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Discovery of 100–160-Year-Old Iceberg Gouges and Their Relation to Halibut Habitat in Glacier Bay, Alaska

PAUL R. CARLSON[1]
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025, USA

PHILIP N. HOOGE[2]
U.S. Geological Survey, Glacier Bay Field Station, Glacier Bay, Alaska 99826, USA

GUY R. COCHRANE[3]
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025, USA

Abstract.—Side-scan sonar and multibeam imagery of Glacier Bay, Alaska, revealed complex iceberg gouge patterns at water depths to 135 m on the floor of Whidbey Passage and south to the bay entrance. These previously undiscovered gouges likely formed more than 100 years ago as the glacier retreated rapidly up Glacier Bay. Gouged areas free of fine sediment supported greater biodiversity of Pacific halibut *Hippoglossus stenolepis* than nearby sediment-filled gouges, probably due to increased habitat complexity. Small Pacific halibut were found more frequently in sediment-free gouged areas, presumably due to higher prey abundance. In contrast, large Pacific halibut were found more frequently on soft substrates such as sediment-filled gouges, where they could bury themselves and ambush prey.

Introduction

Glacier Bay, in southeastern Alaska (Figure 1), was formed by multiple glacial advances and retreats throughout much of the Pleistocene epoch (Goldthwait 1987). In 1794, members of Captain George Vancouver's crew reported the presence of a massive wall of ice blocking what is now the entrance to Glacier Bay (Vancouver 1798). Since then, the glacier has retreated about 100 km up the bay, exposing a magnificent fjord system (Figure 1). As the ice front retreated, it left remnants of end moraines which were dated at 1845, 1857, and 1860 by tree-ring cores (Figure 1; Cooper 1937; Lawrence 1958). The 1845 and 1857 tree-ring-dated moraines provided dates of the ice terminus position nearest to the study area for Whidbey Passage Pacific halibut *Hippoglossus stenolepis* (Figure 1). Since 1879, when John Muir first visited Glacier Bay, the ice front positions have been systematically and accurately mapped (Figure 1), first by boat by numerous scientists including Muir (1895) and Field (1964), by aerial photography (Post and LaChapelle 1971), and eventually by satellite imagery (Hall et al. 1995).

Following the ice front retreat, ecological successions of plants, soil, and terrestrial animals have been observed in this spectacular natural laboratory (Cooper 1923; Lawrence 1951; Dinneford 1990). In the past two decades, biologists have turned their attention to the marine realm (Sharman 1990; Bishop et al. 1995) and recently have joined forces with marine geologists to study the biological and physical characteristics of bayfloor habitats in Glacier Bay (Carlson et al. 1998b, 2002; Cochrane et al. 1998; Hooge and Carlson 2001). This paper reports the discovery of some large, complex gouges in a deepwater habitat of Pacific halibut within Whidbey Passage, located in the western-central part of the lower bay and even longer gouges in shallower water depths 20 km south of Whidbey Passage in the southernmost part of Glacier Bay (Figure 1). We discuss the probable age of the gouges, their physical characteristics, how they were formed, and how they have been modified, and we make some preliminary associations

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[1] Corresponding author: pcarlson@usgs.gov

[2] Present address: Denali National Park, Post Office Box 9, Denali, Alaska 99755, USA; e-mail: philip_hooge@nps.gov

