Documenting More than a Century of Glacier Bay Landscape Evolution with Historical Photography

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Abstract. Historical photographs, some made as early as the mid-l880s, are being used as a primary component of an integrated effort to characterize the rapid landscape evolution of the Glacier Bay area. Selected historical photographs are analyzed to document former landscape parameters including: glacier extent, thickness, and terminus position; distribution and type of vegetation; wetland location and extent; shoreline characteristics; and sediment characteristics and distribution. In the field, new 'repeat' photographs are made at each historical photograph location. The new photographs are analyzed for the same parameters as the originals and the results compared. In addition to the extracted information, the resulting pairs of photograph provide striking visual documentation of the dynamic landscape evolution occurring in the Glacier Bay area.

Introduction

Alaska's landscapes are among the most dynamic on Earth (Molnia, 2000). They change rapidly in response to active physical processes, such as glaciation, tectonics, seismicity, sedimentation, rapid post-glacial isostatic rebound, and eustatic and relative sea level change (Molnia, 2000). They also are very sensitive indicators of climate change. In Glacier Bay National Park, the most rapidly changing component of the landscape is the glaciers. Their changes effect and often drive all other components of Glacier Bay's physical and biological environment. A joint U.S. Geological Survey-National Park Service project is studying landscape evolution, glacier change, and vegetative succession in Glacier Bay National Park, specifically in the area that was covered by the complex, multi-tributary, Little-Ice-Age glacier system that filled Glacier Bay through the early 18th century. The primary technique being used is comparison of several hundred pairs of modern and historical photographs, each pair having been made at a unique location. The use of historical photography ('repeat photography') to document temporal change at Glacier Bay is not a new concept. As early as 1926, William O. Field was revisiting locations photographed by H.F. Reed in the early 1890s (Field and Brown, 2003). What is unique is the systematic approach being used to obtain maximum spatial and temporal photographic coverage for every fiord in Glacier Bay. Through analysis and interpretation of these photographic pairs, both quantitative and qualitative information is extracted to document the landscape evolution of the Glacier Bay area.

An archeological survey of the Glacier Bay region documented prehistoric habitation of the area dating to at least 9,000 yr B.P. (Ackerman, 1968). Although Tlingit oral histories contain narratives related to the glacier history of the region (Cruikshank, 2001), none extend back to this early Holocene period of habitation. However, several oral histories describe Xunaa Ka`awu (Huna Tlingit Clans) villages being destroyed by Glacier Bay's Little Ice Age glacier advance, resulting in the displacement of Xunaa Ka`awu People to areas outside the Bay (Dauenhauer and Dauenhauer, 1987). However, these histories do not provide an absolute chronology of Glacier Bay events, nor contain any visual documentation of glacier extent.

By the late 1870s, when Glacier Bay was seen by Lt. C.E.S. Wood (Wood, 1882) and explored by John Muir (Muir, 1895), glacier retreat had been underway for more than a century. By that time, the ice edge was more than 60 km from its "Little-Ice-Age" maximum position. There is no photographic documentation to provide insights into the glacier's maximum extent or to document how the first ~130 years of rapid retreat proceeded. However, less than a decade after Muir's 1879 visit, the first photographs of the Glacier Bay landscape were made. In subsequent years, mapping surveys, early scientific expeditions, geological and glaciological investigations, commercial photographers, and tourists brought cameras to Glacier Bay and began to photograph the landscape. By the end of the 19th century, hundreds of photographs had been made, many of which are still extant. With continuing early-20th century glacier retreat, more inlets began to become exposed, each with its own unique retreating ice tongue or tongues and its own history and timing of ice movement. Historical photographs have been acquired that document these early-20th century changes for every fiord in Glacier Bay.

Our goal is to document the dynamic landscape evolution of the Glacier Bay region. To do this, we: (1) locate and acquire historical photographs; (2) interpret these historical photographs to quantify and visualize the appearance of the landscape at the time they were made; (3) revisit locations from which historical photographs were made and rephotograph the same field of view; and (4) document

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changes at each location and provide written and visual products that depict the mechanics and magnitude of the changes that occurred during the intervening period.

