The Journal of Wildlife Management; DOI: 10.1002/jwmg.21592

Research Article

Territory Occupancy by Breeding Yellow-Billed Loons near Oil Development

CHARLES B. JOHNSON,[1] *ABR, P.O. Box 80410, Fairbanks, AK 99708, USA*
ANN M. WILDMAN, *ABR, P.O. Box 240268, Anchorage, AK 99524, USA*
ALEXANDER K. PRICHARD, *ABR, P.O. Box 80410, Fairbanks, AK 99708, USA*
CARYN L. REA,[2] *ConocoPhillips Alaska, P.O. Box 100360, Anchorage, AK 99510, USA*

ABSTRACT Less than 4,000 yellow-billed loons (*Gavia adamsii*) breed in remote and disjunct locations in northern Alaska, USA. Over 75% of the United States population of yellow-billed loons nests in the National Petroleum Reserve–Alaska (NPRA), where impending oil and gas development will intersect their breeding range. We investigated the relationship of recent oilfield development to occupancy of yellow-billed loon territories by breeding pairs (indicated by active nests) and broods using 14 years of aerial surveys on the Colville River delta. We also evaluated the survey requirements prescribed by the Bureau of Land Management (BLM) for NPRA. We began aerial surveys for yellow-billed loons in 1993, prior to construction of the Alpine oilfield in 1998, and followed territories through 2008, after construction of 2 additional satellite drill sites. We used records from 37 breeding territories on 36 lakes in model selection analyses to examine how habitat and disturbance factors (proximity to facilities and construction time period) influenced occupancy by breeding pairs and broods. Annually, 13 ± 2.5 (SE)% ($n = 14$ yr) of broods ($n = 19$) moved from nesting lakes to adjacent brood-rearing lakes, and the remainder stayed in nesting lakes ($n = 128$). Lakes used for nesting and brood-rearing were almost 25 times larger ($\bar{x} = 95.9 \pm 25$ ha, $n = 23$ lakes) than nesting lakes from which broods left ($\bar{x} = 4.0 \pm 1.1$ ha, $n = 7$ lakes, $P < 0.001$). Thirty-eight percent of territories ($n = 14$ territories) were on lakes shared by >1 breeding pair. Lake type (deep open lakes with islands or polygonized margins, deep open lakes without islands or polygonized margins, and tapped lakes with high-water connections) was the most influential covariate on occupancy by breeding pairs, and lake area was most influential on occupancy by broods. Time period and distance to facilities (as discrete zones at 1.6 km and 3.2 km and as linear distance) were factors in the highest-ranked models for 5 of the 6 model sets that included disturbance parameters. Interaction terms for time period and distance to oilfield facilities were factors in 3 of 6 model sets. The pattern of occupancy of breeding territories, however, was not consistent with disturbance-related effects. Occupancy of territories by breeding pairs was lower in the pre-development period (lowest human activity) than in the latest development period (highest human activity) and higher in the zones near oilfield facilities than far from facilities. Occupancy of territories by broods was highest in the latest development period and similarly high in zones near and far from facilities. Application of BLM minimum survey requirements (3 yr with 2 surveys/yr) to the initial 3 years of surveys in this study resulted in detecting 81% of the known territories on the Colville River delta. The BLM restrictions on development were judged conservative in maintaining breeding territories around oilfield developments. Our results did not demonstrate displacement of nests or broods from long-standing territories by oil development. Our findings suggest that territory occupancy by breeding pairs and broods of yellow-billed loons on the Colville River delta was resilient to levels of human activity at recently constructed oilfield facilities. © 2018 The Authors. *Journal of Wildlife Management* published by Wiley Periodicals, Inc. on behalf of The Wildlife Society.

KEY WORDS Arctic Coastal Plain of Alaska, breeding pairs, broods, disturbance, *Gavia adamsii*, lake habitat, nests, oil and gas development, territory occupancy, yellow-billed loon.

The yellow-billed loon (*Gavia adamsii*) in northern Alaska, USA, belongs to a small population with a limited and patchy breeding distribution (Gabrielson and Lincoln 1959, North 1993, Earnst 2004). The mean population size on breeding grounds of Alaska's Arctic Coastal Plain (ACP) was estimated at 3,369 loons (95% CI = 1,910–4,628, $n = 12$ yr) in 2003, and the estimate for Alaska was 6,024 loons (Earnst et al. 2005). The Alaska population was reported as

Received: 23 September 2015; Accepted: 27 June 2018

[1] *E-mail: rjohnson@abrinc.com*

[2] *Present Address: 7041 Potter Heights Drive, Anchorage, AK 99516, USA.*

stable through 2004 (Groves et al. 1996, Earnst et al. 2005) but has grown slowly on the ACP at a rate of 1.3% annually during 1986–2017 (logarithmic rate = 1.013, 90% CI = 1.002–1.024; H. W. Wilson, U.S. Fish and Wildlife Service [USFWS], Migratory Bird Management, unpublished data). Few reliable data are available from Canada and Russia, the primary breeding areas outside Alaska; yellow-billed loons may number 16,000–32,000 on breeding grounds worldwide (Fair 2002, Schmutz 2009).

Most breeding in Alaska occurs in a broad band along the Arctic Coast from Point Lay to the Colville River (North 1994, Mallek et al. 2006). Primary breeding areas in Alaska are in the northern half of the National Petroleum Reserve–Alaska (NPRA), where >75% of the United States population breeds (Schmutz et al. 2014), and on the adjacent Colville River delta (North and Ryan 1989, Earnst 2004). Much of this region is undeveloped but potentially available to expansion of the oil and gas industry (Bureau of Land Management [BLM] 2013), which has led to additional conservation concerns for this largest species of loon (North 1986, Earnst 2004). Yellow-billed loons share life-history traits with their closest relative, the common loon (*G. immer*). Like common loons (Piper et al. 2008, Evers et al. 2010), yellow-billed loons aggressively defend territories during the breeding season (Sjölander and Agren 1976, North 1986). Yellow-billed loons have high retention rates of breeding territories (North and Ryan 1989, Schmutz et al. 2014), and compete with sympatric congeners for territories (Haynes et al. 2014*b*, Schmidt et al. 2014). The density of occupied territories may restrict access of yellow-billed loons to unoccupied territories, as it does in common loons (Hammond et al. 2012). Nests are placed on islands, peninsulas, hummocks, and low-lying shorelines, in sites protected from waves and shifting ice, and in sites with good visibility but isolated from other loon nests (North and Ryan 1989, Haynes et al. 2014*a*). Nests are vulnerable to changing water levels, wave action, shifting ice that can crush nests, predation by birds and mammals, and in rare cases, abandonment (Haynes et al. 2014*a*; J. P. Parrett, ABR, unpublished data). On the ACP, yellow-billed loons feed themselves and young from their breeding territories (North 1994, Schmutz et al. 2014). They appear to be habitat specialists, confined mainly to tundra wetlands with large, clear, deep lakes with fish that survive winter in unfrozen water under lake ice (Sjölander and Agren 1976, North and Ryan 1989, Earnst et al. 2006). Yellow-billed loon prey (primarily fish) are not uniformly distributed in lakes across the loon's breeding range on the ACP (Haynes et al. 2015). Breeding territories on the ACP appear to be more prevalent in lakes near streams or on river deltas, where connections or floods may promote periodic immigration of fish prey. Although it is unclear what factors constrain the Alaska population, evidence suggests availability of breeding habitat may be a limitation (Haynes 2014, Schmutz et al. 2014).

Concern over small population size, restricted breeding distribution, and potential threats led to a petition filed with the USFWS in 2004 to list the yellow-billed loon as threatened or endangered (Center for Biological Diversity 2004). Subsequently, a conservation agreement for the yellow-billed loon was completed among federal, state, native, and local government agencies (USFWS 2006). Using more recent data and analysis (collected through 2013) indicating the ACP population was stable or increasing, that threats (oil development, contamination, human-caused mortality, disease, predation, and climate change) were not causing declines, and that current management practices minimized potential adverse effects in Alaska (USFWS 2014*a*), the USFWS issued a 12-month finding in 2014 not to list the yellow-billed loon as threatened or endangered (USFWS 2014*b*). Management of NPRA, the core of the breeding range in Alaska, is the responsibility of the BLM, which developed stipulations, required operating procedures, and best management practices (BMPs) that are intended to protect breeding yellow-billed loons from disturbance and habitat degradation that may result from oil-development activities (BLM 2008, 2013). The BLM prescribed BMP E11, which mandates that permanent facilities must remain >1.6 km from yellow-billed loon nest sites and >500 m from the shorelines of nesting lakes and requires ≥3 years of aerial surveys for yellow-billed loon nests and broods (2 surveys/yr) prior to construction of permanent oilfield facilities ≤1.6 km from lakes ≥10 ha in size. Deviations or exceptions from E11 buffers can be allowed on a case-by-case basis if the deviations meet the objectives of the BMP.

Yellow-billed loons are thought to be sensitive to disturbance by humans, but little information has been published on the effect of human development on the species (North 1994, Earnst 2004). The effects of human disturbance on yellow-billed loons have been hypothesized to be like those on common loons, their more studied relative. Human disturbance on nesting lakes can reduce productivity of common loons (Titus and VanDruff 1981, Heimberger et al. 1983, Evers et al. 2010) and lead to avoidance of developed lakes (Newbrey et al. 2005; for some exceptions see Caron and Robinson 1994, Ruggles 1994). In northern Alaska, researcher visits to yellow-billed loon nests reduced daily survival rates of nests by 6% (Uher-Koch et al. 2015).

Yellow-billed loon ecology was first studied on the Colville River delta in 1983 and 1984 (North 1986, North and Ryan 1988, 1989), largely in response to concern over future oil development in the Colville River delta region. We expanded North's (1986) study area and surveyed yellow-billed loon nests and broods for 14 years as part of a multi-species monitoring program on the Colville River delta. During that period, the Alpine oilfield became the first industrial development to occur in a yellow-billed loon breeding area on the ACP of Alaska (Fig. 1). Although breeding territory fidelity is thought to be high (North 1986), we could not assess that because individual loons have not been marked nor were they identifiable. The presence of adults was not informative of territory status because adults occurred on lakes and waterbodies (e.g., river channels, tapped lakes, brackish lakes) that did not support nests or broods. Adults were not identifiable as territory holders unless they were associated with nests or broods. We evaluated several lake features that could reflect habitat quality (defined as the capability to support nests and broods). Lake size is a common factor identified in habitat preferences for the species, with large lakes providing more

