GLAUCOUS-WINGED GULL *LARUS GLAUCESCENS* MONITORING IN PREPARATION FOR RESUMING NATIVE EGG HARVEST IN GLACIER BAY NATIONAL PARK

TANIA M. LEWIS[1], CHRISTOPHER BEHNKE[2] & MARY BETH MOSS[3]

[1]*Glacier Bay National Park and Preserve, Gustavus AK 99826, USA (Tania_Lewis@nps.gov)*
[2]*University of Alaska, Fairbanks, School of Natural Resources and Extension, Resilience and Adaptation Program, Fairbanks AK, 99775, USA*
[3]*Glacier Bay National Park and Preserve, Hoonah AK 99826, USA*

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ABSTRACT

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Glacier Bay National Park, Alaska, is the ancestral homeland of the Huna Tlingit people, for whom Glaucous-winged Gull *Larus glaucescens* eggs were an important cultural food source until the 1960s, when the National Park Service (NPS) began to enforce regulations prohibiting harvest. Over the past 20 years, NPS has sponsored several studies as well as a Legislative Environmental Impact Statement to assess the cultural and biological impacts of egg harvests. Based on these findings, the US Congress passed legislation in 2014 authorizing harvest of Glaucous-winged Gull eggs in Glacier Bay National Park. With the long-awaited passage of this legislation, egg harvest may begin as soon as the NPS promulgates the necessary regulations and an annual harvest plan is developed. In preparation for egg harvest, we used ground- and vessel-based surveys to determine 1) the distribution and abundance of nesting gulls, 2) egg-laying phenology, 3) nesting vegetation, and 4) potential impacts of egg harvest on other species. During 2012–2015, we repeatedly surveyed 20 islands and sections of shoreline in Glacier Bay (that were likely colony locations based on historic observations) for gulls and found six potential egg-harvest colonies. The number of nests per colony ranged from 22 to 174. The number of nests at each colony remained consistent among years, whereas the number of eggs showed high interannual variability. Other species observed that could be affected by egg harvest included hauled-out marine mammals and other seabirds nesting nearby. The majority of nests (67%) were found in graminoid vegetation, an early successional state. This study marks the beginning of long-term monitoring of the population parameters to infer potential impacts of gull-egg harvest in Glacier Bay and to manage the harvest. In addition to yearly monitoring of productivity, research on nesting habitat shifts, food availability, and predation could improve the park's ability to understand any impacts of egg harvest on the distribution and abundance of Glaucous-winged Gulls in Glacier Bay National Park.

Key words: Glacier Bay National Park, Glaucous-winged Gull, harvesting impacts, egg harvest management

INTRODUCTION

Glacier Bay is a recently deglaciated fjord currently undergoing rapid vegetative succession (Chapin *et al.* 1994) and isostatic rebound (Larsen *et al.* 2004) as glaciers retreat. Glaucous-winged Gulls *Larus glaucescens*, common in southeast Alaska, likely began nesting in parts of Glacier Bay as soon as glacial retreat created suitable nesting habitat, perhaps as early as the mid-1800s. Glacier Bay is the ancestral homeland of the Huna Tlingit people, who traditionally harvested Glaucous-winged Gull (hereafter gull) eggs annually during the spring and early summer (Hunn *et al.* 2002) until the US National Park Service (NPS) began enforcing the *Migratory Bird Treaty Act* and related NPS regulations in the 1960s. In an effort to improve relations with the Hoonah Indian Association (HIA; the federally recognized tribal government representing the Huna clans), the NPS sponsored an ethnographic study focused on understanding traditional egg-harvest methods and protocols (Hunn *et al*. 2002), as well as a biological study that modeled the effects of traditional harvest methods on the gull population (Zador *et al.* 2006, Zador & Piatt 2007). Data from these studies informed a Legislative Environmental Impact Statement (LEIS) and associated Record of Decision (ROD) for gull-egg harvest (NPS 2010a & 2010b). In 2014, the *Huna Tlingit Traditional Gull Egg Use Act* (Public Law 113-142) was passed, authorizing HIA tribal members to harvest Glaucous-winged Gull eggs after park-specific regulations are promulgated and an annual harvest plan is developed.

Glaucous-winged Gulls typically lay three eggs per clutch and, during egg laying, often replace lost eggs until the clutches are complete. Gulls incubating clutches also re-lay new clutches if all eggs are lost (Vermeer 1963, Parsons 1976). This phenomenon, known as indeterminate laying, may respond to factors such as flooding, predation, and human harvest (Brown & Morris 1996). The likelihood of re-laying diminishes later in the laying season and is influenced by the adult's breeding experience (Parsons 1976, Wooler 1980). Some study results suggest that gull-egg harvest may have negative effects on breeding success and population viability (Hand 1980, Spear & Anderson 1989, Calladine *et al.* 2006, Wood *et al*. 2009). Additionally, egg harvest may delay mean lay date (Vermeer *et al*. 1991). Gulls laying replacement clutches or otherwise laying later in the breeding season may have reduced nesting success (Nisbet & Cohen 1975, Morris *et al.* 1976, Massey & Atwood 1981, Boersma & Ryder 1983). Chicks born later may exhibit lower hatching mass, grow more slowly, and have lower survival, particularly in years of low food availability (Spaans 1971, Parsons *et al.* 1976). As well, chicks hatched from replacement clutches have been found to experience higher post-fledging mortality (Nisbet & Drury 1972). Other studies, however, suggest that moderate gull-egg harvest may not affect a gull population's stability or ability to increase (Vermeer *et al.* 1991, Zador 2006). Zador & Piatt (2007) studied the potential impacts of gull-egg harvest on the Glaucous-winged Gull population on South Marble Island in Glacier Bay using manipulative experiments and population modeling based on stochasticity of parameters including predation and onset of laying date, as observed over two field seasons (Zador & Piatt 1999, 2007; Zador *et al.* 2006). These authors concluded that frequent or late harvests may have a large negative impact on hatching success, but found that infrequent harvests early in the season had little impact on the ability of gulls to re-lay and successfully hatch chicks. Based on these results, the LEIS ROD (NPS 2010a & 2010b) outlined legal requirements for native egg harvest that required collaboration between NPS and HIA, as well as ongoing monitoring of gull populations to inform harvests.

