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Risk of Predation and Weather Events Affect Nest Site Selection by Sympatric Pacific (*Gavia pacifica*) and Yellow-billed (*Gavia adamsii*) Loons in Arctic Habitats

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Abstract.—Pacific (*Gavia pacifica*) and Yellow-billed (*G. adamsii*) loons nest sympatrically in Arctic regions. These related species likely face similar constraints and requirements for nesting success; therefore, use of similar habitats and direct competition for nesting habitat is likely. Both of these loon species must select a breeding lake that provides suitable habitat for nesting and raising chicks; however, characteristics of nest site selection by either species on interior Arctic lakes remains poorly understood. Here, logistic regression was used to compare structural and habitat characteristics of all loon nest locations with random points from lakes on the interior Arctic Coastal Plain, Alaska. Results suggest that both loon species select nest sites to avoid predation and exposure to waves and shifting ice. Loon nest sites were more likely to be on islands and peninsulas (odds ratio = 16.13, 95% CI = 4.64-56.16) than mainland shoreline, which may help loons avoid terrestrial predators. Further, nest sites had a higher degree of visibility (mean degrees of visibility to 100 and 200 m) of approaching predators than random points (odds ratio = 2.57, 95% CI = 1.22-5.39). Nests were sheltered from exposure, having lower odds of being exposed to prevailing winds (odds ratio = 0.34, 95% CI = 0.13-0.92) and lower odds of having high fetch values (odds ratio = 0.46, 95% CI = 0.22-0.96). Differences between Pacific and Yellow-billed loon nesting sites were subtle, suggesting that both species have similar general nest site requirements. However, Yellow-billed Loons nested at slightly higher elevations and were more likely to nest on peninsulas than Pacific Loons. Pacific Loons constructed built up nests from mud and vegetation, potentially in response to limited access to suitable shoreline due to other territorial loons. Results suggest that land managers wishing to protect habitats for these species should focus on lakes with islands as well as shorelines sheltered from exposure to prevailing wind and ice patterns. Received 13 January 2013, accepted 9 April 2013.

Key words.—Alaska, breeding, *Gavia adamsii*, *Gavia pacifica*, nest microhabitat, North Slope, Pacific Loon, Yellow-billed Loon.

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Nest site selection can be an important factor in determining the breeding success of birds (Misenhelter and Rotenberry 2000). The location of a nest can determine degree of exposure to biotic influences such as predation and competition (e.g., Nilsson 1984; Martin and Roper 1988; Misenhelter and Rotenberry 2000), as well as abiotic influences such as microclimate conditions and weather events (e.g., Calder 1973; Burger and Shisler 1978; Donázár *et al.* 1993). Thus, nest site selection can be directly related to fitness, and breeding birds are expected to increase chances of nest survival by selecting nest sites that limit the influences of negative abiotic and biotic factors (Martin 1998, 2001). Adaptive evolutionary pressures on

nest site selection for sympatric and closely related species may lead to habitat partitioning during breeding (Martin 1998, 2001).

Pacific (*Gavia pacifica*) and Yellow-billed (*G. adamsii*) loons commonly nest sympatrically in Arctic regions (Groves *et al.* 1996; Hodges and Eldridge 2001). Both species migrate from coastal marine wintering areas to nest on the extensive lentic habitats available in the Arctic. Individuals of these species are thought to select breeding habitat at two scales: selection of a nesting lake and selection of the nest site within the lake (Russell 2002).