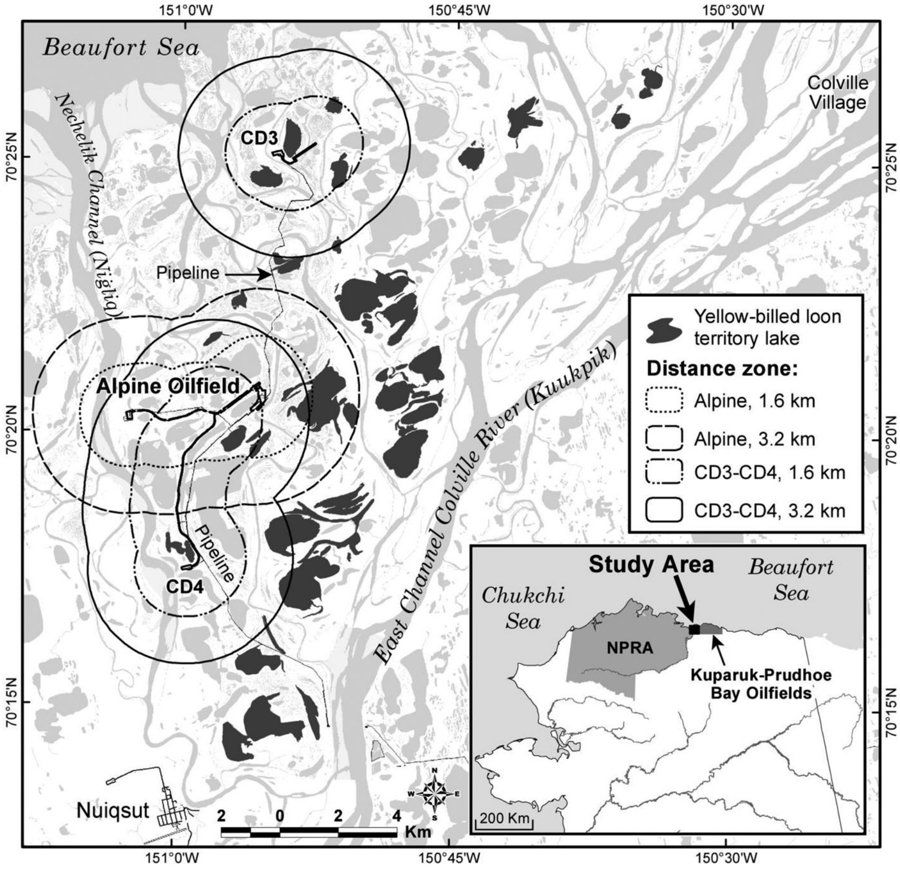

Figure 1. Lakes surveyed, oilfield facilities, and disturbance zones (1.6 km and 3.2 km) used in the analysis of occupancy of breeding territories for yellow-billed loons, Colville River delta, Alaska, USA, 1993, 1995–1998, and 2000–2008. The study area lies between the National Petroleum Reserve-Alaska (NPRA) and Kuparuk-Prudhoe Bay oilfields. Construction of Alpine oilfield began in 1998 and satellite drill pads CD3 and CD4 began in 2005.

prey, more suitable nest sites, and more escape cover (Earnst et al. 2006, Haynes et al. 2014*b*) but with increased costs for territory defense (Schmutz et al. 2014). Some large lakes support multiple territories (North 1994), which could increase intraspecific conflict, and increase nest and brood losses. Lake depth on the ACP determines whether lakes freeze to the bottom, thus eliminating all but freeze-resistant fishes. Lakes >2 m deep generally maintain water under ice, where fish can survive, throughout winter.

We modeled the relationships of habitat covariates and construction of the Alpine oilfield and its satellites on the occupancy of territories by breeding pairs (the proportion of territories with breeding pairs, inferred from presence of active nests) and occupancy of territories by broods (the proportion of territories with broods), independently among time periods and at different spatial scales relative to oil development. After accounting for habitat covariates, we assessed the variation in occupancy of breeding territories explained by time period (before and after construction of the Alpine oilfield) and distance to oil facilities. We hypothesized that, if oilfields reduced occupancy of territories by yellow-billed loon breeding pairs and broods, occupancy should decline after oilfield construction and declines should be most evident in territories near oilfield facilities and less evident in distant territories. We focused our analysis on breeding pairs and broods because of their contribution to population dynamics. To evaluate current management practices, we used a subset of our data to assess the effectiveness of survey requirements designed to identify yellow-billed loon breeding lakes for protective measures in NPRA (BLM 2008, 2013), the next area where yellow-billed loons will likely be exposed to oil development activities.

STUDY AREA

The study area encompassed 36,300 ha on the central portion of the Colville River (Kuukpik to the local Iñupiat) delta, between the Beaufort Sea on the north, the NPRA on the west, and Kuparuk oilfield to the east (Fig. 1). The Colville River is the largest river on Alaska's ACP, where the high volume and heavy sediment load of the Colville River have created a large (~55,200 ha) and dynamic deltaic system.

The delta has an arctic maritime climate (Walker and Morgan 1964). In late May, runoff from the warmer foothills flowed both over and under the river ice of the delta, resulting in river breakup between late-May and mid-June (Walker 1983, Michael Baker Jr., Inc. 2008). The delta provided some of the earliest open water and snow-free areas on the ACP during spring for yellow-billed loons and other waterbirds. Summers were cool, with temperatures ranging from -10° C to 21° C (Michael Baker Jr., Inc. 2008). Freeze-up of lakes and ponds begins in September or October and remain frozen until May or June. Winter consistently has subfreezing temperatures (sometimes $<-40°$ C) with light snow and high winds creating drifts.

Lakes and ponds were dominant physical features of the Colville River delta. Most of the waterbodies were $\leq$2 m deep, but lakes >2 m deep were more common on the delta than elsewhere on the ACP. Waterbodies (not including polygon ponds) covered 32% of the delta (Johnson et al. 2005) and lakes $\geq$10 ha in size covered 13% of the delta's surface. Most large lakes were 2–10 m deep and frozen $\leq$2 m deep until the first half of July (Walker 1978). Many lakes on the delta were tapped (connected to the river by narrow channels), which allowed water levels in the lakes to fluctuate during flood events, storms, and changes in wind direction (Walker 1983). Vegetation types were primarily wet and moist tundra with a mixture of low to prostrate shrubs; taller shrubs along river channels and halophytic marshes occupied coastal areas (Johnson et al. 2005). Well-developed polygonal surface forms arising from permafrost were characteristic of the area. The lakes and wetlands attracted abundant ground-nesting geese, tundra swans (*Cygnus columbianus*), loons, ducks, shorebirds, passerines, gulls, terns, and jaegers. Primary nest predators were arctic (*Vulpes lagopus*) and red foxes (*V. vulpes*), glaucous gulls (*Larus hyperboreus*), parasitic jaegers (*Stercorarius parasiticus*), common ravens (*Corvus corax*), and occassionally brown bears (*Ursus arctos*), golden eagles (*Aquila chrysaetos*), and wolverines (*Gulo gulo*). Polar bears (*U. maritimus*) sometimes den on the delta but were rare during summer.

Two permanent human settlements existed on the Colville River delta: a family home site known as Colville Village (established in the mid-1950s) and the Iñupiat village of Nuiqsut (established in 1973). Neither community was included in our study area to avoid disturbing residents with aircraft overflights. Inhabitants of both villages hunted and fished throughout the delta, but boat traffic was primarily confined to the 2 major channels (forming the east and west boundaries of the study area) during summer.

Construction of oilfield facilities on the Colville River delta, the first in a breeding area for Alaska yellow-billed loons, began with the Alpine oilfield in 1998 (Fig. 1). Construction of 2 satellite drill pads (CD3 and CD4) on the delta followed in 2005. We used the dates of construction to define 3 periods: pre-Alpine (1993–1997, before any oilfield construction), Alpine (1998–2004, during construction and initial operation of Alpine), and CD3-CD4 (2005–2008, during operation of Alpine and construction and initial operation of the CD3 and CD4 drill pads). Low levels of human activity (subsistence hunters, researchers, and surveyors) occurred throughout the delta during the pre-development period of this study (1993–1997). Construction of Alpine increased the level of human activity on the central Colville River delta. Aircraft flights supporting summer construction increased from 2 helicopter flights/day for gravel work in 1998 to 10 aircraft flights/day (fixed-wing and helicopter) supporting 160 people/day in 1999 and peaked at 22 aircraft flights/day supporting 550 people/day in 2000. Levels of activity tapered at Alpine after 2003 but increased at the satellite pads (CD3 and CD4) with summer construction in 2005 and 2006. The Alpine facilities comprised a 54-km pipeline and a 37-ha gravel pad consisting of a 1.8-km-long airstrip, a 3-km in-field road, and 2 drill pads (CD1 and CD2) with a processing plant and 600-person camp on CD1. Alpine supported all 4 drill pads with its processing facility, workforce camp, and airstrip. Summer transportation to CD3 was by aircraft, whereas CD4 had an all-season road to Alpine. The CD3 satellite pad had a 9-ha gravel footprint, including a 0.9-km-long airstrip, a 0.6-km-long road to the drill pad, and an 11-km-long pipeline to Alpine. The CD4 satellite pad had a 15-ha gravel footprint, including a 6-km-long road, and an 8-km-long pipeline. During summer construction and operation phases, human activity (other than air traffic and researchers) was confined to gravel pads and roads totaling 61 ha (i.e., 0.017% of the study area).

METHODS

Field Surveys and Data Preparation

We conducted aerial surveys for nesting and brood-rearing yellow-billed loons on the Colville River delta during 14 years: 1993, 1995–1998, and 2000–2008. Gaps in funding prevented a complete series of annual surveys. Each survey year, we flew 1 survey during nesting between 23 and 30 June and 1 survey during brood-rearing between 16 and 27 August. We conducted June surveys from a Cessna 185 (Cessna, Wichita, KS, USA) or PA-18 Super Cub (Piper, Vero Beach, FL, USA) fixed-wing airplane during 1993 and 1995–1998, and a Bell 206 Long Ranger helicopter (Bell, Fort Worth, TX, USA) during 2000–2008. We conducted August surveys from a Cessna 185 in 1993 and a Bell 206 Long Ranger helicopter in all other years. We flew all surveys at 60 m above ground level circling each lake at 100–130 km/hour. Breeding loons reacted to survey flights by concealing when on nests, by swimming or diving when on water, or by swimming with young. We saw young loons swimming with adults or by themselves along shorelines. Evasive reactions, such as leaving nests or splash diving (North 1994) occurred less commonly. We used maps of nests from North's (1986) surveys to assist in locating yellow-billed loon nesting lakes initially. We surveyed the extent of North's (1986) study area in the central portion of the delta and expanded the survey area north, south, east, and west to the major channels of the delta but avoided the deltaic islands in the northeastern portion where there was a family residence and fewer lakes. We included all freshwater lakes $\geq$10 ha in area and adjacent smaller lakes (<10 ha) within our larger study area. We did not survey brackish coastal lakes or tapped lakes with low-water connections to river channels because yellow-billed loons do not use such lakes for nesting or brood-rearing (North 1986). During August, we surveyed all freshwater lakes $\geq$10 ha in area with the same methods used during nesting.

