Alaska Sea Grant, University of Alaska Fairbanks. Berntson, E.A, P.S. Levin and P.C. Moran (editors). 2007. Conservation of North Pacific rockfishes: Ecological genetics and stock structure. Proceedings of the workshop, March 2-3, 2004, Seattle, Washington. U.S. Dept. of Commerce., NOAA Technical Memo, NMFS_NWFSC-80, 80p.

The Biology and Assessment of Rockfishes in Puget Sound

Wayne A. Palsson, Tien-Shui Tsou, Greg G. Bargmann, Raymond M. Buckley, Jim E. West, Mary Lou Mills, Yuk Wing Cheng, Robert E. Pacunski, Washington Department of Fish and Wildlife

This technical review supports and is a source document for the Puget Sound Rockfish Conservation Plan. It summarizes the current knowledge of rockfish biology in Puget Sound (life history, habitat usage, and ecosystem linkages), provides an overview of the exploitation history of rockfishes, and examines their current stock status. The review also includes a series of recommendations to improve the understanding and management of rockfishes in Puget Sound. Puget Sound includes all the inland marine waters of Washington including the U.S. portions of the Straits of Juan de Fuca and Georgia, the San Juan Islands, Puget Sound proper, and Hood Canal.

Rockfishes are bottom fishes managed under the auspices of the Puget Sound Groundfish Management Plan and are co-managed with the Treaty Tribes of Washington. The present management plan by the Washington Department of Fish and Wildlife implements a precautionary policy for groundfish management. However, previous management efforts have ranged from targeting recreational and commercial fisheries on rockfish to passive management. As rockfish stocks declined during the past three decades, the Department has progressively restricted the harvest opportunities for rockfish by eliminating targeted commercial fisheries, reducing recreational bag limits, and discouraging or eliminating recreational fisheries targeting rockfish in Puget Sound.

Rockfishes in Puget Sound are a diverse group that form mixed species assemblages and require species-specific habitats at different life-stages. Rockfish have evolved complex life strategies adapted for long-term survival, slow growth, late age-at-maturity, low natural mortality rates, and high habitat fidelity. Reproduction follows a pattern of irregular successful recruitment events. Population structure is highly dependent upon the evolutionary and ecological patterns of each species. Copper, quillback, and brown rockfishes living south of Port Townsend form a unique population separate from northern waters. Rockfishes feed on a wide variety of prey, including plankton, crustaceans, and fishes. Rockfishes are prey for a variety of predators including lingcod and other marine fishes, marine mammals, and marine birds. Rockfishes are very susceptible to barotrauma (i.e., being captured and brought to the surface from depth).

The complex oceanography and benthic topography of Puget Sound influences rockfish distributions and population characteristics at all life-stages. Most adult rockfish are associated with high-relief, rocky habitats, but larval and juvenile stages of some rockfishes make use of open water and near-shore habitats as they grow. Near-shore vegetated habitats are particularly important for common species of rockfish and serve as nursery areas for juveniles and later provide connecting pathways for movement to adult habitats. A system of marine reserves in Puget Sound provides rockfishes with protection from harvest and provides a baseline for ecological and natural demographic information for stock assessment and conservation.

Rockfish have been harvested by Native Americans and commercial and recreational fishers in Puget Sound. Rockfish harvests prior to 1970 were small relative to those between the mid-1970s through the mid-1990s when both recreational and commercial fishing effort increased. In 1974, a Federal court decision reallocated salmon harvest on an equitable basis between tribal and non-tribal harvesters. Bottom fish and their fisheries were popularized for their sport, value, and healthful benefits, and previous non-tribal effort shifted to fishing for bottom fish. Since 1995, tribal fishers can harvest up to 50 percent of the rockfish quota. However, tribal harvests have accounted for an average 1 percent the total rockfish harvest since 1991. Regulations enacted during the past decade to conserve rockfishes reduced recent harvests by 90 percent.

The present status of rockfishes in Puget Sound was characterized using fishery landings trends, surveys, and species composition trends to evaluate rockfish stocks' vulnerability to extinction. These evaluations rely upon fishery-dependent and independent information to detect changes over time. Conventional age structure population models or biomass dynamic models were not applied because of the lack of long-term catch data and associated biological information. The American Fisheries Society's Criteria for Marine Fish Stocks were modified as a robust approach to establish stock status. These criteria are based upon life history parameters relating to population productivity and compare the magnitude of stock trends over ecologically appropriate time scales. Four status categories were based upon the magnitudes of trends and included Healthy, Precautionary, Vulnerable, and Depleted. Most rockfish species were in Precautionary condition; however, copper rockfish were Vulnerable in South Sound and quillback rockfishes were Vulnerable and Depleted in North and South Sound, respectively. Based upon stock assessments in adjacent coastal waters, yelloweye and canary rockfish were in Depleted status in North and South Sound. The relatively deepwater greenstriped rockfish, redstripe rockfish, and shortspine thornyheads were in healthy condition as were stocks of Puget Sound rockfish in South Sound. The health of rockfish stocks in Puget Sound is impacted by factors that remove excessive numbers of individuals, chronically alter or degrade their habitats and block life history pathways, or affect other species that increase predation, disease, or competition. Many stressors potentially limit the productivity of rockfish stocks in Puget Sound and include fishery removals, age truncation, habitat disruption, derelict gear, hypoxia, predation, and fishery removals of larger and older individuals. These stressors may have even greater impacts when stocks are at low levels, causing higher mortality rates that can drive stocks to dangerously low levels. Among the potential stressors, fishery removals, derelict gear, hypoxia, and food web interactions are the highest relative risks to rockfish in Puget Sound. Chemical contamination is a moderate risk manifested by undetermined reproductive dysfunction associated with exposure to endocrine disrupting compounds, loading of larvae with persistent organics via maternal transfer, exposure of pelagic larvae to toxics via contaminated prey, and exposure of long-lived adults to toxics like polychlorinated biphenyl compounds that accumulate over the life of the fish. These are most likely to impact rockfish living in urban areas but may be more widespread in the food web.

Based upon this review of information and the condition of rockfish stocks in Puget Sound, a series of recommendations were developed to improve the conservation and management of rockfishes in Puget Sound. Principal recommendations are to improve our knowledge of rockfish in the ecosystem and their habitat requirements; better identify, quantify, and control stressors on rockfish stocks; improve the management of rockfishes by evaluating the effectiveness of marine reserves, minimizing bycatch and accounting for all catch; improve stock assessment by conducting comprehensive and frequent surveys that estimate life history parameters such as maturity, growth, and mortality; better define stocks and populations through genetic analysis; and develop quantitative models to reconstruct and analyze the abundance and demographic population structure.

Ecological History of Rockfish Exploitation in Puget Sound: Understanding the Past to Inform Future Recovery

Gregory D. Williams, Northwest Fisheries Science Center

Rockfish (*Sebastes* spp.) have significantly declined in abundance in Puget Sound, WA (USA), with recent listings of three individual species under the Endangered Species Act. We reviewed the history of rockfish exploitation in Puget Sound and the social and economic factors driving this exploitation to better understand the ecological legacy of fishing to this degraded ecosystem. Over time, rockfish exploitation patterns have changed from an opportunistic subsistence activity by indigenous peoples to a year-round commercial and recreational target. These harvests together peaked (almost 400 million tons) in the early 1980s as anglers' attitudes changed, gear technology improved, rockfish became more familiar to the market, and agency programs promoted fisheries to sustain employment. Rockfishes were generally not managed intensely or with conservation goals in mind until the late 1980s, in part because of scientific shortcomings and lack of resources. However, by the time management actions were deemed necessary, the greatest harvests had already occurred. The low intrinsic productivity of most rockfish species suggests that the legacy of fishing will remain for years to come. As managers strive to restore the integrity and resilience of Puget Sound, they must realize the significance of historical fishery removals to the ecosystem while using the proper social and economic incentives to motivate conservation.

This presentation is based on a previously published paper. Below is the citation and reference for that publication:

Williams, G. D., P. S. Levin, and W. Palsson. 2010. Rockfish in Puget Sound: An ecological history of exploitation. Marine Policy. Volume 34, pages 1010 to 1020.

Reconstructing Historical Trends in Rockfish Abundance from Local Ecological Knowledge in Puget Sound, Washington

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Abstract

In Puget Sound, Washington, long-lived rockfishes (*Sebastes* spp.) have declined from past abundances; however, the magnitude of these changes is difficult to quantify because of limited historical data. This study developed a time series of relative abundance for rockfishes and other bottom fish species over the last 70 years from interviews with fishers, divers, and researchers in Puget Sound.

Introduction

Lacking historical records of fish populations, scientists, managers, and stakeholders may be confronted with a loss of collective memory that leads to misconceptions about the sustainability of fisheries. Pauly (1995) described this phenomenon as the "shifting baseline syndrome," in which successive generations accept the ecosystem state that occurred at the start of their lifetimes as the baseline for evaluating future changes. Shifting cognitive baselines can lead to the use of inappropriate biological reference points, ineffective stock rebuilding measures, and a gradual accommodation of species losses (Pauly 1995). Consideration of present ecosystem changes in the context of the past is challenging when historical data on species abundance and composition are of limited availability, quality, or consistency. In data-poor systems, local ecological knowledge (LEK) can be a valuable source of place-based, historical information about harvested populations (Johannes 1998). Information derived from interviews with resource users has been used in combination with contemporary fisheries data, historical documentation, and archaeological information to identify temporal changes in population structure (Ames 2006), reconstruct historical abundance trends of harvested species (Ainsworth et al. 2008), and facilitate ecological modeling of past systems (Pitcher 2001).

In Puget Sound, Washington, limited historical data for many fishes and invertebrates poses a challenge for setting management targets and evaluating recovery of harvested species. This is of particular concern for rockfishes (*Sebastes* spp.), long-lived species that have declined throughout their range over recent decades (Musick et al. 2001). Puget Sound is home to 13 rockfish species (*Sebastes* spp.) of concern, three of which are federally protected under the Endangered Species Act (NOAA 2010). Abundance, size structure, and catch records are lacking for many rockfish species and available data are insufficient for stock assessment because of coarse aggregation by species or location (Williams et al. 2010). To address information needs for rockfish conservation and management, we developed an historical record of rockfishes and other marine species in Puget Sound over the last 70 years using LEK. Specifically, our objectives were 1) to reconstruct trends in marine populations since ca. 1940 using knowledge collected from interviews with fishers, divers, and researchers; and 2) to evaluate whether shifts in a perceived historical baseline of rockfish abundance have occurred in Puget Sound.

Methods

Interview approach

We used a stratified chain referral approach (Bernard 2006) to identify individuals with specialized knowledge of Puget Sound species acquired through commercial, recreational, and scientific activities. In-person interviews were conducted with 101 individuals residing in twelve counties bordering Puget Sound. Interview respondents ranged in age from 24 to 90 years (median = 60; Table 1). Recreational fishing was the principal activity type for the majority of respondents (55 percent), followed by recreational diving (16 percent), research (14 percent), and commercial fishing (10 percent).

Respondents provided qualitative rankings of abundance for 23 Puget Sound groundfish species, including 7 rockfishes: black rockfish (*S. melanops*), bocaccio (*S. paucispinis*), brown rockfish (*S. auriculatus*), canary rockfish (*S. pinniger*), copper rockfish (*S. caurinus*), quillback rockfish (*S. maliger*), and yelloweye rockfish (*S. ruberrimus*). For each decade from 1940 to 2000, respondents were asked to characterize the relative abundance of each species according to seven qualitative categories: very high (VH), high (H), medium-high (MH), medium (M), medium-low (ML), low (L), and very low (VL). Individuals were asked to base these characterizations on their observations and were allowed to skip time periods for which they had insufficient knowledge. Interview approaches were based on those of Ainsworth et al. (2008). Color photos of fish were used as visual aids to ensure that the interviewer and interviewee were referring to the same species regardless of potential differences in nomenclature.

Table 1. Number of respondents by age group.

Age group	
20-29	2
30-39	7
40-49	9
50-59	30
60-69	32
70-79	13
80-89	5
90-99	3

Analysis of abundance trends

Linguistic abundance categories were converted to numerical indices scaled between 0 (VL) and 1 (VH). Relative rockfish abundance by decade was summarized as the mean and first and third quartiles of abundance scores across respondents. All rockfish species showed declining trends in abundance and were combined into one group for subsequent analysis. If shifts in cognitive baselines have occurred in Puget Sound, we expected to observe the following: 1) older individuals would perceive a greater magnitude of decline over time than younger individuals (e.g., Ainsworth et al. 2008); and 2) the slope of the relationship between mean abundance scores and respondent age would vary by decade. Specifically, older individuals would report lower relative abundance during later time periods compared to younger individuals. To address the first hypothesis, we computed the mean (±SE) change in rockfish abundance scores from 1970 to 2000 across respondents in each age group (Table 1). We limited the period of analysis to decades in which all age groups had made observations of rockfish abundance. To evaluate the second hypothesis, we used a multinomial logistic regression to estimate the probability of categorizing rockfish abundance as low or high as a function of period (decade) and respondent age. To simplify interpretation of the results, linguistic abundance categories were reclassified as low (VL and L), medium (ML, M, and MH), and high (H and VH).

Results

Respondents perceived declines in all rockfishes (Figure 1), though the rate and magnitude of decline varied among species (e.g., Figure 2). Variation in respondents' abundance scores for each decade was related to age, with older individuals reporting relatively lower abundance for all time periods. Based on mean abundance scores from the interviews, rockfishes decreased from relatively high abundance during the 1940s to relatively low abundance during the 2000s, with the greatest rate of decline occurring from the 1960s to the 1990s (Figure 1). Black rockfish (*S. melanops*) showed the steepest rate of decline among rockfishes, with a nearly two-fold decrease in the mean abundance index between the 1970s and the 1990s (Figure 2a). Bocaccio (*S. paucispinis*) were observed to be at relatively lower abundance than other rockfishes during all periods (Figure 2b).

Older respondents perceived a greater magnitude and rate of decline in rockfish abundance since the 1970s than younger individuals ($F_{1,4}$ = 9.58, r^2 = 0.71, P = 0.036; Figure 3). Respondent age and period (decade) were significantly related to the probability of reporting a particular category of rockfish abundance ($P < 0.001$). Predicted probabilities from the fitted multinomial logistic regression showed that: 1) the probability of rockfish abundance being categorized as low increased with age, while the probability of high abundance decreased with age, and 2) the probability of low abundance increased with decade, while the probability of high abundance decreased over time across all respondent age groups (Figure 4).

Discussion

Local ecological knowledge of fishers, divers, and researchers suggests that populations of seven rockfish species in Puget Sound have been in decline since at least the 1960s. This supports scientific claims that rockfishes have diminished throughout the Salish Sea over recent decades (Palsson et al. 2009, Williams et al. 2010). Three species that were recently afforded Federal protection under the Endangered Species Act—bocaccio (*S. paucispinis*), yelloweye rockfish (*S. ruberrimus*), and canary rockfish (*S. pinniger*)—were perceived as relatively less abundant than other rockfishes across all decades. Differences in perception of rockfish decline among respondent age groups were consistent with the shifting baseline syndrome. Overall, the perceived magnitude and rate of decline in rockfish abundance increased with respondent age. Younger respondents were more likely to report high abundance and less likely to report low abundance than older individuals across all periods. The strength of the relationship between age and perceived abundance for each period decreased with time because by the 2000s, the probability that any respondent perceived high rockfish abundance was very small. This is among a growing number of studies that show evidence for shifting baselines in marine ecosystems (e.g., Saenz-Arroyo et al. 2005; Ainsworth et al. 2008).

Information obtained from interviews about fish populations is filtered through the experiences and memory of the respondent and, as our findings suggest, is influenced by an individual's age or years of experience in the marine environment. Perceptions of species abundance may also be influenced by observational biases imposed by fishing, diving, and research practices. For example, harvest regulations, gear selectivity, and limited access to particular depths or habitats will constrain individuals' opportunities to observe fish. As a result, their observations may be temporally and spatially biased or limited to particular species or sizes of fish. Statistically evaluating the effects of resource use practices, geography, and demographic factors on perceived species abundance will help to discern biological patterns from variation imposed by respondent differences.

Limited time series data on rockfish abundance precludes rigorous comparisons between abundance trends derived from interviews and scientific surveys; however, concordance between survey and interview trends for other Puget Sound species (e.g., lingcod, *Ophiodon elongatus*, and harbor seal, *Phoca vitulina*) suggests that expert knowledge in combination with available data may help resolve patterns of abundance for data-poor species. Fuzzy expert systems (Zadeh 1965) provide a quantitative framework for integrating diverse data types, such as relative abundance scores from interviews and catch per unit effort data, into a single abundance index. For instance, Ainsworth et al. (2008) used depletion indicators (body size decrease or price increase) in combination with qualitative abundance scores to derive trends in abundance of eastern Indonesian fish populations. We will use similar approaches to develop time series of rockfish abundance indices from interview responses coupled with available catch and effort data. Continued development of creative analytical tools for use and interpretation of qualitative information may be essential for understanding long-term ecological change in Puget Sound.

Acknowledgements

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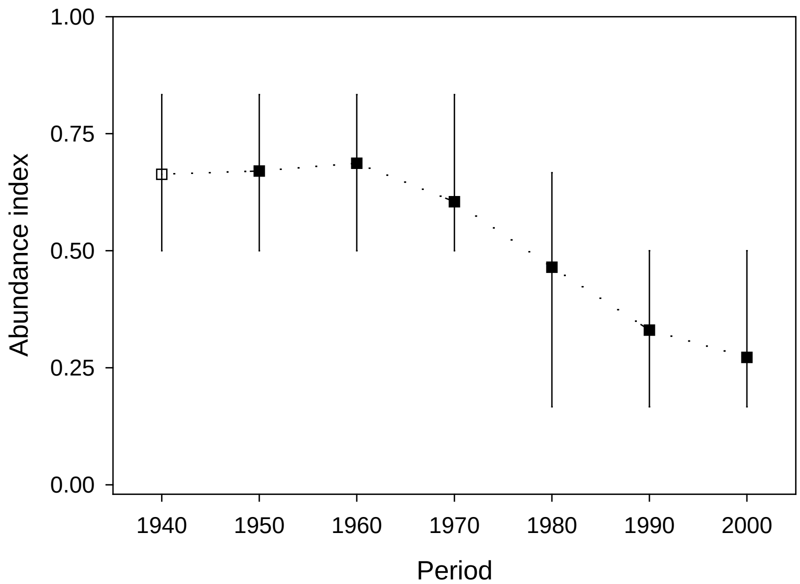

Figure 1. Mean decadal abundance index reported by respondents (N = 101) for all rockfishes combined (*Sebastes* spp.). Whiskers show first and third quartiles of observed values. An index of 1.0 corresponds to a score of "very high" abundance, 0.5 is "medium" abundance, and 0 is "very low" abundance.

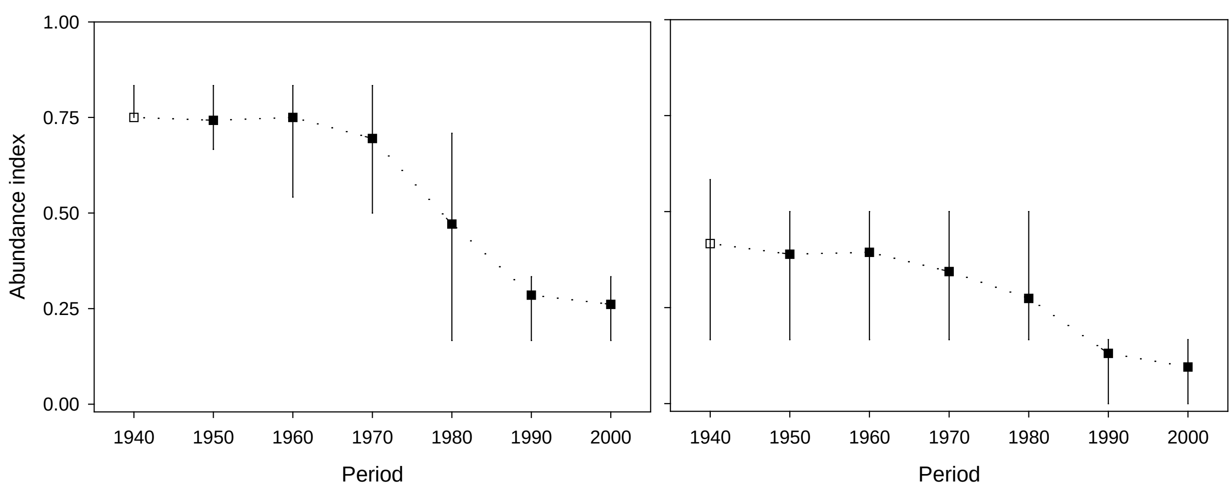

Figure 2. Mean decadal abundance index reported by respondents (N = 101) for (a) black rockfish (*S. melanops*) and (b) bocaccio (*S. paucispinis*). Whiskers show first and third quartiles of observed values. An index of 1.0 corresponds to a score of "very high" abundance, 0.5 is "medium" abundance, and 0 is "very low" abundance.

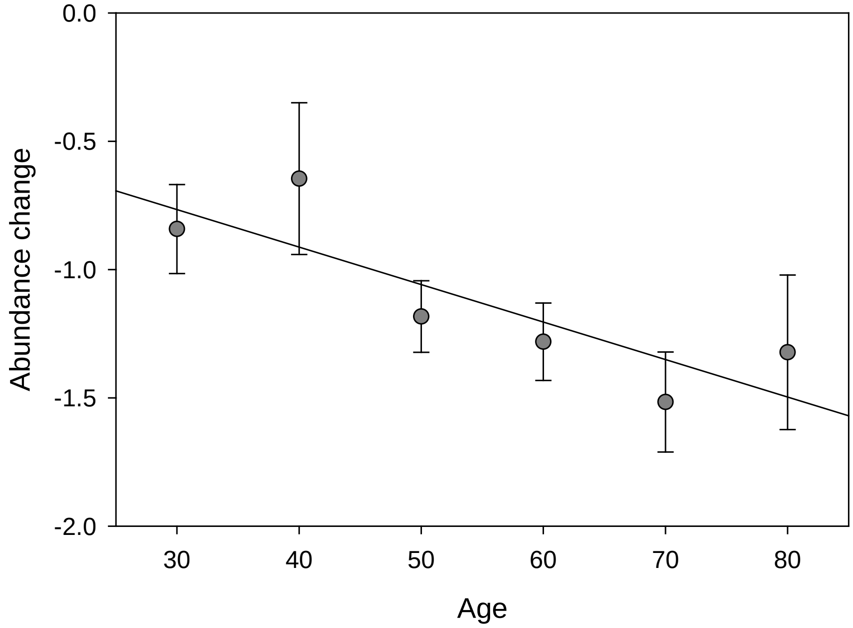

Figure 3. Mean (±SE) change in rockfish (*Sebastes* spp.) abundance scores from 1970 to 2000 across respondent age groups (sample sizes reported in Table 1). The two youngest and two oldest age groups were aggregated due to small sample sizes (i.e., age group 30 includes ages 20-39 and 80 includes 80-99). A change of -1.0 corresponds to a decrease of one linguistic abundance category (i.e., “high” to “medium-high”).

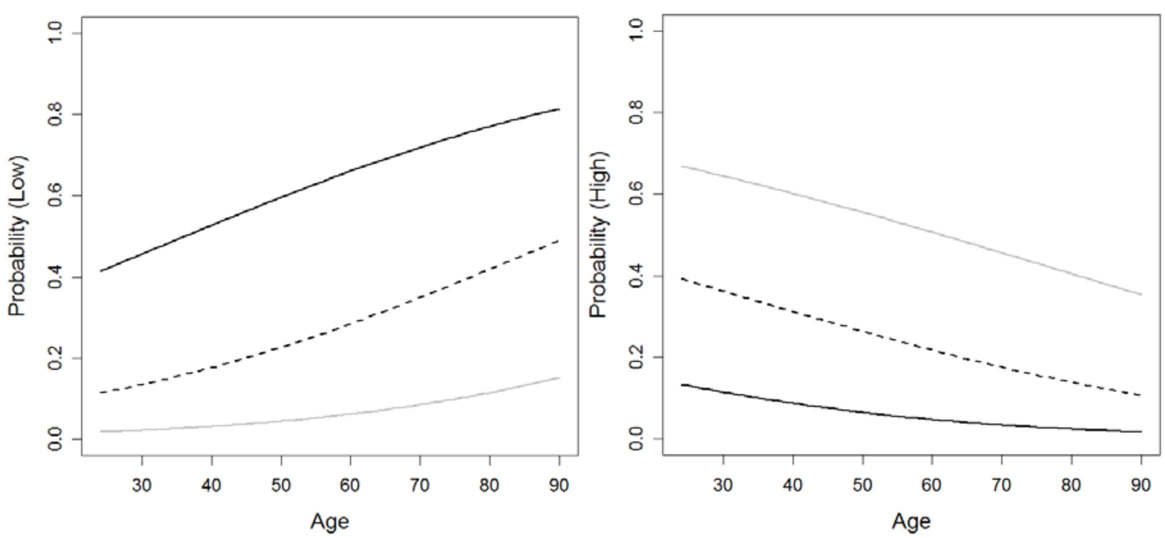

Figure 4. Predicted probability of reporting (a) low and (b) high abundance as a function of respondent age from a multinomial logistic regression for three periods: 1960 (solid gray line), 1980 (dashed black line), and 2000 (solid black line).

Mapping the Salish Sea Floor for Rockfish Habitat

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Abstract

Rockfish like rocks, thus the name “rockfish.” One thing that geologists and geophysicists can do well is to identify rocks on the seafloor. This is especially true today with the most up-to-date geophysical tools available (e.g., multibeam echosounders (MBES), side-scan sonar, and subbottom seismic reflection profile mapping systems). However, there are many different types of rock and rockfish are particular about the rocks they like. For example, flat smooth rock exposures with little relief appear to attract few rockfish, while high relief, rugose, and differentially-eroded rocks attract many rockfish. Different species of rockfish appear to be attracted to rocks of different geometry, texture, and lithology. For example, adult yelloweye rockfish (*Sebastes ruberrimus*) congregate in and around large boulders and broken rock while tiger rockfish (*S. nigrocinctus*) prefer cracks and crevices. Rockfish at different life stages also prefer to congregate on different substrate than adult rockfish. Being able to remotely image these differences is important to indentifying potential marine benthic habitats of rockfish.

For the past 14 years, extensive seafloor mapping has been done in the San Juan Archipelago and southern Georgia Strait with the production of potential marine benthic habitat maps that can be used to identify rockfish habitats. Under a cooperative agreement between Tombolo and the Geological Survey of Canada, extensive Salish Sea floor mapping has been completed and is available in hard copy and electronic map formats. Use of such maps to identify rockfish habitat, manage the fishery, and to monitor marine protected areas and no-take zones is critical to the sustainability of rockfish.

Introduction

The Salish Sea has suffered a severe decline in several species of bottom fish over the past several decades probably because of environmental degradation and over fishing (Puget Sound Ambient Monitoring Program 2002). In the year 2000, no U.S. governmental effort was in place to address marine benthic habitat characterization and analyses of the San Juan Archipelago even though the Federal Government of the U.S. was mandated to manage commercial and recreational demersal shelf fisheries under the Magnuson-Stevens Act, which defines Essential Fish Habitat (EFH) as a tool to be used in the management of fish (Public Law 104-297, 1996). For bottom fish, habitat comprises seafloor morphology, substrate, and other physical, biological, and chemical elements. EFH is defined in the Sustainable Fisheries Act (SFA) as “waters and substrate necessary for spawning, breeding, feeding, or growth to maturity” and constitutes critical habitats within the total available range of a species. To fill this void, and through the support of privately donated funds and the Canadian Government, a major seafloor mapping program was commenced in the inland seas of the Archipelago and in the Gulf Islands. Based on the premise that fish recognize no political boundary and that marine environmental degradation and overfishing can occur regardless of political boundaries, a coordinated Canadian-U.S. Transboundary seafloor-mapping program was established to use modern marine state-of-the-art technology and methodology in the characterization and mapping of benthic habitats.

Because geology plays a major role in habitat characterization, it seems logical that habitat identification and mapping should be based on geomorphology and substrate types. Therefore, not only are potential[2] marine benthic habitat types mapped but geology, geologic hazards, and anthropogenic features, to mention a few, can be mapped with the same data set. The first map series to be produced

[2] “Potential” is used here to indicate that the habitat mapped on the basis of morphology and substrate type may not have a known species or assemblage of organisms that are identified to use the habitat.

from the Salish Sea mapping effort is the "Marine Benthic Habitats of the Southern Gulf Islands and San Juan Archipelago, Canada, and USA (Greene and Barrie 2011; Figure 1).

Objectives

The primary objective of the mapping effort was to characterize marine benthic habitats and geology. The major output is interpretive maps that can be used to identify rockfish (*Sebastes* spp.) habitats, which then can be used by both Canada and the U.S. to manage, conserve, and sustain economically significant fisheries (considered outcomes) in the Transboundary region. A mechanism that has been developed to address fisheries conservation and sustainability is the establishment of Marine Protected Areas (MPAs) and voluntary no-take zones whose evaluation as a benthic habitat can be performed using potential habitat maps; this has been attempted in the San Juan Archipelago. Therefore, a secondary objective of this mapping effort is to provide data where assessment, and if necessary modification, of established MPAs, and the siting of new MPAs, can be made (see Figure 2). Additional mapping objectives evolved from the project and include the identification of specific deep-water foraging habitats (such as dynamic bedforms that harbor the major forage fish, the sand lance (*Ammodytes hexapterus*) that is preyed upon by rockfish and lingcod (*Ophiodon elongatus*)) and the understanding of forage fish habitat relationships (such as proximity to adult rockfish and lingcod habitat) that are critical to the management of rockfish.

Geologic Setting

The San Juan Archipelago-Georgia Basin region is an active tectonic province whose physiography and geomorphology reflect both Mesozoic to Cenozoic convergent (subduction/accretion) plate tectonic processes and Pleistocene glaciation (glacial scouring/deposition). These processes have juxtaposed and deformed Jurassic-Cretaceous metamorphic rocks with Tertiary-Quaternary sedimentary rocks producing a complex of fjords, grooved and polished bedrock outcrops, and erratic boulders and moraines. Banks of till and glacial advance outwash deposits have also formed and contribute to the variety of relief within the region. Present-day tidal action has fashioned much of the relic glacial-marine sediments into dynamic bedforms consisting of sand and gravel wave and dune fields (Figure 3). Modern-day sedimentary deposits (sand and mud banks) represent materials being supplied to the region by the Frazer River of British Columbia, Canada.

This tectonic province can be divided into two distinct zones based on bedrock types: a northern sedimentary bedrock zone and a southern metamorphic rock zone separated by the Haro Strait fault that cuts across northern Orcas Island and just north of San Juan Island. Both zones provide good, hard bedrock exposures; however, the sedimentary rock type is differentially eroded, thus forming ledges and overhangs while the metamorphic bedrock is highly fractured and faulted, forming cracks, crevices, and blocky boulder aprons. The severity and variety of tectonic, geologic, and physical processes active in the province are directly responsible for forming the large variety of potential marine benthic habitat types mapped in the region.