Prior work on the breeding habitat of these two loon species suggests that nest site selection at the lake scale differs among spe-

cies largely according to water body characteristics, particularly size. Yellow-billed Loons select large, connected lakes that have potential refuges for overwintering fish populations (Stehn *et al.* 2005; Earnst *et al.* 2006), while Pacific Loons often choose comparatively smaller, less productive lakes and, thus, may be more likely to forage away from the nesting lake (Russell 2002). Because Pacific and Yellow-billed loons overlap in distribution and have similar habitat requirements, they commonly occupy the same lake (North 1994; Earnst *et al.* 2006; Haynes *et al. in press*). In contrast, a third sympatric nesting species, the Red-throated Loon (*G. stellata*), nests on small, shallow ponds that generally do not contain fish (Davis 1972; Bergman and Derksen 1977; Derksen *et al.* 1981) and, thus, rarely nest on lakes of the size used by Pacific or Yellow-billed loons (Barr *et al.* 2000).

The relative importance of nest site selection within a lake, at the scale of the shoreline, in comparison to selection at the lake scale is not well understood. Only a handful of studies describe nest site selection by Pacific or Yellow-billed loons in the Arctic at the shoreline scale (Davis 1972; Petersen 1976; Bergman and Derksen 1977; North and Ryan 1989). Studies conducted in Alaska suggest that in coastal areas both species generally select low elevation, sheltered lake shorelines that are close to the water and prefer nesting on islands or peninsulas (North 1994; Russell 2002). However, based on earlier work, one hypothesis is that reproductive success of loons that breed in the Arctic is determined by the nest site characteristics that shield nests from predation (Petersen 1979) and waves and shifting ice (North and Ryan 1989), the two primary causes of breeding failure. Further, nest site selection at the shoreline scale may influence lake selection at the larger scale if suitable nest locations are rare or unavailable within a lake.

Thus, in some cases, nest site selection may be more important than nesting lake selection as predation and exposure to waves and ice appear to be two major sources of mortality for these species. Despite extensive co-occurrence, previous research has

not contrasted the microhabitat of selected nest sites within lakes between Pacific and Yellow-billed loons. This study assesses and compares nest site selection within lakes by Pacific and Yellow-billed loons on the interior Arctic Coastal Plain by examining: 1) site characteristics selected by these two species of loons compared to what is available; and 2) differences between the nest site characteristics of Pacific and Yellow-billed loons.

METHODS

Study Area

The Arctic Coastal Plain is a 98,200-km² area of Arctic tundra that extends across the entire northern coastal region of Alaska and is bounded by the Brooks Mountain Range to the south (Liebezeit *et al.* 2009). The low relief landscape is dominated by shallow lakes, making the Arctic Coastal Plain the second largest major lake region in Alaska (Arp and Jones 2009). Most lakes in this region are relatively shallow, with depths < 2 m over most of lake area and many with no water > 2 m in depth (Jefferies *et al.* 1996). Lake ice generally achieves a thickness of 1.5-2.0 m over a winter season (Arp *et al.* 2011); thus, depending on depth, the lake volumes can freeze partially or entirely during the winter months. During spring, melt water from snow and ice causes an initial increase in lake water levels, followed by a general decrease in water levels throughout the summer season (Arp *et al.* 2011).

This study focuses on a region within the National Petroleum Reserve in Alaska west of Teshekpuk Lake bounded longitudinally by the Meade and Ikpikpuk Rivers. The study area was focused in an area of relatively high Pacific and Yellow-billed loon density. To examine characteristics of Pacific and Yellow-billed loon nest sites, lakes > 7 ha in surface area ($\bar{x} \pm SD = 57.9 \pm 79.1$) were selected from 15 plots, 7 x 7 km in dimension, that were randomly distributed across the study area. These plots were chosen from a larger sample of plots that are part of previous and ongoing loon surveys (Stehn *et al.* 2005; T. B. Haynes and J. A. Schmutz, unpubl. data). Lakes > 7 ha in area were chosen because Yellow-billed Loons tend to select lakes larger than this size (Stehn *et al.* 2005; Earnst *et al.* 2006).

