Fisheries and Fisheries Habitat Investigations Using Undersea Technology

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The West Coast & Polar Regions Undersea Research Center (WC&PRURC), founded in 1990, has encouraged and funded innovative approaches to fisheries habitat research along the coasts of California, Oregon, Washington, and Alaska, where fisheries management is a major economic, environmental, and political issue. This has led to development of new interdisciplinary techniques for research on benthic fish habitat. Various government agencies are now incorporating the techniques into their overall science programs.

Initially, the WC&PR Center sponsored workshops in the early 1990s on the use of occupied submersibles and remotely operated vehicles (ROVs) at fisheries meetings. Subsequent workshops involved use of geophysical techniques (e.g., side-scan sonar and multibeam sonars) as a tool for mapping fish habitats in conjunction with undersea vehicle ground-truthing and stock assessments, particularly in untrawlable locations. The center has funded research teams composed of fishery experts and professional geologists on projects that, in part, grew out of these workshops.. These projects have focused on the relationships between fish populations and the geology and ecology of benthic habitats using a combination of high-resolution sonar mapping of the seafloor and visual observations with submersibles, ROVs and SCUBA. In addition, these programs have compared the utility of submersibles vs ROVs; compared different sonar mapping systems; demonstrated the need for a geologically grounded interpretation of the sonar maps; and addressed the issue of marine refugia by developing techniques for systematically locating and monitoring them. This approach now makes it possible to use geophysical techniques to map large areas of fishery habitat and, in some cases, to estimate the size of associated stocks. The Center is currently funding a trial study of laser line scan technology at a site previously studied and mapped by SCUBA, ROV, submersible and side-scan sonar to compare quality and efficiency of the various techniques for investigation and mapping of fish habitats.

The funded studies have been largely directed at economically important rockfish species, though the methods will be applicable to any benthic species. This approach has the potential for providing large-scale, systematic characterization of benthic habitats, and for non-destructive stock assessments in both protected and unprotected regions.

I. Introduction

The West Coast & Polar Regions Undersea Research Center (WC&PRURC), founded in 1990, has encouraged and funded innovative approaches to fisheries habitat research along the coasts of California, Oregon, Washington, and Alaska, where fisheries management is a major economic, environmental, and political issue. In the face of large population declines in commercially-harvested species, there is increasing need for basic biological and ecological information as well as rigorous scientific assessments of the assumptions underlying management strategies. Traditional stock assessments by trawl surveys do not representatively sample all habitats and species and may even contribute to depletion of some species. In addition, significant areas of seafloor are untrawlable due to high-relief rocky areas. The need for better-informed management through improved stock assessments and evaluation of essential fish habitat has become increasingly critical as traditional fisheries have declined and new, less-studied stocks (usually deeper) are exploited.

II. Benthic habitat studies since the late 1970s

Starting in the late 1970s and continuing through the 1980s, a team of researchers on the U.S. east coast experimented with an approach to benthic habiatat studies that combined visual observations and seafloor sonar mapping [1-6]. The team included fish ecologists Ken Able and Churchill Grimes (Rutgers Univ.), and marine geologist David Twichell (USGS Woods Hole). By the early 1990s, others, notably Peter Auster (NURP and Univ. of Conn.) and Page Valentine (USGS Woods Hole), were also conducting *in situ* observations of fish habitat using remotely operated vehicles [7-12]. The use of sonar mapping in conjunction with visual observations, however, had not been adopted by other teams.

Demand for habitat-based fisheries information along the U.S. West Coast grew dramatically during the 1980s, as commercial fisheries grappled with major shifts in species population size and location. These shifts have been attributed to a variety of factors, including climate and oceanographic changes, and overfishing [e.g., 13-15]. U.S. and Canadian habitat-based ecological studies and stock assessments of west coast fish species used visual observations from manned submersibles, remotely operated vehicles, (ROV s) and SCUBA divers [16-25]. This method augmented stock assessments by trawling and provided information on

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issues such as the habitat preferences of fish species and the health of benthic ecosystems.

