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Distribution and Abundance of Mountain Goats in Glacier Bay National Park and Preserve

Natural Resource Report NPS/GLBA/NRR—2015/1094

ON THIS PAGE
Nanny mountain goat nursing her kid on the shoreline of Muir Inlet, Glacier Bay.
Photograph courtesy of T. Lewis/National Park Service

ON THE COVER
Mountain goat in Glacier Bay National Park.
Photograph courtesy of the National Park Service

Distribution and Abundance of Mountain Goats in Glacier Bay National Park and Preserve

Natural Resource Report NPS/GLBA/NRR—2015/1094

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Photo 1. Nanny and kid mountain goats forage on Gloomy Knob, Glacier Bay, Alaska. Photograph courtesy of the National Park Service.

Mountain goats (*Oreamnos americanus*) represent an important wildlife resource providing wildlife viewing opportunities within Glacier Bay National Park and Preserve (GLBA) and sport hunting opportunities in portions of the preserve and lands surrounding the park and preserve. This project was collaborative effort between state and federal agencies to: 1) quantify the summer distribution and abundance of mountain goats in the park; 2) compare current mountain goat distribution and abundance to historical data; 3) examine possible correlations between mountain goat distribution and bedrock geology; 4) and provide baseline data and sampling recommendations for developing long-term monitoring protocols and future research priorities.

Mountain goat aerial surveys were conducted for approximately 30 hours during 4 days from July 25 - August 4, 2012. A total of 841 mountain goats were observed (number of groups = 201, percent kids = 18.1). The distribution of mountain goats in the survey area was not uniform with abundance of mountain goats was highest in the area south of Adams inlet (Excursion/Adams), Tidal Inlet/Tlingit Point (Upper Bay) and the Outer Coast-South and lowest in the upper East and West Arms of Glacier Bay and the Dundas River watershed. Fewer mountain goats (-31.8%) and a lower proportion of kids were observed on the east and north sides of Glacier Bay in 2012 (454) compared to 1985 (665). However, more mountain goats were observed in multiple areas on the west side of northern Glacier Bay in 2012 (56) than 1985 (16), suggesting possible range expansion in this area. Mountain goats in Glacier Bay National Park in 2012 were observed on sedimentary bedrock almost twice as much as on magmatic rock and only 1/3 as much as would be expected if distribution were uniform across the study area.

We offer the following recommendations for future work: 1) Develop a long-term monitoring sampling design, 2) Estimate mountain goat population size using sightability models, 3)Assess the population structure of mountain goats in Glacier Bay, and 4) Identify focal areas to conduct ground and vessel surveys.

Acknowledgments

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Introduction

Glacier Bay National Park and Preserve (GLBA) lies within one of the largest protected wilderness areas in the world. Terrestrial wildlife within GLBA is managed by the National Park Service (NPS) in accordance to the Organic Act of 1916. Wildlife on the adjacent private and state land is under the management jurisdiction of Alaska Department of Fish and Game (ADF&G). Wildlife within National Preserve and National Forest land is managed by both state and federal agencies.

Mountain goats (*Oreamnos americanus*) represent an important wildlife resource within GLBA and are highly valued culturally by the Huna Tlingit (Rofkar 2014). Mountain goats provide visitors with wildlife viewing opportunities within GLBA, and provide sport hunting opportunities in portions of the preserve and lands surrounding the park. Individuals of these highly mobile species may seasonally migrate across NPS, United States Forest Service (USFS), and state boundaries and jurisdictions. Such trans-boundary migrations are strongly suspected for mountain goats in the Alsek River corridor as well as Chilkat Mountain areas on the east side of the park. Migrations between harvested and protected areas necessitate interagency collaboration to foster effective regional management strategies (Hansen and Defries 2007). This project was a collaborative effort between state and federal agencies to obtain information on ungulates in the region for mutually beneficial monitoring and management purposes.

Ungulates can play key roles in the function of ecosystems. Specifically, northern ungulates affect ecosystems directly and indirectly via bottom-up and top-down pathways. Species such as mountain goats can alter plant community productivity and biodiversity directly through selective herbivory (Cazares and Trappe 1994, Houston et al. 1994).

In Glacier Bay, plant community dynamics have been strongly influenced by glacial processes (Chapin et al. 1994). A key justification for the establishment of Glacier Bay National Park was to allow for the scientific documentation of how glacial processes affect terrestrial ecosystems. Understanding how glaciation induced changes in plant communities have influenced patterns in distribution, composition and abundance of large mammalian herbivores, such as mountain goats, is important and is especially relevant because mountain goats are habitat specialists and their distribution is expected to closely track key post-glacial habitats such as early successional and alpine types. In addition, northern ungulates influence carnivore populations that rely on such species as a key food resource (Fox and Streveler 1986, Mieklejohn 1994, Fuller et al. 2003, Lafferty et al. 2014). While patterns of plant succession in GLBA have been well studied, distributions of large mammal species and their relationships to changing habitats have so far been minimally documented.

Ungulates are listed as a National Park Service Southeast Alaska Inventory and Monitoring vital sign for Glacier Bay National Park and Preserve, signifying a need and interest in long-term monitoring of these populations. Justifications for the selection of ungulates as vital signs include their ability to transform vegetation and landscapes, their charismatic character, and their harvest on adjoining lands (Sheinberg 2007). Until recently, there was little known about the distribution and abundance of ungulates in the park. Existing data on ungulates was limited to a single comprehensive mountain goat survey within Glacier Bay conducted over 25 years ago (Adams and Vequist 1986) and yearly mountain goat surveys of the Yakutat forelands including a small portion of the preserve and the Alsek River corridor conducted by the US Forest Service and ADF&G. Consequently, collection of baseline distribution and abundance data was needed to evaluate the current status of these species in GLBA and to provide important information for the design of potential future long-term monitoring efforts as well as research studies. Efforts to obtain baseline information on mountain goats is timely given recent concerns about how predicted changes in climate will affect ecosystems. Mountain goat populations are sensitive to variation in climate and habitat conditions (White et al. 2011a), a particular concern given that the landscape in Glacier Bay is changing quickly as glaciers continue to retreat and climate is predicted to warm. Existing data suggest that mountain goat survival is negatively affected by severe winter weather (White et al. 2011a) but the role of summer weather is more complex. Recent analyses, for example, indicate that growth and survival of juvenile mountain ungulates is favorably influenced by prolonged spring vegetation growth (green-up) due to the high nutritional quality of young forage (Petterolli et al. 2007). Over-winter survival of adult mountain goats in coastal Alaska is substantially higher following cool, as compared to warm, summers (White et al. 2011a). Presumably, this occurs because green-up is protracted resulting in higher nutritional quality of forage on summer range during cooler summers resulting in high rates of over-summer fat deposition, energy stores that are critical for over-winter survival. Overall, climate is likely to play a key role in regulating the abundance of mountain goat populations in Glacier Bay. In addition, given the substantial local variation in climate throughout Glacier Bay (Lawson and Finnegan 2009), distribution and abundance of mountain goats may be linked to local climate conditions.

Baseline data on the spatial distribution and abundance of ungulates is also important for NPS and ADF&G to manage current and potential future harvest on NPS and surrounding lands, including the long-standing request to reinitiate Tlingit harvest of mountain goats in traditional areas for cultural purposes. In addition, areas of concentrations of animals and/or critical habitat will be important to inform future Resource Stewardship and Wilderness/Backcountry Management Plans. This project represents a collaborative effort between NPS and ADF&G to obtain such information.