The current study was designed to meet legal requirements to monitor Glaucous-winged Gull colonies in preparation for future traditional egg harvests. Our specific objectives were to 1) determine current locations of gull breeding colonies, 2) determine the distribution and abundance of nests and eggs in gull colonies likely to be harvested, 3) compare numbers of gull nests and adult gulls at colonies with data from surveys conducted in 2003–2005 (Arimitsu *et al.* 2007), 4) determine timing of onset of laying and hatching, 5) document the presence of other sensitive species including pinnipeds and other bird species that could be impacted by gull-egg harvest, and 6) collect baseline information on nesting habitat.

METHODS

Study area

Glacier Bay National Park and Preserve encompasses 13 289 km^2 in a northern area of southeast Alaska (Fig. 1). The temperate rainforest climate is characterized by cool summers and wet winters. Topography consists of rugged mountains rising to 4 633 m, ice fields with glaciers extending to sea level, and glacially carved mountains and valleys (Boggs *et al.* 2008). Glacier Bay itself is a deep marine fjord 100 km long. The bay was glaciated during the Little Ice Age until approximately 270 years ago (Connor *et al.* 2009); the subsequent rapid glacial retreat (Lawrence 1958) has allowed the land to rise, leading to progressive exposure of new land surface. Successional chronosequences vary in rate and character within the study area, but generally follow this path in low elevation sites: pioneer communities of algae/lichen, seral forbs, graminoids, and *Dryas drummondii* in areas deglaciated within 50 years; open and closed scrub 50–100 years; young forests within 100–300 years; and a mature community mosaic of old-growth forests with *Sphagnum* muskegs in areas that remained ice-free during the Little Ice Age (Chapin *et al.* 1994).

Ground and vessel surveys

Between 8 May and 15 August 2012–2015, we repeated ground surveys (one to five visits per site per year) of 20 islands and sections of shoreline in Glacier Bay for gulls; the islands and shoreline were selected based on historic observations (Fig. 1). We attempted to survey all gull colonies believed to be accessible by future egg harvesters to determine potential egg-harvest sites, the onset of laying, distribution and abundance of nests and eggs, as well as to characterize nesting habitat, and to identify other species present. We considered gull colonies to be potential egg-harvest sites if they had more than five nests, had been documented as gull-nesting sites for at least six years, and were accessible to harvesters without requiring specialized climbing equipment or safety ropes. We determined timing of onset of laying and hatching of gulls at potential harvest sites during these surveys by documenting the date of first eggs and/or date of first hatched chicks. A typical gull clutch contains two to four, but usually three eggs; one egg is laid every other day, from onset until a clutch is complete and incubation begins (Vermeer 1963). To determine the date of onset for a nesting colony when eggs were already present during our survey, we calculated onset as follows: if we located a maximum of one egg in any nest we considered onset to be that day; if we located a nest with 2 eggs we considered onset to have been 2 d previous; if we located one to two nests with three eggs, we considered onset to have been 4 d previous; and if we located three eggs in more than two nests, we did not attempt to calculate onset date. Occasionally, we determined the date of onset by subtracting 31 d from the date of the first chicks hatching, based on Patten's (1974) finding of average incubation duration of 26 d plus an egg-laying period of 5 d (Vermeer 1963). Egg predation may have confounded our determination of onset of egg-laying. Repeat visits were sometimes necessary to determine

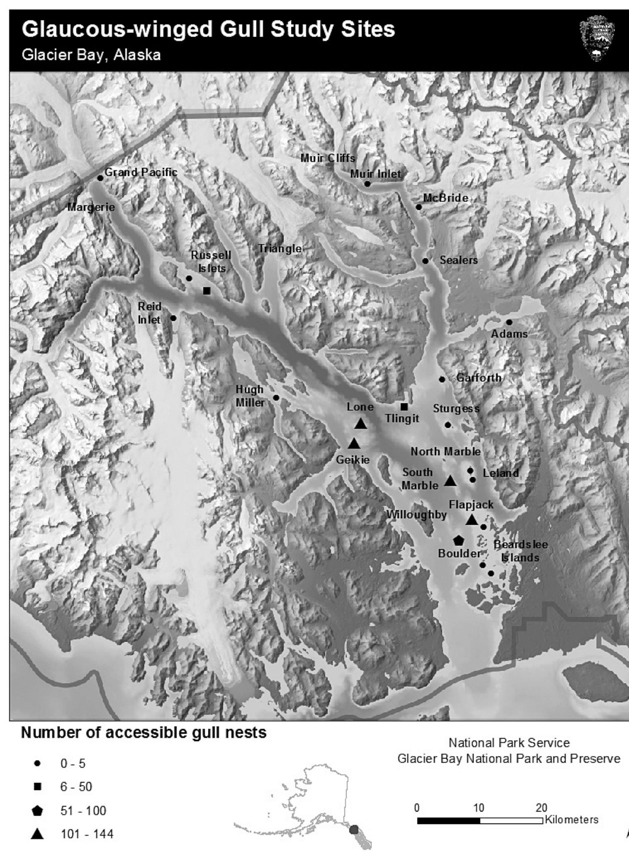

Fig. 1. Study area of Glaucous-winged Gull monitoring program, 2012–2015, Glacier Bay, Alaska. Points denote areas surveyed within this study, and likely harvest sites include colonies with more than five gull nests (see key on map).