During the 1980s, the national NURP office and the NURP Centers on the east coast supported this west coast research with both project funding and on-site demonstrations of the use of submersibles. In 1989, the informal NURP office in Fairbanks, Alaska began sponsoring this work. This office became an official NURP Center in 1990 (WC&PRURC). In January 1992, the WC&PRURC sponsored a special session and a workshop at the Western Groundfish Conference, *In situ* Technology in Fisheries Research, to foster discussion among east and west coast scientists and specialists in submersible and ROV technology.

However, the spatial scope of this type of *in situ* study was necessarily very limited. Spot observations and transects could be made, but it was difficult to extrapolate the results to larger regions, i.e., to the dynamics of fish populations and regional scale fisheries. The primary advantage of adding sonar surveys to the benthic habitat studies was the much greater areal coverage. Sidescan images in particular can easily distinguish hard versus soft bottom, the first-order characteristic of different habitat types. Sonar imagery enabled scientists to map the distribution of various habitat types, and choose dive sites to cover all habitats existing in the region or to target a specific one for detailed study.

III. Soquel Canyon

Integration of sonar mapping with *in situ* habitat studies on the U.S. West Coast began in the early 1990s. In 1991, one of the projects sponsored by the WC&PRURC was a submersible study of hagfish reproduction in Monterey Bay, CA, led by John Wourms (Clemson University). Several scientists from Monterey Bay labs were invited to participate in the *DELTA* dives, including fishery biologist Mary Yoklavich of the National Marine Fisheries Service (then located at Pacific Grove, CA). During a dive in Soquel Canyon in May 1991, the investigators happened across a remarkable rocky oasis with a high concentration of some species of adult rockfish. Individual fish were also unusually large, particularly the species with high commercial value (i.e., those that were targets of commercial fisheries). Yoklavich, seeking a way to systematically locate other rock outcrops in the canyon, contacted geologist Gary Greene, then at the U.S. Geological Survey (Menlo Park, CA), who suggested using geophysical techniques including sidescan sonar and seismic reflection profiling. Together with Gregor Cailliet and Michael Ledbetter (Moss Landing Marine Laboratories), they obtained funding from the WC&PRURC for an interdisciplinary project [26-33].

