Geologic Characteristics of Benthic Habitats in Glacier Bay, Alaska, Derived from Geophysical Data, Videography, and Sediment Sampling

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Abstract. In April 2004, more than 40 hours of georeferenced submarine digital video were collected in water depths of 15–370 m in Glacier Bay to: ground-truth existing geophysical data (bathymetry and acoustic reflectance); examine and record geologic characteristics of the seafloor; investigate the relationships between substrate types and benthic communities; and create a habitat map. Common substrates observed include rock, boulders, cobbles, rippled sand, bioturbated mud, and extensive beds of living *Modiolus* (horse mussels) and scallops. Four principal seafloor geomorphic types were distinguished using video observations:

1. High complexity/high slope/boulder and rock substrate;
2. High complexity/low slope/boulder and rock substrate;
3. Moderate complexity/sand, gravel, and cobble substrate;
4. Low complexity/fine-grained sediment.

The distribution of these seafloor types in lower and central Glacier Bay was predicted using a hierarchical decision-tree statistical classification analysis of geophysical data.

Introduction

Geologic substrates of the sea floor in southeast Alaska provide benthic habitats for recreationally and commercially important species, including king, dungeness, and tanner crabs, halibut, rockfish, and shrimp. In Glacier Bay, where historical rates of glacier retreat are among the highest documented worldwide, the potential for rapid change in seafloor properties is high owing to paraglacial sedimentation. We use geophysical data, underwater video, and sedimentological tools to understand the distribution, character, and rate of change of geologic substrates and benthic communities in this dynamic environment. Seafloor features are revealed in bathymetry and acoustic reflectance data collected in Glacier Bay in 1998 using multibeam and side-scan sonar techniques (Carlson and others, 2002, 2003; Cochrane and others, 1998, 2000). Characterizing the seafloor in real-time while towing video is useful for ground-truthing these geophysical data, resolving unique features, examining areas of transition between contrasting substrate types, and linking the geology and biology of benthic environments.

Methods

The principal objectives of video data collection were to ground-truth geophysical data and construct maps of substrate morphology and habitat distribution, thus transect locations were selected based on the existence, quality, and complexity of geophysical data and on regions of geologic transition and (or) biologic significance. A video sled equipped with forward- and downward-looking video cameras, lights, altimeter, and a pressure (depth) sensor was towed 1–2 m above the seafloor to record geologic and biologic features. Two lasers spaced 20 cm apart provided scale. Height above the seafloor, pitch, roll, water depth, ship GPS position, speed (generally <1.5 knots), heading, and time were imprinted on the digital video tape. Real-time observations of seafloor characteristics were digitally recorded at 30-second intervals during 52 video transects (~41 hours) collected in the lower and central bay, the Beardslee and Marble Islands, off Tlingit Point, and in parts of the east and west arms. Observations at each point included primary and secondary substrate type (e.g. rock, sand, mud), substrate complexity (rugosity), seafloor slope, benthic biomass (low, medium, or high), the presence and absence of benthic organisms and demersal fish, and small-scale seafloor features (e.g. ripples, tracks, burrows). Real-time observations were recorded to a digital data file along with time, GPS position, and other ship data (after Anderson and others, unpub. data.).

In addition to towed video, an underwater sediment-bed camera was deployed to collect *in situ* digital macro images of seafloor sediment to measure the grain-size distribution using a mathematical autocorrelation algorithm (Rubin, 2004). With an image resolution of 65 pixels per mm, changes in grain size as small as 0.04 mm (40 μm, the difference between silt and clay) can be calculated. This technique enables the rapid mapping of sediment properties over a range of spatial and temporal scales, information that is useful in assessing sediment sources and the physical processes that are at work in the depositional environment. Sediment samples (n=24) and short gravity cores (n=28, ranging from 10 cm to 1 m in length) also were collected in water depths of 50–120 m.

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These samples are used to assess sediment thickness, sedimentation rate, and organic carbon content to improve our understanding of benthic habitat change.