Observers accessed plots for nest-searching by amphibious fixed-wing plane and lakes within a plot on foot from late June to mid-July in 2010 and 2011. The number of lakes sampled within a plot depended on field logistics, including ease of access, weather and flight schedules. Lakes were surveyed by one to two observers who walked the entire perimeter of each lake about 1 m from the water's edge. The entire shoreline was checked, but observers also used behavioral cues from breeding loons to locate nests. In the case of two observers, each observer walked a portion of the lake

with no overlap. Observers checked for nests on all islands that were accessible with chest waders. In 2010, observers sampled three random points (available but unused for nesting) along the shoreline of each lake as points of comparison to nest sites. If a random point was within 100 m of a loon nest, a new point was randomly selected to avoid spatial overlap with nest sites. Random point data were not collected in 2011, and comparisons between nests and random points were thus restricted to 2010 data (see below).

For each nest, observers measured the diameter of the inside of the nest bowl and the nest depth (bottom of the bowl to the rim). Based on nest characteristics, observers also identified whether the nest was a “depression type” – constructed on existing shoreline over a few hours (Russell 2002; North 2008) or a “built-up type” – constructed over 2 days in marshy areas by mounding mud and vegetation to build up a nest bowl on a location that would otherwise be covered by shallow water (Davis 1972; Bergman and Derksen 1977). At active nests, the length and width of eggs were measured along the major and minor axes using calipers, and eggs were floated to determine the development stage (Rizzolo and Schmutz 2007). Because no flotation model is currently available for Yellow-billed Loons and because they have similar incubation periods as Pacific Loons (North 1994; Russell 2002), their eggs were aged using the flotation model for Pacific Loons. Estimates of the mean nest initiation for each species in each year were calculated using float stage-specific estimates of hatch and associated sampling error (Rizzolo and Schmutz 2007). Observers identified loon species associated with the nest by directly observing adults or differences in egg size (Bowman 2004).

At each sample location (random point or nest), site characteristics were measured including: 1) shoreline type; 2) degrees of visibility; 3) wind fetch; 4) location relative to prevailing wind; 5) elevation of the site; and 6) water depth. Shoreline type was classified as island, peninsula or mainland. An island was defined as exposed land completely surrounded by water and at least 2 m from shore. The areas of sampled islands (islands with loon nests or random points) were estimated by the observers. Peninsulas were defined as an area of shore 4 m or less in width that projected from the shore at least 3 m. Remaining sites were placed in the mainland category. Although peninsula sites are technically part of the mainland shoreline, they may provide a more defensible nest site, similar to island nest locations (Bergman and Derksen 1977). Thus, shoreline was treated as a binary variable for the analysis of nests vs. random points with the location considered either mainland shoreline or island/peninsula. Visibility of the surrounding landscape from the sample site was determined by estimating the degrees (0-360) of unobstructed view at a height of 0.3 m above the nest (about the eye height of a loon on the nest, North and Ryan 1989) to a distance of 100 and 200 m. The degree of visibility for the site was calculated as the mean of the 100 m and 200 m values. Fetch was estimated in the field as the distance to an adjacent shoreline across the

water (up to 500 m) in five directions from the sample location relative to the shore: perpendicular, 45° angle to the right and left, parallel to the right and left. The value for the site was calculated as the mean of the fetch from the five directions. Exposure to prevailing north-easterly winds (Hinkel *et al.* 2005) was assessed according to site location. Sites on the west or southwest shore of a lake were classified as exposed to prevailing winds, and all other locations were considered unexposed. Using a line level, elevation of the site was measured as the vertical distance from the water line to the nest bowl or 1 m from water's edge for random points. Water depth was calculated as the mean depth of the water measured at 1 m and 5 m perpendicular distance from the shoreline.