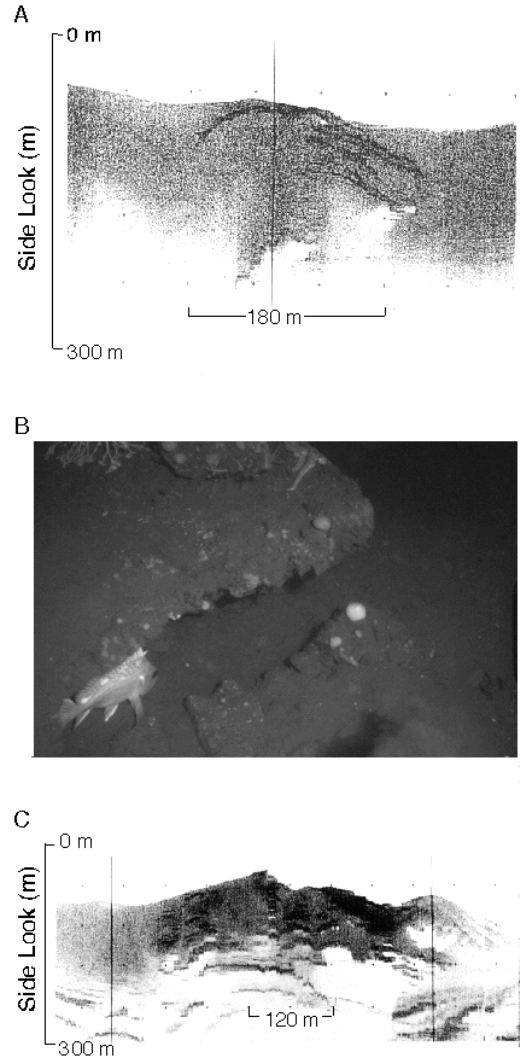


Fig. 1. Seafloor images from the Soquel Canyon study [32].
A. Sidescan sonar image of an isolated rock outcrop surrounded by mud, on the steep canyon wall. Scales in meters represent lateral distances across the seafloor, not water depth. B. Eroded mudstone and greenspotted rockfish (*Sebastes chlorostictus*), photographed from DELTA submersible. C. Sidescan sonar image of a large outcrop of sedimentary rock with strongly defined bedding on the canyon wall.

Soquel Canyon cuts through flat-lying strata of sandstone, mudstone, and shell-rich sediments of the Pliocene Purisima Formation. The rock outcrops that both attracted and protected the rockfish were located on the steep walls of the canyon. To locate the outcrops amid fields of mud that draped the seafloor, the investigators used a combination of 100 kHz side-scan sonar and 3.5 kHz profiler (Fig. 1). These surveys were conducted in March, 1992, less than one year after discovery of the rockfish oasis. The 300-meter wide sidescan images showed variations in acoustic reflectivity of the seafloor, which was a function of the slope angle, seafloor roughness, and acoustic character of the rock or sediment exposed on the seafloor. The 3.5 kHz sonar profiles collected at 20 meter spacing provided high-resolution bathymetry, even in areas where the terrain was too steep for the side-scan sonar.

