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Theme Session on Classification and Mapping of Marine Habitats

Mapping. and Classification of Deep Seafloor Habitats

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Abstract

Using geophysical data collected with a variety of remote sensor systems and *in situ* biological and geological observations, we have constructed a geologically and biologically based template to be used to standardize habitat types in water depths greater than 30 meters. Our scheme has been applied to the characterization of groundfish habitats along the west coast of the US with specific applications in central California and Southeastern Alaska. We present results of the successful applications of this scheme in characterizing commercially important fishery habitats and their usefulness for managing fisheries. Illustrations of species-specific association with distinct and identifiable geologic, geomorphic and biologic characteristics are presented here. We show how suites of instruments such as side scan sonar-s, multibeam echosounders, high-resolution seismic reflection profilers, and *in situ* observations can be used to construct maps that characterize mega-, meso-, macro-, and micro-habitats. In addition, we explain how this scheme can be used within the ICES region.

Habitat Classification Scheme

The use of geophysical techniques to image and map the seafloor has become an important tool for the characterization of deep-water marine benthic fish habitats. A suite of data sets including side scan sonographs, multibeam bathymetry, and seismic reflection profiles have been successfully used by us to map important rockfish habitats in California and Southeastern Alaska. These habitats were defined and described using the deep-water habitat characterization scheme proposed by Greene *et al.* (1999).

Remote sensing geophysical techniques are used to determine hard and soft substrate and to define structure, lithologies, morphologies, and textures of the seafloor. The resultant data sets are mosaiced to produce a map that can be interpreted into habitats. Once a map has been constructed, interpretations are checked ("groundtruthed") by using a submersible or remotely operated vehicle (ROV) to make *in situ* observations and collect substrate and biological samples at selected sites in each habitat. We use a Geographical Information System (GIS), specifically ArcView, for data compilation and mapping. We can add to this GIS other data related to physical habitat parameters, such as current, temperature, and biological parameters including nutrients, fisheries information and CPUEs.

Rockfishes (*Sebastes*) tend to be habitat specific in their distributions. Quantification and characterization of habitats is an important component of sucessful management of these fishes (O'Connell *et al.* 1998 and 1999; Wakefield *et* al. 1998). The declining abundance of commercially valuable deep-dwelling rockfish along the west coast of the United States has further stimulated research into deep-water benthic habitat characterization. We have adopted a deep-water classification scheme developed by Greene *et al.* (1999), which was modified after Cowardin *et al.* (1979) and Dethier (1992), and based on remote sensing geophysical and geological, techniques that are used to define and map the seafloor. The development and use of a standard classification system greatly enhances our ability to compare and contrast results from studies conducted over a wide geographic range.

The interpretations of these geophysical and geological data are "groundtruthed" using *in situ* biological and seafloor observations, a critical element for habitat classification. We define habitats on the basis of scale with the use of geology and geomorphology, a substrate-based scheme. Depth, currents and encrusting or attached biota are also used in our characterization of habitats. Based on scale, we define habitats as follows (after Greene *et* al. 1999):

Megahabitats refer to large physiographic features, having dimensions from kilometers to tens of kilometers, and larger. Megahabitats lie within major physiographic provinces, e.g., continental shelf, slope, and abyssal plain (Shepard 1963). A given physiographic province itself can be a megahabitat, however, more often these provinces are comprised of more than one megahabitat. Other examples of megahabitats include submarine canyons, seamounts, lava fields, plateaus, and large banks, reefs, terraces, and expanses of sediment-covered seafloor.

Mesohabitats are those features having a size from tens of meters to a kilometer, and include small seamounts, canyons, banks, reefs, glacial moraines, lava fields, mass wasting (landslide) fields, gravel, pebble and cobble fields, caves, overhangs and bedrock outcrops. More than one mesohabitat, and similar mesohabitats (in terms of complexity, roughness, and relief), may occur within a megahabitat. Distribution, abundance and diversity of demersal fishes vary among mesohabitats (Able *et al.* 1987; Stein *et al.* 1992; O'Connell and Carlile 1993; Yoklavich *et al.* 1995, 1997). Similar megahabitats that include different mesohabitats are likely to comprise different assemblages of fishes and, following from this, similar mesohabitats from different geographic regions likely comprise similar fish assemblages.