Seafloor observations, sediment grain size, and geophysical data were co-registered, integrated, and analyzed using ArcGIS, ArcGrid, and ERDAS Imagine software to formulate predictions of benthic habitat distribution in the central and lower bay (Cochrane and Lafferty, 2002; Dartnell and Gardner, 2004). We performed ArcGrid calculations on bathymetry and acoustic reflectance data grids (each composed of more than 3 million pixels, desampled from 5 to 20 m resolution) to generate four integrated variables (slope, bathymetric roughness, acoustic reflectance intensity, and textural variability). For example, textural variability was defined as the difference between the maximum and minimum values of acoustic reflectance within a 5×5 group of pixels (a kernel). We performed this calculation on each kernel and binned the results into five classes, assigning an index value to the central pixel to express the relative variability observed in the surrounding 24 pixels. When acoustic reflectance is homogeneous within a kernel, the textural variability index of the central pixel is low (1); when reflectance is diverse within a kernel, the index is high (5). Grids were similarly calculated for the other three derivative variables. These grids were then analyzed using a hierarchical decision-tree statistical classification method to generate a predictive map of substrate distribution in the lower and central bay.

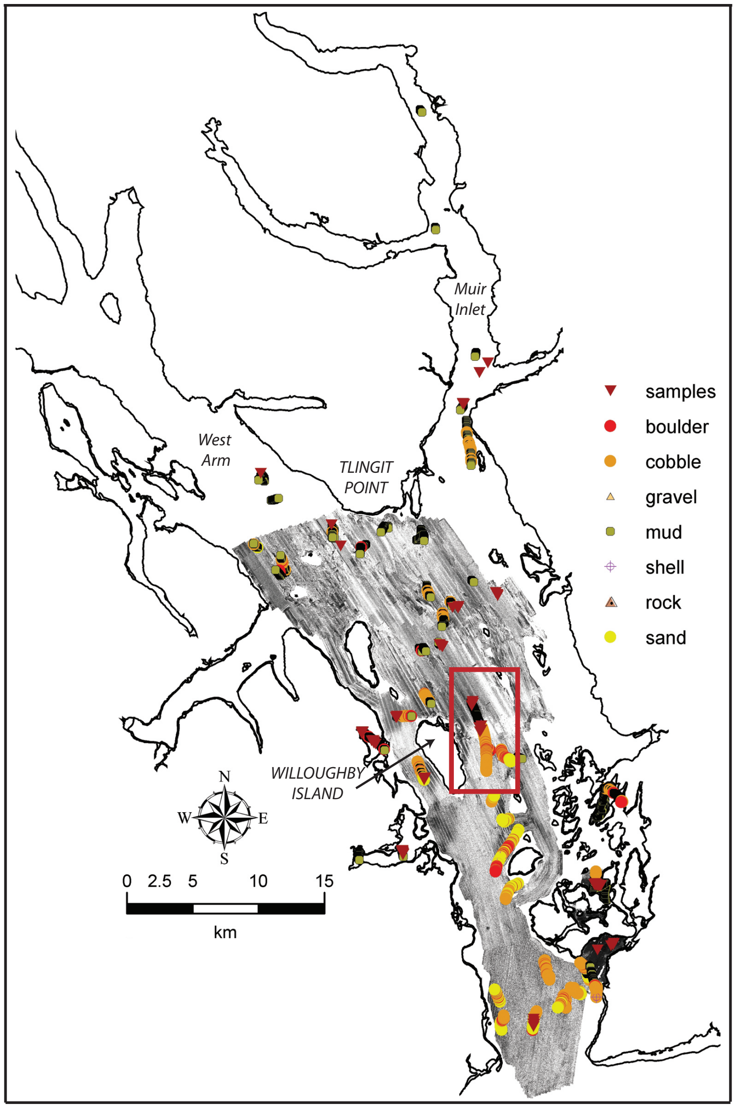


Figure 1. Primary substrate type observed in video transects, georeferenced, and plotted over multibeam acoustic reflectance data. Hard substrates and coarse grain sizes (brighter areas) dominate the seafloor of the shallower lower bay (e.g. sand, gravel, cobbles, and boulders). In contrast, mud is the dominant substrate in the deeper central bay (darker areas). The boxed area corresponds to the region of transition east of Willoughby Island shown in figure 2.