Nests vs. Random Points

Differences between nest sites and random points within a lake were examined using data from 2010. Because the nest site is paired with the set of random points within lakes (1-many matched case-control design, Hosmer and Lemeshow 2000), data were modeled using conditional logistic regression, which links use (nest sites) and availability (random points) within strata (Manly *et al.* 2002; Keating and Cherry 2004; Thomas and Taylor 2006), where stratum here is an individual lake. To accommodate the 1-many paired design, extra nest sites at lakes with multiple nests were excluded such that each lake contributed one nest to the analysis. Nests within a lake were excluded at random except for multi-species lakes where Yellow-billed Loon nests were retained because they were generally rare. Candidate models were built from covariates that could be grouped in terms of relation to nest predation (degree of visibility, water depth and shoreline type) or exposure to waves and shifting ice (elevation, fetch and exposure to prevailing wind). Interactions examined included a quadratic term for elevation and an interaction effect between exposure to prevailing wind and fetch. Continuous covariates were standardized by calculating z-scores (Donovan and Hines 2007) and covariates were tested for collinearity (any $r \geq 0.60$ was considered a violation of model assumptions).

Candidate model sets were evaluated using an information-theoretical approach (Burnham and Anderson 2002). Competing models, including a model containing all covariates and a null model, were ranked using the change in Akaike's Information Criterion corrected for sample size (ΔAIC_c , Burnham and Anderson 2002). In addition to models that contained variables either related only to predator or exposure effects, a model was built that contained the covariates from the top models (according to AIC ranking) of both the predator and exposure subsets. Goodness-of-fit of the most complex model was assessed using the Hosmer and Lemeshow statistic (Hosmer and Lemeshow 1989).

Effect sizes were interpreted by examining the odds ratios because conditional logistic regression can lead to biased beta parameters when calculating resource selection functions (Keating and Cherry 2004). Odds ratios (Exp(B)) can be interpreted as the increase or decrease

in the odds of being selected as a nesting site (nests vs. random points analysis) given a one unit increase in the standardized continuous covariate or change in state of a categorical covariate. This interpretation required the assumption that the probability of use is low for all available habitat (Keating and Cherry 2004), a reasonable assumption in this case.

Pacific vs. Yellow-billed Loon Nests

Logistic regression (non-conditional) was used to contrast nest site characteristics of Pacific and Yellow-billed loons using data from 2010 and 2011. The covariates considered were the same as the covariates listed above for the random point vs. nest site with the following additions: 1) distance of nest to the water was included in the exposure covariate set (creating eight additional models to consider in the exposure subset); and 2) shoreline variable was split into the three original categories (mainland, peninsula and island). Information-theoretic model selection was used as described above for the analysis of random point to nest location. All models were run in SPSS (SPSS, Inc. 2006).

RESULTS

A total of 192 lakes were sampled (2010, $n = 138$; 2011, $n = 54$), 81 of which had Pacific and Yellow-billed loon nests (2010, $n = 45$; 2011, $n = 36$). An additional Pacific Loon nest and two Yellow-billed Loon nests were not included in the analysis of nest site selection because they were located on old river courses that are now cut off, an unusual water body feature in our study area. Seventeen lakes had multiple nests (Range = 2-6 nests), but no lake had more than one Yellow-billed Loon nest. Pacific Loon nests were far more common ($n = 89$ nests) than Yellow-billed Loon nests ($n = 24$). Almost all Pacific Loon nests (88%) and Yellow-billed Loon nests (96%) had two eggs, while the rest of the active nests had one egg, which may be a result of partial predation (Petersen 1979; Götmark *et al.* 1989). Based on egg flotation estimates, nests in 2011 had slightly earlier mean initiation dates and, on average, Yellow-billed Loons initiated nests before Pacific Loons. Pacific Loons had a mean nest initiation date of 22 June (SE = 5, $n = 54$) in 2010 and 21 June (SE = 3, $n = 27$) in 2011. Yellow-billed Loons had a mean nest initiation date of 19 June (SE = 8, $n = 15$) in 2010 and 17 June (SE = 5, $n = 8$) in 2011.