Macrohabitats range in size from one to ten meters and include seafloor materials and features such as boulders, blocks, reefs, carbonate buildups, sediment waves, bars crevices, cracks, caves, scarps, sink holes and bedrock outcrops (Auster *et al.* 1995; O'Connell and Carlile 1993). Mesohabitats can comprise several macrohabitats. Biogenic structures such as kelp beds, corals (solitary and reef-building) or algal mats, also represent macrohabitats.

Microhabitats include seafloor materials and features that are centimeters in size and smaller, such as sand, silt, gravel, pebbles, small cracks, crevices, and fractures (Auster *et al.* 1991). Macrohabitats can be divided into microhabitats. Individual biogenic structures such as solitary gorgonian corals (e.g., *Primnoa)*, sea anemones (e.g., *Metridium*), and basket sponges (taxonomy unresolved) form macro- and microhabitats.

To further refine our characterization scheme we use the Greene *et al.* (1999) system, classes, subclasses and modifiers as descriptors.

In the following section, we apply our classification scheme to the characterization of groundfish habitats along the west coast of the United States with specific applications in central California and Southeastern Alaska. We present results of the successful applications in characterizing habitats for commercially important fisheries. Illustrations of species-specific preferences to distinct and identifiable geological, morphological, and associated biological characteristics are presented. We show how suites of instruments such as side scan sonars, multibeam echosounders, high-resolution seismic reflection profilers and *in situ* observations are used to construct maps that characterize mega-, meso-, macro- and microhabitats.