Project Objectives

The overarching goal of this this project was to gather baseline data that could be used to assess spatial distribution and abundance of mountain goats in GLBA and surrounding areas. Project objectives were implemented via collaborative agreement (Task Agreement # P12AC10221) between GLBA Resource Management and ADFG Division of Wildlife Conservation. The primary objectives of the project are to: 1) Quantify the summer (July – August) distribution, minimum number, and composition of mountain goats on lands surrounding Glacier Bay proper, Icy Strait, the southern outer coast, and Deception Hills to ultimately apply sightability models developed in Southeast Alaska to obtain a population estimate for surveyed areas, 2) Compare current mountain goat distribution to historical data, 3) Examine possible correlations between mountain goat distribution and bedrock geology, and 4) Provide baseline data and sampling recommendations for developing long-term monitoring protocols and future research priorities.

Methods

Mountain Goat Summer Distribution and Abundance

The survey area (~3336 km^2) for mountain goats included all non-glaciated alpine habitats surrounding Glacier Bay, Icy Strait, and the southern outer coast of Glacier Bay National Park (Figure 1) was surveyed July-August 2012. Because mountain goats are white, detection of mountain goats from airplanes is much lower when there is snow cover on the ground (White et al. 2011b). Therefore, mountain goats are extremely hard to detect in their winter range due to forest and snow cover, so aerial surveys are optimally conducted from July-September after goats return to the alpine and after the majority of alpine snow has melted to increase sightability. Aerial surveys were flown using a Piper PA-18 "supercub" fixed-wing aircraft following geographic contours between 2500-4000 feet elevation at ca. 60-70 knots. This elevation allowed for visibility of the alpine zone of entire mountain faces to maximize detectability. Studies using VHF and GPS collars on mountain goats in other areas in southeastern Alaska have shown that all animals remain in the alpine zone from approximately 2500-4000 feet elevation for the duration of the summer from June 1 to late October (White et al. 2012). An experienced observers (K. White or N. Barten, ADFG, Douglas, AK) counted and classified all mountain goats as either adults (includes adults and subadults) or kids. It is not possible to reliably differentiate adult male and female mountain goats during aerial surveys. A track line of the survey route was collected at 5 second intervals and groups of mountain goats were marked using a handheld GPS (Garmin Map 76CSX). The entire survey area was divided up into specific areas based on topography (i.e., mountains, valleys, ridge lines, etc). For each track points and mountain goat location, the specific area in which the point was collected was recorded to aid with data analysis and ensure survey repeatability (Table 1). Polygons were of each specific area as well as broad areas (compising of multiple specific areas) were created (Figure 1). Covariates that are known to influence the detection of mountain goats were also collected and included: weather conditions, terrain and habitat features, snow cover, group size and animal behavior.

Aerial surveys were also conducted around Deception Hills south of the Alsek River in October 2012 to assess the distribution of mountain goats in relation to a proposed Coast Guard Rescue 21 communication station that was slated to be built in the summer of 2013 (U.S. Coast Guard and National Park Service 2010). An aerial survey of the Deception Hills areas was conducted by USFS out of Yakutat to maximize efficiency. These surveys were flown with a Cessna 185 aircraft; however, survey methods were generally consistent.

Data Processing of Historical Aerial Survey Data

To compare results from the 2012 surveys to historic surveys, we digitized mountain goat locations from 1985 surveys (Adams and Vequist 1986) from points marked on 1:63,360 USGS topographic maps into ArcGIS (ESRI, Redlands, CA, USA). Abundance (i.e. minimum count) and distribution of mountain goats were compared spatially between 1985 and 2012 only in areas where surveys overlapped because the 1985 survey was not as spatially comprehensive at the 2012 effort.

Bedrock Geology Correlation Analysis

To gain a preliminary understanding of broad-scale mountain goat distribution patterns, we examined relationships between mountain goat locations (based on the 2012 survey) and bedrock substrate. Specifically, we used ArcGIS to code each mountain goat location and GPS track point along the survey to the corresponding bedrock geology type (sedimentary, metamorphic, magmatic, and ice; Brew 2008). We then employed a "used" vs. "availability" design to calculate selection ratios (i.e. the proportion of mountain goats observed on each bedrock type divided by the proportion of GPS points collected on the track log on each bedrock type) to gain insight into the extent to which certain geologic substrates were used more than expected. In this analysis, we treated mountain goat locations as "used" points and the track log (i.e., GPS locations collected every 5 seconds during the survey) as "available" points.

Results and Discussion

Current distribution and relative abundance of mountain goats

Mountain goat aerial surveys were conducted for approximately 30 hours during 4 days from July 25 - August 4, 2012. The area surveyed encompassed the entirety of Glacier Bay proper, as well as western Excursion Inlet, Dundas/Taylor Bay and the outside coast between Cape Spencer and Lituya Bay (Figure 1, Table 1). A total of 841 mountain goats were observed (number of groups = 201, percent kids = 18.1). The distribution of mountain goats in the survey area was not uniform (Figure 2). Relative abundance of mountain goats was highest in the area south of Adams inlet (Excursion/Adams), Tidal Inlet/Tlingit Point (Upper Bay) and the Outer Coast-South. The upper East and West Arms of Glacier Bay and the Dundas River watershed had particularly low densities of mountain goats. Notably, mountain goats were not observed between Johns Hopkins Inlet and Geikie Inlet on the west side of Glacier Bay. However, because only a single survey was flown in each area it is not possible to definitively conclude that mountain goats are truly absent from such areas.

On Oct. 1, 2012 biologists counted 8 groups of mountain goats totaling 33 (25 adults, 11 kids; proportion kids = 0.33) in Deception Hills which is the only available mountain goat habitat in Glacier Bay National Preserve (USFS 2012; Figure 2). One group of 7 adults and 3 kids was in the vicinity of the future Coast Gurad Rescue 21 facility. In July of 1984, biologists had counted 10 groups totaling 58 mountain goats (47 adults, 11 kids) in the Deception Hills area (Adams and Vequist 1986). Construction of the Rescue 21 station began in the summer 2014 and no mountain goats were reported in the vicinity of the station.

Sighting probabilities of mountain goats observed during aerial surveys vary relative to weather, terrain, group characteristics and other factors (Rice et al. 2009, White and Pendleton 2011). Consequently, the data reported above represent the minimum number of mountain goats in the survey area. As a frame of reference, mark-resight surveys conducted in other areas of southeastern Alaska indicate that survey-level sighting probabilities average 0.61, but can vary considerably between surveys (White and Pendleton 2011). In the future, data collected during the 2012 Glacier Bay mountain goat survey effort will be analyzed to account for survey- and group-level sighting probabilities via sightability models currently being developed for Southeast Alaska (White and Pendleton 2011). Such efforts will enable estimation of the actual number of mountain goats in the surveyed area of Glacier Bay. These results will be summarized in a separate report and will represent an ADFG-DWC furnished in–kind product beyond the scope of the existing cooperative agreement.