Compared to Pacific Loon nests, Yellow-billed Loon nests were, on average, larger in diameter (mean \pm SD = 34 ± 7 cm vs. 24 ± 5 cm) and had a deeper nest bowl (mean \pm SD = 7 ± 5 cm vs. 4 ± 5 cm). Although Yellow-billed Loon nests were generally larger, both diameter and depth were highly variable and differences between species were minor, suggesting that nest size characteristics cannot be used to distinguish species. Most nests (90%) were within 1 m of the water; however, three Pacific Loon nests were found further than 3 m from the lake edge and, at one lake, a Yellow-billed Loon nest was found 10 m from the lake edge. A Yellow-billed Loon chick was detected on this lake 29 days later, suggesting the nest was successful. The majority of the Pacific Loon nests and all Yellow-billed Loon nests were depression-type nests. At least eight pairs of Pacific Loons constructed built-up nests (five in 2010, three in 2011). Similar to Bergman and Derksen (1977), built-up nests were less than 1 m². Over half the Pacific Loon nests (54.9%) were on islands averaging 648 m² (SD = 2,594 m²) in area, while only two nests (2%) were on peninsulas. For Yellow-billed Loons, the majority of nests were either located on islands (31%, mean area = 919 m², SD = 2,564 m²) or peninsulas (34%). The remaining nests were located along mainland shorelines.

For both the nest vs. random point analysis and the Pacific vs. Yellow-billed loon analysis, there were no instances of high correlation among covariates and, therefore, all variables were retained. For the analysis of nests vs. random points, the top two exposure models had Δ AIC_c within one AIC_c unit, and so two "combination" models (models that included the top exposure and predation covariates) were included. The Hosmer and Lemeshow goodness-of-fit test for both model sets suggested that the most complex models of the respective datasets fit the data.

Nests vs. Random Points

The top model comparing nests with random points included two covariates related to predator avoidance (shoreline type and

degree of visibility) and two related to exposure to waves and ice (fetch and location relative to the prevailing wind; Table 1). The second ranked model ($\Delta AIC_c = 2.78$) was similar except it excluded the fetch covariate. The remaining models received little support (summed model weights = 0.07). Only models with a $\Delta AIC_c > 12$ are reported (Table 1). Loons used islands and peninsulas disproportionately compared to what was available (odds ratio = 16.13, 95% CI = 4.64-54.16; Table 2), and sites with a higher degree of visibility to the surrounding area increased the odds of the presence of a nest at the location (odds ratio = 2.57, 95% CI = 1.22-5.39). As fetch increased or if a site was exposed to prevailing winds, the odds that the site was a nest location decreased (fetch odds ratio = 0.46, 95% CI = 0.22-0.96; prevailing winds odds ratio = 0.34, 95% CI = 0.13-0.92).

Pacific vs. Yellow-billed Loon Nests

The top model comparing Pacific Loon nests to Yellow-billed Loon nests included shoreline type covariate and the quadratic relationship for elevation (Table 3). The second ranked model, which was the quadratic elevation model without the shoreline covariate, had a ΔAIC_c score > 3 units. Compared with Pacific Loons, Yellow-billed Loons had higher odds of nesting on peninsulas (odds ratio = 6.23, 95% CI = 1.28-30.29), but had similar odds of nesting on an island (odds ratio = 1.23, 95% CI = 0.32-4.77; Table 4). The odds of the nest being a Yellow-billed Loon nest increased in a quadratic fashion with shoreline elevation (Table 4), suggesting that Yellow-billed Loons can nest at higher elevations up to a certain point, at which they cannot access the shoreline due to the height. To determine whether this relationship was driven by the low elevation of the built-up nests of the Pacific Loon, we excluded these nests and ran the analysis again but found similar results. The best model only increased overall classification error by 4.5% compared with assigning any nest to the most prevalent category (Pacific Loon nest).

Table 1. Model ranking for the logistic regression analysis of Pacific Loon (*Gavia pacifica*) and Yellow-billed Loon (*Gavia adamsii*) nests ($n = 48$) vs. random points ($n = 144$) on the Arctic Coastal Plain, based on differences in Akaike's Information Criterion adjusted for sample (ΔAIC_c), model weight (w), model likelihood ($-2L(L)$), and number of parameters (K). Models with ΔAIC_c values > 12 are not shown.