[3] E-mail: gcochrane@usgs.gov

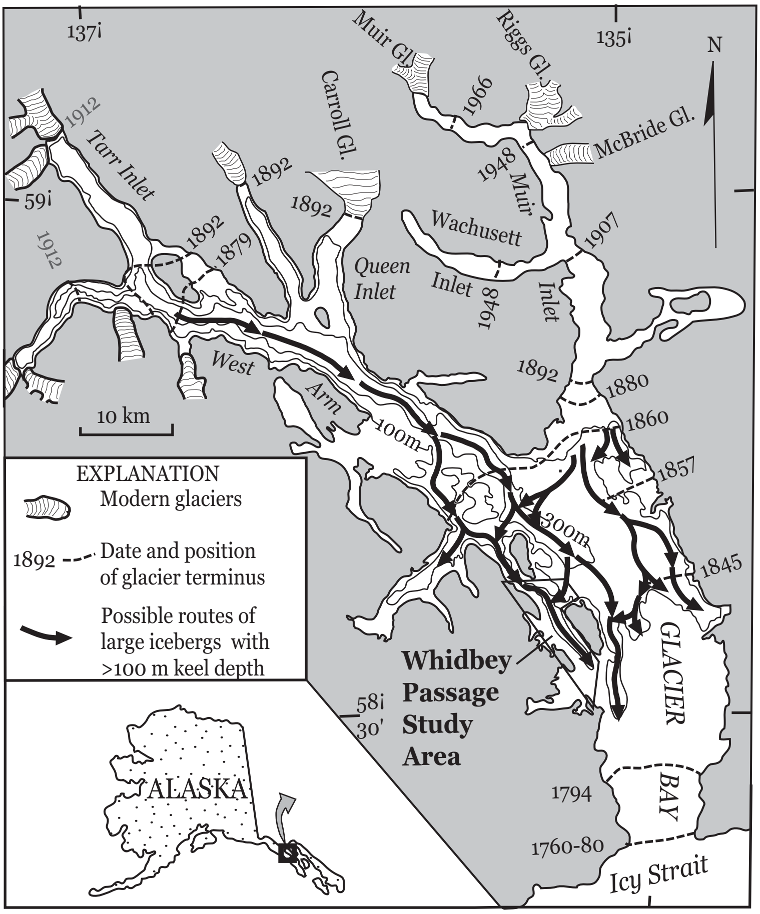

Figure 1. Location map of Alaska and Glacier Bay National Park showing terminus positions and dates during retreat of glacier. Polygon outlines Whidbey Passage study area. Bathymetry measured in meters. Arrows show possible routes of travel of large icebergs with deep keel depths (>100 m) that likely excavated complex and numerous gouge patterns in Whidbey Passage.

of size and age of Pacific halibut occurrences to the variations in benthic substrate.

Effects of Glacial Retreat on the Seafloor

The glacier that filled Glacier Bay began its retreat from the mouth of the bay about 200 years ago (Goldthwait 1963). The massive glacier retreated past the Whidbey Passage study area by about 160 years ago and reached the upper end of the main bay by 1860 (140 years ago), where the bay-filling glacier bifurcated (Figure 1). As the glacier retreated from Whidbey Passage to the head of the lower bay (~1845–1860), calving from the terminus of the massive glacier likely generated huge bergs. Some of the bergs, as they were channeled down Whidbey Passage, had deep enough keel depths to impact the bay floor and form gouges (Figure 2). Subsequently, the West Arm glacier retreated rapidly up the fjord (~2 km/year) until 1879, whereas, in Muir Arm, the glacier was pinned on a shallow entrance moraine from sometime after 1860 until at least 1892 (Seramur et al. 1997) and then began its rapid retreat (Figure 1). Massive icebergs from both West Arm and Muir Inlet may have contributed to the gouging, but the West Arm bergs had the most direct and deeper-water route (up to 400-m depth) into Whidbey Passage (Figure 1). In contrast, the deepest keeled iceberg to come from the Muir terminus soon after 1860 appears to be limited due to the 60-m depth of the moraine at the mouth of the inlet. Additional evidence providing support for abundant ice transiting from West Arm into the main bay