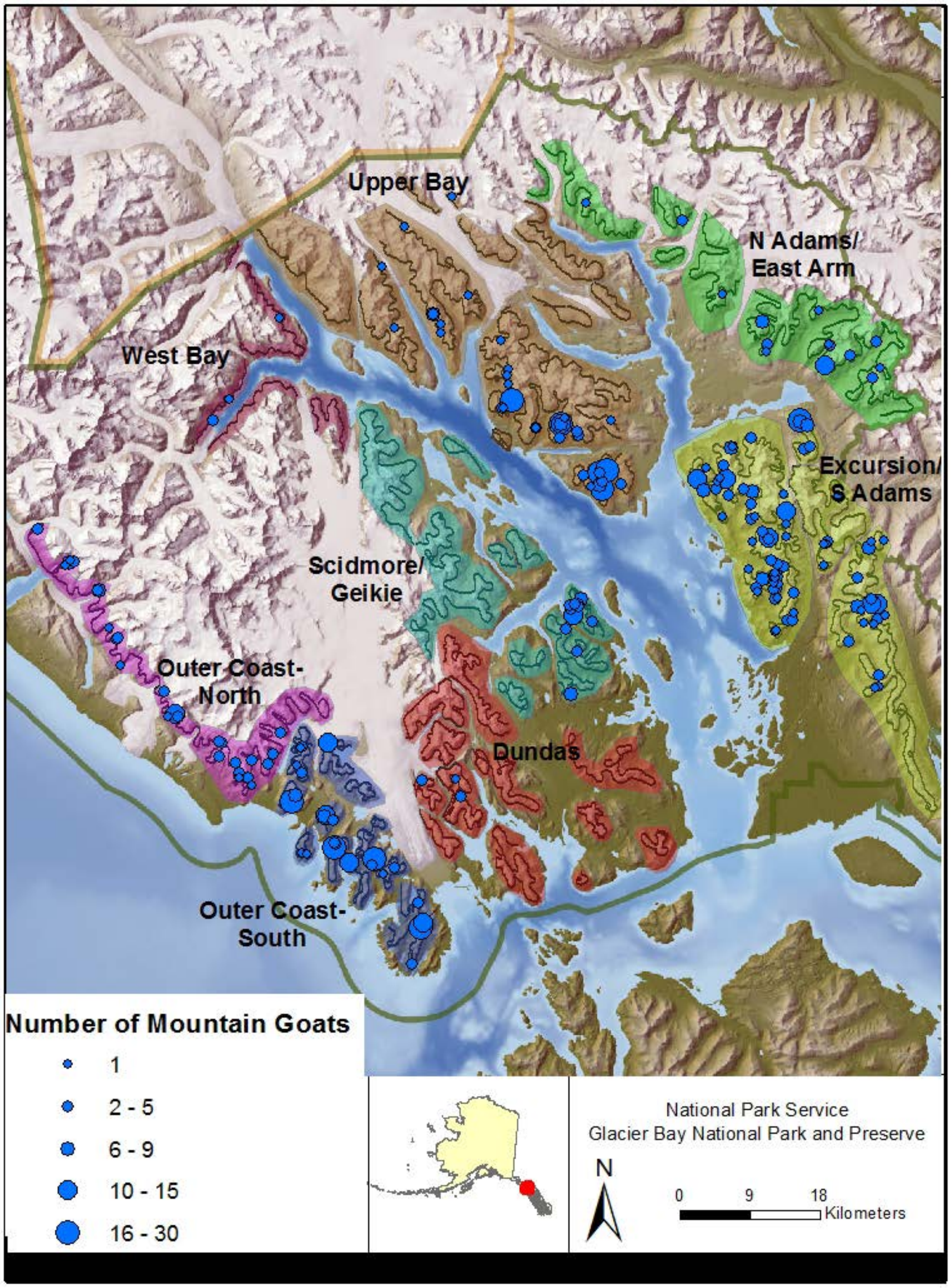


Figure 1. Spatial distribution of mountain goats observed by survey area during aerial surveys in Glacier Bay National Park from July 25-August 4, 2012. The dark lines illustrate the route surveyed.

Table 1. Mountain goat population composition and minimum abundance data collected during aerial surveys in Glacier Bay National Park from July 25-August 4, 2012.

Area	Date	Adults	Kids	Total	Prop Kids	# of Groups	mean group size
Excursion/S Adams							
Beartrack-Mt Wright	7/26/2012	144	24	168	0.14	49	3.4
Tree Mtn	7/26/2012	36	10	46	0.22	5	9.2
U Beartrack	7/26/2012	8	1	9	0.11	5	1.8
Excursion Ridge	7/26/2012	45	10	55	0.18	17	3.2
N Adams/East Arm							
Mt Young-Casement	7/26/2012	34	7	41	0.17	11	3.7
Casement-McBride	7/26/2012	1	0	1	0.00	1	1.0
McBride-Riggs	7/26/2012	2	1	3	0.33	1	3.0
McConnell Ridge	7/26/2012	0	0	0	0.00	0	0.0
Riggs-Muir	7/27/2012	1	0	1	0.00	1	1.0
Muir-Morse	7/27/2012	0	0	0	--	0	--
Upper Bay							
Morse-Cushing	7/27/2012	0	0	0	--	0	--
Minnesota Ridge	7/27/2012	0	0	0	--	0	--
Bruce Hills	7/27/2012	0	0	0	--	0	--
Gable Mtn	7/27/2012	0	0	0	--	0	--
Cushing Nunatak	7/27/2012	1	0	1	0.00	1	1.0
Carroll Nunatak	7/27/2012	0	0	0	--	0	--
Carroll-Rendu	7/27/2012	15	4	19	0.27	7	2.7
Gloomy Knob	8/4/2012	0	0	0	--		--
N Tidal Inlet	7/27/2012	72	15	87	0.21	22	4.0
Tlingit Point	7/27/2012	68	19	87	0.28	11	7.9
Rendu-Abdallah	7/27/2012	2	0	2	0.00	2	1.0
Abdallah-Grand Pacific	7/27/2012	0	0	0	--	0	--
West Arm							
Grand Pacific-Margerie	7/27/2012	0	0	0	--	0	--
Margerie-Topeka	7/27/2012	1	0	1	0.00	1	1.0
Topeka-Hopkins	7/27/2012	2	1	3	0.50	2	1.5
Hopkins-Lamplugh	7/27/2012	0	0	0	--	0	--
Mt Parker	8/4/2012	0	0	0	--	0	--
Scidmore/Geikie							
Skidmore	8/4/2012	0	0	0	--	0	--
Goat Ridge	8/4/2012	0	0	0	--	0	--
Gilbert Pen	8/4/2012	0	0	0	--	0	--
Hugh Miller Mtn	8/4/2012	0	0	0	--	0	--
Mt Favorite	8/4/2012	0	0	0	--	0	--
Marble Mtn	8/4/2012	34	6	40	0.15	8	5.0
Tlingit Pk	8/4/2012	11	1	12	0.08	3	4.0
Mt Wood	8/4/2012	0	0	0	--	0	--
Mt Skarn	8/4/2012	0	0	0	--	0	--

Table 1. Mountain goat population composition and minimum abundance data collected during aerial surveys in Glacier Bay National Park from July 25-August 4, 2012. (Continued)