Model Type	Variables	-2L(L)	K	ΔAIC_c	w
Exposure+Predation	Elevation+Visibility+Shore+PrevWind+Fetch	75.29	6	0.00	0.75
Exposure+Predation	Elevation+Visibility+Shore+PrevWind	80.28	5	2.87	0.18
Most Complex	Elevation+Elevation ² +Fetch+PrevWind+Fetch*PrevWind+Shore+Visibility+WaterDepth	74.90	9	6.06	0.02
Predation	Shore+Visibility	88.86	3	7.29	0.01
Predation	Shore+Visibility+WaterDepth	88.79	4	9.30	0.01
Predation	Shore	93.21	2	9.58	0.00
Predation	Shore+WaterDepth	93.21	3	11.64	0.00

Table 2. Parameter estimates (B) and odds ratios (Exp(B)) for covariates in the top conditional logistic regression model comparing the nest sites of Pacific Loon (*Gavia pacifica*) and Yellow-billed Loon (*Gavia adamsii*) to random points.

Variable	B	SE	Exp(B)	95% CI
Fetch	-0.79	0.38	0.46	0.22-0.96
Shoreline (Island or Peninsula)	2.78	0.64	16.13	4.64-56.16
Elevation	-0.89	1.19	0.41	0.04-4.25
PrevWind (Southwest)	-1.08	0.51	0.34	0.13-0.92
Visibility	0.94	0.38	2.57	1.22-5.39

DISCUSSION

Suitable nesting habitat is a fundamental requirement for breeding birds. Although the landscape of the Arctic Coastal Plain is dominated by lakes and wetlands, loons must find nesting habitat that satisfies breeding requirements at multiple scales. At the landscape scale, loons must choose a breeding lake that provides access to an adequate source of prey. Within a lake, prey are generally distributed throughout the lake (Haynes *et al.* 2013) and loons likely are not limited by prey distributions at this scale. Rather, within a lake, loons must find a suitable location for a nest that promotes nest survival. Results from this study suggest that, on the interior Arctic Coastal Plain, loons select nest locations that limit predation and exposure. Loons were more likely to nest on islands and peninsulas and at sites with higher visibility (minimizing predation risk) and avoid sites with high fetch values and sites exposed to the prevailing wind (minimizing exposure to waves and shifting ice). Both of these factors have been found to be important for these species in previous investigations on the Arctic Coastal Plain (Bergman and Derksen 1977; North and Ryan 1989) and in other loon species (e.g., Common Loons, *G. immer*; Evers *et al.* 2010).

Throughout their range, loons have been shown to select sites that limit wave exposure (e.g., Davis 1972; McIntyre and Mathisen 1977; North and Ryan 1989). However, unlike more southerly portions of their range, loons nesting in the Arctic are not only exposed to waves, but also to shifting lake ice. Shortly after spring break-up, a rapidly melting ice sheet remains on lakes after the first open water appears. As wind direction shifts,

the ice can shift position on the lake and erode or shear the shoreline. Further, wind may shift from the predominant direction and shifting ice can impact a lakeshore that is normally unexposed. On the Arctic Coastal Plain, exposure is important for both species (Davis 1972; North and Ryan 1989), and the threat of shifting ice has been noted (North 1994, 2008; J. A. Schmutz, pers. obs.). This study provided evidence that exposure to waves and shifting ice can cause nest failure. In one case, wave action due to high wind flooded a Pacific Loon nest, causing abandonment. In a second case, a Pacific Loon nest was found completely surrounded by broken lake ice. Although still active, the nest was at risk of swamping, and the ice had the potential to block adult access.