Methods

Data Acquisition and Processing

A pilot mapping project was undertaken in 2000 using a pole-mounted Reson 8101 SeaBat™ (240 kHz) swath (150° swath coverage) MBES system mounted aboard a small boat. From 2001 through 2008 the Canadian Coast Guard vessels *Otter Bay*, *Revisor*, *Young*, and *Vector*, and under the direction of the Canadian Hydrographic Service (CHS), acquired extensive high-resolution bathymetric datasets of the waterways surrounding the Southern Gulf Islands and the San Juan Archipelago. The MBES Simrad EM

Marine Benthic Habitats for the Southern Gulf Islands and San Juan Archipelago, Canada and USA

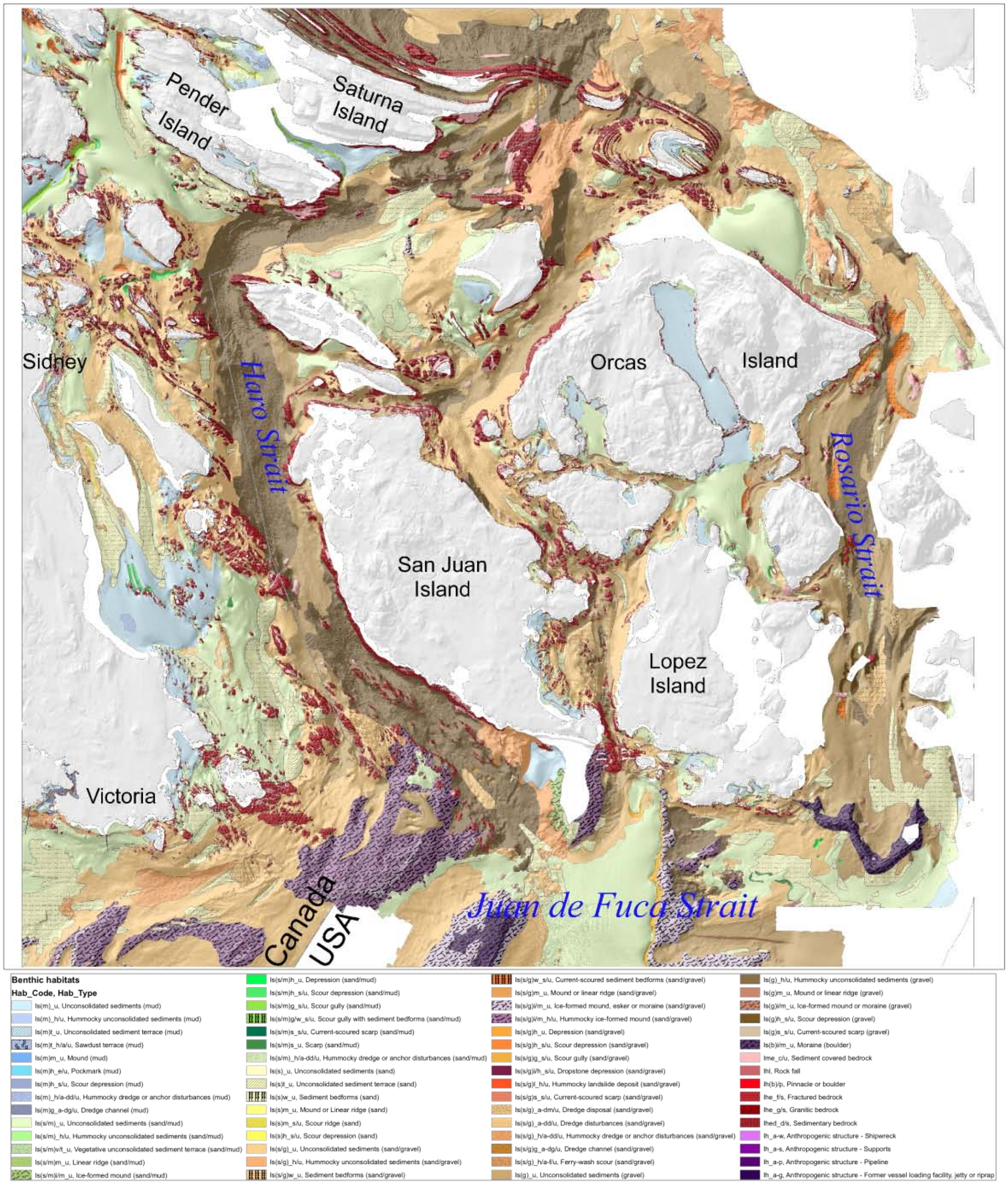

Figure 1. Map of the Transboundary area showing potential marine benthic habitat types based on substrate and geomorphology interpreted from mulitbeam echosounder bathymetry and backscatter data. Map modified after Greene and Barrie (2011), Picard et al. (2011) and (Endris et al., 2011).

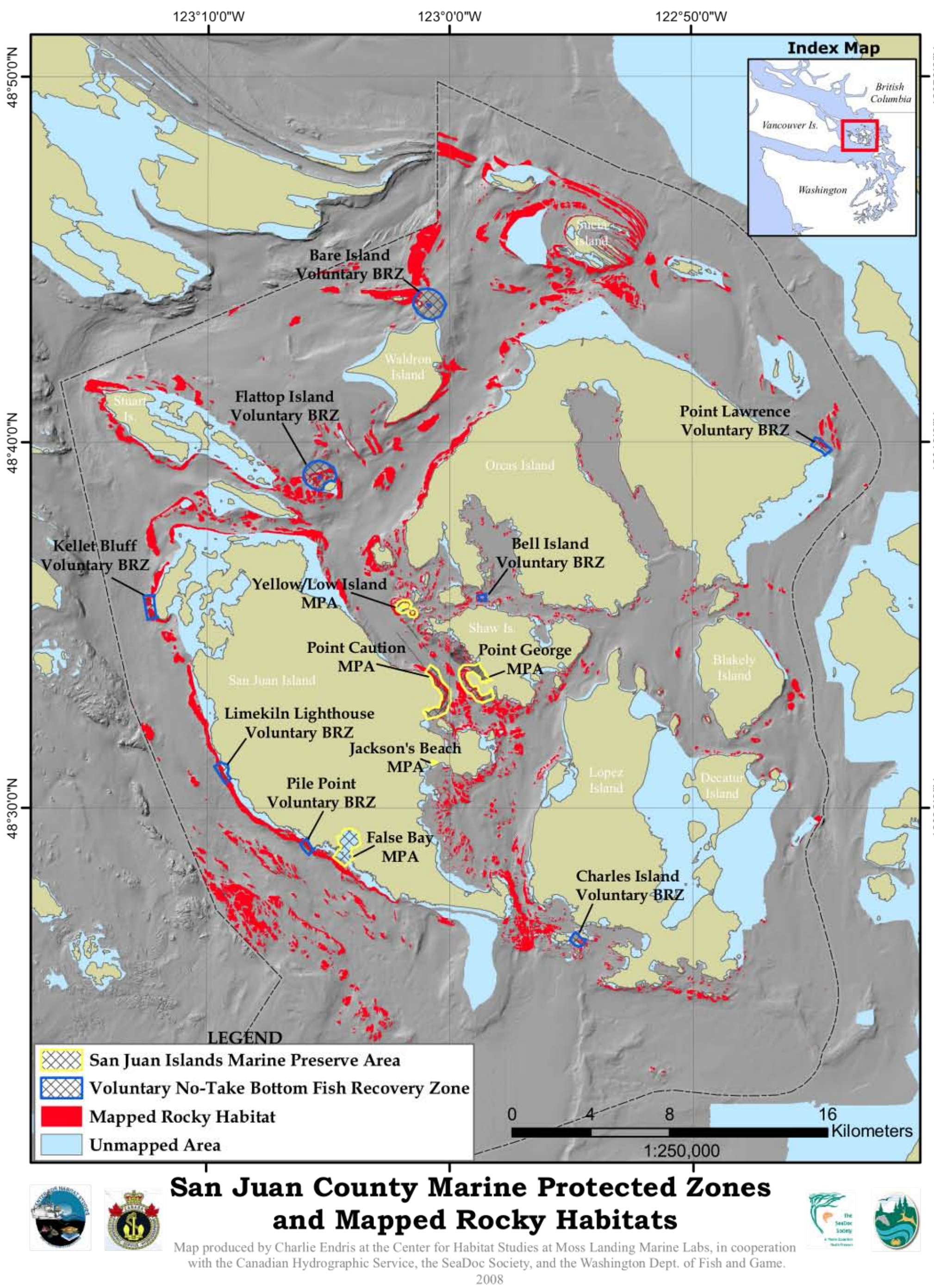

Figure 2. Potential rockfish habitats of the San Juan Archipelago (shown in red) overlain on multibeam echosounder bathymetry based on the geologic and substrate interpretations as shown in Figure 1.

1002 (95kHz frequency) and EM 3000-3002 (300 kHz frequency) systems were used for deep (>262 ft/80 m) and shallow (<262 ft/80 m) waters, respectively. The dataset resolutions were 16.4 and 6.56 feet (5 and 2 m), respectively. In most of the areas, the tracks were positioned so as to insonify 100 percent of the seafloor with a 100 percent overlap, providing 200 percent coverage. Positioning was accomplished using a broadcast Differential Global Positioning System (DGPS) and MBES data were corrected for sound speed variations in the stratified water column using frequent sound speed casts.

In addition to bathymetric data, the MBES systems collected and recorded backscatter intensity. Backscatter intensity is a measure of sound that is scattered back toward the transmitter by acoustic reflection and scattering, both at the sediment-water interface and within the sediment (volume scattering). Many factors influence the intensity value, among them are the angle of incidence of the beam, the volume scattered, the seabed slope, and the surficial sediment type and roughness. With these factors in mind, backscatter strength datasets were used to determine relative sediment differences within one or many datasets and helped to interpret the benthic habitat types. To assure the best interpretation, backscatter images were used in conjunction with other multibeam bathymetry derivative datasets, such as seafloor shaded relief, slope analysis, and bathymetric contours. The multibeam bathymetry and backscatter raster datasets, as well as the benthic habitat layer, were processed using ESRI™ ArcGIS tools.

Results

This work represents the most comprehensive seafloor mapping effort undertaken in the Salish Sea to date. Resultant map products will be useful to marine resource managers, policy makers, and scientific researchers. Using state-of-the-art MBES technology and processing software, these maps reveal for the first time the details of the seabed and can be used to interpret past and present physical seafloor processes. The interpretive potential of marine benthic habitat maps can contribute to better understanding of seafloor conditions in regard to the distribution and abundance of demersal fishes.

Sixty-two potential habitat types were mapped within our surveyed area (1,875.4566 km^2). Of these, 53 potential habitat types were composed of soft unconsolidated sediment; one was a mixture of hard rock and soft sediment, and five were hard ground or bedrock exposures including large boulders and pinnacles (Figure 4). Of the unconsolidated substrate mapped, five are glacial deposits (ice-formed mounds of various grain sizes, moraines or eskers, and drop stone depressions) and two are dynamic bedforms or sediment wave and dune fields of sand and gravel. Four anthropogenic features were mapped in primarily soft, unconsolidated substrate. Potential habitats include such features as hard bedrock exposures (153.5502 km^2, or 8.9 perecent of mapped area); deposits of unconsolidated sediment (1,384.3016 km^2, 73.81 percent of mapped area); dynamic bedforms such as sediment wave and dune fields (172.8972 km^2, 9.17 percent of mapped area); mounds and depressions (17.1032 km^2, 0.91 percent of mapped area); glacial features such as moraines, banks, eskers, and outwash lobes (114.0936 km^2, 6.08 percent of mapped area); erratic boulders and pinnacles (0.2819 km^2, 0.02 percent of mapped area); and human (anthropogenic)-influenced morphologies (6.5600 km^2, 0.35 percent of mapped area). Where possible, grain size (e.g., sand, mud, and mixed or bimodal distribution) of sediment were distinguished. All mapped characteristics are included in the marine benthic habitat scheme and GIS attribute code developed for this work and modified after Greene et al. (1999; 2007).

Of the 1,152.6229 km^2 covered by marine waters in the U.S., San Juan County, the seabed encompassing 948,74.001 km^2, or 82 percent of the total San Juan County submerged lands have been mapped by this work. Of significance to important marine benthic habitat types, mapped hard bedrock exposures that are most promising for rockfish habitat in the County total 70.3093 km^2, or 7 percent of the total mapped area. Areas most promising as forage habitats (potential sand lance habitat) consist of sand wave fields that cover an area of 171.8972 km^2, or 9.17 percent of the total mapped area. Glacial features such as moraines, banks, and eskers are also promising bottom fish habitats and cover a total area of 114.0936 km^2, or 6.08 percent of the total mapped area.

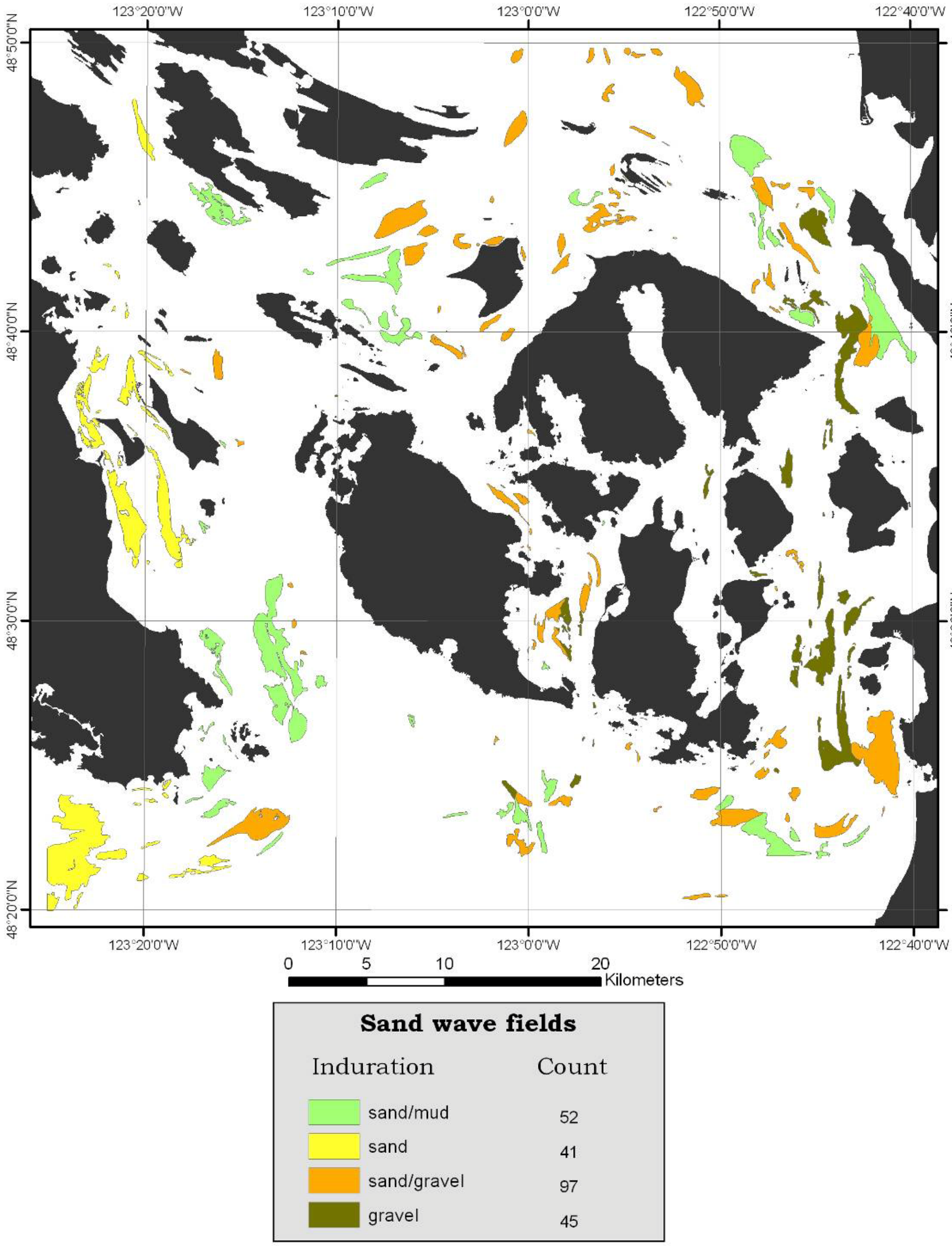

Figure 3. Locations of dynamic bedforms or sediment wave and dune fields that may act as potential forage fish habitat providing prey for rockfish. These morphologic features are based on multibeam echosounder bathymetry and backscatter data.

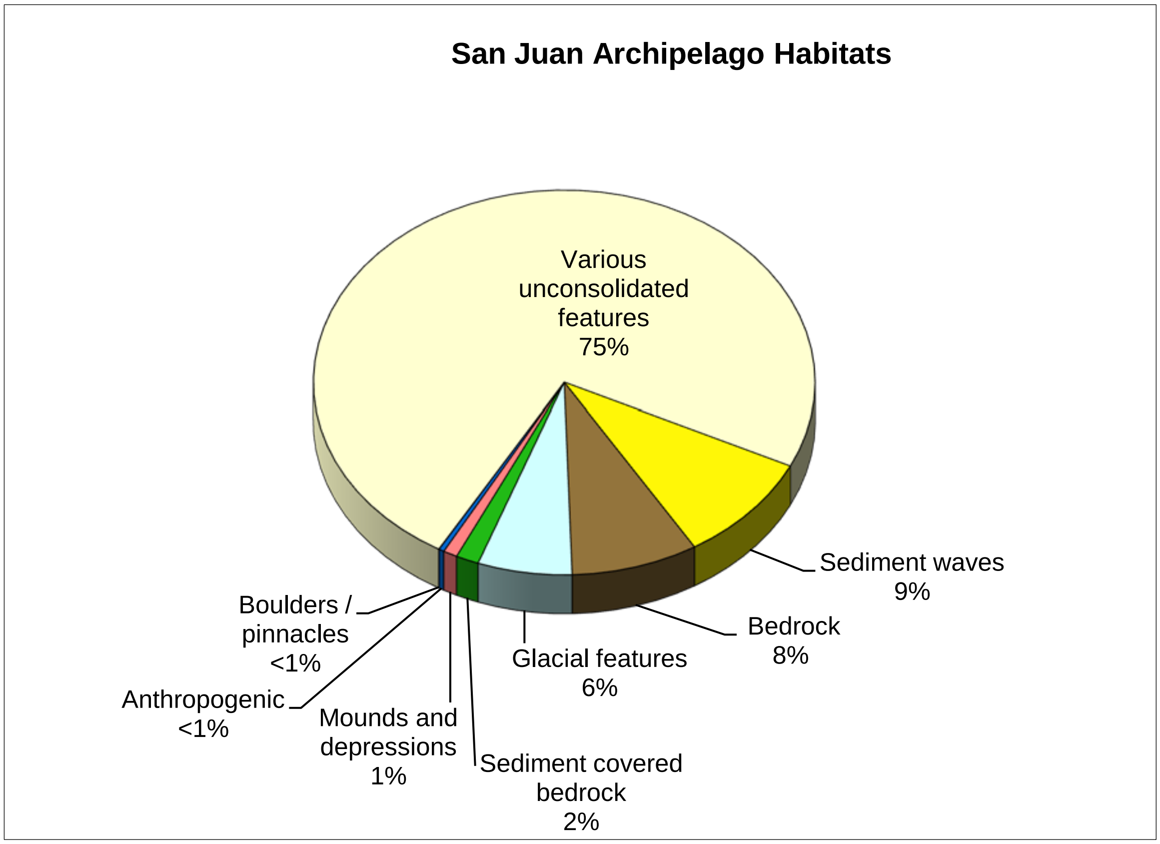

Figure 4. Pie chart showing percent of habitat types mapped in the San Juan Archipelago.

An example of a promising potential rockfish habitat area is given in Figure 5. This area has been imaged using multibeam echosounder bathymetry and backscatter data west of Sucia Island and shows a complex, deformed (folded), sedimentary bedrock outcrop. This highly rugose, differentially-eroded, hard sedimentary bedrock exposure provides cracks, crevices, and overhangs as preferred refugia for such bottom fish as tiger rockfish. In addition, these beds are often broken apart during storm events, which produce extensive aprons of angular boulders at the base of the outcrops, thus providing good boulder habitat with large void-to-clast ratios preferred by yelloweye rockfish as has been reported by Pacunski and Palsson (2001).

This work demonstrates the close relationship between potential marine benthic habitats in the Salish Sea and the geologic processes that form seafloor morphology, induration (hardness), and structure. These processes include 1) the effects from active tectonics (e.g., uplift and subsidence, formation of folds and faults, and the triggering of landslides), 2) sea level fluctuations during the ice ages of the late Cenozoic (approximately the last 2 million years) including the most recent rise of sea level, 3) scouring, erosion, and sediment deposition from the last glacial advance and retreat/stagnation, and 4) erosion, transportation, and deposition of sediment that occurred during the Holocene (about the last 12,000 years). These and other more localized processes (i.e., bottom currents, storms, and fluid flows) have greatly influenced the current locations of exposed bedrock and soft sediment, the shapes of outcrops and small basins, and the presence of other features such as mounds, depressions, and dynamic bedforms.

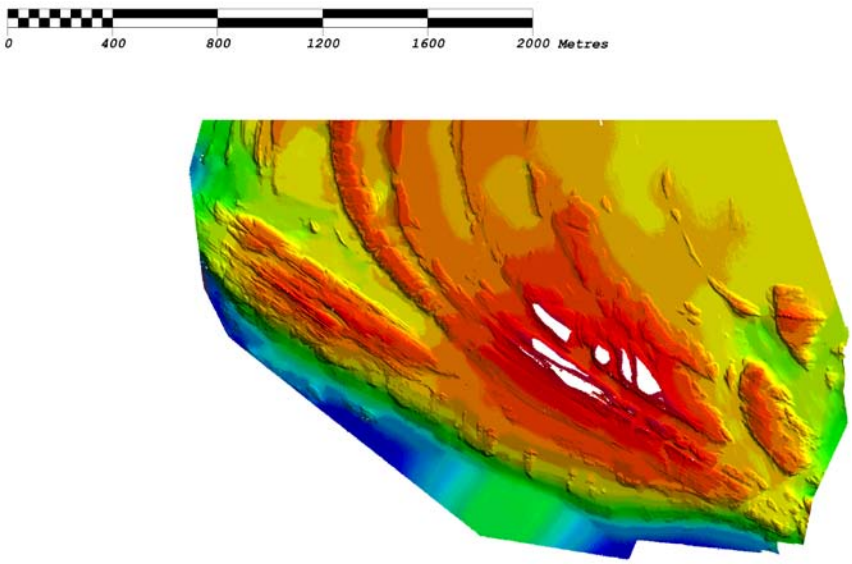

Figure 5. High resolution (2 m gridding) EM 3000 (300 kHz) multibeam echosounder bathymetric image of the deformed (folded) and differentially eroded sedimentary bedrock west of Sucia Island that is potential rockfish habitat.

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Using a Small ROV to Estimate the Abundance of Sensitive Rockfishes and Benthic Marine Fishes in a Broad-Scale Regional Survey

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Washington Department of Fish and Wildlife

Abstract

Many benthic marine fishes, such as rockfishes (*Sebastes* spp.), live in restricted habitats, have sensitive life history characteristics, or are otherwise difficult to assess and manage. Lethal sampling methods such as trawls and hook-and-line may impact population viability or inadequately sample abundance for bocaccio, canary, and yelloweye rockfishes that are now endangered or threatened species. Over the past 20 years, staff of the Washington Department of Fish and Wildlife have developed non-lethal, videographic methods for estimating the abundance of rockfish and other sensitive species. A drop-camera system was used between 1994 and 2002, but its use was limited. In 2004 and 2005, WDFW used a small, remotely-operated vehicle (ROV) to conduct small-scale surveys in San Juan channel, with results confirming its utility as a quantitative survey tool. In 2008, a region-wide study of rocky habitats in the San Juan Islands (SJI) was conducted resulting in population estimates for 42 common and rare species. This depth-stratified and randomized survey resulted in standard errors ranging from 8 to 14 percent for common rocky habitat species.

The federally-protected rockfishes have been rare in trawl surveys with seven encounters of yelloweye rockfish and 25 encounters of canary rockfish among 1,717 trawl samples in Puget Sound. However, 39 yelloweye rockfish, one canary rockfish, and four bocaccio were encountered among 207 ROV transects in 2008. To evaluate the efficacy of the ROV as a survey tool for benthic fishes regardless of habitat type, the WDFW conducted another survey of the San Juan Islands in 2010-2011. We used stratified systematic adaptive sampling (Thompson and Seber 1996; Jackson and Cheng 2001) to lower the uncertainty of the estimates. In addition, a stereological survey method was employed to correct the bias of the edge effect in the spatial sampling. Changes in equipment configuration greatly improved our ability to image flatfish and other small fishes that were rarely detected in previous surveys.

Introduction

Rockfish (genus *Sebastes*) populations in Puget Sound have declined dramatically over the past several decades (Palsson et al. 2009), with much of this decline attributed to historical fishing activities. Recently, canary rockfish (*S. pinniger*) and yelloweye rockfish (*S. rubberimus*) populations in Puget Sound were listed as “threatened” under the provisions of the Endangered Species Act (ESA), while populations of bocaccio (*S. paucispinus*) were listed as “endangered.” The biological characteristics of these and most other rockfish species in Puget Sound present significant challenges for their assessment and management. Rockfish ages can exceed 200 years for some species (Munk 2001), although most species in Puget Sound likely live to between 20-100 years (Love et al. 2002). Most rockfishes grow slowly, reach sexual maturity late in life, have low rates of natural mortality, and exhibit sporadic recruitment. These characteristics, in conjunction with the tendency to inhabit small home ranges (Matthews 1990), render rockfishes highly susceptible to the effects of fishing (Parker et al. 2000). As a result, population viability can be seriously compromised with even modest levels of removal, and populations can be quickly extirpated in areas subject to intensive fishing pressure.

In order to properly manage rockfish in Puget Sound and to meet the Federal requirements for monitoring ESA-listed rockfishes, it is critical that the Washington Department of Fish and Wildlife

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(WDFW) understand the distribution and abundance of these species. However, because rockfish typically inhabit restricted, high-relief habitats, their populations are difficult or nearly impossible to assess using traditional trawl techniques. Further, the lethal nature of sampling trawls and hook-and-line methods may severely impact population viability or provide biased measures of abundance for rarer species. In the early 1990s, WDFW began using non-lethal videographic methods in an effort to obtain fishery-independent estimates of rockfish abundance in Puget Sound. A drop-camera system was used between 1994 and 2002, but its use was limited to depths less than 37 fathoms and WDFW began experimenting with small, remotely-operated vehicles as a way to surpass this depth limitation. In 2004 and 2005, WDFW used a small ROV to conduct small-scale surveys in San Juan channel, with results confirming its utility as a quantitative survey tool. In 2008, a region-wide study of rocky habitats in the San Juan Islands was conducted, resulting in population estimates for 42 common and rare bottom fish species. In 2010-2011 WDFW conducted another ROV survey of the San Juan Islands, but altered the survey design and vehicle equipment configuration to test the efficacy of the system for collecting population data for all species of bottom fish regardless of habitat (i.e., substrate) type. The use of stereological methods in this survey will allow us to correct for the bias of the edge effects encountered in spatial sampling, and to estimate the amount of different habitat types within the SJI for comparison to an existing habitat map of the SJI interpreted from high-resolution multibeam bathymetric imagery.

Methods

The 2008 ROV survey of the SJI used a stratified-random clustering survey design based on a habitat (substrate) map developed from multibeam echosounder (MBES) and backscatter data using the methods of Greene et al. (1999; 2007). Only exposed bedrock and boulders identified in the map were used in the survey frame. To account for areas where no MBES data were available, the survey area was augmented with a low-resolution habitat map derived from the results of previous WDFW video surveys in the SJI. The survey area was stratified by depth along the 20-fathom contour line for comparison to previous WDFW drop-camera and ROV surveys conducted in the region, and individual polygons were created in a geographic information system (GIS) and points were randomly selected for conducting ROV transects (Figure 1).

The 2010 survey used a stratified-systematic design based on a stereological sampling protocol (Cheng 2011) that was independent of habitat type and focused on all species of bottom fish. Further, we incorporated an adaptive-sampling (AS) component to improve the statistical properties of some species when encountered at predetermined levels (Table 1). The SJI was stratified into eastern and western sub-regions based on the distribution of yelloweye rockfish observed in the 2008 survey. To improve the statistical properties of data collected for ESA rockfishes expected in the western sub-region, the sampling rate was designed to be about double the rate of sampling in the eastern sub-region. Stations in both sub-regions were spaced systematically in a grid pattern using a random starting point (Figure 2), with eastern stations and western stations spaced at 9,842.5 feet (3,000 m) and 6,890 feet (2,100 m) intervals, respectively. When an AS threshold was reached, additional transects were conducted at two randomly selected points 820 feet (250 m) from the original station location around the major compass points (0, 90, 180, 270 degrees).

Video imagery in the 2008 and 2010-2011 surveys was collected with a Seaeye Falcon inspection-class ROV. The vehicle measures 1.0 m in length, 0.6 m in width, and 0.5 m in height and was equipped with a 0.35 lx high-resolution (540 lines) electronic color camera and three variable-intensity 50 W incandescent lights. The ROV was connected to the support vessel via a 330 m umbilical, allowing access to all but the deepest areas within the survey region. In 2008, we used two DeepSea Power and Light® 15 mW red diode lasers mounted in parallel at 10 cm separation distance and projected into the center of the camera's field-of-view to provide reference points for estimating transect width and measuring organisms (Caimi and Tusting 1987; Tusting and Davis 1992). This configuration was also used in 2010 except that the red lasers were replaced with 5mW green lasers and additional lighting was provided by two >180 lumen Tritech LED lights. The green lasers are much more visible in high-light/low-contrast conditions, and the LED lights were mounted approximately 0.6 m forward of the camera and aimed at the bottom to improve our ability to image small flatfish and other bottom fish by reducing the backscatter of light caused by the forward facing incandescent lights. Video data in 2008 was collected onto Hi-8 digital videotapes, whereas the video data in 2010 was collected directly to computer hard drive. The time, date, station ID, and ROV position were overlaid on all the video data.

Tracking and navigation of the ROV was accomplished with a LinkQuest® 1500CH ultra-short baseline (USBL) acoustic tracking system linked to a KVH Fluxgate® compass and WAAS-enabled DGPS mounted on the support vessel. The ROV transponder was powered via the umbilical, providing a constant signal to the vessel-mounted transceiver throughout each deployment. The tracking data were collected at 1 to 2-second intervals and the geographically referenced positions of the ROV were calculated with Hypack Max® navigation software. Deployment and retrieval of the ROV are described in detail in Pacunski et al. 2008.

In both survey years, we used a strip transect approach with the assumption that all visible organisms within the strip were detected with equal probability (Barry and Baxter 1993). In 2008, we conducted transects only during daylight hours to minimize the effects of diurnal fish behavior and maintain efficient ROV operations. In 2010-2011 we conducted 15 percent of our sampling during crepuscular and nighttime hours. We conducted a 24-hour study over a 48-hour period during the survey in order to “tune” the survey results to account for possible diurnal differences in sampling periods. In 2008 the minimum target transect length was 820 feet (250 m). In 2010-2011, we used time as our metric, with each transect specified to be a minimum of 30 minutes and transect lengths estimated to range from 1,640 to 3,281 feet (500 to 1,000 m). In both surveys the majority of transects were driven into the prevailing current, although some (<5 percent) transects were conducted while drifting with the current. We attempted to maintain a consistent ROV speed and height-off-bottom although this was not always possible because of the highly variable currents and extreme topography in the study area. Camera tilt angle was maintained at 48-50 degrees below horizontal throughout each transect except when it was necessary to alter the angle for safe navigation (e.g., steep rock walls).

Results

In 2008 we completed 207 transects; 136 in the Shallow stratum (<20 fm) and 71 in the Deep stratum (>20 fm). Population estimates were made for 42 species of bottom fish (including 11 rockfish species) with standard errors ranging from 8 to 14 percent for the most commonly encountered species. Copper and quillback rockfish were the most common rockfishes encountered, with population estimates of 545,859 (14 percent SE) and 440,372 (11 percent SE), respectively (Figure 3). The spatial and depth distribution of the more common rockfishes, lingcod, and kelp greenling were consistent with earlier WDFW video and scuba surveys. Thirty-nine juvenile and sub-adult (<15.75 in. / 40 cm) yelloweye rockfish were observed on 25 transects in the SJI in 2008, resulting in a population estimate of 47,407 (25 percent SE) fish in the SJI (Figure 3). All but one yelloweye rockfish were observed at depths >20 fm, and their distribution was limited to the western side of the study area (Figure 4). Four bocaccio were observed at one station and one canary rockfish was observed at another station, both in the western SJI. The video and tracking data provided consistent confirmation of the rocky substrates on the habitat map although some discrepancies were apparent, and mostly involved incorrectly drawn polygon boundaries and several large rocky substrate areas that were missed (did not have polygons drawn around them). We did note a number of differences in the predicted habitat versus the observed habitat in non-rock areas but made no attempt to quantify the extent of these errors.

In 2010, we completed 180 transects; 61 primary transects and three AS transects in the eastern SJI, and 111 primary transects and five AS transects in the western SJI (Figure 2). Because of numerous weather delays and equipment problems we were unable to complete adaptive sampling at one station in the eastern SJI and eleven stations in the western SJI. Several originally planned stations in both sub-regions were dropped from the survey frame because they were too shallow for safe vessel navigation, and one station in the western SJI was stranded and not completed.

The 2010-2011 video data is currently being reviewed and only preliminary data is presented here. The new lighting configuration on the ROV dramatically improved our ability to detect small flatfish and other bottom fish, with identification often possible to the species level. It is unclear how the new lighting may have affected the detection of fishes in high-relief rock habitats, but they did not appear to have any effect on rockfish behavior based on the pilots' experience during previous surveys. For transects conducted on similar habitats in 2008, encounter rates for copper and quillback rockfishes appeared to be similar between the two surveys. From the field notes we noted a total of 14 yelloweye rockfish on 10 transects in 2010-2011, with all encounters occurring in the western SJI (Figure 4) on complex rocky substrates. Most transects with yelloweye rockfish had only one observation, but two transects had two fish and one transect had three fish. The change in survey design resulted in much less rocky habitat encountered in 2010-2011 and likely accounts for the smaller number of yelloweye rockfish observed. Because the 2010-2011 survey design included all habitat types, the habitat data collected from the video should allow for a more complete ground truthing of the habitat map used for planning the 2008 survey.

Discussion

The 2008 survey produced population estimates for many bottom fish species that until then could not be adequately assessed with traditional survey techniques, with highly acceptable standard errors for the most common species. The ability to detect uncommon and rare rockfishes with the ROV in successive surveys strongly validates the use of this non-lethal technology for assessing and monitoring sensitive rockfishes and other species. Although analysis of the 2010 data is not complete, we are encouraged by the ability to collect video imagery and identify small (10 to 15 cm) groundfish and flatfish to the species level.