Area	Date	Adults	Kids	Total	Prop Kids	# of Groups	mean group size
Dundas							
S Berg Ridge	8/4/2012	0	0	0	--	0	--
Carolus	7/25/2012	0	0	0	--	0	--
White Cap	7/25/2012	0	0	0	--	0	--
Pt Dundas	7/25/2012	0	0	0	--	0	--
Wimbledon	7/25/2012	0	0	0	--	0	--
Dundas Pie	8/4/2012	0	0	0	--	0	--
Blackthorn/Serrated	8/4/2012	0	0	0	--	0	--
Threesome Mtn	7/25/2012	0	0	0	--	0	--
Abyss	7/25/2012	0	0	0	--	0	--
N Dundas Complex	7/25/2012	5	0	5	0.00	2	2.5
East Brady	7/25/2012	2	0	2	0.00	1	2.0
East Taylor	7/25/2012	0	0	0	--	0	--
Outer Coast-South							
Table Mtn	7/25/2012	23	8	31	0.26	4	7.8
S Trick Lk	7/25/2012	3	0	3	0.00	2	1.5
Horn Mtn Complex	7/25/2012	37	8	45	0.18	3	15.0
Hankinson	7/25/2012	20	4	24	0.17	3	8.0
Astrolabe	7/25/2012	2	0	2	0.00	2	1.0
Thistle	7/25/2012	15	3	18	0.17	3	6.0
DeLangle	7/25/2012	19	4	23	0.17	2	11.5
Upper Dixon	7/25/2012	8	1	9	0.11	4	2.3
W Brady Nunataks	7/25/2012	9	3	12	0.25	1	12.0
Outer Coast-North							
Marchainville	7/25/2012	29	11	40	0.28	12	3.3
Finger-LaPerouse	7/25/2012	14	3	17	0.18	4	4.3
LaPerouse-N Crillon	7/25/2012	7	0	7	0.00	4	1.8
N Crillon-Lituya Gl	7/25/2012	18	9	27	0.33	7	3.9

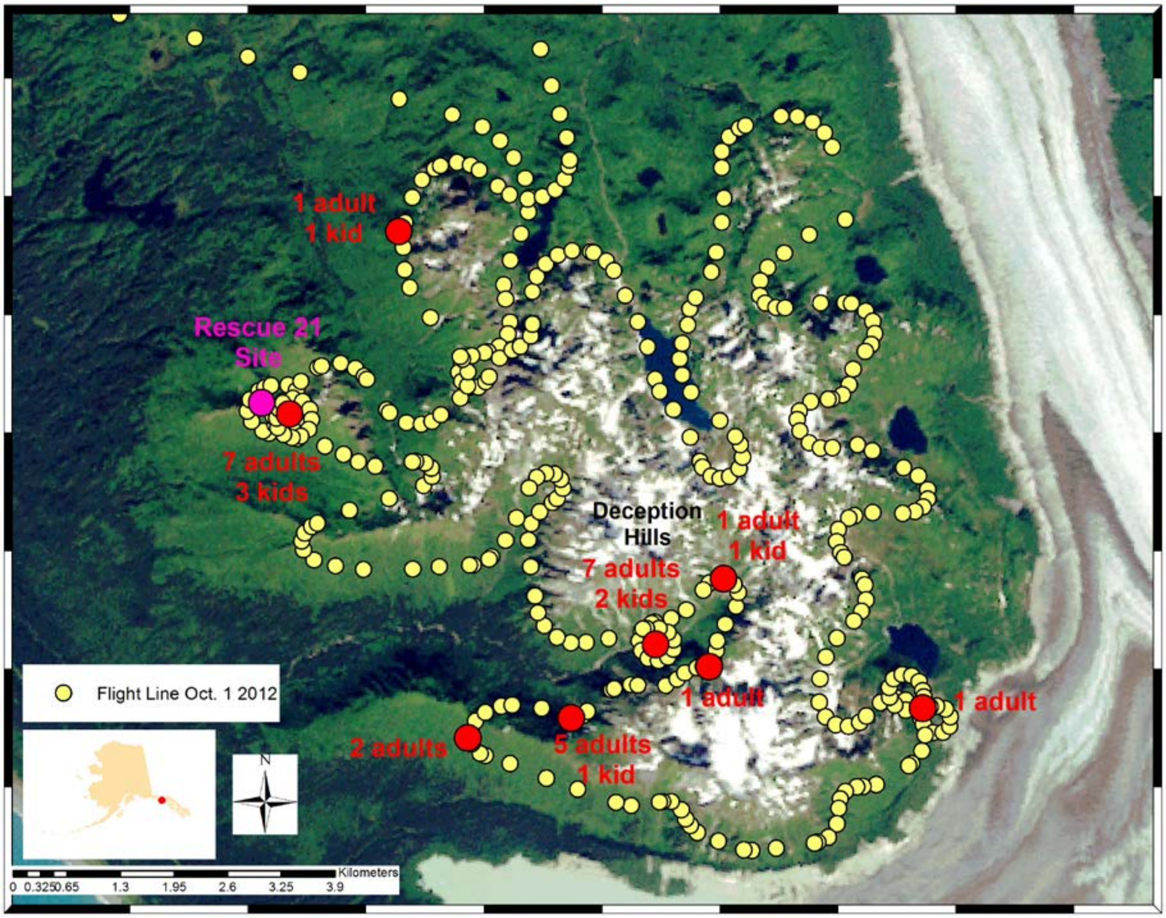


Figure 2. Spatial distribution of mountain goats observed by survey area during aerial surveys in Deception Hills, Glacier Bay National Preserve from October 01, 2012. Yellow dots illustrate the route surveyed, red dots signify mountain goat groups, and the pink dot represents the location of the proposed Rescue 21 Coast Guard communication site.

Comparison with previous surveys (1985 and 2012)

Mountain goat surveys were conducted sporadically in certain areas of the park by vessel, ground, and helicopter from 1968 - 1985 (Vequist 1983, Brown 1985). Researchers using winter ground surveys found a substantial decline in mountain goat numbers in Adams Inlet between 1969 and 1982 possibly caused by severe winters, increases in wolf populations, and post-glacial plant succession caused habitat changes (Vequist 1983). Adams and Vequist (1986) conducted the first somewhat comprehensive aerial survey for mountain goats from July 8-14, 1985. The survey was conducted with 2-3 observers in a Bell 206B Jet Ranger helicopter on floats. Weather and budget constraints prevented surveys of the southern east side of the park and the land surrounding Icy Strait and the outer coast. However, comparisons can be made within many areas that were surveyed both in 2012 and 1985 (Figure 3 & 4). Caution must be taken however due to differences in aircraft and methodologies between the two surveys. For example, helicopters are able fly more slowly and survey complex terrain more thoroughly than fixed wing airplanes, but may not cover as much ground on a given survey (and are more expensive). Yet, despite these qualitative differences, preliminary analyses suggest that sighting probabilities are not statistically different between a Piper

Super Cub (the fixed-wing aircraft used in the 2012 survey) and a Hughes 500 helicopter (White and Pendleton 2011, G. Pendleton, in prep). There are no GPS points or track logs associated with the 1985 surveys, so precise mountain goat locations and the extent of the survey coverage in each survey area may be less accurate. Additionally, both data sets represent minimum counts. Nevertheless, insight can be gained by preliminary comparisons of the two data sets in regards to minimum numbers of animals, distribution, and the proportion of kids in each survey area (Table 2, Figure 3). Fewer mountain goats (-50%) and a lower proportion of kids were observed in the N. Adams/East Arm and Upper Bay areas of Glacier Bay in 2012 (194) compared to 1985 (385). Of special interest is the lack of mountain goats sighted on west side of the Upper Bay area of Glacier Bay in 2012, whereas multiple mountain goats were observed in this area in 1985. However, greater numbers of mountain goats were observed in more areas on the West Arm and Scidmore/Geikie areas in 2012 (48) than 1985 (13), suggesting possible range expansion in this area. Overall numbers in the areas surveyed in both years indicate a decline from 520 animals in 1985 to 422 animals in 2012 (-19%). However, this apparent abundance change may also be influenced by differences in aircrafts, methodologies, and sightability.