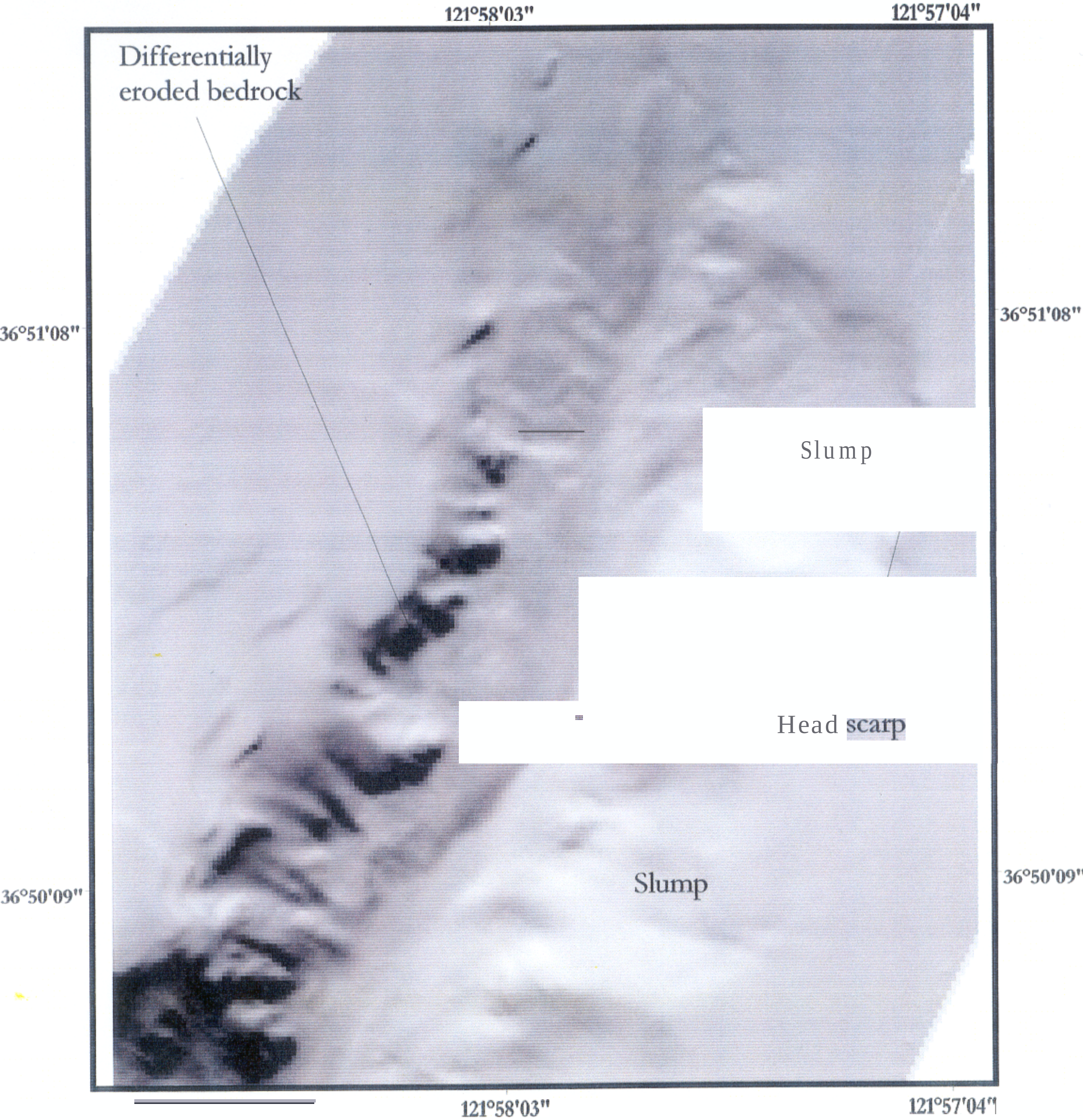


Figure 1. Bathymetric image of mega- and mesohabitats in the head of Soquel Canyon, Monterey Hay, central California, USA. These data were collected by the Monterey Hay Aquarium Research Institute (MBARI) using a Simrad EM 300 kHz swath mapping system. Modified after Greene et al. (1999).

Case Studies

Physical Habitats of the Soquel Submarine Canyon, California

In the case of Soquel Canyon, we found that high resolution EM 300 multibeam bathymetry and side scan data imaged differentially eroded bedrock in the walls of the canyon that are excellent habitat for rockfish. *In situ* observations confirmed the fish association to the geology. Our maps and habitat characterization of Soquel Canyon are being used to identify refugia that can be managed for the sustainability of the local and regional rockfish resources.

Using the habitat characterization scheme of Greene *et al.* (1999), we have'defined and mapped many habitats along the west coast of the United States. One example of a fisheries habitat characterization is Soquel Canyon in Monterey Bay, central California. The headward parts of this canyon act as habitat for rockfish (Family Scorpaenidae; genus *Sebastes)* populations. We characterize this feature as a megahabitat comprising an upper submarine canyon (100-300 m deep) with steeply sloping (30°-45°) walls, and locally including mesohabitats of near vertical to vertical (80°-90°) walls with landslide morphology (slump scars and debris fields) (Fig. 1). Macro and mesohabitats include well-bedded friable outcrops of sandstone, mudstone, and coquina. Differentially eroded beds along the canyon walls form overhangs (>90°) and crevices; landslide debris produces irregular and hummocky seafloor conditions consisting of scattered blocky boulders of sandstone interspersed with fairly well bioturbated mud seafloor. Landslide debris contains 40% boulders, 20% cobble fields, and 40% mud.

High-resolution multibeam bathymetric data (gridded at a scale of 10 m) collected with a Simrad EM 300 30 kHz multibeam echosounder by the Monterey Bay Aquarium Research Institute (MBARI) and backscatter data collected with a 100 kHz side scan sonar by the US Geological Survey (USGS) was used to characterize the habitats. These data sets were "groundtruthed" using the submersible Delta for *in situ* observations and seafloor sampling. High-resolution (3.5 kHz) seismic reflection data were used to determine type and thickness of sediment overlying hard substrate.

Our submersible observations showed that rockfish were most commonly associated with differentially eroded bedrock exposures along the walls of the canyon from 100-300 m deep. The many erosional overhangs and caves found along the walls afforded refugia for the rockfish (Fig. 1). We hypothesize that strong currents, depth, and hard substrate with many fish-sized voids make these areas good habitat for rockfish.