onset of laying; however, only one complete nest count per colony per year in early June was used in analysis. During nest counts, two experienced observers walked adjacent transects throughout all accessible nesting areas; they counted nests that were accessible to humans by foot and therefore had the potential to be harvested. All active nests (including nests with live eggs, predated eggs, or evidence of recent use) were counted in areas accessible to human travel. We did not conduct surveys on cold rainy days, to prevent negative egg exposure. We determined the number of eggs available for harvest or hatching during ground surveys by counting the number of eggs during our last ground survey of each season, approximately 21–28 d after onset. Predation was assessed by counting the number of active nests surrounded by broken eggs with beak marks as well as documenting evidence (tracks, scat, and direct observations) of predators, including Northwestern Crows *Corvus caurinus*, Bald Eagles *Haliaeetus leucocephalus*, black and brown bears *Ursus americanus* and *U. arctos*, gray wolves *Canis lupus*, and river otters *Lutra canadensis*. Predation rate was calculated in 2015 by dividing the number of predated nests by the total number of nests in the colony. We discontinued ground surveys after chicks began to hatch, in order to minimize chick mortality from investigator disturbance. We recorded locations of nests and characterized surrounding vegetation at least once per season with a Trimble global positioning system (GPS) handheld unit (Trimble GeoExplorer3, Trimble Navigation Limited, Sunnyvale, CA, USA). On subsequent surveys in the same year, we tallied nest counts on paper instead of collecting GPS positions, to allow more rapid movement through the colony to minimize disturbance. We classified bird observations into one of five categories: adult, exhibiting nesting behavior; adult, unknown nesting; nest; juvenile (chick of the year); or immature. Adult birds were classified as nesting if they exhibited typical nesting behavior, including defensive behavior (alarm calls, wing displays, dive bombing, etc.), nest building, or incubating. Only birds exhibiting nesting behavior were included in nesting adult counts. Birds that were not chicks of the year yet did not have adult plumage were classified as "immature." During ground surveys, we also counted other species, including marine mammals and bird species that could be impacted by harvest activities.

We analyzed nesting vegetation type by colony for 2014 and 2015 and categorized it based on the vegetation immediately surrounding and adjacent (touching the perimeter of nesting materials) to each nest: graminoid — >75% grass including *Elymus, Puccinelia,* and other genera; herbaceous — >75% non-grass herb species; mixed graminoid/herb — >75% mixed grass and herb species; shrub — >75% low or tall woody vegetation; rock — >75% rock devoid of vegetation; and other — >75 % other substrate, including moss.

Each year we also conducted one to three vessel-based surveys between 15 May and 30 August to determine the number of breeding adult gulls and other species at each colony. Only results from one survey per colony per year (in late July or early August) were considered for analysis. We used high-powered binoculars from the bow of a motor vessel circumnavigating the islands at slow speed (<5 knots) from ~100 m distance. Two observers made consecutive counts of gulls on sections of the island until the difference in replicates was <10% and recorded final counts using a Trimble GPS handheld unit. Herring Gulls *Larus argentatus* are known to nest and hybridize with Glaucous-winged Gulls in Glacier Bay (Patten 1974, Zador & Piatt 1999, and pers. obs. during this study), so we counted both species together. We distinguished adult gulls from juveniles and counted these separately. We timed our vessel counts within 1 h of high tide to minimize the chances of breeding adults being elsewhere foraging in the intertidal zone, and we distinguished breeding adults from non-breeders by their location in the colony. Adults in the nesting areas were considered breeders, while adults and immature gulls in the intertidal zone were considered non-breeders. Before approaching gull-nesting islands for ground- or vessel-based surveys, the vessel circled the island at approximately 500 m while observers recorded hauled-out marine mammals.

We downloaded and exported all spatial data into a geographic information system (GIS) program (ESRI ArcGIS 10.1. Redlands, CA, USA). Spatial and non-spatial data were stored and summarized in an ArcGIS Geodatabase and Microsoft Access. We calculated means and 95% confidence intervals of numbers of gull adults and nests observed yearly over 2012–2015 for comparison with previous surveys using appropriate calculation tools in Microsoft Excel. Nest counts on South Marble Island during 2012–2015 were not comparable with counts during 2003–2005 because increased marine mammal distribution during the later period limited the amount of accessible area to survey.

RESULTS

Location of colonies

Of 15 gull colonies identified in the LEIS, three sites were inaccessible and six sites supported less than five nests. The remaining six sites (Boulder, Flapjack, Geikie, Lone, South Marble, and Tlingit) had five or more nests (Fig. 1) and were considered potential harvest sites. These six gull colonies were all located on islands ranging 1–6 km from the mainland. We also found an additional small colony of seven gull nests on the Russell Islets in 2014. However, the LEIS ROD (NPS 2010b) states that gull colonies must be present and documented for at least six years before that colony becomes open to harvest. Previous bird surveys have documented gulls on these islets (Arimitsu *et al*. 2007), but nesting was not verified before 2014. Russell Islets will therefore not be available until 2020, and thus we did not include this site in analysis.