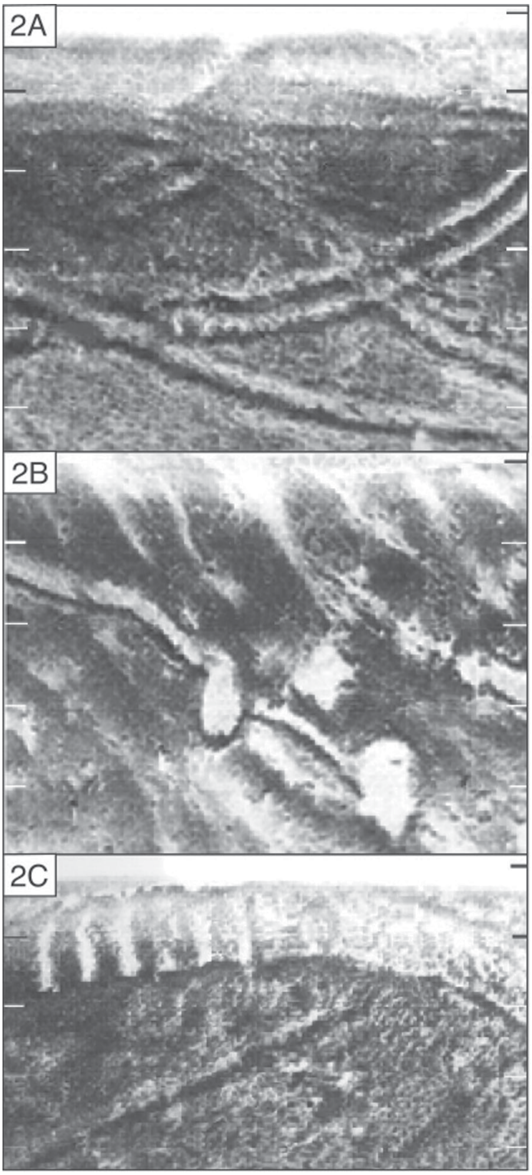

Figure 2. Examples of side-scan sonar images showing variety of iceberg gouges in study area. Scale lines are 25 m apart. Panel (2A) is a portside view of a side-scan sonar image of bottom sediment of Whidbey Passage showing the complex nature of iceberg gouges. Dark shading indicates high backscatter indicative of hard bottom consisting of coarse gravel to boulder-sized sediment. Light shading indicates low backscatter indicative of fine sediment (silt and clay). Note how soft sediment is beginning to obliterate outline of gouges near top of image. Panel (2B) is a side-scan image of iceberg wallow marks, and panel (2C) shows the chatter marks evident on a side-scan image in the northern part of Whidbey Passage.

was reported by Ovenshine (1967). He found many glacial erratics that had mineralogy typical of the West Arm geology (such as staurolite, chiastolite, and biotite-quartz schists) on the beaches of the lower part of the bay.

Water depths of 100 m throughout much of Whidbey Passage and as much as 50 m in the lower bay requires large icebergs, in order for their keels to plow the bottom. Considering that about 85% of a berg's mass is submerged, the total thickness of the berg must be about 120 m in order to scour the bottom in most of Whidbey Passage (Figure 1). Glacial scour, visible as glacial polish, and striations high on the rock walls of adjacent Willoughby Island (elevation 494 m above sea level; USGS 1990) plus 100 m to the floor of the passage, suggests ice thickness of near 600 m; thus, the calving of icebergs less than one-quarter of that thickness is quite reasonable to assume. Iceberg lowing or scouring has been reported from considerably deeper water in other areas in the world. Two examples are the northern Barents Sea, north of Norway and Russia, where Solheim et al. (1988) have imaged intense iceberg flow marks in water depths of 210–220 m, and Scoresby Sund, Greenland, where Dowdeswell et al. (1993) have collected acoustic records of iceberg scours most prevalent at depths of 300–400 m.

Field Methods and Observations

Pacific halibut have been studied in Glacier Bay for several years (Carlson et al. 1998a). In this Whidbey Passage study, Pacific halibut were caught and measured. More than 1,500 have been marked with wire tags. An additional 97 Pacific halibut had 3.5-kHz transmitters surgically implanted. These fish were tracked using a bow-mounted, dual hydrophone that was capable of tracking the fish at distances up to 2 km and at depths to 500 m. Searches for these sonically tagged fish were conducted every 2–3 months for 4 years to assess location and movement of the fish.

In 1998, we used a Klein towed side-scan sonar system (SSS) and an attached 3.5-kHz acoustic profiler to map habitats in Whidbey Passage for comparison to locations of Pacific halibut caught by longline in 1996–1997 (Carlson et al. 1998a). Navigation was by differential global positioning system (DGPS) that provides vessel location to an accuracy of about 1–5 m. Images revealed some spectacular gouges (Figure 2) on the 100-m-deep floor of Whidbey Passage, a *U*-shaped, bedrock-walled, 2.5-km-wide by 15-km-long valley (Figure 1). Some of the SSS images consist primarily of high backscatter (HBS). The HBS indicates a hard surface where little fine sediment filled the gouges and adjacent area. In some places, the SSS image consists mainly of low backscatter (LBS), thus, a softer surface with some faint gouge outlines that suggested the gouges were nearly filled with fine sediment.

Two video camera drift transects were occupied in the Whidbey Passage area at the end of the 1998 SSS cruise. One camera site was located where little fine sediment filled the gouges and the adjacent area. At the second site, the gouges were nearly filled in with fine sediment. We chose the camera sites based on the variation in backscatter on the SSS images. In the area of little fine sediment, there was HBS. At this video station, we observed numerous cobbles and boulders of varying sizes. As our boat drifted, we visually observed a seafloor relief of a couple meters, usually the result of large amounts of cobbles and boulders, in the form of a ridge, likely one wall of a gouge. At the second site, with LBS, the video captured imagery of billowing clouds of fine sediment being stirred up when the video sled contacted the passage floor. There were also noticeably fewer boulders and cobbles, probably because many had been covered by a blanket of fine sediment. Many of the boulders, particularly in the HBS area, were very large (up to several meters in diameter). In the area of HBS, many of the boulders and cobbles had sessile organisms, such as basket stars *Gorgonocephalus* sp., attached.