WDFW staff is currently in the process of adding an HD camera to the ROV, which should dramatically improve our ability to capture high-resolution images of small fish and further improve identification. Also, the addition of a Doppler velocity logger (DVL) and quantitative ranging system will allow for more accurate estimates of area-swept and, thus, improved population estimates. The use of stereological analysis methods in the 2010-2011 survey will allow us to unbiasedly estimate the population density of fish species and the proportions of different types of habitats in the survey area and make inference on the estimates. In addition, the uncertainty of the yelloweye population estimates will be lower because of the application of adaptive sampling.

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Tables and Figures

Table 1. Adaptive sampling thresholds for the 2010-2011 SJI ROV survey.

Species	Adaptive Sampling Trigger
Yelloweye rockfish, canary rockfish, bocaccio	1+
Copper rockfish, quillback rockfish	>10
Tiger rockfish	>2
All other rockfish (except Puget Sound rockfish)	>4

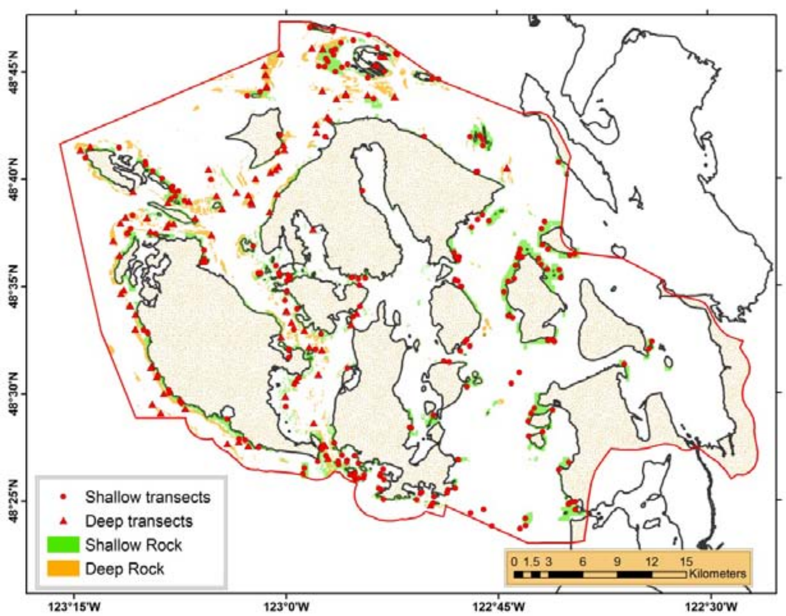

Figure 1. Sampling frame and transect start locations for the 2008 SJI ROV survey. Shallow Rock <20 fathoms, Deep Rock ≥20 fathoms.

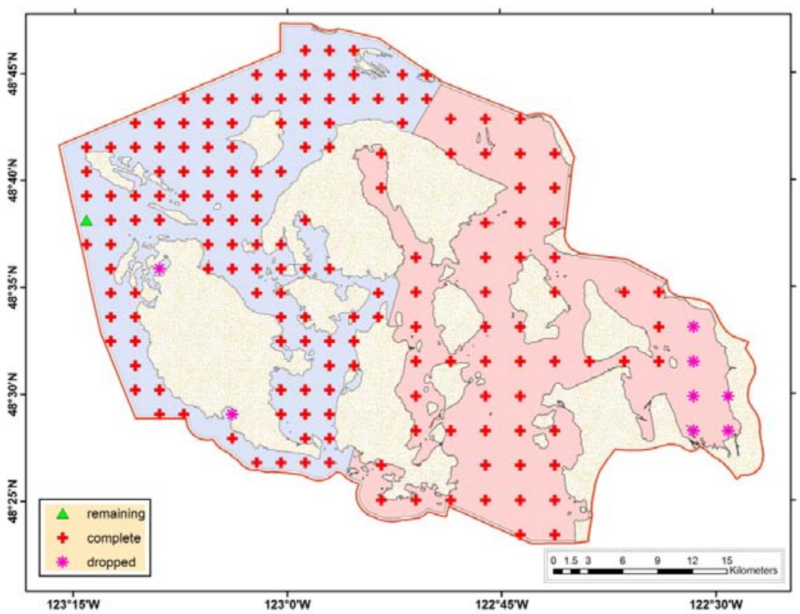

Figure 2. Sampling frame for the 2010-2011 SJI ROV survey with transect status.

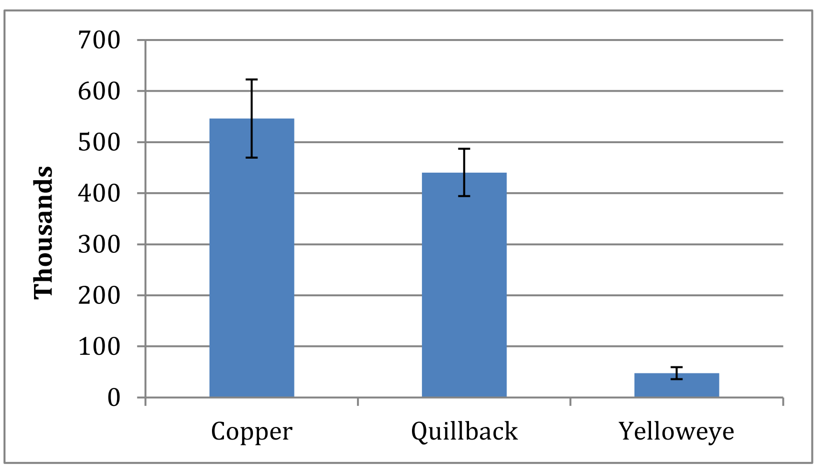

Figure 3. Population estimates and standard errors for copper, quillback, and yelloweye rockfish from the 2008 SJI ROV survey.

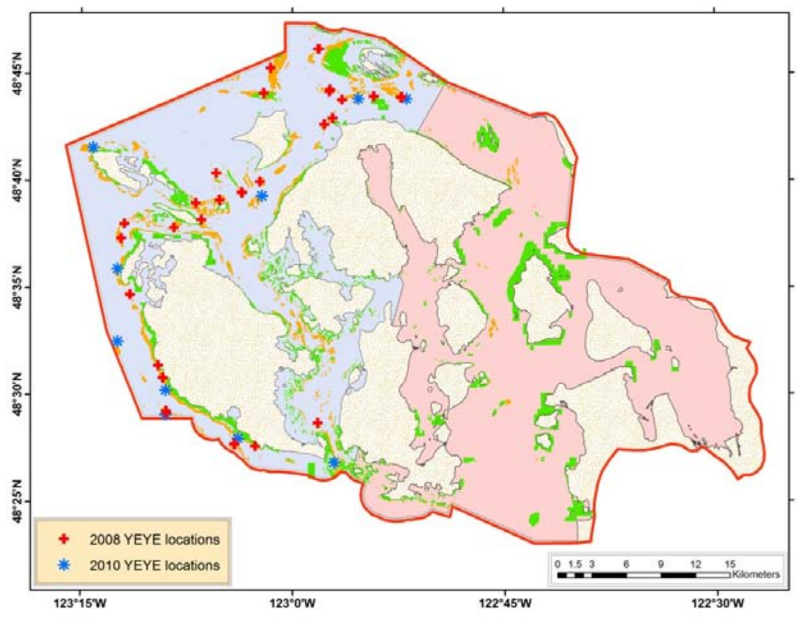

Figure 4. Locations of yelloweye rockfish encountered during the 2008 and 2010-2011 ROV surveys of the SJI, overlain on 2008 rock polygons and 2010-2011 sub-regions.

Observed Impacts to Rockfish in Derelict Fishing Gear in the Salish Sea

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Abstract

Observed mortality of rockfish in shallow water (< 105 feet /32 m) derelict fishing gear in Puget Sound and British Columbia indicates derelict nets may be a significant stressor on multiple rockfish species. Since 2002, the Northwest Straits Initiative has removed thousands of derelict fishing nets and derelict pots and traps from Puget Sound. Five hundred acres of marine habitat was restored by removing this derelict gear. In the derelict gear removed from Puget Sound, 2,402 fish were observed entangled, including 235 rockfish (*Sebastes* spp.) species making up 10 percent of all fish observed. Using an established catch rate model, the Initiative estimates that the 3,860 nets removed since 2002 were entangling more than 67,000 fish every year including over 6,700 rockfish.

The Initiative currently estimates 1,000 derelict nets remain in shallow sub-tidal high priority areas of Puget Sound, where high net fishing effort coincides with seabed characteristics likely to snag nets. The areas include known rockfish habitat, including distribution areas for canary (*S. pinniger*), bocaccio (*S. paucispinis*), and yelloweye rockfish (*S. ruberrimus*). We also know of 74 nets in deeper water. Assuming the 1,000 remaining shallow water nets capture fish at the same rate as the nets that have already been removed, we can estimate these nets are currently capturing more than 16,000 fish every year. If, as suggested by past removal observations, 10 percent of these fish are rockfish, remaining nets are capturing approximately 1,600 rockfish each year in U.S. waters of the Salish Sea.

Introduction

In Puget Sound, most derelict fishing gear are gillnets and crab pots. There are also purse seines, trawl nets, aquaculture nets, and shrimp and octopus traps. This derelict gear is of local origin, meaning it is lost by Puget Sound fishermen, rather than drifting into Puget Sound from elsewhere. Impacts from derelict fishing gear in Puget Sound are far-ranging. Synthetic monofilament nets do not degrade and continue to fish indiscriminately, killing mammals, birds, fish, and invertebrates (Good et al 2010). Derelict pots continue to fish until the escape cord disintegrates or until the pot itself disintegrates, which can sometimes take more than two years.

Derelict fishing nets in waters to 105 feet (32 m) deep have been documented to destroy valuable marine habitat important to rockfish throughout Puget Sound. Impacts include sedimentation, destruction of vegetation, and scouring. Nets also impede access to habitat. Removal of derelict nets allows the habitat to heal naturally and provides immediate access to blocked habitat. Divers have noted immediate increases in fish use after nets were removed. Removing derelict fishing gear is the most effective way to eliminate its impacts on the Puget Sound ecosystem.

The Northwest Straits Initiative has a comprehensive derelict fishing gear program that addresses the problem of derelict gear in Puget Sound through removals, research, and prevention. The cornerstones of the Initiative's removal program are: state-approved protocols, effective surveys, highly trained removal personnel, and data collection and management. The program includes a web- and phone-based, no-fault reporting system, and a web-based statewide derelict fishing gear database.

The Northwest Straits Initiative has removed more than 3,900 derelict nets and 2,495 derelict pots and traps from shallow, sub-tidal (to 105 feet /32 m) habitats of Puget Sound, documenting observed impacts to more than 215,000 animals of 222 species, including eight species of rockfish. Removed derelict gear was damaging more than 500 acres of marine habitats, including habitat important to rockfish.

Palsson (2009) identified derelict gear as a likely stressor limiting populations of rockfishes in Puget Sound. Entanglement in derelict fishing gear is identified as a stressor on rockfish in the *Puget Sound Rockfish Conservation Plan* (WDFW 2011).

Methods

The Initiative focuses net removal in all areas of Puget Sound identified as “high priority” through a collaborative process with NOAA. High priority areas are those where high historical and current fishing effort align with areas where there are obstructions such as rocky reefs, pinnacles, or seabed obstructions that can snag nets. Derelict gear is located using sidescan sonar surveys and diver verification.

The Initiative’s removal operations follow State-approved guidelines published by Washington Department of Fish and Wildlife. Removal teams consist of at least two divers, with a standby diver. Removal divers are equipped with surface-supplied air. Divers have voice contact with the removal vessel at all times. Usually, one diver is in the water while the safety diver is onboard, ready to dive if needed. When derelict gear is located, the diver reports the characteristics of the derelict gear, habitat impacted, and any entangled animals to the onboard biologist. All derelict gear removal operations are conducted by hand with the assistance of air lift bags. In order to protect the habitat, no mechanical advantage is employed during gear removal. For safety reasons, diver removal operations are limited to 105 feet (32 m) in depth. Nets that divers see that are deeper than 105 feet are documented but not removed.

When gear is hauled onto the removal vessel, the onboard biologist documents all species entangled in the gear and returns them to the water. Data collected includes: type of gear, size, estimated age and condition, and whether it is still fishing. For nets, the amount of net that is suspended in the water column is noted by divers. Data is collected about the habitat from which the gear is removed (such as rocky reef, sand bottom, etc.). All animals found in the gear as it is brought on board the removal vessel are documented. Data collected includes species and condition (live or dead).

All data is entered into the statewide database, which is housed on a structured query language web-based platform. Each piece of derelict fishing gear removed is assigned a unique gear identification number (GearID) in the database. All gear, species, and habitat impacts data are associated with this number. The database can be queried for information related to gear and impacts, such as impacts to rockfish. The results discussed below were drawn from the database.

To estimate long-term impacts of derelict nets, research was conducted to document capture of animals in derelict nets over time. Data from this study was used to develop a catch rate model (Gilardi et al 2010). This model factors in rates of carcasses, bones, and shells dropping out of the net during removal (17 percent) as well as the rate at which animals decompose, are scavenged, or are swept away (7-14 days). This model is used to estimate long-term impacts of each net removed and to project future impacts of nets that have yet to be removed.

To quantify habitat restored, the area of a removed net is used as a surrogate for habitat area. The area and location of removed nets are noted and entered into the statewide database. Where nets are stacked together, the coordinates are duplicated in the database. To determine habitat area restored, duplicates are noted and only the area of the largest net is counted. Therefore, habitat area restored is less than acres of nets removed.

Habitat is assumed to be restored when nets are removed based on a post-removal monitoring study completed by the Initiative in 2009. This study monitored four net removal sites for a year after removal operations, comparing them to adjacent control sites. The study documented 90 percent recovery of marine habitat (based on plant abundance) over one growing season without further management action (NWSI 2009).

Results/Discussion

Since 2002, the Initiative has removed more than 3,900 derelict fishing nets and 2,495 derelict pots and traps from shallow sub-tidal waters of Puget Sound. In the gear removed from Puget Sound, more than 215,000 animals representing 222 unique species were observed entangled, including 2,402 fish. Figure 1 shows locations of removed and known remaining derelict nets, as of March 31, 2011.

Two hundred thirty-five (235) rockfish were observed entangled in this gear, making up 9.8 percent of all fish observed. Eight species of rockfish were observed: canary (*Sebastes pinniger*), black (*S. melanops*), brown (*S. auriculatus*), China (*S. nebulosus*), copper (*S. caurinus*), Puget Sound (*S. emphaeus)*, quillback (*S. maliger)*, and yellowtail rockfish (*S. flavidus)*. Eighty-nine of the 235 rockfish (38 percent) observed in removed derelict gear could not be identified to species. Observed rockfish were found in 100 different items of removed gear: 87 derelict gillnets, 2 aquaculture nets, 7 purse seine nets, 2 crab pots, and 2 shrimp pots. Figure 2 shows the numbers and conditions of rockfish observed in removed derelict gear.

In February 2011, the Initiative removed a derelict purse seine net from shallow waters of British Columbia in the first Canadian derelict fishing net removal project. In the purse seine removed from British Columbia waters, one quillback rockfish was found dead. In a video taken of the net several years before it was removed, there is a rockfish pictured alive but entangled under the net. This net was known to have been derelict for over 20 years.

Using Gilardi's catch rate model, we estimate that the nets removed since 2002 were entangling more than 67,000 fish every year including over 6,700 rockfish. The limitations of this model include its reliance on observed impacts to project long-term impacts. If no rockfish are observed in a removed net, then the net is assumed to never have entangled a rockfish. Because fish decompose quickly after being entangled in nets, it is likely that nets with no rockfish observed during removal have entangled rockfish at some time. Therefore, the model probably underestimates impacts to rockfish over time.

We know that newly lost nets tend to be suspended more fully in the water column and fish entanglement increases 3.5 times in newer nets (Good 2010). Therefore, impacts on rockfish of nets lost in the 1970s and 1980s may have been greater when they were newly lost than the impacts observed upon removal many years later. Considering that thousands of nets are estimated to have been lost decades ago, it is possible that derelict nets represented a significant stressor to rockfish species during those decades, when rockfish were more abundant and the nets were more lethal.

Most of the Puget Sound removal operations were conducted in high priority areas identified by the Initiative collaboratively with NOAA. These areas coincide with rockfish habitat throughout Puget Sound. Figure 3 shows high priority areas overlaid on distribution areas for canary, bocaccio, and yelloweye rockfish.

Figure 4 shows the percentage of different types of habitat restored through gear removal from 2002 through 2010. The majority of nets have been removed from low relief rocky substrate and boulders on sand, mud, and gravel. Results show that most rockfish impacts are observed in gear removed from low relief and high relief rocky substrate. Figure 5 shows the habitat types where rockfish impacts were observed during gear removal.

The Northwest Straits Initiative estimates that approximately 5,000 nets have been lost throughout Puget Sound since the early 1970s. Most of these nets became derelict in shallow sub-tidal waters, but some have drifted into deeper water habitats. Derelict nets likely are impacting rockfish in waters deeper than 105 feet (32 m) by direct entanglement and mortality, and by impeding access to and degrading habitat.

Seventy-four derelict nets have been documented in waters deeper than 105 feet (32 m) in rockfish habitat areas in Puget Sound. Very limited surveys looking for derelict fishing gear have been undertaken, so there are likely many more deepwater nets than currently known. Deepwater surveys in California (Waters et al 2010) showed that derelict fishing gear can account for up to 38 percent of observed marine debris in marine waters at depths of 66 to 1,198 feet (20 to 365 m). Figure 6 shows locations of known deepwater nets in Puget Sound, all of which are located in rockfish habitat.

All identified shallow, high priority areas in Puget Sound have been surveyed for derelict fishing nets. We estimate about 1,000 derelict nets remain in those waters. Figure 1 shows locations of known remaining derelict nets. Assuming the remaining shallow-water nets capture fish at the same rate as the nets that have already been removed, we can estimate these nets are currently capturing more than 16,000 fish every year. If, as suggested by past removal observations, 10 percent of these fish are rockfish, remaining nets are capturing approximately 1,600 rockfish each year in shallow U.S. waters of the Salish Sea.

Acknowledgements

Significant funding for the Initiative’s derelict fishing gear research, survey, and removal operations came from NOAA Restoration Center and Marine Debris Program, USFWS Coastal and Recovery Programs, Puget Sound Conservation Fund, and the National Fish and Wildlife Foundation.

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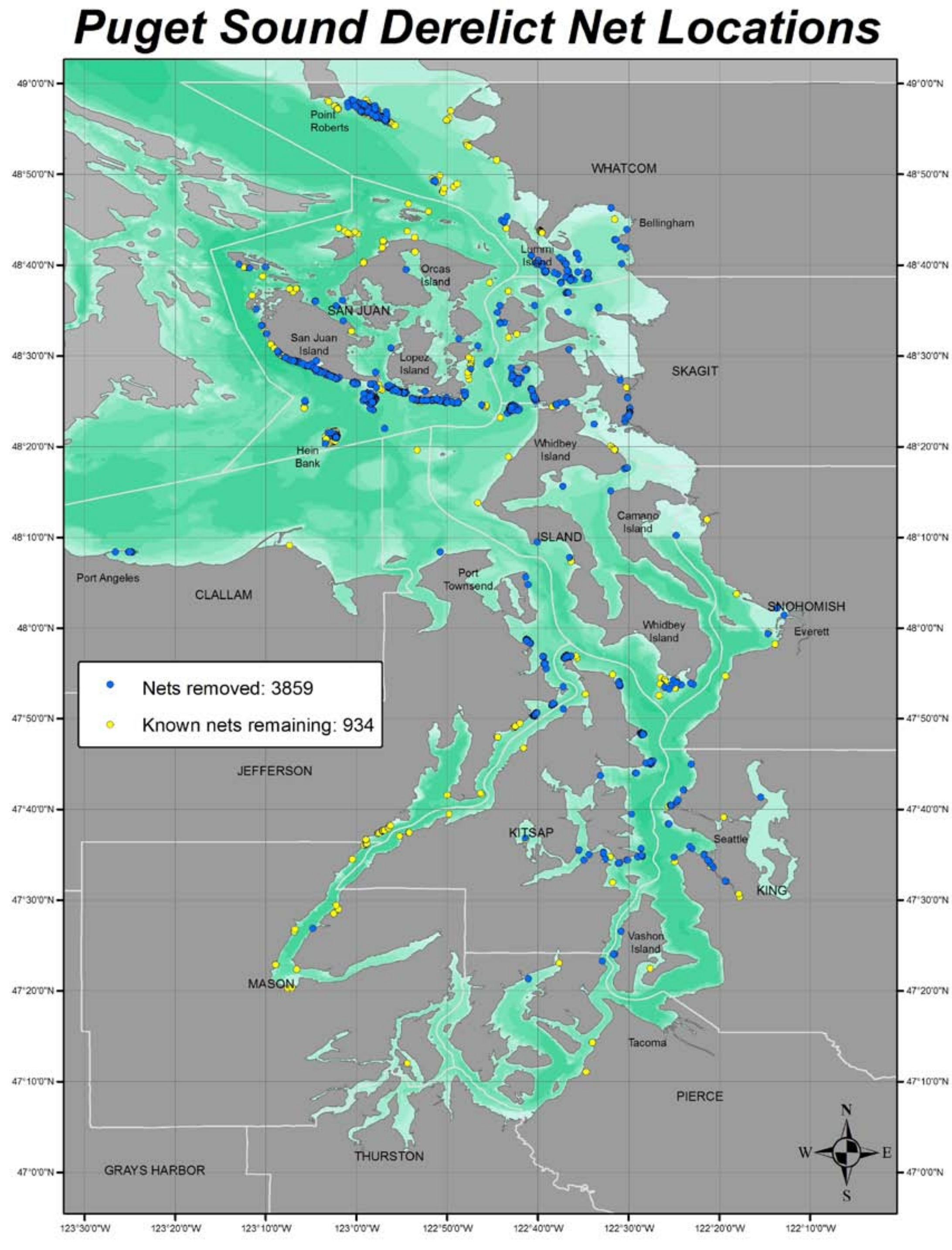

Figure 1. Removed and known remaining derelict nets, as of March 31, 2011.

Species Local Common	Species Scientific	Sum Number of Dead	Sum Number of Alive	Total	Sum of Record Count
black rockfish	*Sebastes melanops*	59	5	64	12
brown rockfish	*Sebastes auriculatus*	1	0	1	1
canary rockfish	*Sebastes pinniger*	1	0	1	1
China rockfish	*Sebastes nebulosus*	0	1	1	1
copper rockfish	*Sebastes caurinus*	17	2	19	15
Puget Sound rockfish	*Sebastes emphaeus*	4	10	14	9
quillback rockfish	*Sebastes maliger*	28	15	43	39
rockfish unid.	*Scorpaenidae sp.*	50	31	81	19
rockfish unid.	*Sebastes sp.*	8	0	8	8
yellowtail rockfish	*Sebastes flavidus*	2	1	3	3
TOTAL		170	65	235	108

Figure 2. Observed rockfish entanglement in derelict fishing gear removed from Puget Sound, 2002-2011.

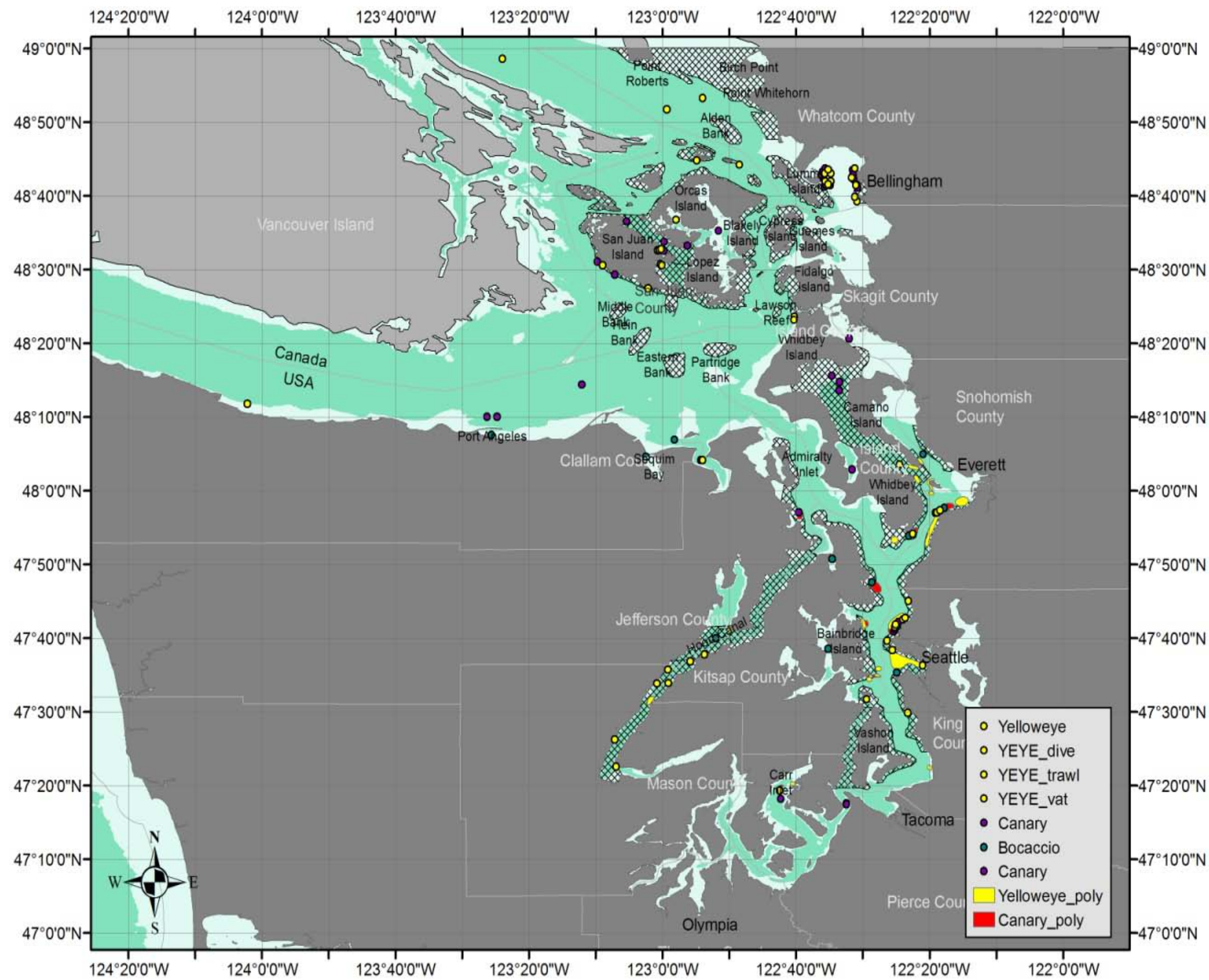

Figure 3. Yelloweye, canary, and bocaccio rockfish distribution and high priority derelict net removal areas (hatched areas) in the Puget Sound.

Habitat Type	Total Habitat Area (acres) Recovered Since 2002	Percent of Total Habitat Area Recovered
boulders on sand/mud/gravel	177.2	34%
high-relief rocky substrate	79.55	15%
low-relief rocky substrate	171.1	32%
mud/sand/gravel/vegetation	88.44	17%
underwater obstructions	11.71	2%
aquatic vegetation	0.32	0%
Total	**528.4**	**100%**

Figure 4. Shallow sub-tidal habitat acreage restored by type through derelict fishing gear removal in Puget Sound, 2002-2011.

Species	Boulders on sand/mud/ gravel	High-relief rocky substrate	Low-relief rocky substrate	Mud/sand/ gravel/ vegetation	Underwater obstructions	Total
black rockfish		4	6	2		12
brown rockfish			1			1
canary rockfish		1				1
China rockfish	1					1
copper rockfish	2	5	7	1		15
Puget Sound rockfish	1	3	3	1	1	9
quillback rockfish	2	9	20	6	2	39
rockfish unid.	4	7	11	1	4	27
yellowtail rockfish		1	2			3
Total	**10**	**30**	**50**	**11**	**7**	**108**
% by habitat	9%	28%	46%	10%	6%	

Figure 5. Numbers of derelict gear with observed rockfish impacts by type of habitat.

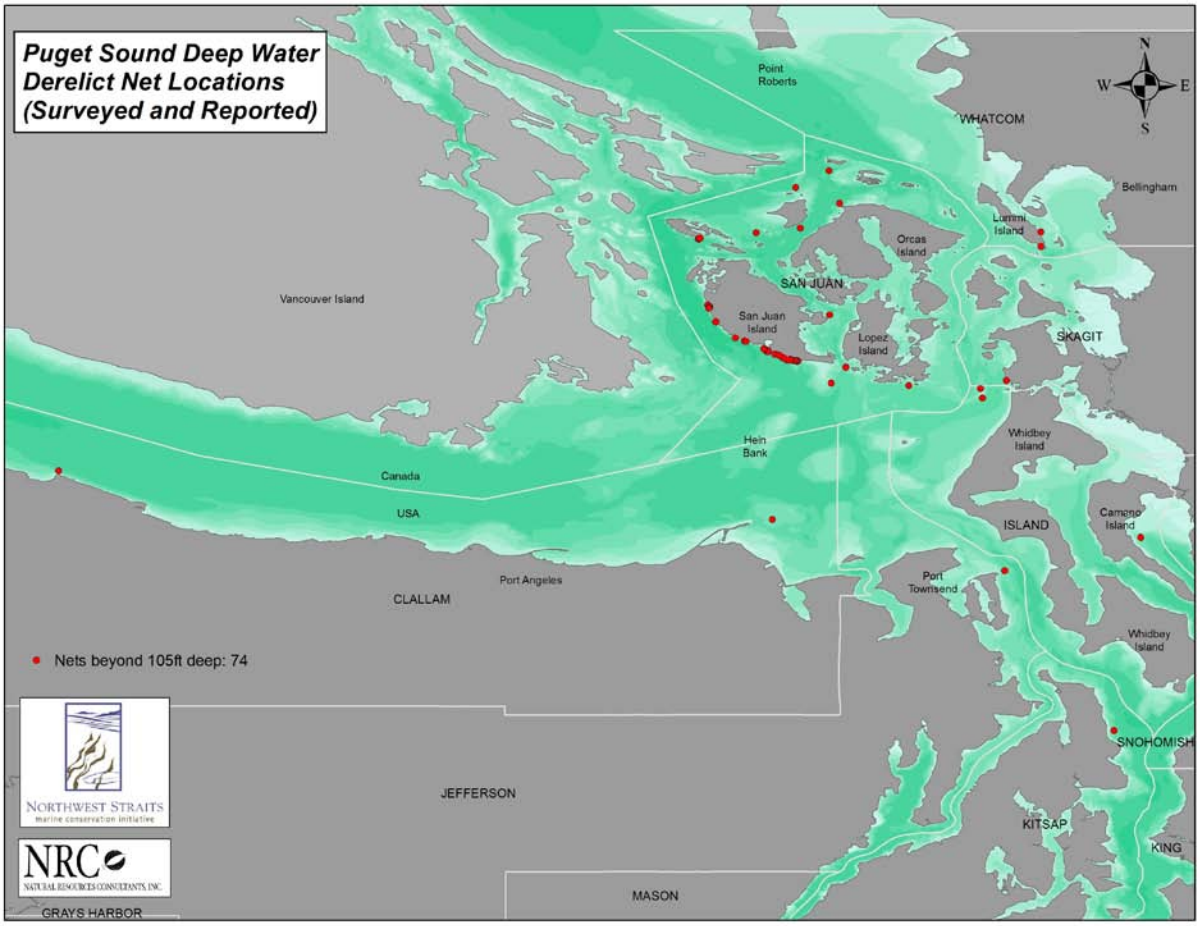

Figure 6. Known locations of deepwater derelict fishing nets in Puget Sound.

Deepwater Sidescan Sonar and Camera Surveys for Derelict Fishing Nets in Rockfish Habitat

Jeff June, Kyle Antonelis, Natural Resources Consultants, Inc.

Abstract

This study tested the feasibility of employing sidescan sonar surveys to locate derelict nets in deepwater (105 to 350 ft /32 to 107 m) rockfish habitat, verify the findings with camera surveys, and assess potential threats to the rockfish populations. Two days of sidescan sonar surveys were conducted off south San Juan and Lopez Islands, covering 20.27 linear nautical miles and identifying 31 potential derelict net targets. Six days of drop camera surveys were conducted, capturing video over a total length of 3.84 linear nautical miles, verifying derelict nets at 11 of 13 targets, and identifying an additional 55 derelict nets near the original net targets. This study proved that sidescan sonar surveys are capable of identifying derelict net targets in rockfish habitat, with some limitations: (a) vertical hard bottom substrate reflects nearly all acoustic sidescan sonar energy, masking derelict net features and (b) geologic patterns in vertical rock walls such as cracks and crevices can display characteristics similar to derelict nets. Drop camera video imaging provided the ability to characterize habitat, observe rockfish behavior, and assess feasibility of net removal. However, findings concluded that because of limitations in the mobility and range of drop camera surveys, the use of a remote operated vehicle (ROV) would better serve to accomplish these goals.