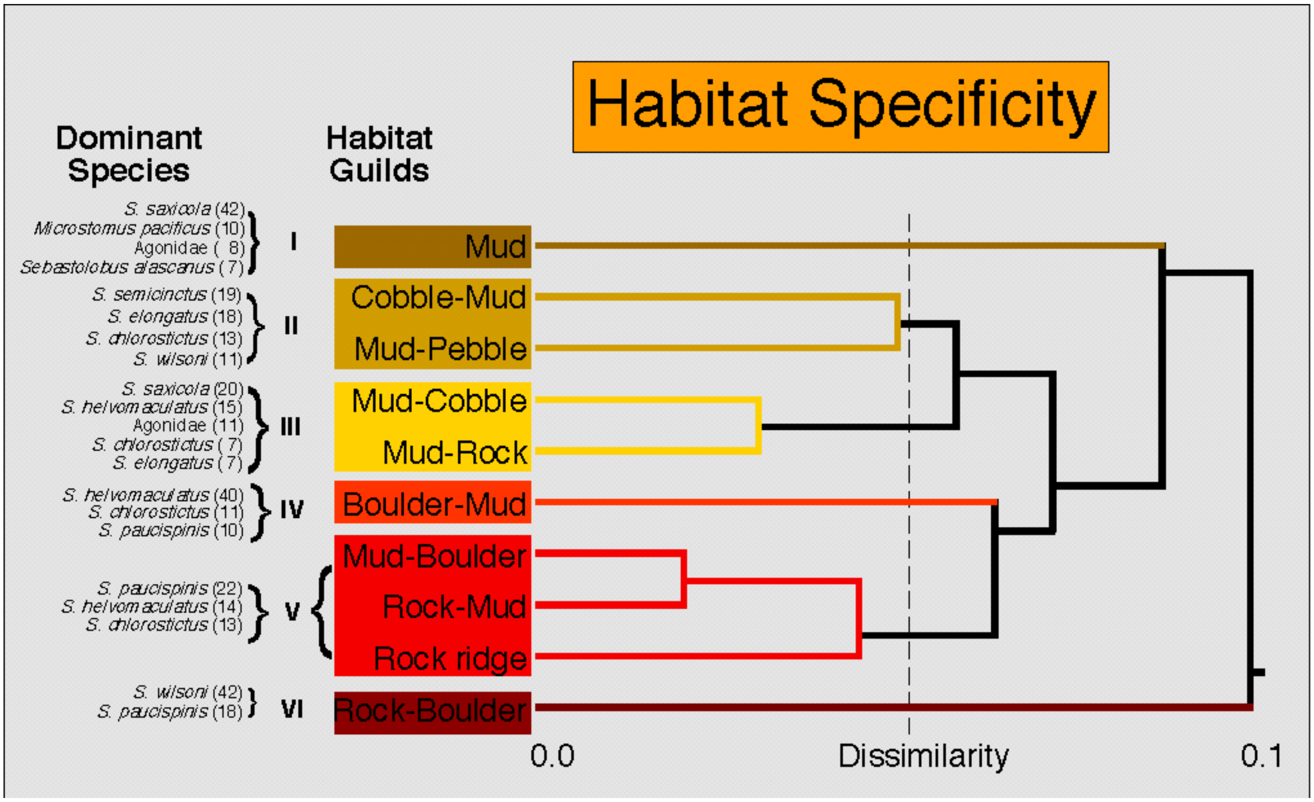


Fig. 2. Diagram showing the relationships between the dominant non-schooling benthic fish species versus benthic habitat types, as observed in Soquel Canyon. This is the most general summary from the study; for more detailed analyses see Yoklavich et al., 2000 [32].

All sonar data were navigated by differential GPS; precise navigation was crucial because it ensured that the features in the images could be quickly located during submersible dives, which were also navigated by differential GPS.

DELTA submersible dives in August, 1992 and October, 1993 accomplished two purposes. First, geological interpretations of the sonar images were ground-truthed by visual observations during the dives. Sonar images are ambiguous in that acoustic reflectivity is controlled by a combination of slope and texture of the seafloor. In this study, the sonar interpretation proved to be relatively straightforward. Features interpreted to be outcrops of sedimentary rock were found to be outcrops of sedimentary rock. Dive observations further suggested that exposure of those outcrops was largely controlled by slumping and bedding exposures on the canyon walls. The headwalls of the slumps are also associated with biological erosion, i.e., benthic invertebrates boring into the soft sedimentary rock.

Second, the fish populations and their relationship to habitat were documented during the dives (Fig 2.), by continuous video recording and by verbal descriptions from the scientist observer in the submersible. A hand-held sonar gun was used to measure the distance from the submersible to specific features on the seafloor, establishing the size of the field of view and the square meters that each observation represented. Parallel lasers mounted next to the video camera provided a way to precisely measure the size of objects in the videotapes (including individual fish). They were also used to determine the distance the submersible traveled over the seafloor, and thus the length of the transect.

Aspects of this innovative project that made it successful and influential include the following: 1) the apparently undisturbed nature of the site meant that it could serve as a valuable comparison to heavily fished areas; 2) the seafloor mapping was done at an appropriate resolution and with precise navigation; and 3) the dive observations were systematic and spatially quantifiable. This enabled future comparisons with other sites [e.g., 33-34], and demonstrated the potential for this type of study as an objective method of habitat-based assessment of fish populations.

IV. Adding Sonar: Workshops

At the 1993 American Fisheries Society Meeting in Portland Oregon, the WC&PRURC sponsored a special session and evening meeting: The Application of *In Situ* Technology in Fisheries Research - With an Emphasis on Direct Observation [35]. This workshop was attended by both fisheries biologists and marine geologists. The discussions resulted in several successful proposals to the WC&PRURC for benthic fisheries habitat studies using combined sonar mapping and *in situ* visual observations.

The high level of interest also led to a second workshop, sponsored by WC&PRURC: Applications of Side-Scan Sonar and Laser Line Systems in Fisheries Research [36]. It was organized by Victoria O Connell (Alaska Dept. of Fish and Game) and Waldo Wakefield (Science Director at WC&PRURC), and held in January, 1994 in conjuction with the Western Groundfish Conference in Nanaimo, British Columbia. The focus of this workshop was a discussion of techniques and approaches that worked, from biological, geological, and industry perspectives. This workshop served to solidify interest in the use of sonar mapping for benthic habitat studies.

