



Trends in Arctic-nesting loon (*Gavia* spp.) populations in North America

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Abstract

Several species of loons (or divers; Gaviidae) breed in Arctic Canada, and concern has been raised about their changes in abundance in light of threats such as bycatch and at-sea industrial development. These loons are not well monitored, but we gathered localized count data for three Arctic-nesting loons (Pacific loon *Gavia pacifica*, red-throated loon *G. stellata*, and yellow-billed loon *G. adamsii*) from multiple sources and estimated mean annual population change to estimate species-specific trends over varying time periods. Most breeding ground information between 1996 and 2022 suggested stable numbers for each species, although data were scarce for yellow-billed loon. Trends during the non-breeding season from 1966 to 2021 were estimated for red-throated and Pacific loons from the Christmas Bird Count, a citizen science general bird count, and suggested overall stable or increasing numbers, despite some substantial regional differences. Again, yellow-billed loon numbers were not captured well during the non-breeding season. Aerial winter waterfowl surveys on the east coast of North America (2008–2011, 2014) showed positive trends for red-throated loons for most locations north of 38° latitude and stable trends elsewhere. The paucity of both breeding and non-breeding count data for yellow-billed loons is unfortunate, as this species is found in high numbers in fishing gear in the Arctic. Overall, the limited available data do not suggest that loon populations breeding in the Canadian Arctic have experienced extensive declines, but monitoring of yellow-billed loons should be a priority.

Keywords Aerial survey · Population trends · Gaviiformes · Christmas Bird Count

Introduction

Seabirds are one of the most threatened bird groups globally, mostly attributable to deleterious effects of human activities on oceans, notably through interactions with industrial fisheries (Dias et al. 2019). These impacts can take several forms, including pollution (especially with plastic fishing gear; Phillips et al. 2010; Linnebjerg et al. 2021), reduction of food supplies (seabird prey) due to competition with fisheries (Sydeman et al. 2017), and direct capture and mortality in fishing gear (bycatch; Weimerskirch et al. 2000; Lewison et al. 2004). At sufficiently high levels, such direct and indirect sources of mortality from fisheries can have negative population-level effects on seabirds (Regular et al. 2013).

Bycatch is a well-known threat to some seabird species, especially albatrosses and petrels (Bull 2007; Anderson et al. 2011). However, with increased fishing in the Arctic (Fau-chald et al. 2021), where large numbers of seabird breed

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(~40 million in the Canadian Arctic and West Greenland; Gaston et al. 2012; Mallory et al. 2019), the potential for increased bycatch has become a concern in this region. From the limited available information, most seabird mortality due to bycatch in the Canadian Arctic appears to be in northern fulmars (*Fulmarus glacialis*) and diving auks, and generally occurs with gillnet and longline gear in the summer and autumn (Hedd et al. 2016). Nonetheless, a recent study (Mallory et al. 2022) showed that loons (*Gavia* spp.) were caught at an exceptionally high rate in gillnets of a commercial Arctic char (*Salvelinus alpinus*) fishery in Arctic Canada. Of particular concern was the bycatch of yellow-billed loons (*G. adamsii*), which are considered near threatened by the IUCN (Earnst 2004; Uher-Koch et al. 2020). However, wildlife biologists have little information on population trends for Arctic-nesting loon species (Smith et al. 2020), and whether Arctic bycatch levels warrant conservation concern for loons in general.

Three loon species breed in the Canadian Arctic: Pacific loon (*G. pacifica*), red-throated loon (*G. stellata*), and yellow-billed loon. The Arctic loon (*G. arctica*) breeds in small numbers in western Alaska, and was not considered in this study. The common loon (*G. immer*) breeds primarily at temperate latitudes although some do reach the treeless Arctic. However, we excluded common loon from our study

because most breed outside of Arctic habitats. Furthermore, through ongoing investigations for decades, conservationist and wildlife managers generally have a good understanding of the population trends and population threats for common loon, compared to other loon species (Evers 2004; Bianchini et al. 2020; Piper et al. 2020).

While the breeding ranges of the Arctic-nesting species are largely sympatric, they do not necessarily overlap at finer scales. Red-throated and Pacific loons tend to nest in boreal and taiga habitats, around small, shallow ponds, whereas yellow-billed loons breed around or on islands of larger lakes, in treeless tundra (Rizzolo et al. 2020; Russell 2020; Uher-Koch et al. 2020). Breeding ranges of all three species are at high northern latitudes, and generally outside of the limits of large-scale annual surveys, such as the North American Breeding Bird Survey (Sauer et al. 2019) and the Waterfowl Breeding Population and Habitat Survey (WBPHS; U.S. Fish and Wildlife Service 2022). Hence, to date, it has been difficult to gauge how loon populations in the North American Arctic are faring. Regarding their migration, circumpolar-nesting red-throated loons are medium-distance migrants with the northern Alaska population migrating to Asian waters, southern Alaska breeding population migrating along the Pacific coast of North America, and the eastern population migrating through Hudson Bay and the Great Lakes to winter along

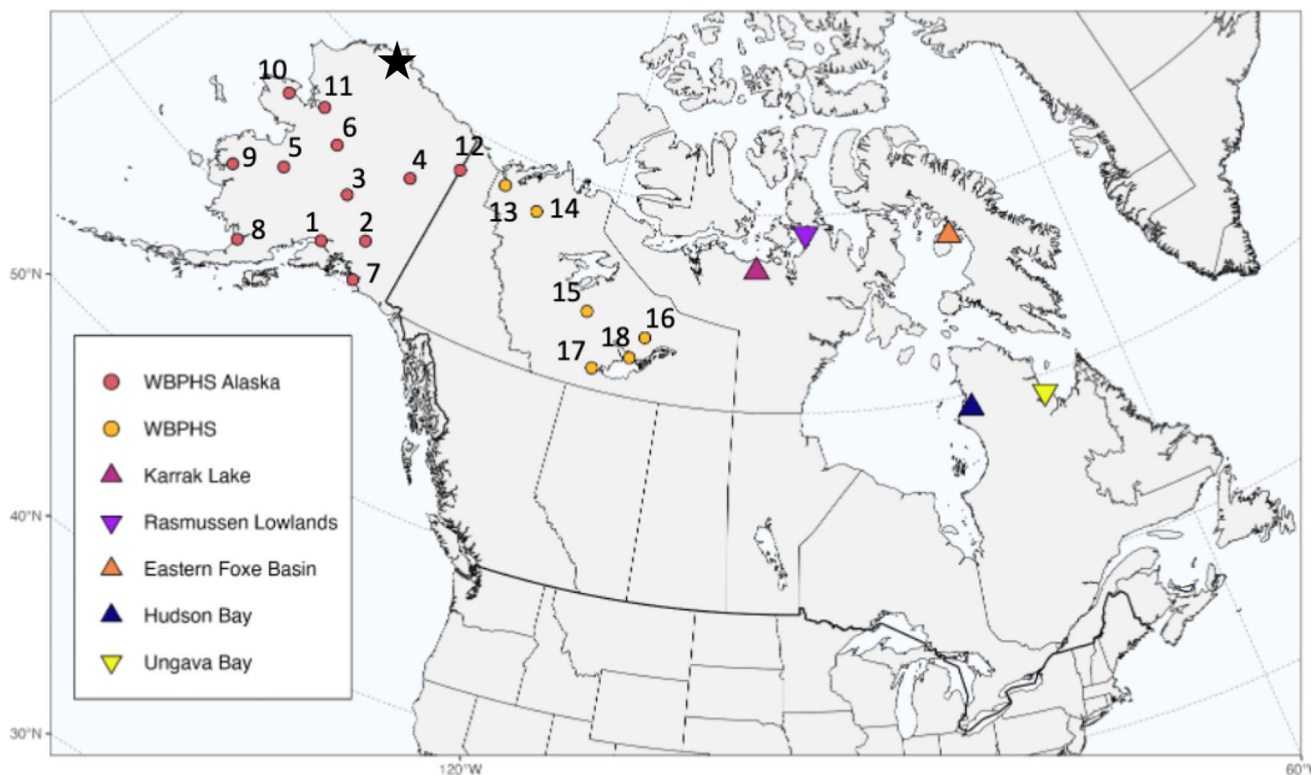


Fig. 1 Location of the different breeding surveys for loon. Circles: Waterfowl Breeding Population and Habitat Survey with strata number; Triangles: Individual surveys. Black star indicates the Arctic Coastal Plain Survey

the Atlantic Coast. Pacific loons, nesting largely in North America, are short- to medium-distance migrants and travel to coastal marine habitats along the Pacific coast, mostly to Mexico. Yellow-billed loons breeding in Canada migrate along the Pacific coast of North America, while those breeding in northern Alaska mostly migrate to Asian waters.