Introduction

The study tested the feasibility of surveying for deepwater derelict fishing gear (DG), particularly derelict nets, with sidescan sonar, verifying that sidescan sonar targets were actually derelict nets using a drop camera, assessing the derelict net's potential threat to deepwater rockfish, and collecting information necessary to develop a removal plan.

Yelloweye rockfish (*S. ruberrimus*), canary rockfish (*S. pinniger*), and bocaccio rockfish (*S. paucispinis*), were recently listed under the Endangered Species Act in Puget Sound. There is an increasing interest from resource managers in understanding the extent of impacts of derelict fishing gear on rockfish populations in the Puget Sound. Derelict net removals performed by the Northwest Straits Initiative (NWSI) in Puget Sound have been ongoing since 2002 and the entanglement and mortality of rockfish have been documented in derelict fishing gear, particularly derelict gillnets. Because of diver safety regulations, the NWSI net surveys and removals focus only on water depths less than 105 feet (32 m), leaving the extent and impact of derelict nets in waters deeper than 105 feet virtually unknown. The three ESA-listed rockfish species (and many others) are known to commonly reside in water deeper than 105 feet, being common in depths between 200 and 350 feet (61 and 107 m). Therefore, identifying the extent of the derelict nets and assessing their level of impact on these species is needed in order to implement effective methods for future management of the rockfish in Puget Sound.

The use of sidescan sonar has proven to be an effective method to locate derelict fishing nets in shallow water (<105 ft / 32 m). Previous to the use of sidescan sonar, drop camera and diver surveys were the most common methods for finding derelict nets in Puget Sound. Diver and drop camera surveys have many limitations in their effectiveness, most of all through a lack of area covered and problems with poor visibility. However, camera surveys can be effective in characterizing the size and condition of nets when in the field of view. From past drop camera surveys and diver reports, we know that there are derelict nets in water over 100 feet deep. The study tested the feasibility of using sidescan sonar to detect derelict nets in deepwater and using a drop camera to characterize the risk of the nets to rockfish and develop a plan for net removal with a remotely operated vehicle (ROV).

Funding from the National Fish and Wildlife Foundation and NOAA, Department of Commerce was provided to the Northwest Straits Foundation (NWSF) to conduct deepwater sidescan sonar and camera surveys in areas of known rockfish critical habitat. NWSF contracted with Natural Resources Consultants, Inc (NRC) to manage the deepwater surveys. NRC contracted with Fenn Enterprises to conduct the survey work.

Methods

Two days of sidescan sonar surveys were conducted, as well as one half day of data post-processing. The surveys focused on locating deepwater derelict fishing nets and rockfish habitat on the southeast tip of Lopez Island and the west side of San Juan Island, from Small Pox Bay to Salmon Bank (Figure 1). Six days of drop camera surveys were conducted in areas where derelict net targets and rockfish habitat were found using the sidescan sonar surveys.

Sidescan Survey

Fenn Enterprises conducted sidescan sonar to locate deepwater derelict fishing nets and rockfish habitat on the southern tip of Lopez Island and the west side of San Juan Island. The surveys on San Juan Island focused on the area between Small Pox Bay and the western side of Salmon Bank (Figure 1). The surveys were conducted using a Marine Sonics® 300 kHz transducer, mounted in a Fenn Enterprises heavy stainless-steel towfish. A Trimble® differential global positioning system antennae (DGPS) mounted on a davit over the stern of the vessel was used to geo-reference the track line of the vessel during the survey that was recorded by the Marine Sonics sidescan system. Nobletec®, a marine navigation software system, was also used to track the progress of the vessel during the survey.

The towfish was deployed off the stern of the 40-foot research vessel R/V *Surveyor II*. A hydraulic winch with cable controlled the altitude of the towfish. The survey image was displayed on a video monitor onboard the vessel and recorded onto a computer hard drive for later processing. Generally, the sidescan sonar survey was conducted at 2.5 knots (4.63 km/hr). Because of the steepness of the underwater terrain in the survey areas, the majority of the sidescan surveys were conducted using only one side channel, with the signal covering the base of the rock structures (and up the structure) a calculated distance. This distance varied depending on depth and terrain, with the majority (approximately 78 percent) of the survey swath width of 328 feet (100 m) with the remaining survey swath width of 490 to 650 feet (150 to 200 m). Survey depths ranged from 105 feet (32 m) to 351 feet (107 m), as per contract specifications, although surveys at deeper depths are certainly feasible.

The sidescan sonar images were examined in detail during post-survey processing, and counts and precise locations of derelict nets and rockfish habitat were recorded. The products from the sidescan sonar survey included a track line file of the area surveyed, calculation of the amount of the seabed area covered, and the positions (latitude and longitude) of likely derelict net targets found.

Drop Camera Survey

Fenn Enterprises conducted six days of drop camera surveys to ground truth the targets found during the sidescan survey. In addition to the sidescan sonar targets, existing deepwater targets in the NWSI Derelict Fishing Gear Database and targets reported by WDFW from a 2008 fish habitat ROV survey were also investigated.

A Canon® Vixia HFS11 recording in 1920 x 1080 full high definition (HD) video combined with two Deep Sea Power & Light® Mini C Series underwater lights each with a 250 watt frosted bulb with 4500 lumens and a color temperature rating of 2900 were used for lighting of the camera's field of view. A custom titanium housing with wide-angle lens was built for the camera including a telemetry system for video control in the vessel cabin via an RS485 connection to a laptop. This allows control of features such as power to the camera, record, zoom, and focus. The camera system was tethered to the boat by a 1,000-foot long Falmat Xtreme-Cat® ruggedized umbilical with six 18awg copper wires and four pairs of Cat5e with a breaking strength of 1,200 pounds. This cable provided power to the camera and lights, telemetry, and onboard analog video cable. The location of the vessel was geo-referenced using a Trimble survey grade DGPS antenna mounted above the string block that fed the drop camera umbilical from the winch over the stern of the vessel. The GPS was connected to a GeoStamp+® system that allowed the latitude and longitude of the vessel location to be overlaid on the analog video output. Generally, the drop camera remained vertically under the GPS antennae so the position of the vessel was an accurate estimate of the position of the drop camera. Nobletec® and the Trimble® DGPS antennae recorded the track line of the vessel and drop camera during each net target survey.

Video was stored on its internal 64 GB flash drive or onto SD memory cards for easy transferability. Frame grabs of captured video were taken at 2 megapixels. The camera system had the ability to record in either digital HD or analog video. For instance, the analog capture was used real-time and when an item of interest occurred, the digital HD record was initiated. Analog video can be encoded in a variety of formats such as .avi, .wmv, .mpg, .mp4, and .mov. A stainless steel crash frame was built for maximum protection of the camera and lights and provided minimal snag points of underwater hazards.

A net target was chosen for investigation, the survey vessel was stationed directly over the target, and the vessel was allowed to drift in the wind and current while keeping track of the drift on the navigation program. Once the drift expected vessel pattern was plotted, a primary anchor was set approximately 490 feet (150 m) up-current and about 165 feet (50 m) to starboard of the net target. The boat was then allowed to drift back over the target, the vessel motored out to the port 325 feet (100 m), and a secondary anchor was set. The vessel again was allowed to settle back onto the target. Positioning the anchors in this way allowed for control over the X and Y position of the vessel relative to the net target. The drop camera was then lowered to the seafloor to image the target. The anchor lines were taken in or let out to maneuver the vessel and camera over the target while keeping track of the search pattern with the Nobletec® navigation program.

The video footage was examined in detail during post-survey processing. Video images were edited to choose items of interest, including rockfish, rockfish habitat, and derelict fishing gear. The locations of derelict nets found during the drop camera survey that were not identified in the sidescan sonar survey images were marked on the navigation program and entered into the final list of derelict nets identified. When a derelict net was observed during post-survey processing, the real-time geographic coordinates from the GeoStamp+® system were displayed in the top left corner of the video image allowing precise location of the derelict net for comparison to the locations from the sidescan sonar system. In general, the vessel was maneuvered using the two-point anchor system in an attempt to document video images of the entire derelict net. However, in some cases time and changing weather and sea conditions did not allow complete documentation of all derelict nets encountered.

Results

During the two days of sidescan survey, 31 targets judged to be derelict nets or lines were identified along the survey length covering 20.75 nautical miles (38.44 km) of deepwater rockfish habitat (Figure 1). A total of 13 net targets (nine sidescan sonar targets and four other reported targets) were investigated during the six days of drop camera surveys, of which 11 targets were identified as derelict net or line and two were not found. The nine targets found with sidescan sonar surveys were all found with the drop camera and proved to be lead line, net, or purse seine rope. Video footage of the net and rockfish habitat was recorded at an additional two target locations from previous derelict gear surveys. Two targets investigated but not found during the drop camera survey were identified from previous camera surveys and dive removals for derelict nets. Drop camera surveys recorded images of nets, rockfish habitat, rockfish, and other organisms over a total length of 3.84 nm (7.11 km) and identified 55 additional derelict nets in close proximity to the original sidescan sonar targets. Twenty-two of the sidescan targets were not investigated (Figures 2, 3, and 4).

Drop camera surveys identified an extensive amount of prime rockfish habitat, such as steep rock structures with intermittent valleys and caverns. Both nets and lead line were found during the drop camera surveys. At one location the net was wrapped around the face of a rock pinnacle and stretched across a flat area at the base of the structure. Eight additional derelict gear targets (lead lines) were identified with the drop camera in one area, and while only lead line was captured on video, it is very likely that the nets' web was buried under the sand. At one target where lead line and net were found, an additional 26 nets were observed and recorded during the drop camera surveys that were not seen in the sidescan sonar images. The majority of these additional derelict nets were hung up on ridges in the rock and draped down through the valleys, in some places causing suspensions of the net above the seabed. Rockfish (*Sebastes* sp.), were observed, as well as other fish species such as lingcod (*Ophiodon elongates*), and kelp greenling (*Hexagrammos decagrammus*). While these fish were observed in close proximity to derelict nets, none were found to be entangled in the nets.

Discussion

This study proved the feasibility of locating derelict nets in deep water with sidescan sonar and ground truthing images, and habitat and associated marine fauna with a drop camera. A total of 31 probable derelict fishing gear targets were identified over 20.75 nm of linear deepwater coastline surveyed during the project for a target density of 1.5 targets per nautical mile or 0.8 targets per kilometer. Of the 31 derelict gear targets imaged with sidescan, nine were investigated during the drop camera survey and all proved to be either derelict gillnet, lead line, or purse seine rope. However, 26 additional derelict nets or lead line not observed by sidescan sonar were found at one of the nine locations indicating sidescan sonar detection of derelict nets was difficult in areas with steep, hard bottom substrate. The nearly vertical hard bottom substrate reflected nearly all of the acoustic energy from the sidescan sonar and masked the patterns in the image characteristic of derelict nets (Figure 5). The study also demonstrated that cracks and crevices in vertical rock walls may look like derelict nets or lines on sidescan sonar images. Sidescan sonar surveys are capable of cost-effectively surveying large amounts of seabed habitat for derelict fishing gear, but some derelict gear may not be detected on steep hard bottom substrate. ROV video surveys may be more appropriate for these hard bottom areas that can be located during the sidescan sonar surveys.

Video imaging provided the opportunity to characterize the habitat, observe rockfish behavior near nets, and assess the feasibility of net removal. Figure 6 provides an example of a typical image of a quillback rockfish (*Sebastes maliger*). The camera surveys proved that sidescan sonar surveys were capable of imaging and distinguishing deepwater rockfish habitat as well as derelict fishing gear. Figure 7 provides an example of a drop camera image of derelict lead line and scraps of net on a deepwater reef face. Sidescan sonar surveys also proved capable of imaging schools of fish, assumed to be rockfish, congregated at the edge of vertical rock walls (Figure 5). Although no rockfish were observed entangled in the derelict nets observed during the study, rockfish were observed in the vicinity (300 feet or 100 meters) of the nets at five of the nine target derelict net locations, and at two of the target derelict net locations (DG #s 6826/6827 and DW 30) the suspended derelict nets (gillnets) presented a significant risk of entanglement to rockfish and other marine animals.

After conducting these surveys using the drop camera technique, we believe ground truthing surveys would be improved by the use of an observational ROV. The use of an ROV would dramatically increase productivity, as an ROV can easily image more than a hundred times the same amount of area as a drop camera over a given period of time. An ROV can drive the length of a net at speeds of 1.5 to 2 knots imaging the net while plotting its position onboard the vessel in real time. The ROV has the ability to change its camera’s aspect or attitude to view a rock face or see under a ledge where the rockfish are likely to be, whereas a drop camera cannot. Also, an ROV equipped with scanning sonar could image and navigate through high relief habitat over 100 feet (30 m) ahead while simultaneously viewing suspended nets and schooling fish. In addition, anchoring on or near a rock face or a shear 300-foot (100-m) wall is impractical for a drop camera survey because the vessel must be anchored directly over the survey area. However, for ROV operations the vessel can be anchored 150 to 250 feet (50 to 75 m) away while efficiently surveying the entire study area. Hence, an ROV would be better suited than a drop camera for surveying the sheer rock walls that are associated with rockfish habitat and probable derelict net locations.

Sufficient information on the length, width, and configuration of the derelict fishing gear in the habitat was gained during the drop camera survey to prepare a derelict gear removal plan. Although a specific protocol for removal of deepwater derelict nets has yet to be developed and is beyond the scope of this study, the derelict fishing gear encountered during the survey appeared to be removable by one or more ROVs.

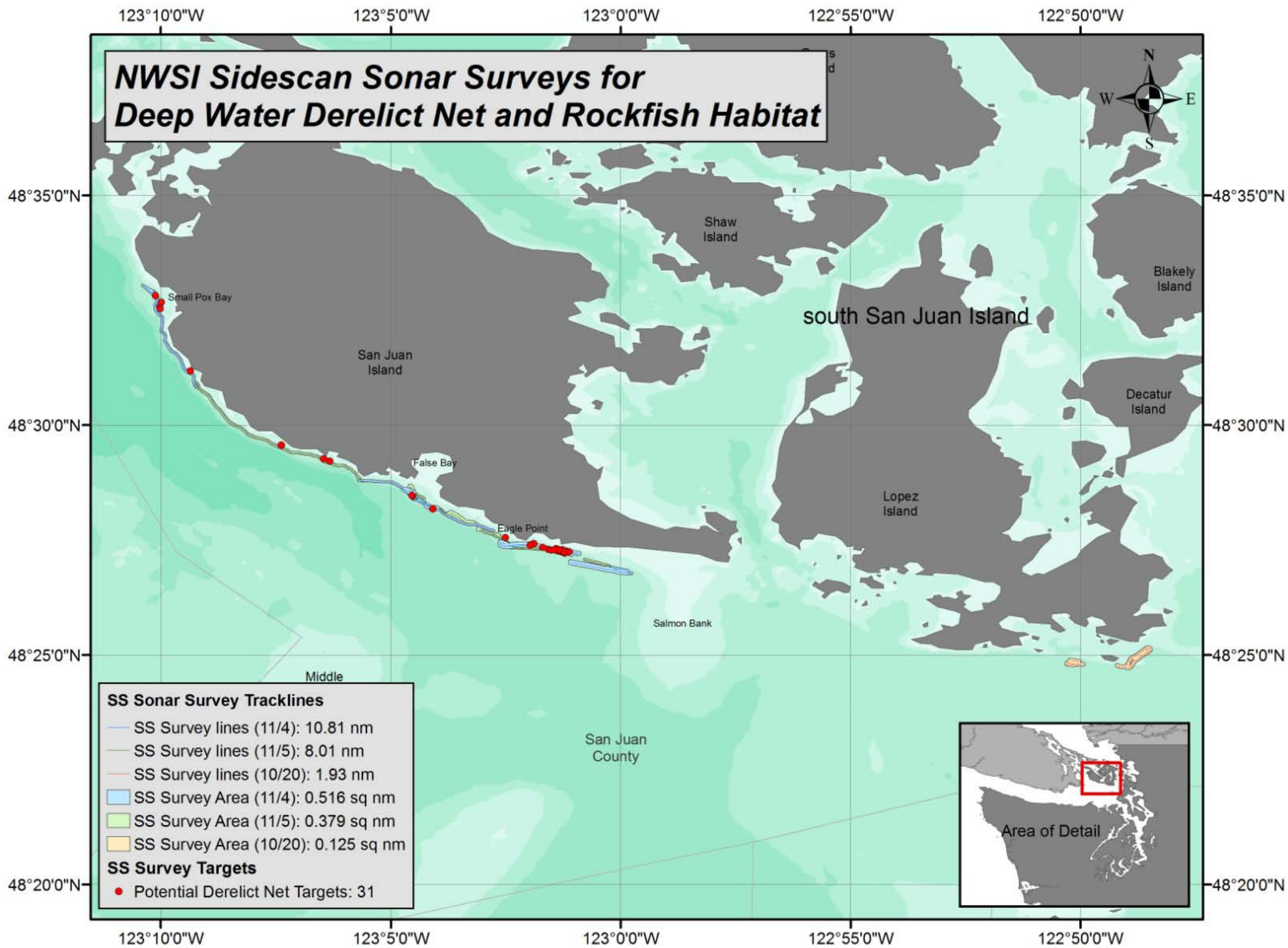

Figure 1. Sidescan sonar survey track lines, area covered, and derelict fishing gear targets identified, 2010.

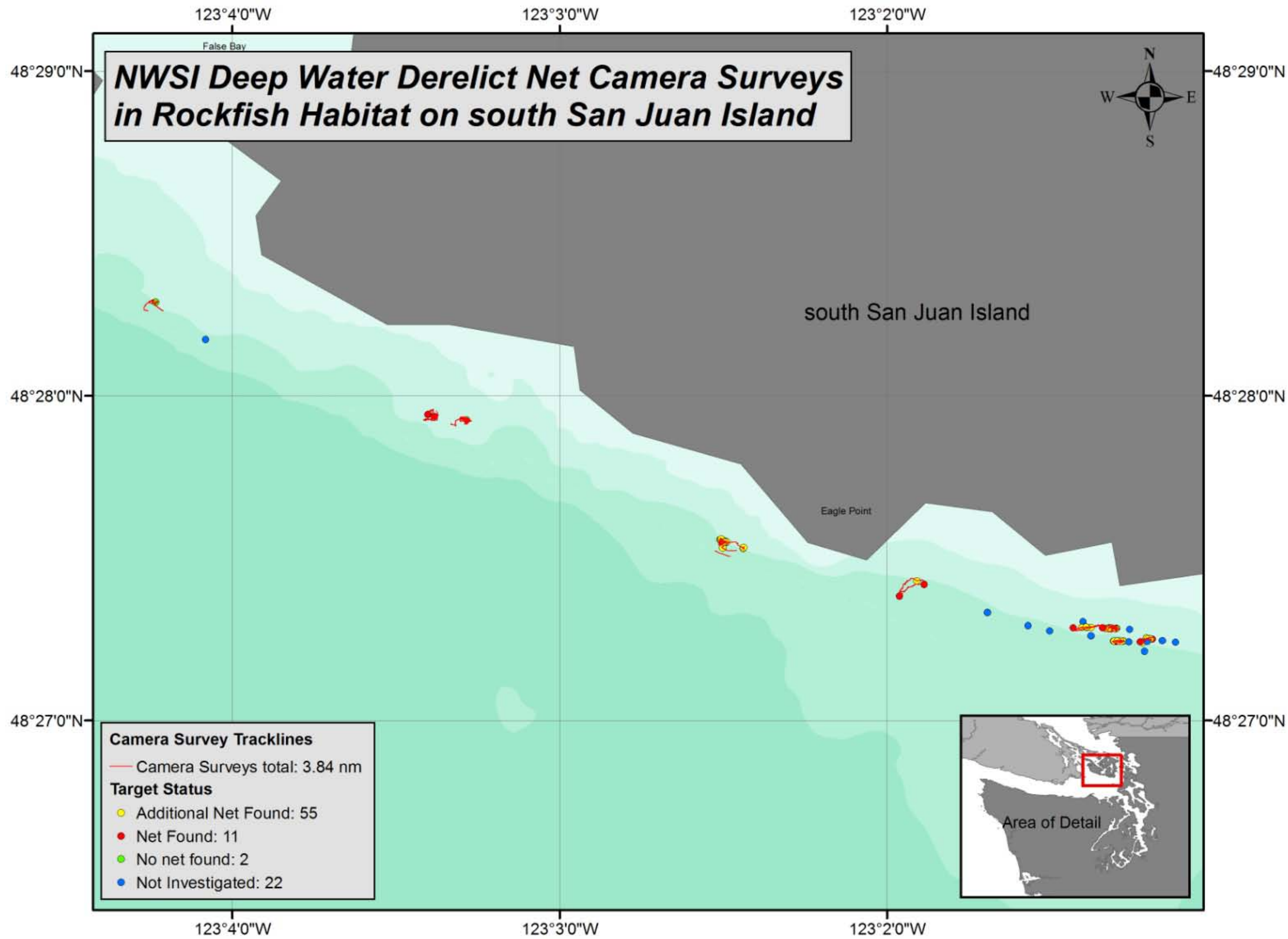

Figure 2. Locations and track lines of drop camera surveys of derelict fishing gear targets conducted, 2010.

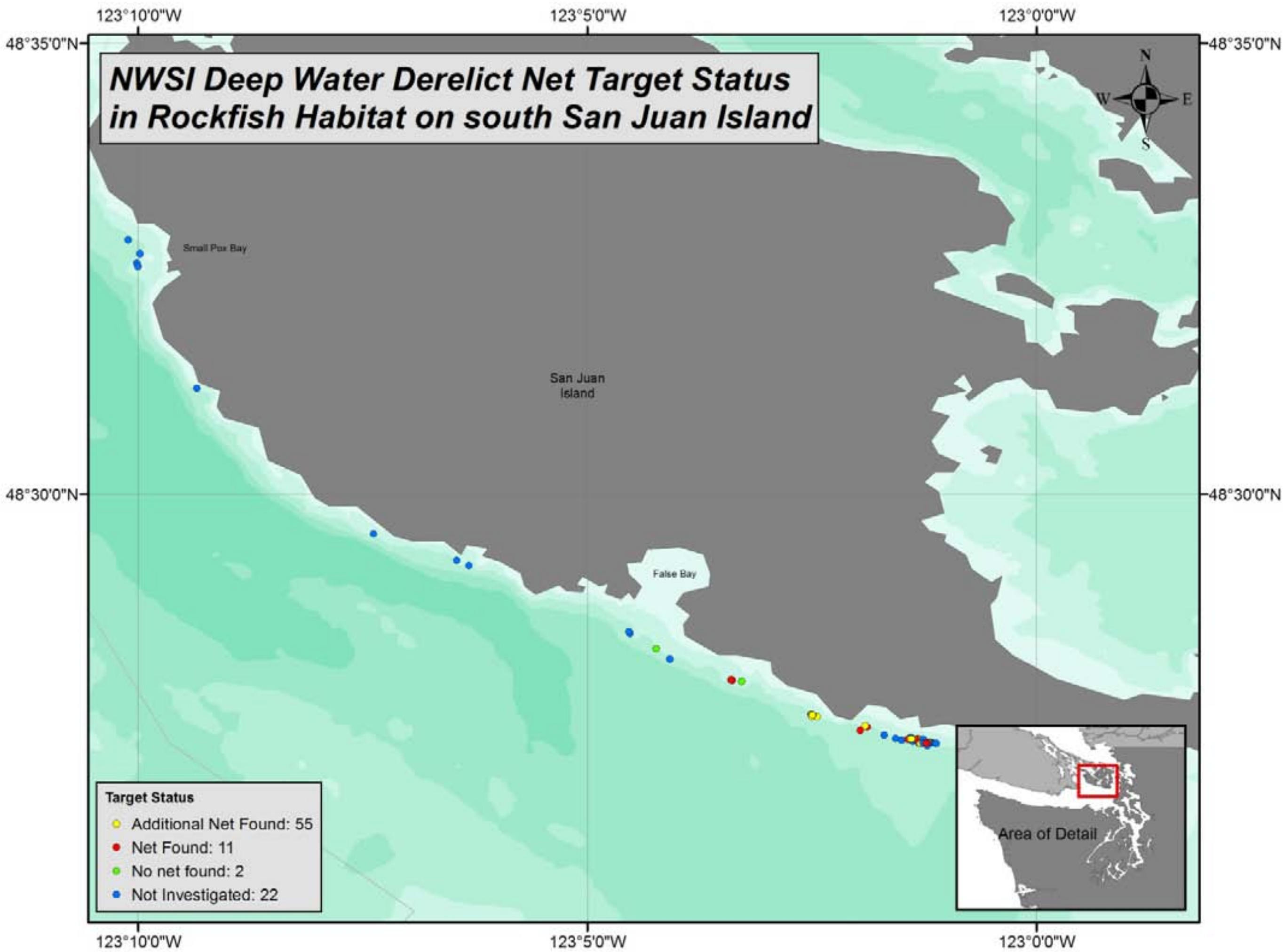

Figure 3. Derelict fishing gear target status (found, not found, not investigated) after completion of the drop camera survey, 2010.

Target ID	Gear Type	Min Depth (ft)	Max Depth (ft)	Investigation Status	Location	Latitide	Longitude	Date of Drop Camera Investigation	Additional Targets Found	Habitat type	Rockfish Habitat	Rockfish Present	Rockfish Risk	Comments
dw2	Gillnet	112	130	Net Found	Eagle Point	48 27.250	123 01.189	11/10/10	6	Sand Bottom with boulders	Nearby	No	Low/Mod	Only lead lines observed by net may be buried in sand
dw4	Gillnet	121	126	Net Found	False Bay	48 27.284	123 01.321	11/10/10	8	Sand Bottom with boulders	Nearby	No	Low/Mod	Only lead lines observed by net may be buried in sand
dw9	Gillnet	118	128	Net Found	Eagle Point	48 27.242	123 01.301	11/10/10	9	Sand Bottom with boulders	Nearby	No	Low/Mod	Only lead lines observed by net may be buried in sand
dw14	Gillnet	114	127	Net Found	Eagle Point	48 27.241	123 01.227	11/10/10		Sand Bottom with boulders	Nearby	No	Low/Mod	Only lead lines observed by net may be buried in sand
dw15	Gillnet	117	130	Net Found	Eagle Point	48 27.284	123 01.341	11/10/10		Sand Bottom with boulders	Nearby	No	Low/Mod	Only lead lines observed by net may be buried in sand
dw16	Gillnet	111	127	Net Found	Eagle Point	48 27.284	123 01.432	11/12/10	5	Sand Bottom with boulders	Nearby	No	Low/Mod	Only lead lines observed by net may be buried in sand
dw18	Gillnet	113	124	Net Found	Eagle Point	48 27.419	123 01.886	11/12/10	1	Sand Bottom with boulders	Nearby	No	Low/Mod	Only lead lines observed by net may be buried in sand
dw30	Gillnet	115	220	Net Found	Eagle Point	48 27.550	123 02.500	11/28/10	26	Large Rock Structure with sand/shell base	Yes	Yes	High	Rockfish, lingcod, kelp greenling, Puget Sound king crab, red sea urchins, sea cucumbers
dw31	Gillnet	118	128	Net Found	Eagle Point	48 27.382	123 01.962	11/12/10		Sand Bottom with boulders	Nearby	No	Low/Mod	Only lead lines observed by net may be buried in sand
6826	Gillnet	115	126	Net Found	False Bay	48 27.936	123 03.383	10/28/10		Sand/shells at base of rock structure	Yes	No	High	Rockfish within 100 meters, but not at net
6827	Gillnet	115	127	Net Found	False Bay	48 27.942	123 03.403	10/28/10		Sand/shells at base of rock structure	Yes	No	High	Rockfish within 100 meters, but not at net
9145	Gillnet	112	130	No net found	False Bay	48 27.925	123 03.285	10/27/10		Rock Pinnacle with vertical walls	Yes	Yes	N/A	Rockfish, Puget Sound king crab
6900	Gillnet	120	300	No net found	False Bay	48 28.288	123 04.235	10/29/10		Rock Pinnacle with valleys	Yes	Yes	N/A	Rockfish, lingcod, kelp greenling

Figure 4. Characteristics of the derelict targets investigated during drop camera survey, 2010.

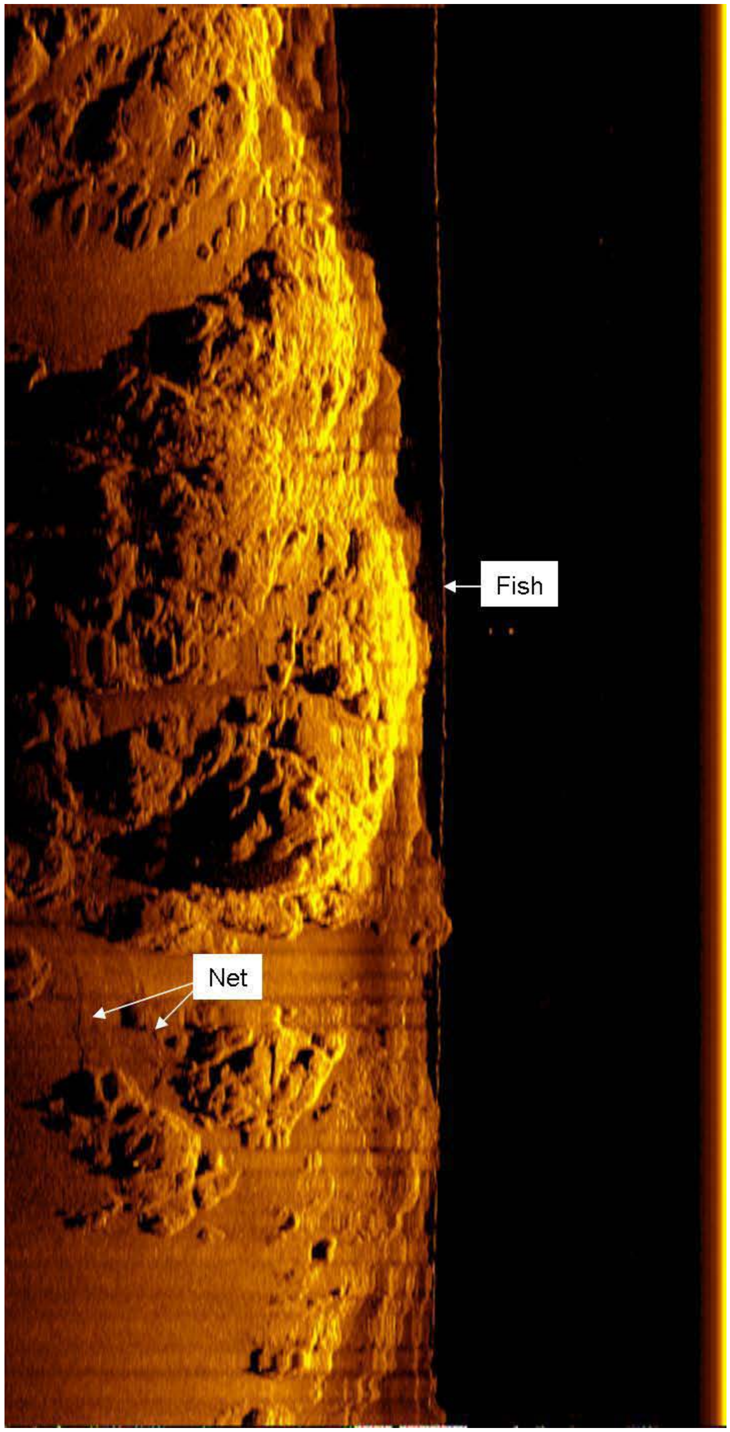

Figure 5. Sidescan sonar image showing rockfish habitat, derelict nets, and fish aggregations, 2010.

Figure 6. An example of a typical image of a rockfish taken in deep water with a drop camera during the project. The image shows a quillback rockfish (*Sebastes maliger*), on a reef face at 120 feet (36 m) off the west coastline of San Juan Island.

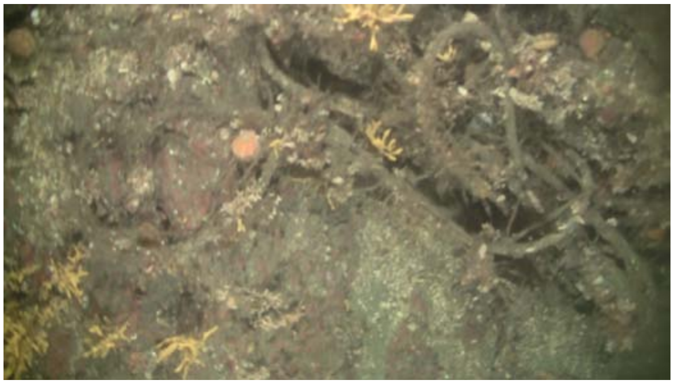

Figure 7. An example of a typical image of derelict gillnet lead line and net scraps taken in deep water with a drop camera during the project and located on a reef face at 120 feet (36 m) off the west coastline of San Juan Island.