V. Mt. Edgecumbe Pinnacles

One of the studies proposed to and funded by WC&PRURC immediately after the 1993 workshop was a study of benthic rockfish habitat in southeast Alaska, on the continental shelf west of Kruzof Island and Mt. Edgecumbe volcano. This region is geologically complex, and contains boulder fields and rock outcrops ranging from metasandstone and shale, to granite, to young lava flows and volcanic cones of the Mt. Edgecumbe lava field. The large areas of complex rocky seafloor host one of the most productive rockfish fisheries in the state. Traditional stock assessment by trawling did not work well for rockfish [37], and in 1989 WC&PRURC funded a comparative evaluation of submersible, ROV, and longline for assessing abundance of rockfish by habitat type. By 1990 the Alaska Department of Fish and Game had begun doing stock assessments using manned submersible transects. Such transects can work well over the limited area that they cover, but the data then had to be extrapolated over large areas for regional stock assessments. This extrapolation relied in part on the distribution of rocky areas as shown in NOAA s hydrographic charts.

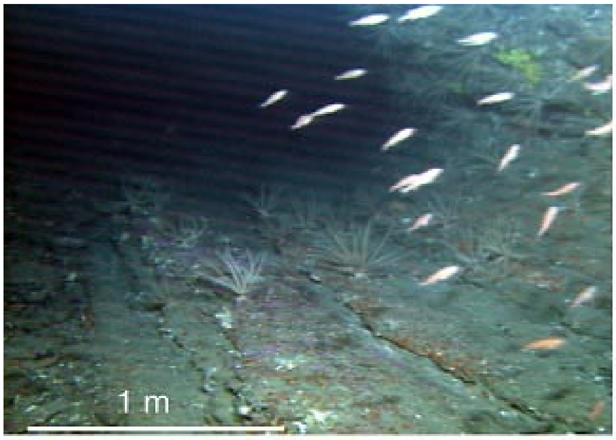
As part of the ongoing effort to improve their methods of stock assessment, a group led by fisheries biologist Victoria O Connell of the Alaska Dept. of Fish and Game (ADF&G) proposed to a) compare the submersible transects with results of longline fishing, and b) survey the area with sidescan sonar, in order to quantify the distribution of different habitat types and identify targets for submersible transects. Co-PIs were David Carlile (ADF&G), Waldo Wakefield (Rutgers Univ.), and Gary Greene (USGS). The sidescan sonar survey was first conducted in 1994 with a 56 kHz system; it produced much higher resolution data than the existing hydrographic charts, but was not adequate for distinguishing the various types of rocky seafloor at the scale necessary for fisheries studies. The problem was that the fish populations varied not only between soft and hard, rocky seafloor but also varied with differences in roughness of shale versus granite versus lava flows. The area was re-surveyed in 1996 with a 150 kHz multibeam sonar that produced both sidescan images and bathymetry. These results were used to construct a geological map of the seafloor, and this map provided the basis for refining estimates of the distribution of different habitat types, and improving estimates of the regional population of rockfish species [33, 38-39]. The volcanic cones associated with the Mt. Edgecumbe lava field in the southern part of the study area, locally referred to as pinnacles, were identified as an unusually productive spawning and nursury habitat for a variety of species. In 1997 this limited area was classified as a permanent no-take marine reserve for groundfish. Thus in the case of southeast Alaska, the new technique for benthic fish population and habitat assessment had immediate benefits to fisheries management.

This work led to a large, ongoing project by the Alaska Dept. of Fish and Game in the nearby Fairweather Ground, a major fishery for groundfish as well as pelagic species. The Fairweather benthic habitat research focuses on yelloweye rockfish (*Sebastes ruberrimus*) as a target species, and uses sonar mapping to extrapolate fish population densities from representative sites to derive biomass and manage the fisheries [40].