On subsequent cruises, in 1999 and 2000, we ground-truthed some of the SSS images using scuba dive transects. Scuba lines transected areas with and without surface expressions of ice gouging, which we will refer to as gouged and ungouged areas. Scuba dive transects were conducted at water depths between 25 and 60 m. On four dive transects across areas imaged on SSS as having little fine sediment (i.e., HBS), one of us (Hooge) observed parallel ridge and trough features with numerous pebbles, cobbles, and boulders and an estimated relief from trough to ridge of 1–3 m. These features were interpreted to be gouges. The central portions of the gouges were covered by sediment, and the troughs of two of the gouges were excavated to greater depth than the surrounding seafloor. Nearby gouge-filled areas were dominated by fine sediments with little or no pebbles or cobbles and only occasional boulders.

In June 2001, a hull-mounted RESON SeaBat 8111 multibeam echo sounding system (MB) was used to collect imagery throughout the main bay to supplement the side-scan coverage of benthic habitats and to determine the broader distribution of gouge features. On this cruise, navigation was also by DGPS. The MB imagery revealed additional seabed features, including bedrock knobs and even longer gouges up to 5 km in length, near the bay entrance. The preservation of these presumably older gouges in the lower part of the bay was even more startling in this shallower water region, previously thought to be an area dominated by sediment deposition.

Morphologic Features and Likely Modes of Formation

Iceberg gouges imaged by SSS and MB systems in Whidbey Passage and the lower part of the bay are quite variable in linear appearance, ranging from single and straight to crisscrossing to sinuous to simple curves and, in some cases, to double gouges (Figure 2a). The gouges most likely were created by deep-draft keels of large icebergs being transported through the bay waters by the tidal currents and perhaps slightly affected by wind acting upon the relatively small part of the iceberg projecting above the water. In several places, we discovered impact pits or wallows about 20 m in diameter, sometimes as a single feature, and once, as many as three pits along a single gouge (Figure 2b). These features form where the berg temporarily comes to rest on the bottom and then lifts off, perhaps due to a flood tide that causes the berg to rise. Similar features were caused by large pieces of sea ice coming to rest in nearshore waters of the Beaufort Sea (Reimnitz and Kempema 1982). Along one gouge track (~20 m wide) in Whidbey Passage, we observed chatter marks (Figure 2c). Apparently the keel was very close to the bay floor and in some rhythmic way bumped along, touching the bottom in a fairly regular manner over a distance of about 500 m. One gouge, several km long, was imaged by MB 20 km south of Whidbey Passage (Carlson et al. 2002). It had a pronounced zigzag pattern probably caused by several reversals of the tide during the time the berg was in intermittent contact with the bay-floor sediment.

The gouges ranged in width from 5 to 20 m and had an estimated relief of 1–2 m. The longest ice gouges that we have imaged on our side-scan sonar records were about 1 km long. However, in the southernmost part of the bay, several gouges imaged by multibeam were several km long (Figure 3), and one gouge measured 5 km long. For comparison, Syvitski et al. (1983) observed iceberg scour marks from a submersible in the Canadian Arctic that varied in width from 10 to 30 m and relief from 0.5 to 6 m.

Various seabed features, from large to small, are present in the passage. Gouges and attendant ridges consisting of boulders (up to 3 m in diameter) to sand-size material built up on sides of gouges (also called berms) are often present. In addition, grounded or drifting bergs in shallower water overturn and dump sediment on the bay floor, sometimes creating mounds of boulders, gravel, and finer sediment. Small boulders to cobbles (often with attached sessile organisms such as sea pens

Ptilosarcus gurneyi and basket stars), small gouges, and sand waves often were observed. The smallest features include pebbles, shells, small pits, and mounds, as well as burrow openings, mud volcanoes, piles of fecal debris, ripple marks, fecal coils, protrusions of infauna such as polychaete worm tubes, siphon expulsion holes, and trails from organisms such as green sea urchins *Strongylocentrotus droebachiensis*, Oregon Triton snails *Fusitriton oregonensis*, hermit crabs (family Paguridae), and Tanner crabs *Chionoecetes bairdi*.

Overlying these bottom features is sediment deposited from suspension in the water column. Suspended particulate matter, including inorganic particles of silt and clay, and organic matter, produced by diatoms and other microscopic plant and animal matter, is constantly raining through the water column in various concentrations. Fine-grained sediment sources include freshwater streams and glacial melt water issuing from glaciers and the surrounding shores and the fine sediment released by melting of the icebergs. Muddy sediment that issues from the glacier terminus as suspended sediment can be carried far down bay before it settles out. However, much of the settling occurs near the active glacial terminus where the concentration of suspended sediment can exceed 500 mg/L (Cowan and Powell 1990). In Whidbey Passage, some of the gouges are comparatively free of the very fine sediment, whereas others have been partially filled in by it. In other places, the suspended sediment has nearly to completely covered the gouges to the extent that only a faint outline of the gouge remains. In the lowermost bay (Figure 3), the ice gouges appear to be relatively free of fine sediment. This is likely due to the strong flushing action of the currents that attain speeds of up to 14.6 km/h (8 knots) through the narrows located about 12 km south of Whidbey Passage (Hooge et al. 2001).