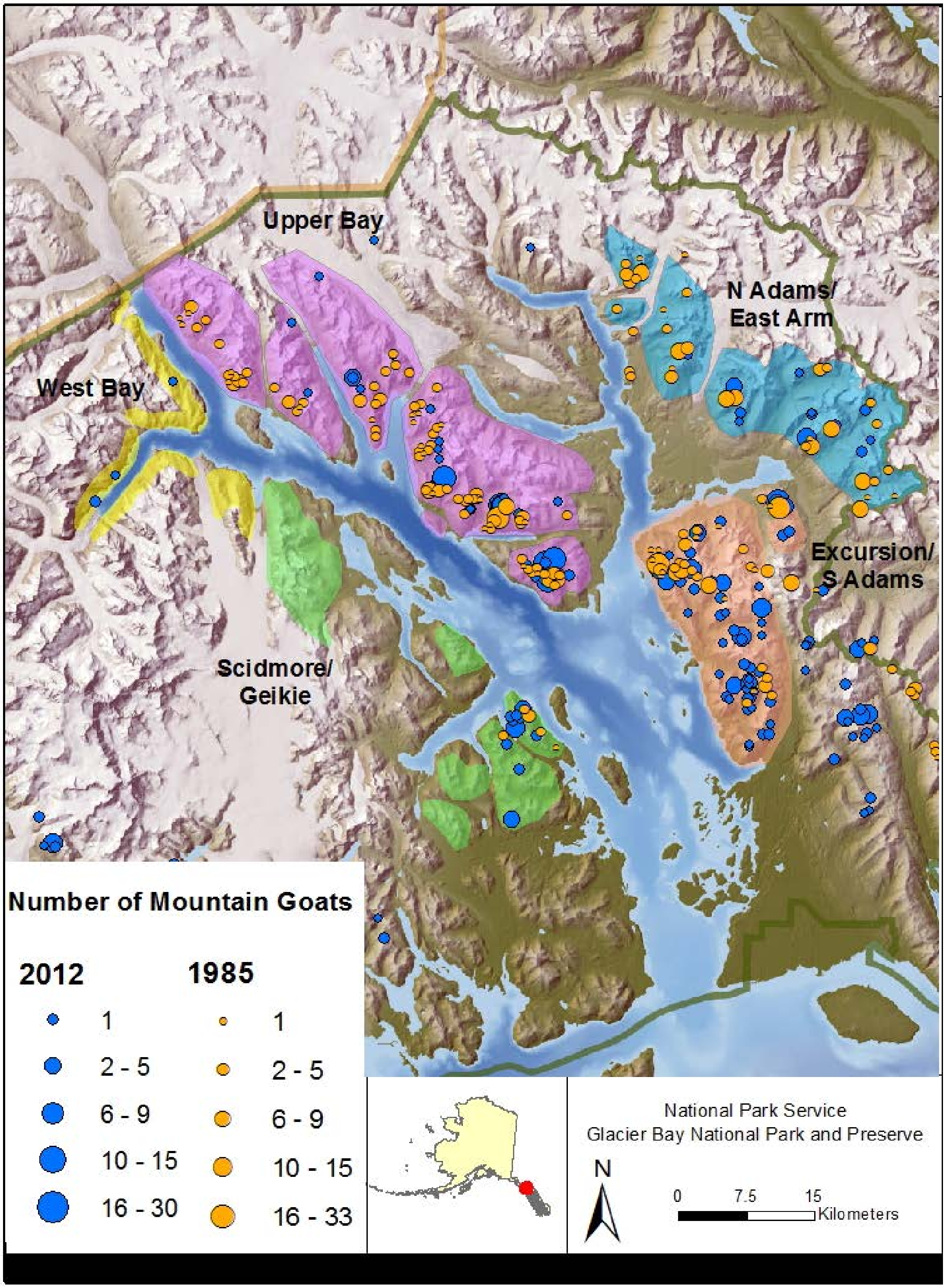
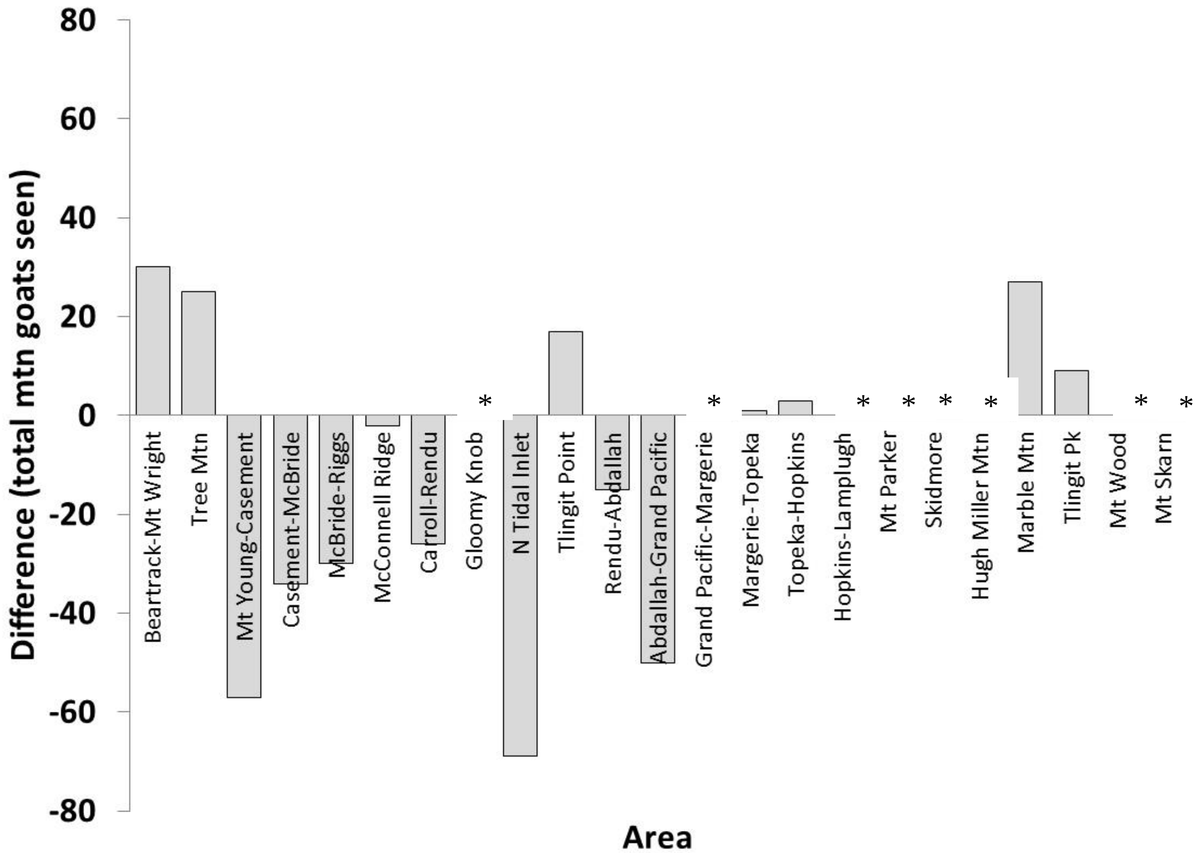


Figure 3. Spatial distribution of mountain goats observed by survey area during aerial surveys in Glacier Bay National Park in 1985 and 2012. Spatial data within shaded polygons where surveys were conducted in both years were used to compare abundance and distribution of mountain goats across time.

Table 2. Mountain goat population composition and minimum abundance data collected during aerial surveys in Glacier Bay National Park in 1985 and 2012. Note that these data only represent areas surveyed in both years, and are not inclusive of all mountain goat observations for either 1985 or 2012.