VI. Heceta Bank

Heceta Bank is the largest of the rocky fishing banks off the Oregon coast. Bedrock exposed on the seafloor is strongly jointed and folded sandstone, mudstone, and siltstone, that was eroded during glacial periods of low sealevel [41]. The complex outcrops are a prime habitat for rockfish, and the area has been heavily fished. Starting in 1988, Mark Hixon, David Stein, Brian Tissot, and William Pearcy (Oregon State Univ.) used *DELTA* dives sponsored by NURP and WC&PRURC, and co-sponsored by the Minerals Management Service (U.S. Dept. of the Interior), to study the behavior and habitat associations of the rockfish species on Heceta Bank [21, 22, 25]. They found a clear correlation between fish abundance and distribution by species, and seafloor habitat characteristics (Fig. 4). By reoccupying a set of 6 transect lines each year, their dives in 1988-1989-1990 also anchored a time series for evaluation of interannual variations in the rockfish populations. However, there was no means of spatially extrapolating their findings beyond the limited area visible during submersible dives.

This project initiated a broader study of the complex offshore fishing banks, funded primarily by the Minerals Management Service, that included Heceta, Stonewall, Coquille, and Daisy Banks. This work involved collaborations between the OSU group and Rick Starr, Dave Fox, and William Barss at the Oregon Department of Fish and Wildlife [e.g., 42].



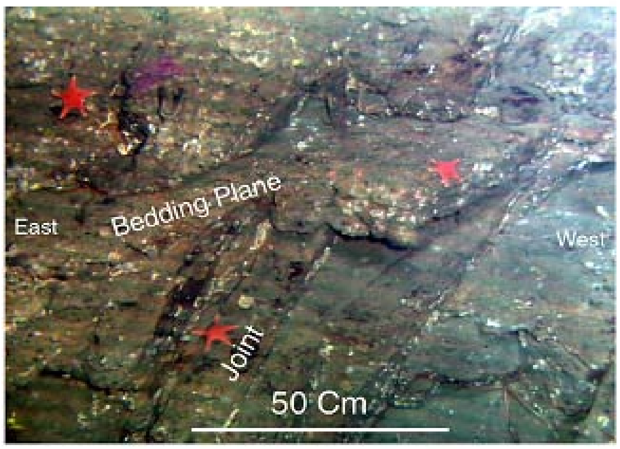


Fig. 4. Video frame grabs of the seafloor on the eastern part of Heceta Bank, from ROV *ROPOS* dives in 2000 [46]. Upper: juvenile rockfish over an outcrop of folded sedimentary rock. Lower: strongly jointed sedimentary rock, with joint and bedding planes marked.

In 1998 an opportunity arose for new seafloor mapping of Heceta Bank, using a 30 kHz multibeam sonar and differential GPS navigation (Fig. 5). State-of-the-art multibeam sonar systems can now produce co-registered bathymetry and high-quality backscatter data (pseudo-sidescan) simultaneously. Acquisition of the bathymetric and backscatter data over the entire bank was funded by NOAA/NMFS and Oregon State University Sea Grant [41]. An interdisciplinary team including fisheries biologist Waldo Wakefield (NMFS), marine geologist Bob Embley (NOAA/PMEL), invertebrate ecologist Brian Tissot (Washington State Univ.), and fish ecologist Mark Hixon and graduate student in marine resource management Nicole Nasby (both at Oregon State Univ.), were able to combine the new sonar maps with re-navigated *DELTA* dive data to produce a GIS-based analysis of habitat distribution on Heceta Bank [41, 43-46].

