Sea Duck Joint Venture
Annual Project Summary
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SDJV Project #154: Integrating Fixed-Wing and Helicopter Survey Platforms to Improve Detection and Species Identification of North American Breeding Scoters

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PROJECT DESCRIPTION

Populations of North American breeding scoters appear to be declining although a large degree of uncertainty remains around estimates of population size and overall trends (Bordage and Savard 1995, Savard et al. 1998, Caithamer et al. 2000) due to observation challenges particular to this group of sea ducks. We propose to conduct experimental fixed-wing and helicopter integrated breeding surveys over portions of the core breeding range, in Québec-Labrador and the Barrenlands of the Northwest Territories, of all three North American scoter species. A secondary objective of the proposed work is to produce habitat selection models which will provide more detailed information on the distribution of breeding scoters across core areas of the breeding range and provide the information required to develop a cost-efficient stratified sampling approach.

We proposed a three-year project to evaluate geographic and annual variation and extent in the following parameters from both fixed-wing and helicopter survey platforms: 1- detection probabilities; 2- species identification /composition; 3- differences in availability bias between the two platforms (i.e. correction factor to apply to the platform with lower detection probability). More specifically, year 1 focused on assessing optimal survey timing from published and unpublished information, developing preliminary habitat models, and determining species composition and helicopter detection probabilities at three sites in the core breeding area of the Northwest Territories and Manitoba. In year 2, fixed-wing transects were introduced to test dual-platform integrated survey approaches. Helicopter and fixed-wing surveys were carried out at two sites in the Taiga Shield Ecozone of the Northwest Territories. Year 3 (2019) activities included helicopter and fixed-wing surveys at two sites in the Northwest Territories and one site in northern Quebec. There will also be activities related to post-survey obligations (e.g. removing fuel containers), data analyses, report writing, and the development of a scoter monitoring strategy in 2019.

The proposed work will be highly relevant to the WBPHS review by addressing issues of coverage, reallocation of survey effort and survey timing for sea ducks. Priority information needs outlined in the SDJV sea duck harvest assessment report will also be partially addressed, by providing estimates of abundance for the experimental survey areas and ultimately proposing an approach for continental population estimation. The principal outcome of the proposed study will be the production of a recommendation document describing the appropriate methodology, potential costs and feasibility of implementing operational continental breeding ground scoter surveys to SDJV and Federal Wildlife Agencies.

OBJECTIVES

The overarching goal of the proposed study is to develop an aerial breeding ground survey methodology for scoters that would be applicable at population or continental scales. We are proposing a survey across the Boreal Region of Canada that would integrate fixed-wing transects and helicopter plots to allow for species identification, assessment of species composition and the estimation of detection probabilities. There are 6 main objectives for the proposed study:

1. Identify the optimal timing for breeding scoter surveys, based on data from previous nesting and productivity studies
2. Develop and evaluate methodology to accurately assess species identification and composition from an integrated fixed-wing and helicopter survey
3. Develop and evaluate methodology for estimating detection probabilities from an integrated fixed-wing and helicopter survey. This will address the perception bias component in both fixed-wing and helicopter components as well as availability bias from the fixed-wing component, allowing the estimation of visibility correction factors
4. Evaluate annual and geographic variation in species composition and detection probabilities to determine whether these components would need to be measured annually and/or across the range in an operational survey
5. Derive baseline abundance estimates for the experimental survey areas for all three populations of eastern scoters
6. Develop habitat selection models and test hypotheses about factors influencing scoter distribution across the survey area

The development of aerial survey techniques and protocols to improve estimates of detection probability, population trends and numbers and to better classify scoters to species have been identified as Priority Science Needs by the Sea Duck Joint Venture for FY2017. Populations of North American breeding scoters appear to be declining although a large degree of uncertainty remains around estimates of population size and overall trends (Bordage and Savard 1995, Savard et al. 1998, Caithamer et al. 2000) due to observation challenges particular to this group of sea ducks. This lack of population information severely limits our ability to manage scoter habitat and harvest (Koneff et al. 2016).

Several aspects of their distribution and biology make these species somewhat challenging to survey. As such, they have been identified amongst the highest priority species for research and monitoring (2016-18 SDJV Implementation Plan). Recent studies using PTT devices have shown that the breeding range of all three scoter species falls largely outside of the survey area of the Waterfowl Breeding Population and Habitat Survey (WBPHS - Traditional and Eastern Waterfowl Survey areas; SDJV 2015). Relatively little information on waterfowl and other migratory birds distribution and trends exists in this area encompassing the northern Boreal forest, the continuous tree line and sub-Arctic tundra of North America, where the influence of global climate change are expected to be important. Finally, there are also issues related to timing of the survey as the WBPHS is timed for early nesting dabbling ducks, primarily mallards (*Anas platyrhynchos*) and American Black ducks (*Anas rubripes*), whereas scoters are considered to be a later-nesting species.

Despite these difficulties, progress has been achieved as experimental scoter surveys in the Northwest Territories, Nunavut, Labrador, the Hudson Bay Lowlands and Northern Québec have confirmed the feasibility of conducting aerial surveys in remote Boreal and sub-Arctic regions of North America, as well as having identified key methodological gaps or biases requiring additional research. We propose to conduct experimental fixed-wing and helicopter integrated breeding surveys over portions of the ranges of all three scoter species in North America. This work, which will draw heavily on previous experimental work supported by the SDJV and partners, is expected to enable us to make recommendations on the appropriate methodology, potential costs and feasibility of implementing operational continental breeding ground scoter surveys. A secondary objective of the proposed work is to produce habitat selection models from the data collected in the course of the experimental surveys. This product will provide detailed information on the distribution of breeding scoters across the landscape and should provide the information required to develop a cost-efficient stratified sampling approach. It will also be useful in Land Use Planning and Environmental Assessment in the proposed survey areas where little information on waterfowl distribution is currently available.

This project will address two SDJV priority science needs:

Specifically, this project will contribute to priority need #1 by focusing on evaluating geographic and annual variation and extent in the following parameters, from both fixed-wing and helicopter survey platforms:

- Detection probabilities
- Species identification /composition
- Differences in availability bias between the two platforms (i.e. correction factor to apply to platform with lower detection probability)

This work is expected to enable us to develop survey methods that allow for survey and observer specific corrections.

The proposed work will also contribute to the ongoing WBPHS review by addressing issues of current coverage relative to new information on the distribution and abundance of waterfowl outside the survey area, and in the consideration of reallocation of survey effort and timing to expand the usefulness of the survey for monitoring northern nesting species. We expect this work to result in a recommendation document for the establishment of a continental scoter breeding ground survey which would allow Canadian and U.S Federal agencies to determine the feasibility and appropriateness of expanding the WBPHS to cover core scoter areas.

The habitat modelling component of the proposed work will also contribute to the review by providing more detailed distribution information within the experimental survey areas and a framework for expanding this approach to eventually cover a larger proportion of the range. Specifically, this will address priority #2 of the SDJV strategic plan: inform habitat conservation actions.

Finally, priority information needs for population estimates for eastern Surf Scoters and eastern Black Scoters outlined in the SDJV sea duck harvest assessment report will be partially addressed, as we will be able to provide estimates of abundance for the experimental survey areas and, ultimately, propose an approach for continental population estimation. Results from this study are expected to be broadly applicable for the development of breeding ground survey methodology for all scoter populations.

METHODS

Survey Timing

Determining the most appropriate time to survey for breeding scoters was done using information from brood observations and satellite tracking studies. Brood surveys that included duckling ages were used to estimate nest initiation dates by back-dating from brood age while satellite telemetry data was used to determine arrival and departure times from breeding sites.

Brood surveys

Brood survey data originated from three sources: (i) brood surveys conducted as part of a 1991 environmental assessment of the Great Whale Hydroelectric Project, Québec (Bordage et. al. 1992), (ii) a brood survey conducted within a 25km^2 plot near Goose Bay, Labrador in 2007 (SGG *unpublished data*), and (iii) notes to file made by W. Barrow (CWS retired) when scouting sites for pre-season banding operations, 1990 to 1992. All broods were aged by plumage development (Gollop and Marshall 1954); broods were aged using mid-points for plumage age classes for Surf Scoters (*Melanitta perspicillata*) described by Lesage et al. (1996). Nest initiation dates were calculated by back-dating the brood's age from the date of the observation minus 7 days, one day for the female to lay each egg in an average surf scoter clutch (mean = 7 eggs; Morrier et. al 1997). See Table A.1 for estimated nest initiation dates by source.

Satellite telemetry data

We downloaded unfiltered telemetry data from the SDJV's satellite telemetry database in August 2016 for the period that included spring migration, breeding and arrival at molt (1 April to 1 September) for all Surf, Black (*Melanitta americana*) and White-winged Scoters (*M. fusca*) from eastern North America. We also accessed telemetry data from scoters collected in western North America that were provided by Jason Schamber. Sources of satellite tags are identified in Table A.2.

Migration tracks for each bird were mapped and labeled by year. We determined whether or not a bird went to a breeding area by visually classifying tracks for each year/bird combination. Tracks were classed as: i) Yes - went to a breeding area and settled (Breeding), ii) Maybe - went to a breeding area but unsure if they settled, and iii) No – did not go to a breeding area. All year/bird combinations that did not go to a breeding location were filtered from the dataset. For the remainder, we created a Google Earth KMZ file with the track and individual locations labeled with dates. Each track was examined in detail; we recorded if the bird appeared to settle on a breeding site, and if yes, the date of its arrival and departure from the site. All year/bird combinations that did not settle on a breeding site were removed. Arrival and departure dates were merged with the telemetry data and locations outside this period were filtered from the data. For each year/bird combination that remained in the dataset we calculated the mean breeding location using the function 'geomean' (Package Geosphere; Hijmans 2016) and determined the province of each breeding attempt.

For female Black Scoters that attempted to breed in the year they were tagged but also attempted to breed in subsequent years, we were able to examine data tagging effects. Arrival dates averaged about 2 weeks earlier (9 June ± 10d, n=32) in the year subsequent to tagging compared to the year of tagging (23 June ±13d, n=28); there was no effect of tagging on departure dates. As a result, we excluded all observations made in the year of tagging from the analysis. For individuals that had observations for multiple breeding seasons we used only one season of data per bird. We summarized arrival and departure dates (Table A.3-5), and length-of-stay (Table A.6) by species, sex and province that the breeding attempt occurred.

Survey Area and Plot Selection

2017 survey areas were selected by delineating breeding habitat of female scoters using telemetry data from the SDJV's satellite telemetry database. The database was first filtered to identify females that went to a breeding area. For each of the females that settled during the nesting period we assigned a spatial data point that was associated with the area where the female spent most of her time. These spatial points were subsequently used to identify the habitat that females selected for breeding. Given that we had presence only data (i.e. points where we knew the females were breeding) we used a Maxlike approach to estimate the probability of occurrence of breeding females (Lele and Kleim 2006; Royle et al. 2012). We used the Land Cover Map of Canada and multi-spectral remotely-sensed data at a 1km resolution to make spatial predictions. From these habitat models, we made predictions of scoter occupancy for the Canadian Barrenlands region and selected 4 possible survey areas. These survey areas were located along the transition line between the northern boreal forest and the Barrenlands, Northwest Territories. Based on the logistical constraints of helicopter surveys (i.e. access to lodging and fuel caches), we selected 2 (Little Duck and Lynx Lake) out of the 4 possible survey areas; a third survey area was included in the Northwest Territories (the Ramparts River Wetlands) given its consideration for receiving legal protection (Fig. 1).

In 2018 and 2019, site selection was further informed by the results of habitat selection analysis (see *Statistical Analysis*) conducted using 2017 and 2017-2018 data. We used the predicted relationship between the habitat variables and the number of IBPs from the best model for each species to predict IBP densities at potential sites. The intercept from the Lynx Lake site was used. Additional considerations during 2018/2019 site selection included: evidence of scoter presence (from satellite telemetry or aerial surveys, Fig. 2), aiming to survey new/under-sampled habitat types to better inform the habitat model and thus, make more accurate predictions across the landscape, proximity to accommodations, and survey cost.

The landscapes of the selected study areas is highly diverse, including wetlands, coniferous forest, and open tundra. See Fig. 3-8 for examples of habitat typical of each area. Given this level of heterogeneity, obtaining a representative sample of plots within each survey area presented a challenge. This issue is particularly true for surveys where sampling intensity is low (~ 2.5%) in order to keep costs at reasonable levels. Analyses of previous waterfowl surveys conducted in the northern boreal forest region demonstrated that using simple random and systematic designs result in poor coverage of some potentially important but rare habitats (Roy et al. *unpublished data*). Therefore, we opted to use a stratified-random sampling design. We first divided our sampling/study areas into cells of 5 x 5 km (survey plot size). Next, we developed three weighting indices to select a sample of plots. The first index was based on the landscape composition within each cell. We averaged the Z-score values for the habitat variables that were identified as important for waterfowl in the boreal forest (i.e. number of lakes, lake area, shoreline index, river density and proportion of coniferous forest). This index provided an idea of how representative each possible grid cell/plot was for the survey area. Cells with an average Z-score near zero were representative of the survey area, while cells with high or low averaged Z-scores were identified as unique. The second and third weighting variables were composed of the predicted total indicated breeding pairs (IBPs) of Black Scoters and Surf Scoters within each cell. These predictions were derived from a habitat model developed from previous surveys in Labrador and Northern Quebec (Roy et al. *unpublished data*). Predictions were based on the same habitat models that were included in the Z-score index. Given that our objective was to obtain a sample of plots as representative as was possible, we divided the posterior distribution of each of the weighting variables into 5 categories (very low, low, average, high, very high) and calculated the proportion of each cell falling into each category. Cells were subsequently assigned a score equal to the proportion to which they belong. We then averaged the scores across all three weighting variables (Z-score, predicted Black Scoter IBP, and predicted Surf Scoter IBP). The combined scores were then divided into 5 categories and we applied a sampling procedure that ensured all categories were represented in the sample. We proceeded to draw a sample of 25 sites for each study area (20 only for Ramparts) and scored the dataset for its spatial coverage of the survey area. Maintaining adequate spatial coverage ensured that we would be able to detect any spatial pattern present in our habitat model that could not be explained by the explanatory variables. If the sample of selected plots was deemed too spatially clumped it was rejected and another sample was drawn. Any drawn set that contained an immediate neighbor was also discarded. We repeated the sampling procedure in each study area until we found a dataset that satisfied our conditions.

Survey Methods

From 2017-2019, we conducted aerial surveys for breeding scoters in six study areas across North Canada (Fig. 1, 9-14): Lynx Lake, NWT (2017-2019), Little Duck Lake, Manitoba (2017), Ramparts River Wetland, NWT (2017), Yellowknife, NWT (2018), North Lynx Lake, NWT (2019), and the George River, QC (2019). We surveyed 25 survey plots (5x5km) within each study area, with the exception of the Ramparts site (20 plots). Time and fuel permitted the Lynx Lake crew to survey an additional plot in 2017. Study area sizes were: 21,750km^2 for Lynx Lake, 18,225km^2 for Little Duck Lake, 4,384km^2 for the Ramparts River Wetlands, 20,300km^2 for Yellowknife, 21,779km^2 for North Lynx Lake, and 31,375 km^2 for the George River (sampling intensities of 2.9%, 3.4%, 11.4%, 3.1%, 2.9%, and 2%), respectively.

Surveys were conducted using a Bell 407 (Ramparts) or Bell 206L (all other sites) helicopter in early to mid-June of each year. All helicopters were equipped with skids, and only the helicopters used at the Ramparts and Yellowknife sites did not have bubble windows. Observations were made from 15 – 50 m above ground level (depending on topography), and at flight speeds ranging from a hover to 100km/h. Flights were delayed if wind speeds exceeded 40km/h, during heavy precipitation, or if visibility was reduced. Surveys were conducted throughout the day but began no earlier than one hour after sunrise and concluded no later than one hour before sunset to avoid identifying birds in difficult light conditions.

The helicopter pilot at each of the sites was directed to fly over every water body, watercourse, and wetland within the plot; moving map software (PC-MAPPER AI Version 4.0 C14) was used to ensure complete coverage of all water on plots (Fig. 15). Survey crews consisted of a pilot and three biologist observers – one seated in the front left seat and two in the rear on either side of the machine. The role of navigator was retained by the front observer while seat position of the data recorder(s) varied among crews. A double dependent observer approach was used to assist in assessing detectability. In this sampling scheme, the front seat observer acted as a single observation unit (although the pilot assisted in surveying if comfortable) and the two rear seat observers as a second observation unit. The pilot was asked not to direct the helicopter towards birds unless instructed to do so by the navigator. At each plot, one observation unit (i.e. front or back seat) was designated as Primary and the other as Secondary. The Primary observer marked birds detected in front of the midline (perpendicular the direction of travel) of the helicopter and reported their observations to the Secondary observer. The Secondary observer then reported all observations missed by the Primary observer. Primary location changed on alternate plots. Each crew consisted of one experienced observer, one intermediate and one observer that was inexperienced with the helicopter survey protocols. Therefore, to avoid confounding observer position with observer experience, the front left seat was only ever occupied by one of the two more experienced observers. Experienced surveyors changed seat position every other plot so that upon survey completion, they had spent approximately equal time in the role of Primary or Secondary observer and approximately equal time in the front or rear seat (Fig. 16).

For each observation, the geographic location, species, sex, age and number of birds was recorded using the GPS-Voice feature of the PC-MAPPER software. Observers were permitted to redirect the helicopter path to ensure that species, sex and age information of birds was classified accurately. Image Stabilising binoculars and/or photos were taken in many cases to help identification (e.g. Fig. 17). Any additional observations that were made while the helicopter was being redirected (i.e. previously missed by all observers) were recorded as 0-0, meaning not detected. Birds were recorded as the number of males and females by species within each observation. If thought to be paired, they were entered as such while large groups not deemed to be local breeders were entered as groups.

Phenology Index

To determine survey timing relative to nest initiation, we calculated a phenology index (PI), which uses the ratio of the number of pairs to male only groups (lone males and flocked drakes). For species where the sex ratio is near unity, a PI near 0.5 suggests about half of the females are attending their nest, and unavailable to be detected, while the other half are attended by males and available to be detected. A PI value close to 1.00 indicates a survey conducted before the peak of nest initiation, and a PI close to zero indicates a survey conducted after the peak, and or, there is a male biased sex ratio.

Statistical Analysis

Detection

We developed a three-step model to estimate detection. Given that most of the birds were observed in pairs or in groups we used the 'cluster' as the unit of observation (Sollmann et al. 2016). Our modelling approach is divided into three steps. The first step estimates the detection rate of the clusters of birds observed during the survey, the next step estimates the "true" number of clusters that are present in a given site, and finally we estimate the size of the clusters of birds that were missed based on the size of the clusters we observed in the survey area. Each component of the detection model is explained in detail below.

