Glacier Bay Seafloor Habitat Mapping and Classification—First Look at Linkages with Biological Patterns

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Abstract: Ocean floor bathymetry and sediment type are the base of marine benthic communities. Due to limited knowledge of seafloor habitats and their associated communities within Glacier Bay, we conducted video surveys along 52 transects in the lower and central Bay to ground-truth an initial geological classification of substrate type. We collected geological data of primary and secondary substrate, depth, habitat complexity, habitat relief, and current exposure, along with biological data of animal presence and biomass. Ordination analyses were used to examine biological-geological relationships and to identify those habitat variables that were most influential in determining community composition. Benthic habitats were distinguished primarily based on substrate type and current exposure, but habitat complexity, habitat relief, and water depth were also influential. These data provide a first look at biological-geological interactions within Glacier Bay's seafloor environment and will be useful in understanding the distribution of various species of commercial and ecological importance, as well as their associated habitats.

Introduction

Mapping and characterization of marine benthic habitat is crucial to an understanding of marine ecosystems and can serve a variety of purposes including: understanding species distributions, monitoring and protecting critical habitats, assessing habitat change due to natural or human impacts, and designing special management areas and marine protected areas. Benthic habitats are an expression of past and present physical processes and influence animal community composition. Glacier Bay is a diverse fjord ecosystem with complex benthic habitats due to historic advance and retreat of glaciers, as well as the present day influence of glaciers on the marine environment. In Glacier Bay National Park there is limited knowledge of bathymetry, distribution of sediment types, and various benthic habitats of ecological importance (Hooge and others, 2004).

Multibeam and side-scan sonar imaging have been conducted in the lower and central regions of Glacier Bay providing bathymetric and substrate reflectance data (Carlson and others, 1998; Cochrane and others, 1998; Cochrane and others, 2000; Carlson and others, 2003; Hooge and others, 2004). To ground-truth an initial substrate classification map, video surveys were conducted in the central and lower Bay. We capitalized on this sampling effort, which was primarily based on geological objectives, to also include biological measurements of the benthic community. This opportunistic sampling enabled us to examine the relationships between habitat type and benthic community composition within Glacier Bay. This paper represents a preliminary assessment of linkages between seafloor habitat characteristics and biological patterns.

Methods

Video surveys were conducted along 52 transects, covering various bottom types and depths in the lower and central regions of Glacier Bay (fig. 1). These transects covered areas where sonar reflectance habitat mapping data previously have been collected (Hooge and others, 2004), with the primary goal of ground-truthing an initial substrate classification map. Video surveys were conducted using the U.S. Geological Survey mini-camera sled outfitted with two digital video cameras, one facing forward and one facing downward. The sled also held paired lasers set at 20 cm apart used in size reference, a pressure transducer, and altimeter. The camera sled was lowered to 1–2 meters above the sea floor, and the vessel's speed was kept between 1 to 1.5 knots. Real-time visual observation data were collected at 30 second intervals using the methodology of Anderson and others (written communication). Geological observations included: primary and secondary substrates (classified as rock, boulder, cobble, gravel, sand, mud (silt and clay), and shell, according to a modified Wentworth scale of sediment grain size; Greene and others, 1999), habitat relief (flat, slope, or steep), and habitat complexity (low, medium, high). Biological observations included presence of various taxa, and biomass (low, medium, high). Other habitat variables that were included in our analysis of habitat-animal relationships include depth and current exposure. Depth was determined for each

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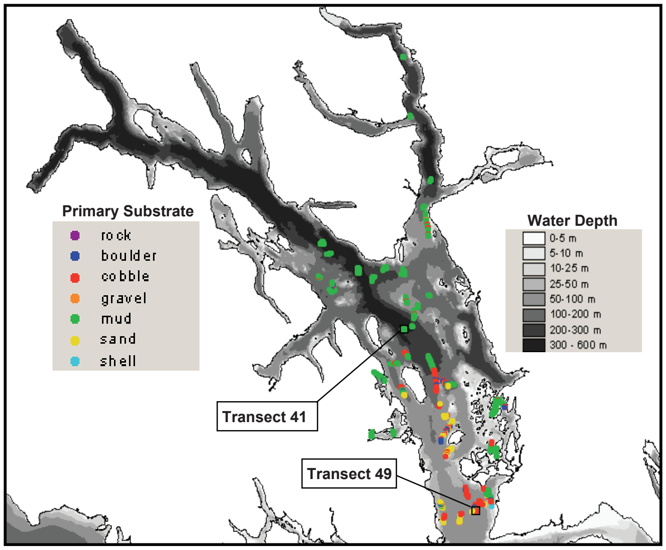

Figure 1. Transects covered by towed camera are illustrated by colored dots/lines. Color variation represents classification of seven primary substrate types as measured through real-time data logging. Note the predominance of harder substrates/larger grain sizes in the shallower lower Bay (e.g., cobble, gravel, boulders, sand), as opposed to mud in the deeper central Bay.