Globally, the population of Pacific loon is thought to be increasing (likely > 500,000 individuals; Russell 2020), with that of red-throated loon declining or stable (Groves et al. 1996; Larned et al. 2012; Mallek and Groves 2012). The global estimate is 200,000–600,000 individuals, with probably > 40,000 individuals (~ 6 to 20% of the population) in North America (Rizzolo et al. 2020). Abundance of yellow-billed loons is also assumed declining, currently believed to be < 32,000 individuals (Uher-Koch et al. 2020). With its wide but patchy distribution, yellow-billed loons are difficult to survey, and population size is likely seriously undercounted (Schmidt et al. 2014). During migration, they move to coastal marine habitats where they form part of subsistence harvest (i.e., for food and ceremonial clothing) for Indigenous communities from Alaska to Nunavut (Priest and Usher 2004; Driscoll-Engelstad 2005; Naves and Zeller 2017). While subsistence harvest likely has local impacts on yellow-billed loon population, mortality of adults specifically has the most considerable influences on loon populations (Mitro et al. 2008). Indigenous communities tend to target juvenile loons based on time of year and plumage (Naves and Zeller 2017). Given (i) limited information on population trends, (ii) the assessment that at least one species of loon may be in decline due to human activity, and (iii) recent evidence that a second human activity (incidental fisheries bycatch) might deleteriously affect loons, we summarized available information on numbers of Arctic-nesting loon species to infer population trends.

With a focus on Pacific, red-throated, and yellow-billed loons, we collated available data on loon breeding populations in the North American Arctic, using the WBPBS within our study area (conducted annually by the U.S. Fish & Wildlife Service and the Canadian Wildlife Service, see <https://ecos.fws.gov/ServCat/Reference/Profile/47314> for more information), and other localized breeding period surveys. We also investigated changes in the number of non-breeding loons counted during the Christmas Bird Count (CBC; a citizen science monitoring program), and aerial winter surveys conducted along the Atlantic Coast of the United States (Atlantic Coast Wintering Sea Duck Survey; AWSDS, see <https://ecos.fws.gov/ServCat/Reference/Profile/142409>) to provide a more broad-scale overview of regional patterns in population trends across North America.

Methods

Our objective was to estimate trends over time for varying spatial units of surveyed populations, counted either during breeding or non-breeding seasons, using various monitoring methods. We describe each of these in detail below in sections for each data source, including time period and number of years monitored, count methods, species monitored, and number of sites or strata. Loons were identified at the species level.

Study area

Breeding season

To estimate Arctic breeding loon population trends, we used four available datasets: (1) WBPBS (Alaska, Yukon, and the Northwest Territories); (2) Ungava Peninsula surveys (Quebec); (3) Eastern Foxe Basin and Rasmussen Lowlands surveys (Nunavut); and (4) Central Arctic (Karrak Lake, Nunavut) surveys. WBPBS locations within the Arctic region included an Alaska crew (11 strata in Alaska and 1 in the Yukon) and a Canadian crew (6 strata in the Northwest Territories; Fig. 1). Data from WBPBS were collected annually between 2000 and 2019 by the U.S. Fish and Wildlife Service and the Canadian Wildlife Service using a standardized, long-running international aerial survey (U.S. Fish and Wildlife Service 2022). The survey is geared toward waterfowl (ducks and Canada geese), but crews also record a few other species of large waterbirds, including loons. The survey transects are distributed among strata delineated according to habitat differences and political boundaries. Within each stratum, loons were counted along transects (400 m wide) from fixed-wing aircraft at about 50 m above ground level. Counts were summarized by 29-km-long segments. Data from Ungava Peninsula surveys were obtained for red-throated loons from aerial surveys over the Ungava Peninsula between 1996 and 2022 (Harvey et al. 2022). The data were split between the west (Hudson Bay coast, $n = 12$ years) and east part of this peninsula (Ungava Bay coast, $n = 15$ years; Fig. 1). Survey aircraft were flown at a ground speed of 140 km/h at 30–45 m above ground level. Eastern Foxe Basin and Rasmussen Lowlands surveys are part of the Program for Regional and International Shorebird Monitoring (PRISM). Data were obtained for Pacific and red-throated loons from Eastern Foxe Basin between 1997 and 2019 ($n = 2$ years), and for Rasmussen Lowlands between 1994 and 2019 ($n = 3$ years). Surveys in the Eastern Foxe Basin occurred on Prince Charles Island and nearby islands. The Rasmussen Lowlands is a coastal wetland complex located at the base of the Boothia Peninsula. It is

a designated Ramsar wetland of international importance. Monitoring was performed on foot by counting all adults on 400×400 m plots subdivided into adjacent transects 50 m wide with observers 25 m apart across several plots (Bart et al. 2012). The region around the Karrak Lake field station has been used for > 3 decades for goose research (Ross et al. 2017; Weegman et al. 2022; Alisauskas et al. 2024). During much of that time, islands on Karrak Lake were monitored by researchers walking on foot, and recording Pacific and red-throated loon nests found from 1999 to 2019 ($n=21$ years) as part of a wider waterfowl breeding survey (Kellett and Alisauskas 2011).

In addition, we present already published data for three loon populations between 1992 and 2016 obtained by aerial surveys by the US Fish and Wildlife Service Migratory Bird Management program and the Arctic Coastal Plain survey on the North Slope in Alaska (Amundson et al. 2019).

Non-breeding

To estimate loon population trends during non-breeding, we used: (1) the Atlantic coast Wintering Sea Duck Survey (AWSDS) and (2) Christmas Bird Count (CBC) data. AWSDS was conducted yearly between January and March along the Atlantic coast of the United States between 2008 and 2011 and again in 2014 (Silverman et al. 2013). Fixed-wing aircraft were flown at 110 knots at an altitude of 70 m while sea ducks and seabirds were counted within 200 m on either side of the aircraft. Transects were 8 nm (14.82 km) wide and spaced every 5 nm (9.26 km).