Cluster detection model— Let $y_{1_{i,j}}$ and $y_{2_{i,j}}$ be the numbers of clusters of birds detected by the primary observer and secondary observer, respectively and $y_{T_{i,j}}$ be the total number of birds detected by both observers in plot *i* for a given species *j*. The dependence between counts of primary and secondary observers may be specified using a multinomial model such as:

$$y_{1:2_{i,j}} \sim Multinomial\left(p_{1_{i,j}}, \left(1 - p_{1_{i,j}}\right) p_{2_{i,j}}\right) \qquad \text{Eq. 1}$$

where $p_{1_{i,j}}$ and $p_{2_{i,j}}$ denote the detection rate of primary and secondary observers for a given species *j* while surveying the plot *i*. Given the observers' detection rate, the total detection rate for a given species in a plot can be calculated as $p_{T_{i,j}} = 1 - \left(1 - p_{1_{i,j}}\right)\left(1 - p_{2_{i,j}}\right)$ and the true number of clusters in the the survey plot ($C_{i,j}$) estimated via a binomial distribution such as:

$$C_i = \text{Binomial}\left(y_{T_{i,j}}, p_{T_{i,j}}\right) \qquad \text{Eq. 2}$$

Sources of variation in detection rates during the survey for the pairs of observers *k* can be assessed via a logistic link:

$$\text{logit}\left(p_{k_{i,1:j}}\right) = \alpha + \beta\mathbf{X} + \gamma_1 \text{Seat}_i + \gamma_2 \text{Observer}_i \quad \text{Eq. 3}$$

$$\beta_j \sim \text{normal}\left(0, \sigma_\beta^2\right) \quad \text{Eq. 4}$$

where α is the intercept, β is a species specific effect, **X** is a matrix that contains the species identity, γ_i is the effect of the position of the observer in the helicopter, and γ_2 is the effect of the secondary observer. We modelled the species specific effect as a random effect where the variance parameters σ_β^2 specify the levels of variation in detection rate among species.

Cluster Abundance— We estimated the variation in cluster abundance via a compound Poisson-gamma distribution.

$$C_{i,j} \sim \text{Poisson}\left(\lambda_{i,j}\, \rho_{i,j}\right) \quad \text{Eq. 5}$$

$$\log\left(\lambda_{i,j}\right) = \mu_j + \log(\text{Area}_i) \quad \text{Eq. 6}$$

$$u_j \sim \text{Normal}\left(0, \sigma_\mu^2\right) \quad \text{Eq. 7}$$

$$\rho_{i,j} \sim \text{Gamma}(r, r) \quad \text{Eq. 8}$$

where $\lambda_{i,j}$ is the expected number of clusters in plot *i* for species *j*, μ_j is the mean abundance of clusters in the survey area on the log scale for species *j*, and $\rho_{i,j}$ is the over-dispersion term for each observation in each plot. The species specific mean abundance was modelled as a random effect and the over-dispersion parameter *r* was shared across species.

Cluster size model— The last step of the model was to estimate the size of the clusters missed during surveys. To that end, we have used a data augmentation scheme. For each species we created a vector containing the size with the observed clusters and padded the vector with missing entries. Those missing entries acted as surrogates for the missed observations. We then used a Gamma-Poisson compound model to estimate the size of the cluster for a given species.

$$\text{Birds}_{j,k} \sim \text{Poisson}\left(\lambda_j^*\, \rho_{j,k}^*\right) \quad \text{Eq. 9}$$

$$\log\left(\lambda_j^*\right) = \mu_j^* \quad \text{Eq. 10}$$

$$\mu_j^* \sim \text{Normal}\left(0, \sigma_\mu^2\right) \quad \text{Eq. 11}$$

$$\rho_{j,k}^* \sim \text{Gamma}(r, r) \quad \text{Eq. 12}$$

Where birds in a cluster of size *k* of species *j*, λ_j^* is the expected size of the clusters for species *j* in the survey area, μ_j the mean size of the clusters in the survey area on the log scale for species *j*, and $\rho_{i,j}$ is the over-dispersion term for the cluster *k* of species *j*. The species specific mean cluster size was modelled as a random effect and the over-dispersion parameter *r** was shared across species.

We derived the total abundance for a species (T_j) in the survey area by summing over the size of all clusters across the sites. To avoid including too many clusters in the sum we use the total number of clusters predicted in the area as the upper bound of the summation.

$$T_j = \sum_{k=1}^{C_j} Birds_k \quad \text{Eq. 13}$$

We estimated the parameters using a Bayesian framework that was implemented in JAGS (Plummer 2003) from R using the jagsUI package (Kellner 2016; R Core Team 2017). We used non-informative priors for all parameters and we ran three chains with randomized initial values for 60,000 iterations, with the first 27,000 iterations used as a burn-in and saved every thirtieth iteration. Chain convergence was visually evaluated and verified using the Gelman-Rubin statistic ($\hat{\boldsymbol{R}}$) with both measures indicating a reasonable assumption of convergence. We used the sums of the squared Pearson residuals to assess the model fit via posterior predictive checks (Kéry 2010) and did not find any evidence of lack of fit for the model. We report results as posterior means and 2.5 and 97.5 percentiles of the posterior distribution for credible intervals (95% BCI). For the discussion, we consider covariate effects as strong/significant if their 95% BCI do not overlap 0.

Habitat selection

We used two major data sources to extract a set of explanatory variables for habitat selection analysis; the CanVec database (v 6.18), a digital cartographical reference at the 1:50000 scale distributed by the Centre for Topographic Information, Natural Resources Canada (http://geogratis.ca/) and Ducks Unlimited Canada's Hybrid Wetland Layer, a raster layer that classifies the Canadian land base into three general categories: Water, Wetland, and Upland (Jones 2011).

Based on published literature we extracted a number of variables from these geographic data sources: the number of lakes in a specified cell, the average lake size, the variance in lake size, total shore length, total river length, and the proportion of the cell covered by open water, wetlands and coniferous forest. We derived a shoreline index (SDI) from the total shore length, the average lake size and the total number of lakes within a cell. Values of 1 indicated that the amount of shoreline in the cell was equal to the amount of shoreline that would exist if all lakes in the cell were perfect circles, values above 1 indicated a more complex shoreline, and a value below 1 indicated that there was less shoreline than expected in the cell. The latter may arise if, for example, the cell was covered in part by a large lake.

Landscape metrics often result in multicollinearity problems among predictor variables. Therefore, we used a variance inflation factor approach (VIF) to select a subset of explanatory variables to use in our model. We used a VIF threshold of 2.5. Based on output from different possible permutations, we kept 6 explanatory variables: the number of lakes on the log scale, the total lake area on the log scale, the shoreline index, river density, the proportion of wetlands, and the proportion of coniferous forest on the landscape. We felt that the combination of these 6 variables captured the landscape variability inherent in the survey areas, maintained an acceptable level of collinearity among explanatory variables while also having sufficient explanatory power to detect possible differences in the distribution of duck species owing to unique habitat requirements.

During preliminary data screening some species demonstrated a quadratic relationship with select habitat variables. Therefore, we built a candidate set of models that contained all possible combinations of quadratic terms (64 models). We fit the complete candidate set to each species and used bridge sampling to estimate the likelihood ratio among competing models

(Meng and Wong 1996, Gelman and Meng 1998). A complete list of all models considered is provided in Table A.7.

For each species, we estimated the number of indicated breeding pairs associated with each survey cell (5x5km plot). We estimated the variation in waterfowl IBP in the survey cells via a negative binomial model. We used the Negative Binomial distribution with a quadratic mean–variance relationship as the probability distribution explaining the abundance of IBP at survey sites (i.e. NB2; Hilbe 2014). This distribution is parametrized in function of the mean and an over-dispersion parameter:

$$\mathrm{IBP}_i \sim \mathrm{NB}(\eta_i, \kappa) \quad \text{Eq. 14}$$

$$\log(\eta) = \mathbf{X}\beta + \log(\mathrm{area}) \quad \text{Eq. 15}$$

where IBP_i is the number of pairs at site *I*, η is the expected mean IBP at location *I*, κ is the over-dispersion parameter, **X** is a matrix holding the explanatory variables, and β is a vector holding the estimate of the effect of the explanatory variables. We included the log of site area as an offset. The explanatory variables were standardized to zero mean and unit variance to ease interpretation and convergence of the model (Kéry 2010).

We ran the complete model set for each species independently in a Bayesian framework that was implemented in Stan from Program R using the rstan package (Stan Development Team 2016). We used a non-informative prior for all parameters and ran two chains with randomized initial values for 1500 iterations, with the 500 first iterations used as a burn-in. Chain convergence was visually evaluated and verified using the Gelman-Rubin statistic ($\hat{R}$). We used the package bridgesampling (Gronau and Singmann 2017) to estimate the model posterior probability and kept the model with the highest probability for each species. Results are reported as the posterior means and 2.5 and 97.5 percentiles of the posterior distribution for credible intervals (95% BCI). We considered explanatory variable effects as "significant" if their 95% BCI did not overlap 0.

RESULTS

Breeding Phenology

The phenology index varied by year and location for all species (Figure 18-19, Table 1).

2017 - For Little Duck Lake and Lynx Lake, the phenology index suggested that the timing of the surveys, relative to nest initiation, was good for all focal species (scoters, scaup, Long-tailed Duck; 0.3-0.6) except White-winged Scoters (0.79-0.82). The survey at the Ramparts site was conducted earlier than the other study sites in 2017, and the phenology index suggests that this was possibly too early for Surf Scoters (0.81) and White-Winged Scoters (0.83).

2018 - Spring was delayed by more than two weeks relative to 2017, and the phenology index for Black Scoters, Surf Scoters, and Greater Scaup at Lynx Lake were all higher in 2018 than in 2017. Lesser Scaup breeding phenology did not appear to be influenced by the later spring (0.45

in 2017 vs. 0.51 in 2018). Despite the late spring, the phenology index values still suggest that the surveys at Lynx Lake and Yellowknife were well timed for most focal species, but again, too early for White-winged Scoters (0.73).

2019 - Spring phenology was later than in 2018, and the smaller water bodies were just beginning to open up at Lynx Lake and North Lynx Lake. The phenology index indicates that the survey at Lynx Lake may have been too early for the three scoter species (BLSC=0.77, SUSC=0.65, WWSC=0.76), and the survey at North Lynx Lake appears to have been too early for Greater Scaup (0.85), Lesser Scaup (0.86) and Black Scoter (0.86). Due to the small number of observations for Wing-winged Scoter and Surf Scoter at North Lynx Lake, there is considerable uncertainty in phenology index estimates for these species. Spring was also late in Northern Quebec, but most lakes were thawed during the George River surveys. For Black Scoters, Surf Scoters, and Greater Scaup (the main species encountered), the phenology index was 0.71, 0.42, and 0.46, respectively.

At all sites, the penology index for White-winged Scoters approached 1, indicating that the survey may have occurred before many White-wing Scoters initiated egg-laying. The phenology index was well below 1.00 for the dabbling species (American Green-winged Teal, Mallard and Northern Pintail) at most sites, suggesting that many of the males seen at these sites may have been post breeders.

This phenology index was originally developed based on dabbling duck pair behaviour (Bordage et al. 2017), where males defend a breeding territory for the female. Scoter and scaup behaviour may differ as they do not appear to defend territories as aggressively as dabbler ducks. More work is required to develop a phenology index that represents their breeding behaviour accurately.

Detection

Detection probability estimates by observer position and experience level were overall quite high (Fig. 20-22), but some variability was evident across sites. With the exception of the North Lynx Lake crew, the experienced observers had higher detection probabilities than the inexperienced observers. With the exception of the George River crew, detection probabilities for rear observers were consistently greater than for observers seated in the front of the helicopter, despite greater visibility from the front seat. Detection probabilities across waterfowl species and survey sites varied but were high (Fig. 23-25; Tables 2-4). Overall, for key survey species (i.e. scoters, scaup, mergansers, long-tailed ducks) detection probabilities appeared highest at the Yellowknife site (Range: 0.931 [BLSC] to 0.982 [LESC]), and lower at the Ramparts site (0.636 [HOME] to 0.850 [SCAU])). Across all survey sites, scaup species generally had the highest detection rates while long-tailed ducks (*Clangula hyemalis*) and hooded mergansers (*Lophodytes cucullatus*) had some of the lowest detection rates. Detection probabilities for dabbler species (i.e. AGWT, AMWI, MALL, NOPI) and Canada geese (*Branta canadensis*) were again, highest at the Yellowknife site and lower at the Ramparts site.

Density Corrected for Detection

Scoters & scaup –At Lynx Lake, North Lynx, and Little Duck Lake, Black Scoter was the most frequently observed species, followed by Surf Scoters and White-winged Scoters. At Yellowknife, Surf Scoters were seen in the highest densities, then White-winged Scoters and Black Scoters. At the Ramparts site, White-winged Scoters were the most frequently observed species. When all scoter species were pooled at each site, Lynx Lake had a higher scoter densities in all three years than the other survey sites (Tables 2-4). However, scoter densities varied across the three years of surveys, with the observed densities of Surf Scoters and White-winged Scoters in 2018 being almost double that of 2017. Surf Scoters and White-winged Scoters densities were intermediate in 2019, and Black Scoter densities in 2019 were close to half that observed in 2017.

Scaup density was highest at the Yellowknife site by a large margin (Table 2-4). When Greater (*Aythya marila*), Lesser (*Aythya affinis*) and unidentified scaup were pooled, the density of scaup at Yellowknife was estimated at 3.402 (3.398 – 3.414) pairs per 25 km^2 plot. The high density of scaup, combined with the effort and time required to identify them to species (circling the ducks with the helicopter), likely explains why many of the observations were not classed to species at the Yellowknife site. The density of scaup was lowest at the North Lynx Lake and George River sites, estimated at 0.333 (0.333 - 0.345) and 0.061 (0.06 - 0.068) pairs per 25 km^2 plot, respectively. Across the three years of surveys at Lynx Lake site, scaup densities were similar between 2017 and 2018, and lower in 2019.

Mergansers & other seaducks – Densities of the three merganser species – Common Merganser (*Mergus merganser*), Hooded Merganser (*Lophodytes cucullatus*) and Red-breasted Merganser (*Mergus serrator*), varied considerable among survey sites. Red-breasted mergansers were found at all six survey sites, and were generally more abundant than the other two species. A notable exception is the Little Duck Lake site, which had higher densities of Hooded Mergansers (0.477 pairs per 25 km^2). Many of the Hooded Mergansers observed were mostly brown without the typical adult feather pattern, leaving observers to consider whether they might have been hatch-year birds and not breeding adults. Long-tailed ducks were observed at all six survey areas, but densities at Lynx Lake and North Lynx Lake were considerably greater that the other sites. Bufflehead (*Bucephala albeola*) were also observed at the Lynx Lake, Ramparts, Yellowknife, and Little Duck Lake sites, but in relatively low densities.

Dabblers, geese and other divers –Blue-winged teal (*Spatula discors*) were observed at the Yellowknife and Ramparts sites, and Northern Shovelers (*Spatula clypeata*) at Ramparts, but both species were too scarce to estimate density or detection. American Wigeon (*Mareca americana*) were only found in appreciable numbers at the Little Duck Lake and Ramparts sites. Ring-necked ducks were observed at the greatest densities at Ramparts, while having only 6 observations at the George River site. Estimated densities for American Green-winged Teal (*Anas crecca*) and Mallard (*Anas platyrhynchos*) were highest at Ramparts, and Northern Pintail

(*Anas acuta*) at North Lynx Lake. American Black Ducks (*Anas rubripes*) were only observed during surveys at the George River site, but two were seen while ferrying between plots at the Lynx Lake site.

Results from our surveys (2017-2019) can also be compared with previous surveys conducted elsewhere in Canada to better understand the distribution and abundance of scoters across their range (Figure 26). Based on the number of indicated breeding pairs (uncorrected for detection), there are fewer breeding scoters per 25 square kilometers in Eastern Canada, based on data collected in Labrador in 2009 as part of SDJV Project No. 115 (Gilliland et al. 2010), the Hudson Bay Lowlands of Ontario in 2009 (Brook et al. 2012), and the George River (this study). Population estimates derived from modelled densities for scoters and scaup (projected to a surface area the size of the Lynx Lake site for direct comparison) are shown for our six survey sites and Labrador in Figure 27.

Habitat Selection

The best-approximating model to estimate the number of indicated breeding pairs per 25km^2 plot based on available habitat varied by species (Table 6), indicating that different species selected for different landscape features. However, a number of models were deemed competitive for most species based on calculation of the Bayes Factor and the Kass and Raftery classification (Kass and Raftery 1995). Parameter estimates from the best models are shown in Table 7. An example of the spatial distribution generated from these habitat relationships are shown for Black Scoters in each study area in Figure 28.

Black Scoter – Predicted pair density increased as the proportion of the plot covered by wetlands increased (Fig. 29A). There was also a negative quadratic relationship between the number of breeding pairs within a cell and total lake area, where pair density slowly began to decline once lake area exceeded approximately 8 km^2 (Fig. 29B).

Surf Scoter – Predicted pair density increased linearly with the proportion of the plot covered by coniferous forest (Fig. 30A). There was also a negative quadratic relationship between the number of breeding pairs within a cell and total lake area, where pair density began to decline once lake area exceeded approximately 5 km^2 (Fig. 30B).

White-winged Scoter – The top-ranked model for White-winged Scoters included negative quadratic effects of lake area, proportion of the cell covered by wetlands, and coniferous forest (Fig. 31A-C). Predicted pair density also increased linearly with river density (Fig. 31D).

Greater Scaup – The top-ranked model for Greater Scaup included a negative quadratic effect of total lake area. The predicted number of breeding pairs quickly increased until lake area reached approximately 5 km^2, after which the number of predicted pairs decreased (Fig. 32).

Lesser Scaup – The top-ranked model for Lesser Scaup included a negative quadratic effect of the proportion of coniferous forest cover, number of lakes, and wetland cover (Fig 33A-C). The predicted number of breeding pairs highest when the proportion of coniferous forest cover and wetland cover were both approximately 40%, and when the number of lakes was approximately 50. There was also a positive linear effect of river density (Fig. 33D).

Long-tailed Duck – The best-approximating model for Long-tailed Ducks included negative quadratic effects of river density and total lake area (Fig. 34A-B). The predicted number of breeding pairs also decreased linearly with the proportion of coniferous forest cover, and increased linearly with the proportion of wetland cover (Fig. 34C-D).

DISCUSSION

The variety of habitats encountered at the six survey sites, ranging from tundra to tree line to boreal, resulted in a diverse assemblage of sea ducks. These results, together with information from the Canadian Barrenlands Experimental Breeding Survey (Rhodes et al. 2015) and from satellite telemetry studies, confirm that the Barrenlands region of Canada is indeed a core breeding area for North American scoters. Both Black and Surf Scoter densities from Little Duck, Lynx Lake, and Yellowknife were significantly higher than those observed in previous surveys conducted in eastern Canada (Labrador- Gilliland et al. 2010, Hudson Bay Lowlands, Ontario- Brook et al. 2012). The Ramparts site also provided substantial estimates for breeding White-winged Scoters (0.26 pairs/km^2 compared to 0.01/km^2 in Labrador and 0.06/km^2 in the Hudson Bay Lowlands) although our estimates are much lower than the 0.80 pairs/km^2 reported in Québec by Gauthier and Aubry (1996).

As part of SDJV Project No.141, fixed-wing transects were flown in the Canadian Barrenlands region of Canada in 2014 and 2015. Rhodes et al. (2015) found that most of the scoters (89%) that were identified to species were Black Scoters. Based on density estimates generated from the detection analysis, we also found Black Scoters to be the most abundant scoter species within the Barrenlands region (i.e. Lynx Lake, North Lynx Lake, and Little Duck sites). Importantly, with further analyses, we hope to be able to demonstrate a shift in species composition attributed to habitat changes (transition from boreal forest to tundra) along a north-south gradient within the scoter breeding range.