30 second observation, whereas current exposure levels were defined for each transect. Current exposure levels were defined categorically as: (1) minimal current in protected bays; (2) low current in deep areas greater than 200 m water depth; (3) medium current in areas 75 to 200 m water depth; and (4) high current in shallow areas less than 75 m of water.

To summarize the benthic community variation relative to underlying environmental gradients, we analyzed the video observation data by ordination of transects and species using detrended correspondence analysis (DCA). This multivariate technique arranges sites along multi-dimensional axes based on species composition data (Jonman and others, 1995). Ordination analyses arranges points so that those that are close together correspond to sites that are similar in species composition, and points that are far apart correspond to sites that are dissimilar in species composition. Ordination plots were made using the transect composition data obtained from the visual observations. Further, to determine what habitat variables explained the separation of transects and species within ordination space, we examined the correlation between individual habitat variables and each of the principle axes (axis 1 and 2).

Results

Video observations from the 52 transects demonstrated large scale differences in substrate types within different regions of Glacier Bay (fig. 1). The shallower lower Bay region exhibited primarily harder substrates and larger grain sizes, such as sand, cobble, gravel, and boulder. In the central Bay deeper waters, softer substrates with smaller grain size (i.e., mud) were predominant. These patterns correspond with differences in the mean depth that different substrate types were found in throughout the Bay. For example, for the primary substrate type, gravel and sand were in the shallowest depth (mean depth in meters ±1 standard error: 52.99±3.15, 63.24±1.07, respectively), while cobble, rock, and boulder substrates also were in relatively shallow areas (76.28±1.54, 77.36±4.67, 78.80±2.96, respectively), and mud and shell were predominant in deeper areas (123.67±2.12, 145.75±16.97, respectively). Mean depth associations of secondary substrates followed similar patterns as the primary substrate types.

Ordination analyses separated taxa into a gradient of community compositional change in multiple dimensions (fig. 2). Species that coexist in similar habitats are displayed closer together, while those species that are in differing areas and dissimilar habitat types are located far apart in ordination space. In figure 2 there is a general progression from taxa predominantly associated with mud on the left to taxa associated with larger grain sizes and harder substrates on the right. These taxa can be divided into three main groups. Those that were predominantly detected in mud substrate are grouped to the left of the graph and include gastropod, algae, flatfish, tanner crab, shrimp, sea pen, and other crustaceans (fig. 2). The process of bioturbation (indicated by tracks, mounds, and holes in the substrate) also was associated with mud substrates. The cluster of species towards the middle of the plot includes those taxa that preferred mud/cobble or cobble/mud substrate (fig. 2). This group is comprised of sea star, rockfish, sculpin, anemone, sea cucumber, worm, pollock/cod, basket star, and other fish. To the right of the ordination plot is a group of taxa including urchin, horse mussel, and scallop, which prefer the substrates of sand/cobble or cobble/sand (fig. 2). Further, soft coral and sponge are the only taxa that demonstrated a strong association with boulder substrates, with soft coral falling within the central part of the ordination space and sponge within the grouping on the right side (fig. 2)

To define what environmental gradients could be responsible for the ordination of transects and species in multidimensional space, we examined the correlation between the principle ordination axes (axis 1 and axis 2) with each of the substrate types (both primary and secondary) and each of our four habitat variables (current exposure, depth, habitat complexity, and habitat relief). For substrate type, the proportions of primary and secondary substrates of all sediment types were significantly correlated with axis 1, except for rock (both primary and secondary substrate) and shell secondary substrate. The presence of mud substrates and cobble substrates were the most strongly associated with the gradient in species composition. In contrast, none of the substrate type variables were significantly associated with axis 2 of the ordination space. All habitat variables were