Elevation is an important component of exposure; however, it can also be related to the accessibility of the shoreline to loons because they are limited in their ability to walk on land due to the posterior location of their legs (Schaefer 1955; Russell 2002). If a shoreline is elevated beyond what is practical for a loon to access, then that shoreline is essentially unavailable for nesting (Davis 1972). For example, Fair (1979) found that Common Loons were unable to access the nest site when the water level dropped 25 cm. In the case of water bodies where the entire shoreline is elevated beyond what is accessible to loons, the water body as a whole would not be a suitable nesting lake, which was noted for Pacific and Red-throated loons (Davis 1972). Over the past 35 years, the level of evaporation for Arctic Coastal Plain lakes has been exceeding levels of precipitation at an increasing rate, leading to a more rapid decrease in the water levels of lakes over the summer period (Arp *et al.* 2011).

Table 3. Model ranking for the logistic regression analysis for Pacific Loon ($n = 103$) vs. Yellow-billed Loon nests ($n = 24$) based on differences in Akaike's Information Criterion adjusted for sample size (ΔAIC_c), model weight (w), model likelihood ($-2L(L)$), and number of parameters (K). Models with ΔAIC_c values > 12 are not shown.

Model Type	Variables	$-2L(L)$	K	ΔAIC_c	w
Exposure+Predation	Shore+Elevation+Elevation ²	88.31	5	0.00	0.68
Exposure	Elevation+Elevation ²	95.52	3	3.05	0.15
Exposure	Elevation+Elevation ² +West	95.18	4	4.78	0.06
Exposure	Elevation+Elevation ² +Fetch	95.48	4	5.08	0.05
Exposure	Elevation+Elevation ² +Fetch+West	95.12	5	6.81	0.02
Exposure	Elevation+Elevation ² +Fetch+West+Fetch*West	93.04	6	6.85	0.02
Most Complex	Elevation+Elevation ² +Fetch+West+West+Fetch*West+ DistWater+Shore+DegrecVis+WaterDepth	84.40	11	9.05	0.01

Table 4. Parameter estimates (B) and odds ratios (Exp(B)) for covariates in the logistic regression model comparing nest locations of Pacific and Yellow-billed loons.

Variable	B	SE	Exp (B)	95% CI
Shore (Peninsula)	1.83	0.81	6.23	1.28-30.29
Shore (Island)	0.21	0.69	1.23	0.32-4.77
Elevation	2.31	0.61	10.08	3.07-33.12
Elevation ²	-0.35	0.11	0.70	0.56-0.88

This suggests that the water levels of lakes may decrease more dramatically over a season as the climate changes, which could, in turn, affect access to nests by breeding loons and, ultimately, nest success. Rapid water level change (on the scale of hours-days) has been shown to have a strong negative effect on nest success of Common Loons on reservoirs (Fair 1979). With greater within season water level changes in these natural lakes, it is possible that nest success for these tundra breeding loons is or will be similarly impacted. Yellow-billed Loons were more likely than Pacific Loons to choose nest sites that are higher in elevation, likely owing to their larger body size. This relationship was quadratic rather than linear because, at a certain point, Yellow-billed Loons were also limited by elevation.

Loons can experience high levels of nest failure when predation pressure is high (Petersen 1979) and, thus, predation is likely a strong selection pressure on nest site selection. Similar to other studies, results from this study suggest that Pacific and Yellow-billed loons use sites that provide a good view of approaching terrestrial predators, physical separation (islands), or a single access point to defend (peninsulas; Bergman and Derksen 1977; North and Ryan 1989). The ability to sight predators from a distance may allow incubating loons to leave the nest before detection. When loons were observed entering the water from a nest during surveys, they often sunk their body into the water such that only their head was exposed as they distanced themselves from their nest or immediately dove underwater, presumably to avoid detection. However, similar to North and Ryan's (1989) study on Yellow-

billed Loon nest habitat, we did not find that loons were much more likely to nest directly adjacent to deep water, despite this preference having been noted for Common Loons (Evers *et al.* 2010).