We recorded locations of yellow-billed loons, active loon nests, and loon broods on United States Geological Survey (USGS) topographic maps (1:63,360 scale) or color photomosaics (1:30,000 scale) and later digitized the locations into a geographic information system (GIS) database. We defined an individual lake as the aggregate of all waterbodies $\geq$0.25 ha linked by continuous surface water (not including tapped lakes, which are linked by connections to river channels) $\geq$0.5 m across as visible on satellite photomosaics taken in July. We reasoned that connections $\geq$0.5 m wide were not physical barriers to movement of adults or young. Yellow-billed loon pairs can nest and raise a brood on individual lakes, multiple lakes, or share large lakes with other breeding pairs (North 1994). For this study, we defined breeding territories as lakes or portions of lakes used for nesting and brood-rearing exclusively by 1 breeding pair. Individual loons were not identifiable. We identified territories based on location of active nests and broods observed throughout the study. Where >1 yellow-billed loon nest or brood occurred on a lake, we classified it as a shared lake and assigned different portions of that lake to separate territories based on nest locations. A single territory also could comprise multiple lakes, as where a brood moved from a nesting lake to an adjacent brood-rearing lake. We delineated a cumulative territory map from 14 survey years and compared it with maps of nests and broods recorded in the 1980s (North 1986; M. R. North, Minnesota Department of Natural Resources, unpublished data), which demonstrated long-term territory use. When we observed new territories with active nests, we assumed those territories were available but unoccupied by breeding pairs or broods in years before discovery. Because we surveyed a consistent set of lakes, we assumed that all territories on these lakes were surveyed and equally available for breeding. We could not define complete boundaries between territories on shared lakes nor could we determine territory size from our periodic surveys. To measure the distance of each territory to an oil facility, we used the minimal distance of nests in each territory (among all years) and assigned that distance as a constant for each territory for all years. In 13 cases when we found broods in territories where we had not detected nests in that same year, we registered the territory in which we found the brood as occupied by a nest, but we could not assign map coordinates to the nest site for that year. We assumed each brood was from a nest on the same territory based on 14 years of observations of nest and brood locations from these territories and evidence of long-term occupancy of territories (North 1994). In the analyses of territory use for these 13 broods, we used the minimal distance to oil facilities of nests we found in those territories in other years. We used these additional nests in the analysis of occupancy of territories by breeding pairs. We defined the spatial extent of oilfield facilities as the gravel footprint and all buildings and equipment thereon. We did not consider pipelines crossing over tundra to be facilities in analyses because they were not associated with human activity during the breeding season. We used ArcGIS 9.3a (Environmental Systems Research Institute, Redlands, CA, USA) to measure lake area and distance of nests from oilfield facilities using satellite imagery (0.3-m resolution) taken in July 2004 and 2006 provided by ConocoPhillips Alaska.

We surveyed the same 34–37 territories comprising the same 36 lakes each year and recorded whether an active nest, brood, or adult yellow-billed loons were present. We were unable to observe hatch in all years, but based on observed hatch dates of 4 July–3 August and a median hatch date of 13 July (ABR, unpublished data), young were likely 2–7 weeks old during August surveys.

We did not measure detection error of the surveys. Because detection of loon nests and broods likely was lower during surveys from airplanes than from helicopters, we supplemented our data acquired from airplane surveys (1993–1998) with nests ($n = 18$) and broods ($n = 5$) that were detected during foot surveys or other aerial surveys conducted across the delta (S. L. Earnst, USGS, unpublished data; ABR, unpublished data). These additional nests and broods allowed us to correctly classify breeding territories as occupied, where we had observed adults but saw no evidence of current breeding. We did not identify new breeding territories or lakes from the additional nests and broods. All airplane surveys but those in 1998 were during the pre-Alpine period. The inclusion of nests from foot surveys in pre-Alpine nest data should result in more conservative temporal comparisons (i.e., more likely to find a decrease in occupancy from pre-Alpine to later time periods) but have no effect on comparisons among disturbance zones (see Stage 2 description in Data Analysis below).

Data Analysis

We evaluated territory occupancy by yellow-billed loons separately for nesting and brood-rearing. We defined territory occupancy as the proportion of breeding territories occupied by breeding pairs (determined by presence of active nests) or their broods, given territories were identified as used for breeding sometime during our study. We did not count yellow-billed loons without an active nest or young as occupying breeding territories. Our general analytical strategy to evaluate the temporal and spatial relationships of oilfield development to territory occupancy was to treat the oilfield facilities as a point source from which effects were assumed to attenuate with distance (Ellis and Schneider 1997).

We used model selection (Burnham and Anderson 2002) to investigate relationships between territory occupancy and habitat and disturbance covariates. We used generalized estimating equations, a repeated measures extension of generalized linear models, to evaluate factors affecting 2 response variables—territory occupancy by breeding pairs (territory with or without active nest) and territory occupancy by broods (territory with or without brood)—as binary response variables modeled with a logit link. Each territory was a subject with repeated measurements of occupancy for each year. We used an autoregressive-1 matrix as our working correlation structure to model the correlation of data within individual territories. We conducted the analysis in 3 stages. In stage 1, we compared alternative habitat models (using 4 covariates describing lakes supporting breeding) using a subset of the territories that were undisturbed (see Stage 1 description below). We included the covariate(s) from the most parsimonious habitat model as covariates in the next 2 model selection stages to account for possible habitat factors. In stage 2, we compared models with habitat, time period, and disturbance zone factors. In stage 3, we repeated the same set of models as stage 2 but used continuous distance covariates in place of disturbance zones. We used these same 3 stages and the same model sets for model selection for both response variables, resulting in 6 model selection sets. The selection procedures were the same for all stages. We sorted the models in ascending order of corrected quasi-likelihood information criterion score ($QAIC_c$), an extension of Akaike's Information Criterion (Burnham and Anderson 2002) and used Akaike weights (ω_i) to evaluate relative support for each model. We used Wald chi-square to test whether parameter estimates were significantly different from zero, and thus whether the individual parameter was influential in the top models (models with highest ω_i). We used Sidak pairwise comparisons to identify significant differences between levels of categorical parameters. Unless otherwise stated, we judged significance at $P \leq 0.05$. We conducted generalized estimating equations in SPSS 16.0.2 (SPSS, Chicago, IL, USA). Specifics for the 3 modeling stages are described below.

In stage 1 we developed habitat models from all possible combinations of the 4 habitat covariates without interaction terms: lake area (ha), the number of lakes used in a territory for nesting and brood-rearing, whether or not a lake was shared with other breeding pairs, and lake type. We measured lake area in a GIS and transformed it by natural logarithm for analysis. We conducted Wilcoxon rank sum exact tests in the R package coin (Torsten et al. 2006) to compare lake areas among types of lake use. We classified territories as containing 1 or ≥2 lakes (range = 2–4 lakes). Territories either contained lake(s) used exclusively by 1 yellow-billed loon breeding pair and brood, or lake(s) shared with other yellow-billed loon breeding pairs and broods; if sharing occurred in any year, we classified the lake(s) as shared for all years of analysis.

We classified lakes into 3 types: deep (>2 m deep) open lakes with islands or polygonized margins (deep lakes with islands), deep open lakes without islands or polygonized margins (deep lakes), and tapped lakes with high-water connections (tapped lakes HWC). Islands or polygonized margins (remnant polygon rims that form a crenate patterned shoreline) may provide more nest sites and nest sites that are more protected from wave and ice action than the simpler shorelines of lakes without those features. Tapped lakes HWC are a subset of tapped lakes that function much as isolated deep lakes but their connections to river channels have silted in and vegetated, which prevents incursions of river water except in high-water events. Tapped lakes HWC usually have clear, deep water, a feature breeding yellow-billed loons prefer (Earnst et al. 2006).

We ran habitat models with territories that we considered undisturbed over the first 2 time periods of the study (pre-Alpine and Alpine): the 29 territories that were ≥3.2 km from Alpine facilities. We assumed the territories ≥3.2 km from development would be unlikely to be affected by disturbance or other factors associated with oil facilities. We did not include data after 2004 in this analysis, because some undisturbed territories were <3.2 km from CD3 or CD4 after construction began in 2005. We included the parameters from the best habitat models (1 model for breeding pairs, 1 for broods) in model selection for stages 2–3.

In stage 2 we evaluated 2 scales of disturbance zones around oilfield facilities simultaneously along with the habitat parameter(s) and time periods. We chose the 1.6-km zone for the initial scale because it matches the no-development buffer prescribed around yellow-billed loon nests in NPRA (BLM 2008, 2013). We selected the 3.2-km zone to evaluate effects at a larger scale. To account for the influence of oilfield facilities constructed in different portions of the study area, we divided territories into 3 disturbance zones at each scale. Territories were either in the reference zone (≥1.6 km from facilities in all time periods), in the Alpine disturbance zone (≤1.6 km from Alpine), or in the CD3-CD4 disturbance zone (≤1.6 km from CD3 or CD4 but >1.6 km from Alpine). We divided territories likewise into 3 disturbance zones at the 3.2-km scale. Three of 37 territories were ≤1.6 km from Alpine and 8 were ≤3.2 km from Alpine. Four territories were ≤1.6 km from CD3 and 5 were ≤3.2 km, whereas 3 territories were ≤1.6 km from CD4 and 6 were ≤3.2 km. Some territories were within overlapping disturbance zones around Alpine and CD4. Eight territories were ≤1.6 km and 15 territories were ≤3.2 km from at least 1 oilfield facility.

In stage 3 we evaluated the change in territory occupancy with distance to oilfield facilities with 2 continuous covariates: distance (km) and the natural logarithm (ln) of distance. Because Alpine and its satellites CD3 and CD4 were constructed at different times and the distance of territories to facilities likewise changed by time period, we conducted 2 separate but parallel analyses (i.e., model selection processes) to evaluate all 3 time periods for this stage. We first modeled the relationship of occupancy to distance to Alpine in the pre-Alpine and Alpine periods. Secondly, we modeled the relationships of occupancy to distance to nearest facility (Alpine, CD3, or CD4) in the Alpine and CD3-CD4 periods.

Evaluation of BLM Survey Requirement

We used 14 years of survey data on the Colville River delta to evaluate the performance of BLM-prescribed BMP E11 to identify yellow-billed loon nesting lakes in NPRA (BLM 2008, 2013). Although BLM does not manage oil development on the Colville River delta, which currently occurs on state and Kuukpik Corporation (Nuiqsut village corporation) lands, the long-term dataset of breeding yellow-billed loons on the delta is the most complete available for evaluating the effectiveness of E11 for identifying breeding lakes. We treated our first 3 years (1993, 1995, and 1996) of aerial surveys as a naïve set of 3 years, to approximate surveys that might be conducted in an area previously unsurveyed.

For nests and broods found in the first 3 years of our study (prior to construction of Alpine), we used ArcGIS to draw 1.6-km buffers around nests and 500-m buffers around nesting and brood-rearing lakes to simulate the protection zones that would be implemented by BMP E11. We merged intersecting buffers and then examined the area to determine how many nest locations and territories were outside those buffers in subsequent years of surveys.

RESULTS

Territory Use and Lake Characteristics

We surveyed 157 lakes annually over the 14 years of study and identified 43 lakes comprising 45 territories that contained yellow-billed loon nests or broods. Of those territories, we surveyed 36 lakes comprising 37 territories in all 3 time periods (pre-Alpine, Alpine, and CD3-CD4) and used these as our index set of lakes and territories for analysis. Seventy-eight percent (29 of 37) of territories contained single lakes and 22% (8 of 37) contained 2–4 lakes. Most yellow-billed loon breeding territories contained lakes used exclusively in single territories (62%, 23 of 37) compared with territories that shared lakes (38%, 14 of 37). Territories that shared lakes most often occupied single lakes (71%, 10 of 14) and in these cases nests and broods from different pairs shared the same lake. One shared lake supported ≥4 active nests for 3 years. Lakes that were shared among territories averaged 6 times larger ($\bar{x} = 279.6 \pm 64.2$ ha, $n = 5$) than lakes that contained single territories ($\bar{x} = 44.0 \pm 9.8$ ha, $n = 31$; $P < 0.001$, Wilcoxon rank sum).