With reliable knowledge of the distribution of all habitat types, results of *in situ* observations from accurate estimate of the fish populations and distribution

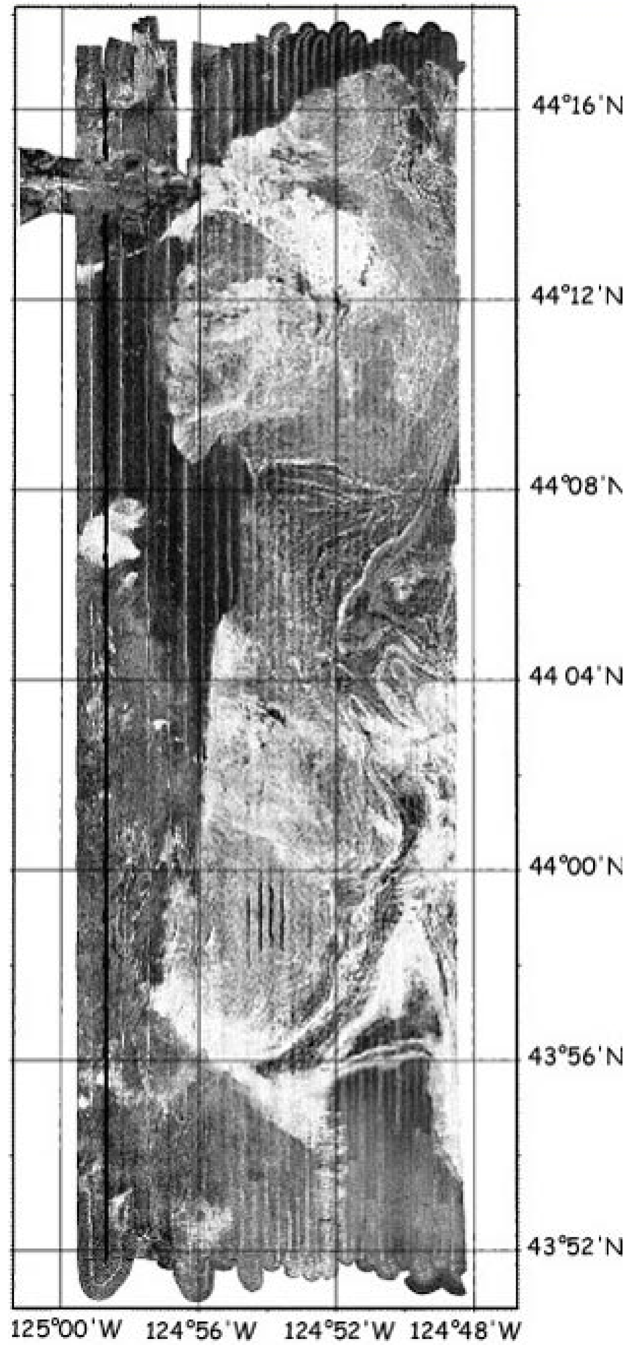


Fig. 5. Backscatter intensity over Heceta Bank, with high intensity shown as white and low intensity as black. The complex deformation of the sedimentary bedrock is visible even in this low-resolution version of the map. Survey area is approximately 50 km N-S x 18 km E-W. Data collected with 30kHz multibeam sonar. [41].

over the entire bank. The analysis did produce a high correlation between seafloor terrains as defined in the representative locations may be extrapolated for an sonar images, and habitat types as defined in the *DELTA* dives. However, the successful interpretation of the sonar maps required both groundtruthing (visual observations from the dives), and a geological understanding of the outcrop lithology and structure. In this region there was not a simple relationship between backscatter intensity and seafloor roughness or lithology. Low backscatter intensity was produced by mud, intermediate intensity by low ridges of eroded mudstone, and high backscatter intensity correlated with both carbonate patches and cobble/ boulder fields. The geological map constructed by Embley et al. [41] was necessary for resolving ambiguities in the identification of habitat types from the sonar images alone.

One of the conclusions from this comparison of new maps with old dive data was that the dives had not actually sampled the full range of benthic habitats on the bank. To correct this, and to compare the fish populations observed in 1988-1990 with observations a decade later, Waldo Wakefield, Bob Embley, Brian Tissot, and Mary Yoklavich were funded by WC&PRURC to return in 2000 and 2001 with the ROV *ROPOS* [46].