Physical Habitats of Fairweather Ground, Alaska

On the Fairweather Ground, located northwest of Sitka in southeastern Alaska, we discovered that the greatest abundance of yelloweye rockfish *(Sebastes ruberrimus)* were in areas of complex rock habitats where rugged bottom dominated smooth rock and soft bottom habitats. Shallow water banks (maximum depth 100 m) were less attractive to rockfish than deep water areas (to 160 m deep) of bedrock, pinnacles and boulders, and interfaces comprised of structural and erosional scarps adjacent to sand and gravel sea floor. We speculate that the shallow water banks were subjected to glaciation, resulting in a reduction in the number of "refuge" spaces and complex

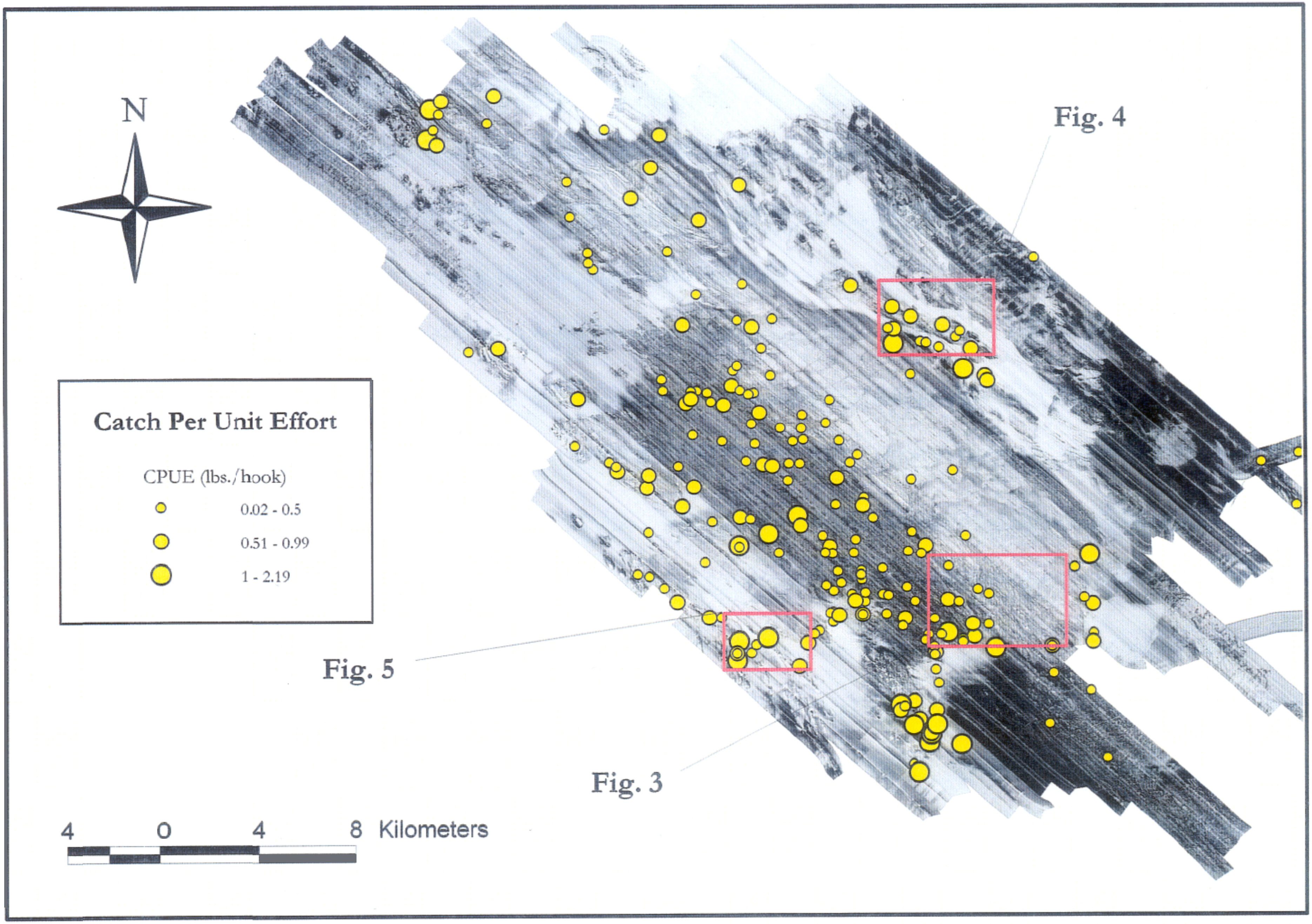


Figure !. An AMS 120, 120 kHz, side scan sonar mosaic of the western Fairweather Ground showing acoustic reflectivity images that have been interpreted