The mean area of yellow-billed loon nesting and brood-rearing lakes was 76.7 ± 18.1 ha (range = 0.07–508.1, $n = 36$). Nesting lakes were somewhat smaller (78.9 ± 18.4 ha, $n = 35$) than brood-rearing lakes ($\bar{x} = 92.0 \pm 24.3$ ha, $n = 24$), but sizes overlapped because 23 lakes were used for both nesting and brood-rearing. At least 1 pair nested on a lake <10 ha in area during 13 of 14 years and on average 7 ± 1.1% of the nests were on lakes <10 ha.

Five of 37 territories (14%) had yellow-billed loon pairs that routinely moved their young from nesting lakes to different brood-rearing lakes in years that broods were recorded on those territories. Loons were not marked, but we assumed movement between lakes when no other nesting pair was within 100 m. North (1994) reported broods could move overland ≤70 m. Broods moved between lakes in 11 of 14 years, and a mean of 13 ± 2.5% ($n = 14$ yr) of the broods produced each year changed lakes. Nesting lakes that doubled as brood-rearing lakes were 20 times larger ($\bar{x} = 95.9 \pm 25.0$ ha, range = 12.5–508.1, $n = 23$; $P < 0.001$, Wilcoxon rank sum) than lakes from which yellow-billed loons moved their broods ($\bar{x} = 4.0 \pm 1.1$ ha, range = 1.5–9.7, $n = 7$).

Factors Related to Territory Use

We observed a general increase in numbers of yellow-billed loon nests, broods, and territory occupancy after 2003 (Table 1). We recorded the highest territory occupancy by breeding pairs in 2008 and the lowest occupancy by breeding pairs in 1993, 1997, and 2000. Territory occupancy by broods was highest in 2005, 2007, and 2008, and lowest in 2000 and 2001.

Habitat models.—The best habitat model explaining territory occupancy by breeding pairs in undisturbed territories during 1993–2004 included the single covariate lake type ($\omega_i = 0.21$; Table 2). The second-best model included lake type and the shared-lake covariate ($\omega_i = 0.11$), and several other models had some support as the best model. Because additional covariates did not improve the model substantially, we chose lake type as the only habitat covariate included in subsequent modeling of territory occupancy by breeding pairs. Deep lakes with islands had the highest territory occupancy by breeding pairs (60 ± 4.7%), compared

Table 1. Annual number of yellow-billed loon nests and broods, mean distance (km) of nests to nearest oilfield facilities (as constructed in 2005), and territory occupancy by breeding pairs or broods ([number of nests or broods/number of territories] × 100), Colville River delta, Alaska, USA. Construction of the Alpine oilfield began in 1998, and construction of the CD3 and CD4 satellites began in 2005.

				Distance to facilities[a]		Occupancy of territories (%)		Number of surveyed territories	
Construction period	**Year**	**Nests**	**Broods**	$\bar{x}$	**SE**	**Pairs**	**Broods**	**Nest**	**Brood**
Pre-Alpine	1983[b]	17		3.50	0.37				
	1984[b]	21		3.69	0.39				
	1993	16	10	3.16	0.76	44.4	29.4	36	34
	1995	20	11	3.98	0.70	54.1	29.7	37	37
	1996	20	8	3.36	0.49	57.1	22.9	35	35
	1997	17	5	3.79	0.63	45.9	13.5	37	37
Alpine	1998	21	12	4.13	0.62	56.8	32.4	37	37
	2000	16	2	3.08	0.52	45.7	5.7	35	35
	2001	19	4	3.18	0.42	52.8	10.8	36	37
	2002	20	8	2.84	0.48	54.1	21.6	37	37
	2003	24	12	3.29	0.51	64.9	32.4	37	37
	2004	25	11	2.82	0.38	67.6	29.7	37	37
CD3-CD4	2005	30	16	3.48	0.50	81.1	43.2	37	37
	2006	27	13	4.12	0.50	73.0	35.1	37	37
	2007	27	16	3.94	0.51	73.0	43.2	37	37
	2008	33	19	3.90	0.44	89.2	51.4	37	37

[a] Distance to nearest gravel footprint of the Alpine, CD3, or CD4 facilities.

[b] North (1986) and M. R. North, Minnesota Department of Natural Resources, unpublished data.

Table 2. Summary of model selection results for relationships of lake habitat covariates on occupancy of undisturbed (>3.2 km from infrastructure) yellow-billed loon territories by breeding pairs and by broods, Colville River delta, Alaska, USA, 1993–2004. Habitat covariates include lake type (type, 3 categories), lakes shared or not shared with other breeding pairs (shared), number of lakes in a territory (number), and lake area (ln area).

Model	K^{a}	$QAIC_c^{b}$	$\Delta QAIC_c$	ω_i^{c}
Occupancy by breeding pairs				
Type	3	397.98	0.00	0.21
Type + shared	4	399.23	1.24	0.11
Type + number	4	399.72	1.74	0.09
Shared	2	399.91	1.93	0.08
Type + ln area	4	399.97	1.99	0.08
Ln area	2	400.37	2.39	0.06
Type + number + shared	5	400.63	2.65	0.06
Occupancy by broods				
Shared + ln area	3	303.12	0.00	0.20
Ln area	2	303.18	0.06	0.20
Intercept	1	304.06	0.94	0.13
Number + shared + ln area	4	304.84	1.72	0.09
Number + ln area	3	304.97	1.85	0.08

[a] Number of parameters.

[b] Quasi-Akaike's Information Criterion corrected for small sample sizes.

[c] Akaike weights.

with deep lakes (52 ± 4.8%) and tapped lakes HWC (40 ± 7.5%); however, only 1 pairwise comparison (deep lakes with islands vs. tapped lakes HWC) approached significance (Sidak pairwise comparisons, $P = 0.058$).

The best habitat model explaining territory occupancy by broods in undisturbed territories included the lake area and shared-lake factors ($\omega_i = 0.20$; Table 2), and the second-best model included only lake area and had the same amount of support ($\omega_i = 0.20$). Because the top 2 models were equivalent and the shared-lake coefficient was not significantly different from zero in the best model ($P = 0.194$), we chose lake area as the only habitat covariate included in subsequent models of territory occupancy by broods. Territory occupancy by broods decreased with increasing lake area ($\beta = -0.234$, Wald chi-square = 3.83, $P = 0.05$).

Disturbance zone models.—Three models had some support ($\omega_i \geq 0.1$) as the best model explaining territory occupancy by breeding pairs based on disturbance zones, time period, and lake type. All 3 included the 3.2-km disturbance-zone and time-period covariates, and the top 2 models also included lake type (Table 3). Models including the 1.6-km disturbance zone had little support ($\omega_i \leq 0.01$). The best model ($\omega_i = 0.56$) included the 3.2-km disturbance-zone, time-period, and lake-type covariates with no interactions. The model including the interaction term had less than half the support ($\omega_i = 0.23$) of the best model.

In the best model, the reference zone (territories ≥3.2 km from any facility) had the lowest average territory occupancy by breeding pairs (57 ± 3.7%), the Alpine disturbance zone (territories <3.2 km from Alpine) had the second highest territory occupancy by breeding pairs (70 ± 6.8%), and the CD3-CD4 disturbance zone (territories <3.2 km of CD3-CD4) had the highest territory occupancy by breeding pairs (76 ± 4.9%). The reference zone had lower territory occupancy by breeding pairs than the CD3-CD4 disturbance zone (Sidak pairwise comparison, $P = 0.002$) but not lower than the Alpine disturbance zone ($P = 0.294$), nor did the Alpine zone and CD3-CD4 zone differ in territory occupancy by breeding pairs ($P = 0.825$). The CD3-CD4 time period had higher territory occupancy by breeding pairs (83 ± 3.1%) than both the pre-Alpine period (55 ± 5.7%, $P < 0.001$) and the Alpine period (62 ± 4.4%, $P < 0.001$). The pre-Alpine and Alpine periods did not differ ($P = 0.595$). Territory occupancy by breeding pairs differed by lake type overall ($P = 0.049$) but not in pairwise comparisons (all $P > 0.142$).

Based on the model selection results, we could not rule out the possibility of a time period by disturbance zone interaction. The interaction was not significant in the model ($P = 0.293$) and the pattern of territory occupancy by breeding pairs among the 3 zones was not consistent with a disturbance relationship (Fig. 2). The disturbed zones (≤3.2 km) had increased occupancy by breeding pairs after construction of facilities in the Alpine and CD3-CD4 periods and the reference zone territories had an increase in the CD3-CD4 period.

The best model of territory occupancy by broods, which had strong support ($\omega_i = 0.70$; Table 3), included the 1.6-km disturbance zone, time period, and lake area. The second-best model included time period and lake area but had much less support ($\omega_i = 0.11$). Based on the best model, territory occupancy by broods declined with increasing lake area ($\beta = -0.248 \pm 0.081$, $P = 0.002$). After adjusting for lake area, territories within 1.6 km of Alpine had the lowest territory occupancy by broods (13 ± 4.6%), the reference zone had the second highest occupancy (29 ± 2.6%), and the 1.6-km zone at CD3-CD4 had the highest occupancy (35 ± 5.0%). Territory occupancy by broods was significantly lower in the Alpine disturbance zone than in the reference zone ($P = 0.004$) and

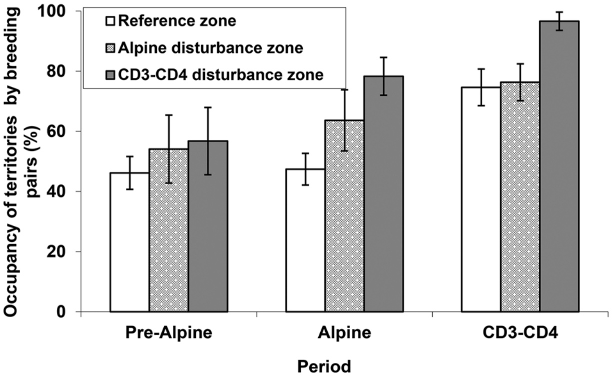

Figure 2. Interaction of time period and disturbance zone on percent occupancy of yellow-billed loon territories by breeding pairs on the Colville River delta, Alaska, USA, 1993–2008. Time periods were pre-Alpine (1993, 1995–1997), Alpine (1998, 2000–2004), and CD3-CD4 (2005–2008); disturbance zones were reference zone (>3.2 km to all facilities), Alpine disturbance zone (≤3.2 km to Alpine oilfield), and CD3-CD4 disturbance zone (≤3.2 km to CD3 or CD4 satellite drill pads). The interaction term ($P = 0.293$) in the second-most plausible model did not indicate a disturbance relationship; territory occupancy by breeding pairs increased from the reference zone to the Alpine and CD3-CD4 disturbance zones, and the pattern was similar with increasing occupancy from the pre-Alpine to later time periods.

Table 3. Summary of model selection results for relationships of disturbance zones (1.6 km, 3.2 km), 3 time periods (period), lake type (type), and lake area (ln area) on occupancy of yellow-billed loon territories by breeding pairs and by broods, Colville River delta, Alaska, USA, 1993–2008.