Methods

More than 1,200 late-19th-century and early-20th-century, ground- and sea-surface-based photographs have been found that show landscape features in Glacier Bay National Park and Preserve. More than half of these historical photographs depict glacier termini and related features in the geographic area that was covered by Glacier Bay's Little-Ice-Age glacier system. Nearly all of these historical photographs lack important elements of metadata, most significantly, geographic coordinates of the photo-point from which a photograph was made, but also camera specifics, lens information, film type, exposure data, and date of collection. The earliest of these photographs may predate 1885. Sources of these photographs include national archives, museums, publications, libraries, internet sites, antique dealers, and individuals. Photographs acquired in an analog format (paper) are scanned and converted to a digital format. More than 600 of these photographs have been compiled into a dual mode (digital and analog) database. As possible, supporting metadata are developed for each historical image. Historical photographs included in this study were 'taken' by Alfred H. Brooks, Grove K. Gilbert, William O. Field, the International Boundary Commission, Frank LaRoche, John B. Mertie, John C. Reed, Harry F. Reid, Charles W. Wright, Juneau-based commercial photographers Lloyd Winter and E. Percy Pond, and others.

During the 2003 and 2004 field seasons, nearly 100 locations from which historical photographs had been made were identified and revisited. At about 20 locations, cairns built by the original or subsequent photographers, were found and reoccupied. At each site, date, time, latitude and longitude, elevation, and bearing to the center of each photographic target were determined with GPS receiver and compass. Using a paper copy of the appropriate historical photographs as a composition guide, a suite of digital images and color-film photographs were made of the same areas displayed in the historical photograph, often using multiple lenses of different focal length. Many of the historical photographs were made with rotating-lens panoramic or mapping cameras, typically with fields-of-view that exceed those of most modern 'normal' or even 'wide-angle' lenses. To duplicate these photographs, overlapping sequential photographs were made so that they could be digitally joined as panoramas. Fourteen photo-sites from which the first author photographed Glacier Bay glaciers prior to 1980 also were revisited.

In the laboratory, new images and photographs were compared with corresponding historical photographs to determine differences, and to better understand rates, timing, and mechanics of landscape change and evolution. Particular emphasis was placed on understanding the response of specific glaciers to changing climate and environment.

Results

Comparisons of historical and modern photo-pairs provide great insight into the post-Little-Ice-Age evolution of the Glacier Bay landscape. With respect to glaciers, derived information was useful in documenting: (1) the post-late-1880s timing and magnitude of glacier retreat in East Arm, a trend continuing to the present (figs. 1 and 2); (2) a similar continuous retreat of the glaciers in the Geikie and Hugh Miller Inlet areas of West Arm; (3) early-20th century retreat and subsequent variability of Reid and Lamplugh Glaciers (fig. 3); (4) early-to-late-20th century readvances of Johns Hopkins and Grand Pacific Glaciers; (5) continued late-20th century and early-21st century advance of Johns Hopkins Glacier; (6) late-20th century and early-21st century retreat and thinning of Grand Pacific Glacier; (7) decadal-scale fluctuations of smaller glaciers, such as hanging glaciers in Johns Hopkins Inlet, including Hoonah and Toyatte Glaciers; and (8) transitions from tidewater termini to land-based, stagnant or retreating, debris-covered, glacier termini in a number of locations including Muir, Carroll, and Rendu Glaciers.

Elsewhere in Glacier Bay, the comparisons of historical and modern photo-pairs document: (1) the filling of upper Queen Inlet with more than 100 m of sediment (fig. 4); (2) the rapid erosion of fiord-wall moraines following ice retreat; and (3) the development of outwash and talus features at many locations. Also universally evident is the rapid influx of vegetation and the transformation and progression from essentially bare bedrock to forest.

Annotated photo-pairs are being posted on publicly-accessible websites [such as: The U.S. Geological Survey Photographic Library (http:// libraryphoto.cr.usgs.gov); a National Park Service website depicting animated pairs of historical and modern photographs (http://www2.nature.nps.gov/geology/GLBA/glaciers.htm), and The National Snow and Ice Data Center (NSIDC) Long-Term Change Photographic Pairs Special Collection (http://nsidc.org/data/glacier_photo/special_collection.html)], and provided to National Park Service managers and interpreters. Beginning in 2004, similar studies have been conducted in Kenai Fjords and Denali National Parks.