nto yelloweye rockfish habitats. Acoustically dark areas represent coarse-grained deposits such as gravel, cobbles and pebbles, hard rugged bedrock, or steep relief, while the acoustically light areas represent soft sand or smooth hard bedrock areas. Filled circles are CPUE with larger circles representing greater quantities of fish caught. Note sand stringers in the north-central part of the mosaic that trail off toward the southeast indicating a southeastward flowing bottom current. Boxes indicate areas of figures 3, 4, and 5.

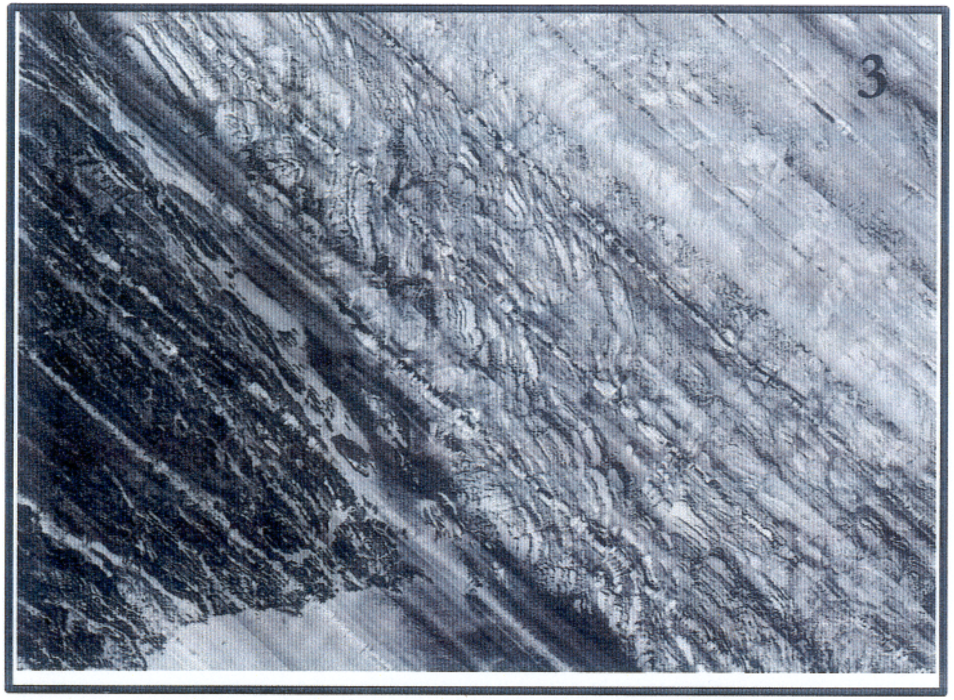
structure attractive to yelloweye rockfish. In addition, sand stringers and gravel shadows observed in the Fairweather Ground sidescan mosaic infer strong currents that gyre in a clockwise direction. This information is now being used to better manage the yelloweye rockfish fishery in Southeastern Alaska (O'Connell et al. 1999).