Results

Hard substrates composed of sand, gravel, cobbles, and boulders generally dominate lower Glacier Bay, however, the seafloor in deeper waters of the central bay is composed of homogeneous, bioturbated mud (fig. 1). Regions of transition exist between these geomorphic end members, as shown in the transect collected just east of Willoughby Island (fig. 2A). Acoustic reflectance of the seafloor is low in the deeper northern part of the transect line, appearing dark in sonar imagery (location B; 200 m water depth). Video confirms the seafloor is low in relief and composed of soft, muddy, bioturbated sediment (fig. 2B). Southward along the transect, acoustic reflectance increases (brightens) as seafloor sediment coarsens to gravel, cobbles, and boulders (locations and images C-D; 50–90 m water depth). These complex substrates provide habitat for gorgonians, molluscs, and other benthic organisms (fig. 2E-F).

Figure 3A illustrates the gridded result of seafloor textural variability calculations. Textural variability is highest in the relatively shallow, high-current lower bay where cobbles and boulders are the dominant benthic substrate. It is lowest in deeper waters and low-energy settings where homogeneous, fine-grained sediment covers the seafloor. The four grids derived from geophysical data (slope, bathymetric roughness, acoustic reflectance intensity, and textural variability) were analyzed in supervised statistical classifications to generate a predictive map of substrate and habitat distribution in the

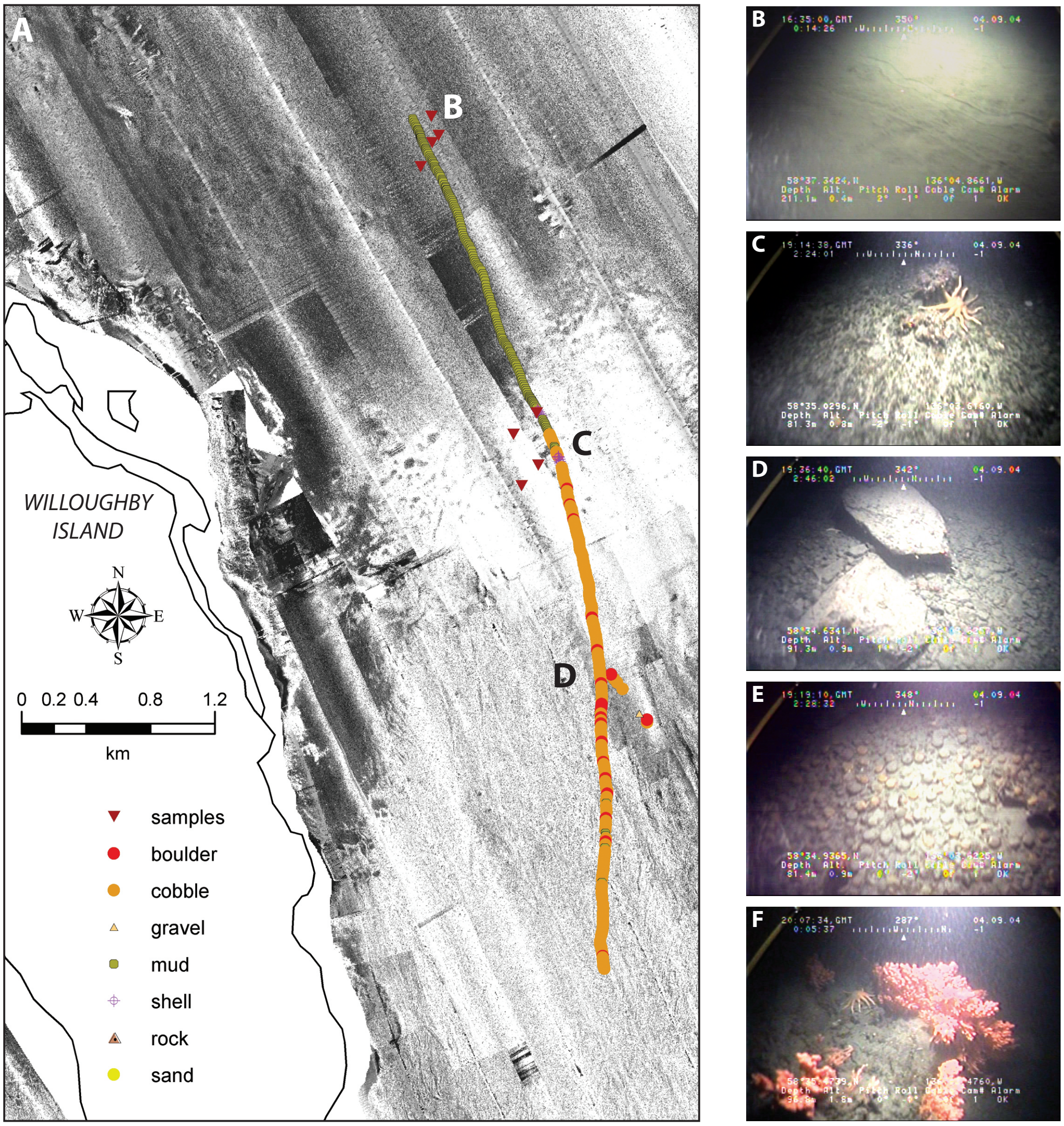
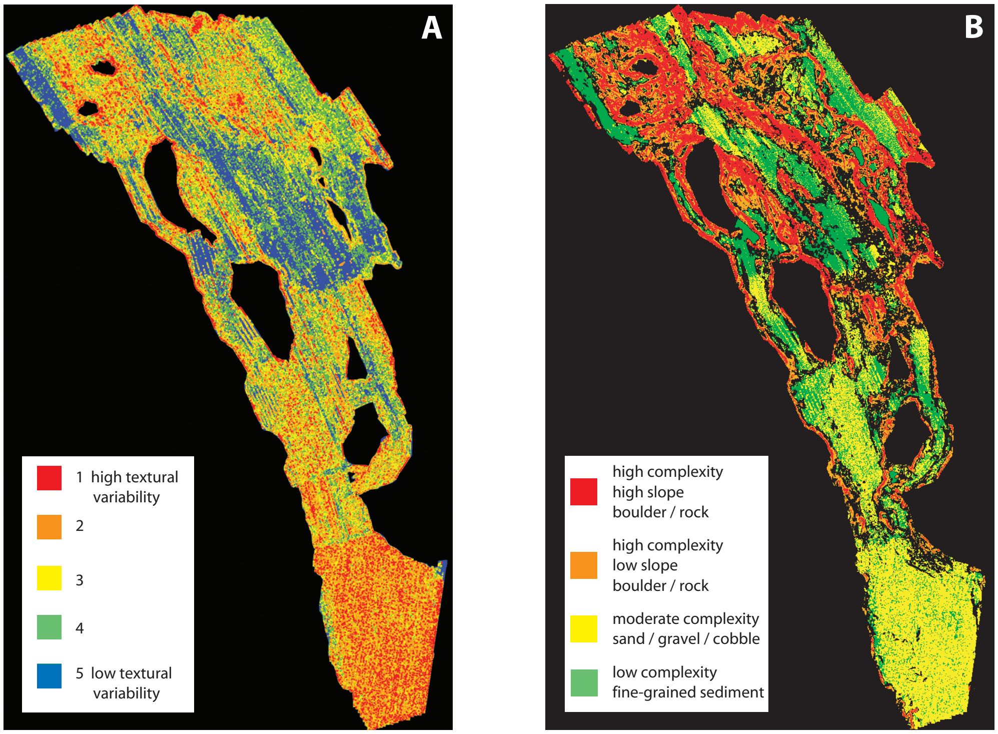