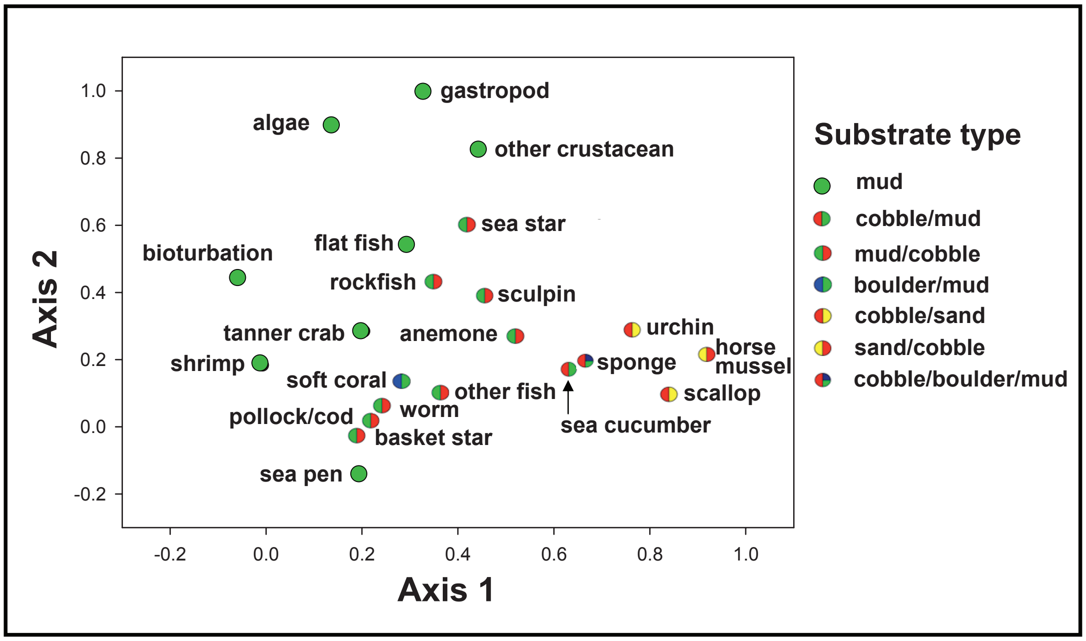

Figure 2. Taxa distribution within the ordination space. The location of a taxa point in the multidimensional space denotes the centroid of transects that contained the given taxa. Species that co-exist are close together in ordination space, while those that are in differing areas occupy different locations in ordination space. Color symbols represent the primary substrate type that the species were predominantly in. Multiple colors in the symbols indicate that the taxa most often was in the color on the left, but also was predominant in the color on the right. Bioturbation represents the presence of mounds, holes, and (or) tracks in the substrate. Note the general increase in grain size from mud on the left to larger grain sizes/harder substrates towards the right of the figure.

significantly correlated with at least one principle ordination axis, with current exposure and habitat complexity having the strongest influence on variation in axis 1, while habitat relief and current exposure were the only variables that were significantly correlated with axis 2. For axis one, significant correlations were found with (from strongest to weakest) current exposure, habitat complexity, depth, and habitat relief. For axis two, significant correlations were found for habitat relief and current exposure. From these statistical results we summarized the directional influence of each of these substrate and habitat variables on the position of transects and species within the ordination space (fig. 3).

Ordination plots of two contrasting substrates, mud and cobble, display the extreme contrast of location in ordination space between these two substrate types (fig. 4a). Also shown on the same principle axes are the distribution of two contrasting taxa, shrimp and scallop (fig. 4b). Comparison of the geological and biological figures illustrates that shrimp and mud are in the same ordination space, while scallops and cobble occupy similar positions in the ordination space, providing examples of strong biological-geological relation.