Based on the above, seabed features of Whidbey Passage can be characterized by four different substrates based on the SSS imagery (Figure 4): (1) bedrock (high backscatter, irregular but unpatterned); (2) gouges nearly free of fine sediment (linear gouges that have mostly high backscatter; it is not likely that any gouge areas are completely free of fine-grained sediment deposited from the overflow plume that issued from the glacier terminus); (3) gouges partly filled with fine sediment (a mix of high and low backscatter indicating that the suspended sediment has been deposited in sufficient quantities to partially fill in the gouge areas); and (4) areas of low backscatter (the gouge outlines are nearly to completely obliterated by the blanket of fine suspended sediment).

Effects of Ice Gouging on Pacific Halibut Community

The Pacific halibut catch locations were superposed on an SSS-derived substrate map (Carlson et al., Geo-

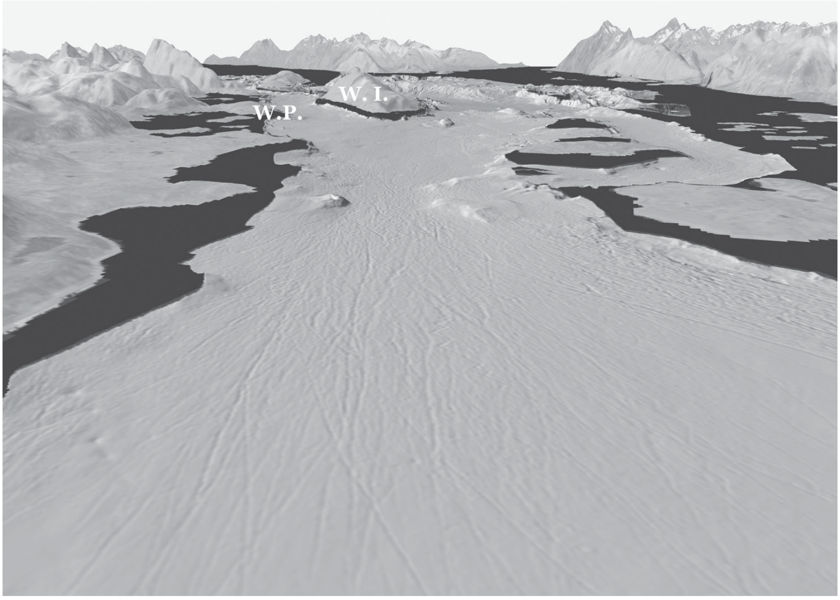

Figure 3. Multibeam image of lower Glacier Bay. Extensive iceberg gouges from just above Icy Strait to Willoughby Island (W.I.) through Whidbey Passage (W.P.) are visible beyond the narrows.

logical Society of America abstract, 1999). The effects of ice gouging on the benthic community were examined by both direct observations of the number of sessile species and by the distribution of Pacific halibut. The number of species observed in gouged areas by the drop camera and on scuba transects was significantly higher than in nearby gouge-filled or ungouged areas. Four scuba transects ($N = 4$) were combined with two video transects from the drop camera ($N = 2$). Presence and absence of all identifiable sessile fauna were recorded (Wilcoxon matched pairs signed rank test, $N = 6$, $Z = –2.201$, $P = 0.027$; Hooge, unpublished data). Differences in species numbers between the substrate types were large; a total of 55 species from 9 phyla