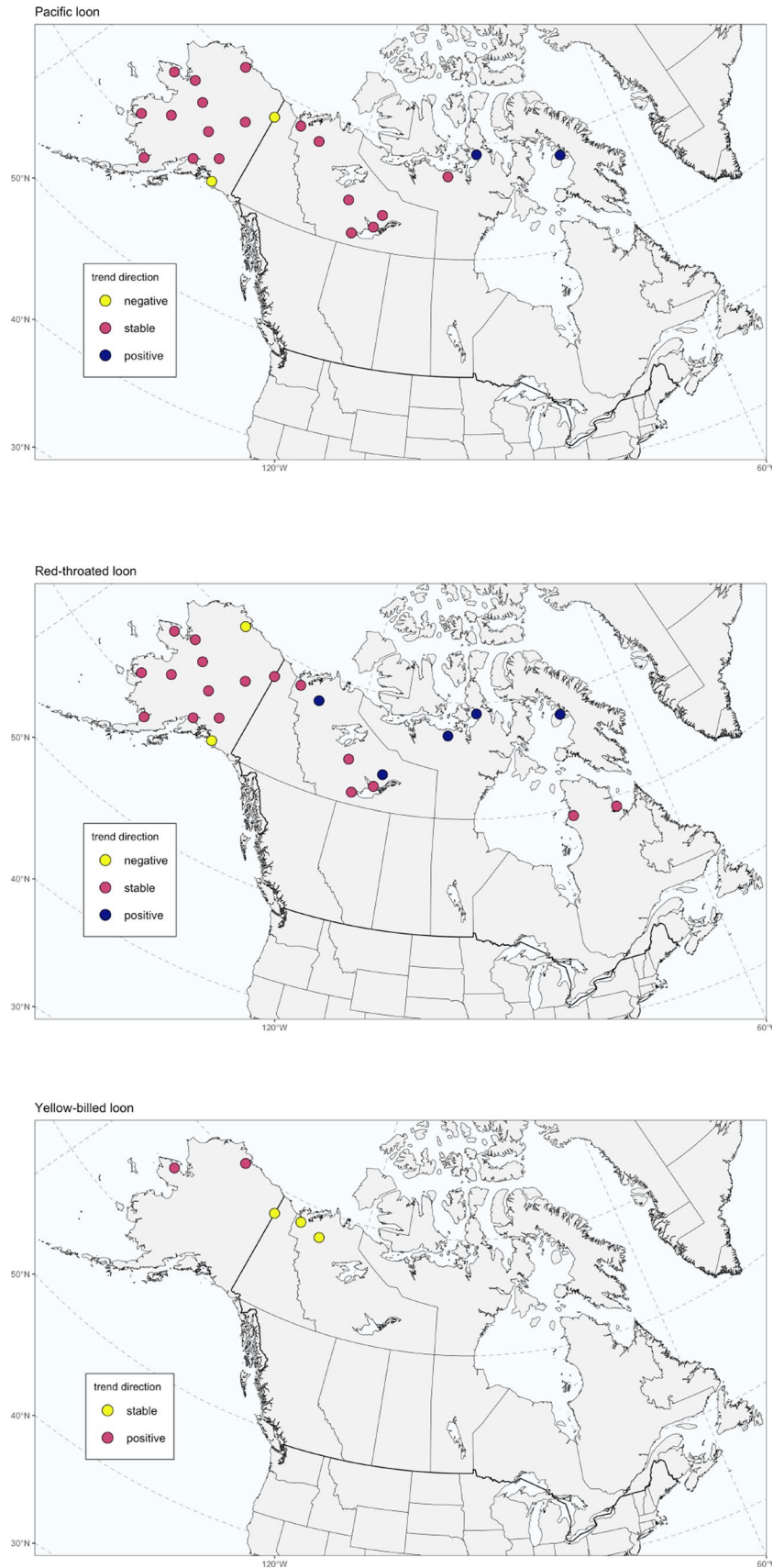
The CBC is an annual land-based winter bird survey carried out by volunteers since the onset of the twentieth century. Participants record the count of each bird species observed within a single day between December 14 and January 5. These counts occur within predefined circles of ~12 km radius (Dunn et al. 2005). Observer groups make efforts to cover all types of habitats within the circle, including nearshore regions if touching coastlines. Annual count data from the CBC were obtained for all circles reporting at least one of three loon species (red-throated, Pacific, and yellow-billed) since 1965. Most CBC data were acquired from the National Audubon Society by request (National Audubon Society 2020), with the exception of six circles in New Brunswick (NB). Data from these counts have not been reported to the National Audubon Society in most years, but can be extracted from online archives of the NB Naturalist (<https://www.naturenb.ca/archives-nb-naturalist/>). The year of a CBC circle count is defined as the year of that winter's December, despite some counts taking place in the first week of January (i.e., the count from 2020 is representative of the winter of 2020/2021). In years where CBC circles were surveyed but no individuals of a species were reported, zeros were assumed. We opted to analyze CBC data at the

localized circle level rather than a broader regional/provincial level, which would result in the loss of transparency in the spatial coverage underlying the trends. This would be exacerbated in areas of relatively high and low abundance pooled together for a single region-level trend.

Statistical analysis

All data were analyzed using the software R (v.3.6.1; R Core Team, 2020). We derived species-specific trends as λ at either the site, strata, or circle level based on $\lambda = e$, where the coefficient is calculated from a linear regression, or a generalized linear regression with a negative binomial distribution (Gutowsky et al. 2022), depending on data availability and structure. Values of λ above 1 indicate population increase (e.g., 1.02 indicates a 2% annual increase in the population) and values below 1 indicate population decline (e.g., 0.98 indicates a 2% annual decline in the population). We report change in abundance with 95% confidence intervals (CI) where values with 95% CI bounding 1 indicate lack of detectable trend or population stability. We did not include unidentified loons in our analyses. For each year of WBPHS, species-specific density (birds/km²) was calculated for each segment and averaged per stratum. Change in density over time for other breeding data (Ungava Peninsula, Eastern Foxe Basin, and Karrak Lake) was modeled with linear regression and species-specific trends were derived as change/year in total individual count. In the Ungava Bay and Hudson Bay regions, data sparseness precluded estimation of λ for each transect. Instead, species-specific trends (λ) were estimated with linear regression of total individual count per year and per region. For winter aerial surveys, we calculated density (birds/km²) for each species for each transect, based on the length and width of each survey transect. We averaged species-specific density for each degree latitude, including transects surveyed with no loons detected. We then estimated λ from linear regression in mean annual density over time, as above. To model localized trends for the CBC data, we employed standard techniques to analyze count data using generalized linear models (GLMs; Zurr et al. 2009) at the level of CBC circles. We estimated λ for each species for the period 1966–2021 using data from circles meeting the following criteria: (i) at least one survey reported within 10 years of the start (1966) and end (2021) of the study period (zeros included); (ii) a minimum count of 5 loons of a given species reported at least once; (iii) no time series gaps greater than 10 years; and (iv); a maximum of 50% zeros on reported counts. These criteria ensured that our models were limited to sample circles with acceptable temporal coverage and suitable loon habitat with sufficient numbers of birds to detect trends. We first considered GLMs with Poisson distributions and year (trend) effects to examine levels of overdispersion (R packages

Fig. 2 Trend directions for Pacific loon (*G. pacifica*; top panel), red-throated loon (*G. stellata*; middle panel), and yellow-billed loon (*G. adamsii*; bottom panel) at different breeding locations. Trend direction is based on lambda where positive indicates λ with lower 95% confidence interval > 1, negative indicates λ upper 95% confidence interval < 1, and stable indicates cases where the 95% confidence interval includes $\lambda = 1$



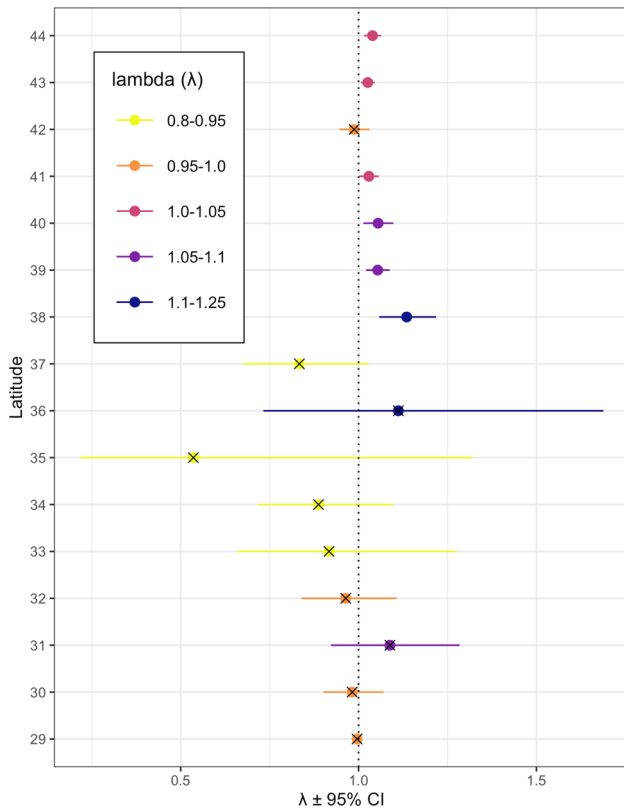


Fig. 3 Annual change in density during the winter aerial surveys of red-throated loon (*G. stellata*) within one latitude block along the East Coast on North America. \times symbol indicates cases where the 95% confidence interval includes $\lambda = 1$