Overall, each crew was effective at detecting waterfowl from the helicopter. Detection probabilities were usually higher from the rear seat compared to the front seat. This is likely due to the added challenge of navigation when in the front, in addition to variable effort by the pilot as he maneuvered the aircraft. The only exception was the George River crew, which had higher detection probabilities from the front seat of the aircraft. This is likely attributed to the experience of the pilot, who needed very little navigational direction. Crews also opted to record data differently among sites. Most crews chose to have the two rear observers record data on their respective sides of the helicopter and the front observer be tasked only with navigating and observing, while the Lynx Lake crew opted to have the front observer navigate, record data and observe birds, leaving those in the rear seats to observe birds only.

Spatial predictions made by the habitat model generally support the qualitative assessments of shifts in species composition across the study area made by crews from the helicopter. For example, Long-tailed Ducks and Black Scoters at the Little Duck Lake and North Lynx Lake sites were largely observed in tundra habitats with very few stands of trees. In contrast, White-winged Scoters were not observed in this habitat type, and the predicted number of White-winged Scoters was low in areas with a low proportion of coniferous forest cover. The Little Duck Lake and Lynx Lake crews reported large stands of burned coniferous forest in various stages of succession across the study area. However, the CanVec database does not currently differentiate between burned and intact coniferous forest. Therefore, species' relationships with the 'Conif' or '$Conif^2$' explanatory variable may be somewhat misleading if species that would normally select forested cover are avoiding burned stands and settling elsewhere. Haszard (2004) found that scoters in the Mackenzie Delta region of the Northwest Territories tended not to settle on wetlands surrounded by burned habitat for up to two years following a fire event, but that after three years settling patterns were unaffected.

However, we did not detect some habitat relationships that have been described in other studies. For example, Perry et al. (2006) found that the presumed nest sites for Surf Scoters tracked with satellite telemetry were adjacent to ponds associated with rivers. In the case of Black Scoters, there is evidence of avoiding of rivers (Bordage and Savard 2011). However, we did not find any significant relationships between river density and Black or Surf Scoter abundance. Similarly, none of the species considered in the habitat modelling analysis selected for the shoreline index (SDI) variable. A more complex shoreline (SDI value >1) would be indicative of more islands within the plot and given that some species, white-winged scoters in particular, have been shown to use islands for nesting (Brown and Fredrickson 1997, Morrier et al. 1997), we might have expected some positive relationships. Instead, White-winged Scoters appeared to be more selective regarding the size of waterbodies and their coverage across the landscape, as were most species.

Of particular interest are the differences in habitat selection identified between Greater and Lesser Scaup, since an inability to differentiate the two species in most breeding surveys (e.g. WBPHS) has largely limited our capacity to accurately identify species-specific habitat requirements as well as monitor them as distinct units (Anteau et al. 2014). Notably, we found that the predicted number of Lesser Scaup pairs declined at very high and very low proportions of coniferous forest cover. This corroborates previous work that has described Lesser Scaup as preferring boreal habitats (Kessel et al. 2002, Anteau et al. 2014). However, we did not find a negative relationship between coniferous forest and Greater Scaup, a species which has been described as nesting largely north of the Lesser Scaup breeding range in treeless habitats (Kessel et al. 2002, Anteau et al. 2014).

PROJECT STATUS

We proposed three study areas for 2019: two new study areas in the Taiga Shield Ecozone of Nunavut and Quebec and a third consecutive year of survey at the Lynx Lake study area in the Northwest Territories. We were not successful in obtaining a research permit in Nunavut so we instead surveyed a new area north of the original Lynx Lake area. This was the last year of surveys for this project.

Sampling intensity objectives were met in 2019 by both the helicopter and fixed-wing crews. Lynx Lake, Lynx Lake North and George River sites encompassed a variety of habitats, ranging from tundra to Boreal forest, which resulted in a diverse assemblage of habitats and sea duck species observed across the study areas. The Lynx Lake North site was predominantly above the treeline and allowed us to obtain important information on the extent of the breeding range for all three scoter species as well as other waterfowl. The George River site had much lower densities of waterfowl than other sites surveyed over the course of this project, typical of the less productive eastern Canadian boreal landscapes. The Lynx Lake site was surveyed for a third consecutive year which will allow the quantification of annual variation in detection probabilities, breeding densities and habitat selection.

The data collected over the three years of the study is entered, proofed and partially analysed. All waterfowl data collected from the helicopter component of the survey has been analysed for detection, density, indicated pairs, breeding phenology, and habitat selection. The data collected from the fixed-wing component has not yet been fully analysed.

Survey results were presented at the 8th North American Duck Symposium in Winnipeg, 26-30 August 2019, in four separate presentations:

- Eric T. Reed, Alice D. Domalik, Scott G. Gilliland, Christine Lepage, Megan V. Ross, Cindy Wood and Christian Roy. **Breeding habitat selection of scoters and scaup in the Boreal-Arctic transition zone.** Oral presentation
- Eric T. Reed, Alice D. Domalik, Matthew English, Mark Koneff, Christine Lepage, Shirley Orichefsky, Walt Rhodes, Megan V. Ross, Christian Roy, Emily Silverman, Cindy Wood and Scott G. Gilliland. **The Boreal-Arctic transition zone of Canada: duck factory of the not-so-famous?** Oral presentation
- Christian Roy, Scott G. Gilliland, Eric T. Reed, Christine Lepage, Megan V. Ross, Matthew English, and Cindy Wood. **A Double Dependent Observer Method to Estimate Detection Rate During Helicopter Waterfowl Surveys.** Oral presentation
- Cindy Wood, Eric T. Reed, Alice D. Domalik, Scott G. Gilliland, Matthew English, Mark Koneff, Christine Lepage, Walt Rhodes, Megan V. Ross, Christian Roy, and Emily Silverman. **Phenology and Distribution of Waterfowl in the Boreal-Arctic Transition Zone.** Poster presentation

The focus in 2019 – 2020 will be to finalize data analyses, including the fixed-wing data, and writing of manuscripts on the breeding ecology of waterfowl in the Boreal-Arctic transition zone, integrated survey methodology, and approaches to estimate detection from aerial waterfowl surveys. A committee will also be formed to develop monitoring recommendations for scoters and other waterfowl in the Boreal-Arctic transition zone. We expect this recommendation document to be completed in early 2021. Results from the experimental scoter surveys and monitoring recommendations will be presented at the 2019 Sea Duck Joint Venture meeting, and at both Atlantic and Pacific Flyway Council meetings in 2020.

Project Funding Sources (US$). Complete only if funded by SDJV in FY19; this is used to document: 1) how SDJV-appropriated funds are matched, and 2) how much partner resources are going into sea duck work. You may Include approximate dollar value of in-kind contributions in costs. Add rows as needed for additional partners.

SDJV (USFWS) Contribution	Other U.S. federal contributions	U.S. non-federal contributions	Canadian federal contributions	Canadian non-federal contributions	Source of funding (name of agency or organization)
$100,000					SDJV (USFWS)
			$402,850 (includes $119,000 in-kind contribution)		CWS
	$81,000 (includes $46,000 in-kind)				USFWS

Total Expenditures by Category (SDJV plus all partner contributions; US$). Complete only if project was funded by SDJV in FY19; total dollar amounts should match those in previous table.

Activity	BREEDING	MOLTING	MIGRATION	WINTERING	TOTAL
Banding (include only if this was a major element of study)					
Surveys (include only if this was a major element of study)	**$583,850**				**$583,850**
Research					

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TABLES

Table 1. Phenology index (number of detections) by species, site and year.

	2017 Survey Sites			2018 Survey Sites		2019 Survey Sites		
Species	**Little Duck**	**Lynx Lake '17**	**Ramparts**	**Lynx Lake '18**	**Yellowknife**	**Lynx Lake '19**	**North Lynx**	**George River**
AGWT	0.12 (270)	0.08 (162)	0.43 (255)	0.11 (204)	0.26 (197)	0.22 (162)	0.32 (29)	0.08 (52)
AMWI	0.22 (9)	-	0.56 (386)	0.5 (11)	0.36 (98)	0.67 (3)	-	-
BLSC	0.48 (207)	0.6 (369)	-	0.79 (374)	0.68 (54)	0.77 (336)	0.86 (170)	0.71 (36)
BUFF	0.3 (32)	0.4 (52)	0.32 (34)	0.38 (36)	0.31 (62)	0.28 (33)	-	-
COME	0.14 (16)	0.23 (58)	-	0.48 (65)	0.26 (29)	0.21 (28)	0.05 (53)	0.08 (9)
GRSC	0.48 (58)	0.3 (109)	-	0.44 (86)	0.36 (24)	0.49 (36)	0.85 (41)	0.46 (13)
HOME	0.26 (146)	0.52 (70)	0.33 (3)	0.58 (75)	0.23 (71)	0.38 (63)	-	-
LESC	0.49 (155)	0.45 (144)	0.48 (53)	0.51 (195)	0.39 (324)	0.53 (133)	0.86 (8)	0.08 (16)
LTDU	0.51 (63)	0.38 (253)	-	0.38 (282)	0.71 (62)	0.55 (428)	0.52 (583)	0.27 (14)
MALL	0.32 (135)	0.38 (56)	0.34 (187)	0.27 (84)	0.54 (148)	0.4 (35)	-	-
NOPI	0.28 (107)	0.27 (176)	0.78 (28)	0.35 (239)	0.49 (59)	0.39 (231)	0.34 (239)	0.2 (9)
RBME	0.56 (47)	0.58 (86)	-	0.68 (93)	0.56 (135)	0.63 (179)	0.63 (96)	0.46 (56)
SCAU	0.31 (82)	0.46 (121)	0.54 (472)	0.62 (77)	0.47 (461)	0.72 (96)	0.79 (24)	-
SUSC	0.47 (144)	0.48 (129)	0.81 (68)	0.57 (251)	0.42 (280)	0.65 (189)	0.2 (7)	0.42 (80)
WWSC	0.82 (57)	0.79 (34)	0.83 (126)	0.73 (70)	0.83 (86)	0.76 (54)	0.57 (8)	-

Table 2. Mean number of indicated breeding pairs (standard deviation; uncorrected estimate) per surveyed plot ($25km^2$), predicted probability of detection (lower and upper 95% Bayesian credible interval) and estimated density of ducks per square kilometer (lower and upper 95% Bayesian credible interval) by species for each of the three study sites surveyed in 2017.

Species	Little Duck Lake			Lynx Lake			Ramparts		
	IP / Plot	Detection	Density	IP / Plot	Detection	Density	IP / Plot	Detection	Density
Scoters									
BLSC	8.52 (10.39)	0.937 (0.899 - 0.967)	0.745 (0.742 - 0.757)	14.73 (12.05)	0.810 (0.748 - 0.862)	1.352 (1.33 - 1.381)	0.05 (0.22)	0.685 (0.234 - 0.925)	0.005 (0.004 - 0.012)
SUSC	6.52 (5.21)	0.909 (0.841 - 0.956)	0.444 (0.440 - 0.456)	5.15 (5.69)	0.870 (0.801 - 0.925)	0.366 (0.363 - 0.375)	3.4 (6.39)	0.702 (0.512 - 0.834)	0.340 (0.326 - 0.374)
WWSC	2.84 (6.35)	0.944 (0.869 - 0.987)	0.214 (0.213 - 0.219)	1.38 (3.65)	0.838 (0.709 - 0.934)	0.101 (0.100 - 0.109)	6.4 (11.84)	0.824 (0.717 - 0.916)	0.573 (0.566 - 0.594)
ALL	-	-	1.402 (1.395 - 1.419)	-	-	1.819 (1.798 - 1.849)	-	-	0.917 (0.896 - 0.956)
Scaup									
GRSC	3.00 (3.45)	0.948 (0.877 - 0.987)	0.183 (0.182 - 0.188)	5.54 (5.05)	0.900 (0.830 - 0.953)	0.385 (0.383 - 0.394)	-	-	-
LESC	7.6 (7.77)	0.979 (0.947 - 0.996)	0.592 (0.592 - 0.597)	7.77 (9.59)	0.874 (0.808 - 0.927)	0.507 (0.503 - 0.518)	2.45 (4.38)	0.848 (0.717 - 0.956)	0.269 (0.266 - 0.282)
SCAU	3.64 (3.74)	0.962 (0.913 - 0.991)	0.317 (0.317 - 0.323)	5.88 (5.36)	0.806 (0.715 - 0.880)	0.467 (0.458 - 0.486)	27.05 (29.46)	0.850 (0.802 - 0.890)	2.262 (2.244 - 2.292)
ALL	-	-	1.093 (1.091 - 1.101)	-	-	1.358 (1.345 - 1.382)	-	-	2.531 (0.010 - 0.026)
Mergansers									
COME	0.88 (2.07)	0.937 (0.806 - 0.993)	0.069 (0.069 - 0.074)	2.92 (4.82)	0.792 (0.647 - 0.895)	0.187 (0.183 - 0.202)	-	-	-
HOME	4.16 (4.07)	0.917 (0.855 - 0.960)	0.477 (0.474 - 0.490)	1.46 (1.88)	0.823 (0.720 - 0.907)	0.200 (0.197 - 0.211)	0.15 (0.49)	0.636 (0.207 - 0.868)	0.010 (0.008 - 0.020)
RBME	1.80 (3.49)	0.927 (0.841 - 0.979)	0.146 (0.146 - 0.152)	3.38 (3.29)	0.823 (0.716 - 0.908)	0.245 (0.242 - 0.257)	0.05 (0.22)	0.686 (0.236 - 0.922)	0.003 (0.002 - 0.008)
Other Seaducks									
BUFF	1.28 (2.09)	0.954 (0.860 - 0.995)	0.148 (0.147 - 0.154)	2.31 (3.56)	0.851 (0.751 - 0.927)	0.246 (0.243 - 0.258)	1.50 (2.52)	0.818 (0.662 - 0.940)	0.093 (0.092 - 0.102)
COGO	0.80 (1.76)	0.941 (0.825 - 0.994)	0.061 (0.061 - 0.066)	-	-	-	0.25 (0.72)	0.733 (0.383 - 0.941)	0.017 (0.016 - 0.024)
LTDU	2.00 (3.35)	0.770 (0.601 - 0.891)	0.165 (0.157 - 0.187)	10.42 (9.00)	0.799 (0.728 - 0.858)	0.665 (0.654 - 0.683)	0.05 (0.22)	0.689 (0.277 - 0.918)	0.003 (0.002 - 0.008)

Table 3. Mean number of indicated breeding pairs (standard deviation; uncorrected estimate) per surveyed plot ($25km^2$), predicted probability of detection (lower and upper 95% Bayesian credible interval) and estimated density of ducks per square kilometer (lower and upper 95% Bayesian credible interval) by species for the two study sites surveyed in 2018.

Species	**Lynx Lake**			**Yellowknife**		
	IP / Plot	Detection	Density	IP / Plot	Detection	Density
Scoters						
BLSC	16.52 (13.93)	0.804 (0.731 – 0.859)	1.256 (1.245 - 1.275)	2.12 (3.93)	0.931 (0.847 – 0.975)	0.166 (0.165 - 0.174)
SUSC	11.24 (11.53)	0.858 (0.799 – 0.907)	0.782 (0.769 – 0.803)	10.48 (9.97)	0.958 (0.931 – 0.977)	0.890 (0.888 – 0.898)
WWSC	3.08 (5.76)	0.912 (0.833 – 0.966)	0.211 (0.209 – 0.218)	3.84 (4.07)	0.964 (0.926 - 0.987)	0.339 (0.338 – 0.346)
ALL	-	-	2.339 (2.318 – 2.370)	-	-	1.451 (1.446 – 1.464)
Scaup						
GRSC	4.16 (4.27)	0.936 (0.870 – 0.980)	0.284 (0.283 – 0.292)	1.28 (2.41)	0.965 (0.914 – 0.993)	0.082 0.082 – 0.085)
LESC	10.08 (9.62)	0.895 (0.838 – 0.938)	0.719 (0.712 – 0.735)	15.92 (10.24)	0.982 (0.966 – 0.993)	1.287 (1.286 – 1.292)
SCAU	3.48 (3.69)	0.821 (0.707 – 0.904)	0.310 (0.302 – 0.332)	22.16 (18.30)	0.972 (0.955 – 0.985)	1.902 (1.900 – 1.914)
ALL	-	-	1.366 (1.349 – 1.397)	-	-	3.402 (3.398 – 3.414)
Mergansers						
COME	2.40 (3.44)	0.880 (0.792 – 0.948)	0.212 (0.209 - 0.223)	0.96 (1.31)	0.971 (0.931 – 0.994)	0.097 (0.097 – 0.100)
HOME	2.24 (2.93)	0.767 (0.630 – 0.872)	0.226 (0.215 – 0.249)	3.08 (3.12)	0.956 (0.904 – 0.985)	0.185 (0.185 – 0.189)
RBME	3.52 (3.68)	0.792 (0.672 – 0.883)	0.267 (0.257 – 0.289)	5.24 (5.69)	0.941 (0.897 – 0.971)	0.364 0.362 – 0.371)
Other Seaducks						
BUFF	1.64 (3.26)	0.856 (0.709 – 0.948)	0.152 (0.149 – 0.166)	2.60 (4.04)	0.963 (0.919 – 0.988)	0.170 (0.169 – 0.174)
COGO	-	-	-	-	-	-
LTDU	11.12 (9.79)	0.770 (0.699 – 0.834)	0.687 (0.665 – 0.718)	2.24 (3.11)	0.971 (0.937 – 0.992)	0.166 (0.166 – 0.169)

Table 4. Mean number of indicated breeding pairs (standard deviation; uncorrected estimate) per surveyed plot ($25km^2$), predicted probability of detection (lower and upper 95% Bayesian credible interval) and estimated density of ducks per square kilometer (lower and upper 95% Bayesian credible interval) by species for the three study sites surveyed in 2019.