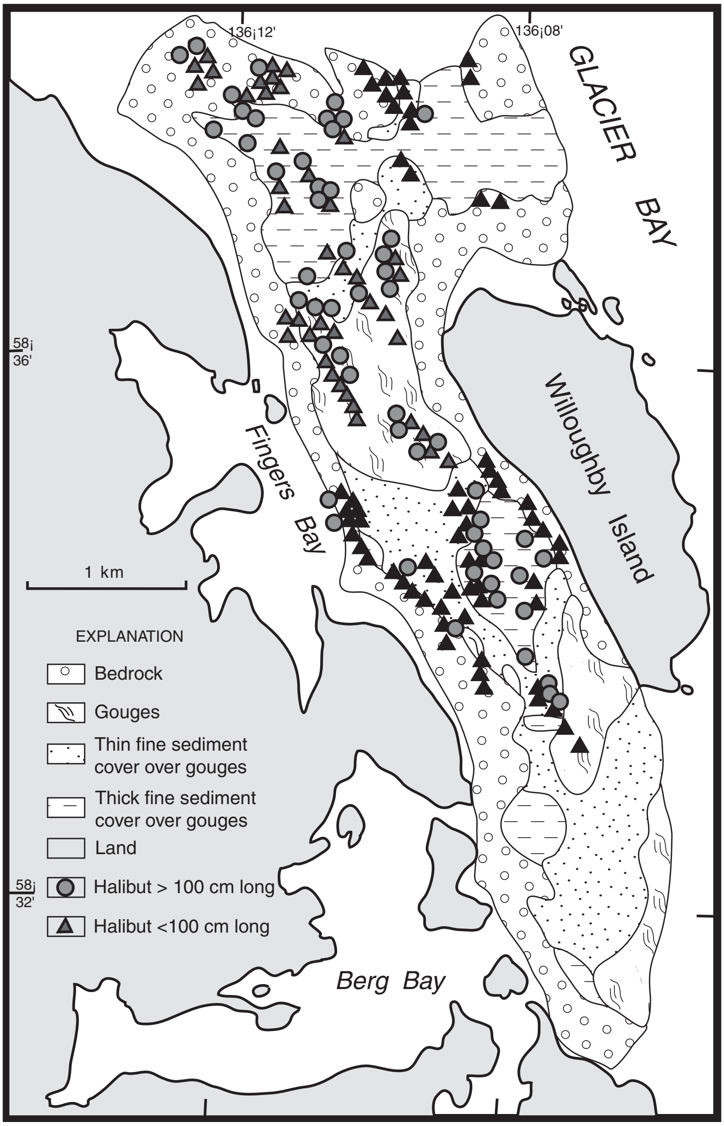

Figure 4. Map of bayfloor habitats based on SSS imagery in Whidbey Passage area and catch locations of large (>100 cm long) and small (<100 cm long) halibut. Types of bay floor habitat in Whidbey Passage are: bedrock; ice gouges essentially free of fine sediment cover; gouges partially filled with fine sediment; and gouges barely perceptible to completely covered by fine suspended sediment (clayey silt) deposited from meltwater runoff plumes.

were present in gouged areas, while 24 species from 4 phyla were found in gouge-filled areas. Gouged areas displayed a mix of species, including all 24 of those from the soft-bottomed areas, as well as additional species associated with harder substrates. The species composition observed in gouged areas was similar to that of other areas in Glacier Bay with a mix of both hard and soft substrates and similar vertical structure from rocks and boulders.

Pacific halibut locations were correlated with the four categories of physical characteristics of the floor of Whidbey Passage derived from the SSS imagery (Figure 4). Of 304 Pacific halibut captured on research longlines in Whidbey Passage, there was a highly significant tendency for smaller halibut (<100 cm fork length) to be caught both on bedrock and on substrate with detectable gouges. In contrast, large Pacific halibut were found more frequently on soft substrates. Small Pacific halibut (>30 cm and <100 cm fork length) were found more frequently on bedrock and exposed gouges (categories 1 and 2) than on soft-bottomed habitats (categories 3 and 4; Fisher's exact test, $P < 0.02$). Removing the high association between small Pacific halibut and bedrock habitats (category 1), there was still a significant tendency for small Pacific halibut (<100 cm fork length) to be captured on exposed gouge habitats (category 2) as compared to soft-bottomed habitats (categories 3 and 4; Fisher's exact test, $P < 0.05$). After adjusting the expected Pacific halibut numbers for the proportions of habitat types found within the area fished, there was a highly significant difference between expected and actual habitat use (chi-square = 14.32, df = 3, and $P < 0.003$). Areas with bedrock and unfilled gouges (categories 1 and 2) were selected more frequently than expected by small Pacific halibut, and soft-sediment areas (category 3 and 4) were selected more frequently than expected by large Pacific halibut (Figure 4). These trends correspond to ontogenetic diet differences that we have observed in Glacier Bay, where small Pacific halibut appear to forage by active predation and large Pacific halibut by sit-and-wait tactics (Chilton et al. 1995; Carlson et al. 1998a). We hypothesize that active foraging should be more productive in rocky habitats, where preferred or more abundant prey may be available due to both the increased sessile species diversity and to the enhanced physical structure of the environment. Likewise, ambush foraging should be more successful in soft-bottomed habitats where the larger Pacific halibut could bury themselves. Rocky iceberg-gouged zones, therefore, represent unrecognized productive benthic habitat.