Toxic Contaminants in Demersal Rockfishes (*Sebastes* spp.) from Puget Sound

James E. West, Sandra M. O'Neill, Washington Department of Fish and Wildlife

Exposure to toxic contaminants is a stressor faced by many fish species in Puget Sound. The Washington Department of Fish and Wildlife's (WDFW) Toxics in Fish component of the Puget Sound Assessment and Monitoring Program (PSAMP) has sporadically tracked exposure of three rockfish species to contaminants over the past 20 years. We summarize the major classes of chemicals to which rockfish are exposed and discuss life-history factors that control their risk of exposure. Some persistent bioaccumulative and toxic (PBT) chemicals accumulate to high levels in quillback (*Sebastes maliger*), copper (*S. caurinus*), and brown (*S. auriculatus*) rockfish from Puget Sound, especially individuals from urban habitats. This high exposure is related to (a) where they live (i.e., their proximity to contaminants), (b) their long life span (older individuals have a longer time to accumulate PBTs), and (c) relatively high trophic level (they consume prey in which PBTs have been trophically magnified). Male rockfish exhibit a greater risk for accumulation of PBTs, and we present evidence for female rockfish depurating PBTs to their larvae. Male rockfish from one urban embayment (Elliott Bay) also exhibited vitellogenin in their plasma, a protein normally associated with egg production only in females. Vitellogenin in male fish is generally considered to be an indicator of exposure to external estrogenic chemicals. We present effects thresholds for PBTs where possible and discuss the potential effects of contaminant exposure to recovery of *Sebastes* spp. in Puget Sound.

Editor's Note: No extended abstract was submitted for this presentation.

Effects of Lingcod Predation on Copper Rockfish Recovery in Marine Reserves

Iris A. Gray, Anne H. Beaudreau, Alejandro Frid, Chris J. Harvey, Northwest Fisheries Science Center

Abstract

Populations of several species of rockfish (*Sebastes* spp.) have declined significantly throughout the West Coast of the U.S., due in part to overharvesting. In the San Juan Archipelago, marine reserves have been established in key habitat areas to facilitate recovery for a suite of rockfish species. Inhabiting the same rocky habitats, lingcod (*Ophiodon elongatus*) is an important predator in these systems. A fundamental management question is whether the predation pressure imposed by lingcod is strong enough to impede recovery of depleted rockfish populations within marine reserves. We designed a discrete time population model with size- and density-dependent predation of lingcod on copper rockfish (*S. caurinus*), a common rockfish species in the Salish Sea. Here we use the model to examine the effect of lingcod predation on a hypothetical population of copper rockfish at various initial densities.

Introduction

Many species of rockfish (*Sebastes* spp.) have declined significantly along the U.S. West Coast in recent decades, due in part to overharvesting (Parker et al. 2000). In the San Juan Archipelago, marine reserves have been established in important habitat areas in an effort to facilitate recovery for a suite of rockfish species. Lingcod (*Ophiodon elongatus*) inhabit the same rocky, coastal habitats as many species of rockfish and are upper-level predators in these systems. Densities and reproductive potential of many rockfishes and lingcod have increased inside marine reserves (Palsson and Pacunski 1995); however, lingcod presence may undermine the intended effect of the reserve, as the frequency of predation events on rockfish by lingcod is greater in reserves compared to non-reserve areas (Beaudreau and Essington 2009).

A fundamental management question is whether or not the predation pressure imposed by lingcod is strong enough to impede recovery of depleted rockfish populations within marine reserves. Field experiments addressing this question would be costly and generally infeasible. Mathematical models, however, can offer insight into the plausibility of different ecological processes and guide management decisions when empirical data are lacking. Further, lingcod diets are now sufficiently known to allow for empirical parameterization of a theoretical model that examines the role of lingcod predation on rockfish recovery in reserves (Beaudreau and Essington 2009).

In this study, we present a model that describes hypothetical, interacting populations of lingcod and copper rockfish (*S. caurinus*) as they might persist in marine protected areas of the San Juan Archipelago. The model describes changes in density because of natural mortality for both species. For copper rockfish, we also model decreases in density because of size- and density-dependent predation by lingcod. The goal of our study is to determine whether lingcod predation affects the recovery of the rockfish in our theoretical habitat.

Methods

We designed a discrete time population model with annual recruitment and dynamic predation of lingcod on copper rockfish, a common rockfish species in the Salish Sea (Stout et al. 2001). The theoretical study area represents any marine reserve area around the San Juan Islands and therefore lacks fishing mortality.

Our model consists of one system of equations for rockfish denoted by R_i, and two systems of equations for the lingcod, one for females (LF_i) and one for males (LM_i). Sexually dimorphic growth and size in lingcod dictate that we model the sexes separately. We update our model annually (i.e., $\Delta t = 1$). The values r_R and r_L represent recruit density (i.e., age-0 juveniles following settlement) for rockfish and lingcod, respectively. Recruitment events occur in the spring every year, which occurs at the beginning of each time step. Survival ($S, PF,$ and PM for rockfish, female lingcod, and male lingcod, respectively) is determined by a relationship relating length and growth characteristics with natural mortality in marine fish (Gislason 2010).

Population Model

Below we present our model equations for all stages of rockfish and lingcod. We specify the 25th year class for rockfish to show the self-loop, a feature that allows for the survival of rockfish beyond 25 years.

Recruits:

$$R_0(t) = r_R$$

$$LF_0(t) = \frac{r_L}{2}$$

$$LM_0(t) = \frac{r_L}{2}$$

Juveniles and Adults:

$$R_i(t+1) = S_{i-1}(R_{i-1}(t) - D_{i-1}(t)), \qquad for\ i = 1, 2, \ldots, 24$$

$$R_{25}(t+1) = S_{24}(R_{24}(t) - D_{24}(t)) + \underbrace{S_{25}(R_{25}(t) - D_{25}(t))}_{\text{Self-loop}}$$

$$LF_i(t+1) = PF_{i-1}LF_{i-1}(t), \qquad for\ i = 1, 2, \ldots, 25$$

$$LM_i(t+1) = PM_{i-1}LM_{i-1}(t), \qquad for\ i = 1, 2, \ldots, 25$$

Recruitment

To our knowledge, recruitment for these species within our study area has not been studied in depth. We used a relationship involving natural mortality and steady-state population size to estimate appropriate recruitment densities. The recruitment parameters for rockfish and lingcod, r_R and r_L respectively, are normally-distributed random numbers with mean values set to the assumed recruitment densities. Variance for lingcod recruitment was arbitrarily chosen at 5 percent of its mean estimated recruitment, so there would be little, but some, variation between recruitment. Rockfish recruitment is known to be highly variable from year to year (King and McFarlane 2003); however, the degree to which their recruitment varies is unknown.

Predation

The model is based on empirical observations of size structure in lingcod-rockfish predation, whereby the probability of predation is related to the size of both prey (rockfish) and predator (lingcod). Specifically, we used observed counts of rockfish consumed by lingcod of various size classes to parameterize our model.

Because rockfish is not the dominant prey for lingcod, we modeled interactions through the simplest representation, whereby predation scales linearly with prey and predator abundance, and lingcod density or growth is not appreciably affected by rockfish availability. We estimated the per-capita predation rate of lingcod on rockfish (Beaudreau and Essington 2009) as a function of rockfish density in reserves and non-reserve areas (Eisenhardt 2001).

Using lingcod diet data along with a bioenergetics model (Beaudreau and Essington 2009) and our functional response curve, we developed a dynamic model of rockfish consumption by lingcod. The diet data consisted of the sizes of rockfish found within the stomachs of different-sized lingcod (Beaudreau and Essington 2007). This information was organized according to length class bins determined from length-at-age relationships for lingcod (Jagielo and Wallace 2005) and rockfish (Gowan 1983). We fit gamma density functions to frequency distributions of rockfish sizes consumed by lingcod (Beaudreau and Essington 2007; 2009) for 5 cm size-classes of lingcod; the largest size class was composed of lingcod greater than 30 to 43 inches (75 to 110 cm) because of a small sample size of large individuals (gamfit.m, MATLAB; Figure 1). We used this information to compose our prey length preference matrix, which is a fixed measure of how likely a lingcod is to prey on a rockfish as a function of its length.

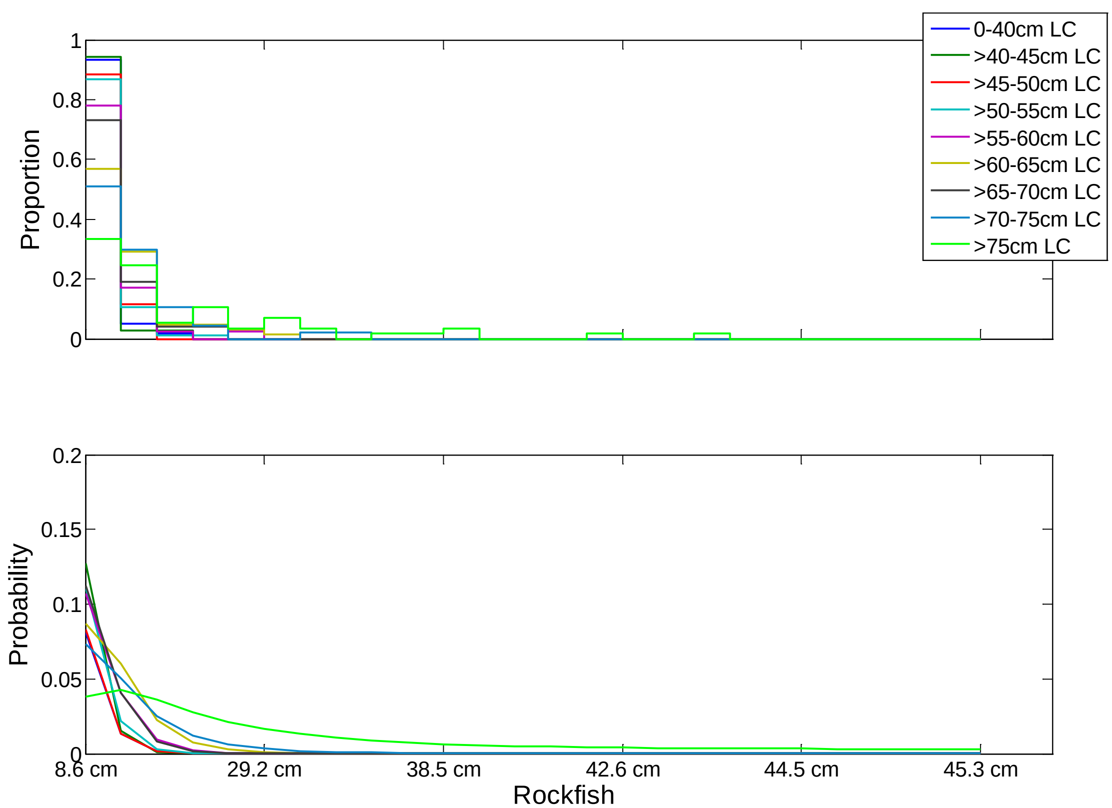

Figure 1. Frequency of rockfish sizes in lingcod stomachs (top) and gamma PDFs fitted to the data (bottom). The different colored bars and lines distinguish the size classes of lingcod that had enough data points to warrant PDF fitting. Each bar represents each stage of rockfish. Average length measurements for 0-, 5-, 10-, 15-, 20-, and 25-year-old rockfish are provided on the tick marks of the bottom plot for reference.

Thus, we have all the components needed to construct predation terms (D_i) for each rockfish stage i involving all lingcod stages j.

$$D_i(t) = \sum_{j=0}^{25} CR_{ratio}(t)\left(PRM_{i,j} \cdot \frac{CM_j}{W_i} \cdot LM_j(t) + PRF_{i,j} \cdot \frac{CF_j}{W_i} \cdot LF_j(t)\right), \qquad for\ i = 0, 1, 2, \dots, 25$$

The functional response (CR_{ratio}) is dynamic and dependent on the current time rockfish density. PRM and PRF are prey length preference probabilities (shown in bottom Figure 1) for male and female lingcod, respectively. CM and CF are weight-specific consumption rates for male and female lingcod (taken from Beaudreau and Essington 2009). W_i is the average stage-specific weight of an individual rockfish (Gowan 1983). Modeling this lingcod predation in addition to natural mortality on rockfish allows us to examine the effect increased predation may have on the rockfish population in the long term.

Hypothesized Results

Using this model, we will evaluate the effects of lingcod predation on a hypothetical copper rockfish population in a marine reserve. We will simulate the size structure and abundance of rockfish and lingcod over 50 years. We will explore various initial size distributions for both species, shown in Figure 2.

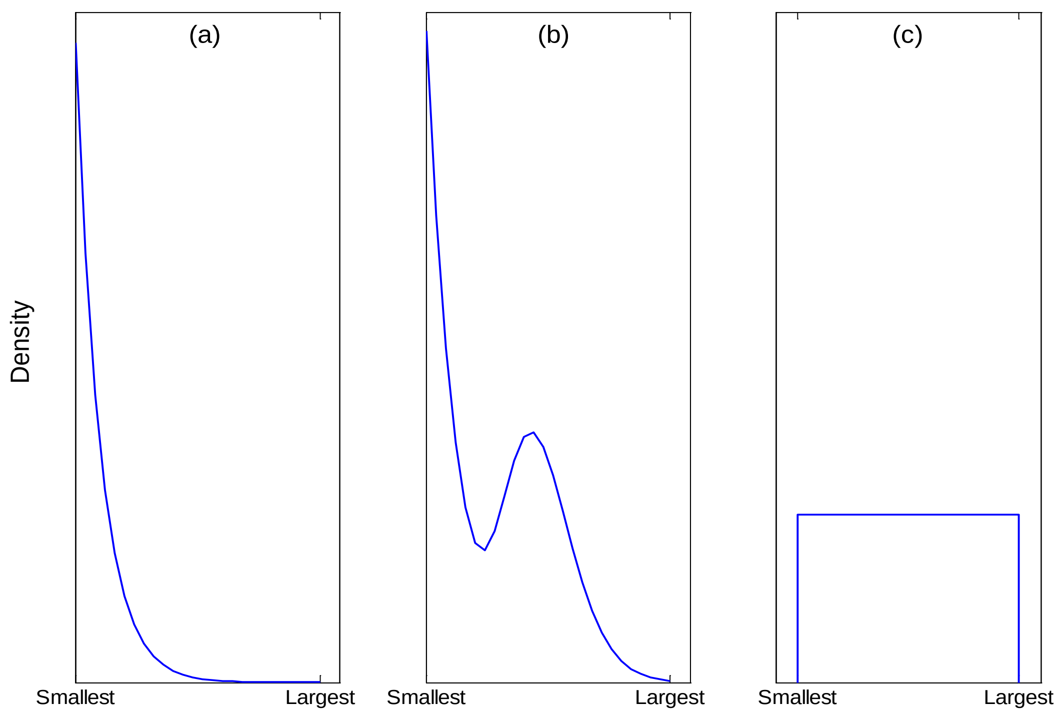

Figure 2. General representations of size distributions that will govern the initial state of our hypothetical populations.

Depending on the shapes of the initial size distributions chosen, we will assume certain biological starting conditions. For example, we will investigate the effect of lingcod predation on rockfish in a reasonably established (5- to 10-year-old) reserve. We would then impose a lingcod size distribution shown in Figure 2 (b), where there is a distinct mode of larger sized fish because those individuals have been protected from harvest within the reserve. Alternatively, we might assume the rockfish size distribution would look like Figure 2 (a), exhibiting very few larger rockfish. Furthermore, investigating lingcod predation effects in a new reserve, we would assume initial size distributions similar to Figure 2 (a) for both species, reflecting the fishing pressure that had been imposed on larger fish. We expect that the new reserve simulation would spell faster recovery (if any) for rockfish than an established reserve, because of the markedly lower density of larger lingcod in our assumed initial condition. Additionally, uniform size distributions (Figure 2 (c)) will be instituted for both species, conjunctively and with other initial size distributions, to test the sensitivity of the population densities of both species to some of our parameter choices.

In the event that rockfish are unable to achieve target recovery densities within the reserves under any initial size distribution scheme, we will entertain the implementation of size-specific targeted removal of lingcod. We anticipate the release of rockfish from lingcod predation pressure gradually over various removal proportions on certain larger stages of lingcod. These scenarios would essentially test the effect of letting reserve areas serve as protection for rockfish from fishing and some lingcod predation. Targeted removal of lingcod within reserves may be necessary to allow rockfish to establish healthy populations because lingcod grow faster than rockfish and are opportunistic hunters, tending to prey on rockfish more frequently when the rockfish population is relatively more dense.

This study serves to illuminate the effect of added predation pressure on a recovering rockfish species in a marine reserve and investigate the management of that predation pressure.

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Impacts of Lingcod and Rockfish on Benthic Community Structure in the San Juan Islands, Washington

Kevin R. Turner, Kenneth P. Sebens, University of Washington

Abstract

Commercial and recreational fishing can dramatically alter fish populations and thus marine ecosystems. Management decisions affect not just target fishes, but also species related to target fishes through ecological networks. Predator removals can significantly change the composition of the entire marine community. We are studying the effects of large carnivorous fishes (lingcod and rockfishes) on the rocky sub-tidal communities of San Juan Channel. We use surveys of all trophic levels in this system, combined with exclusion cages designed to restrict fish access from large swaths of the benthos, to determine the community-wide impacts of predatory bottom fishes. Our preliminary results show that predator abundance does vary across San Juan Channel sites, as do species at lower trophic levels. However, correlations between predators and other trophic levels are not consistent at all sites. We have also examined the diets of two species of rockfishes to aid in the construction of a food web for this sub-tidal community. Our analyses of the diets of copper and Puget Sound rockfish demonstrate close agreement with the findings from previous studies, although the copper rockfish in our study were less reliant on fish prey. In addition, this work supports other findings that gastric lavage, a non-lethal means of examining diet, is a successful method for use with fishes whose populations may be vulnerable to overharvesting.

Introduction

Fishing worldwide typically targets high trophic level species first, before later switching to or adding lower trophic level species (Essington et al. 2006). By removing top predators, significant impacts to many lower levels of prey species are possible. Prior to the 1960s, large predatory fishes were common in Jamaica, for example, but as fishing pressure removed these species, fishermen were forced to switch to smaller herbivorous species such as parrotfish. As fishing pressure continued, these herbivores eventually were removed. This fishing, along with a simultaneous collapse in urchin populations because of disease, caused the coral reefs to become overgrown with macroalgae, leading to a significant change in the type of ecosystem present (Hughes 1994). Other similar examples of top-down control of coral reef ecosystems have been observed in other parts of the world as well (Kenya: McClanahan and Shafir 1990; Bahamas: Mumby et al. 2006). In all of these examples, dramatic shifts in the ecosystems were triggered by significant reductions of herbivores, but the establishment of marine protected areas (MPAs) returned the ecosystem function to something approximating original levels and restored the ecosystems to coral dominance.

Trophic cascades triggered by MPAs in temperate zones have shown results similar to those from tropical studies. Temperate examples share a unifying characteristic of a very strong chain of predator-urchin-kelp embedded in the broader food web. Urchins feeding on algal or plant matter have absorption efficiencies as low as 20 to 30 percent (*reviewed in* Lawrence 1975), so they are forced to consume large amounts of algae to meet their caloric needs. *Strongylocentrotus* spp. urchins prefer to feed on kelp species, particularly species with minimal chemical defenses (Vadas 1977). Because of this preference for kelp and the low absorption efficiency, sea urchins can be highly destructive herbivores when their numbers are allowed to increase without check, converting productive three-dimensional kelp forests to simplified "urchin barrens." Examples of urchin-controlled communities have been studied in MPAs in the Mediterranean Sea, New Zealand, California and other temperate locations (Shears and Babcock 2003; Behrens and Lafferty 2004; Micheli et al. 2005). In all cases, the MPAs prohibit fishing on fish or invertebrate species whose primary prey are the dominant local urchins. Inside MPAs, urchin populations are kept in check and kelp forests are allowed to re-grow, leading to significant changes in the abundance of other species present in the communities, either through biological or physical interactions with the kelp (e.g., Eckman and Duggins 1991).

The MPA network in San Juan Channel would appear to be a prime candidate for another example of a strong urchin-mediated trophic cascade. Large red urchins (*S. franciscanus*) are abundant (K. Sebens and K. Turner, unpublished data), and a large fraction of the nearshore primary production comes from kelp growth (Mann 1973). However, the rocky sub-tidal ecosystem in the San Juan Islands is unique among the studied temperate food webs in that its community structure does not appear to be heavily reliant on the presence or absence of sea urchins. Although there are very few significant urchin predators, there is no evidence of extensive urchin barrens or other impacts on kelp abundance (Carter et al. 2007, personal observations). Strong tidal currents appear to allow the urchins to depend on drifting instead of standing kelp (Britton-Simmons et al. 2009). This fact gives us the unique opportunity to study the impacts of demersal piscivorous and invertebrate-feeding fishes on community structuring instead of the impacts of urchin predators. In a world where many of the top trophic level fishes have been seriously overharvested or depleted, and where management actions are focusing on recovering these predators through the use of spatial planning, this research will allow us to determine what changes we may expect in sub-tidal communities as lingcod and rockfish populations are allowed to rebound. Our objectives in this research are to characterize the current status of the rocky sub-tidal community in San Juan Channel, and to determine to what degree that community is structured by top-down control from lingcod and rockfish. We are addressing this question with a combination of broad community surveys, predator exclusion experiments, and diet analysis.

Methods

Widespread community surveys.

Predatory fish abundance is variable within San Juan Channel, providing us with the opportunity to explore the top-down processes that may drive sub-tidal community structure. We have begun surveys of the benthic community at twelve sites nested within six different locations throughout the northern portion of San Juan Channel with the goal of characterizing the complete community structure and how it is affected by predator abundance (Figure 1). We selected the six study locations with two criteria in mind. First, we chose sites as similar in physical parameters to each other as possible. All locations have solid sloping bedrock extending from at least 16 to 98 feet (5 to 30 m) below sea level. Sites are located on both sides of San Juan Channel, in areas exposed to strong tidal currents. Secondly, we chose locations that have been the sites of scientific research over the past many decades. This will allow us to use previous surveys and experiments as comparisons and background for our current studies. Three of the locations we have selected are marine protected areas (UW Marine Research Preserves / National Wildlife Refuge / WDFW), in order to take advantage of sites that are likely to have higher abundances of predatory fishes.

At each of the twelve sites we conduct annual surveys between September and December. These surveys include quantifying the large predatory fishes; smaller fishes such as gobies and sculpins; mobile invertebrates such as cucumbers, sea stars, crabs, and shrimp; and sessile organisms such as bryozoans, hydroids, tunicates, and encrusting and erect algae. We survey these species using methods chosen based on the size of the organisms and frequency of encounter. These methods include belt transects for large mobile organisms (33 ft x 6.5 ft / 10 m x 2 m), point-intersect transects for canopy species, and 10 photoquadrats (1.08 ft^2 / 0.1 m^2) along each transect for basal species and small (<1 in / <3 cm) mobile organisms. Most surveys take place along horizontal transects located at depths spaced every 10 feet (3 m) between 29.5 and 69 feet (9 and 21 m) below sea level. Predatory fish transects extend 443 feet (135 m) diagonally from 79 feet (24 m) to the surface in order to bracket the depth range of the horizontal transects. In addition to the fall sampling, we also conduct predatory fish surveys in the spring and summer to adequately quantify predator abundance throughout the year.

Predator exclusion experiment.

We have affixed large (6.6 x 6.6 ft / 2 m x 2 m) cages to solid bedrock surfaces at two locations in San Juan Channel. One-half of each cage is fully enclosed, effectively prohibiting access of predators to the 6.6 foot by 3 foot (2 m x 1 m) swath. The other half of the cage is missing one side and has large windows in the mesh, allowing predator access to this swath while controlling for cage artifacts. Each cage is paired with a 6.6 foot by 3 foot (2 m x 1 m) uncaged swath. We have permanently installed five of these treatment blocks at each of the two study locations.

At each cage we are monitoring the response of the benthic community to reduced predator abundance. We are measuring these responses using similar methods to those listed above for the widespread community surveys, including 6.6 foot by 3 foot (2 m x 1 m) belt transects for large mobile invertebrates and small fishes and photoquadrats for small mobile invertebrates and primary space-occupying organisms.

To capture fast responses to caging, we conducted the first sampling immediately prior to cage installation, followed by sampling 1 month and again 3 months after the cages were installed. Additional monitoring is also planned for 6, 9, and 12 months after caging, as well as biannual monitoring thereafter, as warranted by results from the first year.

Rockfish diet.

Rockfish were captured from rocky habitats in San Juan Channel at depths less than 65.6 feet (20 m) to decrease the risks of barotrauma. We caught copper rockfish using barbless artificial lures and Puget Sound rockfish using hand nets while on SCUBA. Once on board the research boat, the fish were anesthetized using a buffered seawater solution of tricaine methanosulfonate (MS-222; 100 mg/L for copper rockfish, 70 mg/L for Puget Sound rockfish). The fish were left in the anesthetic for 5 to 7 minutes, or until they became unresponsive to handling and lost their righting response.

Each fish was placed upside down in a padded cradle. A tube attached to a hand-pumped garden sprayer (copper rockfish) or a syringe (Puget Sound rockfish) was gently inserted through the esophagus and into the stomach. We pumped seawater through the hose to flush stomach contents out through the mouth. Forceps were used to help extract any items that became lodged in the tube. A total of 37 copper rockfish and 11 Puget Sound rockfish were examined.

After we acquired the stomach contents we took morphological measurements of each fish, then placed them in a cooler filled with clean seawater to recover from sedation (5 to 15 minutes). The fishes were then lowered back to the capture depth using an inverted, weighted basket. No mortality or obvious injury was observed in the field or during methods testing in the laboratory.

Results

Our initial surveys of predatory fish abundance have confirmed that predator abundance is spatially variable in San Juan Channel. This allows us to be certain that we are able to compare benthic community structure between sites with higher and lower predator abundance.

Diet analyses of copper and Puget Sound rockfish closely resemble the results from other studies. Copper rockfish were found to feed primarily on demersal crustaceans. While small demersal fishes were observed in their diet, these were much rarer in our samples than in previous studies. Puget Sound rockfish stomach contents were dominated by copepods, with other small planktonic organisms making up the remainder. Only a single benthic organism (a caprellid amphipod) was found among the samples studied.

We have only just begun looking at the community composition of epibenthic organisms. These are the sessile invertebrate and algal species that are several trophic levels below the lingcod and rockfish. Our preliminary results show that different sites do have significantly different community compositions, but the two paired sites within each location are more similar to each other than to sites from other locations. We have not yet teased apart the community data to draw conclusions that will explain why these sites differ, but these analyses will be possible once we have finished processing all of our photographs of the benthos.

Preliminary results from the caging experiment show that while sculpin abundance is not significantly different between treatments, shrimp are more abundant in the predator exclusion cages than in uncaged areas.

Discussion

Rockfish stomach contents were successfully sampled without incurring any mortality. The results of our analyses closely agreed with past studies of copper and Puget Sound rockfish diets. We verified that Puget Sound rockfish are primarily planktivores. Puget Sound rockfish are one of the species fed upon by large lingcod, and therefore help link the pelagic and benthic food webs. Copper rockfish are known to feed largely on benthic crustaceans and our results reinforce this pattern. However, our results disagree with previous studies in that the diets of the fish we sampled seemed not to include a significant quantity of fish. The few fish species found in copper rockfish stomachs were demersal species, while past studies have shown a greater abundance of pelagic fishes in their diet. Importantly, given the concerns about rockfish population recovery, we have established that gastric lavage may be used to study rockfish diets without incurring mortality or even obvious injury.

Our predatory fish surveys have determined that there is variation in rockfish and lingcod abundance among the six survey locations. Three of the locations, Shady Cove, Point George, and Yellow Island, are Marine Research Preserves. Although these are the areas where fishing is prohibited, these are not always the areas where fish predators are most abundant. For example, while Yellow Island has the most rockfish of all our sites, it also has the fewest lingcod. Because lingcod feed on rockfish, their absence from this site may be allowing rockfish populations to recover here faster than in other places (Beaudreau and Essington 2007).

Bottom fish exclusion cages do seem to be triggering changes in the abundance of shrimp at two sites with high predator abundance. However, sculpin and other small fish abundance does not seem to have responded to the caging. This pattern is not surprising, given that the copper rockfish in San Juan Channel are primarily feeding on crustaceans instead of small fishes. As we continue to monitor these cages we will be carefully examining further impacts on shrimp abundance and how shrimp may be impacting the remainder of the benthic community.

Our results from the widespread community surveys have not shown clear patterns in epibenthic community composition related to predatory fish abundance. Although we are unable to associate rockfish and lingcod abundance, we have noted some important differences in community structure. All of the sites analyzed so far have clusters of communities significantly different from each other. Although each site clusters apart from all others, sites from within the same locations tend to cluster closer to each other than to other sites.

Our goal with this series of observational studies and experiments is to determine the level to which predatory fishes are responsible for structuring the rocky sub-tidal community in San Juan

Channel. Our findings indicate that rockfish abundance may locally inhibit shrimp and other crustacean abundance. Frid and Marliave (2010) have noted lingcod- and rockfish-induced changes in the species of shrimp present in rocky communities and we will be carefully documenting the identities of the shrimp we encounter. In the future we will be continuing the benthic surveys and our monitoring of the exclusion cages. We are also using suction sampling within the cages to quantify mesofaunal responses. Similar predator exclusion studies in New England have found that very small animals such as amphipods and copepods respond quickly to predator removals on this scale (K. Sebens and J. Witman, unpublished data). We will also be adding a tethered feeding experiment to quantify relative predation pressure by rockfish on shrimp and crabs. By studying the trophic relationships of the predatory fishes and other members of the food web in San Juan Channel, we hope to make predictions about the future of rocky sub-tidal communities in Washington as rockfish populations recover in response to decreased harvest rates or the establishment of marine protected areas.

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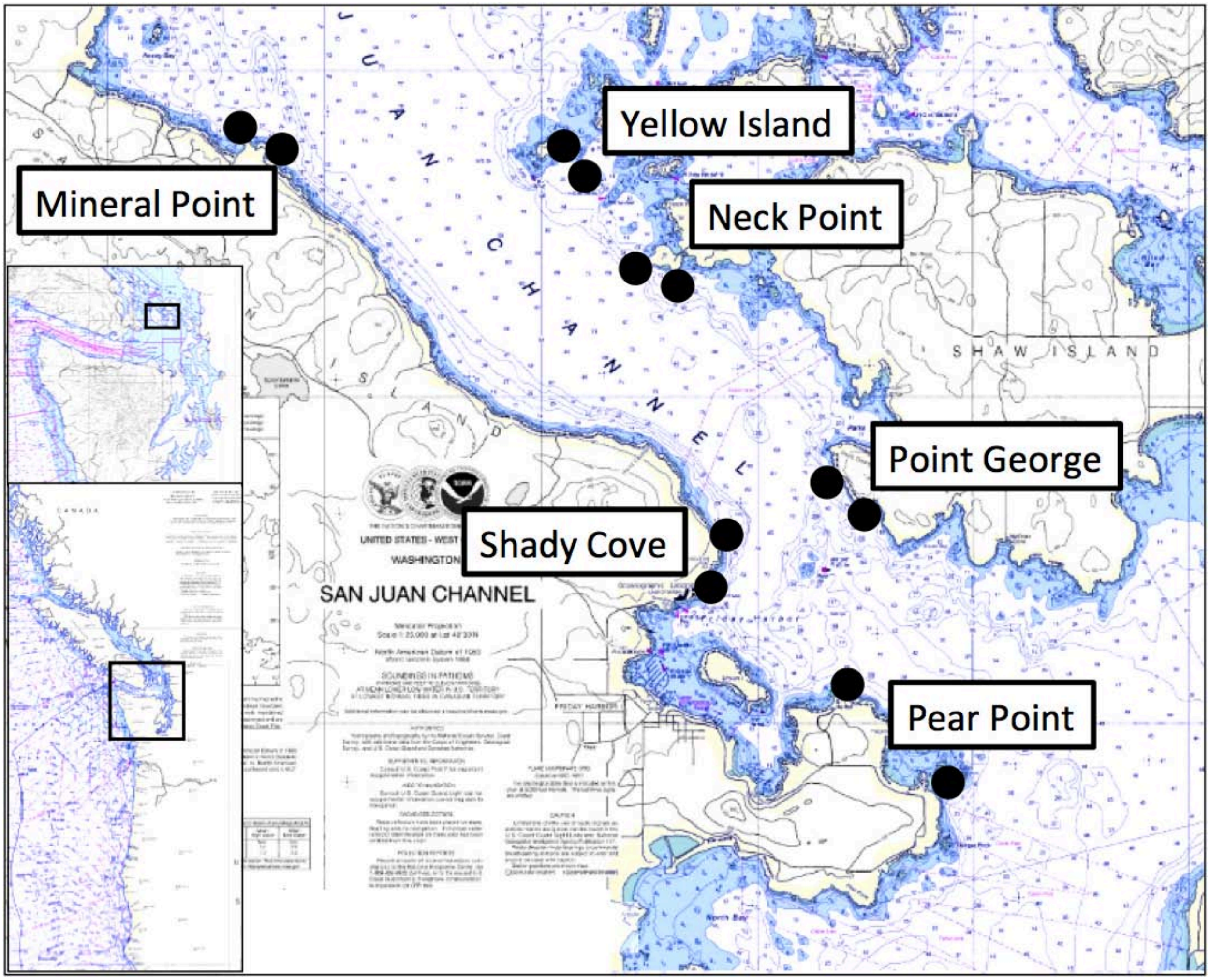

Figure 1. Map of study sites in San Juan Channel.