Species	Lynx Lake			North Lynx Lake			George River		
	IP / Plot	Detection	Density	IP / Plot	Detection	Density	IP / Plot	Detection	Density
Scoters									
BLSC	14.2 (9.06)	0.904 (0.847 - 0.949)	0.839 (0.835 - 0.854)	7.12 (5.97)	0.943 (0.905 - 0.972)	1.28 (1.278 - 1.289)	1.48 (1.69)	0.924 (0.848 - 0.973)	0.103 (0.102 - 0.111)
SUSC	7.96 (9.44)	0.935 (0.887 - 0.971)	0.484 (0.483 - 0.491)	0.20 (0.58)	0.949 (0.826 - 0.999)	0.114 (0.114 - 0.117)	3.64 (4.60)	0.934 (0.874 - 0.976)	0.221 (0.218 - 0.229)
WWSC	2.32 (4.60)	0.919 (0.829 - 0.978)	0.176 (0.175 - 0.182)	0.40 (1.44)	-	-	0.12 (0.60)	-	-
ALL									
Scaup									
GRSC	1.68 (2.67)	0.929 (0.836 - 0.985)	0.245 (0.245 - 0.254)	1.92 (2.47)	0.934 (0.772 - 0.999)	0.065 (0.065 - 0.068)	0.64 (1.15)	-	-
LESC	6.64 (6.51)	0.911 (0.839 - 0.963)	0.324 (0.323 - 0.332)	0.28 (0.68)	0.931 (0.811 - 0.993)	0.16 (0.16 - 0.166)	0.96 (1.77)	0.91 (0.799 - 0.97)	0.061 (0.06 - 0.068)
SCAU	4.44 (5.03)	0.896 (0.816 - 0.954)	0.313 (0.311 - 0.322)	1.20 (2.20)	0.944 (0.812 - 0.999)	0.108 (0.108 - 0.111)		-	-
ALL									
Mergansers									
COME	1.2 (2.18)	0.864 (0.743 - 0.945)	0.191 (0.189 - 0.202)	2.92 (3.38)	0.923 (0.727 - 0.999)	0.119 (0.118 - 0.126)	0.52 (1.12)	-	-
HOME	1.16 (2.70)	0.839 (0.714 - 0.931)	0.133 (0.131 - 0.142)	-	-	-	0.12 (0.44)	-	-
RBME	7.92 (6.41)	0.766 (0.647 - 0.858)	0.448 (0.434 - 0.472)	4.00 (2.57)	0.878 (0.799 - 0.938)	0.388 (0.386 - 0.398)	2.56 (3.14)	0.92 (0.849 - 0.968)	0.165 (0.163 - 0.175)
Other Seaducks									
BUFF	1.48 (3.10)	0.909 (0.796 - 0.981)	0.121 (0.12 - 0.126)	0.04 (0.20)	-	-	-	-	-
COGO	-	-	-	-	-	-	0.2 (0.58)	-	-
LTDU	16.96 (14.44)	0.834 (0.784 - 0.878)	1.32 (1.305 - 1.342)	23.04 (17.08)	0.867 (0.82 - 0.908)	1.361 (1.352 - 1.377)	0.6 (1.38)	-	-

Table 5. Predicted probability of detection (lower and upper 95% Bayesian credible interval) and estimated density per square kilometer (lower and upper 95% Bayesian credible interval) for non-target waterfowl species in each study site surveyed.

Species	**Little Duck Lake**		**Ramparts**		**Lynx Lake 2017**		**Yellowknife**	
	Detection	Density	Detection	Density	Detection	Density	Detection	Density
Dabblers and Geese								
AGWT	0.882	0.706	0.709	0.812	0.786	0.424	0.953	0.466
	(0.824 - 0.925)	(0.698 - 0.723)	(0.608 - 0.785)	(0.790 - 0.849)	(0.718 - 0.836)	(0.415 - 0.438)	(0.926 - 0.972)	(0.465 - 0.472)
AMWI	0.869	0.018	0.793	1.329	-	-	-	-
	(0.601 - 0.980)	(0.018 - 0.024)	(0.729 - 0.848)	(1.310 - 1.358)				
CAGO	0.915	1.184	0.775	0.728	0.797	2.148	0.935	0.060
	(0.870 - 0.952)	(1.176 - 1.206)	(0.691 - 0.847)	(0.714 - 0.756)	(0.720 - 0.865)	(2.108 - 2.222)	(0.833 - 0.981)	(0.060 - 0.066)
MALL	0.904	0.376	0.705	0.564	0.745	0.158	0.910	0.366
	(0.833 - 0.952)	(0.373 - 0.387)	(0.607 - 0.792)	(0.548 - 0.592)	(0.591 - 0.858)	(0.152 - 0.172)	(0.849 - 0.955)	(0.362 - 0.377)
NOPI	0.825	0.277	0.788	0.092	0.642	0.522	0.940	0.158
	(0.707 - 0.907)	(0.269 - 0.294)	(0.626 - 0.916)	(0.090 - 0.102)	(0.513 - 0.748)	(0.495 - 0.567)	(0.874 - 0.977)	(0.157 - 0.165)
Other Diving Ducks								
RNDU	0.959	0.260	0.762	1.237	0.873	0.047	0.968	0.612
	(0.892 - 0.993)	(0.259 - 0.266)	(0.690 - 0.825)	(1.214 - 1.272)	(0.744 - 0.967)	(0.046 - 0.051)	(0.941 - 0.986)	(0.611 - 0.618)

Species	**Lynx Lake 2018**		**North Lynx Lake**		**Lynx Lake 2019**		**George River**	
	Detection	Density	Detection	Density	Detection	Density	Detection	Density
Dabblers and Geese								
AGWT	0.804	0.543	0.775	0.246	0.78	0.247	0.899	0.131
	(0.731 - 0.859)	(0.529 - 0.565)	(0.581 - 0.888)	(0.24 - 0.265)	(0.634 - 0.869)	(0.24 - 0.265)	(0.794 - 0.958)	(0.128 - 0.143)
AMWI	-	-	-	-	-	-	-	-
CAGO	0.886	2.416	0.866	2.228	0.845	3.381	0.898	0.448
	(0.832 - 0.930)	(2.391 - 2.474)	(0.798 - 0.92)	(2.214 - 2.271)	(0.786 - 0.892)	(3.338 - 3.451)	(0.819 - 0.951)	(0.438 - 0.468)
MALL	0.738	0.236	-	-	0.88	0.073	-	-
	(0.588 - 0.844)	(0.222 - 0.263)			(0.744 - 0.968)	(0.072 - 0.078)		
NOPI	0.749	0.724	0.716	0.741	0.781	0.516	-	-
	(0.656 - 0.826)	(0.697 - 0.768)	(0.625 - 0.792)	(0.723 - 0.772)	(0.687 - 0.858)	(0.503 - 0.538)		
ABDU	-	-					0.917	0.064
			-	-	-	-	(0.852 - 0.963)	(0.063 - 0.069)
Other Diving Ducks								
RNDU	0.716	0.063	0.807	0.053	0.858	0.05	-	-
	(0.441 - 0.881)	(0.057 - 0.086)	(0.388 - 0.979)	(0.051 - 0.066)	(0.659 - 0.969)	(0.049 - 0.057)		

Table 6. Model selection used to determine habitat selection preferences for scoters (*Melanitta* spp.), scaup (*Aythya* spp.) and Long-tailed Ducks (*Clangula hyemalis*) using data from all sites (2017-2019). Only models with a Bayes Factor less than three (Kass and Raftery 1995) are shown.

Model	Weight	BF
Black Scoter		
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$	0.334	0.00
Surf Scoter		
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$	0.23	0.00
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$	0.21	1.10
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$ + $Conif^2$	0.12	1.95
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$ + $Conif^2$	0.10	2.28
White-winged Scoter		
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$ + $Wetlands^2$ + $Conif^2$	0.22	0.00
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$ + $River^2$ + $Wetlands^2$ + $Conif^2$	0.16	1.37
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$ + SDI^2 + $Wetlands^2$ + $Conif^2$	0.13	1.66
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$ + SDI^2 + $River^2$ + $Wetlands^2$ + $Conif^2$	0.09	2.44
Greater Scaup		
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$	0.15	0.00
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$	0.12	1.30
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$	0.11	1.34
NLake + Area + SDI + River + Wetlands + Conif	0.07	2.10
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + SDI^2	0.06	2.67
NLake + Area + SDI + River + Wetlands + Conif + SDI^2	0.06	2.69
Lesser Scaup		
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Wetlands^2$ + $Conif^2$	0.27	0
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$ + $Wetlands^2$ + $Conif^2$	0.25	1.07
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Conif^2$	0.13	2.06
NLake + Area + SDI + River + Wetlands + Conif + $NLake^2$ + $Area^2$ + $Conif^2$	0.12	2.20
Long-tailed Duck		
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$ + $River^2$	0.09	0.00
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$	0.07	1.27
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$ + SDI^2 + $Wetlands^2$	0.07	1.29
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$ + $Wetlands^2$	0.07	1.36
NLake + Area + SDI + River + Wetlands + Conif + SDI^2 + $River^2$	0.07	1.39
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$ + SDI^2 + $River^2$	0.06	1.47
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$ + $River^2$ + $Wetlands^2$	0.06	1.62
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$ + SDI^2 + $River^2$ + $Wetlands^2$	0.06	1.69
NLake + Area + SDI + River + Wetlands + Conif + $Area^2$ + SDI^2	0.05	1.77
NLake + Area + SDI + River + Wetlands + Conif + SDI^2	0.05	1.84

NLake = number of lakes (log scale); Area = total lake area (log scale); SDI = shoreline index; River = river density; Wetlands = the proportion of wetland cover on the plot; Conif = proportion of coniferous forest cover on the plot

Table 7. Parameter estimates and 95% Bayesian Credible Intervals (BCI) from the best-approximating habitat model predicting the number of indicated breeding pairs per plot using 2017-2019 survey data. Bolded values indicate strong effects (95% BCI does not overlap 0).

Species	***Parameter estimates and 95% BCI***											
	Int.	NLake	Area	SDI	River	Wetlands	Conif	$NLake^2$	$Area^2$	$River^2$	$Wetlands^2$	$Conif^2$
BLSC	**-0.93**	0.24	**0.71**	0.06	-0.08	**0.67**	0.02	-	**-0.44**	-	-	-
	-1.28, -0.57	-0.05, 0.51	**0.38, 1.04**	-0.12, 0.25	-0.33, 0.18	**0.45, 0.88**	-0.22, 0.27		**-0.82, -0.08**			
SUSC	**-1.17**	-0.14	0.28	0.03	0.01	0.02	**0.42**	-	**-0.73**	-	-	-
	-1.62, -0.7	-0.48, 0.2	-0.07, 0.64	-0.22, 0.28	-0.24, 0.27	-0.23, 0.27	**0.2, 0.64**		**-1.1, -0.38**			
WWSC	**-1.2**	-0.47	0.25	0.44	0.56	0.33	**0.96**	**-0.5**	**-0.82**	-	**-0.48**	**-0.69**
	-2.06, -0.29	-1.13, 0.18	-0.43, 0.92	-0.03, 0.93	0.02, 1.12	-0.2, 0.86	**0.42, 1.49**	**-0.93, -0.09**	**-1.42, -0.25**		**-0.93, -0.09**	**-1.11, -0.39**
GRSC	**-1.54**	0.29	-0.07	0.18	-0.26	0.04	-0.12	-	**-0.46**	-	-	-
	-1.98, -1.09	-0.09, 0.67	-0.49, 0.35	-0.08, 0.43	-0.64, 0.11	-0.22, 0.3	-0.37, 0.13		**-0.94, -0.06**			
LESC	**-0.55**	-0.34	0.07	0.12	**0.46**	0.26	**0.55**	**-0.46**	-	-	**-0.2**	**-0.3**
	-1.01, -0.07	-0.71, 0.03	-0.23, 0.37	-0.08, 0.32	**0.16, 0.76**	-0.04, 0.55	**0.29, 0.81**	**-0.66, -0.27**			**-0.35, -0.05**	**-0.49, -0.16**
LTDU	**-1.3**	0.28	**0.64**	0.09	0.36	**0.32**	**-0.36**	-	**-0.47**	**-0.11**	-	-
	-1.67, -0.91	-0.09, 0.64	**0.26, 1.04**	-0.11, 0.28	-0.09, 0.82	**0.11, 0.55**	**-0.6, -0.12**		**-0.87, -0.08**	**-0.19, -0.03**		

NLake = number of lakes (log scale); Area = total lake area (log scale); SDI = shoreline index; River = river density; Wetlands = the proportion of wetland cover on the plot; Conif = proportion of coniferous forest cover on the plot

FIGURES

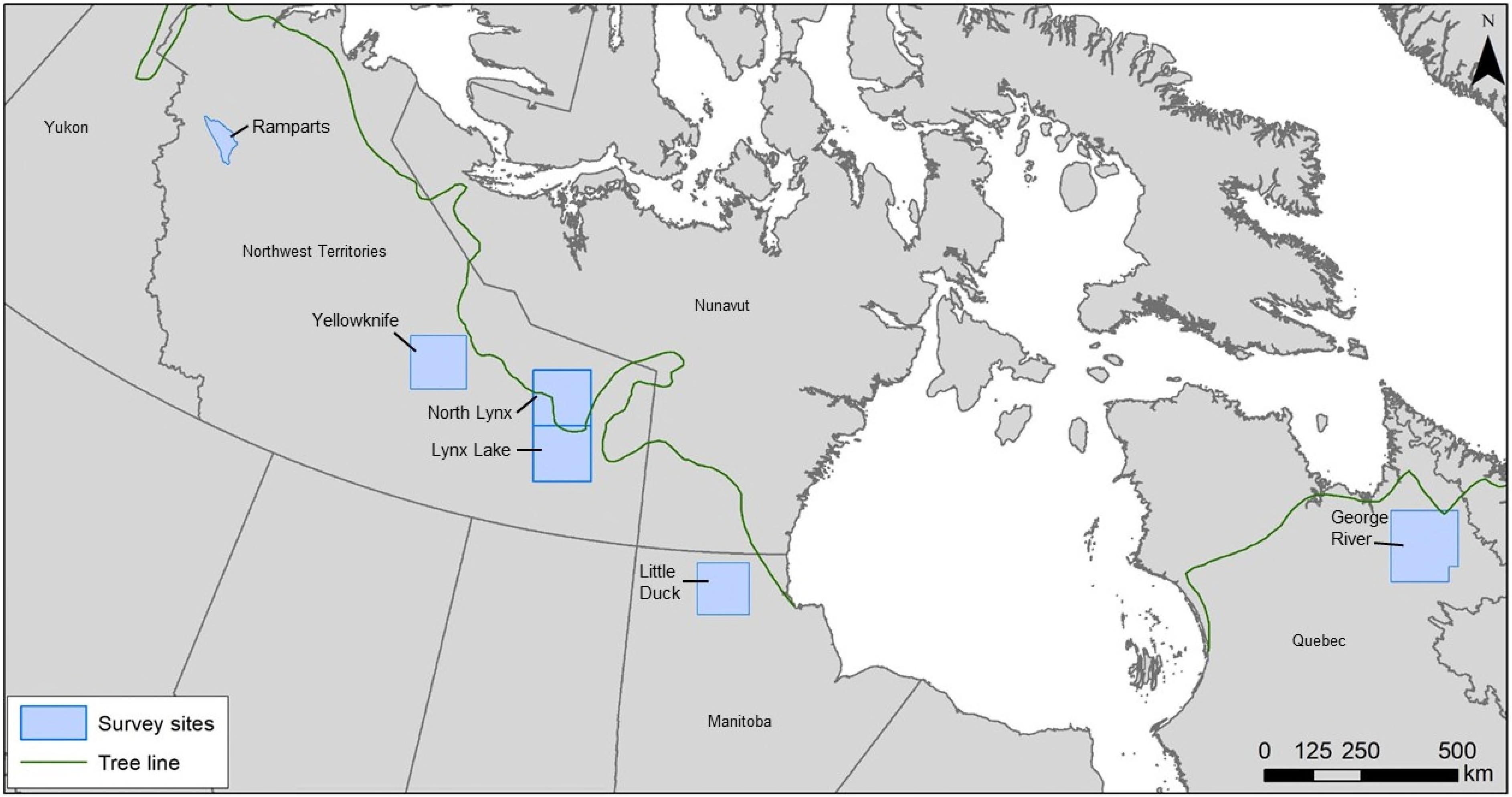

Figure 1. Distribution of the six areas surveyed for breeding scoters and other waterfowl in northern Canada, 2017-2019. Study area size was 21,750km^2 for Lynx Lake, 18,225km^2 for Little Duck Lake, 4,384km^2 for the Ramparts River Wetlands, 20,300km^2 for Yellowknife, 21,779km^2 for North Lynx Lake, and 31,375 km^2 for the George River.

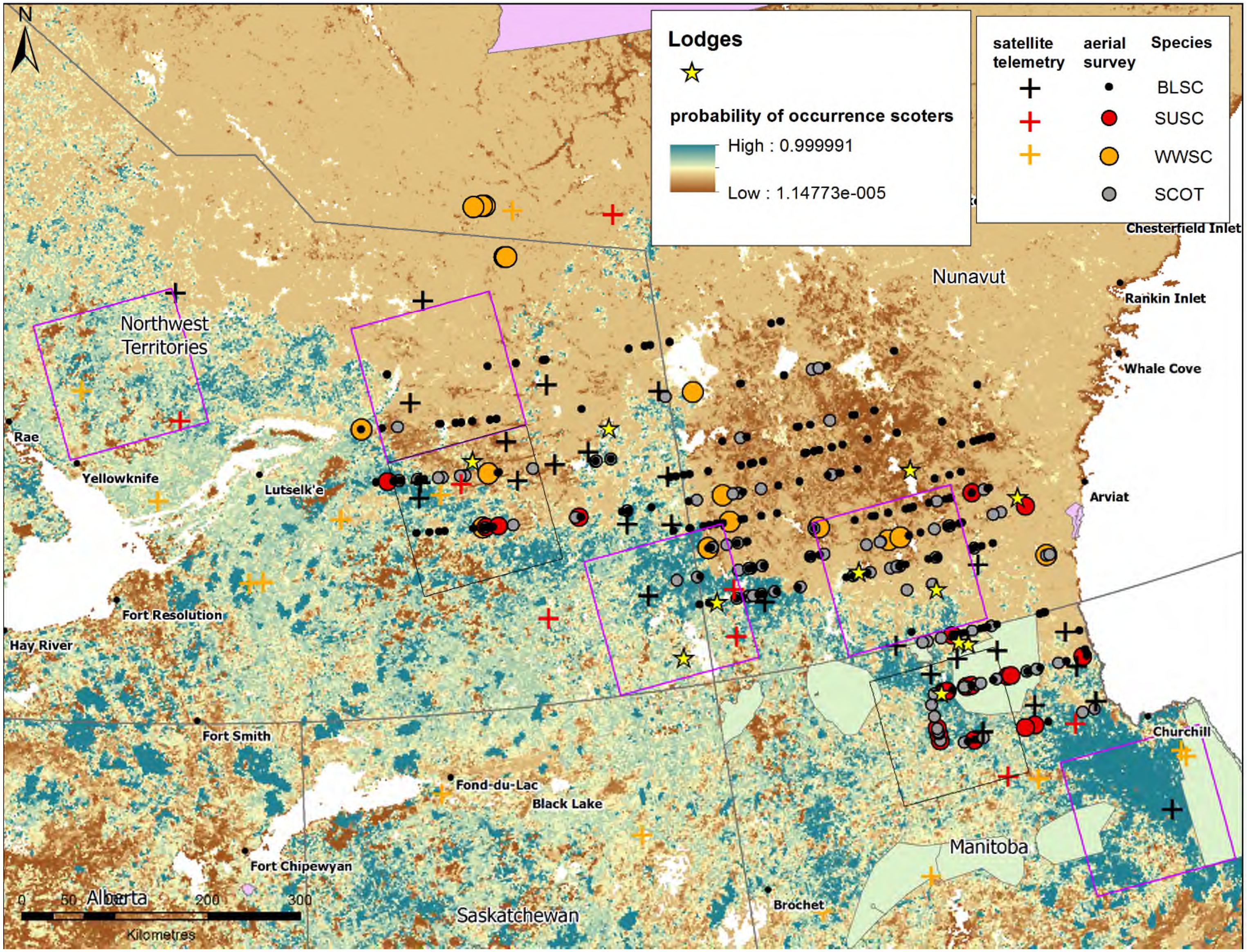

Figure 2. Base map used for site selection. Lynx Lake and Little Duck Lake study areas (black squares) and the potential survey sites for 2018 (purple squares) are overlaid on a map of Northern Canada containing predicted scoter occurrence, locations of birds tracked with satellite transmitters, and observations from fixed-wing surveys (Rhodes et al. 2015). Manitoba Provincial Parks are shown as green polygons.