‘MASS’ and ‘performance’; Venables and Ripley 2002; Lüdecke et al. 2021), which was pervasive. We then fitted GLMs with negative binomial distributions to address the extra variance; these models fit the data well (overdispersion ≤ 1.2), so we did not consider zero-inflation models further. Species-specific trends for each CBC circle were derived as mean population change per year (λ). CBC data are often adjusted for observer effort since variable numbers of volunteers participating in a count can affect total number of birds detected. However, large and conspicuous coastal waterbirds are easily found and identified by birders, rendering them far more likely than songbirds or cryptic species to be reported in similar numbers regardless of total effort within a count circle (Dunn et al. 2005; Bowman et al. 2015; Gutowsky et al. 2022). Thus, we did not adjust for observer effort in our reported CBC trend models for loons.

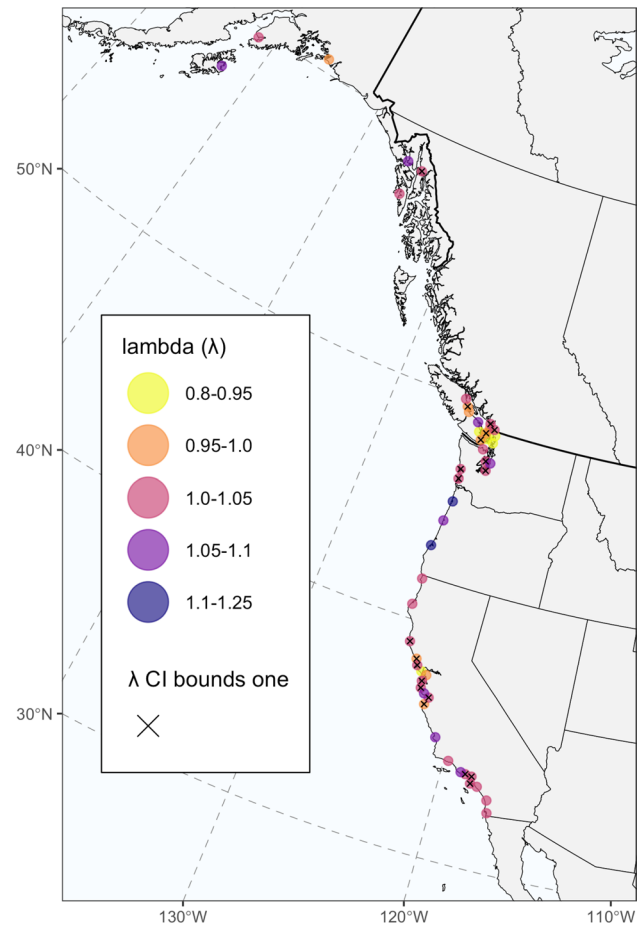


Fig. 4 Values of mean population change per year for Pacific loon (*G. pacifica*) at the different circles from Christmas Bird Count

Results

Trends during breeding

Pacific loons were present in all 18 WBPHS strata, and modeling trends indicated that most strata had λ values overlapping 1.0 in Alaska (83%; Fig. 2) and in Canada (100%; Fig. 2, Online resource 1). The remaining strata in Alaska (17%) showed negative trends. In the Eastern Foxe Basin regions and the Northern Hudson Barrens, trends were positive, but stable at Karrak Lake.

Red-throated loons were present in all 18 WBPHS strata. Most strata had λ values overlapping 1.0 in Alaska (92%; Fig. 2) and in Canada (67%; Fig. 2, Online resource 1). Remaining strata showed a negative trend in Alaska (8%) and a positive trend in Canada (33%). We inferred population stability in the Hudson Bay and Ungava Bay regions but population increase at Karrak Lake, the Northern Hudson Barrens, and the Eastern Foxe Basin regions.

Yellow-billed loons were present in only four WBPHS strata, showing population stability or growth in Alaska,

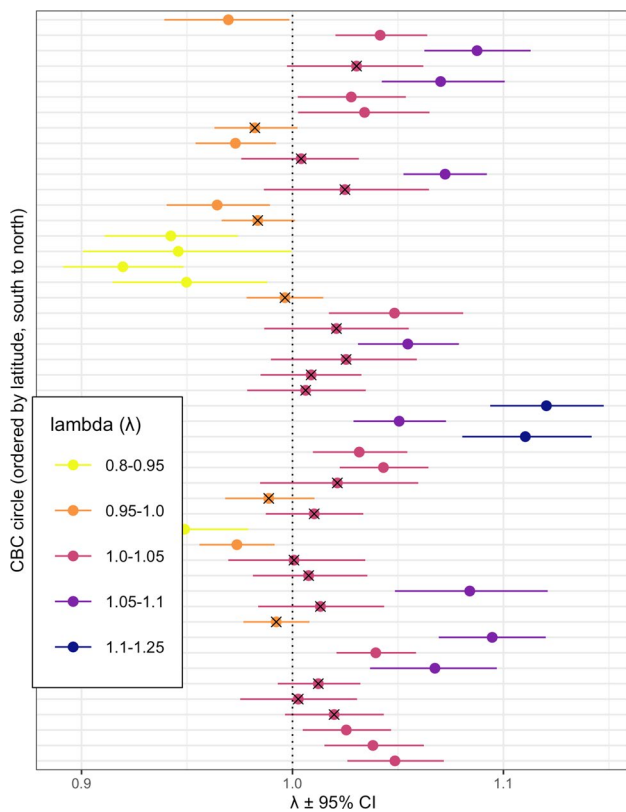


Fig. 5 Pacific loon (*G. pacifica*) annual population growth rate estimates at Christmas Bird Count circles on West Coast of North America, organized according to latitude. x symbol indicates cases where the 95% confidence interval includes $\lambda = 1$

Table 1 Number of circles of Christmas Bird Count where the different loon species (Pacific loon-PALO; red-throated loon-RTLO; yellow-billed loon-YBLO) were detected between 1965 and 2021, with percent of those circles presenting negative, stable, or positive long-term trends of λ values on the West coast and East coast of North America

Species	PALO		RTLO		YBLO
	W. coast	E. coast	W. coast	E. coast	
# circle	49	91	49	91	2
% Negative	9 (18%)	6 (7%)	14 (29%)	6 (7%)	1 (50%)
% Stable	20 (41%)	22 (24%)	23 (47%)	22 (24%)	
% Positive	20 (41%)	63 (69%)	12 (24%)	63 (69%)	1 (50%)

and stability in Canada (Fig. 2). Published data from the Arctic Coastal Plain Survey (1992–2016) indicated stable trend for Pacific loon, negative trend for red-throated loons, and positive trend for yellow-billed loon (Amundson et al. 2019; Fig. 2).