Figure 2. (A) Acoustic reflectance of the seafloor east of Willoughby Island illustrates a region of transition in seafloor substrate type. Mud dominates the seafloor of the deeper northern part of the transect (B; 200 m water depth), appearing darker because sound is absorbed by the fine sediment. In the shallower southern part (C-D; 50–90 m water depth), seafloor sediment coarsens to cobbles and boulders, appearing brighter because sound is reflected off these hard substrates. Images B, C, and D were captured from seafloor video collected on this transect, corresponding to locations marked in (A). Images E and F were captured from seafloor video collected on nearby transects to provide examples of benthic organism observations.

lower and central bay. We defined four general classes of seafloor morphology (based on bottom complexity, slope, and primary substrate observed in seafloor video) and described each class as a composite function of the four geophysical variables. A hierarchical decision-tree method was used to classify each pixel as one of the four classes based on statistical analysis of the four geophysical variables. The result is a preliminary map of the bay-wide distribution of seafloor morphology predicted from statistical analysis of geophysical data alone (fig. 3B).



A. Textual variability

B. Geomorphic classification

Figure 3. (A) Index of seafloor textural variability (ranked 1–5) computed from multibeam acoustic reflectance data. Calculations were performed using ArcGrid on 5×5 kernel of pixels (desampled from 5 to 20 m resolution). When acoustic reflectance is homogeneous within a kernel, the textural variability index of the central pixel is low (1); when reflectance is variable, the index is high (5). (B) Preliminary map of seafloor morphology based on statistical analysis of integrated multibeam geophysical data, videographic observations, and sediment sampling.

Discussion and Conclusions

Statistical analysis of geophysical data and video observations provide insight into the physical characteristics of habitats in Glacier Bay, their classification, and prediction of their distribution in the bay. This information offers the opportunity to examine what physical properties control the distribution of substrates and the development of benthic communities.

Collaboration between geologists of the U.S. Geological Survey Coastal and Marine Geology Program and biologists of the Alaska Science Center (National Park Service–U.S. Geological Survey) enables integrated study of the relationships between geological features of the seafloor and the biological communities that inhabit them. Ecological analysis of these data by Etherington and others (this volume) suggests that geologic substrate type and degree of current exposure are the principal physical factors controlling the distribution and abundance of benthic organisms in Glacier Bay. The authors observe three principal but patchy habitat types in Glacier Bay: shallow-water, high-current sand and cobble habitat; deep-water mud habitat; and intermediate-depth, mixed mud and cobble habitat.

We define four principal seafloor geomorphic classes based on our statistical analysis of integrated video observations and geophysical data (fig. 3B):

1. High complexity/high slope/boulder and rock substrate;
2. High complexity/low slope/boulder and rock substrate;
3. Moderate complexity/sand, gravel, and cobble substrate; and
4. Low complexity/fine-grained sediment.

Complexity refers to the bathymetric variability within a group of pixels. Seafloor complexity is low when local bathymetry is relatively homogeneous, such as in flat, muddy areas. Complexity is high in rocky, rugose areas. Seafloor slope represents the rate of bathymetric change between neighboring pixels. The direct influence of bathymetric complexity and seafloor slope on benthic communities is not fully understood, but is an important direction of future study, particularly in dynamic environments such as fjords and inlets. The preliminary map of seafloor morphology shown in figure 3B will continue to be tested and improved by comparing data derived from video (more than 50,000 observations) with geophysical classifications.

Ongoing work involves linking the distribution of seafloor geomorphology with the distribution and abundance of associated benthic organisms to generate maps of benthic habitat in Glacier Bay. Efforts also are directed toward expanding the range of existing bathymetric and reflectance data, permitting application of our seafloor classification method in the bay's east and west arms. Importantly, the tools and techniques developed in Glacier Bay are exportable as a model for collaborative, integrated study of benthic habitat structure, function, and change.

Management Implications

Maps of geologic substrate and habitat distribution in Glacier Bay are products that enable scientists and managers to understand benthic habitat characteristics and their rate of change. This information is increasingly important in making decisions about the management of critical environments and resources, the design and utility of marine reserves, and policies on tourism and development. In addition, the integrated tools and techniques developed in Glacier Bay serve as models to study other regions experiencing change on scales relevant to resource management and the function of benthic habitats. The importance of Alaskan fisheries as a global resource, and the pressure of climate change in high latitudes, compels the examination of benthic habitat characteristics, function, and variability in this unique and vital region.

Acknowledgments

Funding was provided by the U.S. Geological Survey. Logistical assistance was provided by Glacier Bay National Park and Preserve. This project represents integration between geologists of the U.S. Geological Survey Coastal and Marine Geology Program (Santa Cruz and Menlo Park, CA) and biologists of the Alaska Science Center (Gustavus and Juneau, AK). Many thanks to Jim de La Bruere, Paul Carlson, David Wayne, Janine Bird, Angela Lam, and the CMG Marine Facility for field and lab support. We appreciate CMG reviews by Nadine Golden and Jane Reid.

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Suggested Citation

Harney, J., Cochrane, G., Etherington, L., Dartnell, P., and Chezar, H., 2007, Geologic characteristics of benthic habitats in Glacier Bay, Alaska, derived from geophysical data, videography, and sediment sampling, *in* Piatt, J.F., and Gende, S.M., eds., Proceedings of the Fourth Glacier Bay Science Symposium, October 26–28, 2004: U.S. Geological Survey Scientific Investigations Report 2007-5047, p. 37-41.