Model	K[a]	QAIC$_c$[b]	ΔQAIC$_c$	ω_i[c]
Occupancy by breeding pairs				
3.2 km + period + type	7	645.32	0.00	0.56
3.2 km + period + 3.2 km × period + type	11	647.13	1.81	0.23
3.2 km + period	5	648.09	2.77	0.14
3.2 km + period + 3.2 km × period	9	650.03	4.71	0.05
Occupancy by broods				
1.6 km + period + ln area	6	589.20	0.00	0.70
Period + ln area	4	592.81	3.61	0.11
1.6 km + period	5	593.50	4.30	0.08
1.6 km + period + 1.6 km × period + ln area	10	594.59	5.39	0.05

[a] Number of parameters.
[b] Quasi-Akaike's Information Criterion corrected for small sample sizes.
[c] Akaike weights.

the CD3-CD4 zone ($P = 0.003$), but these last 2 zones had similar occupancies ($P = 0.617$). Territory occupancy by broods in the pre-Alpine period (20 ± 3.6%) and the Alpine period (18 ± 3.4%) was low and nearly equal ($P = 0.986$). Territory occupancy by broods in the CD3-CD4 period (38 ± 4.6%) was higher than both the pre-Alpine and Alpine periods (both $P < 0.001$).

Distance covariate models: pre-Alpine versus Alpine periods.— No model using continuous distance covariates was clearly the best model of territory occupancy by breeding pairs during the pre-Alpine and Alpine time periods (Table 4). The best model contained only the lake-type parameter ($\omega_i = 0.15$), but the intercept-only model had similar support ($\omega_i = 0.10$), indicating that none of the covariates included were good predictors of occupancy by breeding pairs. None of the models with a distance by time period interaction had Akaike weights ≥ 0.05, suggesting that there was little evidence of a disturbance relationship with occupancy by breeding pairs during the Alpine period. Distance to Alpine and ln distance to Alpine were included with lake type in models with some support ($\omega_i \geq 0.09$). In both these models, territory occupancy by breeding pairs decreased with distance from Alpine, although the slope was not significantly different from zero ($P \geq 0.271$).

Similarly, no model using continuous distance covariates was clearly the best model of territory occupancy by broods during the pre-Alpine and Alpine time periods (Table 4). The best model contained only the lake-area parameter ($\omega_i = 0.25$), and the second-best model included lake area, distance to Alpine, time period, and a distance by time period interaction ($\omega_i = 0.20$). The distance by time period interaction was significant ($P = 0.001$), but the relationship of occupancy by broods was opposite that expected for a disturbance effect (Fig. 3). Territory occupancy by broods in the pre-Alpine period was lower in territories close to Alpine

Table 4. Summary of model selection results for relationships of distance to Alpine facilities (Alpine dist and ln Alpine dist), pre-Alpine and Alpine time periods (period), lake type (type), and lake area (ln area) on occupancy of yellow-billed loon territories by breeding pairs and by broods, Colville River delta, Alaska, USA, 1993–2004. The pre-Alpine time period was 1993–1997 before construction of Alpine, and the Alpine time period was 1998–2004 during construction and operation of Alpine.

Model	K[a]	QAIC$_c$[b]	ΔQAIC$_c$	ω_i[c]
Occupancy by breeding pairs				
Type	3	507.61	0.00	0.15
Alpine dist + type	4	508.20	0.59	0.11
Type + period	4	508.46	0.85	0.10
Intercept	1	508.48	0.87	0.10
Ln Alpine dist + type	4	508.63	1.02	0.09
Alpine dist + period + type	5	509.05	1.44	0.07
Period	2	509.30	1.69	0.06
Ln Alpine dist + period + type	5	509.48	1.87	0.06
Alpine dist	2	509.60	1.99	0.06
Occupancy by broods				
Ln area	2	387.71	0.00	0.25
Alpine dist + period + Alpine dist × period + ln area	5	388.16	0.45	0.20
Ln area + period	3	389.56	1.86	0.10
Alpine dist + ln area	3	389.56	1.86	0.10
Ln Alpine dist + ln area	3	389.57	1.87	0.10
Ln Alpine dist + period + ln Alpine dist × period + ln area	5	390.31	2.61	0.07

[a] Number of parameters.
[b] Quasi-Akaike's Information Criterion corrected for small sample sizes.
[c] Akaike weights.

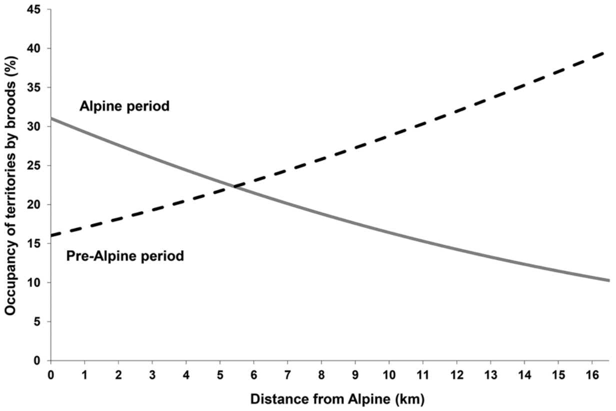

Figure 3. Interaction of distance to Alpine oilfield facilities and time periods on percent occupancy of yellow-billed loon territories by broods on the Colville River delta, Alaska, USA, 1993–2004. Time periods were pre-Alpine (1993, 1995–1997) and Alpine (1998, 2000–2004). The interaction term ($P = 0.001$) was in the second-best model. The interaction term did not support a disturbance relationship; territories close to Alpine had higher occupancy by broods after Alpine was built than before, the pre-construction slope indicated increasing occupancy in territories far from Alpine, and the post-construction slope indicated decreasing occupancy in territories far from Alpine.

and increased with distance from Alpine ($\beta = 0.075 \pm 0.043$, $P = 0.079$), whereas occupancy after Alpine was built was high in territories close to Alpine and declined with increasing distance ($\beta = -0.083 \pm 0.041$, $P = 0.045$).

Distance covariate models: Alpine versus CD3-CD4 periods.—Four models using continuous distance covariates had some level of support as the best model for territory occupancy by breeding pairs during the Alpine and CD3-CD4 periods (Table 5). The model with the most support included distance to facilities, time period, a distance by time period interaction, and lake type ($\omega_i = 0.53$). The same model without the interaction term had about half the support of the top model ($\omega_i = 0.23$).

In the top model, the interaction term was not quite significant ($P = 0.078$). Territory occupancy by breeding pairs declined with increasing distance to Alpine during the Alpine period ($\beta = -0.197 \pm 0.063$, $P = 0.002$; Fig. 4), but occupancy was high over all distances from facilities in the CD3-CD4 period ($\beta = -0.008 \pm 0.095$, $P = 0.931$).

No model with continuous distance was clearly best for territory occupancy by broods during the Alpine and CD3-CD4 periods (Table 5). The top-ranked model included lake area and time period ($\omega_i = 0.21$). A model with a distance by time period interaction had some support ($\omega_i = 0.11$). The interaction term was not significant ($P = 0.132$), but mean occupancy of territories by broods declined with increasing distance to facilities in the Alpine period ($\beta = -0.122 \pm 0.067$, $P = 0.068$) and increased slightly with increasing distance to facilities in the CD3-CD4 period ($\beta = 0.023 \pm 0.062$, $P = 0.715$).

Evaluation of BLM Minimum Survey Requirements

We discovered most of the yellow-billed loon territories in the first 3 years (1993, 1995, 1996) of aerial surveys that we used to simulate the minimum survey effort required by BLM (BLM 2008, 2013). We identified 35 nests and 23 broods in 30 territories (81% of 37 territories identified for 14 years) in the first 3 years (Fig. 5). The cumulative number of territories detected increased each subsequent year, reaching a plateau at 5–7 years (Fig. 6). Among the 7 territories not detected during the initial 3-year period, 4 territories (11% of the 37 territories) contained nests that were found on other surveys conducted those same 3 years (e.g., additional aerial surveys, ground-based surveys, or surveys for other species). We could not determine whether those 4 territories were occupied at the time we conducted the initial aerial surveys (i.e., detection error) or were unoccupied (i.e., nests failed before the survey or were initiated afterwards). The 7 undetected territories (19% of 37 territories) produced a proportional number of nests and broods in subsequent years: 17% of the nests (44 of 259) and 14% of the broods (17 of 118) found after the initial 3-year survey period.

About half the undetected nests and territories would have been subject to BMP E11 restrictions (BLM 2008, 2013)

Table 5. Summary of model selection results for relationships of distance to post-construction infrastructure (facility dist and ln facility dist), Alpine and CD3-CD4 time periods (period), lake type (type), and lake area (ln area) on occupancy of yellow-billed loon territories by breeding pairs and by broods, Colville River delta, Alaska, USA, 1998–2008. The Alpine time period was 1998–2004, and the CD3-CD4 time period was 2005–2008.

Model	K^a	$QAIC_c^b$	$\Delta QAIC_c$	ω_i^c
Occupancy by breeding pairs				
Facility dist + period + facility dist × period + type	6	435.82	0.00	0.53
Facility dist + period + type	5	437.47	1.65	0.23
Ln facility dist + period + type	5	438.51	2.70	0.14
Ln facility dist + period + ln facility dist × period + type	6	439.59	3.77	0.08
Occupancy by broods				
Ln area + period	3	438.71	0.00	0.21
Period	2	439.82	1.10	0.12
Facility dist + period + ln area	4	439.88	1.17	0.12
Facility dist + period + facility dist × period + ln area	5	439.97	1.26	0.11
Ln facility dist + period + ln area	4	440.23	1.52	0.10
Facility dist + period + facility dist × period	4	440.24	1.53	0.10
Facility dist + period	3	440.41	1.69	0.09
Ln facility dist + period	3	440.49	1.78	0.09

[a] Number of parameters.
[b] Quasi-Akaike's Information Criterion corrected for small sample sizes.
[c] Akaike weights.

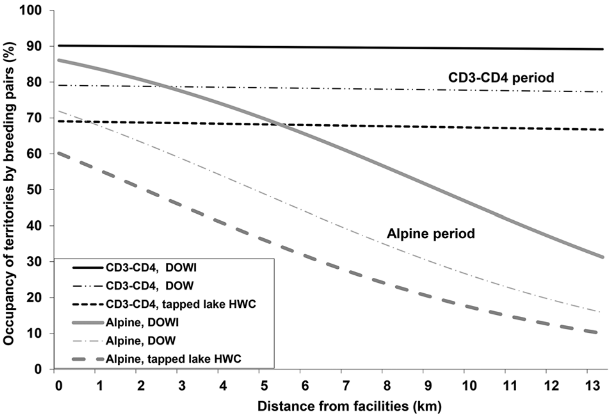

Figure 4. Interaction of distance to facilities and time periods on percent occupancy of yellow-billed loon territories by breeding pairs on the Colville River delta, Alaska, USA, 1998–2008. Time periods were Alpine (1998, 2000–2004) and CD3-CD4 (2005–2008). The interaction term ($P = 0.078$) in the most plausible model did not support a disturbance relationship. For 3 lake types (deep open water with islands [DOWI], deep open water [DOW], and tapped lakes with high-water connections [tapped lakes HWC]), territory occupancy by breeding pairs declined from high levels in territories close to any facility, to low levels far from facilities during construction and operation of the Alpine oilfield. During construction and operation of CD3 and CD4 satellite drill pads, territory occupancy by breeding pairs was high regardless of distance to facilities.

because of their proximity to detected nests and nesting lakes (Fig. 5). Three of 7 undetected territories (43%) lay entirely within 1.6-km nest buffers or 500-m lake buffers around detected nests, 3 were entirely outside all buffers, and 1 territory was bisected by buffer lines. The buffers encompassed 21 of the 44 nests (48%) in undetected territories found after the initial 3-year survey period.