Seal and Sea Lion Predation on Rockfish in Puget Sound

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During the 1970s, many species of rockfish in Puget Sound declined dramatically as a result of overfishing and currently rockfish populations are in critical condition throughout many areas of Puget Sound. At the same time, populations of the three most common pinniped species, harbor seals, California sea lions, and Steller sea lions, have been increasing and are at or near carrying capacity levels in the Salish Sea. In general, pinnipeds are opportunistic predators that feed on locally abundant prey and commonly exhibit switching behaviors as prey abundances change in time and space. Although pinniped diet is typically dominated by a few species including salmon, herring, and gadids, a small amount of localized predation by regionally abundant pinnipeds could have a considerable negative effect on rockfish recovery. Harbor seals are the most abundant pinniped in the Salish Sea; diet studies conducted in Hood Canal, south Puget Sound, and Protection Island by WDFW and in the Strait of Georgia by Department of Fisheries and Oceans Canada indicate that predation on rockfish is not likely a concern. In this study, we collected pinniped scat at all known haul-out sites in the San Juan Islands to document the frequency of occurrence of rockfish in pinniped diet. Harbor seals consumed both juvenile and adult rockfish during 2005-2008 with the highest occurrence (5.4 percent, n=1,683) during winter, when diet overall became more diverse and significantly more rockfish were consumed at haul-out sites adjacent to Padilla and Samish Bays. However, a much different picture has been recently revealed through fatty acid analyses of blubber samples collected in 2007-2008 from harbor seals captured at Bird Rocks, Vendovi Island, Belle Chain, and Padilla Bay. Puget Sound rockfish composed 42 percent and 61 percent of harbor seal diet in spring (n=6) and winter (n=4), respectively, at Bird Rocks; 35 percent in winter (n=9) at Belle Chain; and 28 percent in fall (n=6) at Vendovi Island. Copper rockfish were grouped with Plainfin midshipman using discriminant function analyses and this group was most important during fall (n=4) and spring (n=6) at Bird Rocks and spring (n=17) in Padilla Bay, composing 26 percent, 16 percent, and 18 percent, respectively, of seal diet. Black and yellowtail rockfish were also grouped and were 18 percent of harbor seal diet during winter (n=9) at Belle Chain. Steller sea lion numbers in the San Juan Islands have increased steadily over the past decade with 80 to 100 adult animals present during fall and winter. From a limited number of scats collected from Steller sea lions in the San Juan Islands in 2006-2008, rockfish occurred in <1.5 percent of scat samples (n=67). No diet data have been collected for California sea lions in the San Juan Islands, but their numbers are low in this area and this species likely does not pose a predation threat to rockfish at this time. Current knowledge of pinniped abundance and predation on rockfish can help resource managers make informed decisions about potential impacts on rockfish. Our study suggests that a more detailed look at the response of rockfish to the level of harbor seal predation recorded by our two different techniques (scat and fatty acids) is warranted.

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The REEF Survey Project – An Ongoing Data Collection Effort

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Abstract

Volunteer data collection, or citizen science, provides a valuable alternative for scientists and resource agencies needing information but lacking sufficient resources to gather it. The Reef Environmental Education Foundation (REEF) Volunteer Survey Project is one such citizen science program. REEF volunteers collect distribution and abundance data on all marine fishes and a subset of invertebrates using a standardized visual method during diving and snorkeling activities. This citizen science program has generated one of the largest marine life databases in the world, with over 150,000 surveys conducted to date at thousands of sites throughout the coastal waters of North and Central America, the Caribbean, Hawaii, and the South Pacific. The Project, which started in the Florida Keys in 1993, was launched in the Pacific Northwest in 1998. Since then, over 700 divers have conducted 12,690 surveysof 835 sites in Oregon, Washington, and British Columbia. The program has resulted in a collaborative enterprise in which the general public engages in inquiry and investigation that results in practical management solutions. Data generated through the VSP have been used in a variety of conservation and management applications, including in the development of the stock assessments, the assessment of marine reserve effects, and the assessment of at-risk species. REEF Survey data are available in summary reports on the REEF website (www.REEF.org) and raw data files are provided to researchers and agencies upon request. REEF surveyors become keen observers and field naturalists. Beyond providing valuable data, REEF's efforts empower volunteers to take an active role in support of effective marine resource management as well as serve an important role in educating the public about issues and threats facing marine resources. We will present a summary of rockfish sightings in the Salish Sea by REEF volunteers, provide examples of how REEF data have been used for science and management, and discuss how to access the REEF data.

Overview of the REEF Program and Method

The Reef Environmental Education Foundation (REEF) is an international, non-profit, marine conservation organization that implements hands-on grassroots programs to engage local communities in conservation-focused activities. REEF is based in Key Largo, Florida, with a Pacific Office in Seattle, Washington. The mission of REEF is to conserve marine ecosystems for their recreational, commercial, and intrinsic value by educating, enlisting, and enabling divers and other marine enthusiasts to become active stewards and citizen scientists.

REEF connects the diving community with scientists and resource managers through marine-life data collection and related activities. This is primarily accomplished through the REEF Volunteer Survey Project, which has trained and involved over 14,000 divers and snorkelers in marine life identification and the collection of fish population and distribution data. This citizen science program has generated one of the largest marine life databases in the world, with over 150,000 surveys conducted to date. The Project started in the coral reef ecosystems of Florida and the Caribbean. Today, REEF volunteers conduct surveys throughout the coastal waters of North and Central America, the Caribbean, and Hawaii. REEF expanded to the U.S. Pacific Coast region in 1997 and the program has since generated over 21,000 surveys at over 1,250 sites in the marine waters between California and British Columbia.

Participants use standardized survey (Schmitt and Sullivan 1996) and training materials (Pattengill-Semmens and Semmens 2003). REEF volunteers use the Roving Diver Technique (RDT) (Schmitt and Sullivan 1996). The method is a non-point survey and allows the surveyors to swim freely around the dive site. The diver records all fish species positively identified and estimates categorical abundance for each species: Single (S) -1; Few (F) - 2-10; Many (M) - 11-100; Abundant (A) - >100. A companion invertebrate and algae monitoring program is part of REEF's Pacific Coast program. Forty-two native invertebrate species, plus three species of invasive tunicates, are monitored as part of the Pacific Northwest program (see list at http://www.REEF.org/programs/invertebrate).

All species data, along with survey time, depth, temperature, and other environmental information are transferred to REEF. Volunteers submit survey data through an online data interface (optically-read paper scanforms are also available to volunteers without Internet access). Quality control programs are run prior to entry into REEF's database. Visitors to the REEF website (www.REEF.org) can query a variety of data summary reports. REEF staff generate raw data files on request.

REEF surveyors advance through five experience levels (Novice: 1-3 and Expert: 4-5), based on the number of surveys completed and passing scores on comprehensive identification exams. Expert level (4 and 5) surveyors make up the Pacific Advanced Assessment Team (AAT).

Interested persons can get started doing REEF surveys anytime. REEF staff and REEF Field Stations (dive shops, dive clubs, etc.) periodically offer training sessions in the region. Training is not required to participate.

Summary of REEF Survey Effort and Data in the Salish Sea

As of June 15, 2011, REEF volunteers have submitted 12,495 surveys from 781 sites throughout the Salish Sea to the REEF database (Table 1). The number of sites surveyed varies each year (Table 1). REEF volunteers can conduct surveys anywhere and anytime they are diving or snorkeling.

Since 2007, REEF has coordinated free training programs in the region that include a combination of opportunities to enlist new volunteers and provide incentive for existing surveyors to stay involved and increase their survey experience level. This successful program has resulted in exponential increases in the number of Expert-level surveyors in the region and in the number of REEF surveys submitted each year (Table 1).

Just over 700 Survey Project volunteers have conducted surveys in the Salish Sea region; fifty members are rated as Expert surveyors (members of the REEF Advanced Assessment Team). Expert-level volunteers have conducted over one-third of all surveys submitted in the region to date (4,950). It is clear that as volunteers improve their skills, they are more likely to stay actively involved in data collection.

REEF surveyors have sighted 168 species of fish in the Salish Sea, including 18 species of rockfish (Table 2). This includes 6 very rarely sighted species (seen in less than 1 percent of all surveys). REEF surveyors report the presence and abundance category of young-of-the year (YOY) rockfish separately from adults (general guideline is 2 inches (5 cm) or less). There is an unidentified YOY category, as well as the opportunity to report the YOY to species if the surveyor is certain of the identification. The most frequently sighted rockfish is the copper rockfish (*Sebastes caurinus*) (Figure 1). It is also the most frequently sighted fish species of all those reported in the REEF database, sighted in 65 percent of surveys (8,061 surveys) in the region (Table 2). Copper rockfish have been sighted at 627 sites (Figure 1). Tiger rockfish (*Sebastes nigrocinctus*) is one of the more rare species in the database; it has been sighted at 136 sites and reported in 492 surveys (Table 2, Figure 2).

Table 1. REEF Volunteer Survey Project Effort in the Salish Sea.

Year	# of Surveys	# of Sites
1998	182	18
1999	187	68
2000	242	121
2001	521	138
2002	991	207
2003	910	174
2004	1,041	222
2005	751	154
2006	1,105	148
2007	1,370	232
2008	1,247	220
2009	1,616	235
2010	1,967	301
2011	365	95
TOTAL	12,495	781

*submitted as of June 15, 2011

Table 2. Rockfish encountered during REEF surveys in the Salish Sea.*

Species	# of Sites	%SF
Copper Rockfish	626	64.5%
Quillback Rockfish	531	35.8%
Brown Rockfish	262	31.9%
Black Rockfish	371	30.1%
YOY Rockfish – all species combined	405	21.8%
Puget Sound Rockfish	278	13.5%
Yellowtail Rockfish	263	12.2%
Vermilion Rockfish	134	6.9%
China Rockfish	120	6.9%
Tiger Rockfish	136	3.9%
Blue Rockfish	68	2.6%
Yelloweye Rockfish	115	2.4%
Canary Rockfish	68	2.1%
Unidentified Rockfish	83	1.3%
Bocaccio	7	0.2%
Widow Rockfish	6	0.1%
Dusky Rockfish	5	0.0%
Silvergray Rockfish	4	0.0%
Sharpchin Rockfish	1	0.0%
Greenstriped Rockfish	2	0.0%

*For each species, the number of sites the species has been reported (out of the total 781 surveyed) and the percent sighting frequency (out of the 8,061 surveys conducted in the region).

Use of the REEF Data

REEF provides raw data files upon request. Government agencies, conservation organizations, and scientists increasingly use the REEF database to address key management and conservation issues. REEF data have been used in the development of stock assessments (NOAA 2009; Kingsley 2004), in the evaluation of trends of fish and invertebrate species (Pattengill-Semmens and Nichols 2009; Semmens et al. 2000), as an indicator of population pressure on natural resources (Stallings 2009; Burke and Maidens 2004), to evaluate interactions between species and species-habitat relationships (Auster et al. 2005), to assess the effect of restoration efforts (REEF 2008), and to assess the status fish species that are experiencing significant declines (Ward-Paige et al. 2010a and 2010b). REEF volunteers have been instrumental in the identification and removal of exotic species (Nichols and Pattengill-Semmens 2009; Semmens et al. 2004) and in the identification of new species (Victor 2010; Holt et al. 2010; Taylor and Akins 2007; Weaver and Rocha 2007). PDFs of most of these articles and a full listing of scientific papers and reports that have used REEF data are included on REEF's website (http://www.REEF.org/db/publications).

The resulting data have facilitated the application of REEF data in several regional programs that include the following:

- REEF survey locations and survey effort were used to evaluate non-consumptive diver use by the Central Coast Stakeholder Group as part of the Marine Life Protection Act in 2007.
- REEF data were used in a NOAA Fisheries analysis of Puget Sound rockfish populations published in April 2009. The report recommendation was to list three of the species under the Endangered Species Act.
- REEF data on rock scallop, a commercially harvested species, were used by Washington Department of Fish and Wildlife in 2010 to evaluate current fishing rules for the species. As a result, the harvest rules were changed from 12 to 6 scallop per person.

Summary

Marine environments along the western U.S. are home to a rich array of species and a diversity of critical habitats. In addition to the intrinsic value of biodiversity, the health of these environments is vital to providing opportunities for recreation, tourism, commercial harvest, and education to a worldwide audience. Effective management of coastal marine ecosystems requires information on the distributions, abundances, and trends of organisms. However, field scientists are often too few and too little funding is available for large-scale data collection programs. Volunteer data collection programs such as REEF provide a valuable alternative for scientists and resource agencies needing information but lacking sufficient resources to gather it.

The REEF Volunteer Survey Project generates valuable data on sub-tidal populations, while expanding scientific awareness and increasing ocean science literacy among a key marine resource user group: scuba divers. The extensive REEF data set has become an important source of information for marine managed areas. Continuation of this effort will document shifts and changes in populations and community structure as well as catalogue biological diversity.

According to Dr. Steve Lonhart, lead scientist at the Monterey Bay National Marine Sanctuary: "Trained citizen scientists become excellent stewards of the resources, and coupled with the complementary nature of REEF survey data, the REEF program continues to be an important partner in the Sanctuary's efforts to involve the diving community, manage effectively, and educate the public."

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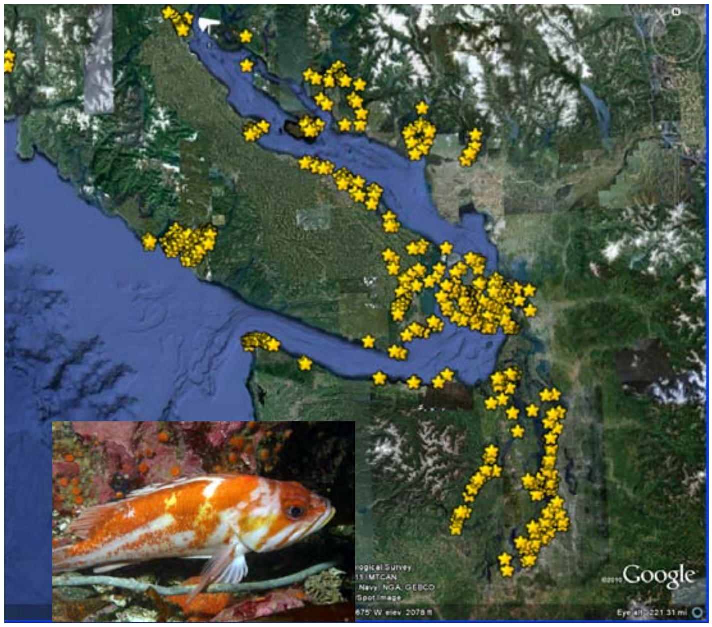

Figure 1. Sighting locations of copper rockfish in the REEF database. It has been reported in 8,061 surveys at 627 sites. As of June 15, 2011, REEF volunteers have submitted 12,495 surveys from 781 sites throughout the Salish Sea. Photo by Chad King.

Figure 2. Sighting locations of tiger rockfish in the REEF database. It has been reported in 492 surveys at 136 sites. It is the most frequently sighted species in the database. Photo by Janna Nichols.

Do Rockfish Conservation Areas Work?

Ryan Cloutier, Isabelle M. Côté, Simon Fraser University

Many rockfish (*Sebastes* spp.) populations are at low levels of abundance because of overexploitation. In an effort to curb declines of inshore rockfishes, Canada's Department of Fisheries and Oceans has established a network of Rockfish Conservation Areas (RCAs) along the coast of British Columbia to provide spatial refugia from fishing. However, the lack of post-establishment monitoring is preventing an evaluation of the effectiveness of RCAs at rebuilding depleted stocks. We conducted scuba-based assessments (26 to 49 ft / 8 to 15 m depth) of abundance of rockfish and other fish species within RCAs and at adjacent, ecologically-equivalent unprotected sites in three areas of the Strait of Georgia. We quantified effectiveness by comparing the presence/absence, as well as the abundance when present, of various species of rockfish in and out of RCAs. We also evaluated the contribution of important biotic and abiotic environmental characteristics and their interactions in order to more fully understand why rockfish occur where they do. In addition, we found no significant differences in community structure between protected and non-protected sites. These results suggest that the effects of protection are minimal and likely are because of the "slow" life histories of rockfish, poor enforcement of reserves, and the relatively young age of protected areas.

Editor's Note: The extended abstract of this paper will be published in a separate professional journal.

Jackpot Recruitment and Conservative Management Effects on Rockfish Abundance Inside and Outside Marine Reserves in Puget Sound

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In response to a multi-decadal decline of rockfish populations in Puget Sound, the Washington Department of Fish and Wildlife (WDFW) has implemented conservative management rules and initiated monitoring programs to protect the resources. One of these long-term programs monitored rockfish and other fish abundance within and outside several marine reserves in Puget Sound for the past 15 years and has conducted other sampling to characterize rockfish populations. The primary technique has been visual surveys with two scuba divers who identified, counted, and measured important marine fishes within permanently-marked footprints of rocky habitats. In 2006, we initiated young-of-the year (YOY) surveys at 18 sites in the central and southern basins and increased collected YOY information from sites in Hood Canal. Other information obtained from recreational fishers and bottom trawl surveys was used to corroborate and supplement our observations on rockfish abundance and recruitment.

We have observed increased abundances and sizes of rockfish in many of the reserves over time and in comparison to nearby fished areas. However, as conservative management measures have been implemented, the differences in these measures between fished areas and reserves have become less clear. We have been following a large-scale recruitment of copper and quillback rockfishes in the central and southern basins of Puget Sound that occurred in 2006 and a similar recruitment in Hood Canal in 2008. As these cohorts have developed, we have observed high numbers of sub-adult copper and quillback rockfishes in both reserves and fished areas, and patchy geographic patterns in recruitment both inside and outside reserves. We have also observed strong recruitments in black rockfish and invasions of vermillion rockfish in Puget Sound. These patterns of recruitment, together with conservative management, have a strong likelihood of improving long-term abundance of these sensitive species.

Editor's Note: No extended abstract was submitted for this presentation.

Dispersal Processes in Puget Sound Brown Rockfish from Parentage and Oceanography

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Introduction

The extent of dispersal in marine species has attracted great interest by ecologists, evolutionary biologists, and resource managers alike, not only because data on dispersal and retention mechanisms provide powerful insights into the distribution, phylogeography, and evolution of marine species, but also because assumptions on self-recruitment of marine stocks underpin many of the commonly used strategies in fish stock assessment and conservation. With the emphasis on marine protected areas (MPAs) as a tool for marine conservation, the question of realized dispersal of pelagic larvae has found renewed significance, as the function of MPAs in a regional context depends critically on the demographic exchange between the MPA and surrounding areas. On one extreme, retention of all life history stages within an MPA negates any positive effects on surrounding areas, while on the other extreme, total export of larvae or juveniles from the MPA may limit the conservation value of the protected area. Some information on realized dispersal from MPAs is therefore required, and although data on adult migration are accumulating, little is known about the effect of larval dispersal, which most likely dominates the level of demographic connectivity of protected areas with surrounding regions.

Most estimates of larval dispersal have been derived indirectly by inferences from current speeds, larval duration, or genetic differentiation among adult populations. Such estimates are inherently imprecise, and although cross-species correlations between, for example, genetic differentiation among populations and larval duration could be demonstrated, the predictive value of such indirect inferences for MPA design remains limited. More informative are isolation-by-distance patterns, where genetic differentiation increases linearly with geographic distance and which allow the estimation of mean dispersal distances. However, although such estimates are useful for management, their direct ecological application to a specific MPA is difficult, because dispersal distances are estimated over large geographic areas and extended time periods. Direct estimates of dispersal, on the other hand, either by identifying parent-offspring pairs or by oceanographic prediction of dispersal trajectories, allow real time assessment of larval connectivity, and may thus be more applicable to MPA design.

Here, we estimate dispersal rates and distances in brown rockfish (*Sebastes auriculatus*) in Puget Sound by combining oceanographic modeling, genetic parentage analysis and otolith microtagging. Brown rockfish is an ideal species, because limited adult movement facilitates the estimation of larval dispersal and because their patchy distribution in southern Puget Sound provides point sources of larvae. Previous research on coastal brown rockfish estimated mean dispersal distances of about 6.2 miles (10 km), suggesting that about 40 percent of offspring should settle within 3.1 miles (5 km) of the parent. In addition, Puget Sound, an oceanic inlet in northwestern Washington, has well known oceanography and limited exchange with the Pacific Ocean, thus facilitating prediction of larval dispersal trajectories and recovery of tagged larvae.

Methods

Sampling: We collected 1,837 adult and juvenile brown rockfish in the south Puget Sound from 18 locations in 2004-2009. Adults (>7.83 inches / >19.9 cm total length, n = 875) and recently settled recruits and juveniles (<7.87 inches / <20 cm total length, n = 962) were live-captured via fine-mesh hand nets (11.8 in. / 30 cm in diameter) by pairs of SCUBA divers at depths up to 65.6 feet (20 m). Tissue was clipped from the caudal fin of all individuals and preserved in 95 percent ethanol. We injected 157 females with strontium solution to induce a mark in the otoliths of developing larvae. A total of 688 juveniles were lethally sampled and preserved for otolith microchemistry analysis to verify genetic parentage results. The majority of samples (n = 1,282) were collected from the main study site, an artificial reef at Point Heyer, Vashon Island, while the remaining samples (n = 555) were collected from other locations in the Puget Sound representing natural and artificial habitat. There were 10 locations where we collected greater than 20 adults (Point Heyer, Elliot Bay Pier, Maury Island Barge, Maury Island Marine Park, Orchard Rocks, Point Glover Reef, Slag Pile, Taylor Bay, West Seattle Reef, Zee's Reef).

Oceanography: Dispersal was predicted from oceanographic models using a detailed circulation model (PRISM) developed by the School of Oceanography, University of Washington (Kawase 1998). We used this model to predict the dispersal of passively moving larvae, and thus the most likely settlement areas of juveniles born at Point Heyer. Simulated trajectories of 1,000 particles were released from Point Heyer over a larval dispersal period from July 15, 2007 and tracked until October 13, 2007. Shoreline end locations were determined from the particle trajectories to determine areas of recruitment and settlement from juveniles originating from Point Heyer. In addition, drogued drifters with a sail set at 59 feet (18 m) were used to test model predictions empirically.

Genetic analysis: Samples were genotyped at 16 microsatellite loci. Individuals genotyped for less than 12 microsatellite loci were excluded from the data set. Also excluded from analyses were individuals identified as unintentional recaptures. Two approaches to parentage assignment were used: first, a maximum likelihood method based on population-wide LOD scores obtained from simulations in CERVUS v 3.0 and second, an exclusion approach, which allows for estimation of the probability of data containing false parent-offspring pairs and if that probability is unacceptably high, a Bayesian approach is implemented to separate true from false parent-offspring pairs. Pairwise relatedness values were calculated among 1,810 individuals, and the most likely relationship was determined using maximum likelihood. The proportion of full siblings and parent offspring pairs in pairwise comparisons between sites was regressed against geographic distance between sites with more than 20 adults.

Otolith microchemistry: Gravid females were injected with a strontium solution at 60 mg per kg body mass. Preliminary experiments with captive fish validated a clear identifiable strontium mark in the otolith of larvae of such females (Buckley et al. 2007; Kuroki et al. 2010). Otoliths were extracted from 55 potential juveniles (matching a strontium-marked parent at more than 13 of the 16 loci) and analyzed using an electron microprobe analyzer at the University of Tokyo.

Results

Oceanography: Dispersal projections suggested a primarily clockwise circulation around Vashon Island, with a higher density of particles released at Point Heyer in the southern part of Puget Sound. Settlement of offspring of Point Heyer adults were more likely to settle south of that site near Tacoma Narrows than at Point Heyer itself. These results were confirmed by empirical drifter experiments.

Genetic analysis: Our dataset had high exclusionary power, and simulations showed that no random parent-offspring matches would be expected and the probability of any putative parent-offspring pair being false when using strict exclusion was 0.001. We identified seven offspring that had parents in the sample, one of which could be assigned to both parents. All offspring were caught at Point Heyer, and four offspring had parents at Point Heyer while three offspring originated from other sites (Port Orchard, West Seattle Reef, Maury Island Barge). There was a significant decline in the proportion of full siblings with increasing geographic distance.

Otolith microchemistry: None of the mothers of genetically identified offspring were injected, and consequently none of the offspring had a detectable strontium mark in their otolith. However, none of the potential offspring mismatching adults at one or more loci had an otolith mark either, thus confirming the false match.

Discussion

Our study demonstrates the feasibility to directly estimate larval dispersal from oceanography, genetic parentage assignment, and otolith analysis. Oceanography suggested settlement in southern Puget Sound of larvae originating from Point Heyer. Correspondingly, only four offspring could be assigned to parents at Point Heyer, despite the high power of our genetic markers and a high proportion of adults sampled. Otolith microchemistry did not confirm any of the parental assignment, because none of the mothers were injected with strontium, but it could exclude potential parent-offspring pairs that mismatched at one or more loci. This interdisciplinary approach provided high power to assess larval dispersal from the focal site.

Oceanographic predictions of larval dispersal provided useful indications for setting priorities of sampling locations for potential offspring originating from Point Heyer. However, these predictions did not always coincide with suitable juvenile habitat. For example, no juveniles could be found at the entrance of the Tacoma Narrows, which was predicted to be a major destination site for larvae from Point Heyer. It would be interesting to test these predictions by creating artificial habitat that provides shelter for juveniles at sites with high predicted settlement. These predictions could be expanded to a wider range of adult source locations and potentially improve recruitment of rockfish in Puget Sound. Further research validating such oceanographic predictions of larval dispersal in Puget Sound is needed, especially with regard to the effect of larval behavior on dispersal trajectories.

Point Heyer appeared to support little self-recruitment—only four offspring at Point Heyer could be assigned to parents from the same site. We estimate that we sampled a minimum of half the adults on that reef, confirmed by the successful assignment of one offspring to both parents. From relative frequencies of offspring with one and two parents, we estimate that about 40 percent of parents were sampled, and that there were about eight offspring originating from Point Heyer (including offspring from unsampled parents).Only about 1 percent of recruits were locally produced (816 recruits were sampled at this site, much less than the 40 percent offspring recruiting within 3.1 miles (5 km) of the parent predicted by isolation by distance patterns in previous research. This low self-recruitment is unlikely to correspond with particular conditions in a single year, as juveniles were collected over three consecutive seasons. Instead, the low self recruitment may either be due to low reproductive success of adults at Point Heyer (possibly related to unsuitable habitat at settlement sites) or due to essentially random spatial distribution of recruitment of brown rockfish in Puget Sound. It would be interesting to repeat the study described here at a natural reef, as previous research suggested that habitat quality may be lower at artificial than natural reefs.

Although otolith microchemistry did not confirm any of the parent-offspring assignments, it was useful in confirming the rejection of putative parent-offspring pairs by revealing no strontium mark in dubious juveniles. The integration of both methods can therefore prevent false positives of either method. For example, a preliminary study of Point Heyer brown rockfish identified a likely offspring of an injected female (Hauser et al. 2007), but the addition of more genetic markers excluded the parent-offspring relationship. As both methods are liable to such false positive results, a combination of methods is likely to provide the most accurate results.

Our results also have considerable management implications. Low self-recruitment at Point Heyer suggests that this site relies heavily on recruitment from other sites. Juveniles from Point Heyer may recruit elsewhere, but may also be lost from the population. In any case, these results emphasize the importance of MPA networks, as relatively small areas such as artificial reefs in otherwise unsuitable habitat are highly connected and depend on outside recruitment. Further research may provide further insights into more optimal placement of MPAs within Puget Sound.

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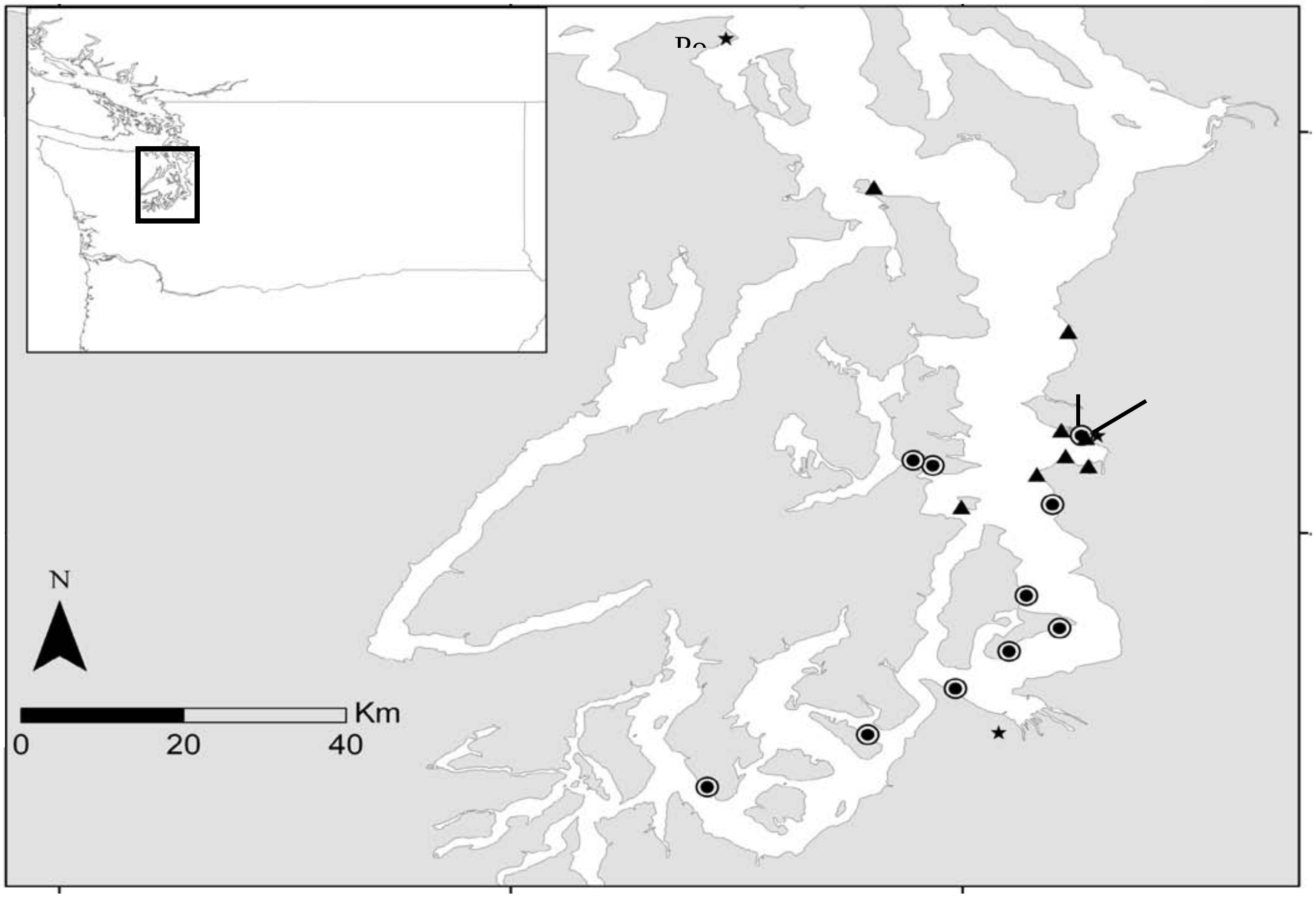

Figure 1. Map of collection sites in the south Puget Sound. Upper left inlay is indicating the location of the south Puget Sound (defined as south of Port Townsend) in Washington State. Circles and triangles represent collections with greater than 20 and less than 20 individuals, respectively.

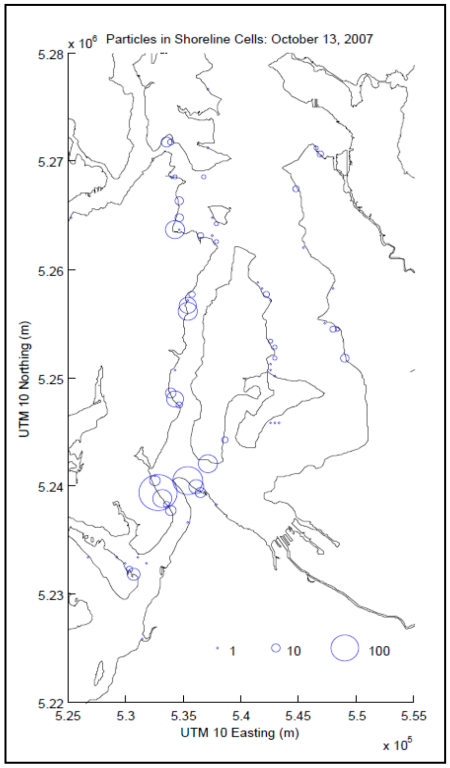

Figure 2. PRISM model showing end locations of 1,000 simulated particle trajectories released from Point Heyer after a 60 larval dispersal period (Kawase et al., unpublished data).