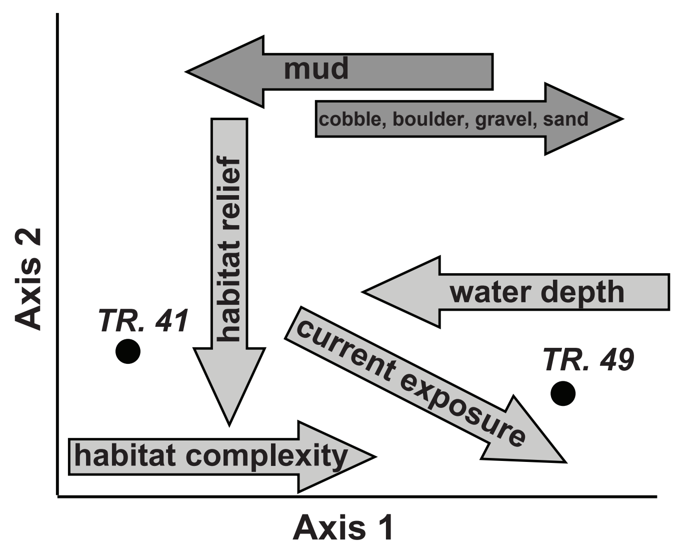

Figure 3. Simplified directional influence of substrate types and habitat variables on ordination axes. Arrows point from lower to higher values within the ordination space. For example, transect 49 (*TR. 49*) has higher current exposure, shallower depth, higher habitat relief, and higher habitat complexity and contains cobble, sand, and boulder substrates, whereas transect 41 (*TR. 41*) has lower current exposure, deeper depth, lower habitat relief, and lower habitat complexity and contains mud substrates. See figure 1 for transect locations.

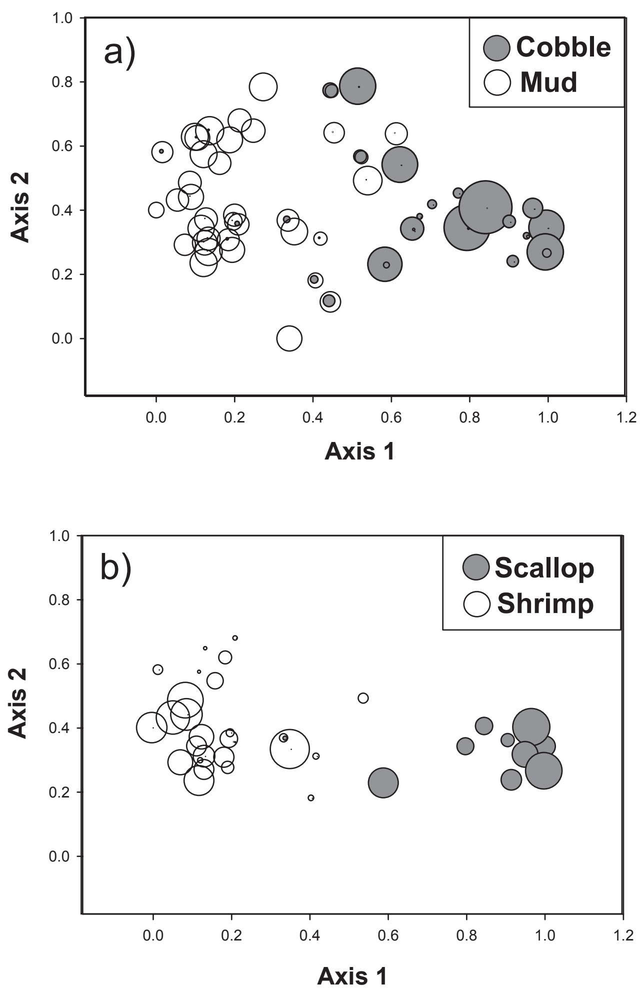

Figure 4. a) Distribution of two contrasting primary substrates, mud and cobble, within the ordination space. b) Distribution of two contrasting species, shrimp and scallops, within the ordination space. Each dot represents one transect's position within ordination space. The size of the circle indicates the relative proportion of observations in a transect with the specific primary substrate or taxa presence.

Discussion and Conclusions

A broad range of benthic habitats are found in Glacier Bay and a variety of benthic species assemblages are associated within these differing habitats. We defined these habitats on the basis of substrate type, water depth, habitat complexity, current exposure and habitat relief, all playing a major role in characterizing the benthic community. Of these habitat characteristics, substrate type and current exposure were most strongly associated with species distributions. These results support the notion that sediment grain size alone is not the primary determinant of benthic species distributions (Snelgrove and Butman, 1994, Kostylev and others, 2001).