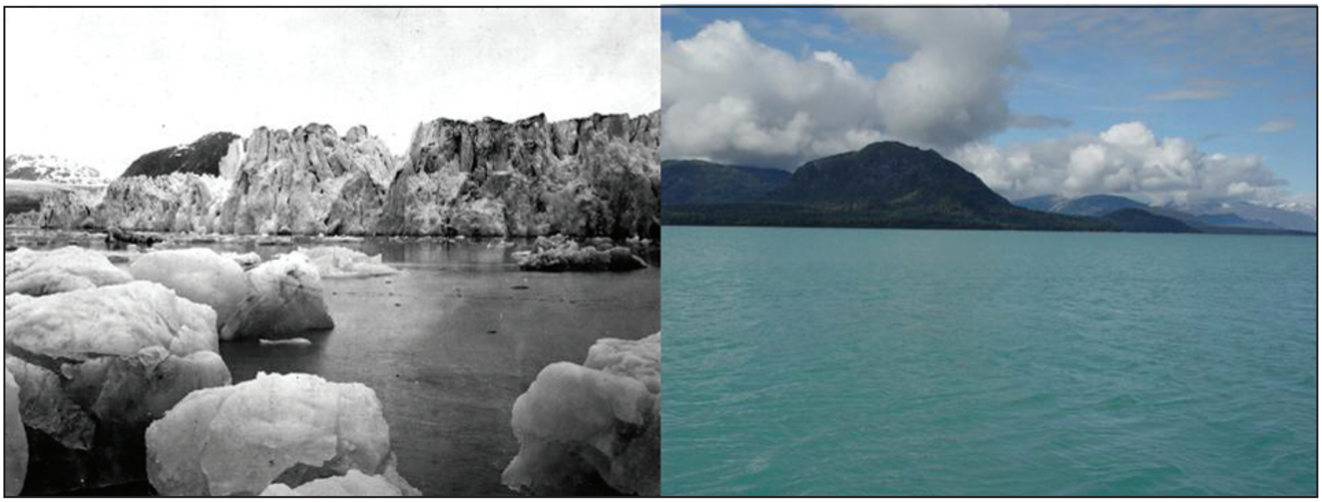

Figure 1. A pair of north-looking photographs, taken from the same shoreline location near Muir Point that show changes that have occurred between June 1899 (left) and September 2003 (right). The photograph on the left shows the calving terminus of Muir Glacier extending almost to the photo point and the absence of any identifiable vegetation (USGS Photo Library Photograph-Gilbert 276). The photograph on the right shows the total disappearance of Muir Glacier. The glacier at the extreme right is Riggs Glacier, 35 km to the north. Note the extensive vegetation (Photograph by B.F. Molnia, U.S. Geological Survey.)

Figure 2. A pair of northeast-looking photographs, both taken from Field's Station 4 on White Thunder Ridge, that show changes that have occurred between August 13, 1941 (left) and August 31, 2004 (right). The photograph on the left shows Muir and Riggs Glaciers filling Muir Inlet and extended south, beyond the edge of the photograph. Note the absence of any vegetation (Field 41-64). The photograph on the right shows the total disappearance of Muir Glacier and the significant thinning and retreat of Riggs Glacier. Note the dense growth of alder and the correlation between Muir Glacier's 1941 thickness and the 2004 trimline. (Photograph by B.F. Molnia, U.S. Geological Survey.)