DISCUSSION

Lake features were the most consistent indicators of breeding territories that were occupied by breeding pairs and broods. Lake size is a primary criterion for determining which lakes will be inventoried for yellow-billed loons in the NPRA because the species uses large, deep, clear, fish-bearing lakes for nesting and brood-rearing (North 1994, Earnst et al. 2006, Haynes et al. 2014*b*). The minimum area of lakes required to be surveyed for yellow-billed loons under the BMP E11 is 10 ha (BLM 2008, 2013), an area derived from early studies (Sage 1971, Sjölander and Algren 1976) and a species account (North 1994). However, smaller lakes are used for nesting on the Colville River delta (North and Ryan 1989), and in the NPRA (Earnst 2004). Recent surveys on the Seward Peninsula and in the NPRA included all lakes ≥7 ha (Haynes 2014, Schmidt et al. 2014). Our study found breeding lakes could be smaller than previously reported (minimum of 0.07 ha for nesting and 1.3 ha for brood-rearing), with 7% of nests on lakes <10 ha. Furthermore, multi-lake territories and lake-sharing among territories were common. Thus, breeding territories comprise a variety of configurations, which should be considered in survey designs.

Oil leases in NPRA have raised concerns about adverse effects on yellow-billed loons because of the species' small population size, low fecundity, and habitat specificity. The NPRA supports >91% of Alaska's segment of the population (Earnst 2004, USFWS 2014*b*). Yellow-billed loons are listed as a Sensitive Species by BLM-Alaska, which requires several BMPs to protect yellow-billed loon breeding lakes from industrial development (BLM 2013). Potential developers in NPRA must conduct ≥3 years of nesting and brood-rearing surveys prior to construction (BMP E11; BLM 2008, 2013). Based on our first surveys from a fixed-wing airplane in the early 1990s, 81% of the yellow-billed loon territories could be identified in 3 years. The number of territories with nests increased by another 11% when we included ancillary surveys conducted on different dates those same years, suggesting that survey replication within years could increase detection. We suspected that detection rates would improve if surveys are conducted from helicopters, which are capable of slower flight than fixed-wing aircraft. A comparison of loon nest detection among 3 types of survey platforms found the slower aircraft (Cessna 206) was similar to ground-based surveys and had 2–3 times the detection from the faster aircraft (Quest Kodiak, Quest Aircraft, Sandpoint, ID, USA; Haynes et al. 2014*b*). We used a Cessna 185, which is similar in size and flight speed to a Cessna 206, in the first years of surveys because it had greater range, greater availability, and lower costs relative to helicopters. We used helicopters when they were based at Alpine after its construction, which improved their cost-effectiveness.

Human disturbance (e.g., facilities, vehicles, machinery, aircraft, noise, and people) was assumed to be the principle factor to which yellow-billed loons were responding, but responses also could result from increased predation, habitat degradation, or contamination. We expected that if oilfield activities had adverse effects on occupancy of yellow-billed loon territories, annual territory occupancy would be lowest near facilities during or after construction of Alpine or CD3 and CD4, when vehicle, aircraft, and workforce numbers were highest. Similarly, territory occupancy should be highest prior to construction of Alpine and its satellite drill pads, and away from facilities after construction. We failed to find a consistent response in occupancy of territories by yellow-billed loons to oilfield facilities, where human disturbance was centered, on the Colville River delta over 14 years of pre-construction, construction, and operation. Mean distance of nests to facility footprints varied among years within a relatively narrow range (3.2–4.1 km) but did not suggest that loons were avoiding oilfield facilities. We found no evidence of decreasing numbers of nests or broods with increasing levels of human activity from before oil development to the period with 4 operating drill pads. Nest and brood numbers fluctuated between similarly low and high values before, during, and after construction of oilfield facilities. Modeling territory occupancy at 3 distance scales and 3 time periods that bracketed human activity levels did not demonstrate adverse responses of territory occupancy by breeding pairs or broods. Models were either inconclusive, with no model clearly superior and parameters that were not significant, or the relationships were not indicative of disturbance. A possible disturbance relationship was suggested by low occupancy of territories by broods within

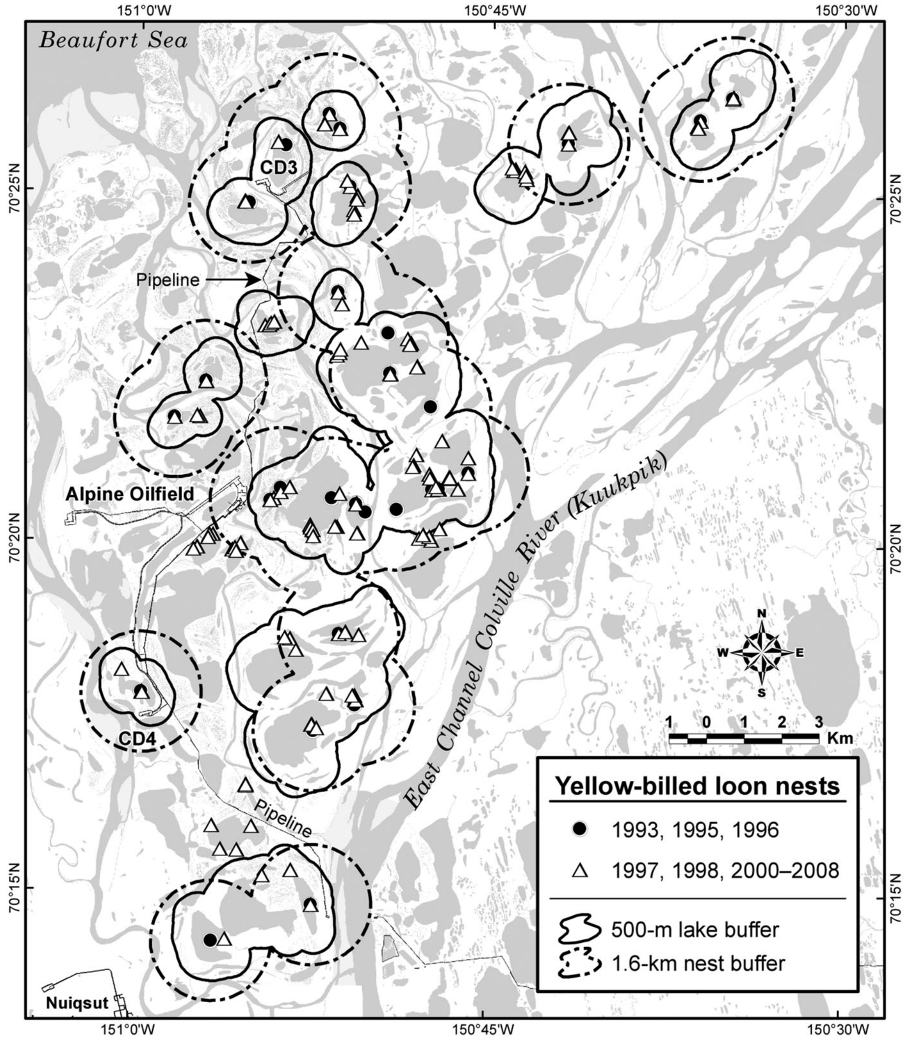

Figure 5. Example National Petroleum Reserve–Alaska (NPRA) management buffers (Bureau of Land Management 2008, 2012) applied around yellow-billed loon nests and lakes with nests or broods found during aerial surveys conducted twice annually in 1993, 1995, and 1996, and nests found during aerial surveys conducted twice annually in 1997, 1998, and 2000–2008, Colville River delta, Alaska, USA. We detected 30 (81%) of 37 territories in the first 3 years and added 1.6-km buffers around nests and 500-m buffers around nest lakes. Another 21 of the 44 nests found after the initial 3-year survey period incidentally occurred within the buffers.

1.6 km of Alpine, but the absence of an interaction with time period indicated that territories near Alpine had low occupancy before and after construction of the oilfield.

Detection of disturbance relationships at smaller scales was constrained by sample size. Of 3 territories ≤1.6 km from Alpine and 8 territories ≤1.6 km from CD3 or CD4, only 2 were ≤500 m to facilities. These 2 territories, one 330 m from a road and the other 500 m from a drill pad, had higher territory occupancy by breeding pairs in the later time periods, when disturbance levels were highest. Territory occupancy by broods in these 2 territories also increased from pre-Alpine to the CD3-CD4 time periods. Obviously, 2 territories are not a representative sample of how yellow-billed loon pairs will respond to nearby oil development. The number of loon pairs available to investigate responses to oil facilities is limited by low density and patchy distribution of breeding yellow-billed loons, which result from narrow habitat preferences, non-uniform distribution of suitable lakes, and pronounced territorial behavior. These factors in combination with the low density of oilfield facilities built under current technology (Gilders and Cronin 2000) resulted in few breeding territories occurring near oilfield facilities, even in the absence of land use restrictions (e.g., BMP E11).

Yellow-billed loons may have habituated over time to the human activities associated with oil development, including air and vehicle traffic, construction, noise, and research activities. Habituation is a reduction in response to repeated stimuli in the absence of reward or punishment (Alcock 1975). North (1994) observed habituation in some yellow-billed loons to disturbance, which presumably was research related. Common loons have been reported to habituate to human presence, recreation activity (Heimberger et al. 1983, Ruggles 1994), and regular float plane landings (Evers 2004). Habituation has been noted in other long-lived, territorial nesting birds: trumpeter swans (*Cygnus buccinator*) to jet air traffic (Henson and Grant 1991), bald eagles (*Haliaeetus leucocephalus*) to noise (Brown et al. 1999), and red-tailed

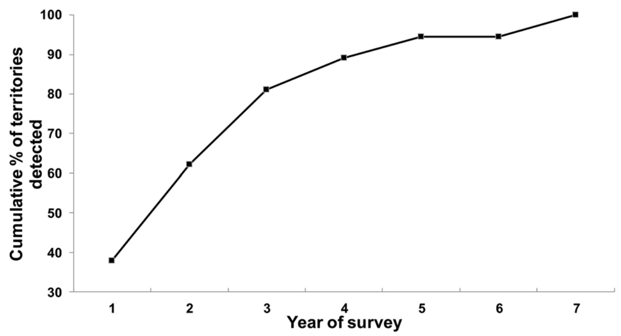

Figure 6. Cumulative percentage of yellow-billed loon breeding territories (based on 37 territories) detected with annual aerial surveys, 1 during June and 1 during August, Colville River delta, Alaska, USA, 1993, 1995–1998, 2000, and 2001.

hawks (*Buteo jamaicensis*) to low-level helicopter flights (Andersen et al. 1989). Habituation or increased tolerance (Nisbet 2000) may allow yellow-billed loons to establish nests near oilfield facilities without compromising nest attendance, nest defense, and rearing of young.