VII. Laser line scan

Although the combination of sonar imagery and in situ observations has been a great advance in the study of benthic fish habitats, this technique is labor-intensive. The great advantage of sonar mapping is the increase in areal coverage. The scientists must then bridge the gap between the scale of seafloor sonar mapping by multibeam systems and the scale of visual observations by submersible or ROV.

A possible alternative is laser line scan. This seafloor imaging technique may be able to image both fish and seafloor features. The images resemble grainy, low-resolution black and white photographs. Although laser line scan would operate in the swath mapping style of multibeam sonars, the potential coverage is much less because of the attenuation of laser beams through the water column. However, the coverage may be greater than that of dive transects, again depending on water clarity (Fig. 6). Several companies now manufacture commercial versions of this technology. WC&PRURC funded a workshop held in March, 2001, to facilitate discussion between scientists and industry

water clarity	typical imaging range	maximum swath width	sampling resolution
very clear Hawaii	45 m	65 m	3 cm
clear San Diego	22 m	30 m	1.5 cm
moderate Wash. State, Mass. Bay	9 m	13 m	0.6 cm
poor Boston Harbor	3 m	4 m	0.2 cm

Fig. 6. Representative laser line scan system performance, from Science Applications International Corporation (SAIC) [48].

representatives about use of this technology [47]. Field tests of a laser line scan system, directed by Mary Yoklavich and funded by WC&PRURC, will be conducted in late fall, 2001, in the Big Creek Ecological Reserve (central California). This area has been previously surveyed by 100/500 kHz sidescan sonar, 30 kHz multibeam bathymetry and backscatter, *DELTA* dives, and SCUBA video transects, facilitating a comparison between laser line scan and other methods of habitat characterization.

VIII. Wider applications

One of the outcomes of the research funded by WC&PRURC was initiation of a major effort in the South Pacific to characterize benthic habitat. An international conference focused on this research was convened in 1997 by Jean-Marie Auzende (IFREMER) and Gary Greene (Moss Landing Marine Laboratory, CA). Presentations at the conference ranged from technology and methodologies of benthic habitat assessment, to specific studies in coral reef, volcanic seamount, and continental shelf environments [49].

As this technique of combining sonar mapping with *in situ* observations for benthic habitat research has spread worldwide [e.g., 49-50], the potential for comparisons between different regions has grown. To facilitate this type of comparison, habitat classification schemes have been proposed. Allee and coworkers developed a universal classification scheme for all marine habitats in the U.S. [51]. Greene and coworkers have devised a classification scheme for deep (>30 m) seafloor habitats [33, 52-53]. These classification schemes are intended to provide a systematic and consistent framework based on physiographic and geological characteristics, and are an outgrowth of the west coast research described above.

Many of the scientists involved in these projects worked for government agencies with an interest in the marine environment, e.g., NOAA, National Marine Fisheries Service (NMFS), Alaska Dept. of Fish & Game (ADF&G), California Dept. of Fish & Game (CDF&G), and the U.S. Geological Survey (USGS). WC&PRURC provided opportunity and tools for these scientists to push the envelope, to develop new techniques that were not part of the routine operations of the federal and state agencies. The timing of the successful completion of these projects has coincided with a major development in U.S. fishery management. The reauthorization of the Magnuson-Stevens Fishery Conservation and Management Act passed by the U.S. Congress in 1996 contained a new mandate for government agencies to incorporate habitat-based assessments into fishery management. The strategy of sonar mapping + *in situ* observations has been adopted to varying degrees by federal and state agencies, and is now part of the range of options. It is particularly suited to areas where traditional stock assessment by trawling or longline fishing is undesirable or impossible, for example in marine reserves or untrawlable areas. It also has the potential for accurate and systematic assessments of large areas.

The role of the WC&PRURC in development of this technique was two-fold. First, funding from the Center functioned as seed money; now that this type of research is relatively well established, it is attracting funding from numerous other organizations and agencies. Second, the Center acted as a clearinghouse for information, and actively encouraged discussion and exchange of information among interested researchers.

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