Trends during non-breeding

During AWSDS along the Atlantic coast of the United States, red-throated loons were present in 16 sections and trends were stable in most (62%), but positive for other Sects. (38%, Fig. 3). All positive sections were north of 38°N latitude. There were 49 CBC circles, all on the Pacific coast, with sufficient data to model Pacific loon density (Fig. 4). Most circles suggested population increase (41%) or stability (41%), while 18% showed declines (Fig. 5, Table 1). Most declines occurred in the Strait of Juan de Fuca and Strait of Georgia (Fig. 4). There were 140 CBC circles with sufficient data to model red-throated loon populations: 49 on the Pacific coast (longitude > 100°W) and 91 on the Atlantic coast (Fig. 6). Density of red-throated loons was stable in most cases on the Pacific coast, but increasing along the Atlantic coast (Figs. 6, 7, Table 1). As for Pacific loons, clusters of local decline were detected in coastal B.C. and Washington (Fig. 5). Only two circles had sufficient data to model trends for yellow-billed loon, one of which showed a decline in Alaska but an increase in Oregon.

Discussion

Using available data for loons from several sources, we assessed trends in current Arctic-nesting loon populations, motivated by the increased potential from threats they may be exposed to in the Arctic marine environment, particularly fisheries bycatch (Mallory et al. 2022). We used different methods, seasonal timing, and time period covered to estimate loon population trends. Consequently, trends from different methods (aerial or ground breeding surveys, Christmas Bird Count, winter aerial surveys) should not be compared directly. For example, breeding surveys only account for adults or their nests while winter surveys (aerial and CBC) record counts of adults and young. Consequently, estimates of λ presented should only be compared when using the same methods and dataset. Still, an effort to estimate and consider trends from all available data sources together is a worthwhile undertaking, given the general lack of published information for Arctic-nesting loons. Most regional populations of each species appeared to be stable on breeding areas across the surveyed range (Fig. 2). CBC data suggested negative trends for red-throated and Pacific loons at surveyed sites in the Salish Sea/Juan de Fuca Strait area on the Pacific coast, and along the southeastern U.S. Atlantic coast for red-throated loons on the Atlantic coast, but mostly stable or increasing populations elsewhere. Winter aerial surveys along the Atlantic coast showed mainly stable trends, but wide confidence intervals suggested data sparseness from low numbers of sample years (Lougheed et al. 1999). It is worth noting that aerial surveys were

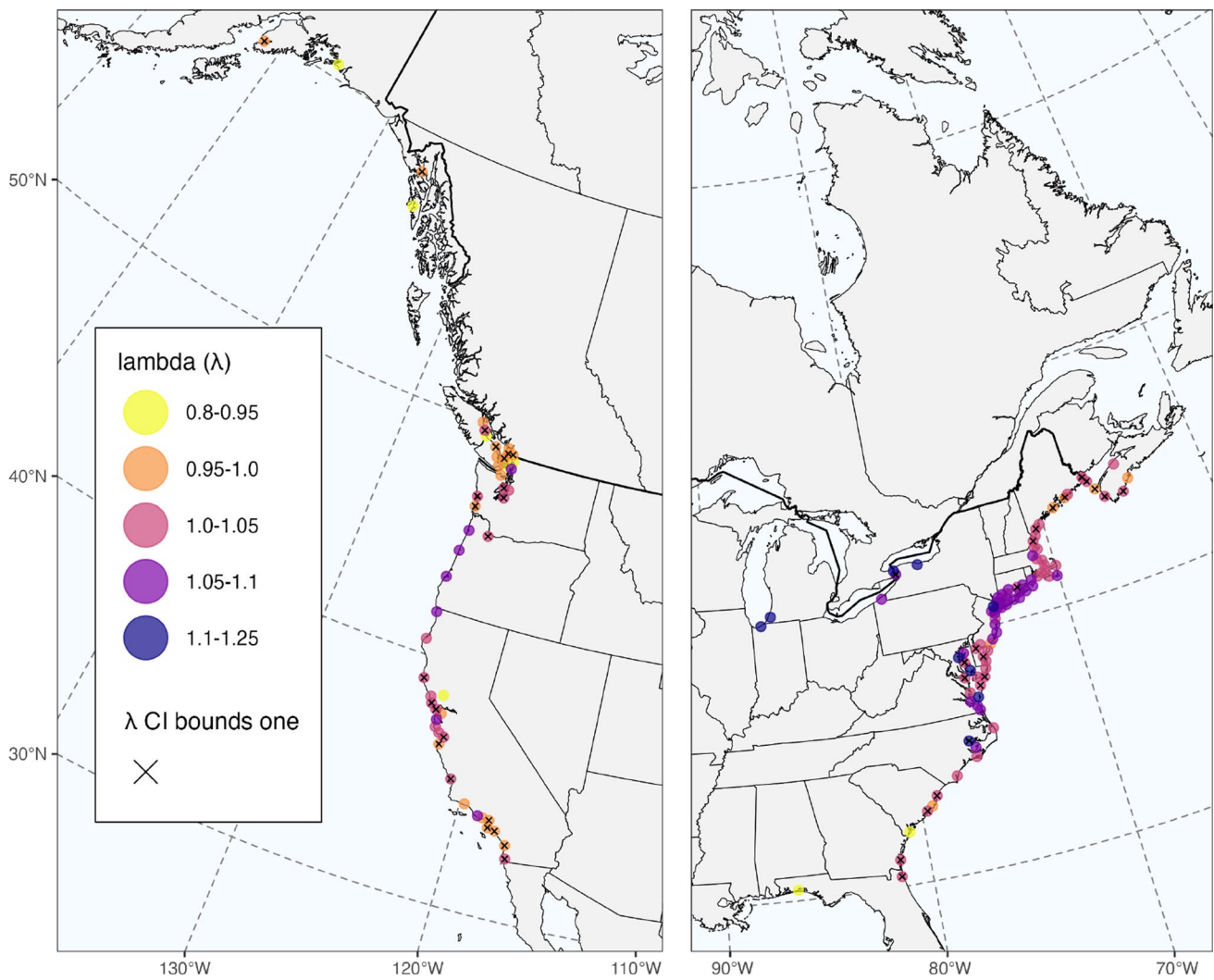


Fig. 6 Values of mean population change per year for red-throated loon (*G. stellata*) at the different circles from Christmas Bird Count

performed while red-throated loons were still migrating, and difference in the timing of the surveys could influence our results. However, surveys were generally conducted in the first half of February. Estimates around population trend were sometimes accompanied by large confidence intervals which limit inference about population change. For example, aerial surveys for yellow-billed loons in Alaska between 1986 and 2003 had such large confidence intervals that the population trend could range between -48 and $+38\%$ during that period (Earnst et al. 2005). Despite these limitations, the vast majority of local or broad-scale surveys that we examined suggested that loon numbers are generally

stable or increasing (Fig. 2). This is consistent with other surveys in Alaska (Parrett et al. 2023). It is well known that estimates for abundance or rate of population change can vary between counts from breeding grounds versus those from wintering grounds. For example, blue-winged teal (*Spatula discors*) continental abundance in North America has remained relatively stable or even increased over the past several decades (Rohwer et al. 2020), but has declined dramatically in the last few decades on the breeding grounds of eastern North America (Palumbo et al. 2020). For common loons, numbers of birds encountered on the Breeding Bird Survey between 1965 and 2005 increased, but at the