Factors independent of the location or timing of construction of oilfield facilities affect occupancy of yellow-billed loon breeding lakes. Weather, timing of lake thawing, and changing water levels affect loon nesting (North and Ryan 1989, Götmark et al. 1989, Mudge and Talbot 1993, North 1994). Shifting ice on thawing lakes can crush nests (North and Ryan 1989; ABR, unpublished data) and spring flooding of lakes can deter pairs from nesting. In 2000 and 2001 (Alpine period), ice jams caused flooding over large portions of the delta. Both years produced the fewest broods and nearly the fewest nests since our study began in 1993.

Variation in habitat quality of lakes probably explains many of the patterns we observed in territory occupancy near oilfield facilities. Other than the size and type of lakes indicated in our models, water levels, ice cover, protection from shifting ice, turbidity, fish populations, and presence of Pacific loons (*Gavia pacifica*) are likely influencing nesting yellow-billed loons (North 1994, Earnst et al. 2006, Haynes 2014) but also are more difficult to monitor. Given the temporal variability in some lake features, habitat quality is unlikely to be static, and can change non-uniformly across the delta.

Although territory occupancy by breeding pairs or broods was not negatively related to oilfield activities, incubation behavior, or productivity (e.g., nesting and fledging success) could be more sensitive to the high levels of aircraft overflights, traffic, drilling, and workers required to construct and operate facilities. Disturbance effects from various forms of human activity have been documented for a variety of avian species, including loons. Kertell (1996) observed Pacific loons flushed from nests in roadside impoundments by workers in Prudhoe Bay, Alaska. Nesting success of arctic loons (*Gavia arctica*) in Sweden increased after recreational access to nest islands ceased (Götmark et al. 1989). Common loons spent more time off their nests on lakes with more human disturbance (Caron and Robinson 1994). Productivity of common loons declined with increased human activity (Titus and VanDruff 1981) and cottages on lakes (Heimberger et al. 1983). However, 1 study found productivity unrelated to high disturbance levels (Caron and Robinson 1994). In the studies reviewed here, human disturbance often involved dwellings and recreation on breeding lakes, where disturbances can occur unpredictably and close to nests. Close encounters between humans and yellow-billed loon nesting pairs in our study area, however, are probably rare except for research directed at loons. Virtually no recreation, hunting, fishing, or dwellings occur on breeding lakes in our study area, although there are some habitations on lakes outside the study area. Native residents primarily hunt, fish, and travel on river channels and streams, where loons do not nest. Oilfield workers and equipment are restricted to the oilfield facilities during summer. Although some yellow-billed loons on the Colville River delta are exposed to vehicle and aircraft traffic, people or watercraft almost never approach loon nests in this breeding area. We expect that the behavior of individual loons near oilfield facilities may exhibit signs of disturbance from aircraft and vehicles (e.g., increased alert or concealment behaviors, possibly reduced nest attendance), as was documented for nesting greater white-fronted geese (*Anser albifrons*) and tundra swans during construction of Alpine (Johnson et al. 2003).

Modern design and best-management practices for oil development (Gilders and Cronin 2000) can ameliorate many of the direct and indirect effects on wildlife such as nesting birds (National Research Council [NRC] 2003). Baseline data on nest and brood locations and habitat preferences were used on the Colville River delta for siting roads, pads, and airstrips to avoid and reduce direct and indirect loss of nest sites and preferred habitats for a variety of species including yellow-billed loons (ARCO et al. 1997, BLM 2004). With directional drilling and other technical advances, the gravel footprint of new oilfields is 25–70% smaller than in older oilfields (Gilders and Cronin 2000), thus reducing the density of oil facilities, the wildlife habitat directly lost to oilfield footprints, and the area indirectly subject to disturbance. The rate of gravel deposition, an index of oil development as all permanent facilities are placed on gravel pads to keep the permafrost under-laid tundra from thawing, declined from 320 ha/year to 23 ha/year between 1988 and 2000 because of new technology and slowing development (NRC 2003). Off-road tundra travel is prohibited without special permits during summer and during winter is restricted to seasonal ice roads and pads to minimize tundra damage. Heavy construction (e.g., gravel road and pad building, pipeline construction) is limited to winter seasons, when few wildlife species are near oil development. Aircraft are required to maintain a minimum flight altitude of 305 m except when landing, taking off, or when conducting wildlife surveys. All personnel are trained in wildlife interaction, waste handling, and spill prevention (BP et al., 2015). Waste management plans and penalties for feeding wildlife reduce the availability of human food and food waste (Gilders and Cronin 2000), which, when uncontrolled, can supplement predator diets (gulls, ravens, foxes, and bears) and concentrate predators near oilfields (Eberhardt et al. 1982, 1983; Day 1998, Burgess 2000, Shideler and Hechtel 2000). Recently constructed oilfields on the ACP, such as the Alpine development, have been designed around these considerations and yellow-billed loons on the Colville River delta are benefiting from improved management practices.

Our study confirmed the long-term persistence of all the yellow-billed loon territories that North (1986) identified 1–2 decades previously. We suspect that the yellow-billed loon's longevity, territoriality, and preference for specific lake types and nest sites (North and Ryan 1989, North 1994, Earnst et al. 2006, Haynes 2014) are strong incentives to remain on traditional nesting and brood-rearing lakes despite the proximity of oil facilities. Individual common loons return to territories for several years and have higher success in reused territories (Piper et al. 1997, 2008). The tendency to reoccupy territories should be even stronger if suitable nesting lakes are limited. Vigorous defense of breeding territories against yellow-billed and Pacific loons, excess adults in alternate plumage during the nesting period, and decreased nesting during years when breeding lakes are flooded (North 1994, Earnst 2004, Johnson et al. 2005) are suggestive but not conclusive evidence that suitable breeding habitat is limiting. Low rates of extinction and colonization of nesting yellow-billed loons on lakes near the Meade and Ikpikpuk rivers are further evidence of habitat limitation in the NPRA (Haynes 2014).

Our findings suggest that territory occupancy by yellow-billed loons has been resilient to recent levels of human activity on the Colville River delta, the first breeding area of this species that has experienced oilfield development. We did not observe avoidance of breeding lakes near oilfield facilities (including those <1.6 km from oil facilities) among yellow-billed loons nesting and raising broods during construction and operation of the Alpine oilfield and 2 satellite drill sites over a 10-year span. We suspect this resilience may vary with habitat quality, breeding density, and disturbance regimes. Research into habitat constraints and factors affecting nest and brood survival will be important to define the limits to yellow-billed loon productivity and to actively manage for this species on its arctic breeding grounds.

MANAGEMENT IMPLICATIONS

Our findings suggest that prohibiting development within 1.6 km of nests is conservative of breeding territory occupancy (i.e., more protective of breeding lakes than may be necessary to ensure continued use) under the current pattern of oil development in low-density satellite fields. We could not evaluate the effectiveness of smaller buffer zones around nests or breeding lakes because of small sample sizes (due to low densities of nests) in areas nearest oil development. Because the nest and lake buffers prescribed in BMP E11 have the potential to affect yellow-billed loons and the location and cost of oil development, their effectiveness in maintaining loon productivity and territory occupancy should be monitored in other areas and modified if necessary.

Spatially explicit protections of breeding lakes, which is the objective of BLM management prescriptions (BLM 2008, 2013), depends on high detection rates and accurate locations for nests. Modifications to the BLM survey requirements could increase the detection of occupied nests and lakes. A small improvement (7% in this study) in detection of nests could be achieved by decreasing the minimum lake size surveyed from 10 ha to 1 ha but would require a disproportionate increase in survey effort. More breeding lakes could be identified with replication of surveys within years. Early and late initiated nests are more likely to be detected if replicate surveys are conducted periodically each year over the range of incubation start dates (3 Jun–8 Jul, median $= 18$ Jun, $n = 122$ nests; ABR, unpublished data). Research into optimal survey schedules and techniques could improve detection of nest territories.

ACKNOWLEDGMENTS

The conclusions are those of the authors and not necessarily those of ConocoPhillips Alaska. We thank pilots J. S. Hamilton, Arctic Air Alaska, and J. Dell, Maritime Helicopters. J. G. King, R. J. Ritchie, and D. A. Nigro were aerial observers prior to 2000. L. N. Smith managed this study in 1993. A. L. Zusi, D. Dissing, and M. J. Macander managed GIS data and map figures. We thank M. R. North, S. L. Earnst, and J. P. Parrett for generously sharing unpublished data. We thank R. M. Burgess and J. P. Parrett for their reviews. W. M. Block, H. Mathewson, P. R. Krausman, A. S. Cox, and 2 reviewers greatly improved this manuscript. ConocoPhillips Alaska, funded this study under the direction of M. R. Joyce and others.

LITERATURE CITED

Alcock, J. 1975. Animal behavior: an evolutionary approach. Sinauer Associates, Sunderland, Massachusetts, USA.

Andersen, D. E., O. J. Rongstad, and W. R. Mytton. 1989. Response of nesting red-tailed hawks to helicopter overflights. Condor 91:296–299.

ARCO Alaska, Inc. [ARCO], Anadarko Petroleum Corporation, and Union Texas Petroleum Corporation. 1997. Alpine Development Project environmental evaluation document. Prepared for U.S. Army Corps of Engineers, Anchorage, Alaska, USA.

BP Exploration Alaska, Inc., Caelus Energy Alaska, LLC, ConocoPhillips Alaska, Inc., Eni Petroleum Company Inc., ExxonMobil Alaska Production Inc., Hilcorp Alaska, LLC, and Savant Alaska, LLC. 2015. North slope environmental field handbook. Environmental Staff, Anchorage, Alaska, USA.

Brown, B. T., G. S. Mills, C. Powels, W. A. Russell, G. D. Therres, and J. J. Pottie. 1999. The influence of weapons testing noise on bald eagles. Journal of Raptor Research 33:227–232.

Bureau of Land Management [BLM]. 2004. Alpine Satellite Development Plan. Final Environmental Impact Statement. Volumes 1, 2, and 3. U.S. Department of the Interior, Bureau of Land Management with assistance from Minerals Management Service, Anchorage, Alaska, USA.

Bureau of Land Management [BLM]. 2008. Northeast National Petroleum Reserve-Alaska Integrated Activity Plan/Environmental Impact Statement Record of Decision. U.S. Department of Interior, Bureau of Land Management, Anchorage, Alaska, USA.

Bureau of Land Management [BLM]. 2013. National Petroleum Reserve-Alaska Integrated Activity Plan Record of Decision. U.S. Department of the Interior, Bureau of Land Management, Anchorage, Alaska, USA.

Burgess, R. M. 2000. Arctic fox. Pages 159–178 *in* J. C. Truett and S. R. Johnson, editors. The natural history of an arctic oilfield—development and biota. Academic Press, San Diego, California, USA.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information–theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Caron, J. A. Jr., and W. L. Robinson. 1994. Responses of breeding common loons to human activity in upper Michigan. Hydrobiologia 279/280:431–438.

Center for Biological Diversity. 2004. Petition to list the yellow-billed loon, *Gavia adamsii*, as an endangered or threatened species under the Endangered Species Act. Center for Biological Diversity, Sitka, Alaska, USA.