Distribution and abundance of nests and eggs

The number of nests at potential egg-harvest sites ranged from a low of 22 nests on Tlingit Island in 2014 to a high of 174 nests on Flapjack Island in 2013. At each colony, the number of nests varied little among years (Fig. 2a). The total number of nests across all colonies was 667 in 2013 and 673 in 2015. Mid-season ground surveys could not be conducted on Geikie Island in 2012 or Lone Island in 2014 because of the presence of hauled-out harbor seals *Phoca vitulina*. As a result, the total nest count was considerably lower in these years. Although the number of nests remained relatively stable across years at a given colony, we found a substantial difference in productivity (Figs. 2b, 2c). In 2012, we observed total counts across colonies of 170 eggs in 519 nests (0.33 eggs/nest, excluding Geikie Island) and only one hatched chick. In 2013, we observed total counts of 1403 eggs in 667 nests (2.10 eggs/nest) and 437 hatched chicks. In 2014, we observed 1143 eggs in 466 nests (2.45 eggs/nest, excluding Lone Island) and 62 hatched chicks. In 2015, we observed a high count of 633 eggs in 673 nests (0.94 eggs/nest) and 41 hatched chicks.

The number of juveniles observed on South Marble Island during the vessel surveys represents a larger nesting area than that of the nests and eggs counted during the ground surveys because terrain and marine mammals limited access to portions of several colonies for ground surveys. Additionally, vessel-based surveys of juveniles may have been subject to high error rates because of the combination of cryptic chick behavior and plumage, seasonal density of island vegetation, low angle of sightability into topographically complex colonies, and variation in ambient light conditions at the time of survey. We were unable to count juveniles on Flapjack Island because of an extensive reef system surrounding the island that prevented vessel circumnavigation. As well, the number of eggs at Flapjack Island in 2015 may have been influenced by an experimental egg harvest (97 eggs) of a portion of the colony by members of the Hoonah Indian Association on 26 May 2015. Therefore, 2015 nest data were excluded from analysis. No other sites were affected in this way.

The number and percentage of predated nests, calculated from a 2015 ground survey, ranged from a low of 10% at Lone Island to a high of 28% at Tlingit Island. Predation rates were difficult to determine from our monitoring methods, because our observations were limited to shell fragments near nests. Additionally, predation may not be evident if eggs are carried away from the nest or consumed whole. Predation appears to differ among sites and was quite extensive in some locations. We observed crows and eagles at all gull colonies at least once during the study. We observed Northwestern Crows nesting in four of six gull colonies and one Bald Eagle's nest on South Marble Island. In 2012, all nesting gulls at Flapjack Island had abandoned their nests by 22 August, and multiple tracks and scats of bears were observed in the immediate area. No bear sign was documented at this colony or at any other potential egg-harvest site in any other year.

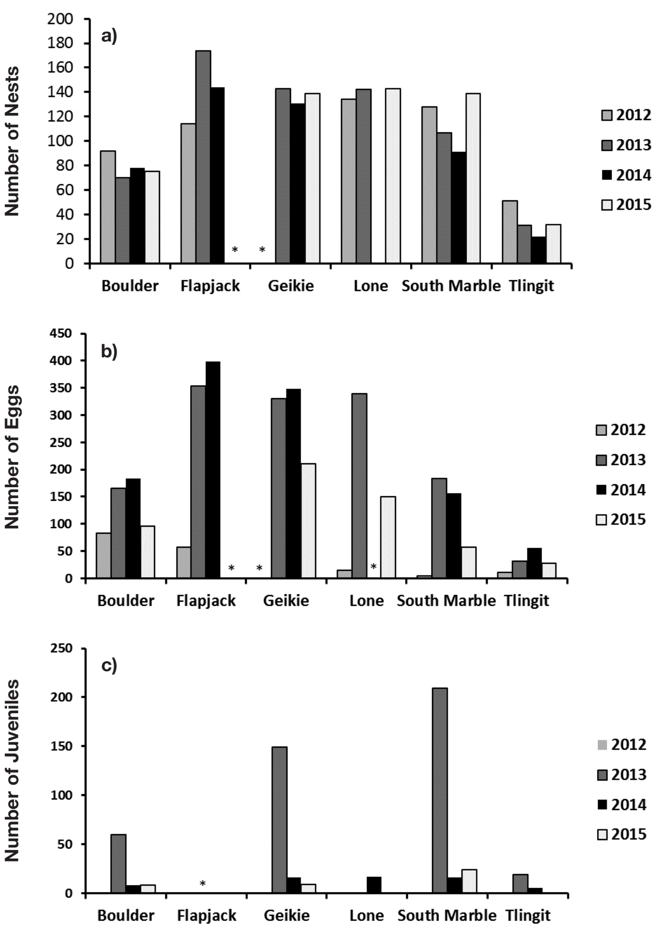

Fig. 2. Number of Glaucous-winged Gull nests (a), eggs (b), and juveniles (c) observed by year and colony in Glacier Bay, Alaska, 2012–2015. *The number of nests and eggs were not determined at Lone Island in 2014, and the number of juveniles at Flapjack Island was not determined in any year (see text for details).

Number of adults

The mean number of adult gulls varied by colony and year from a low of 51 (standard error [SE] 5.6; Tlingit Island) to a high of 805 (SE 58.1; South Marble Island), with Lone and South Marble islands showing the greatest variance among years (Fig. 3).