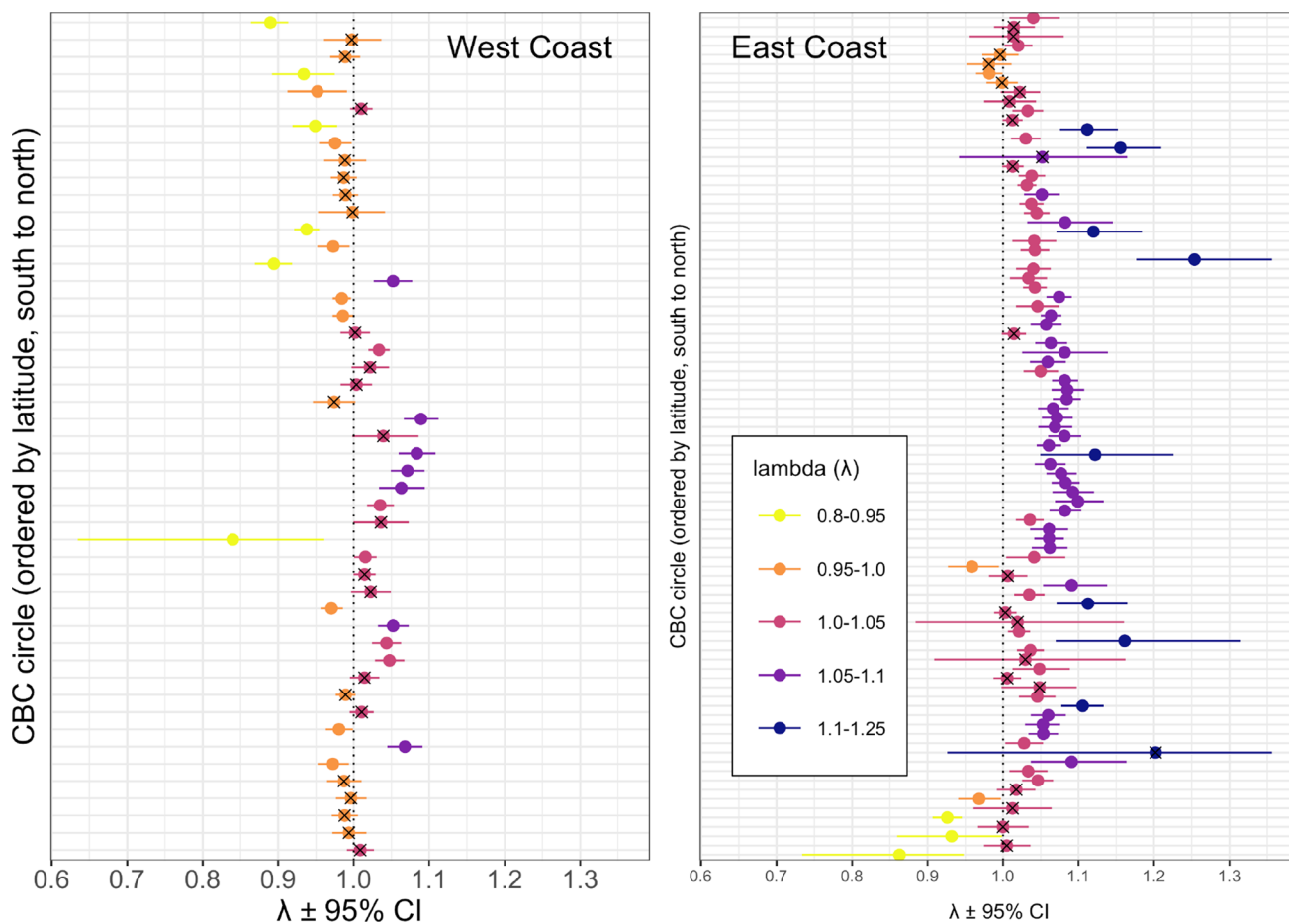


Fig. 7 Red-throated loon (*G. stellata*) annual population growth rate estimate at Christmas Bird Count circles on West (min latitude: 32, max latitude: 60) and East (min latitude: 30, max latitude: 45) Coast

of North America, organized according to latitude. x Symbol indicates cases where the 95% confidence interval includes $\lambda = 1$

same time numbers declined during the Christmas Bird Count (Butcher et al. 2005). We found some evidence of this in our data; Karrak Lake clearly showed a positive trend in red-throated loon numbers, whereas most aerial survey strata showed stable, long-term trends in abundance of red-throated loons. The disparity in counts observed between breeding and wintering grounds can of course be attributed to the migratory behavior of some red-throated loons, which migrate to Asian waters and are not counted during the winter surveys. This could explain specific discrepancies between stable trends in WBPBS Alaska but declines in CBC counts for this species. Redistributions among different breeding areas but within the same overall breeding range may also give rise to discrepancies in different counts. For example, the increase in nests of red-throated loon at Karrak Lake may have resulted from positive long-term (but local) effects on breeding success stemming from local increases to ultra-high nesting densities of sympatric Ross’s (*Anser rossii*) and lesser snow geese (*Anser caerulescens*) (Alisauskas et al. 2024), as has been suggested for a similar local

response in cackling goose (*Branta hutchinsii*) nests (Kellett and Alisauskas 2011). The decline in loons counted during CBCs in the Juan de Fuca Strait/Salish Sea region has been well documented (Crewe et al. 2012; Vilchis et al. 2014; Ethier et al. 2020). Loons are among the most numerous species found dead in derelict fishing gear (13.2%) in the Salish Sea after cormorants (*Phalacrocorax* spp. 39.5%) and ducks (*Melanitta* spp., *Mergus* spp., *Aythya marila* 13.6%; Good et al. 2009). Bycatch of wintering loons in gillnets also occurs on the Atlantic coast (Warden 2010), as does bycatch of loons from longlines in Alaska (Stehn et al. 2001). Declines in loons from the Juan de Fuca Strait/Salish Sea region might also stem from reduced abundance of forage fish in the area (Vilchis et al. 2014). Shifts in wintering distribution to more offshore waters not sampled by CBC circles may result in reduced counts closer to shore, although some broader aerial surveys in the same areas suggest an increase in loon density (Nysewander et al. 2005). Finally, changes in migration schedules by loons may further confound counts resulting in apparent declines in this area

while CBC circles farther south showed increasing trends (Figs. 6, 7). A total of 3.1% of the CBCs reported counts of unknown loon species since 1996, comprising 4.6% of the total individual loons ever counted that were reported as “loon” but not identified to species. This is a small fraction of total loon observations precluding the need to account for unidentified birds with a ratio unknown to known species observed (Wilson et al. 2013). The decline in number of unidentified loons may have resulted from improved species identification from improved optics (binoculars and spotting scope). Pacific and red-throated loons were well represented in the different survey types, with most trends either stable or positive (Fig. 2), but our review uncovered a paucity of suitable count data for yellow-billed loons. Yellow-billed loons are mostly/only found at low densities and are limited by specific habitat requirements, yet have a breeding range over large unpopulated areas, rendering population trend estimation difficult (Earnst 2004) and expensive (Mallory et al. 2018). Increased focus on migrating or wintering yellow-billed loons in Alaska may be the most cost-effective approach. Importantly, this low-density species has been recorded as entangled in gillnets (Bentzen and Robards 2014; Mallory et al. 2022), but the extent of this threat to the overall population remains unknown to date. Thus, we recommend greater attention to yellow-billed loon abundance. Like most other seabirds, loons nesting in the Arctic face a suite of threats throughout the year, but unlike other seabirds (Gaston et al. 2012), few if any Arctic-nesting loon species are well monitored, especially on the breeding grounds. Nonetheless, the limited available data do not suggest substantial declines in numbers of Pacific or red-throated loons, although a robust inference remains elusive for population trends of yellow-billed loons. This uncertainty about population trend coupled with recent concerns over bycatch and harvest for this species may justify conservation action in conjunction with improved understanding of status of this species in particular (Uher-Koch et al. 2020). Conservation actions should prioritize their freshwater breeding habitat, as well as mitigating human disturbances due to oil and gas development, shipping, and fishing traffic. Conservation actions should benefit from collaborative efforts involving government agencies, Indigenous communities, and environmental organizations.