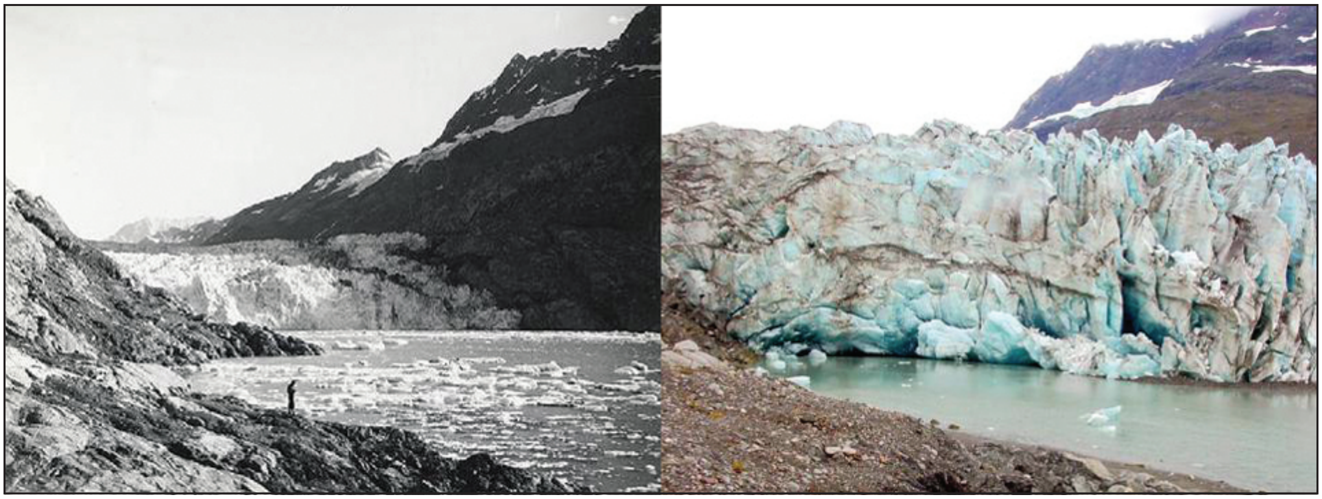

Figure 3. A pair of southwest-looking photographs, both taken from the same location adjacent to Lamplugh Glacier showing the changes that have occurred at the lower end of Lamplugh's inlet between August 1941 (left) and September 8, 2003 (right). The photograph on the left shows the calving terminus of Lamplugh Glacier extending to within a kilometer of the photo point (Field 430-41). No vegetation is visible. The photograph on the right shows that the terminus of Lamplugh Glacier is ~0.8 km forward of its 1941 position. However, till on the closest bedrock ridge indicates that the glacier had advanced beyond the photo point at some time during the interval between photographs, probably in the late-1960s. Note the developing vegetation. (Photograph by B.F. Molnia, U.S. Geological Survey.)

Figure 4. A pair of northwest-looking photographs, both taken from the same location, several hundred meters up an steep alluvial fan located in a side valley on the east side of Queen Inlet showing the changes that have occurred to Carroll Glacier and upper Queen Inlet during the 98 years between August 1906 (left) and June 21, 2004 (right). The photograph on the left shows the calving terminus of Carroll Glacier sitting at the head of Queen Inlet (USGS Photo Library Photograph-Wright 335). No vegetation is visible. The photograph on the right shows that the terminus of Carroll Glacier has changed to a stagnant, debris-covered glacier that has significantly thinned and retreated from its 1906 position. The head of Queen Inlet has been filled by sediment. An examination of early 20th century nautical charts suggests that the sediment fill exceeds 125 m. Note the developing vegetation on the sediment fill. (Photograph by B.F. Molnia, U.S. Geological Survey.).

Discussion

Glaciers are one of the most significant and dynamic resources of Glacier Bay National Park. Of all the Park's resources, they are the one most often cited as the reason that tourists choose to visit Glacier Bay as opposed to other destinations in Alaska. Therefore, understanding their histories is a critical part of managing Park resources. As shown above, changes to Glacier Bay's glaciers have driven the post-Little-Ice-Age evolution of the Glacier Bay landscape. Their changes have directly or indirectly shaped the physical landscape, the local hydrologic regime, and the diversity and spatial distribution of biologic communities in and around the Bay. Understanding the magnitude and timing of past change in Glacier Bay glaciers and the resulting landscape evolution provides critical insight into how these glacier-driven changes may continue in the future.

This study will continue to collect 'new' historical photographs, continue to identify and revisit historical-photo sites, continue to 'repeat' images, and continue to systematically analyze photo pairs and extract information documenting the landscape evolution of the Glacier Bay area until as complete an understanding as is possible has been generated documenting the complex post-Little-Ice-Age history of Glacier Bay.

Conclusions

Glaciers are one of the most important resources within Glacier Bay National Park. Their dynamic post-Little-Ice-Age change and the catalytic effect that they have on landscape evolution are one of the rarest extreme natural events ever documented in a National Park. The 1916 Organic Act which established the NPS calls for the promotion and regulation and conservation of the scenery, natural objects, and wildlife within the Parks, as well as the unimpaired preservation of these resources for the enjoyment of future generations. The dynamic character of glaciers makes them impossible to conserve and preserve. However, what can be done is the development of a clear understanding of the natural variability of this unique resource, coupled with a promotion of the significance of glaciers as the driving force that has shaped Glacier Bay National Park.

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Evening light highlights termination dust covering a peak overlooking a glacier. (Photograph by Bill Eichenlaub, National Park Service.)