Comparisons with 2003–2005 surveys

The mean number of nests observed during 2012–2015 was significantly higher than those observed in single surveys taking place during 2003–2005 at every colony except South Marble Island (Fig. 4a). The number of nests on South Marble Island decreased substantially (200 nests in 2003–2005 and mean 116.25 SE 21 nests in 2012–2015), but these data cannot be compared because the survey areas differed between the two data sets owing to limited access due to Steller sea lions *Eumetopias jubatus* on portions of the island during 2012–2015. The area for the vessel surveys, however, remained the same between sampling periods, and the number of adult gulls on South Marble Island also decreased (Fig. 4b). The number of adult gulls on Lone Island also decreased, although the change was within the 95% confidence intervals of the 2012–2015 mean. The number of adult gulls in all other colonies increased significantly between single visits during 2003–2005 and mean totals increased during 2012–2015 (Fig. 4b). The mean combined decrease in nesting adults on South Marble and Lone islands (-287) does not equal the mean combined increase in nesting adults found on the other four main colonies (+446), indicating that gulls have not simply moved from one island to the other.

Onset of laying

Onset of egg-laying varied by year and colony (Table 1) from 9 May (Flapjack Island in 2014) to 26 May (Boulder Island in 2012 and

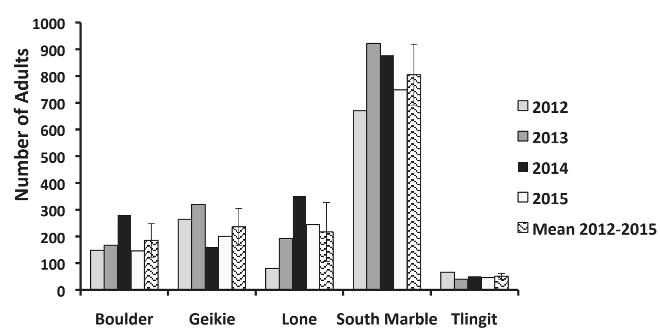

Fig. 3. Number of adult Glaucous-winged Gulls observed by year and colony in Glacier Bay, Alaska, 2012–2015. Error bars represent 95% confidence intervals. Adult gull numbers at Flapjack Island were not determined (see text for details).

2015). Onset of egg-laying did not appear to be synchronous across sites within Glacier Bay within a given year, even at sites near to each other. For example, onset of laying at Flapjack Island was 13 May but at nearby (~3.8 km) Boulder Island it was 26 May 2015.

Other species present at gull breeding sites

Hauled-out marine mammals protected from disturbance under the *Marine Mammal Protection* and/or *Endangered Species* acts were repeatedly present at various gull-nesting colony sites. Harbor seals were frequently present on land on Lone Island and Geikie Rock and occasionally observed at Flapjack and Boulder islands as well. Steller sea lions were always present on South Marble Island, although it was usually possible to access portions of the gull colony without approaching within 100 yards of sea lions. Sea otters *Enhydra lutris* were occasionally observed hauled out on Lone, Geikie, and Boulder islands and were observed a single time at Tlingit Island.

Several aquatic bird species, including Black Oystercatcher *Haematopus bachmani*, Arctic Tern *Sterna paradisaea*, Pigeon Guillemot *Cepphus columba*, Mew Gull *L. canus* and Canada Goose *Branta canadensis*, nested on the gull islands and could be disturbed by harvesting. Perhaps more sensitive would be Caspian Terns *Hydroprogne caspia,* also observed nesting at gull-egg collection sites (Table 2). Black-legged Kittiwakes *Rissa tridactyla* nest near several gull colonies, but disturbance from gull-egg harvest is unlikely to affect them, as the kittiwakes nest on inaccessible cliff faces. In addition, non-nesting birds such as Harlequin Duck *Histrionicus histrionicus,* scoters *Melanitta* spp., and Pelagic Cormorant *Phalacrocorax pelagicus* were observed on or near many gull colony islands. These birds could be vulnerable to disturbance from research and egg-harvest activities, particularly when molting in the later summer.

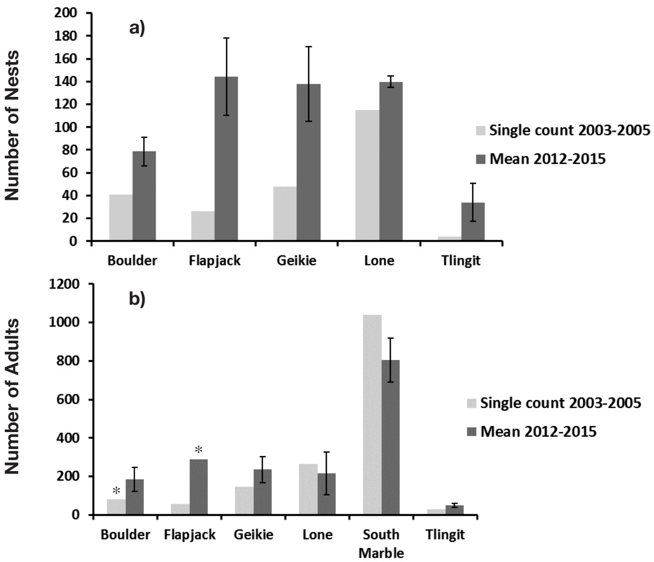

Fig. 4. Mean number of Glaucous-winged Gull nests (a) and adults (b) observed by colony in Glacier Bay Alaska, 2012–2015, compared with single surveys conducted during 2003–2005. Error bars represent 95% confidence intervals. *The mean number of adults on Flapjack Islands during 2012–2015 and the number of adults on Boulder Island in 2003–2005 were not counted directly but estimated by multiplying the number of nests observed at those locations in those years by two (assuming two adults for each nest).