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Author contributions Conceptualization: JFP, MLM Methodology: ILP, MLM Validation: ILP Formal analysis: ILP, SEG Investigation: ILP, PAS, RTA, DKK Data curation: ILP, EDS Writing—Original Draft: ILP Writing—Review and Editing: all authors Visualization: ILP, SEG, MLM Project administration: MLM, JFP Funding acquisition: JPF, MLM, RTA

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

- Alisauskas RT, Kellett DK, Samelius G, Slattery SM (2024) Geese as keystone species in the Low Arctic of central Canada: the Karrak lake research station. *Arctic Science* 10: in press
- Amundson CL, Flint PL, Stehn RA, Platte RM, Wilson HM, Larned WW, Fisher JB (2019) Spatio-temporal population change of Arctic-breeding waterbirds on the Arctic Coastal Plain of Alaska. *Avian Conserv Ecol* 14:18. <https://doi.org/10.5751/ACE-01383-140118>
- Anderson ORJ, Small CJ, Croxall JP, Dunn EK, Sullivan BJ, Yates O, Black A (2011) Global seabird bycatch in longline fisheries. *Endang Species Res* 14:91–106. <https://doi.org/10.3354/esr00347>
- Bart J, Johnston V, Smith PA, Manning A, Rausch J, Brown S (2012) Methods. In: Bart J, Johnston V (eds) *Arctic shorebirds in North America: a decade of monitoring*. University of California Press, Berkeley, *Studies in Avian Biology*
- Bentzen R, Robards MD (2014) Review of seabird bycatch in set-gillnets with specific reference to mitigating impacts to yellow-billed loons. *Wildlife conservation society*, Brno
- Bianchini K, Tozer DC, Alvo R, Bhavsar SP, Mallory ML (2020) Drivers of declines in common loon (*Gavia immer*) productivity in Ontario, Canada. *Sci Total Environ*. <https://doi.org/10.1016/j.scitotenv.2020.139724>
- Bowman TD, Silverman E, Gilliland SG, Leirness JB (2015) Status and trends of North America sea ducks: reinforcing the need for better monitoring. In: Savard J-PL, Derksen DV, Esler D, Eadie JM, Skean VW (eds) *Ecology and conservation of North American sea ducks*. CRC Press, New York, p 27
- Bull LS (2007) Reducing seabird bycatch in longline, trawl and gillnet fisheries. *Fish Fisher* 8:31–56. <https://doi.org/10.1111/j.1467-2979.2007.00234.x>
- Butcher GS, Niven DK, Sauer JR (2005) Using Christmas Bird Count data to assess population dynamics and trends of waterbirds. *American Birds* 59:23–25
- Crewe T, Barry K, Davidson P, Lepage D (2012) Coastal waterbird population trends in the Strait of Georgia 1999–2011: results from the first 12 years of the British Columbia Coastal waterbird Survey. *British Columbia Birds* 22:8–35
- Dias MP, Martin R, Pearmain EJ, Burfield IJ, Small C, Phillips RA, Yates O, Lascelles B, Borboroglu PG, Croxall JP (2019) Threats to seabirds: a global assessment. *Biol Conserv* 237:525–537. <https://doi.org/10.1016/j.biocon.2019.06.033>

- Driscoll-Engelstad B (2005) Dance of the loon: Symbolism and continuity in Copper Inuit ceremonial clothing. *Arctic Anthropol* 42:33–46. <https://doi.org/10.1353/arc.2011.0010>
- Dunn EH, Francis CM, Blancher PJ, Drennan SR, Howe MA, Lepage D, Robbins CSS, Rosenberg KV, Sauer JR, Smith KG (2005) Enhancing the scientific value of the Christmas Bird Count. *Auk* 122:9. <https://doi.org/10.1093/auk/122.1.338>
- Earnst SL (2004) Status assessment and conservation plan for the yellow-billed loon (*Gavia adamsii*), US Geological Survey, Scientific Investigations Report 2004–55258, 42
- Earnst SL, Stehn RA, Platte RM, Larned WW, Mallek EJ (2005) Population size and trend of yellow-billed loons in Northern Alaska. *Condor* 107:289–304
- Ethier D, Davidson P, Sorenson GH, Barry KL, Devitt K, Jardine CB, Lepage D, Bradley DW (2020) Twenty years of coastal waterbird trends suggest regional patterns of environmental pressure in British Columbia. *Canada Avian Conserv Ecol* 15:20. <https://doi.org/10.5751/ACE-01711-150220>
- Evers DC (2004) Status assessment and conservation plan for the Common Loon (*Gavia immer*) in North America. U.S. Fish and Wildlife Service, Hadley
- Fauchald P, Arneberg P, Debernard JB, Lind S, Olsen E, Hausner VH (2021) Poleward shifts in marine fisheries under Arctic warming. *Environ Res Lett* 16:074057. <https://doi.org/10.1088/1748-9326/ac1010>
- Gaston AJ, Mallory ML, Gilchrist HG (2012) Populations and trends of Canadian Arctic seabirds. *Polar Biol* 35:1221–1232. <https://doi.org/10.1007/s00300-012-1168-5>
- Good TP, June JA, Etnier MA, Broadhurst G (2009) Ghosts of the Salish Sea: threats to marine birds in Puget Sound and the northwest straits from derelict fishing gear. *Mar Ornithol* 37:67–76
- Groves DJ, Conant B, King RJ, Hodges JI, King JG (1996) Status and trends of loon populations summering in Alaska, 1971–1993. *Condor* 98:189–195. <https://doi.org/10.2307/1369136>
- Gutowsky SE, Robertson GJ, Mallory ML, McLellan NR, Gilliland SG, Paquet J, d'Entremont AA, Ronconi RA (2022) Increased abundance and range expansion of harlequin ducks *Histrionicus histrionicus* wintering in eastern Canada. *Endang Species Res* 49:187–198. <https://doi.org/10.3354/esr01213>
- Harvey W, Lepage C, Lefebvre J, Sprangler R (2022) A breeding pair survey of Canada geese in Northern Québec–2022. Unpublished report. Canadian Wildlife Service, Ste. Foy, Quebec, pp 8
- Hedd A, Regular PM, Wilhelm SI, Rail JF, Drolet B, Fowler M, Pekarik C, Robertson GJ (2016) Characterization of seabird bycatch in eastern Canadian waters, 1998–2011, assessed from onboard fisheries observer data. *Aquat Conserv* 26:530–548. <https://doi.org/10.1002/aqc.2551>
- Kellett DK, Alisauskas RT (2011) Clutch size and nest survival of cackling geese in a lesser snow and ross's goose colony. *Waterbirds* 34:400–411. <https://doi.org/10.1675/063.034.0402>
- Larned W, Stehn R, Platte R (2012) Waterfowl Breeding Population Survey Arctic Coastal Plain, Alaska 2011. US Fish and Wildlife Service Division of Migratory Bird Management Report
- Lewis RL, Crowder LB, Read AJ, Freeman SA (2004) Understanding impacts of fisheries bycatch on marine megafauna. *Trend Ecol Evol* 19:598–604. <https://doi.org/10.1016/j.tree.2004.09.004>
- Linnebjerg JF, Baak JE, Barry T, Gavrilov MV, Mallory ML, Merkel FR, Price C, Strand J, Walker TR, Provencher JF (2021) Review of plastic pollution policies of Arctic countries in relation to seabirds. *FACETS* 6:1–25. <https://doi.org/10.1139/facets-2020-0052>
- Lougheed L, Breault A, Lank DB (1999) Estimating statistical power to evaluate ongoing waterfowl population monitoring. *J Wildl Manag* 63:1359–1369. <https://doi.org/10.2307/3802855>
- Lüdecke D, Ben-Shachar M, Patil I, Waggoner P, Makowski D (2021) performance: an R package for assessment, comparison and testing of statistical models. *JOSS* 6:3139. <https://doi.org/10.21105/joss.03139>
- Mallek EJ, Groves DJ (2012) Alaska-Yukon waterfowl breeding population survey. US Fish and Wildlife Service Report
- Mallory ML, Gilchrist HG, Janssen M, Major HL, Merkel F, Provencher JF, Strøm H (2018) Financial costs of conducting science in the Arctic: examples from seabird research. *Arctic Sci* 4:624–633. <https://doi.org/10.1139/as-2017-0019>
- Mallory ML, Gaston AJ, Provencher JF, Wong SN, Anderson C, Elliott KH, Gilchrist HG, Janssen M, Lazarus T, Patterson A, Pirie-Dominix L (2019) Identifying key marine habitat sites for seabirds and sea ducks in the Canadian Arctic. *Environ Rev* 27:215–240. <https://doi.org/10.1139/er-2018-0067>
- Mallory ML, Robertson GJ, Keegan S, Pollet IL, Harris LN, Jivan T, Provencher JF (2022) Bycatch of loons assessed in coastal Arctic char fisheries in the Canadian Arctic. *N Am J Fish Manage* 42:1215–1225. <https://doi.org/10.1002/nafm.10813>
- Mitro MG, Evers DC, Meyer MW, Piper WH (2008) Common loon survival rates and mercury in New England and Wisconsin. *J Wildl Manag* 72:665–673. <https://doi.org/10.2193/2006-551>
- National Audubon Society (2020) The Christmas Bird Count historical results. <http://christmasbirdcount.org>. Accessed Dec 2022
- Naves LC, Zeller TK (2017) Yellow-billed loon subsistence harvest in Alaska: challenges in harvest assessment of a conservation concern species. *J Wildl Manag* 8:114–124. <https://doi.org/10.3996/112016-JFWM-086>
- Nysewander DR, Evenson JR, Murphie BL, Cyra TA (2005) Report of marine bird and marine mammal component, Puget sound ambient monitoring program, for July 1992 to December 1999 period. [Unpublished report prepared for Washington state department of fish and wildlife and Puget Sound action team]. Olympia : Washington State Department of Fish and Wildlife. 194
- Palumbo MD, Kusack JW, Tozer DC, Meyer SW, Roy C, Hobson KA (2020) Source areas of blue-winged teal harvested in Ontario and Prairie Canada based on stable isotopes: implications for sustainable management. *J Field Ornith* 91:64–76. <https://doi.org/10.1111/jof.12324>
- Parrett JP, Obritschkewitsch T, Bankert AR (2023) Avian studies for the alpine satellite development project, 2022. ConocoPhillips Alaska, Inc., Anchorage, AK, by ABR Inc, Fairbanks, AK, Twentieth Annual Report, p 72
- Phillips RA, Ridley C, Reid K, Pugh PJ, Tuck GN, Harrison N (2010) Ingestion of fishing gear and entanglements of seabirds: monitoring and implications for management. *Biol Conserv* 143:501–512. <https://doi.org/10.1016/j.biocon.2009.11.020>
- Piper WH, Gear J, Hoover B, Lomery E, Grenzer LM (2020) Plunging floater survival causes cryptic population decline in the Common Loon. *Condor* 122:1–10. <https://doi.org/10.1093/condor/duaa044>
- Priest H, Usher P (2004) The Nunavut wildlife harvest study. Nunavut wildlife Management Board, Iqaluit, Nunavut
- Regular P, Montevecchi W, Hedd A, Robertson G, Wilhelm S (2013) Canadian fishery closures provide a large-scale test of the impact of gillnet bycatch on seabird populations. *Biol Lett* 9:20130088. <https://doi.org/10.1098/rsbl.2013.0088>
- Rizzolo DJ, Gray CE, Schmutz JA, Barr JF, Eberl C, McIntyre JW (2020) Red-throated loon (*Gavia stellata*), version 2.0. In: Rodewald PG, Keeney BK (eds) *Birds of the world*. Cornell Lab of Ornithology, Ithaca, New York
- Rohwer FC, Johnson WP, Loos ER (2020) Blue-winged Teal (*Spatula discors*), version 1.0. In: Poole AF, Gill FB (eds) *Birds of the world*. Cornell Lab of Ornithology, Ithaca
- Ross MV, Alisauskas RT, Douglas DC, Kellett DK (2017) Decadal declines in avian herbivore reproduction: density-dependent