Area	Year	Adults	Kids	Total	Prop Kids	# of Groups	Mean group size	Year	Adults	Kids	Total	Prop Kids	# of Groups	Mean group size
Beartrack-Mt Wright	2012	144	24	168	0.14	49	3.43	1985	107	31	138	0.22	30	4.60
Tree Mtn	2012	36	10	46	0.22	5	9.20	1985	15	6	21	0.29	3	7.00
TOTAL Excursion/ S Adams	2012	**180**	**34**	**214**	**0.16**	**54**	**3.96**	1985	**122**	**37**	**159**	**0.23**	**33**	**4.82**
Mt Young-Casement	2012	34	7	41	0.17	11	3.73	1985	70	26	98	0.27	16	6.13
Casement-McBride	2012	1	0	1	0.00	1	1.00	1985	26	9	35	0.26	7	5.00
McBride-Riggs	2012	2	1	3	0.33	1	3.00	1985	24	9	33	0.27	6	5.50
McConnell Ridge	2012	0	0	0	0.00	0	0.00	1985	2	0	2	0.00	1	2.00
TOTAL N Adams/ East Arm	2012	**37**	**8**	**45**	**0.18**	**13**	**3.46**	1985	**122**	**44**	**168**	**0.26**	**30**	**5.60**
Carroll-Rendu	2012	15	4	19	0.27	7	2.71	1985	35	9	45	0.20	11	4.09
Gloomy Knob	2012	0	0	0	--	0	--	1985	0	0	0	0.00	0	0.00
N Tidal Inlet	2012	72	15	87	0.21	22	3.95	1985	129	24	156	0.15	39	4.00
Tlingit Point	2012	68	19	87	0.28	11	7.91	1985	48	22	70	0.31	12	5.83
Rendu-Abdallah	2012	2	0	2	0.00	2	1.00	1985	11	6	17	0.35	5	3.40
Abdallah-Grand Pacific	2012	0	0	0	--	0	--	1985	40	9	50	0.18	15	3.33
TOTAL Upper Bay	2012	**157**	**38**	**195**	**0.19**	**42**	**4.64**	1985	**263**	**70**	**338**	**0.21**	**82**	**4.12**
Grand Pacific-Margerie	2012	0	0	0	--	0	--	1985	0	0	0	0.00	0	0.00
Margerie-Topeka	2012	1	0	1	0.00	1	1.00	1985	0	0	0	0.00	0	0.00
Topeka-Hopkins	2012	2	1	3	0.50	2	1.50	1985	0	0	0	0.00	0	0.00
Hopkins-Lamplugh	2012	0	0	0	--	0	--	1985	0	0	0	0.00	0	0.00
Mt Parker	2012	0	0	0	--	0	--	1985	0	0	0	0.00	0	0.00
TOTAL West Arm	2012	**3**	**1**	**4**	**0.25**	**3**	**1.33**	1985	**0**	**0**	**0**	**-**	**0**	**-**
Skidmore	2012	0	0	0	--	0	--	1985	0	0	0	0.00	0	0.00
Hugh Miller Mtn	2012	0	0	0	--	0	--	1985	0	0	0	0.00	0	0.00
Marble Mtn	2012	34	6	40	0.15	8	5.00	1985	10	3	13	0.23	4	3.25
Tlingit Pk	2012	11	1	12	0.08	3	4.00	1985	3	0	3	0.00	1	3.00
Mt Wood	2012	0	0	0	--	0	--	1985	0	0	0	0.00	0	0.00
Mt Skarn	2012	0	0	0	--	0	--	1985	0	0	0	0.00	0	0.00
TOTAL Scidmore/ Geikie	2012	**45**	**7**	**52**	**0.13**	**11**	**4.73**	1985	**13**	**3**	**16**	**0.19**	**5**	**3.20**
TOTAL Glacier Bay	**2012**	**422**	**88**	**510**	**0.17**	**123**	**4.15**	**1985**	**520**	**154**	**681**	**0.23**	**150**	**4.54**

Figure 4. Differences in number of mountain goats observed per survey during aerial surveys in Glacier Bay National Park between 1985 and 2012. Note that these data only represent areas surveyed in both years, and are not inclusive of all mountain goat observations for either 1985 or 2012. Asteric (*) indicates no mountain goats were observed in either year.



Bedrock geology correlations

Over 50% (436 of 841) of the mountain goats in Glacier Bay National Park in 2012 were observed on sedimentary bedrock whereas only 29% (6402 of 21708) of the track points of the survey fell on sedimentary rock (Table 3, Figure 5). The selection ratio (proportion of mountain goat locations/proportion of track points) for sedimentary bedrock was 1.76 indicating that mountain goats were found on sedimentary bedrock almost twice as much as would be expected if distribution were uniform across the study area. Conversely, only 10% (88) of mountain goats were observed on magmatic (largely granitic) bedrock, despite 29% of the track points (6356) falling on this rock type. The selection ratio for magmatic bedrock was 0.36 indicating that mountain goats were found only 1/3 as much as would be expected if distribution were uniform across the study area. The selection ratio for metamorphic bedrock, however, was approximately 1, indicating little selection by mountain goats for or against this rock type. The selection ratio of ice cover is less than 1.0 (0.70) as would be expected.

These results suggest that mountain goats in Glacier Bay may be selecting for sedimentary and against magmatic bedrock. Forest growing in a sedimentary karst topography has been found to be more productive than non-karst forest (Albert and Schoen 2006), but there have been few investigations of correlations between plant productivity and bedrock type in alpine ecosystems. Sedimentary rock such as pure limestone may dissolve entirely under chemical erosion, but impure limestone and shale are often quicker to break down into soil than harder magmatic bedrock such as granite. The soil provides substrate for plants to grow which may increase productivity and diversity of plants on sedimentary bedrock. However, there are many other contributing factors that may confound the apparent selection of sedimentary bedrock by mountain goats.

Much of the land surrounding Glacier Bay was covered in ice just 270 years ago, therefore re-colonization of suitable habitat is likely still occurring from eastern, western, and possibly alpine refugia. Colonization patterns likely contribute to the current distribution of mountain goats, potentially explaining the lack of mountain goats on the northwest side of Glacier Bay and discrete geographies in the Dundas Bay area. The land northwest of Glacier Bay also receives some of the highest snow depths during winter (as a result of the proximity to the Brady Ice Sheet; D. Lawson pers. com.) and may further inhibit colonization and/or viability of mountain goats that disperse to such areas. The extent of the last glacial maximum may also influence current mountain goat distributions. The Pleistocene ice sheet eroded peaks and ridges up to 1000 m in elevation. This major landscape change reduced the availability of steep terrain at lower elevation Escape terrain is important for mountain goat survival (Fox and Streveler 1986 Fox et al.1989) and is a key predictor of mountain goat habitat selection in southeastern Alaska (Fox et al. 1989, Shafer et al. 2012, White et al. 2012). Mountain goat distribution is expected to be linked to this landscape feature across the park. Interestingly, steep escape terrain is less likely to be found on sedimentary bedrock due to its greater potential for erosion whereas magmatic bedrock has a greater potential to hold steep terrain features over time. Therefore, we might expect more escape terrain and potentially more mountain goats on magmatic bedrock, but this is clearly not the pattern in Glacier Bay. Proximity to protected winter range habitat such as forest or shrub habitats may also influence summer distribution. Despite these confounding variables that likely influence mountain goat distribution in Glacier Bay, the apparent strong selection of mountain goats towards sedimentary bedrock and away from magmatic rocks warrants further investigation.

Table 3. Selection ratios (proportion of mountain goat locations/proportion of track points) for differing bedrock types in Glacier Bay, 2012.