Day, R. H. 1998. Predator populations and predation intensity on tundra-nesting birds in relation to human development. Report for Northern Alaska Ecological Services, U.S. Fish and Wildlife Service, Fairbanks, Alaska, by ABR, Inc., Fairbanks, Alaska, USA.

Earnst, S. L. 2004. Status assessment and conservation plan for the the yellow-billed loon (*Gavia adamsii*). U.S. Geological Survey, Scientific Investigations Report 2004-5258, Reston, Virginia, USA.

Earnst, S. L., R. A. Stehn, R. M. Platte, W. W. Larned, and E. J. Mallek. 2005. Population size and trend of yellow-billed loons in northern Alaska. Condor 107:289–304.

Earnst, S. L., R. Platte, and L. Bond. 2006. A landscape-scale model of yellow-billed loon (*Gavia adamsii*) habitat preferences in northern Alaska. Hydrobiologia 567:227–236.

Eberhardt, L. E., W. C. Hanson, J. L. Bengtson, R. A. Garrott, and E. E. Hanson. 1982. Arctic fox home range characteristics in an oil-development area. Journal of Wildlife Management 46:183–190.

Eberhardt, L. E., R. A. Garrott, and W. C. Hanson. 1983. Den use by arctic foxes in northern Alaska. Journal of Mammalogy 64:97–102.

Ellis, J. I., and D. C. Schneider. 1997. Evaluation of a gradient sampling design for environmental impact assessment. Environmental Monitoring and Assessment 48:156–172.

Evers, D. C. 2004. Status assessment and conservation plan for the common loon (*Gavia immer*) in North America. U.S. Fish and Wildlife Service, Hadley, Massachusetts, USA.

Evers, D. C., J. D. Paruk, J. W. McIntyre, and J. F. Barr. 2010. Common loon (*Gavia immer*). Account 313 *in* A. F. Poole, editor. The birds of North America. Cornell Lab of Ornithology, Ithaca, New York, USA. https://birdsna.org/Species-Account/bna/species/comloo. Accessed 8 Feb 2017.

Fair, J. 2002. Status and significance of yellow-billed loon (*Gavia adamsii*) populations in Alaska. The Wilderness Society and Trustees for Alaska, Anchorage, Alaska, USA.

Gabrielson, I. N., and F. C. Lincoln. 1959. The birds of Alaska. Stackpole Company, Harrisburg, Pennsylvania, USA.

Gilders, M. A., and M. A. Cronin. 2000. North Slope oil field development. Pages 15–33 *in* J. C. Truett and S. R. Johnson, editors. The natural history of an arctic oilfield—development and biota. Academic Press, San Diego, California, USA.

Götmark, F., R. Neergaard, and M. Åhlund. 1989. Nesting ecology and management of the arctic loon in Sweden. Journal of Wildlife Management 53:1025–1031.

Groves, D. J., B. Conant, R. J. King, J. I. Hodges, and J. G. King. 1996. Status and trends of loon populations summering in Alaska, 1971–1993. Condor 98:189–195.

Hammond, C. A. M., M. S. Mitchell, and G. N. Bissell. 2012. Territory occupancy by common loons in response to disturbance, habitat, and intraspecific relationships. Journal of Wildlife Management 76:645–651.

Haynes, T. B. 2014. Biotic and abiotic influences on the use of arctic lakes by fish and loons. Dissertation, University of Alaska Fairbanks, Fairbanks, USA.

Haynes, T. B, J. A. Schmutz, J. F. Bromaghin, S. J. Iverson, V. M. Padula, and A. E. Rosenberger. 2015. Diet of yellow-billed loons (*Gavia adamsii*) in arctic lakes during the nesting season inferred from fatty acid analysis. Polar Biology 38:1239–1247.

Haynes, T. B., J. A. Schmutz, M. S. Lindberg, and A. E. Rosenberger. 2014*a*. Risk of predation and weather events affect nest site selection by sympatric Pacific (*Gavia pacifica*) and yellow-billed (*Gavia adamsii*) loons in arctic habitats. Waterbirds 37(sp1):16–25.

Haynes, T. B., J. A. Schmutz, M. S. Lindberg, K. G. Wright, B. D. Uher-Koch, and A. E. Rosenberger. 2014*b*. Occupancy of yellow-billed and Pacific loons: evidence for interspecific competition and habitat mediated co-occurrence. Journal of Avian Biology 45:296–304.

Heimberger, M., D. Euler, and J. Barr. 1983. The impact of cottage development on common loon reproductive success in central Ontario. Wilson Bulletin 95:431–439.

Henson, P., and T. A. Grant. 1991. The effects of human disturbance on trumpeter swan breeding behavior. Wildlife Society Bulletin 19:248–257.

Johnson, C. B., R. M. Burgess, B. E. Lawhead, J. A. Neville, J. P. Parrett, A. K. Prichard, J. R. Rose, A. A. Stickney, and A. M Wildman. 2003. Alpine avian monitoring program, 2001. Report for ConocoPhillips Alaska, Inc., and Anadarko Petroleum Corporation, Anchorage, by ABR, Inc., Fairbanks, Alaska, USA.

Johnson, C. B., R. M. Burgess, A. M. Wildman, A. A. Stickney, P.E. Seiser, B. E. Lawhead, T. J. Mabee, A. K. Prichard, and J. R. Rose. 2005. Wildlife studies for the Alpine Satellite Development Project, 2004. Report for ConocoPhillips Alaska, Inc., and Anadarko Petroleum Corporation, Anchorage, by ABR, Inc., Fairbanks, Alaska, USA.

Kertell, K. 1996. Response of Pacific loons (*Gavia pacifica*) to impoundments at Prudhoe Bay, Alaska. Arctic 49:356–366.

Mallek, E. J., R. Platte, and R. Stehn. 2006. Western Alaska yellow-billed loon survey–2005. Natural Resources Report NPS/AKRARCN/NRTR-2006/04. U.S. Fish and Wildlife Service, Waterfowl Management, Fairbanks, Alaska, USA.

Michael Baker Jr., Inc. 2008. 2008 Colville River delta spring breakup and hydrologic assessment. Report prepared for ConocoPhillips Alaska, Inc., Anchorage, Alaska, USA.

Mudge, G. P., and T. R. Talbot. 1993. The breeding biology and causes of nest failure of Scottish black-throated divers *Gavia arctica*. Ibis 135:113–120.

National Research Council [NRC]. 2003. Cumulative environmental effects of oil and gas activities on Alaska's North Slope. National Academies Press, Washington, D.C., USA.

Newbrey, J. L., M. A. Bozek, and N. D Niemuth. 2005. Effects of lake characteristics and human disturbance on the presence of piscivorous birds in northern Wisconsin, USA. Waterbirds 28:478–486.

Nisbet, I. C. T. 2000. Disturbance, habituation, and management of waterbird colonies. Waterbirds 23:312–332.

North, M. R. 1986. Breeding biology of yellow-billed loons on the Colville River delta, arctic Alaska. Thesis, North Dakota State University, Fargo, USA.

North, M. R. 1993. Distribution and migration of yellow-billed loons in North America. Bird Populations 1:36–49.

North, M. R. 1994. Yellow-billed loon (*Gavia adamsii*). Account 121 *in* A. F. Poole and F. B. Gill, editors. The birds of North America. Cornell Lab of Ornithology, Ithaca, New York, USA. https://birdsna.org/Species-Account/bna/species/yebloo. Accessed 8 Feb 2017.

North, M. R., and M. R. Ryan. 1988. Yellow-billed loon, *Gavia adamsii*, breeding chronology and reproductive success in arctic Alaska. Canadian Field-Naturalist 102:485–490.

North, M. R., and M. R. Ryan. 1989. Characteristics of lakes and nest sites used by yellow-billed loons in arctic Alaska. Journal of Field Ornithology 60:296–304.

Piper, W. H., J. D. Paruk, D. C. Evers, M. W. Meyer, K. B. Tischler, M. Klich, and J. J. Hartigan. 1997. Local movements of color-marked common loons. Journal of Wildlife Management 61:1253–1261.

Piper, W. H., C. Walcott, J. N. Mager, and F. J. Spilker. 2008. Nestsite selection by male loons leads to sex-biased site familiarity. Journal of Animal Ecology 77:205–210.

Ruggles, A. K. 1994. Habitat selection by loons in southcentral Alaska. Hydrobiologia 279/280:421–430.

Sage, B. L. 1971. A study of white-billed divers in Alaska. British Birds 64:519–528.

Schmidt, J. H., M. J. Flamme, and J. Walker. 2014. Habitat use and population status of yellow-billed and Pacific loons in western Alaska, USA. Condor 116:483–492.

Schmutz, J. A. 2009. Model-based predictions of the effects of harvest mortality on population size and trend of yellow-billed loons. U.S. Geological Survey open-file report 2009-1040, Reston, Virginia, USA.

Schmutz, J. A., K. G. Wright, C. R. DeSorbo, J. Fair, D. C. Evers, B. D. Uher-Koch, and D. M. Mulcahy. 2014. Size and retention of breeding territories of yellow-billed loons (*Gavia adamsii*) in Alaska and Canada. Waterbirds 37(sp1):53–63.

Shideler, R., and J. Hechtel. 2000. Grizzly bear. Pages 105–132 *in* J. C. Truett and S. R. Johnson, editors. The natural history of an arctic oilfield—development and biota. Academic Press, San Diego, California, USA.

Sjölander, S., and G. Agren. 1976. Reproductive behavior of the yellow-billed loon, *Gavia adamsii*. Condor 78:454–463.

Titus, J. R., and L. W. VanDruff. 1981. Response of the common loon to the recreational pressure in the Boundary Waters Canoe Area, northeastern Minnesota. Wildlife Monographs No. 79.

Torsten H., K. Hornik, M. A. van de Wiel, and A. Zeileis. 2006. A Lego system for conditional inference. American Statistician 60:257–263.

Uher-Koch, B. D., J. A. Schmutz, and K. G. Wright. 2015. Nest visits and capture events affect breeding success of yellow-billed and Pacific loons. Condor 117:121–129.

U.S. Fish and Wildlife Service [USFWS]. 2006. Conservation agreement for the yellow-billed loon (*Gavia adamsii*). USFWS, Fairbanks, Alaska, USA.

U.S. Fish and Wildlife Service [USFWS]. 2014*a*. Species status assessment report, yellow-billed loon (*Gavia adamsii*). USFWS, Fairbanks, Alaska, USA.

U.S. Fish and Wildlife Service [USFWS]. 2014*b*. Endangered and threatened wildlife and plants; 12-month finding on a petition to list the yellow-billed loon as an endangered or a threatened species. Federal Register 79:59195–59204.

Walker, H. J. 1978. Lake tapping in the Colville River delta, Alaska. Pages 233–238 *in* Proceedings of the 3rd International Conference on Permafrost, volume 1. National Research Council Canada, Edmonton, Alberta, Canada.

Walker, H. J. 1983. Guidebook to permafrost and related features of the Colville River delta, Alaska. Guidebook 2. Alaska Division of Geological and Geophysical Survey, Anchorage, Alaska, USA.

Walker, H. J., and H. H. Morgan. 1964. Unusual weather and river bank erosion in the delta of the Colville River, Alaska. Arctic 17:41–47.

Associate Editor: Bill Block.