TABLE 1
Dates of onset of egg laying of Glaucous-winged Gull colonies determined from ground surveys, 2012–2015, Glacier Bay, Alaska

Location	Date onset	How onset was determined
Boulder	26 May 2012	Nest with 2 eggs found on 28 May
Boulder	18 May 2014	Nest with 1 and 2 eggs found on 20 May
Boulder	26 May 2015	Nests with 1 egg on 26 May
Flapjack	9 May 2014	Chicks hatching on 9 June
Flapjack	13 May 2015	Nest with 1 egg found on 13 May
Geikie	10 May 2014	Chicks hatching on 10 June
South Marble	21 May 2013	Nests with 1 and 2 eggs on 23 May
Tlingit	22 May 2013	Nests with 1 egg on 22 May

TABLE 2
Hauled-out marine mammals and nesting seabirds present at Glaucous-winged Gull colonies, 2012–2015, Glacier Bay, Alaska

Location	Harbor Seal	Steller Sea Lion	Sea Otter	Proportion of visits with marine mammals present	Arctic Tern	Black-legged Kittiwake	Black Oystercatcher	Canada Goose	Caspian Tern	Common Murre	Mew Gull	Pigeon Guillemot	Tufted Puffin	Number of species of nesting seabirds
Boulder	X	–	X	0.44	X	–	X	–	–	–	–	–	–	2
Flapjack	X	–	X	0.44	X	–	X	–	X	–	–	–	–	3
Geikie	X	–	X	0.56	X	–	X	X	–	–	–	X	–	4
Lone	X	–	X	0.86	–	X	X	–	–	–	–	X	X	4
Russell	–	–	–	0.00	X	–	X	–	–	–	X	–	–	3
South Marble	–	X	–	1.00	–	X	X	–	–	X	–	X	X	5
Tlingit	–	–	X	0.09	X	–	X	X	–	–	X	X	–	5

Nesting habitat

We documented vegetation type surrounding gull nests at five potential egg harvest locations once per year during 2014 and 2015. We could not access Lone Island in 2014 because of marine mammal presence, so we used data from 2013 and 2015 to analyze vegetation type at that location. Among a total of 1 281 nests spanning two years, we found 861 nests (67%) in graminoid vegetation, 192 nests (15%) in mixed graminoid/herbaceous vegetation, 156 nests in non-vegetated rock (12%), and 61 nests (5%) in herbaceous vegetation (Fig. 5). Flapjack and South Marble islands had the highest number of nests in herbaceous and mixed graminoid/herbaceous vegetation; Boulder Island and Geikie Rock had the highest proportion of nests built on rock; and South Marble Island was the only location where a small number of nests ($n = 3$) were found in scrub vegetation.

DISCUSSION

Colony distribution and abundance

We found Glaucous-winged Gull nesting colonies accessible to harvest at only six of 15 locations listed for potential egg harvest in the LEIS. Because preference for egg harvest will be given to sites that have not incurred recent disturbance (NPS 2010b), the low number of harvestable colonies may make site selection difficult to minimize repeated harvesting at the same sites. Four of the six harvestable nesting colonies have grown since 2005 (Boulder, Flapjack, Geikie, and Tlingit), which may allow for a yearly egg harvest from single islands yet still allow for rotation of harvest sites. High recruitment, immigration, decreased mortality, or a combination of factors appear to have led to an increased number of nesting gulls on at least four of six colonies.

Glaucous-winged Gulls nested most frequently (67%) in graminoid vegetation and least frequently in woody/scrub vegetation among colonies in Glacier Bay. Historic biological inventories and NPS ranger logs in Glacier Bay document several Glaucous-winged Gull nesting colonies that no longer exist, likely as a result of vegetative succession. For example, Patten (1974) studied over 1 000 gulls nesting on North Marble Island, but Arimitsu *et al.* (2007) found only six nests. Baily (1927) and Wik (1967) documented several other notable gull nesting sites, including Triangle, Sealers, Willoughby, and many of the Beardslee islands, that were found to be inactive (less than five nests) by Arimitsu *et al.* (2007) or this study. These islands were described in the 1920–1950s as treeless, with bare rock and some grass cover, whereas today these islands are dominated by herbaceous and woody vegetation. Conversely, Lone and South Marble islands have been documented as gull nesting sites since at least in the 1930s (NPS, unpublished data) and still support abundant, although possibly declining, gull nesting activity. Herbaceous and woody vegetation is present on these islands, but fairly large areas of rock and grass areas are also present, supporting the majority of the gull nests found there. Gull nesting colony locations will likely change over time, as graminoid plant communities mature into shrubs and eliminate nesting substrate, while new islands emerge as a result of isostatic rebound and develop into future nesting habitat.