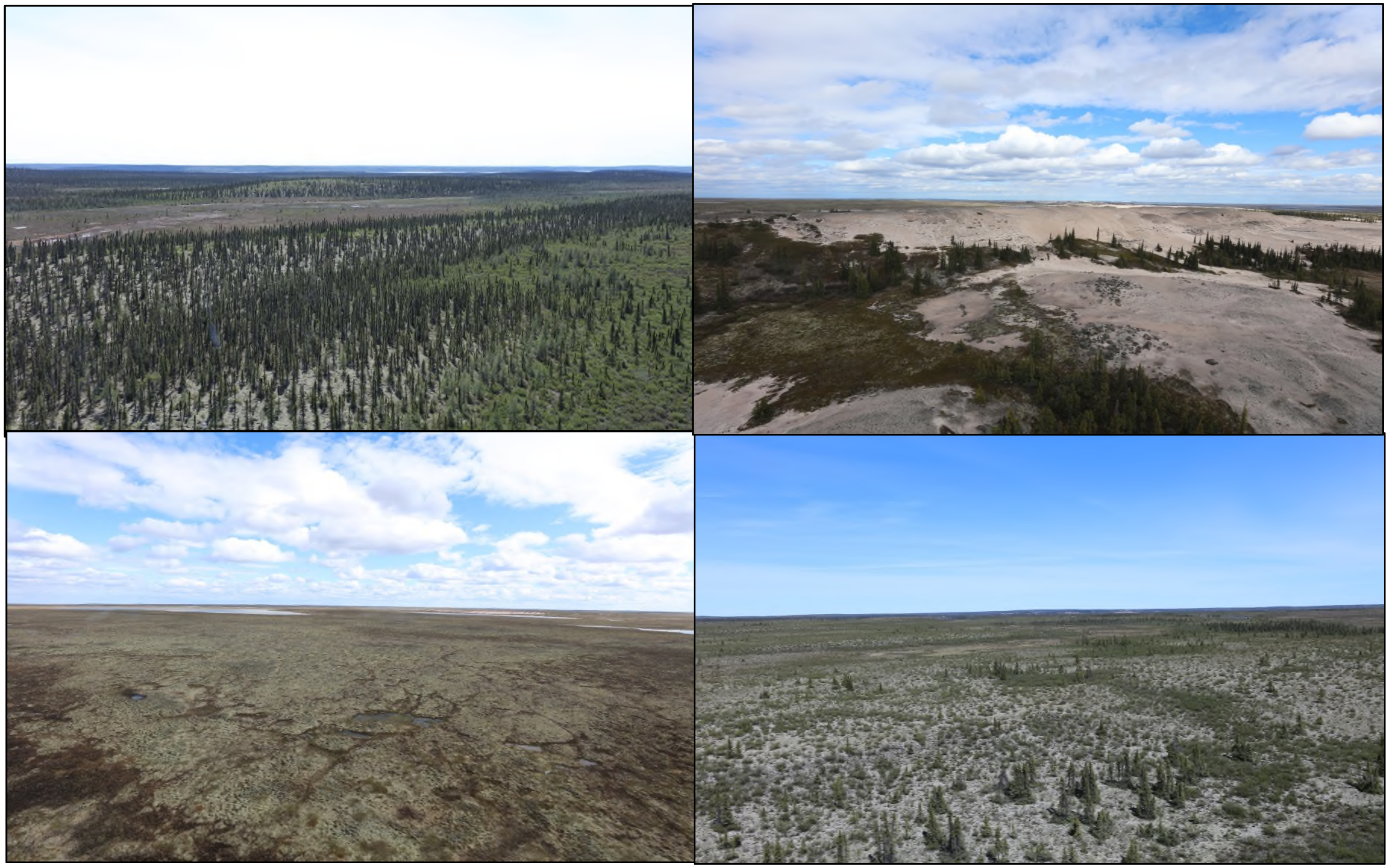

Figure 3. Examples of the range of habitats observed in the Lynx Lake study area surveyed in June 2017, 2018, and 2019.

Figure 4. Examples of the range of habitats observed in the Little Duck Lake, Manitoba study area surveyed in June 2017.

Figure 5. Examples of the range of habitats observed in the Ramparts River Wetlands study area surveyed in June 2017.

Figure 6. Examples of the range of habitats observed in the Yellowknife study area surveyed in June 2018.

Figure 7. Examples of the range of habitats observed in the North Lynx Lake study area surveyed in June 2019.

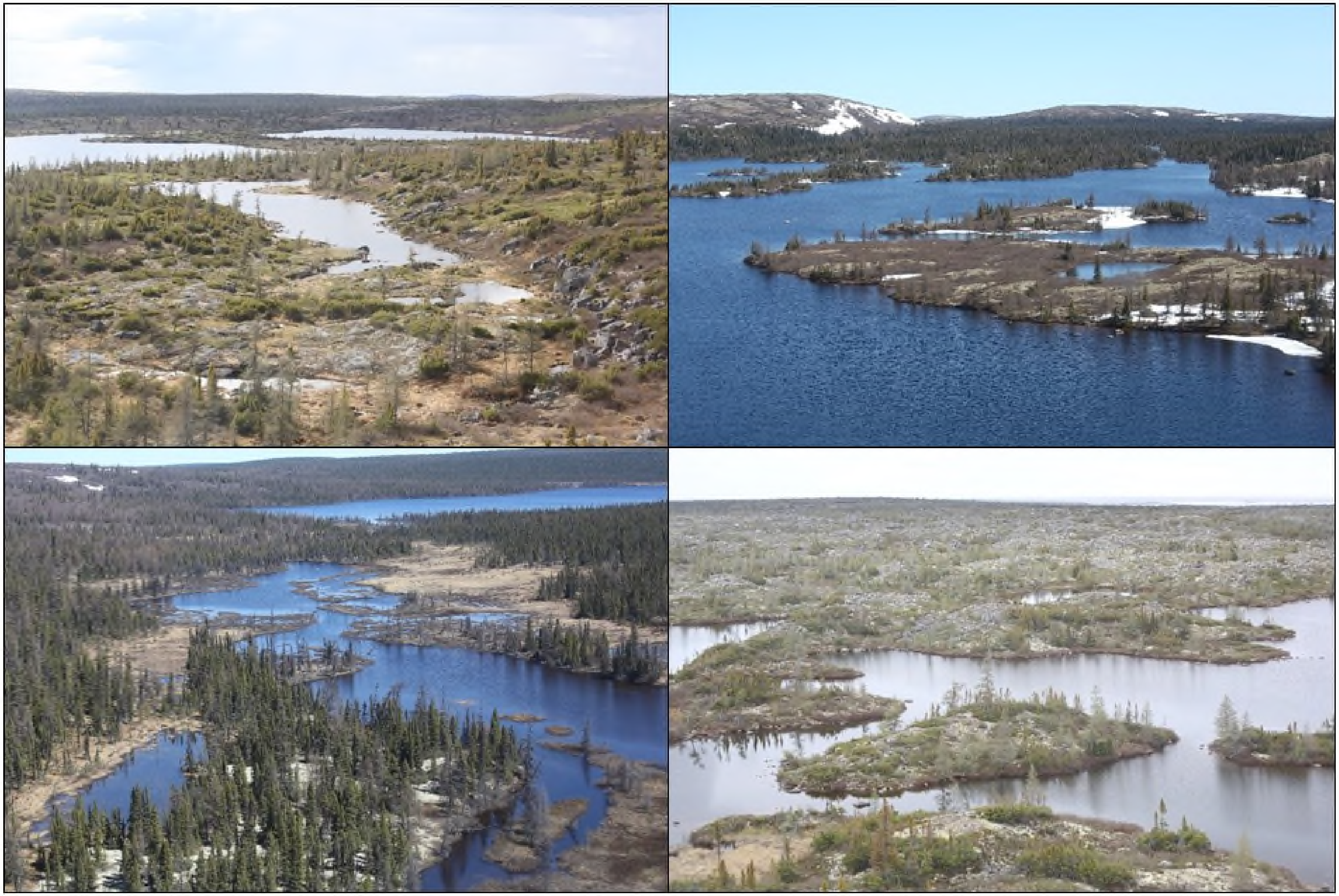

Figure 8. Examples of the range of habitats observed in the George River study area surveyed in June 2019.

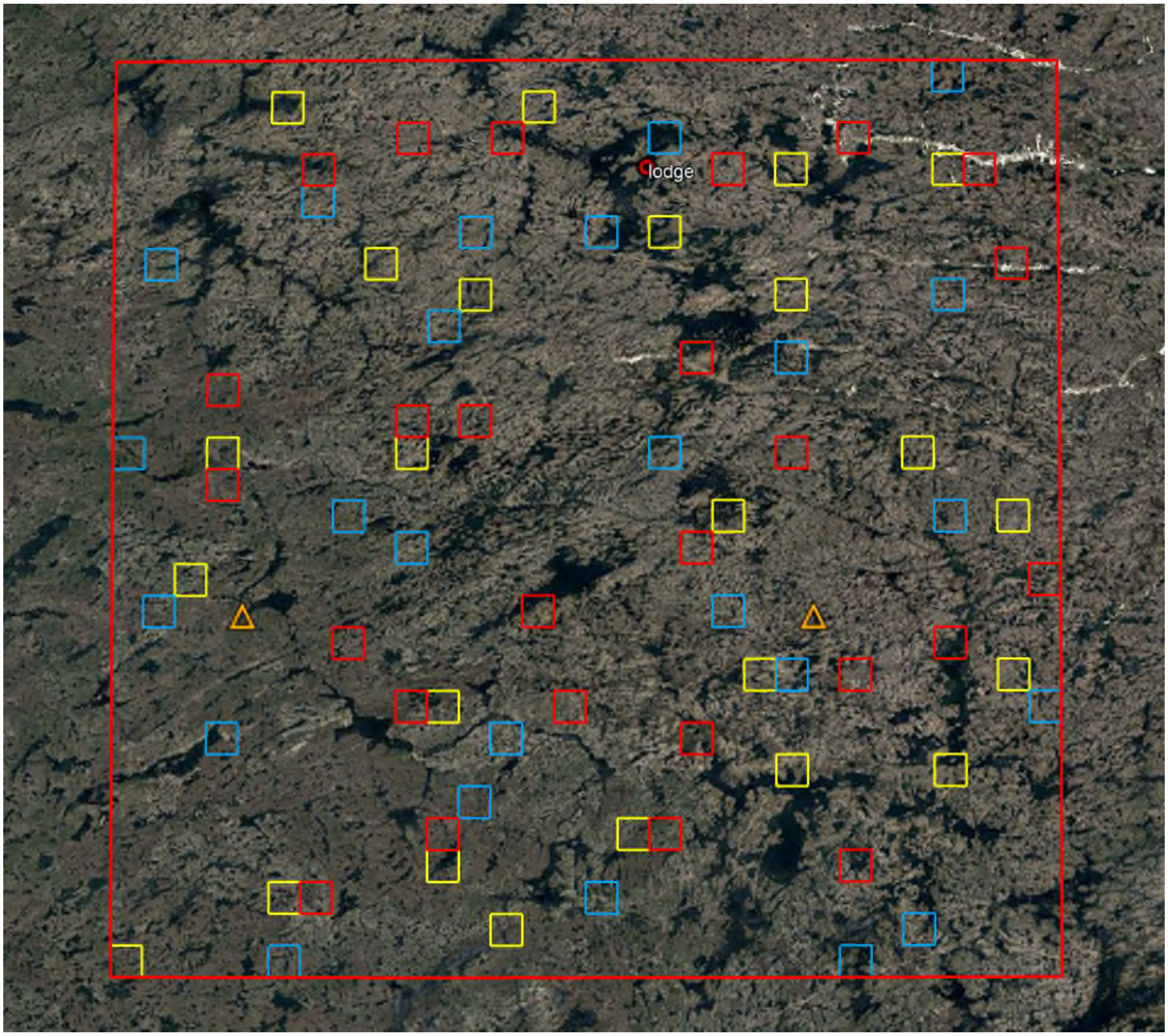

Figure 9. The Lynx Lake survey area in southeastern Northwest Territories, Canada. Red squares (n=26) were surveyed in 2017, blue squares (n=25) in 2018, and yellow squares (n=25) in 2019. Triangles represent fuel caches.

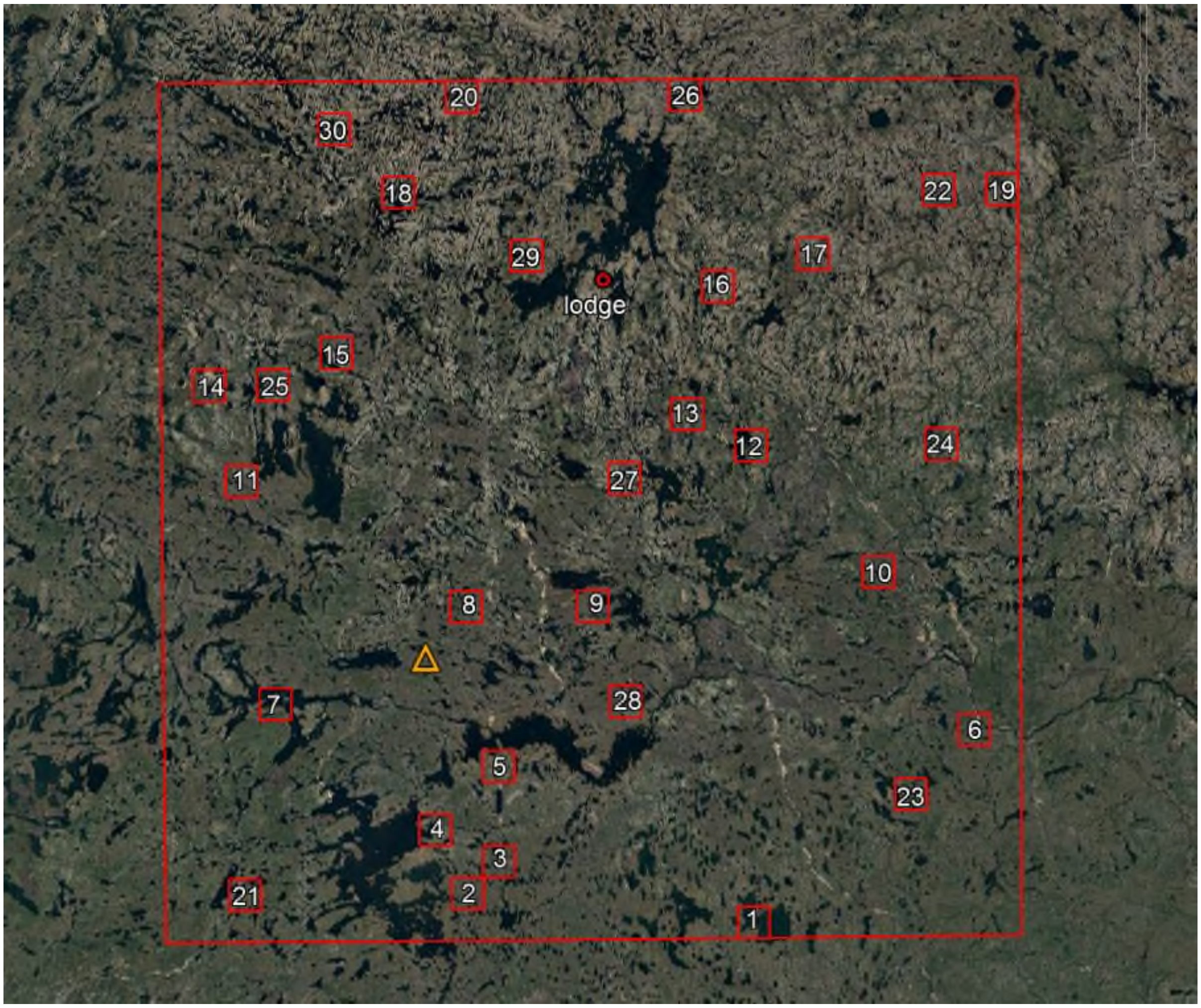

Figure 10. Map of the Little Duck Lake study area in northern Manitoba, Canada. Shown are the basal 20 plots (each 25km^2) and extra ten plots (numbers 21-30) that were to be surveyed provided fuel and time were sufficient. Plots 1 to 24 and 26 were surveyed in June 2017. Fuel was available at the lodge and at one cache indicated by the orange triangle.

Figure 11. The Ramparts River Wetlands study area in northwestern Northwest Territories, Canada. Shown are the 20 plots surveyed in June 2017. Extra plots were not identified for this site. Fuel was available at the community of Fort Good Hope, Northwest Territories.

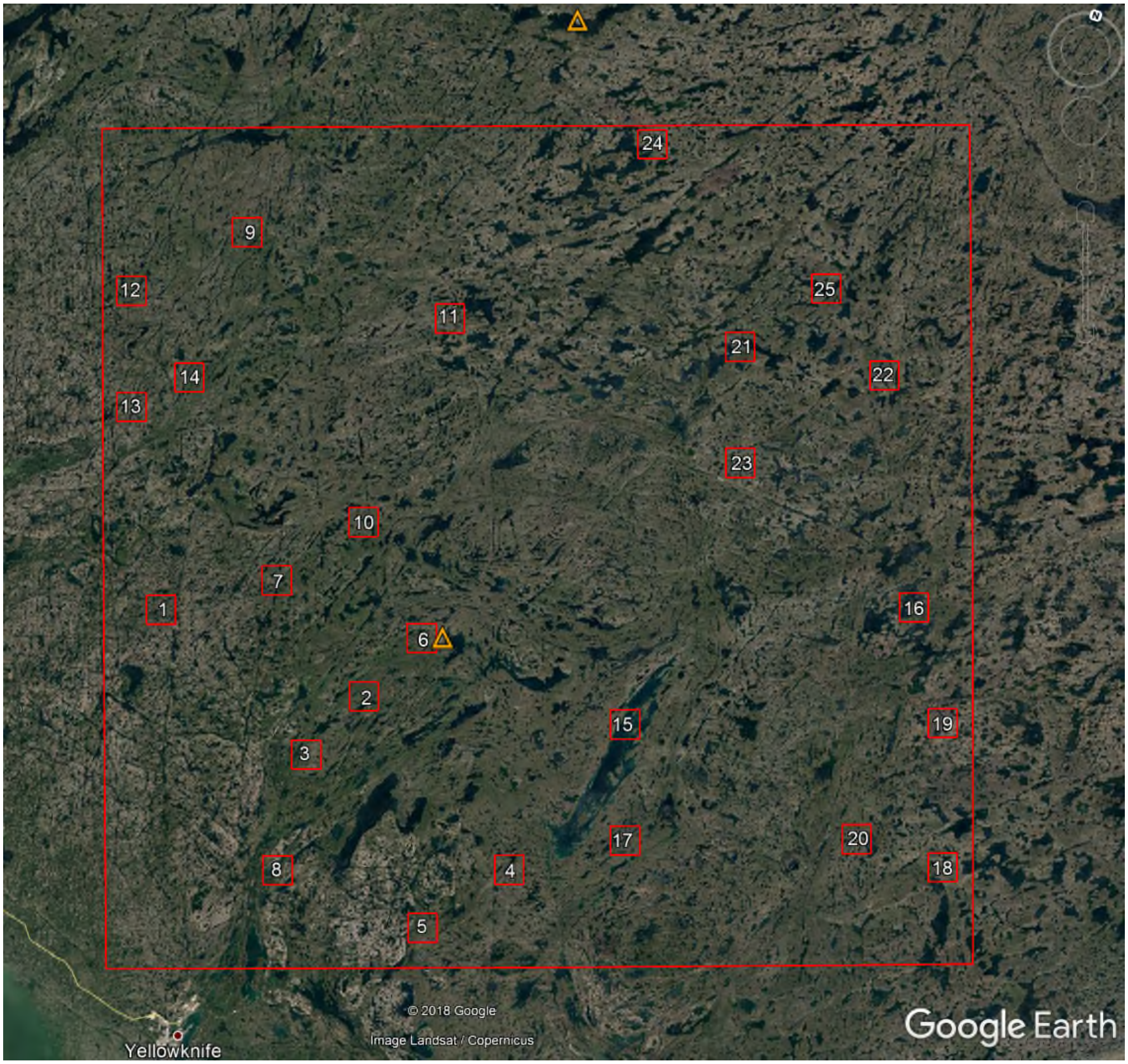

Figure 12. The Yellowknife survey area in central Northwest Territories, Canada. Shown are the 25 plots surveyed in June 2018. Triangles represent fuel caches.