- nutrition and phenological mismatch in the Arctic. *Ecology* 98:1869–1883. <https://doi.org/10.1002/ecy.1856>
- Russell RW (2020) Pacific loon (*Gavia pacifica*), version 1.0. In: Rodewald PG (ed) *Birds of the world*. Cornell Lab of Ornithology, Ithaca
- Sauer JR, Link WA, Niven DK, Hines JE (2019) The North American breeding bird survey, analysis results 1966–2017. Geological Survey data release. <https://doi.org/10.5066/P9A4OAEH>
- Schmidt JH, Flamme MJ, Walker J (2014) Habitat use and population status of yellow-billed and Pacific loons in western Alaska, USA. *Condor* 116:483–492. <https://doi.org/10.1650/CONDOR-14-28.1>
- Silverman ED, Saalfeld DT, Leirness JB, Koneff MD (2013) Wintering sea duck distribution along the Atlantic coast of the United States. *J Fish Wild Manage* 4:178–198. <https://doi.org/10.3996/122012-JFWM-107>
- Smith PA, McKinnon L, Meltoffe H, Lanctot RB, Fox AD, Leafloor JO, Ssoloviev M, Franke A, Falk K, Golovatin M, Sokolov V, Sokolov A, Smith AC (2020) Status and trends of tundra birds across the circumpolar Arctic. *Ambio* 49:732–748. <https://doi.org/10.1007/s13280-019-01308-5>
- Stehn RA, Rivera KS, Fitzgerald S, Wohl KD (2001) Incidental catch of seabirds by longline fisheries in Alaska. In: Melvin EF, Parrish JK (eds) *Seabird bycatch: trends, roadblocks, and solutions*. University of Alaska Sea Grant, Anchorage, pp 61–77
- Sydeman WJ, Thompson SA, Anker-Nilssen T, Arimitsu M, Bennison A, Bertrand S, Boersch-Supan P, Boyd C, Bransome NC, Crawford RJ, Daunt F (2017) Best practices for assessing forage fish fisheries-seabird resource competition. *Fish Res* 194:209–221. <https://doi.org/10.1016/j.fishres.2017.05.018>
- Uher-Koch BD, North MR, Schmutz JA (2020) Yellow-billed loon (*Gavia adamsii*), version 10. In: Billerman SM (ed) *Birds of the world*
- U.S. Fish and Wildlife Service (2022) Waterfowl population status, 2022. U.S. Department of the Interior, Washington, D.C.
- Venables WN, Ripley BD (2002) *Modern applied statistics with R*, 4th edn. Springer, New York
- Vilchis LI, Johnson CK, Evenson JR, Pearson SF, Barry KL, Davidson P, Raphael MG, Gaydos JK (2014) Assessing ecological correlated of marine bird declines to inform marine conservation. *Conserv Biol* 29:154–163. <https://doi.org/10.1111/cobi.12378>
- Warden ML (2010) Bycatch of wintering common and red-throated loons in gillnets off the USA Atlantic coast, 1996–2007. *Aquat Biol* 10:167–180. <https://doi.org/10.3354/ab00273>
- Weegman MD, Alisauskas RT, Kellett DK, Zhao Q, Wilson S, Teleneský T (2022) Local population collapse of Ross's and lesser snow geese driven by failing recruitment and diminished philopatry. *Oikos*. <https://doi.org/10.1111/oik.09184>
- Weimerskirch H, Capdeville D, Duhamel G (2000) Factors affecting the number and mortality of seabirds attending trawlers and longliners in the Kerguelen area. *Polar Biol* 23:236–249. <https://doi.org/10.1007/s003000050440>
- Wilson S, Anderson EM, Wilson ASG, Bertram DF, Arcese P (2013) Citizen science reveals an extensive shift in the winter distribution of migratory Western grebes. *PLoS ONE* 8:e65408. <https://doi.org/10.1371/journal.pone.0065408>
- Zurr A, Ieno E, Walker N, Walker N, Saveliev AA, Smith GM (2009) *Mixed effects models and extensions in ecology with R*. Springer, New York

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