The results of our analyses suggest that there are three general groups of benthic habitats based on geological and physical habitat characteristics and dominant benthic associations. These benthic habitat groups include: shallow water high current sand and cobble habitat; deep water mud habitat; and moderate depth cobble and mud habitat. The association of groups of taxa with these three habitat types is the result of the interaction of various physical and biological factors. One factor that could influence animal presence and abundance is the recruitment of organisms to the habitat, which would be dependent on currents influencing supply and delivery of individuals, as well as whether suitable substrate is available for settlement. Another important component of benthic habitat type could be food supply and the role of currents in delivering organic matter to the benthos. Of particular importance in Glacier Bay, due to high sedimentation rates and high currents, is the stability of the substrate and the amount of sediment re-suspension from the seafloor, which has the potential to bury organisms and clog feeding appendages. Substrate type can also influence an organism's ability to seek refuge from predation, whether the organism uses burial, hiding within cryptic or complex habitats, or escape techniques.

On a Bay-wide scale, there was a large contrast in benthic habitats and communities between the lower Bay shallow water high current environment and the deep water environment within the central Bay. The area east of Willoughby Island, where the depth changes dramatically (fig. 1), appears to be a transition zone between these two regions, characterized by large differences in sediment characteristics and benthic assemblages within a small area. Nevertheless, the larger scale contrasting regions were not continuous in their habitat and community composition and exhibited small-scale variations. Understanding the causes and consequences of the patchy nature of habitats and their benthic associations requires further study to understand the landscape patterns of the seafloor environment.

Management Implications

The habitat-community linkages presented here provide a first look at biological-geological interactions within Glacier Bay's seafloor environment. Continued efforts to interpret Glacier Bay's benthic substrates will allow for these relations to be extrapolated to a large proportion of the fjord's seafloor. These tools will be valuable to decision makers about critical habitats, marine reserve design, fishery management, and environmental change within Glacier Bay and other fjord estuarine systems.

Acknowledgments

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References Cited

Carlson, P.R., Hooge, P.N., Bruns, T.R., Evans, K.R., Gann, J.T., Hogg, D.J., and Taggart S.J., 1998, 1996 Cruise report: Physical characteristics of dungeness crab and halibut habitats in Glacier Bay, Alaska: U.S. Geological Survey Open-File Report 98-134.

Carlson, P.R., Hooge, P.N., Cochrane, G.R., Stevenson, A.J., Dartnell, P., and Stone. J.C., 2003, Multibeam bathymetry and selected perspective views of Glacier Bay, Alaska: U.S. Geological Survey Water-Resources Investigation Report 2003-4141, http://geopubs.wr.usgs.gov/open-file/of02-391/.

Cochrane, G.R., Carlson, P.R., Denny, J.F., Boyle, M.E., Taggart, S.J., and Hooge, P.N., 1998, Cruise report M/V Quillback cruise Q-1-97-Gb, physical characteristics of dungeness crab and halibut habitats in Glacier Bay, Alaska: U.S. Geological Survey Open-File Report 98-791, http://geopubs.wr.usgs.gov/open-file/of98-791/ofr98-791.html

Cochrane, G.R., Carlson, P.R., Denny, J.F., Boyle, M.E., and Hooge, P.N., 2000,. Cruise report R/V Tamnik cruise T-1-98-GB, physical characteristics of dungeness crab and halibut habitats in Whidbey Passage, Alaska: U.S. Geological Survey Open-File Report 00-032, http://geopubs.wr.usgs.gov/open-file/of00-032/

Greene, H.G., Yoklavich, M.M., Starr, R.M., O'Connell, V.M., Wakefield, W.W., Sullivan, D.E., McRea J.E., Jr., and Cailliet. G.M., 1999, A classification scheme for deep seafloor habitats: Oceanologica Acta v. 22, p. 663-678.

Hooge, P.N., Carlson, P.R., Mondragon, J., Etherington, L.L., and Cochrane. G.R., 2004, Seafloor habitat mapping and classification in Glacier Bay, Alaska, phase 1 and 2 1996–2004, Summary report to the National Park Service, Glacier Bay National Park, U.S, Geological Survey Alaska Science Center, Anchorage, Alaska, 182 p.

Jonman, R.H.G, terBraak, C.G.F., Vantongeren, O.F.R., 1995, Data analysis in community and landscape ecology: Cambridge, Cambridge University Press,

Kostylev, V.E., Todd, B.J., Fader, G.B.J., Courtney, R.C., Cameron, G.D.M., and Pickrill, R.A., 2001, Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs: Marine Ecology Progress Series, v. 219, p. 121-137.

Snelgrove, P.V.R., and Butman. C.A., 1994, Animal-sediment relationships revisited: Cause versus effect: Oceanography and Marine Biology Annual Review, v. 32, p. 111-177.

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