These results demonstrate that extensive gouging observed in the seafloor of central and lower Glacier Bay is most likely a product of historical ice scour from large bergs calved during the catastrophic retreat of the glacier. These gouges, with little or no soft-sediment fill, are associated with significant differences in benthic habitat and community structure compared with sediment-filled gouges or areas lacking evidence of gouging. Whereas ice scour has detrimental effects on community structure on short time scales (Conlan et al.1998), over a longer time period, it may increase species diversity by providing a variety of interspersed habitat types.

Conclusions

(1) Ice gouges are plentiful on the floor of much of the lower portion of Glacier Bay, as observed first by side-scan sonar collected in Whidbey Passage and then by multibeam imagery of the lower bay.

(2) Gouges observed in Whidbey Passage require large icebergs with keel depths more than 100 m. These icebergs probably traveled through the area shortly after the glacier retreated (between 1845 and 1860) when the lower bay was being deglaciated and until about 1879 when the West Arm glacier bifurcated and began retreating into Johns Hopkins and Tarr inlets. West Arm was a major contributor of large icebergs, because the deeper waters of this arm as compared to Muir Inlet allowed deeper draft bergs to enter Whidbey Passage.

(3) Four types of seafloor geologic habitats were identified—(1) bedrock, (2) gouges with sparse fine–sediment cover; (3) gouges partly filled with fine sediment; and (4) gouges nearly to totally covered by the fine glacial flour (clayey silt).

(4) Pacific halibut caught in the study area were divided into two size-groups. Large halibut, more than 100 cm in length, preferred an unstructured seafloor of soft, fine sediment, where they likely burrowed into the substrate to wait for prey. Small Pacific halibut, less than 100 cm in length, that are much more active pursuing their prey, preferred the harder substrate of bedrock and coarse sediment prevalent in the unfilled ice-gouge complexes.

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References

Bishop, G. H., P. N. Hooge, and S. J. Taggart. 1995. Habitat correlates of Pacific halibut and other groundfish species in Glacier Bay National Park. Pages 215–220 *in* D. R. Engstom, editor. Proceedings of the third Glacier Bay science symposium, 1993. U.S. National Park Service, Anchorage, Alaska.

Carlson, P. R., T. R. Bruns, G. R. Cochrane, K. R. Evans, P. N. Hooge, and S. J. Taggart. 1998a. Marine geology of benthic biohabitats in Glacier Bay, Alaska: 10th western groundfish conference. National Marine Fisheries Service, Pacific Grove, California.

Carlson, P. R., T. R. Bruns, K. R. Evans, J. T. Gann, D. J., Hogg, S. J. Taggart, and P. N. Hooge. 1998b. Cruise report of M/V *QUILLBACK* in Glacier Bay, Alaska: physical characteristics of Dungeness crab and halibut habitats. U.S. Geological Survey Open-File Report 98-134.

Carlson, P. R., P. N. Hooge, G. R. Cochrane, A. J. Stevenson, P. Dartnell, and K. Lee. 2002. Multibeam bathymetry and selected perspective views of main part of Glacier Bay, Alaska. U.S. Geological Survey Open-File Report 02-391. Available: *http://geopubs.wr.usgs.gov/open-file/of02-391* (November 2003).

Chilton, L., P. N. Hooge, and S. J. Taggart. 1995. Prey preference of Pacific halibut (*Hippoglossus stenolepsis*) in Glacier Bay National Park. Pages 209–214 *in* D. R. Engstrom, editors Proceedings of the third Glacier Bay science symposium, 1993. U.S. National Park Service, Anchorage, Alaska.

Cochrane, G. R., P. R. Carlson, J. F. Denny, M. E. Boyle, S. J. Taggart, and P. N. Hooge. 1998. Cruise report M/V Quilback cruise Q-1-97-GB. Physical characteristics of Dungeness crab and halibut habitats in Glacier Bay, Alaska. USGS Open-File Report 98-791. Available: *http://geopubs.wr.usgs.gov/open-file/of98-791/ofr98-791.html* (November 2003).

Conlan, K. E., H. S. Lenihan, R. G. Kvitek, and J. S. Oliver. 1998. Ice scour disturbance to benthic communities in the Canadian High Arctic. Marine Ecology Progress Series 166: 1–16.

Cooper, W. S. 1923. The recent ecological history of Glacier Bay, Alaska. Ecology 4:223–246.

Cooper, W. S. 1937. The problem of Glacier Bay, Alaska: a study of glacier variations. The Geographical Review 27(1):37.

Cowan, E. A., and R. D. Powell. 1990. Suspended sediment transport and deposition of cyclically laminated sediment in a temperate glacial fjord. Pages 75–89 *in* J. A. Dowdeswell and J. D. Scourse, editors. Glacimarine environments: processes and sediments. The Geological Society, Special Publication 53, London.