The lack of substantial differences between Pacific and Yellow-billed loon nest characteristics in this study suggests that both species have similar site preferences when choosing a nest location. Should suitable nest sites become limited due to lake drainage and increased shoreline elevation, then the stronger competitor (Yellow-billed Loons; North 1994, Haynes *et al. in press*) would occupy much of the suitable nesting habitat, and there would likely then be greater differences in nest site characteristics between the species on the Arctic Coastal Plain. However, our sampling scheme did not capture all potential nesting sites of Pacific Loons, which frequently nest in smaller lakes. If these lakes were included, there may have been a larger difference in nest site characteristics. For lakes we examined (> 7 ha), there was only limited evidence for differences between species including differences in nest construction. Pacific Loons frequently constructed built-up nests by placing vegetation and mud in marshy areas with shallow water to create a nest bowl just above the water level (Davis 1972). Construction of nest bowls in low-elevation sites may reflect species-specific nesting preferences or compensation for movement to suboptimal habitat due to intra- and inter-specific competition for ideal nesting habitat. By constructing built-up nests, Pacific Loons have more options for nest locations, which may avert competition by other nesting loons holding territories on that lake. Interestingly, seven of the eight identified built-up nests constructed by Pacific Loons were on lakes with multiple loon nests (six lakes) or had a pair of Yellow-billed Loons that appeared to be prospecting for a nest site (one lake). Thus, built-up nests may be a way for Pacific Loons to gain the advantage of island nests when suitable naturally-occurring island sites are not available. Yellow-billed Loons may not have to construct built-up nests because, as the stronger competitor in territo-

rial disputes with Pacific Loons, they likely have the choice of the best nest locations.

Terrestrial predators, mainly Arctic fox (*Vulpes lagopus*), can be responsible for a substantial proportion of the predation of loon nests (Bergman and Derksen 1977; J. S. Schmutz, unpubl. data). Both species readily use islands, likely to limit access to terrestrial predators; however, Yellow-billed Loons were more likely to nest on peninsulas. When suitable islands were not available, Pacific Loons sometimes built their own islands to nest on rather than nesting on a peninsula or mainland shoreline. This difference may be related to the ability of each species to defend nests against terrestrial predators. Although peninsula nest sites are more defensible to terrestrial predators compared to the mainland shoreline (Bergman and Derksen 1977), these sites may be more accessible to terrestrial predators than islands. Yellow-billed Loons are far larger (4.0-6.4 kg, North 1994) than Pacific Loons (1.0-2.5 kg, Russell 2002) and, thus, are likely better able to fend off terrestrial predators, such as the Arctic fox.

This study corroborates previous research suggesting that loons use particular shoreline habitats within a lake to minimize predation and exposure, and found only subtle differences between the nest site characteristics of Pacific and Yellow-billed loons. However, although Pacific Loons would be expected to nest on smaller lakes, lakes < 7 ha in area were not examined in this study. Thus, inclusion of smaller lakes may have yielded different information on nest site selection. Further, nest survival was not examined in this study. Nonetheless, other studies have shown that loon nest sites on islands have higher success (Bergman and Derksen 1977; Petersen 1979) and, thus, island locations may be generally preferred when available. The persistence of non-island nests and the propensity of Pacific Loons to construct built-up nests suggest that island nesting locations may be limiting. Conversely, variation in shoreline type selected may simply reflect differences between inexperienced or unsuccessful breeders and experienced or successful breeders (Martin 1998).

Regardless, suitable nesting habitat may not be available at each lake; thus, the suitability of a shoreline within a water body for nesting can influence the selection of the water body at the landscape scale (Davis 1972). Ultimately, nest site selection at the scale of the shoreline should be considered in studies or management decisions that examine loon habitat use at larger scales. As the aquatic environment in the Arctic changes with a warming climate, volatility in lake levels may affect loon habitat at the shoreline scale more quickly than other attributes, such as fish community composition at the whole lake scale.

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