Arimitsu *et al.* (2007) documented 77 adult Glaucous-winged Gulls with 31 nests in northern Muir Inlet in 2004 and 2005. During the current study, we surveyed this area multiple times by ground and vessel and found a maximum of only two nests. The area is covered with early successional vegetation that likely has not changed significantly in the past 10 years. The reduction in nesting at this colony does not appear to be driven by recent vegetation shift, but may be related to terrestrial predators, including brown bears, whose activity levels in this area appears to be increasing (T. Lewis, field obs.). Avian or mammalian predation on gull eggs can lead to reproductive failure, triggering dispersal or even complete colonial abandonment (Ewins 1991, Oro 1999, Spear & Anderson 1989, Sullivan *et al.* 2002, Cowles *et al.* 2012). Eagles prey on adult, juvenile, and nestling gulls, as well as on eggs (Hayward 2010, Cowles *et al.* 2012), and colony disturbance by eagles has been found to facilitate predation by corvids (Verbeek 1982). Several studies found eagle predation contributing to significant declines in Glaucous-winged Gull populations over time (Sullivan 2002, Hayward 2010, Blight *et al.* 2015). We suspect that the more advanced vegetation succession on South Marble Island not only reduces suitable gull nesting habitat, but may also support predators such as eagles and crows, explaining the gull nesting decline. Ewin (1991) found predation to be higher on wooded islands, and Cowles *et al.* (2012) found eagle predation higher for gull nests in tall grass, presumably because the trees and grass offer protection to eagles from gull attacks. We found no evidence of egg cannibalism by gulls. Zador (2001) observed conspecific predation upon chicks, but did not observe egg cannibalism on South Marble Island. Burger (1977) found that territorial aggression by conspecifics decreases with increased vegetation, decreased inter-nest visibility, or increased territory size. The dense vegetation at some colony sites of Glacier Bay may facilitate eagle predation, while decreasing interspecies conflict by reducing territorial vigilance, conspecific predation, and egg cannibalism.

Onset of laying

A key component to the timing of future egg harvests is the onset of laying; the LEIS ROD requires that the first harvest occur within five days of laying onset. We found onset of laying to be highly variable across years and among colonies during the same year, making the use of a single reference site impractical. Verhulst & Nilsson (2008) found that "exceptional" individuals may lay significantly earlier than the bulk of the colony in years of high food availability, exhibiting higher reproductive success than later breeders. Varying predation across sites may further affect egg-laying synchronicity. Predation will also affect how many eggs are present when harvesters arrive.

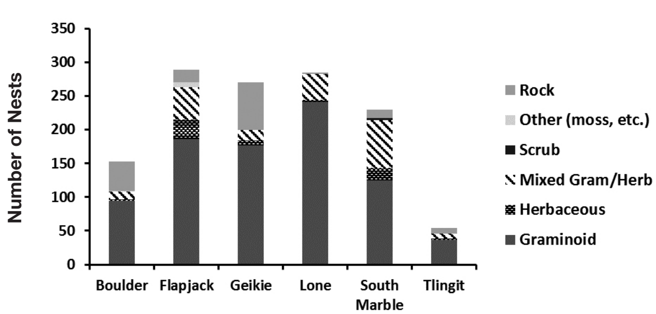

Fig. 5. Vegetation type surrounding Glaucous-winged Gull nests during 2014 and 2015 (with the exception of Lone Island, for which data were collected in 2013 and 2015) at colonies in Glacier Bay, Alaska.

Factors to consider for effective management strategies

Potential disturbance of other species. Hauled-out marine mammals can limit harvesters' access to gull eggs, particularly on South Marble Island, because vessels will not be permitted to approach within 100 yards (91.44 m) of hauled-out marine mammals (NPS 2010b; note that the regulations use British imperial rather than the SI international system of units).

In addition to the 100-yard minimum approach distance to hauled-out marine mammals, sites that do not serve as marine mammal haul-outs are preferred harvest locations (NPS 2010b). Unfortunately, we found that all of the larger gull colony islands currently serve as haul-out locations for marine mammals, although some are used more frequently than others (Table 2). South Marble Island (Steller sea lions present during 100% of visits), Lone Island (harbor seals and/or sea otters present during 86% of visits), and Geikie Rock (harbor seals and/or sea otters present during 56% of visits) had the highest frequencies of hauled-out marine mammals during this study. Additionally, marine mammals are most likely to be disturbed during egg harvest at these locations because of the proximity of haul-out locations to either gull nesting areas or to vessel access points on the island. At Boulder and Flapjack islands (harbor seals and sea otters present during 44% of visits), marine mammals usually hauled out on the south side of the islands, whereas gull colonies and access points are located on the north side and could generally be accessed without disturbing the marine mammals. Tlingit Island (sea otters present during 9% of visits) was the only island that did not frequently support hauled-out marine mammals.

Sites that support few other nesting bird species are preferred gull-egg harvest locations (NPS 2010b). Boulder Island had only two other nesting species, whereas South Marble and Tlingit islands had the greatest diversity of nesting birds with five each, followed by Geikie Rock and Lone Island with four other nesting species. As is the case with hauled-out marine mammals, each island has unique potential for disturbance of other bird species, based on the topography and spatial segregation of Glaucous-winged Gulls versus other nesting birds. On South Marble and Lone islands, accessible gull nests are largely segregated from other nesting birds, so little disturbance to other birds would be expected. However, on Geikie, Flapjack, Tlingit and Boulder islands, Black Oystercatchers, Arctic Terns, Caspian Terns, and Pigeon Guillemots were found nesting close to Glaucous-winged Gulls and could be affected by gull-egg harvest.