Dinneford, B. 1990. Moose colonization of post-glacial sites in southeastern Alaska. Pages 83–85 *in* A. M. Milner and J. D. Wood, Jr., editors. Proceedings of the second Glacier Bay science symposium. U.S. National Park Service, Anchorage, Alaska.

Dowdeswell, J. A., H. Villinger, R. J. Wittington, and P. Marienfeld. 1993. Iceberg scouring in Scoresby Sund and on the East Greenland continental shelf. Marine Geology 111:37–53.

Field, W. O. 1964. Observations of glacier variations in Glacier Bay, southeastern Alaska, 1958 and 1961. American Geographical Society, New York.

Goldthwait, R. P. 1963. Dating the little ice age in Glacier Bay, Alaska. Pages 37–46 *in* International geological congress, 21st session Norden, part 27. International Geological Congress, Copenhagen.

Goldthwait, R. P. 1987. The glacial history of Glacier Bay park area. Pages 5–16 *in* P. J. Anderson, R. P. Goldthwait, and G. D. McKenzie, editors. Guidebook for INQUA Commission II field conference, June 1986. Byrd Polar Research Center, Miscelaneous Publication 236, Columbus, Ohio.

Grove, J. M. 1988. The little ice age. Cambridge University Press, Cambridge, UK.

Hall, D. K., C. S. Benson, and W. O. Field. 1995. Changes of glaciers in Glacier Bay, Alaska, using ground and satellite measurements. Physical Geography 16(1):27–41.

Hooge, P. N., and P. R. Carlson. 2001. Benthic mapping at Glacier Bay, Alaska: integrating physical structure and biohabitats. Available: *www.absc.usgs.gov/glba/benthic_mapping.htm* (November 2003).

Hooge, P. N., P. R. Carlson, and A. J. Stevenson. 2001. Mapping benthic habitat using geological and oceanographic tools—Glacier Bay, Alaska. U.S. Geological Survey, Information sheet, October 2001, Menlo Park. California.

Lawrence, D. B. 1951. Recent glacier history of Glacier Bay, Alaska, and development of vegetation on deglaciated terrain with special reference to the importance of alder in the succession. Yearbook of the American Philosophical Society 1951:175–178.

Lawrence, D. B. 1958. Glaciers and vegetation history in southeastern Alaska. American Scientist 46:89–122.

Muir, J. 1895. The discovery of Glacier Bay. Century Magazine. New Series 28:234–247.

Ovenshine, A. T., 1967. Provenance of recent glacial ice in lower Glacier Bay, southeastern Alaska. U.S. Geological Survey Professional Paper 575D:198–202.

Post, A., and E. R. LaChapelle. 1971. Glacier ice. University of Washington Press, Seattle.

Reimnitz, E., and E. W. Kempema. 1982. Dynamic ice-wallow relief of northern Alaska's nearshore. Journal of Sedimentary Petrology 52:451–461.

Seramur, K. C., R. D. Powell, P. R. Carlson, and E. C. Cowan. 1997. Muir Inlet morainal bank complex, Glacier Bay, southeast Alaska. Pages 92–93 *in* T. A. Davies, T. Bell, A. H. Cooper, H. Josehans, L. Polyak, A. Solheim, M. S. Stoker, and J. A. Stravers, editors. Glaciated continental margins: an atlas of acoustic images. Chapman and Hall, London.

Sharman, L. 1990. Marine intertidal community; development following glacial recession in Glacier Bay, Alaska. Pages 108–115 *in* A. M. Milner and J. D. Wood, Jr., editors. Proceedings of the second Glacier Bay science symposium. U.S. National Park Service, Anchorage, Alaska.

Solheim, A., J. D. Milliman, and A. Elverhoi. 1988. Sediment distribution and sea-floor morphology of Storbanken: implications for the glacial history of the northern Barents Sea. Canadian Journal of Earth Science 25:547–556.

Syvitski, J. P. M., G. B. Fader, H. W. Josenhans, B. MacLean, and D. J. W. Piper. 1983. Seabed investigation with Pisces IV. Geoscience Canada 10:59–68.

USGS (U.S. Geological Survey). 1990. Glacier Bay National Park and Preserve 1:250,000 scale topographic map. USGS, Gustavus, Alaska.

Vancouver, G. 1798. A voyage of discovery in the North Pacific Ocean and round the world in which the coast of Northwest America has been carefully and accurately surveyed…performed in the years 1790, 1791, 1792, 1793, 1794, and 1795, etc. G. G. and J. Robinson and J. Edwards, London. (Not seen; cited *in* Grove 1988.)