Hybridization of *Sebastes maliger, Sebastes caurinus*, and *Sebastes auriculatus* in the Puget Sound Basin, Washington

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and Lorenz Hauser, Piper Schwenke, University of Washington

Hybridization is a major conservation and management issue in many freshwater and terrestrial species, but has so far received little attention in marine species. In Puget Sound, rockfish abundance has declined and many populations have been designated vulnerable or at risk for extinction. The implications of interspecific hybridization in Puget Sound for species of concern are significant, in particular where anthropogenic influences may increase the frequency of hybridization. Our objective for this project was to determine the geographic distribution of hybridization and level of introgression between copper (*Sebastes caurinus*), quillback (*S. maliger*), and brown (*S. auriculatus*) rockfish in Puget Sound, Washington, USA. Although these three species are sympatric along the Pacific Coast and in Puget Sound, there are reports of hybridization only from within Puget Sound. We analyzed sequence data of five molecular genetic markers (one mitochondrial and four nuclear) to identify hybrids in Puget Sound between *S. caurinus*, *S. maliger*, and *S. auriculatus*. Thirty-five percent of the rockfish samples from Puget Sound showed evidence of genetic introgression. Later generation hybrids were detected between all species pairs, but no first generation hybrids were found. In Puget Sound, we found a significantly higher number of hybrids where most of these hybrids were originally identified as *S. caurinus* or *S. auriculatus*. Analyses on the evolutionary age of hybridization are still ongoing, but our results show wide-spread introgression among these rockfishes in Puget Sound, possibly leading to a breakdown of species barriers and rapid evolutionary change.

Editor's Note: The extended abstract of this paper will be published in a separate professional journal.

Use of Pacific Oyster *Crassostrea gigas* (Thunberg, 1793) Shell to Collect Juvenile Rockfish, *Sebastes* (Cuvier, 1829) in the Salish Sea

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Abstract

Some populations of rockfish (*Sebastes*) species in the Puget Sound have been listed as "threatened" or "endangered" under the Federal Endangered Species Act, but very little is known about juvenile rockfish settlement and abundance trends, or their interaction with other fish species. For fishery managers to develop management practices that accelerate the recovery of over-fished areas they need an understanding of the spatial and temporal trends in juvenile rockfish distribution and abundance as well as cost-effective recruitment monitoring techniques. In 2005, a pilot experiment was conducted by the Washington Department of Fish and Wildlife to collect juvenile sea cucumber (*Parastichopus californicus*). The collector (Cheng and Hillier 2011) was made of a commercial oyster cultch bag filled with Pacific oyster (*Crassostrea gigas*) shell. Accidentally, 12 juvenile rockfish were collected, with sizes ranging from 1.8 to 2.4 inches (46 to 62 mm). From the study results, it is clear that location, depth, and substrate influenced the collection of juvenile rockfish. The proposed collector may be used as a cost-effective tool to define rockfish nursery areas and monitor recruitment of a highly diverse and vulnerable species. Further experimental design has been suggested to test the effectiveness of different types of collectors.

Introduction

Once considered a staple of the Pacific Northwest fishing community, rockfish (*Sebastes*) have shown drastic declines over the past 25 years. Within the marine waters of the Puget Sound, 26 species can be found inhabiting most marine habitats from the intertidal zones to depths greater than 3,281 feet (1,000 meters) (Haldorson and Love 1991). Many of these species, which used to be plentiful, have been showing signs of depletion. Currently in the Georgia Basin, which encompasses the Puget Sound, both yelloweye (*S. ruberrimus*) and canary (*S. pinniger*) rockfish have been listed under the Endangered Species Act as "threatened" and bocaccio (*S. paucispinis*) has been listed as "endangered."

Rockfish, as a group, are difficult to manage because they are quite vulnerable to the effects of fishing (Parker et al. 2000) and to other natural and man-made factors. Rockfishes are some of the longest-lived fishes known in the Puget Sound, with maximum ages for several species spanning more than 50 years. Elsewhere in their range, rockfishes can attain ages between 100 years and 205 years (Munk 2001). This longevity combined with a slow maturity rate, a slow growth rate, low natural mortality rates, maturity late in life, and sporadic reproductive success from year to year make them susceptible to over fishing. Impacts from fishing pressure and habitat degradation are compounded because rockfish display high fidelity to specific habitats and locations, and require a diverse genetic and age structure to maintain healthy populations (Love et al. 2002). In addition to these biological factors, rockfish that are caught at depth often experience physical trauma and die from pressure-related complications, making catch-and-release fisheries and size limitation fisheries generally unfeasible.

There is limited information on juvenile rockfish species' life stages in the northeast Pacific. Ammann (2004) conducted a study along the central California coast to examine the effects of seasonal and temporal patterns of recruitment indexing for juvenile reef fishes. It appeared in the study that collectors provided acceptable habitat for some species and it was concluded that collectors may provide a good estimate of recruitment. Understanding variations in recruitment can be a major factor for forecasting dynamics of marine populations, especially for organisms with a pelagic larval stage (Sale 1990). Understanding and monitoring juvenile rockfish recruitment trends would improve the ability of fisheries managers to modify catch allocations based on strong or weak recruitment years and provide a more clear understanding of species distribution. Recruitment trends for the giant red sea cucumber (*Parastichopus californicus*) were explored during a pilot study conducted in 2005 by the Washington Department of Fish and Wildlife (WDFW). During this study, biologists found that not only did the oyster cultch bag used as a collector for juvenile sea cucumber (JSC) provide habitat for invertebrates, but it also provided a means to collect juvenile rockfish (JRF).

In the pilot study conducted by WDFW, the hypothesis that the large cup-like shell of the Pacific oyster, with its coarsely ridged and fluted exterior would provide suitable settlement habitat for wild JSCs was tested. During the course of the study, researchers observed that not only were invertebrates found within the interstitial spaces of the oyster shell, but JRF were also occupying these same collectors.

In the Puget Sound, wild sub-adult sea cucumbers (3 to 5 in. / 8 to 13 cm) are occasionally observed inhabiting commercial grow racks and bag culture of Pacific oysters, *Crassostrea gigas* (Thunberg 1793). This culture method was developed for substrate types that do not support beach culture. Essentially, it involves growing single oysters in polyethylene grow-out bags that are clipped to rebar racks. Similarly, oyster growers in British Columbia have found that wild sub-adults of *P. californicus* can form a significant population within the community of organisms that settle and grow on the oyster culture gear (Paltzat et al. 2006; Paltzat et al. 2008). This motivated the use of Pacific oysters in JSC collector design.

Figure 1. Locations of the three juvenile sea cucumber collector sites.

Table 1. Summary of collection sites, deployment dates, dominant substrate, plants on site, sampling dates, and number of JRFs collected in different depth strata.

Collection Site	Deployment Date	Dominant Substrate	Plants on Site	Sampling Dates	Depth (m) and # of JRF
Long Island	March 2005	Solid Rock	*Laminaria* sp., small red algae, large red algae, *Pterygophora californica*	June 2005	
				January 2006	
Discovery Bay	April 2005	Sand	*Ulva* sp., small red algae, large red algae	September 2005	
				December 2005	3m (8 fish), 5m (3 fish), and 7m (1 fish)
Oro Bay	May 2005	Cobble with mud, sand, and shell hash	*Laminaria* sp., *Ulva* sp., large red algae	July 2005	
				January 2006	

In 2005, the Washington Department of Fish and Wildlife (WDFW) implemented a pilot study using JSC collectors in the Puget Sound to gather wild juvenile *P. californicus* data. Study sites were selected based on several criteria including substrate composition, exposure to tidal currents, depth gradient, and diver accessibility, as well as previously recorded commercial and scientific diver sightings of JSCs. Twelve collectors were installed at each of three sites: Long Island (48°26.337N, 122°55.155W), Discovery Bay (48°00.960N, 122°50.090W), and Oro Bay (47°08.442N, 122°41.166W) (Figure 1), between March and May 2005 and allowed two months soaking time. Deployment dates, dominant substrate, macroalgae present, and sampling dates for each of the three study sites are summarized in Table 1. Collectors were constructed from 4-foot- (1.2-meter-) long commercial oyster cultch bags with a mesh size of 5 inches (130 mm) filled with broken and whole Pacific oyster shells (cultch) up to 5 inches (130 mm) in length. The number of shells and shell fragments were not necessarily the same in each bag.

At the three study sites, three depth strata (9.8, 16.4, and 23 ft / 3, 5, and 7 m) (Mean Lower Low Water [MLLW]) were selected and four collectors were placed on the substrate in each stratum. To reduce the potential for displacement by tidal currents, each collector was attached to cinder blocks using non-floating line. Each of the collector sites was then monitored for JSC recruitment from May 2005 to January of the following year. Each collector was retrieved by a diver and brought to the surface where they were placed in a container. The collectors were sliced open lengthwise and each shell or shell fragment was removed and individually examined. This study was not designed to collect JRFs; however, biologists examining the collectors realized that rockfish in the Puget Sound may be vulnerable so JRF collection information was also recorded. When JRFs were observed within the collector, they were placed on a board adjacent to a measuring device (caliper) and photographed. JRF length information was taken from photo documentation during the post processing period. All JRF were then safely returned to the water following examination and photographing. Associated organisms were recorded, as well as notes pertaining to sedimentation. Upon completion of the examination, a new intact commercial oyster bag was filled with the examined cultch and returned to the same approximate location.

Results

During the study, 12 JRFs with a mean length of 2.10 inches (53.42 mm) (min. 46 mm, max. 62 mm, s.d. = 4.70) were retained within the collectors. The coefficient of variation was 11 percent, which implies that the adult rockfishes spawn within a similar timeframe. All rockfishes collected were at the Discovery Bay site in December 2005 (Table 1). Eight individuals were collected in two bags from the 9.8 foot (3 meter) depth strata. Three were collected from the 16.4 foot (5 meter) depth strata and one was collected from the 23 foot (7 meter) depth strata.

Thirteen JSCs with a mean length of 1.63 inches (41.4 mm) (min. 3 mm, max. 85 mm, s.d. = 27.9) settled within the collectors. The coefficient of variation was 67.49 percent (<1), which implies that adult sea cucumber in the Puget Sound spawn over a 1 to 2 month period. Only 9 of 12 collectors placed in the shallow stratum (9.8 ft / 3 m MLLW) were surveyed. Three of the collectors were displaced during storm events and could not be located. Two of the three sites, Long Island and Discovery Bay, attracted JSCs, with 69 percent of the recruits settling on collectors that were placed on rocky habitat. It is not likely that JSC and JRF show a relationship from location and time where they were caught.

Collectors placed over heavy silt deposits could have been influenced by anoxic sediments below the collector. Collector success was hindered by several factors including predation, collector destruction, and the ability of surveyors to observe very small recruits of JSC within the collector. Predation and siltation were major concerns for successful collection of juveniles in each collector. A summary of all known collected marine organisms collected from the three study sites is listed in the paper (Cheng and Hillier 2011) and includes many known or possible predators of JSCs. There were also many non-species-specific animals present.

Discussion

Among the three sites selected for the pilot study, only one site, Long Island, is considered to be the ideal habitat for adult rockfish. However, JRF were only present during the December survey of collectors placed at the Discovery Bay site. This implies rocky habitat is a necessary but not sufficient condition for living JRF.

The development of JRF collectors would enable us to identify spatial and temporal trends in recruitment and better understand the distribution and behavior of larvae and juveniles in various environments. Rockfish exhibit a transition period coming after a pelagic juvenile phase in which there is a transition of juveniles to their first substrate. This period encompasses settlement to substrate and then subsequent transition of juveniles to other substrates or habitats during approximately the first year of habitat associations (Buckley 1997). The collector methods developed here may also be applied to other managed species that are lacking in larval recruitment information around the world. The implementation of larval collectors as a method of monitoring sea cucumber and rockfish recruitment provides a cost-effective alternative to other survey methodologies such as SCUBA, submersible, or underwater camera transect surveys.

In the wild, JRF are preyed upon by various adult fishes. The use of collectors may provide some protection from many of these predators, thereby increasing their survival rate. In an upcoming study by WDFW, JSC collectors will be modified to maximize their use as JRF recruitment modules and refuge from predators. At present, all the JSC collectors were placed and recovered by divers. Modification of the collectors to reduce the use of divers will be considered for future JRF experiments. The proposed new JRF collectors will be mounted with metal frames and a concrete base and will be retrieved by use of a winch. A JRF collector optimized to reduce predation would also be useful for re-stocking programs. This second study will provide information crucial to restoration and enhancement efforts worldwide, by increasing our knowledge of JRF biology, juvenile population dynamics, and the breadth and reliability of recruitment.

The use of advanced experimental design, e.g., Latin square and balanced Latin square, should be considered in the development of JRF collectors. Collectors containing Pacific oyster shell hash have been proven to collect JRF. However, there are other materials such as rock, artificial rock, and concrete block with holes that can also be considered as collector material. Schlosser and Bloeser (2006) have successfully attempted to use traps to collect juvenile rockfish, cabezon, and kelp greenling on both the California and Oregon coasts. There is an urgent need to compare the effectiveness of different types of collectors in order to maximize the efficiency of JRF capture. The effective size of the collector should also be investigated in future studies. Once collectors designed to maximize JRF capture are tested, the spatial and temporal effect on the distribution of JRFs should be investigated with change-over designs (Cheng and Street 1997).

Collectors can help scientists to identify spatial and temporal distribution of JRFs, but JRFs are morphologically distinct from larvae and adults (Kendall 2000). Additionally, juvenile stages of many species, especially the pelagic juvenile stage, have not yet been described; only a few species have complete ontogenetic descriptions (Matarese et al. 1989; Moser 1996). The species of a few *Sebastes* larvae can be determined and adults can be misidentified, e.g., yelloweye. The ability to identify *Sebastes* accurately and efficiently at all developmental stages will, in turn, greatly increase our knowledge of their life histories as well as our management and conservation efforts. Orr et al. (2000) have developed a guide on juvenile *Sebastes* in the Pacific Northwest based on color and head spine strength. A mixture methods based on morphological characteristics and a genetics method is recommended (Li et al. 2004) to insure JRF are identified in a cost effective way.

Acknowledgements

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What We Know and Don't Know about ESA-listed Rockfish of the Puget Sound/Georgia Basin

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The Puget Sound/Georgia Basin Distinct Population Segments (DPSs) of yelloweye rockfish and canary rockfish are listed as threatened, and the DPS of bocaccio is listed as endangered under the Endangered Species Act (75 Fed. Reg. 22276, April 28, 2010). These DPSs include all yelloweye rockfish, canary rockfish, and bocaccio (ESA-listed rockfish) found in waters of the Puget Sound, the Strait of Georgia, and the Strait of Juan de Fuca east of Victoria Sill (Figure 1). There have been few studies that focus on yelloweye rockfish, canary rockfish, and bocaccio within the DPSs. Encounters with these fish have commonly come from happenstance or during studies that are focused on other species or a range of fish species within the Puget Sound (e.g., Reum 2006).

Habitats of the Puget Sound/Georgia Basin

The Puget Sound can be subdivided into biogeographic regions that encompass contiguous, ecologically unique, and spatially isolated freshwater, estuarine, and marine habitats (Downing 1983; Burns 1985). These five interconnected basins include: (1) The San Juan/Strait of Juan de Fuca Basin, (2) Main Basin, (3) Whidbey Basin, (4) South Puget Sound, and (5) Hood Canal. The sills largely define the boundaries between the biogeographic regions (except where the Whidbey Basin meets the Main Basin) and feature relatively fast water currents during portions of the tidal cycle. The sills, in combination with bathymetry, freshwater input, and tidal exchange, influence environmental conditions such as the movement and exchange of biota from one region to the next, water temperatures and water quality, and restricting water exchange. In addition, each region differs in biological condition; depth profiles and contours; sub-tidal benthic, intertidal habitats; and shoreline composition and condition (Downing 1983; Ebbesmeyer et al. 1984; Burns 1985; Rice 2007; Drake et al. 2010). Most rocky benthic habitats occur in the San Juan area (approximately 90 percent), with the rest occurring within Puget Sound proper.

Figure 1. Puget Sound/Georgia Basin Distinct Population Segments of ESA-listed Rockfish.

We summarize our general knowledge of each species at the DPS level according to the following demographic viability criteria: abundance and productivity, spatial structure/connectivity, and diversity. These viability criteria are outlined in McElhaney et al. (2000) and reflect concepts that are well founded in conservation biology and are generally applicable to a wide variety of species. These criteria describe demographic conditions that individually and collectively provide strong indicators of extinction risk (Drake et al. 2010).

Abundance and Productivity

There is no single reliable historic or contemporary population estimate for yelloweye rockfish, canary rockfish, or bocaccio within the Puget Sound/Georgia Basin DPS (Drake et al. 2010). Despite this limitation, there is clear evidence that each species' abundance has declined dramatically (Drake et al. 2010). The total rockfish population in the Puget Sound region is estimated to have declined approximately three percent per year for the past several decades, which corresponds to an approximate 70 percent decline during the 1965 to 2007 time period (Drake et al. 2010). Catches of yelloweye rockfish, canary rockfish, and bocaccio have declined as a proportion of the overall rockfish catch (Drake et al. 2010).

The WDFW ROV surveys within the San Juan archipelago (Pacunski, this volume) provide population estimates for yelloweye rockfish, canary rockfish, and bocaccio on or near mapped rocky habitats in the survey area. There are no historical or contemporary population estimates for these species within Hood Canal, the South and Central Sound, or the Whidbey Basin, though each species has been detected in these regions (Delacy et al. 1972; Washington 1977; Washington et al. 1978; Walton 1979; Miller and Borton 1980; Gowan 1983; Moulton and Miller 1987; Reum 2006; Palsson et al. 2009).

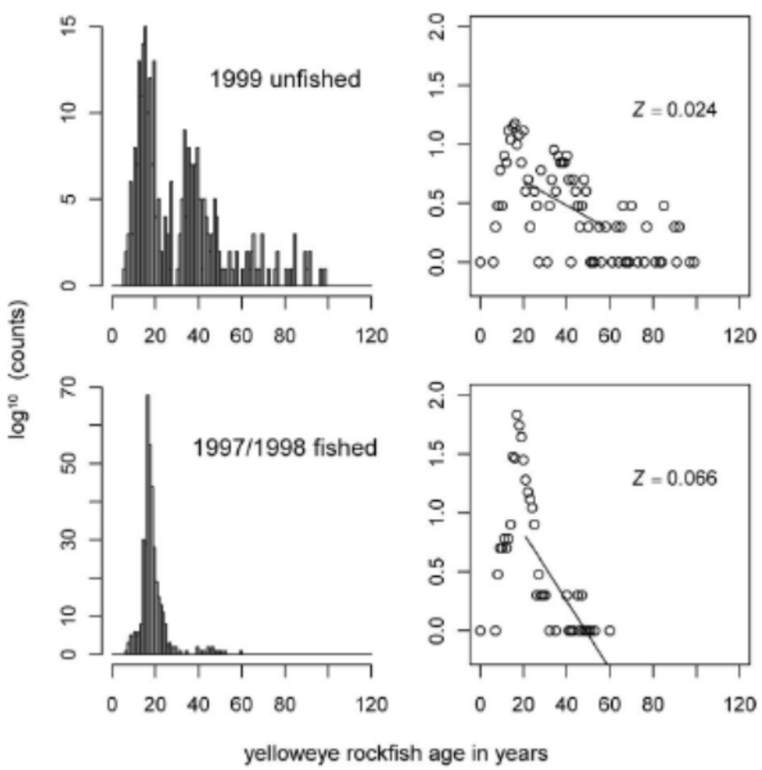

Figure 2. Yelloweye rockfish age frequencies (left images) and catch curves (right images, z = total mortality rate) from largely unfished (top left) and fished (bottom left) habitats in British Columbia. From Yamanaka and Logan (2010). Figure used with permission of the authors.

Productivity of rockfishes is influenced, in part, by the size distribution of the population because larger and older females generally produce more and larger larvae (Berkeley 2004; Sogard 2008). Yelloweye rockfish, canary rockfish, and bocaccio size (and age) distributions have been truncated. Recreationally caught ESA-listed rockfish in the 1970s spanned a broad range of sizes. By the 2000s, there was some evidence of fewer older fish in the population (Drake et al. 2010). Because anglers can no longer retain rockfish in the Puget Sound, there are no opportunities to assess population demographics from fishery bycatch. More recent evidence of yelloweye rockfish size truncation comes from the WDFW ROV surveys in which no adults where observed. An example of age truncation because of fishery removals can be found from fished and unfished habitats within British Columbia waters (Figure 2). One result of size and age truncation may be the shift of the reproductive burden to younger and smaller fish. This shift would reduce the total number of larvae released, and could reduce the overall size of the individual larvae potentially reducing the viability of offspring (Drake et al. 2010). Though we have strong evidence that productivity of each species in the DPSs is depressed from historic levels, we do not know the relative reduction of productivity in each basin and the precise implications to recovery potential for each species.

Spatial Structure and Connectivity

Spatial structure consists of a population's geographical distribution and the processes that generate that distribution (McElhaney et al. 2000). A population's spatial structure depends on habitat quality, spatial configuration, and dynamics as well as dispersal characteristics of individuals within the population (McElhaney et al. 2000). Characterizing spatial structure of rockfish populations involves knowing where fish are and what kind of habitat they occupy. Prior to contemporary fishery removals, each of the major basins of the DPSs likely hosted populations of yelloweye rockfish, canary rockfish, and bocaccio, yet our knowledge of precisely where these fish were documented and caught is generally coarse because there have not been historic or contemporary systematic surveys of rockfish populations in all of the basins of the Puget Sound (Drake et al. 2010). Fisheries catch data can be used to assist in determining rockfish habitat (Yamanaka and Login 2010), but the lack of systematic record-keeping and inaccurate species identification from commercial and recreational fishing in the Puget Sound limits the utility of available fishery data (Palsson et al. 2009; Sawchuck 2012). The documented occurrences of yelloweye rockfish, canary rockfish, and bocaccio in the Puget Sound are from a wide range of years and with diverse sampling methods such as research trawls, drop cameras, scuba, ROV, and commercial and recreational fishing. Most of these documented occurrences are for sub-adult and adult life-stages, with relatively few young-of-the-year fish documented. Some of the best remaining evidence of these distributions are unreferenced notes on historic maps, tips in popular guidebooks (Haw and Buckley 1971; Olander 1991), or anecdotal observations via personal interviews with fishermen (Williams et al. 2010).

Spatial structure of rockfish populations can be characterized on several scales of the seafloor that include megahabitats, mesohabitats, and microhabitats[4] (Greene et al. 1999). The benthic terrain model (BTM) provides habitat classifications on the megahabitat scale across the Puget Sound/Georgia Basin. The BTM classifies benthic habitats at a 98-foot (30-meter) scale in several categories that include *flats*, *depressions*, *crests*, *shelves*, and *slopes*, but does not delineate benthic substrate type. The BTM also provides a "rugosity" value, which is a measurement of variations or amplitude in the height of a surface—in this case, the seafloor (Kvitek et al. 2003; Dunn and Halpin 2009). Rugosity values range from 0 (i.e., flat habitat) to 5.7 (very complex habitat). We can use rugosity values to characterize the general suitability of the seafloor habitats for adult rockfish over relatively large areas, but our knowledge of microhabitat usage would be enhanced with targeted surveys such as conducted in the San Juan Islands (Pacunski, this volume).

Our knowledge of contemporary spatial structure within the Puget Sound/Georgia Basin is most precise in the San Juan Archipelago because of recent benthic habitat mapping (Green, this volume) and WDFW ROV surveys (Pacunksi, this volume). Though the BTM delineates megahabitats within the Puget Sound, our knowledge of contemporary spatial structure (outside of the San Juan Islands) is limited by: 1) the lack of high resolution benthic habitat maps across all habitats and 2) the lack of systematic fish surveys.

Habitat use in Puget Sound proper is likely dependent upon habitat structure that includes steep clay walls with crevices and ledges, boulders from glacial outwash, sunken logs and other benthic debris, and sponge gardens. For instance, Dinnel et al. (1987) observed benthic habitats in Port Gardiner from a submersible and reported that rockfish (not identified to species) were associated with sunken logs and other "large solid objects." Though each of these benthic habitat features have been documented in Puget Sound proper (Palsson et al. 2009), a systematic mapping and survey effort would further enlighten

[4] Megahabitats refer to large features of the seafloor that are from kilometers to tens of kilometer scales and include canyons, seamounts, plateaus, reefs, and terraces. Mesohabitats refer to seafloor features from tens of meters to a kilometer including smaller versions of megahabitat features listed above; gravel, pebble, and cobble fields; caves; overhangs; and bedrock outcrops. Microhabitats refer to seafloor features that are one to ten meters, including boulders, blocks, sink holes, and bedrock outcrops.

specific habitat associations within Hood Canal, the Main Basin, South Sound, and the Whidbey Basin for each species. The use of these relatively non-rocky, yet complex benthic habitats may be a unique ecological feature of rockfish along the Pacific coast.

Rockfish population resilience is sensitive to changes in connectivity among various groups of fish (Hamilton 2008). Hydrologic connectivity of the basins of the Puget Sound is naturally restricted by relatively shallow sills located at Deception Pass, Admiralty Inlet, the Tacoma Narrows, and in Hood Canal (Burns 1985). The Victoria Sill bisects the Strait of Juan de Fuca and runs from east of Port Angeles north to Victoria (Drake et al. 2010). These sills regulate water exchange from one basin to the next, and thus likely moderate the movement of rockfish larvae (Drake et al. 2010). When localized depletion of rockfish occurs, it can reduce stock resiliency (Hilborn et al. 2003; Hamilton 2008). The effects of localized depletions of rockfish are likely exacerbated by the natural hydrologic constrictions within the Puget Sound. We do not know the extent of possible localized depletions within the Puget Sound, nor the precise effects it would have upon recovery of ESA-listed rockfish. Our understanding of connectivity is influenced by research of fish movements at various life-stages. Studies of rockfish movements have occurred along the Pacific coast (Berntson et al. 2007), but studies of ESA-listed rockfish movement and distribution at larval, juvenile, or adult life-stages within the DPSs have not been completed in the Puget Sound.

Diversity

Characteristics of diversity for rockfish include fecundity, timing of the release of larvae and their condition, morphology, age at reproductive maturity, and physiology and molecular genetic characteristics. In spatially and temporally varying environments, there are three general reasons why diversity is important for species and population viability: 1) diversity allows a species to use a wider array of environments; 2) it protects a species against short-term spatial and temporal changes in the environment; and 3) genetic diversity provides the raw material for surviving long-term environmental changes. The natural hydrologic constrictions within the Puget Sound, and unique habitat conditions within each basin, may influence diversity characteristics. Studies of quillback rockfish (*S. maliger*) and brown rockfish (*S. auriculatus*) in Puget Sound have found evidence of genetic divergence (Burr 1999; Bounaccorsi 2005). Though there are no genetic data for ESA-listed rockfish within the Puget Sound/Georgia Basin DPSs, the unique oceanographic features and relative isolation of some of its basins may have led to unique adaptations, such as timing of larval release (Drake et al. 2010). In addition, the relative isolation of some of the basins of the Puget Sound (i.e., Hood Canal) may influence diversity characteristics of ESA-listed rockfish, though there is a lack of research to assess these possible geographically-based behaviors, characteristics, and adaptations.

Summary

The five interconnected basins of the U.S. portion of the ESA-listed rockfish DPSs have unique bathymetry, freshwater input, and tidal exchange that influence environmental conditions such as the movement and exchange of water (and biota) from one region to the next, water temperatures, and water quality (Ruckelshaus and McClure 2007). Yelloweye rockfish, canary rockfish, and bocaccio have been documented in each of these basins.

Present-day knowledge of abundance, spatial structure (of fish and benthic habitat types), and habitat associations are most precise within the San Juan Basin. Our knowledge of ESA-listed rockfish in the Puget Sound would be enhanced by studies that assess historic abundance levels and current abundance. Contemporary estimates of population demographics, including size and age distributions, would enable assessments of productivity. High resolution benthic habitat maps across all habitats, and systematic fish surveys within Hood Canal, the Main Basin, South Sound, and the Whidbey Basin would further enlighten our knowledge of specific habitat associations for each species. The use of these relatively non-rocky, yet complex benthic habitats may be a unique ecological feature of rockfish along the Pacific coast. Rockfish population resilience is sensitive to changes in connectivity among various groups of fish, and our understanding of relative connectivity is hindered by a lack of data regarding the movements of yelloweye rockfish, canary rockfish, and bocaccio in the Puget Sound. Hydrologic connectivity may influence diversity characteristics of ESA-listed rockfish, though there is a lack of research to assess these possible geographically-based behaviors, genetic characteristics, and localized adaptations.

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Tribal Perspectives on Rockfish Recovery in the Salish Sea

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Introduction

After the retreat of the continental glacier approximately ten thousand years ago, fish, wildlife, plants, and people concurrently colonized the region we now call the Salish Sea. In the ensuing period, the people evolved a complex way of life that included sustainable use of the abundant natural resources upon which they depended for survival. After Europeans arrived just over two hundred years ago, the people's way of life was greatly disrupted. In treaties signed with the United States in the 1850s, the people gave up title to most of the land draining into the Salish Sea in exchange for small reservations and limited monetary payments. They also retained a portion of their aboriginal rights to harvest the fish, wildlife, and plants that had sustained them for millennia. In the 1970s, the United States Federal court interpreted these treaty rights to include co-equal management authority and responsibility with the State and the opportunity to harvest up to one-half the harvestable portion of the resource. Today, the tribes exercise resource management authority through their sovereign governments recognized by the United States.

Immediately after the Federal court decisions, tribal management focused on developing capacity to harvest and to carry out management responsibilities, with the emphasis on salmon fisheries. Although rockfish were undoubtedly harvested historically, the tribes did not focus on increasing that fishery during the 1970s and 1980s. Meanwhile, non-Indian sport fishers increased effort on rockfish to compensate for the diminishment of some salmon opportunities because of the need to provide more opportunity to the tribes. With the decline of rockfish stocks over the past couple of decades, the non-Indian fishery has been reduced to almost nothing and the tribal fishery was never developed (Figure 1).

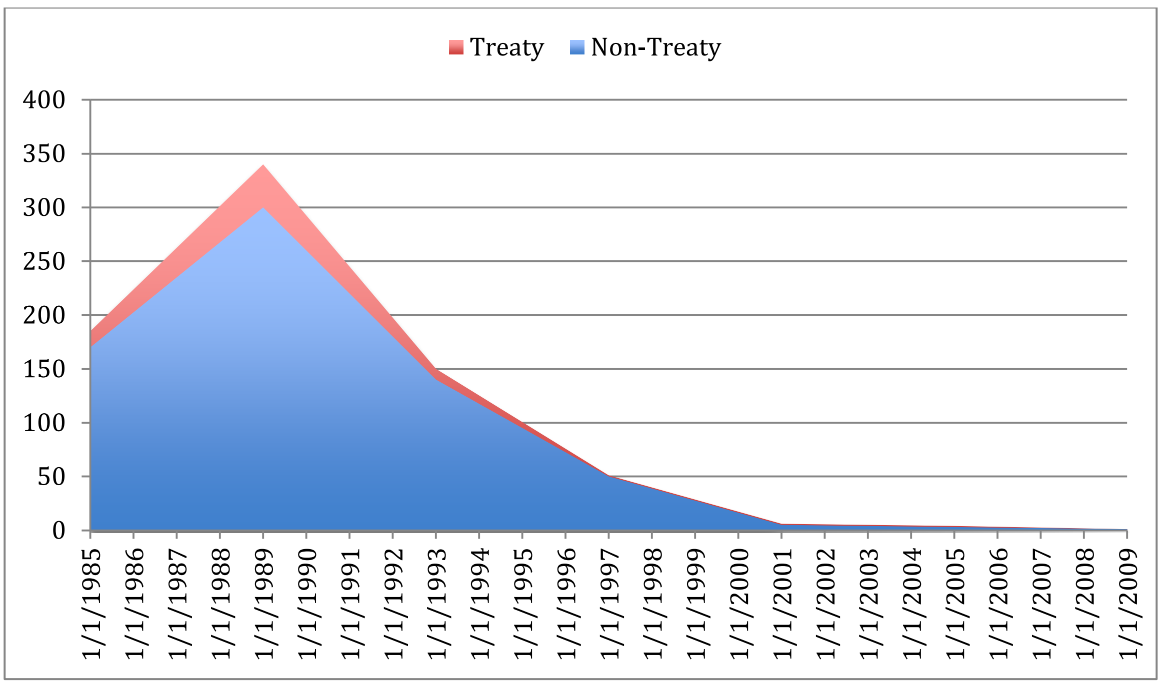

Figure 1. Annual harvest of all rockfish species in U.S. waters of the Strait of Juan de Fuca and the U.S. portion of the Salish Sea, 1985-2009 (thousands of pounds harvested). From fish ticket data; recreational harvest not included.