Recently acquired (1998) side scan sonar data, and observations made from the submersible Delta (1999) in Southeastern Alaska indicate that the western Fairweather Ground, located northwest of Sitka, is composed of highly deformed, faulted and fractured Cretaceous sedimentary rocks. Differential erosion, glacial advance and retreat, and the last marine transgression sculptured the sandstone and shale that form this bedrock marine benthic environment into variable relief features that provide excellent habitat for rockfish. In addition, glacial deposits consisting of boulders and till offer further benthic habitats for rockfish. We characterize the western Fairweather Ground as a large continental shelf bedrock (bank) megahabitat that is comprised of various mesohabitats. Twelve different types of mesohabitats have been defined, primarily including: bedded sedimentary rocks with high relief; fractured and deformed bedded rock, glaciated sedimentary rock; highly folded sandstone with sculptured high relief; sand; and glacial deposits including boulders and pinnacles, cobbles, pebbles and gravel. Many of these habitats are heavily fished for yelloweye rockfish, the target of a longline fishery on the bank.

Submersible observations showed that concentrations of the target yelloweye rockfish exist along high relief near vertical bedrock faces that are the interface between rock exposures and sediment. In addition, areas of poorly sorted large boulders and rock pinnacles also showed a high concentration of yelloweye rockfish. The well-defined outline of rock exposures allowed for an accurate estimation of hard bottom that is now being used for managerial purposes.

A high-resolution 120 kHz AMS 120 side scan sonar system was used to collect seafloor image data on the Fairweather Ground. The resultant mosaic (Fig. 2) exhibits, in great detail, the textural, structural, and lithologic characteristics of the sea floor. In addition, based on sediment type, texture, and distribution patterns observed in the mosaic, we have determined direction and estimated velocities of bottom currents.

By comparing the geologic and geomorphologic features imaged in the mosaic with commercial catch-per-unit-effort (CPUE) data, we are able to show relationships between fishing locations and habitat types. Examination of the side scan sonar mosaic (Fig. 2) in conjunction with fishery catch per unit effort data (CPUE) indicates that a high abundance of yelloweye rockfish are caught in an extensive habitat we characterize as gravel covered fractured bedded rock (acoustically dark area in central part of mosaic). This area is adjacent to an erosional scarp (boundary between acoustically dark and light areas in central part of the mosaic; Fig. 3). Less extensive areas, but with higher individual CPUEs, consisting of more complex habitat types are concentrated in the north-central and southern parts of the mosaic (Fig. 2). In the north-central area (Figs. 2 and 4), the habitat consists of a moderate reiief (-55-80 m) glaciated sedimentary outcrop (bank) with erosional basal scarps (acoustically dark areas) bounded by sand (acoustically light areas) with adjacent patches of gravel, pebbles and cobbles (acoustically dark areas south of the southern sand areas). This is an area of strong southeasterly flowing current as indicated by sand stringers (Fig. 2) and lag gravel shadows behind pinnacles and boulders (Fig. 5).