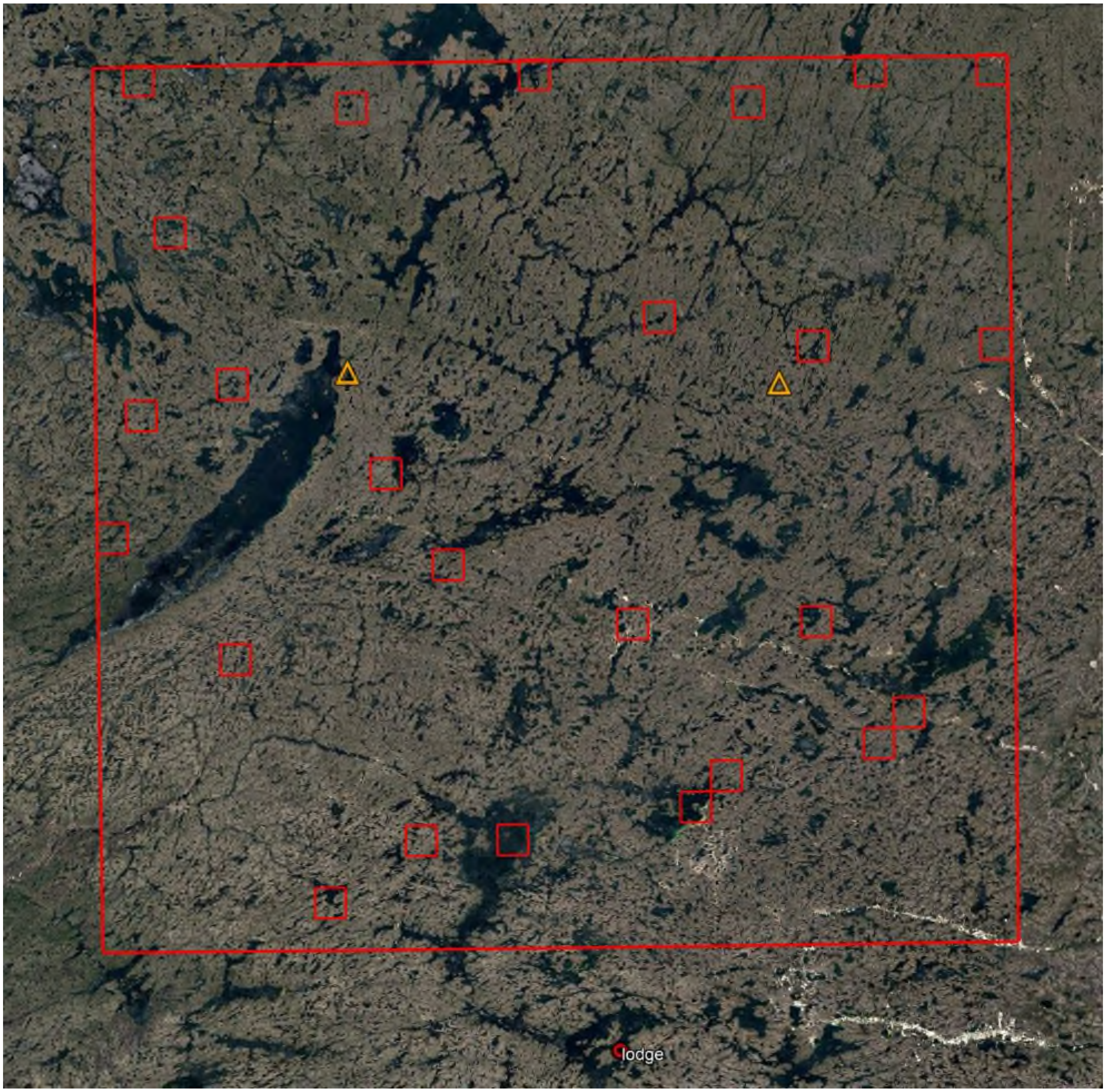

Figure 13. The North Lynx Lake survey area in southeastern Northwest Territories, Canada. Shown are the 25 plots were surveyed in June 2019. Triangles represent fuel caches.

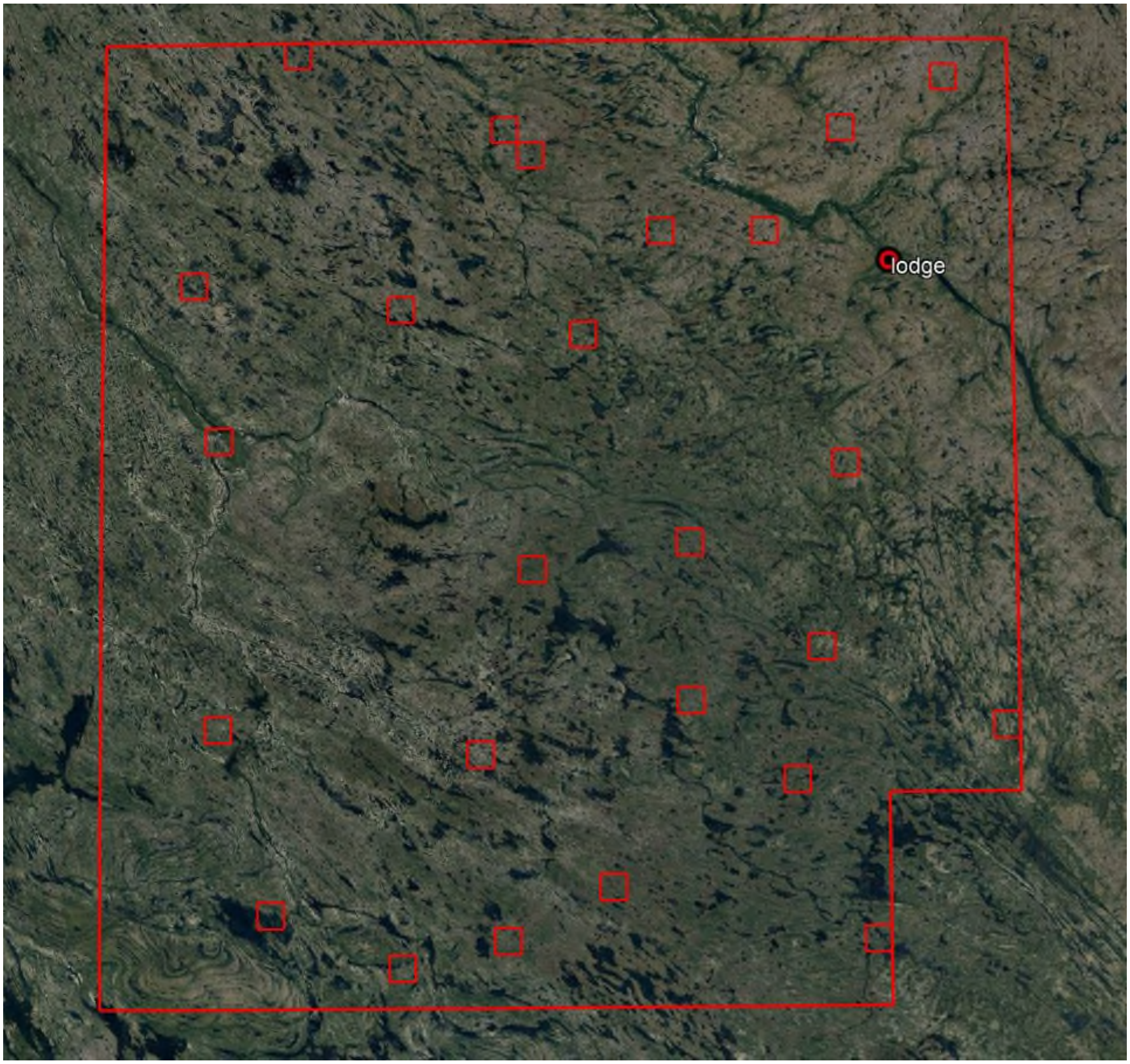

Figure 14. The George River survey area in northern Quebec, Canada. Shown are the 25 plots were surveyed in June 2019.

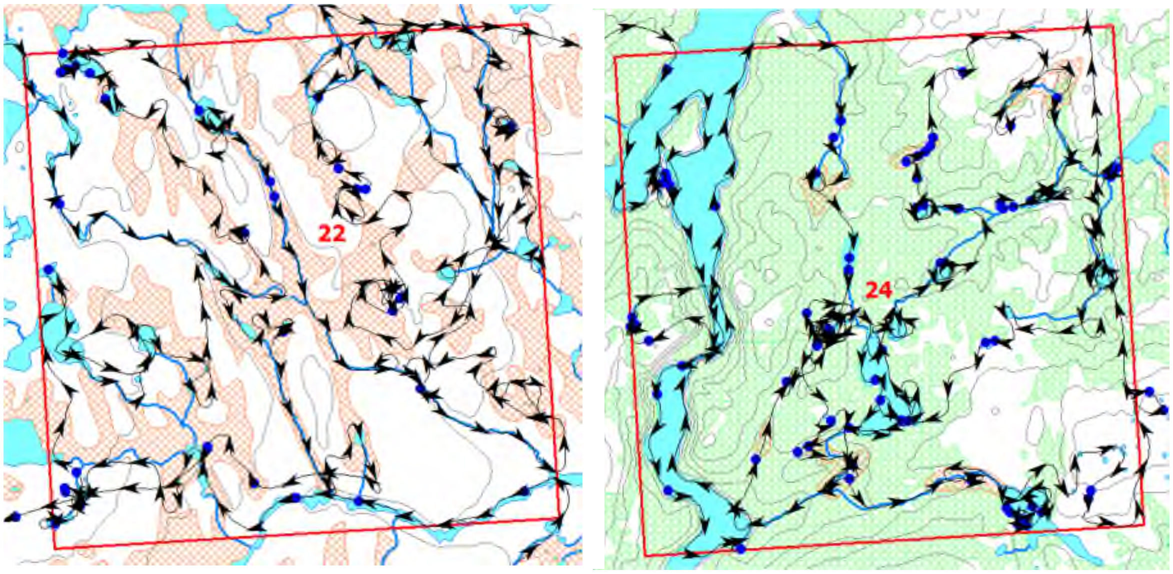

Figure 15. Examples of helicopter flight paths for plot numbers 22 and 24 (each 25 km^2) with recorded observations (blue points) at the Little Duck Lake study area in Manitoba.

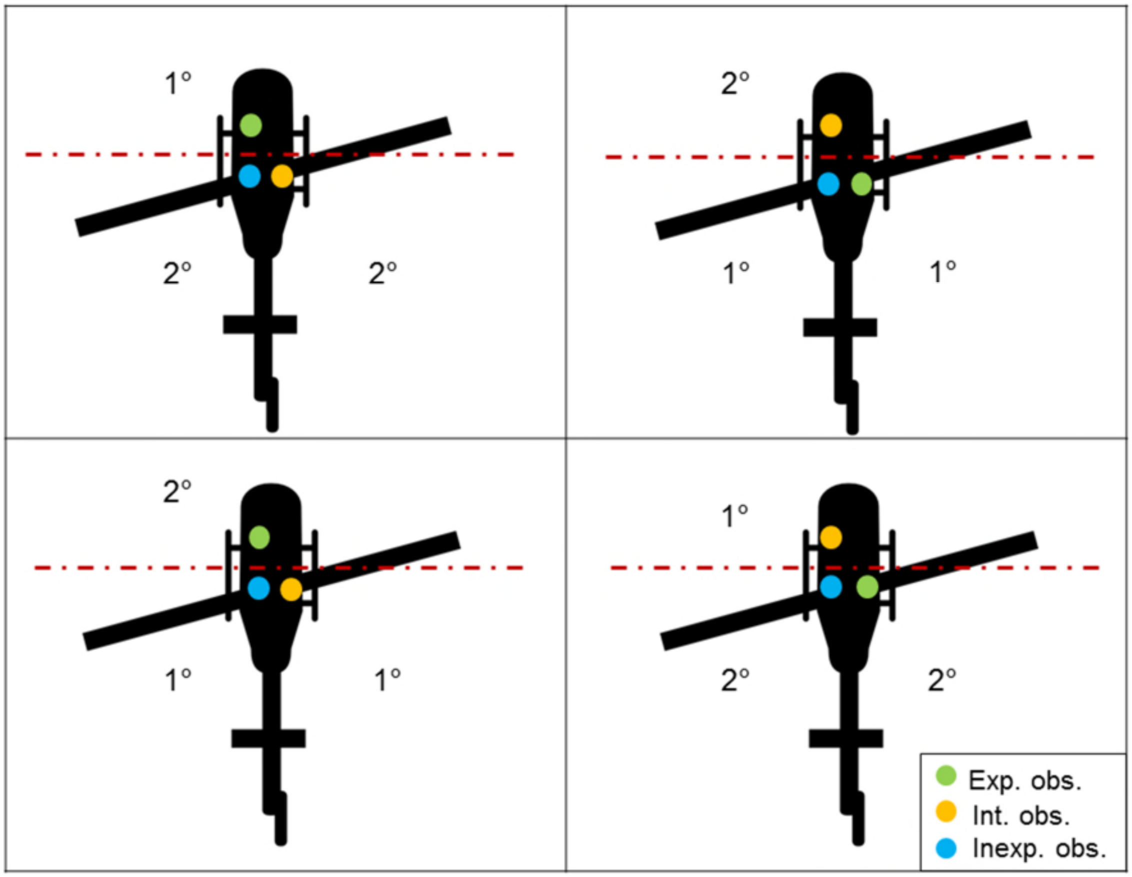

Figure 16. Schematic showing seat and detection configurations in the helicopter. Each of the four possible configurations was repeated an approximately equal amount of times at all 2017 study areas. Pilots were seated in the front right seat and assisted with detections if comfortable doing so while maneuvering the aircraft.

Figure 17. Examples of scoters observed from the helicopter; two male White-winged Scoters (*Melanitta fusca*; A), two male Surf Scoter (*Melanitta perspicillata*; B) and one pair of Black Scoters (*Melanitta americana*) accompanied by a pair of Hooded Mergansers (*Lophodytes cucullatus*; C).

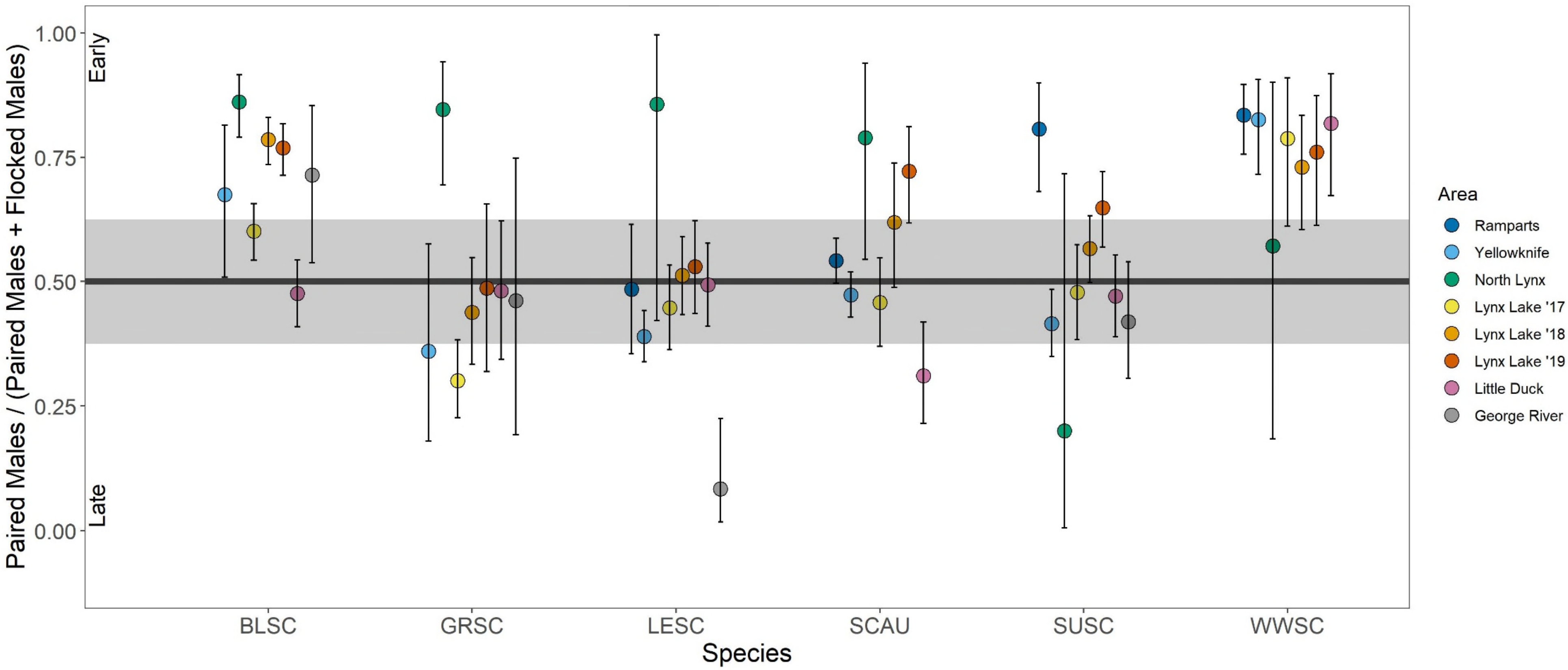

Figure 18: Phenology Index (0-1) for focal waterfowl species, by study site and year.