Geologic Origin	Goats	Prop. goats	Tracks	Prop. tracks	Selection Ratio
Ice	70	0.08	2565	0.12	0.70
Magmatic	88	0.10	6356	0.29	0.36
Metamorphic	246	0.29	6124	0.28	1.04
Sedimentary	436	0.52	6402	0.29	1.76
unmarked	1		20		
Total	**841**		**21708**		

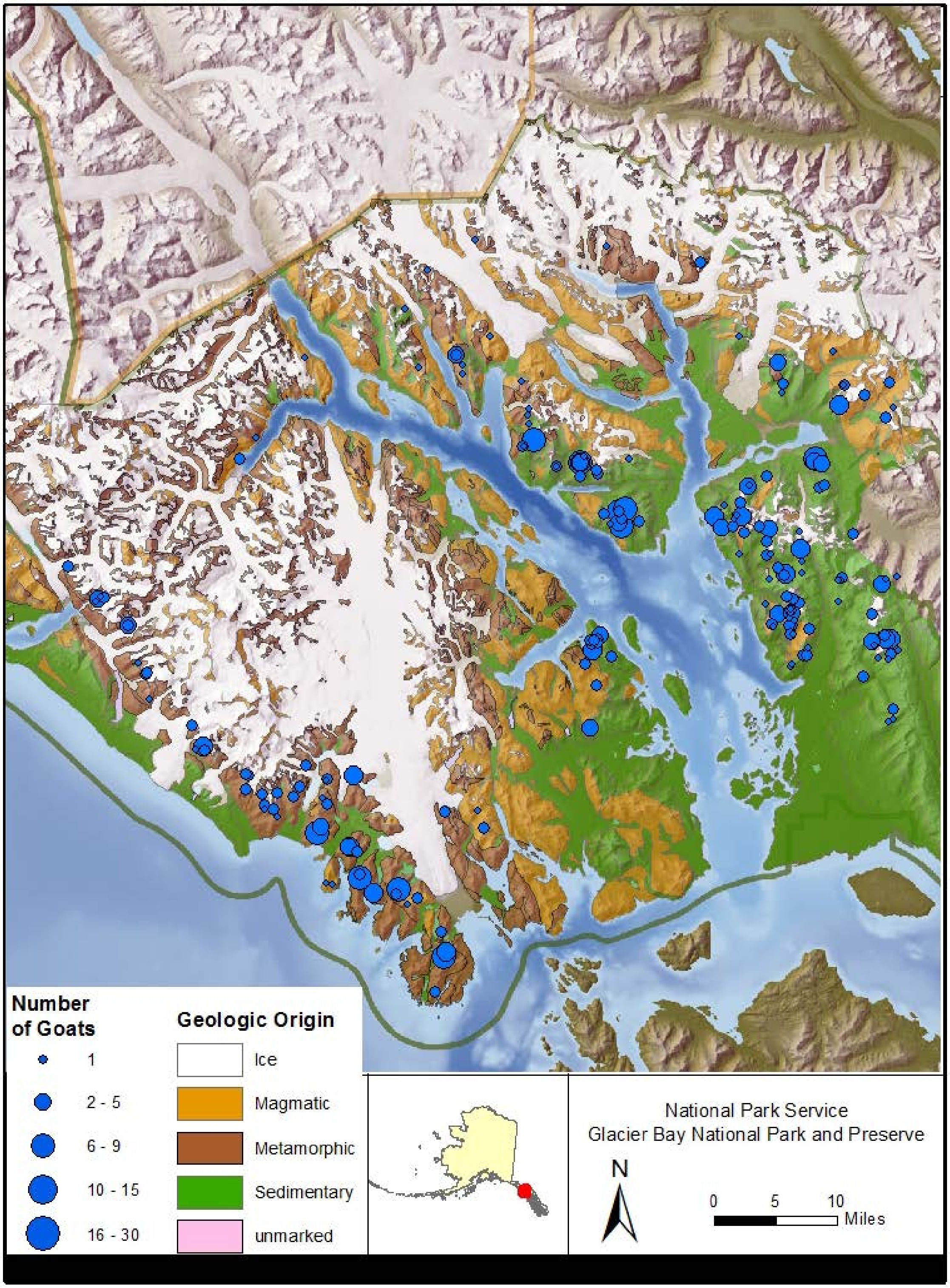


Figure 5. Geologic origin of bedrock (Brew 2008) and spatial distribution of mountain goats observed during aerial surveys in Glacier Bay National Park in 2012.

Recommendations for Future Work

Develop a long-term monitoring sampling design

A key justification for the establishment of Glacier Bay National Park was to allow for the scientific documentation of how glacial processes affect terrestrial ecosystems. Mountain goats are habitat specialists that are tightly linked to the distribution of post-glacial lowland and alpine habitats. As such, these species offer unique insights into how glacial processes (and by extension climate change) influence vertebrate communities. Knowledge of how populations of ungulates change over time is crucial for understanding the broader dynamics of terrestrial ecosystems in Glacier Bay National Park. Such species exert both top-down and bottom-up effects on terrestrial ecosystems in ways that can be profound and far reaching. For example in Olympic National Park, mountain goats have played a major role in the structure and function of plant communities (Houston et al. 1994). As such, we recommend that routine monitoring of mountain goat populations in Glacier Bay National Park should be prioritized and implemented in the future.

The intent of the current effort was to provide baseline data that can be used to design and develop a rigorous monitoring program for this species in Glacier Bay National Park. As such, we recommend the implementation of a formal follow-up effort to design a long-term monitoring protocol that includes explicit consideration of appropriate spatial and temporal sampling design and power analyses to detect changes in population size and distribution. Ideally, such an effort would involve collaboration with other National Parks in Alaska and elsewhere to ensure that data collected are spatially comparable.

We suggest a monitoring program that would involve annual monitoring of mountain goats in a subset (or trend site areas) of the total area surveyed in this current project. At less frequent intervals (i.e. 5-10 years) a complete survey could be conducted. Areas surveyed on an annual basis would enable a higher degree of temporal resolution for population trend determination. Such areas would need to be strategically selected in order to ensure they are meaningful “barometers” for the overall population. Census level data collected at lower frequency could be oriented towards assessing changes in distribution and “ground truthing” overall population trend inferences derived from annual surveys. Importantly, such a sampling design needs to be cost-effective in order to be sustainable over the long-term. Fortunately, the field work associated with monitoring mountain goats via aerial surveys is relatively inexpensive. For example, the entire census of Glacier Bay proper for mountain goats in 2012 cost ~$10,000 (not including salaries); an exceedingly low cost for estimation of any species over such a large area. This sum, however, does not including salaries to cover the time surveying, data management and analysis, and report writing.

Overall, there is an important opportunity for Glacier Bay National Park to gain long-term, foundational knowledge about mountain goat populations and by extension post-glacial plant community dynamics, climate change and other dimensions of terrestrial ecosystem dynamics. In time, population monitoring data collected for these species could represent an invaluable resource and highlight the unique contributions National Parks have made in furthering our understanding of terrestrial ecology and conservation. National Parks have an exemplary record in this regard and previous NPS long-term monitoring programs involving caribou in Denali National Park and Preserve, wolves and moose in Isle Royale National Park, elk and wolves in Yellowstone National Park are just a few examples of the key role that National Parks can play in advancing our scientific knowledge of vertebrate population dynamics and conservation capacity. Extending the tradition of long-term monitoring of terrestrial vertebrates in National Parks to include one of the most visible and iconic species of North Pacific coastal ecosystems in the context of a rapidly changing, glacially dominated environment represents an important opportunity for scientific advancement and conservation that is consistent with the mission of the National Park Service and guiding legislation for Glacier Bay National Park.