It soon became clear that rockfish populations were not quickly responding to fishery reductions. At the same time, there was a national and regional movement to establish marine protected areas (MPAs), which was thought to be a potentially effective tool for restoring long-lived non-migrating species, such as rockfish. When MPAs were proposed within the Salish Sea, the question of how these could be established in light of treaty rights and tribal co-management immediately arose. In response, the tribes of the Northwest Indian Fisheries Commission (NWIFC) developed a policy statement on marine protected areas to explain some basic tribal positions (NWIFC 2003). At the same time, the SeaDoc Society sponsored a study using semi-structured interviews of tribal leaders to list and explain key points regarding tribal views of spatial management in the marine environment (Whitesell, Schroeder, and Hardison 2007).

Among the points articulated in these documents are the following:

1. Treaty rights are paramount and non-negotiable.
2. The continuity of tribal culture and identity depends upon continued use of the resources that the people have depended on for millennia.
3. Tribal people have been here since time immemorial and are committed to staying in their homelands forever. Therefore, environmental protection for long-term sustainability is essential.
4. Tribes have always managed the marine environment. They have used protected area strategies from ancient through present times.
5. The tribes must be involved in all phases of MPA discussion, planning, and implementation through government-to-government relationships.
6. Tribal treaty rights and tribal traditions are place-based. Therefore, tribes have special concerns and considerations related to spatial management.
7. MPAs require clear scientific justification with clearly stated goals, objectives, monitoring, and triggers for adaptive management. When the purpose of an MPA is no longer present, the MPA may no longer need to exist.
8. Co-management requires cooperation at all levels of data collection and full sharing of information.
9. Mutual trust is the foundation of successful partnerships.

It is important to note that tribes regard the concept of marine protected areas or marine reserves under the broad category of spatially-based management rather than simply an exercise in prohibiting harvest. Thus, while closing fishing in an area may be the appropriate strategy in one reserve, controlling upland development or vessel traffic may be the appropriate strategy for another reserve. The key is to clearly articulate management objectives, develop appropriate strategies to achieve those objectives, and adjust management based on the results of careful monitoring. Adaptive management might include reversing a strategy, such as a fishery closure, when the strategy’s expected objective has been realized. These principles are among the basic management concepts articulated in the tribes’ MPA policy document.

Tribes have been involved to one degree or another in development and implementation of some of the MPAs that have been established to date in the U.S. portion of the Salish Sea. A group of MPAs in the San Juan Islands, originally proposed by the Friday Harbor Laboratories, to protect important teaching and research sites are closed by all tribes in the area in their fishing regulations. Tribes in the San Juan Islands are participating in the San Juan Marine Stewardship Area (MSA), and two tribes are leading development of a marine stewardship area in Port Susan Bay. A tribal body advises the National Marine Protected Areas Center. To date, with the possible exception of the Port Susan MSA project, tribal participation has been reactive to proposals from others rather than proactively introducing proposals for establishing marine managed areas. However, in their own fishing regulations, tribes continue to use spatial management, applied to their own tribal members, for specific resource conservation or allocation purposes.

Despite being limited to no directed harvest, rockfish affect tribal fisheries management in a number of ways beyond MPAs. Tribal groundfish regulations often include limitations on the incidental harvest of rockfish. A very small number of tribal members harvest groundfish for subsistence purposes in the Salish Sea, and typically they are allowed to keep one or two rockfish per day as part of this subsistence fishing. We have little data on the actual number of rockfish harvested for this purpose, but it is likely *de minimus*. Of greatest significance are the implications to tribal salmon fisheries of the listing of three rockfish species under the Endangered Species Act. As a condition of approving the current co-managers' salmon fishery management plan, NOAA is requiring immediate reporting of lost fishing nets to reduce or eliminate the recruitment of new derelict gear that might capture listed rockfish. To help implement this requirement, the tribes are using funding through the Northwest Straits Commission to enhance awareness and increase reporting of lost gear. Outreach and communication have already resulted in development of reporting systems tailored for tribal needs, and enhanced awareness among tribal fishers and managers of the need to immediately report lost gear.

First contact with Europeans occurred just over 200 years ago—only a tiny fraction of the time that people have lived here and managed this ecosystem. Despite the great disruption of tribal culture since that time, tribal culture persists. Tribes have a greater stake than anyone else in the perpetuation of all components of the Salish Sea marine ecosystem because it is essential for the maintenance of their culture and identity as a people. Today, with increased recognition of treaty rights, tribal culture is being revived throughout the region. We believe that restoration of rockfish in the Salish Sea will only be accomplished by tribes and non-Indians working together in an atmosphere of mutual respect. This can happen if tribal managers remain open to non-tribal approaches and non-tribal managers work to understand and incorporate tribal approaches to ecosystem management.

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Rockfish Conservation: The British Columbia Experience

Gary Logan, Lynne Yamanaka, Fisheries and Oceans Canada

The coastline of British Columbia offers a large and diverse area for fishing. The three primary fishing sectors in British Columbia are the commercial, recreational, and First Nations fisheries. Contained within the commercial sector are the hook-and-line, long-line, trap, and trawl fishing sectors. In the 1990s, Fisheries and Oceans Canada expanded the fishery for the inshore rockfish species but quickly realized that the management of the fishery was not adequate to contain the fishery within acceptable levels of catch. Inadequate stock assessment advice, unknown factors associated with their life-history, and poor catch monitoring within all of the fishing sectors led the Department to develop the Rockfish Conservation Strategy.

The Rockfish Conservation Strategy was announced in 2001. The strategy contained the following four key elements:

- Better catch monitoring
- Reduction in fishing mortality
- Increased stock assessment and monitoring
- Closed areas

In 2001, fishing mortality was reduced by 75 percent in the protected waters of Georgia Strait and 50 percent in the outside waters along the coast of British Columbia. The fishing mortality was reduced through significant reductions in the total allowable catch (TAC) in all fishing sectors. Stock assessment was also accelerated and better monitoring and catch recording programs were implemented. In addition, the Department began developing the closed area strategy that resulted in the formation of 164 closed areas (Rockfish Conservation Areas, or RCAs) along the coast of British Columbia.

The closed areas were defined using catch history and a model that measured bathymetric complexity. By over-laying the known areas of rockfish catch per effort and measuring the change in marine floor slope, the Department was able to determine areas along the coast of British Columbia that would create the network of RCAs.

The process used by the Department was key to the success of the over-all strategy. A cross-governance team was established that included not only technical staff from various branches of the Department but also environmental, commercial, and recreational organizations; local community government; and First Nations participants. Extensive consultation that began in 2001 culminated with the final suite of closed areas for full implementation into the fishing regulations in 2007. The team established to implement the closed area component of the strategy recognized early in the process that failure to establish effective communication with all stakeholders would result in failure. Therefore, a key objective of the consultation was to ensure that impacts on stakeholders associated with the fishery would be minimized. Identification and description of the potential RCAs were vetted through stakeholders numerous times for their input and modification. The resultant suite of RCAs created a network of closed areas along the coast of British Columbia with high levels of fishing compliance.

Assessment of the closed areas continues. A broad framework for measuring their success was developed in concert with Fisheries and Oceans scientific staff and local universities. The evaluation of the RCAs will take many years of study, with many graduate programs at several universities focused to provide the financial and technical continuity necessary to fulfill this requirement.

Concluding Plenary Session:
Collaboration, Legitimacy, and Awareness in Puget Sound MPAs

Clara Hard, Kristin Hoelting, Patrick Christie, School of Marine and Environmental Affairs, University of Washington, Seattle, Washington; Richard Pollnac, Department of Marine Affairs and Coastal Resources Center, University of Rhode Island, Kingston, Rhode Island

MPA sites in Puget Sound have not been systematically evaluated, even against their designation objectives, although some efforts have been made to evaluate biological response. It can be argued that the lack of progress in some of the policy dimensions can be attributed in part to a lack of understanding of how MPA management is taking place and the basis for public interest and support (or lack thereof) for management measures. Washington has a long history of developing MPAs of various definitions and with differing authorities (e.g., State Parks, Department of Natural Resources, Washington Department of Fish and Wildlife). Most recently, the declines in abundance of certain species of rockfish drove development of a new spate of no-take fisheries zones under WDFW auspices. In 2008, the Washington State legislature required the Department of Ecology to convene a Marine Protected Areas Work Group to provide recommendations on how MPAs could be developed in Puget Sound and elsewhere. In 2010, a social survey was conducted in seven communities near Puget Sound MPAs to determine MPA public awareness and whether government agency-public collaboration can be empirically connected to increased process legitimacy and public support. Over a thousand interviews were conducted.

While 44 percent of waterfront users in the Puget Sound region were aware of the nearby MPA, males and respondents with at least a college degree were more likely to have heard of the sites. Perceptions varied on the potential environmental impact of MPAs and whether waterfront users thought that their opinion had an impact on the MPA establishment. A dependent variable, "perceived collaboration," was built using resource user survey responses to measure the degree of collaboration between state agencies and the nearby community at each site. Two independent variables—a) whether resource users perceived that adequate information was used, and b) whether all views were taken into consideration—are key factors explaining variance in perceived collaboration. Both were significantly correlated with perceived collaboration with Spearman Rho rank-order correlations of 0.56 and 0.64, respectively ($p<0.05$). In addition, there was a significant difference between government official and resource user perceptions regarding the openness of the process and the degree of community influence in MPA establishment. Perceptions of collaboration are significantly correlated with measures of process legitimacy and public support, while tangible measures of collaboration (meeting attendance, information sharing, opinion solicitation) are not significantly correlated. Perceived collaboration is shown to account for 38.9 percent of the variance in process legitimacy and 13.8 percent of the variance in public support. Process legitimacy is shown to mediate the relationship between perceived collaboration and public support. The importance of understanding how society values the marine environment both culturally and economically becomes of increased importance in policy decisions. Future social survey research for 25 Puget Sound MPA sites is introduced.

Editor's Note: The full text of this paper has been published in a separate professional journal:

Clara H. Hard, Kristin R. Hoelting, Patrick Christie, Richard B. Pollnac. 2012. Collaboration, Legitimacy, and Awareness in Puget Sound MPAs. Coastal Management. Volume 40(3), pages 312 to 326. http://www.tandfonline.com/doi/abs/10.1080/08920753.2012.677640

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APPENDIX A

Workshop Participants

Workshop Participants		
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APPENDIX B

Workshop Sessions

Tuesday, June 28, 2012

- Historical Context
- Benthic Habitat Surveys/Rockfish Abundance Estimates
- Stressors
- Ecosystem/Species Interactions
- Juvenile Recruitment and Genetics

Wednesday, June 29, 2012

- Agency, Tribal, and Canadian Perspectives
- Concurrent Sessions on Reserves

  Session a: Modeling and Monitoring (i.e., larval dispersal/food web/sampling techniques)

  Session b: Design (placement/habitat/size/number)

  Session c: Socioeconomic Aspects of Reserves (stakeholder input and communications, allowed uses within reserves, etc.)

- Concurrent Sessions on Population Biology

  Session a: Research Needs to Better Understand Rockfish Biology, Habitat, and Threats

  Session b: Establishing Rockfish Population Benchmarks (stock assessments/recovery goals/ monitoring)

- Concluding Plenary Session: Collaborative Planning and Additional Research Needs

APPENDIX C

Notes from Concurrent Sessions on Marine Reserves

Session a: Modeling and Monitoring (i.e., larval dispersal/food web/sampling techniques)

Participants:

- Kit Rawson
- Phil Green
- Claude Dykstra
- Sean Rooney
- Dave Smith
- Kevin Turner
- Farron Wallace
- Chris Harvey
- Stephanie Ehinger
- Bert Rubash
- Jeff June
- Emily Whitney
- Tim Carpenter
- Erika Hoffman
- Laura Inouye
- Jeff Laufle
- Jamie Glasgow
- Mary Bhuthimethee
- Joan Drinkwin
- Bob Pacunski
- Jim West
- Shawn Larson
- Ron Garner
- Janna Nichols
- Bear Holmes
- Anne Beaudreau
- Piper Schwenke

In this session, participants were asked to list the various modeling tools needed for the establishment of rockfish reserves. Participants were also asked to elucidate monitoring needs and priorities for reserves. Reserves were defined as areas where no fishing/take would occur.

Summary

The group found that there are two general categories that need to be addressed for modeling potential reserve sites and monitoring a reserve system: fish population parameters and environmental variables. Population parameters are essential for modeling a reserve system. They include abundance, size and age distribution, larval distribution patterns, and larval recruitment. Using acoustic tags to collect data on movements and range is a great option to fill these data gaps. Captive brood stock, such as that at the Seattle or Pt. Defiance Aquarium, could be used for studies looking at larval dispersal.

Understanding and accounting for environmental parameters of potential reserve sites is essential. Water quality and other environmental stressors all need to be looked at long-term. Sampling at optimal times is critical for capturing seasonal data. There was discussion about needs for information on food webs, including marine mammal predation, growth rates for same species in different locations, and use of growth hormones to age animals.

In addition, centralizing data in a single clearing house, as well as centralizing the storage of samples taken, would be beneficial. The scope of reserves (large- or small-scale) is very important, especially when considering recruitment. Finally, they discussed funding and collaborating for applying for funding sources.

The following is a list of the aspects of reserve location and establishment principles that arose during the group discussion:

Location principles:

- Prioritize establishment of reserves where good data coverage exists
- Nested reserve with central, long-term focal point
- Prioritize placement based on enforcement capacity; enforcement of boundaries and regulations is critical
- Locate reserves based on existing baseline data

- Use Bangor military base as a *de facto* reserve test site
- Assess how DNR aquatic reserves could fit into a larger system
- Account for the impact of seal and sea lion populations on reserve locations

Establishment principles:

- Messaging regarding the purpose and locations of reserve overlay is critical to success
- Expert panel required to jump-start the process
- Focus efforts to prevent conflict and maintain buy-in
- Tribal collaboration is essential
- Establish MPAs now, and allow continued research and adaptation
- Aligning goals of different protected areas
- Utilize and coordinate with existing programs
- Poaching problem; poaching is too easy
    - Is citizen enforcement a viable option?
- SS or SL: encompass home ranges and minimum viable populations
- Stakeholder buy-in: provide opportunities to participate early in the process; need to gauge responses
- Inclusion of non-indicator species and habitat types
- Rockfish diet protection
- Need population modeling to inform reserve design

Session b: Design (placement/habitat/size/number)

Participants:

- Ken Kumasawa
- David Kendall
- Barbara Seekins
- Nick Gayeski
- Zeke Steele
- Eric Soderlund
- David Jennings
- Joe Pursley
- Randy McIntosh
- Calvin Douglas
- Ginger Shoemaker
- Pete Naylor
- Gary Greene
- Doug Myers
- Larry LeClair
- Phil Green

In this session, participants were asked to list the various considerations for the design of a rockfish reserve system. Reserves were defined as areas where no fishing/take would occur.

Summary

When looking at establishing new reserves, important considerations include enforcement, and possible known threats like pinniped haulouts or contaminated areas. Other important variables include size, spacing, and percent cover—but there are no ready answers to these questions for Puget Sound without further analysis. When designing a reserve system it is essential that covering a diversity of habitats for life stages for the target species occurs. Ideally, we use data we have and fill in the gaps later. A focus on nearshore habitats should occur because most areas below 120 feet are closed to anglers targeting bottom fish. There are existing data from the PSNERP that can help nearshore assessments. Data needs include increased mapping of unmapped areas as well as diets of rockfish.

Location Considerations for Designing Reserves:

- Review existing reserves for possible expansion
- Review existing literature for effectiveness and existing concerns
- Target maximum biodiversity and diversity of habitats
- Account for spatial relationships between reserve sites
    - Percentage of rare species
    - Prioritize sites with existing data
- Account for enforceability and ensure easily identifiable boundaries
- Account for proximity to threats
- Organize reserves as part of larger fisheries management system

Size/ Spacing questions:

- Percentage of area needed for recovery (e.g., 30%?)
- Habitat needs
    - Ecosystem design vs. rockfish-specific?
- Dependent upon life-stage
- Population capacity
- Stage the implementation of reserves

Identify Data Gaps:

- Diet considerations
- Trophic relationships

Session c: Socioeconomic Aspects of Reserves (stakeholder input and communications, allowed uses within reserves, etc.)

Participants:

- Jennifer Sawchuck
- Noel Larson
- Alan Chapman
- Norman Baker
- Elizabeth Kilanowski
- Joe Thoran
- Clara Hard
- Alan Lovwell
- Suzanna Stoike
- Dan Tonnes

In this session, participants were asked to list the priorities and considerations for integrating socioeconomic considerations into the design of a reserve system.

Summary

Accounting for socioeconomic considerations in the design of a reserve system requires meaningfully integrating natural and social sciences. Socioeconomic integration requires demographic information, user data, understanding different habits for users of each area, mapping social uses, and including the different user groups. In addition, identifying what the motivations would be for the different groups to establish and comply with reserves is needed. Understanding recreational fisheries and fisher attitudes based on region and demographics is essential. Establishing a baseline of the preceding variables should occur, which would enable the monitoring of attitudes and perceptions over time. Learning from experiences in other regions, such as Australia, Canada, and California, would be helpful. Widening the focus from one species of fish to the ecosystem so more people would have buy-in is recommended.

Considerations for Socioeconomic Integration:

- Design of reserves should include explicit consideration of the view of people, but do managers need to provide motivation for participation (e.g., reward)?
    - Consider "extractive/participatory" research—is there room for participatory research that's led/designed/collected by users?
    - Quantitative vs. qualitative information—narratives are as important as numbers
- Start with common goal/incentives to identify management strategies
- Identify ways that different user groups can contribute
- Examine management actions with user groups to understand how/if/when people would support them: 1) process, 2) equity, 3) distribution of benefits
    - Localize efforts/stakeholder groups
    - Ask stakeholders "what would you consider a 'restored' number of rockfish?" "What should the goal be?"
    - Should the threats to rockfish be ranked?
- Think about three data needs for integration of models and management measures:
    1) context—demographic, user data, usage, habitats/perceptions
    2) process—how are we moving ahead for creating marine reserves, etc.?
    3) mapping/spatial—use/how much use?

Recreational Angler Research/Management Data Needs:

- Need more information on the recreational fishery—attitudes, practices, etc.
- How can we work with anglers on reserve establishment in a non-threatening way?
- How can we get accurate responses?
- Need accurate baseline data on bycatch of rockfish
    - NOTE: bycatch data are based on anglers' self-reports

- Monitoring of recreational boat ramps may need improvement
- Understand conflict more (see Sara Singleton on lowering conflict)
- CA/Great Barrier Reef lessons may help in lowering conflict
- Set expectations correctly (long-term)
- How can we manage and educate long-term?
- How to quantify values of rockfish?
- Social/ecosystem services of the future?
- What will motivate people to make difficult, long-term decisions? (set short-term milestones)
- Short time steps are important (lingcod would be beneficial metric)
- Advocate for multiple benefits for sites
  - Consider cooperative, systematic scenario planning
  - Reserves aren't the ONLY tool; examine ALL tools (consider tools with best compliance in addition to closures/reserves)
- Would anglers prefer complex take regulations or simple "no take?"
- Quantify rockfish bycatch by bait/lure type
  - Study needed
  - Doesn't replace social research
    - Need report, workshops on marine reserves
    - Perceptions of abundance—build on Anne Beaudreau's research
- Examine research/citizen research on lowering rockfish mortality
- Design handout regarding best fishing practices to lower rockfish mortality
- Research techniques on how to best reduce rockfish mortality
  - Fizzing, etc.?
  - Would anglers have this gear on the boat for bycatch that may be rare?

APPENDIX D

Notes from Concurrent Sessions on Population Biology

Session a: Research Needs to Better Understand Rockfish Biology, Habitat, and Threats

Participants:

- Ken Kumasawa
- David Kendall
- Nowl Larson
- Alan Chapman
- Sean Rooney
- Zeke Steele
- Kevin Turner
- Chris Harvey
- Randy McIntosh
- Stephanie Ehinger
- Jeff June
- Ginger Shoemaker
- Eric Soderlund
- Gary Greene
- Joe Thoran
- Emily Whitney
- Larry LeClair
- Tim Carpenter
- Joan Drinkwin
- Jim West
- Shawn Larson
- Bob Pacunski
- Jamie Glasgow
- Ron Garner
- Alan Lovwell
- Anne Beaudreau
- Mary Bhuthimethee
- Jon Lee
- Piper Schwenke
- Patrick Christie

In this session participants were asked to list research needs to better understand rockfish biology, habitat, and threats.

Summary

Research to better understand rockfish biology should include a goal of performing stock assessments using fisheries-independent data. Population genetics, connectivity, and hybridization should be assessed throughout the Puget Sound, as well as movement and behavior patterns by species and life-stages. Research to better understand rockfish habitats in Puget Sound should prioritize better benthic habitat mapping and characterization, the effects of the major sills, and circulation modeling (related to low dissolved oxygen, etc.). In addition, research to understand sub-lethal and lethal effects of toxicity should occur. Research that investigates habitat changes relevant to rockfish, including nearshore development, and longer term changes that include sea level rise, altered temperature regimes, climate changes, and food web change is necessary. In addition, an independent ecosystem assessment should occur to examine the trade-offs and benefits of non-targeted actions on rockfish populations. The role and appropriateness of artificial reefs as a recovery tool should be assessed. Research to better understand non-habitat related threats include better ways to quantify bycatch and release techniques, the effects of salmon hatchery releases, and the possible impact of predation on larvae and young-of-the-year juveniles. The role of hatchery production of rockfish as a recovery tool should be investigated.

Biology:

- Need basic stock data, mortality data, and prioritize gathering fishery-independent data
- Integrated ecosystem assessment should occur to assess a “wide swath” of the ecoregion
- What non-rockfish management activities have positive and negative effects on rockfish?
- Why are there “jackpot recruitment” years and what environmental conditions in the Puget Sound support them?
- What are the movement patterns of different species; what are the stock locations?
- Hydroacoustic stock analysis can:
    - show rockfish populations as well as prey stock and food web data
    - provide South Puget Sound assessment for less money than ROV
    - provide size, gender, and habitat data that is also needed

    - be used as a coarse tool to choose spots for ROV survey
- What are the risks/benefits to rockfish hatchery augmentation?
    - How can we improve on the hatchery model?
    - What is the optimal point in the lifecycle to release hatchery stock?
        - Larval stage?
        - Release larger fish?
        - How can genetic integrity be assured?
- What effects have food chain changes had on the ability of various rockfish stocks to recover?
- What have the effects of low dissolved oxygen events had on rockfish populations?
- What are hybridization’s effects on demographics and population viability?
- Need better interagency coordination and sample sharing; need data clearinghouse

<u>Habitat</u>:

- Bring together existing data to flesh out habitat knowledge
- Better access to WDFW data is needed
- DNR is limited in data on nearshore habitat conditions
- What are the effects of tire reefs?
    - Twenty-seven tire reefs—how toxic are they?
    - Are artificial reefs a good idea?
    - Are artificial reefs simply aggregating existing fish?
- What effect does geologic disruption have on rockfish?
- In the South Puget Sound, is rockfish proliferation episodic?
- Why are yelloweye rockfish found in shallow water further north?
- What is the range of habitat for juveniles?
- Waterflow and circulation in the Puget Sound
    - Looking at the three distinct waterflows, how does this affect larva dispersal? Toxin spread?
- How does water circulation affect the genetic makeup of rockfish stocks?

<u>Threats</u>:

- What impact does bycatch have on population numbers, demographics, spatial structure, and productivity?
    - Primarily recreational
        - What effects do salmon trolling and lingcod fishing have?
        - How do we collect bycatch data accurately?
        - Are there effective techniques for returning rockfish to sea?
- Salmon hatchery impacts
    - Timing and abundance impacts on rockfish
- Deep-water derelict gear needs research
- Do we need multiple small reserves or one large one?
- What are the deleterious effects thresholds for rockfish?
- What are the population level effects?
    - What are the functional effects of sub-lethal deleterious effects?
    - How do multiple toxins interact? For example, impacts on pH. immune response?
- How do we capture rockfish to study without killing them?
- Are seals having an impact on rockfish populations?

Climate:

- How do rising water temperatures affect rockfish location and growth rates?
    - What effect does Pacific cod predation/population abundance have on rockfish?
    - Is there an effect like that on Dungeness crab profiles?
- What effect has climate change had on nearshore stocks?

Session b: Establishing Rockfish Population Benchmarks (stock assessments/recovery goals/monitoring)

Participants:

- Wayne Palsson
- Kit Rawson
- Claude Dykstra
- Nick Gayeski
- Farron Wallace
- David Smith
- Janna Nichols
- Joel Moribe
- David Jennings

In this session, participants were asked to list the considerations and principles for research that assist in establishing metrics for rockfish population benchmarks.

Summary

The group discussed a number of criteria for establishing benchmarks to support recovery goals. Understanding historic and current abundance will guide de-listing criteria. De-listing criteria will also need to account for historical and current distribution (spatial structure) and reproduction (an age-length composition that is sustainable). The group stated that conducting accurate stock assessments is the gold standard for setting fisheries benchmarks. The goal is to determine the historical unfished biomass. The WDFW is assessing unfished biomass by analyzing historical calculations and they hope to rebuild the catch history and past fishery effort. A long-term adaptive monitoring system was important. Monitoring is critical for on-going stock assessments and should include ROV work and dive monitoring to identify the spatial distribution for all life stages. Gathering incidental information with low-cost monitoring of traps or cages for juveniles and using REEF data for augmenting stock assessment data is warranted. In the future, catch records will have to be improved. Setting population goals is important and will help with de-listing criteria. Also, habitat requirements specifically for adult, juvenile, and larval life stages need to be identified. The over-arching focus is that there are three stages: (1) prevent extinction, (2) try and provide sustainable fisheries, and (3) make sure to provide for ecosystem function.

Parameters to build a population dynamics model:

- Abundance
- Diversity
- Productivity
- Geo-spatial distribution
- Age-length relationships
- Length-based model
- Key factors: numbers, distribution, reproduction
- Need to establish benchmarks for non-listed species too
- Can resource use goals help determine benchmarks? Such as fishing, ecotourism, conservation, and ESA needs?

Tools to conduct stock assessments:

- Catch (historical reconstruction)
- Length-age composition/interaction
- Growth rates/mortality rates
- Fecundity
- Virgin biomass
- Alternate aging techniques: mercury, hormones, current abundance for rare species
- Historical effort reconstruction (TEK)

- REEF data for trends and gaps
- Historical photo/record collection

Benchmarks to measure success:

- Historical abundance—percent of recovery
- De-listing criteria
    - Prevent extinction
    - Sustainable fishery
    - Ecosystem needs
- Relate biological indices to total population
- Develop adaptable monitoring systems for the long term
- Monitoring for episodic events (such as juvenile recruitment)
- Tension of rockfish population vs. ecological processes (minimum number of rockfish to define recovery (?)
- Density of mature fish over geographic range
- Restore to historical/natural low population sizes/ecosystem assemblages (relative abundance); TEK (?)
- Restore based on source and receiver populations
- Age and size structure
- Genetic structure and change over time
- Young-of-the-year recruitment
- Scale benchmarks to monitoring and funds

Monitoring to support a population dynamics model:

- Expand ROV and diver monitoring throughout Puget Sound
- Identify spatial and density distribution for life-stages
- Prioritize low cost monitoring such as REEF data to augment data and increase outreach
- Observer data for recreational and commercial fisheries
- Link recreational permitting and reporting to improve catch records

APPENDIX E

Workshop Survey and Results

Two surveys were given to participants at the end of the second day of the workshop. Participants were instructed to prioritize potential actions to recover rockfish in the Salish Sea with a 1, 2, or 3 (1 indicating the highest priority). Actions that the participants thought were not necessary or appropriate to enable recovery of rockfish were given an "NA." For each corresponding recovery action, participants were instructed to indicate the relative level of research necessary to support its implementation on a scale of 1 to 5 (1 indicating a high level of research, 5 indicating little or no research). One survey was given for all rockfish of the Salish Sea, and an identical survey was given for yelloweye rockfish, canary rockfish, and bocaccio (ESA-listed rockfish) of the Salish Sea. The surveys were turned in at the end of the workshop (n=44).

Survey Results

ESA-listed Rockfish Recovery Priorities

	Priority 1 (%)	Priority 2 (%)	Priority 3 (%)	Not Applicable (%)
Nearshore restoration & protection	32.56	25	29.55	6.81
Artificial reefs	4.651	15.38	27.277	59.09
Benthic habitat protection/restoration	44.191	21.165	25	6.81
Managing for Climate change	23.26	23.08	22.73	15.91
Contaminant clean-up and prevention	27.91	44.23	11.36	11.36
Nutrients input reduction	16.3	46.155	11.36	15.91
Reserve system	44.19	19.233	31.81	6.82
Fishery management w/o reserves	27.914	26.92	22.73	18.18
Barotrauma reduction	23.26	30.77	22.73	15.91
Education & outreach	30.23	30.77	27.27	9.09
Hatchery supplementation	9.30	15.38	15.91	59.09

All Rockfish Species Recovery Priorities

	Priority 1 (%)	Priority 2 (%)	Priority 3 (%)	Not Applicable (%)
Nearshore restoration & protection	34.09	29.55	31.82	6.82
Artificial reefs	2.27	15.91	25	54.55
Benthic habitat protection/restoration	40.9	25	27.27	6.82
Managing for Climate change	18.18	31.81	34.09	13.64
Contaminant clean-up and prevention	27.27	50	11.36	11.36
Nutrients input reduction	15.9	54.55	11.36	15.91
Reserve system	38.64	22.73	29.55	6.82
Fishery management w/o reserves	50	22.73	9.09	18.18
Barotrauma reduction	22.73	29.55	20.45	15.91
Education & outreach	27.27	34.09	22.73	9.09
Hatchery supplementation	9.09	13.64	20.45	65.91

Relative Level of Research Needed

Restoration Actions		Level of Research Needed to Fully Implement Measure All numbers are %				
		Extensive		Moderate		Low/None
Nearshore habitat protection and restoration	All Rockfish	22.73	9.09	29.55	4.55	15.91
	ESA-Listed Rockfish	22.73	15.91	40.91	4.55	13.64
Habitat augmentation through artificial reefs	All Rockfish	11.36	4.55	20.45	4.55	40.91
	ESA-Listed Rockfish	0	2.27	20.455	11.36	45.45
Benthic habitat protection/restoration (i.e., derelict fishing gear clean-up/prevention)	All Rockfish	6.8	11.36	25	13.64	27.27
	ESA-Listed Rockfish	13.64	11.36	29.55	13.64	27.27
Predicting and managing for climate change	All Rockfish	25	11.36	18.18	9.09	22.73
	ESA-Listed Rockfish	38.64	13.63	22.73	9.09	13.64
Contaminant clean-up and prevention	All Rockfish	18.18	4.55	31.82	9.09	22.73
	ESA-Listed Rockfish	22.73	6.82	38.64	9.09	18.18
Nutrient input reduction (to prevent low dissolved oxygen)	All Rockfish	13.64	9.09	31.82	6.82	22.73
	ESA-Listed Rockfish	18.18	13.64	31.82	9.09	25
Establishment of a system of reserves (designed to prevent rockfish catch/bycatch)	All Rockfish	34.09	6.82	31.82	4.55	6.82
	ESA-Listed Rockfish	38.64	9.09	38.64	2.27	6.82
Implement measures for fishers to reduce barotrauma (expansion of the swim bladder) from bycatch	All Rockfish	11.36	11.36	25	6.82	27.27
	ESA-Listed Rockfish	13.64	11.36	36.36	11.36	25
Establishment of a system of reserves (designed to prevent rockfish catch/bycatch)	All Rockfish	20.45	9.091	29.55	9.09	15.91
	ESA-Listed Rockfish	25	11.36	34.09	9.09	15.91
Public education/outreach about rockfish conservation	All Rockfish	18.18	2.27	18.18	11.36	29.555
	ESA-Listed Rockfish	22.73	4.56	25	13.64	31.82
Hatchery supplementation intended to restore populations	All Rockfish	20.45	0	20.45	0	43.18
	ESA-Listed Rockfish	34.09	2.27	9.091	4.55	43.18

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Survey of Recovery & Research Priorities for Rockfish of the Salish Sea[5]

Prioritize w/ #'s 1, 2, 3 or NA	Restoration Actions	Level of Research Needed to Fully Implement Measure				
		Extensive		Moderate		Low or None
	Nearshore habitat protection & restoration					
	Implement measures for fishers to reduce barotrauma (expansion of the swim bladder) from bycatch					
	Benthic habitat protection/restoration (i.e. derelict fishing gear clean-up/prevention)					
	Hatchery supplementation intended to restore populations					
	Habitat augmentation through artificial reefs					
	Fishery management to reduce catch/bycatch without a reserve system					
	Establishment of a system of reserves (designed to prevent rockfish catch/bycatch)					
	Predicting and managing for climate change					
	Contaminant clean-up & prevention					
	Nutrient input reduction (to prevent low dissolved oxygen)					
	Public education/outreach about rockfish conservation					
	Other:					
	Other:					

Priority 1: Actions that should be taken to prevent extinction or to prevent the species from declining irreversibly and facilitate recovery.
Priority 2: Actions that should be taken to prevent a significant decline in the population or its habitat quality, and facilitate eventual recovery.
Priority 3: Action necessary to provide for full recovery of the species.
NA: Action should not be a priority for recovery of listed rockfish.

[5] An identical survey was given for yelloweye rockfish, canary rockfish, and bocaccio (ESA-listed rockfish) of the Salish Sea.