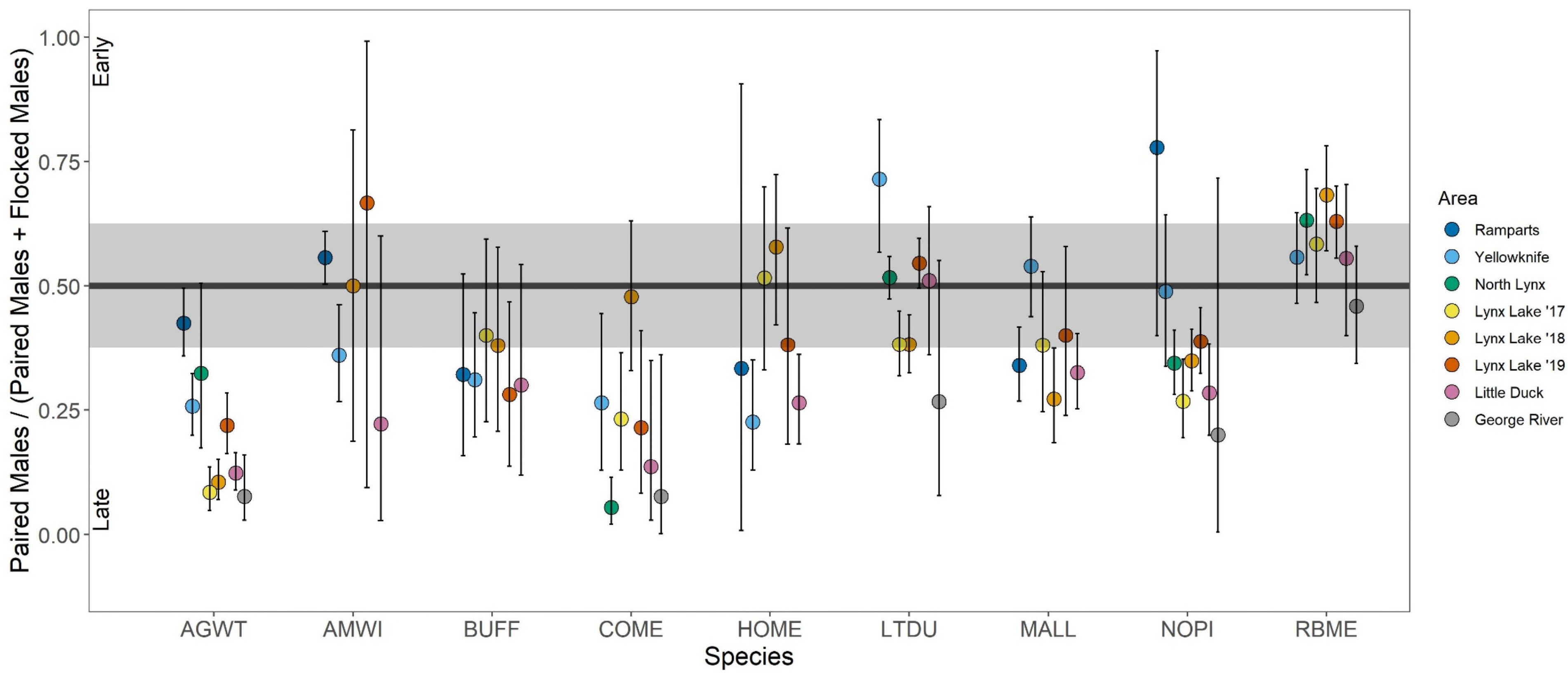

Figure 19: Phenology Index (0-1) for non-focal waterfowl species, by study site and year.

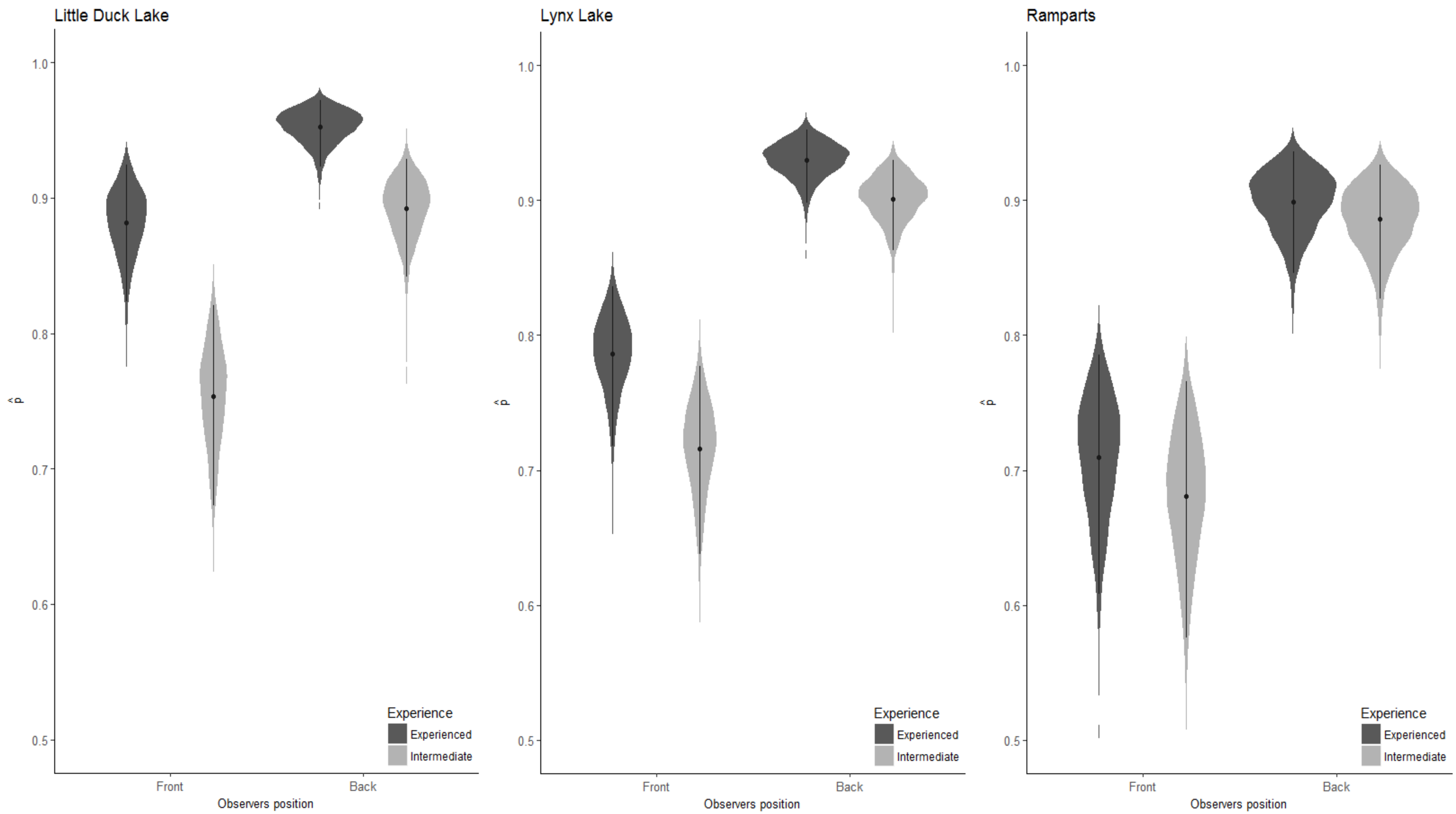

Figure 20. Predicted detection probability by observer and seat position in the helicopter for each of the three sites surveyed in 2017. Inexperienced observers were always seated in the rear of the helicopter paired with either the experienced or intermediate observer. Error bars represent upper and lower 95% Bayesian credible intervals.

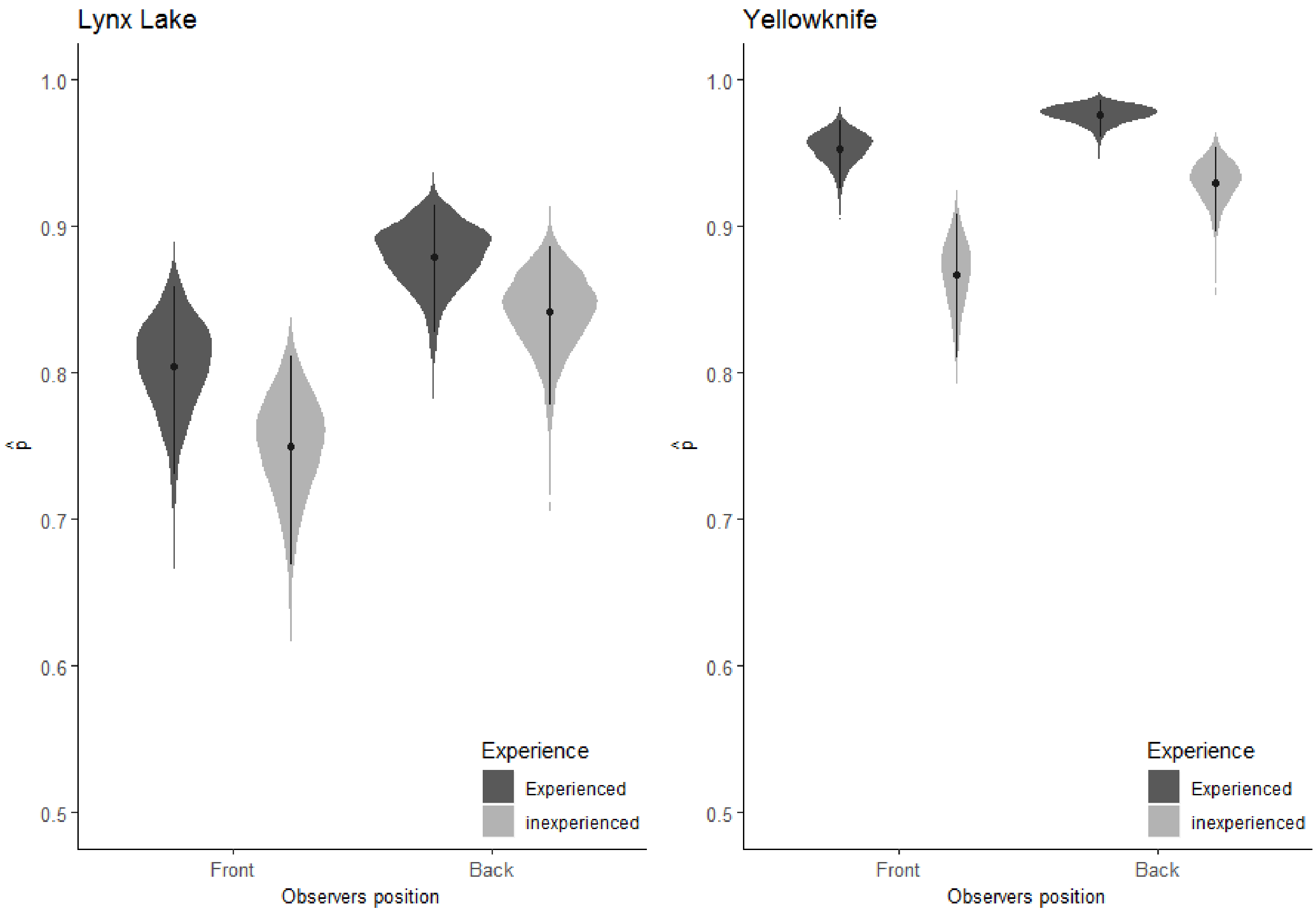

Figure 21. Predicted detection probability by observer and seat position in the helicopter for each of the two sites surveyed in 2018. Inexperienced observers were always seated in the rear of the helicopter paired with either the experienced or intermediate observer. Error bars represent upper and lower 95% Bayesian credible intervals.

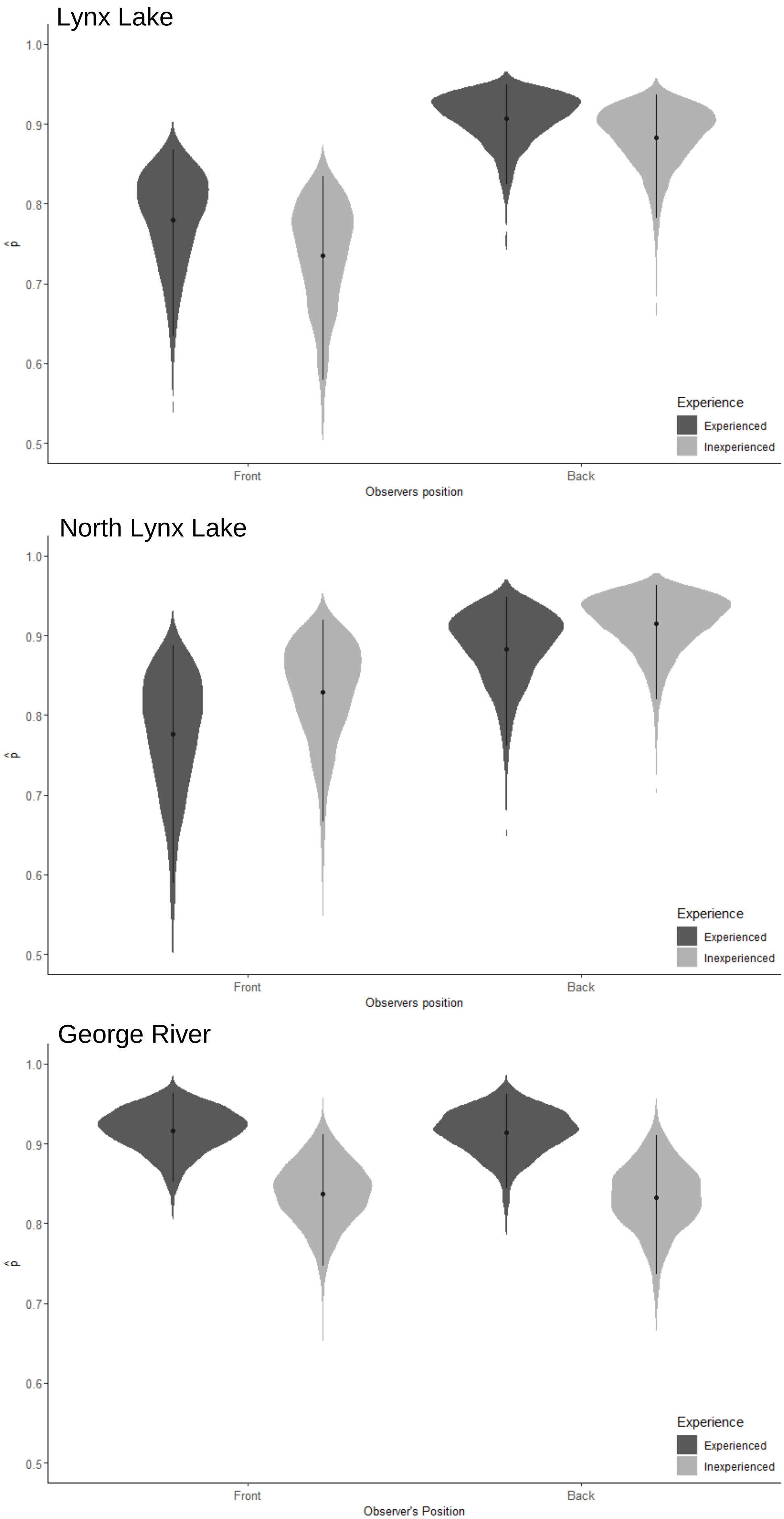

Figure 22. Predicted detection probability by observer and seat position in the helicopter for each of the three sites surveyed in 2019. Inexperienced observers were always seated in the rear of the helicopter paired with either the experienced or intermediate observer. Error bars represent upper and lower 95% Bayesian credible intervals.

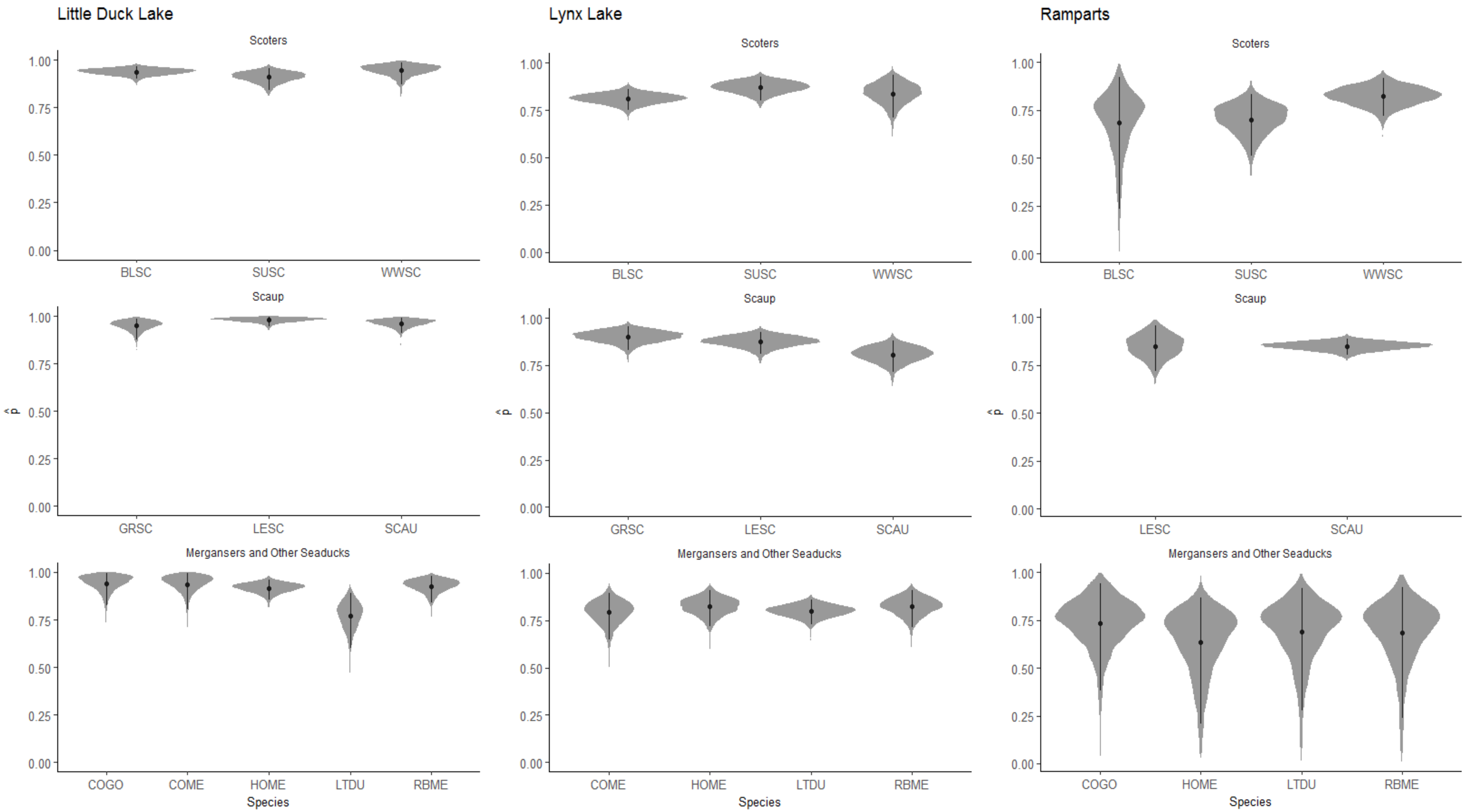

Figure 23. Predicted detection probability by species for each of the Little Duck Lake, Lynx Lake and Ramparts sites surveyed in 2017. Error bars represent upper and lower 95% Bayesian credible intervals.