We recommend that the distribution and abundance of mountain goats be monitored by conducting aerial surveys, as described above. Distribution will undoubtedly change over time and documenting these changes, along with changes in landcover, is crucial to understanding and managing this species. Similarly, abundance of mountain goats will likely change over time and after sightability models are developed, trend estimates can be calculated and tracked over time. These trends will be used to manage current and potential future harvest on NPS and surrounding lands, determine areas of concentrations of animals and/or critical habitat important to protect, and assess the impacts of climate change on ungulate species in Glacier Bay National Park.

Estimate mountain goat population size using sightability models

During 2012, mountain goat aerial survey data were collected following specific protocols that will enable such data to be used in concert with sightability models to estimate population size in the future (White and Pendleton 2011). Development of sightability models is part of a separate ADFG project and is still ongoing. As such, use of sightability models to estimate population size was not part of the existing cooperative agreement. Nonetheless, such analyses will be conducted in the future and will be submitted to the NPS informally by ADFG and represent an in-kind contribution. In the future, sightability models are expected to be packaged such that field-level biologists will be able to routinely use them with relative ease (currently models require biometrician support for implementation).

The models currently being developed for mountain goats are comparable to those developed by Rice et al. (2009). The sightability models developed by Rice et al. (2009) are specific to mountain goats and were developed in partnership with the NPS and currently used as the standard tool for long-term monitoring of mountain goats in Olympic, Mt. Rainer and North Cascades National Parks (also see Jenkins et al. 2011). The models currently being developed by White and Pendleton (2011) extend the analytical approach developed by Rice et al. (2009) and, more importantly in the context of this study, are parameterized using data from collared animals in southeastern Alaska. These models have been used to estimate mountain goat abundance in the Lynn Canal area and will be the basis for future population estimates throughout southeastern Alaska. Use of such methods for population estimation work in Glacier Bay would allow comparisons between Glacier Bay and other populations in the region that have been intensively studied.

Estimating actual population size (in contrast to indexing population size via minimum counts) can be critical for conservation and management of mountain goats. For example, a true population estimate is an essential prerequisite for modeling population dynamics, and more deeply understanding factors that influence mountain goat populations. Matrix population models have been developed for mountain goats (Hamel et al. 2006, Rice and Gay 2010, White et al., in prep.) and offer the potential to understand how natural (e.g., climate change) or anthropogenic (e.g., hunting) perturbations are likely to affect mountain goat populations in the future. As such, acquisition of actual population size estimates will enable biologists to add a powerful tool to their conservation toolbox, and gain more sophisticated and biologically meaningful understanding of how and why future changes to the environment will influence mountain goat populations.

A note about distance sampling - The distance sampling methods, such as those developed by Schmidt et al. (2011) represent an alternative method and appear to be well suited for estimating Dall sheep abundance in northern and interior Alaska landscapes. It is unclear whether such methods could be successfully used to estimate mountain goat abundance in coastal environments. Distance sampling generally assumes a linear (or in some cases nonlinear; Quang and Becker 1996) animal detection decay function. This requires precise estimation of distance between a survey platform and an animal. While it is theoretically possible to develop distance-based models for mountain goats, certain logistical constraints should be recognized that are possibly unique to coastal mountain goat populations, relative to interior Dall sheep. In southeastern Alaska, mountain goats utilize habitats with very low detection probabilities (i.e. alder thickets, sub-alpine forest, montane conifer forest). In order to develop distance-detection functions for such habitats, animals must be detected in each habitat at least one time per distance class. Because detection probabilities are so low in these habitat types, a very high (possibly logistically unfeasible) number of sampling occasions would be required to derive precise distance-detection functions. This would require a commensurately large, expensive survey effort. Ultimately, such an effort could be of limited utility if the distance function is too complex to model accurately or simply not a relevant predictor of sighting probability in certain habitats or contexts. Additionally, distance methods require accurate distances between the observer and the animals, so the airplane must leave the transect line and circle directly over the group, thus increasing the potential disturbance to animals (and in some terrains may not be safe). As a result of the above constraints and issues, in addition to the proven and logistical feasibility of sightability models, we consider distance sampling a less promising method for determining abundance of mountain goats in Glacier Bay National Park.

Assess the Population Structure of Mountain Goats in Glacier Bay

Assessing population structure of mountain goats in the park would provide an important part of understanding connectivity, which may help park wildlife managers reduce anthropogenic barriers to gene flow. Determining barriers and connectivity between the Park and the Preserve may have implications on managing both habituated and hunted populations. Identifying key biological corridors will help inform the park's upcoming Backcountry Management Plan by steering human use away from these areas thereby increasing the protection of mountain goats. Learning the origins of Glacier Bay mountain goat immigrants may shed light on colonization patterns of other recent mammalian colonizers. In addition, determination of landscape features that limit mountain goat connectivity in a region with very little human development may help differentiate natural from anthropogenic fragmentation in disturbed landscapes at a regional scale. Determining the number and distribution of genetically discrete mountain goat sub-populations within the park and preserve will also inform future monitoring efforts. Aerial surveys could be focused towards areas with specific independent populations of interest as opposed to a broad sweep of the entirety of mountain goat range, thus saving time and money.

Non-invasive methods for collecting genetic material, such as collection of fecal pellets, have been successfully implemented for mountain goats (Poole et al. 2011, G. Roffler, pers. comm.) and represent a promising method for future studies in National Parks. In Glacier Bay, samples could be safely and efficiently collected in several relatively accessible winter range habitats during March-April. Such data can be combined with an existing ADFG mountain goat tissue sample archive (that includes over 1000 samples collected from most areas throughout mountain goat range in Alaska) and enable a comprehensive spatial analyses capable of addressing key questions about population structure and gene flow in Glacier Bay National Park.

Identify Focal Areas to Conduct Ground and Vessel Surveys

On May 4, 2012, we opportunistically conducted a boat based survey of mountain goats on winter/spring range habitat along the western shore of Mt. Wright (N Sandy Cove – Garforth Island, total distance = 4.5 miles, duration = 52 minutes). During this survey, 4 observers scanned the largely snow-free hillside (sea-level to ~2000 ft.) and recorded the age class of each mountain goat group observed. Overall, 74 mountain goats were observed (13.5% kids).

The results of this survey were encouraging relative to the feasibility of conducting these types of surveys as a routine monitoring tool for assessing population trends in key focal areas. Nonetheless, further data would be needed to assess sightability biases and sampling intensity/design prior to formal implementation of this method. Advantages of this approach include: 1) lower cost, relative to aerial surveys, 2) possible comparison to historical boat based surveys (i.e. Vequist and others), 3) ability to collect more detailed population composition data (i.e. sex and multiple age classes), 4) ability to collect additional data (see population genetics section). Disadvantages include: 1) relatively small area for spatial inference, 2) less apriori knowledge about sightability/methodological biases (but see Belt 2010).

Another avenue for obtaining data on mountain goat distribution and abundance in focal areas from ground and vessel surveys is to utilize citizen science. Belt (2010) found that uncorrected population estimates from ground counts of mountain goats in focal areas by volunteers were similar to population estimates from aerial survey counts by biologists in Glacier National Park. These results indicate that as long as the sample size is reasonably large, volunteers are capable of collecting valuable population data that can be incorporated into populations estimates. In light of these results, GLBA may consider soliciting mountain goat ground and vessels counts at focal areas by volunteers and/or opportunistically by park staff.

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