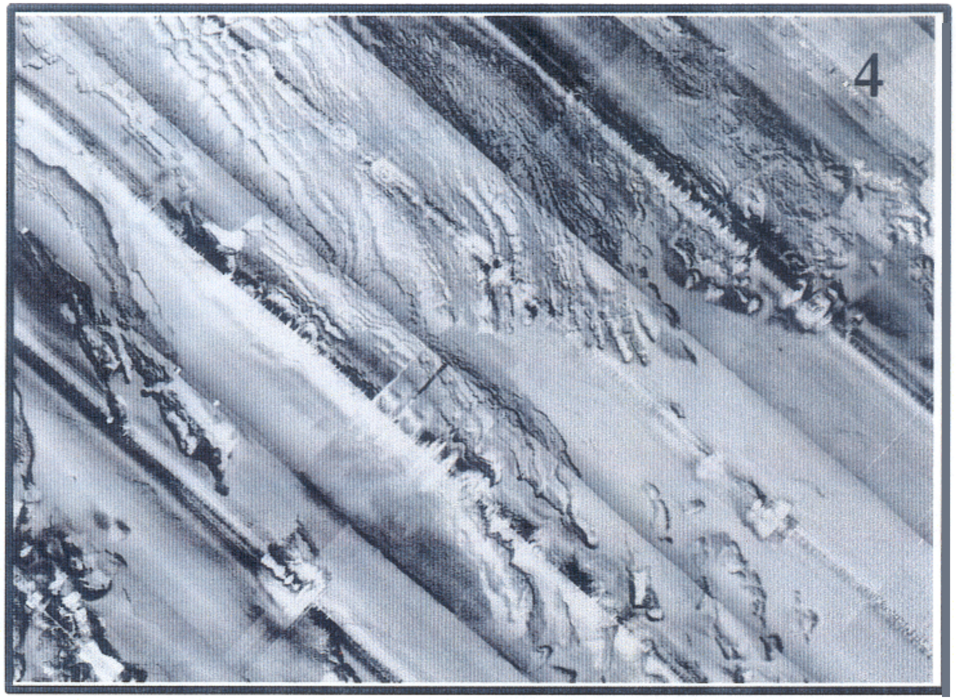


Figure 3. AMS 120 side scan sonar mosaic showing the relationship of the gravel covered fractured sedimentary outcrop (area of acoustically dark reflectivity, left side of mosaic) with moderate relief and glaciated fractured sedimentary bedrock to the right. Note diagonal band from top left corner of figure to lower center, which is a sediment (sand and gravel) filled trough that separates the two habitats. An erosional scarp occurs along the right side of the trough and forms a good vertical relief interface between the two habitat types. High fish catches are associated with the trough area and the high reflectivity area to the left (see Fig. 2 for location and CPUE data).

Figure 4. AMS 120 side scan sonar mosaic of the linear glaciated sedimentary rock outcrop where high catches of rockfish have been made. The rock exposure, which trends diagonally across the figure from top left to bottom right, is heavily grooved by glacial scour and bounded by soft sediment composed of sand with local gravel patches. The base of the rock outcrop contains erosional scarps. (see Fig. 2 for location and CPUE data).

Figure 5. AMS 120 side scan sonar mosaic showing relationship of soft sand bottom with bedded sedimentary rock outcrops, boulders and pinnacles, high numbers of rockfish have been caught in this area (see Fig. 2 for location and CPUE data). Gravel lag deposits fan out toward the northwest behind boulders and pinnacles indicating strong bottom currents flow toward the northwest in this region.

Two other areas, located in the southern part of the mosaic, are associated with high CPUEs and are comprised of high relief (-10-40 m high in -180 m of water) bedded sedimentary rocks and pinnacles surrounded by sand with occasional gravel patches (Figs. 2 and 5). These areas are of diverse relief where sedimentary rocks'appear not to have been smoothed by glaciation. These areas lie at a depth of around 100 m, and were likely exposed during the last Pleistocene low-stand of sea level. There is a conspicuous absence of fish catch along the central high area where sedimentary bedrock has been smoothed by glaciation (acoustically light area in central part of mosaic; Fig. 2), and in extensive areas of sand and gravel (northwestern, north-central, and southeastern parts of mosaic, where sand is represented by acoustically light areas and gravel by acoustically dark areas).

Conclusions

Deep-water marine benthic habitats are just now being addressed. The initiation of these habitat studies has been with the use of geophysical and geologic data as these are the best and most abundant data sets available for assessment. These data, along with detailed bathymetry, are being used by used to establish habitat types based on substrate. However, a habitat as such is considerably more complex than just substrate type and chemical, biological and other physical parameters need to be considered. By placing the geological and geophysical data into a GIS, we can then add additional data to further define and refine habitat types. As data collection progresses and disparate, yet pertinent, data are collected and complied, deep-water marine benthic habitat characterization will approach the sophistication now afforded to shallow-water and coastal (intertidal) habitat characterization such as described by Hiscock (1987, 1997) and Conner *et al.* (1995, 1997a,b).

Methodologies, technologies and the application of the deep-water habitat characterization scheme of Greene *et al.* (1999) used in our studies of rockfish habitats along the west coast of the US are directly applicable to ICES countries. Similar types of geology and geologic processes including glaciation, submarine canyon erosion, and the existence of remnant geomorphology from the last low-stand of sea level in the Pleistocene, to mention a few, found in our study areas of California and Alaska exist in the ICES region. Therefore, our studies should be useful to those ICES countries that want to understand marine benthic habitats for the purpose of managing and sustaining a bottom fish resource.

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