Other biophysical factors that could affect gull populations. In addition to shifts in nesting habitat and predation, several other physical and biological variables likely influence the nesting distribution, abundance, and yearly productivity of gulls in Glacier Bay. Population dynamics and reproduction of seabirds are influenced by food supply (Monaghan *et al.* 1992), and poor food availability may contribute to decreased productivity, particularly among younger gulls (Sydeman *et al.* 1991). Mature gulls are found to breed earlier, lay larger clutches, and fledge more chicks than younger gulls, which show greater rate of decline in productivity under conditions of poor food availability (Sydeman *et al.* 1991). Food availability may also be a factor in nesting location and yearly productivity of seabirds, and decreased food availability may increase predation and cannibalism rates (Gonzalez-Solis 1997, Regehr & Montevecchi 1997, Stenhouse *et al.* 1999). Blight (2011) argues that long-term forage fish reduction has resulted in egg and clutch size decline in Glaucous-winged Gulls in the Salish Sea, Canada.

Mills *et al.* (2008) found that climate fluctuations and annual weather conditions affected food availability and the reproductive performance of gulls. Cold weather or high-precipitation seasons may be associated with altered nesting behavior to compensate for egg temperature in Herring Gulls (Drent 1970), increasing energetic demand upon parents, which may reduce long-term adult fecundity (Hannsen 2005). Cold-water conditions can cause delays in the arrival of capelin *Mallotus villosus* and thus food shortage during the pre-laying period, reducing egg and clutch size in kittiwakes and gulls (Regehir & Montevecchi 1997). During years of low forage fish availability, gulls in Aialik Bay, Alaska, which feed primarily on blue mussels *Mytilus* spp. before egg laying, exhibited poor reproductive performance (Murphy *et al.* 1984). In 2012, in our study, May daytime temperatures were 8°F (4.44 °C) below normal, and June was the wettest on record (NWS 2015). These factors may have influenced the poor productivity of Glaucous-winged Gulls that year. The summer of 2013, on the other hand, was consistently warm and sunny (NWS 2015), possibly influencing the high number of eggs and chicks observed that year.

Increasing evidence indicates that warming sea surface temperature (SST) may have negative effects on gull productivity. Hayward *et al.* (2014) found that cannibalism increased and natality decreased in Glaucous-wing Gulls during years of high SST. Similarly, Tomita *et al.* (2009) found that high early-season (March) SST was associated with reduced clutch size in Black-tailed Gulls *Larus crassirostris*, possibly due to a mismatch in timing with the euphausiid life-cycle during warm years. Hipfner (2012), however, found no relationship between SST and productivity in Glaucous-winged Gulls.

Given the interannual variability in weather and egg productivity that we witnessed during 2012–2015, we can anticipate that the number of gull eggs harvested may be highly variable across years. For example, in 2012, the maximum number of eggs counted at a single colony was 83 eggs on Boulder Island, whereas the maximum on South Marble Island was only four eggs (Fig. 2b). In contrast, harvesters may be able to access hundreds of eggs from single colonies in more productive years such as was the case during 2013 and 2014.

Future monitoring

Baseline monitoring is mandated to manage the gull-egg harvest to "help ensure that harvest activities are not impacting park purpose and values" (NPS 2010b). This monitoring, conducted for four years to date in preparation for the Huna Tlingit egg harvest, generated basic information on distribution and abundance of nesting gulls at locations accessible to egg harvest, documented other species that may be affected by egg harvest, and provided snapshots of egg productivity each year. However, this information is inadequate to assess true yearly productivity (i.e., fledging success), the causes of yearly variations in egg numbers and egg mortality, or the effect of human egg harvest on long-term trends in gull populations. Quantifying variables driving yearly productivity is critical to fully understand the impacts of gull-egg harvest, but would require a significantly greater investment in funding, which in turn would affect effort. Recent work by Hayward *et al.* (2014) and Smith *et al.* (2016) correlating yearly gull productivity with

SST from the previous autumn may provide insights for a useful and cost-effective monitoring tool in planning egg harvest. For example, in years of higher fall SST, egg harvest plans for the following spring may be conservative, based on the assumption that breeding success will be minimal, whereas when fall SST are lower, egg harvest plans may be liberalized, assuming gulls will be able to replace clutches readily.

Despite the limitations outlined in the ROD, the current data collection represents a significant advance in monitoring of gull-egg harvests. The effects of egg harvest on seabird breeding success have been studied by Zador *et al*. (2006), Wood *et al*. (2009), and Chen *et al*. (2015), and several studies report on the quantity and species of migratory bird and egg harvest by subsistence users (Wentworth 2004, Naves & Zeller 2013,Young *et al.* 2014, Naves 2015). However, long-term monitoring of the biological impacts of gull-egg harvest in order to manage this harvest is rare to non-existent. The only comparable gull-egg harvests elsewhere in Alaska are regulated by the US Fish and Wildlife Service (FWS) and the Alaska Migratory Bird Co-Management Council under the 1997 amendment to the *Migratory Bird Treaty Act*. The FWS does not conduct biological research or monitoring on the amount or effects of indigenous gull-egg harvest in southeast Alaska, using a comparatively "hands-off" approach to harvest management (Lurman-Joly & Behnke 2016). Gull-egg harvest management is a nascent field, and the NPS has an opportunity for learning and innovation using adaptive management tools. The LEIS ROD (NPS 2010b) and the *Huna Tlingit Traditional Gull Egg Use Act* (Public Law 113-142) direct the NPS and HIA to cooperatively develop a yearly harvest plan to manage the Glacier Bay gull-egg harvest. In combination with yearly monitoring, the harvest plan presents an opportunity for science-based collaborative management by multiple stakeholders. In addition to yearly monitoring of gull colonies, research on nesting habitat shifts, food availability, and predation will be important to ascertain the long-term effects of egg harvest on the distribution and abundance of Glaucous-winged Gulls in Glacier Bay National Park.

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