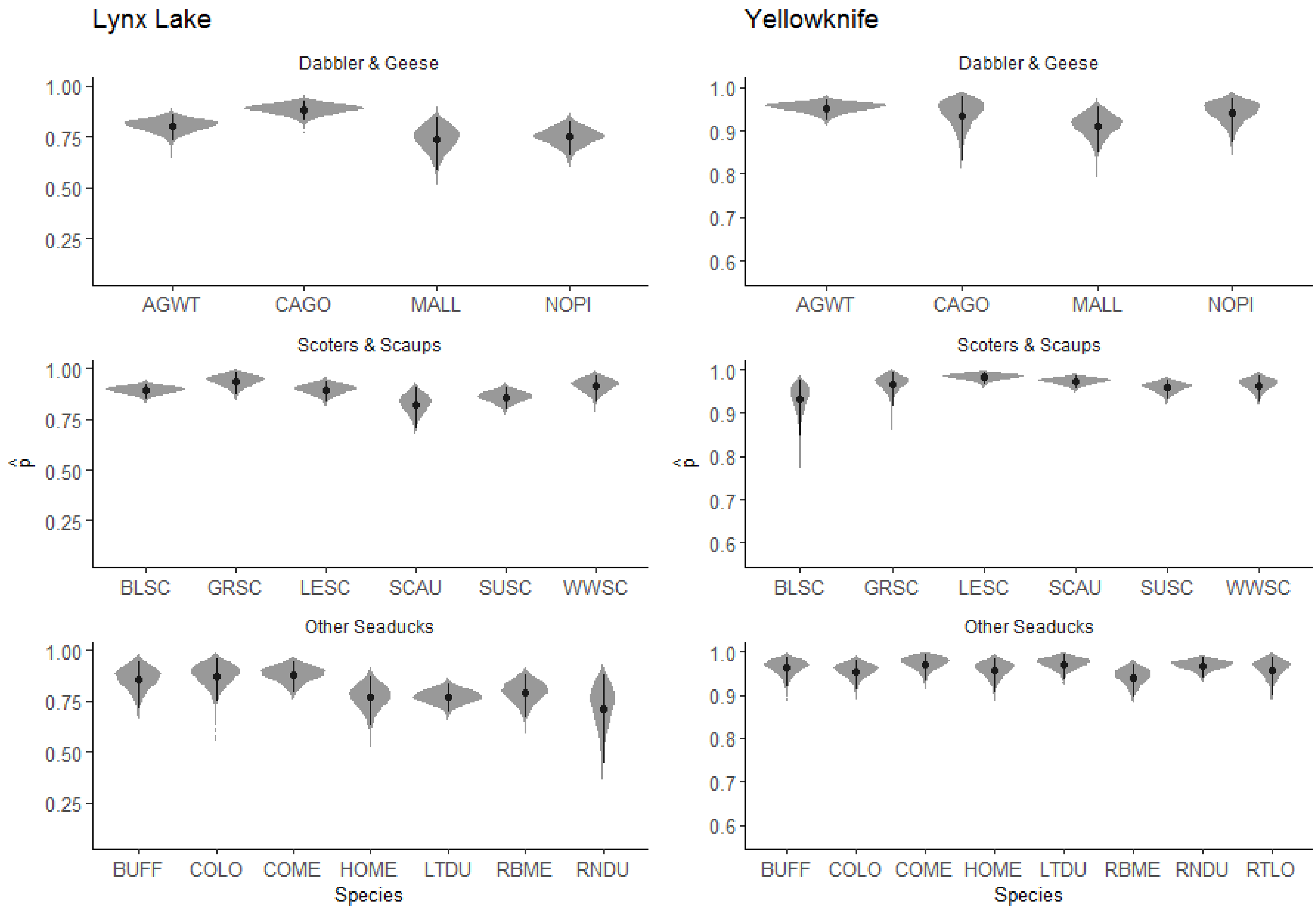

Figure 24. Predicted detection probability by species for each of the two sites surveyed in 2018. Error bars represent upper and lower 95% Bayesian credible intervals.

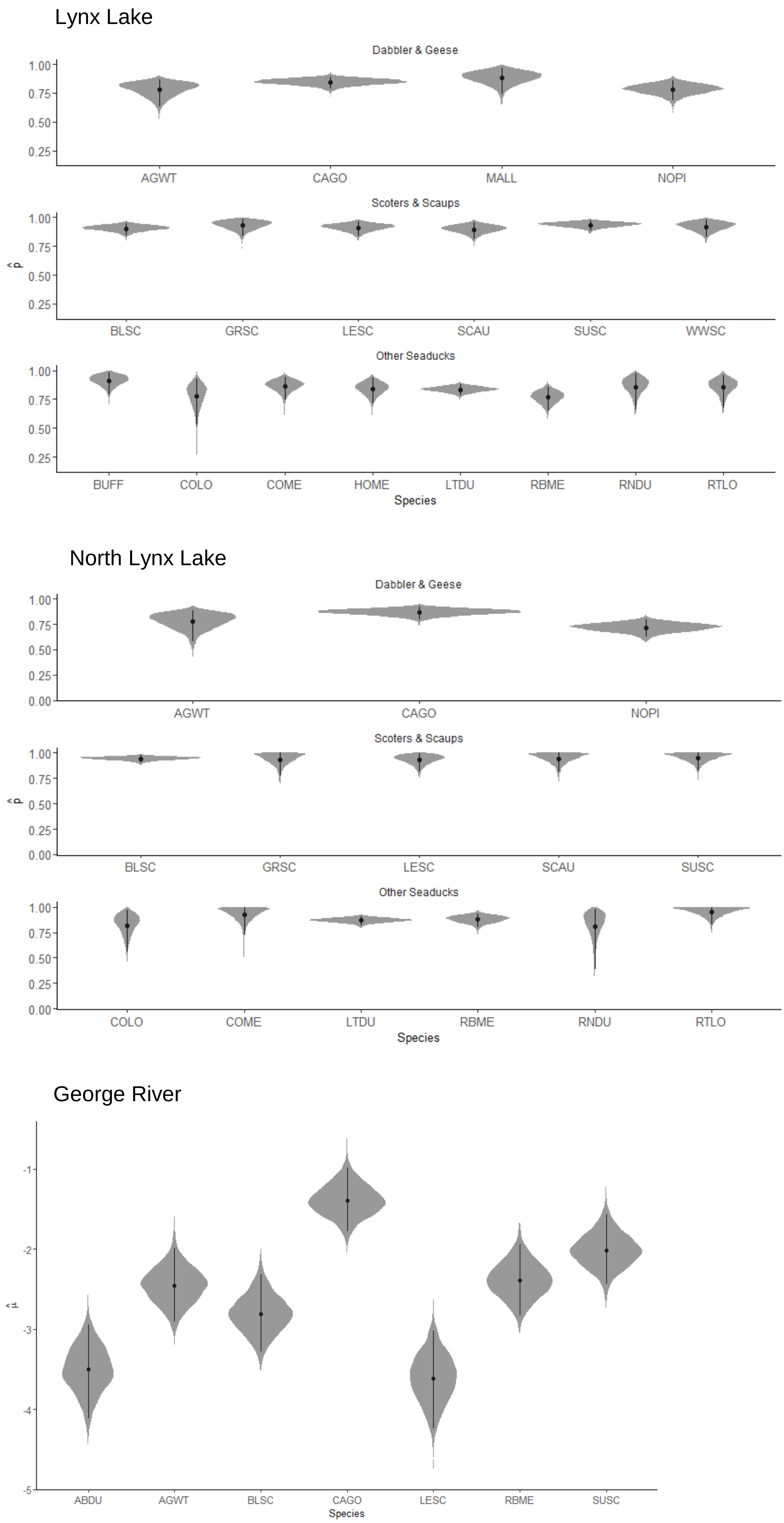

Figure 25. Predicted detection probability by species for each of the three sites surveyed in 2018. Error bars represent upper and lower 95% Bayesian credible intervals.

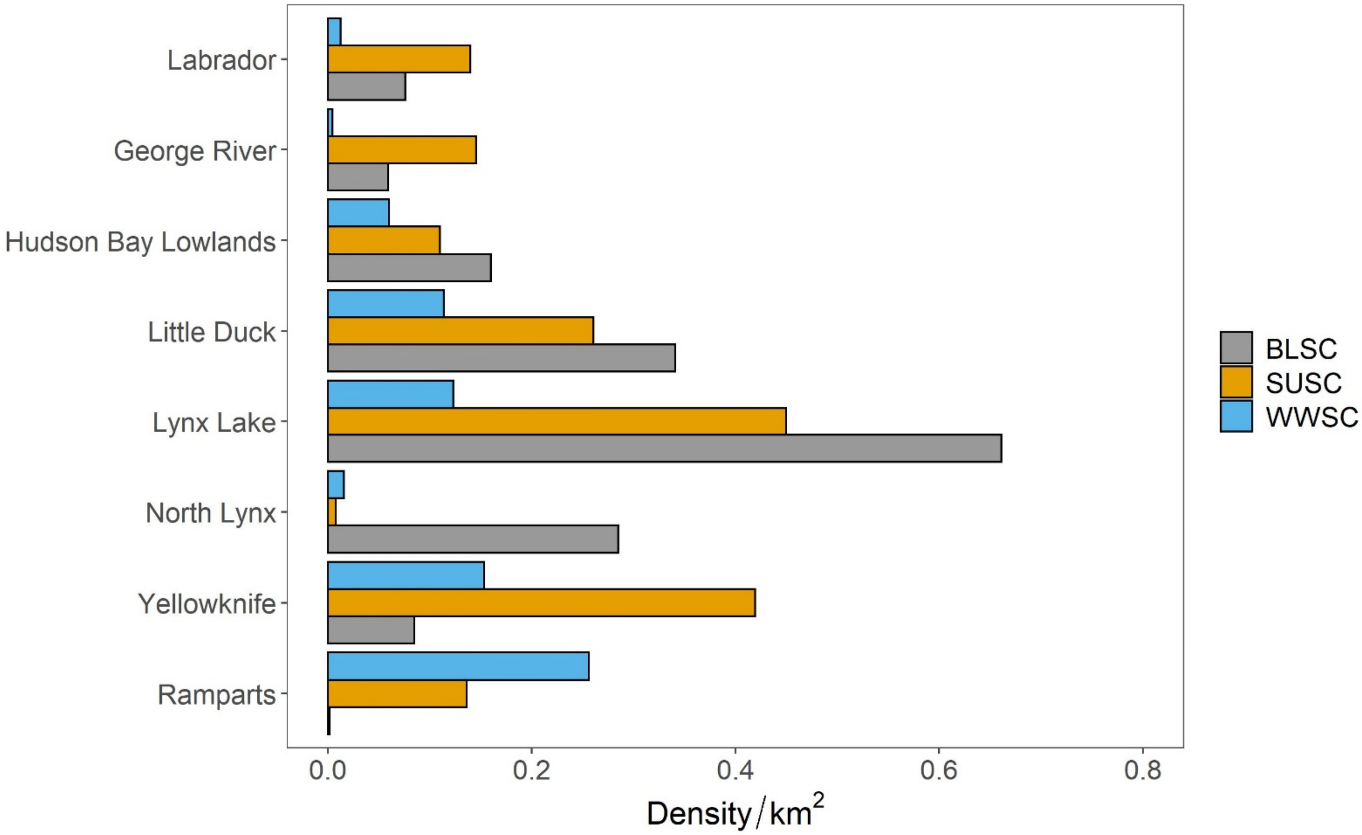

Figure 26. Density per km^2 (uncorrected for detection probability) for White-winged (*Melanitta fusca;*WWSC), Surf (*M. perspicillata;* SUSC) and Black Scoters (*M. Americana;* BLSC) across the six sites surveyed from 2017-2019 (Ramparts, Yellowknife, Lynx Lake, North Lynx, Little Duck, and George River). Density per km^2 for Labrador (surveyed 2009) were taken from Gilliland et al. (2010) and density for the Hudson Bay Lowlands, Ontario (surveyed 2009) were derived from Brook et al. (2012).

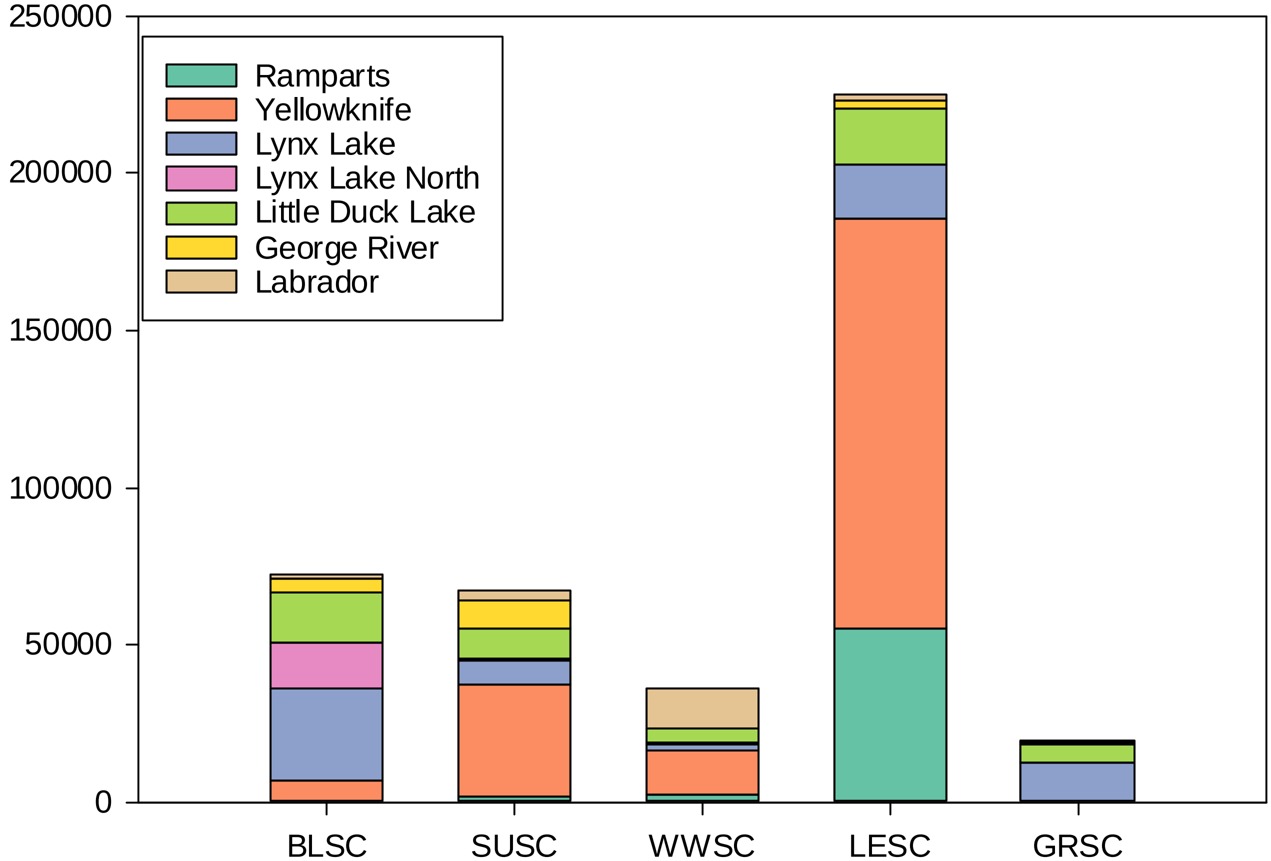

Figure 27. Population size estimates (corrected for detection) for scoters (*Melanitta* spp.) and scaup (*Aythya* spp.) at all 6 study sites (Ramparts, Yellowknife, Lynx Lake, Lynx Lake North, Little Duck Lake, and George River). Population size estimates for Labrador data (projected to a surface area of 21,750km^2 to allow for direct comparison to other sites) were calculated from the Gilliland et al. (2010).

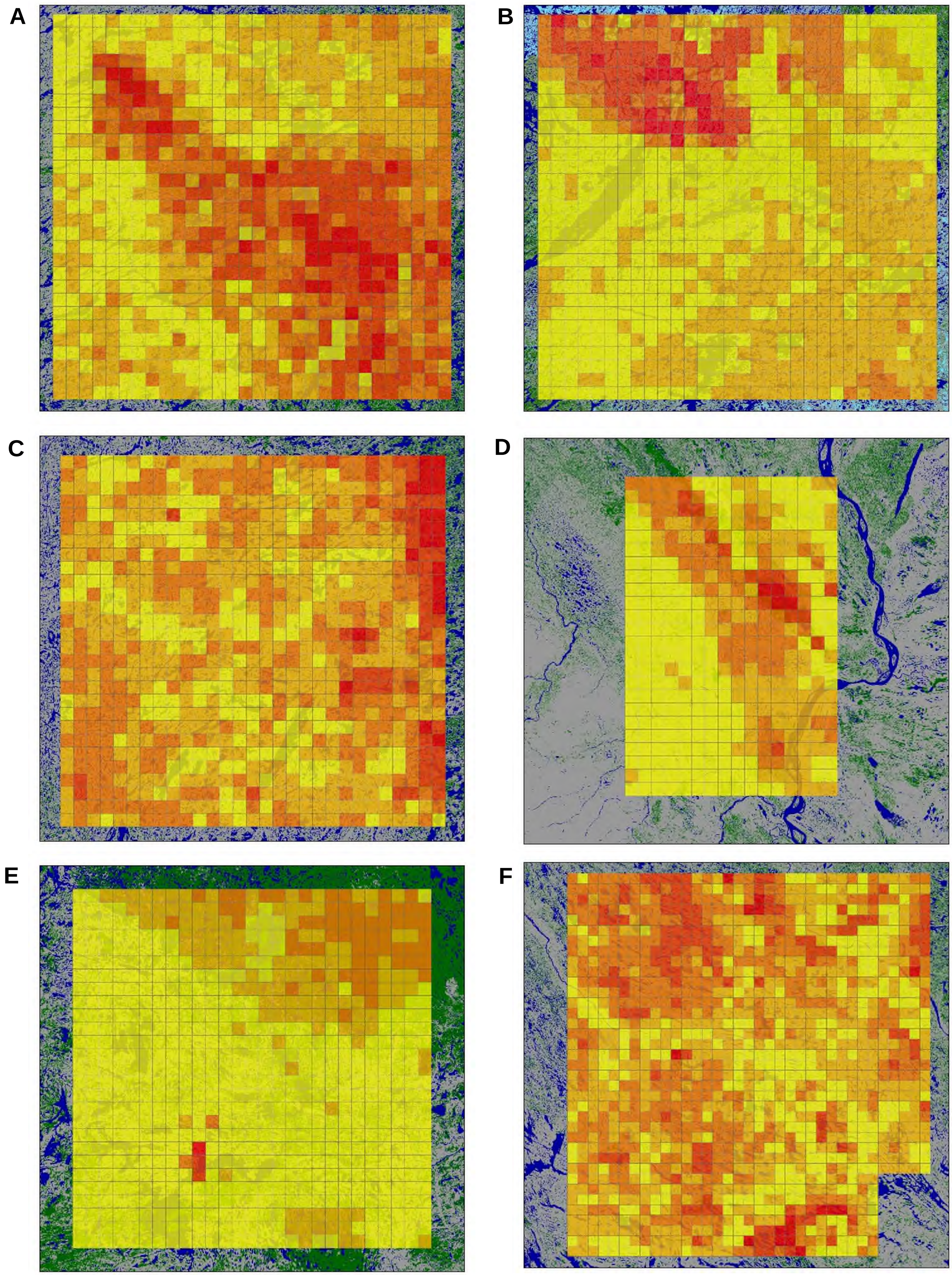

Figure 28. Map of predicted Black Scoter (*Melanitta americana*) breeding pair density (pairs per km^2) at A) Lynx Lake, B) North Lynx Lake, C) Yellowknife, D) Ramparts, E) Little Duck, and F) George River using habitat relationships from the best performing model generated from the 2017-2019 survey data.

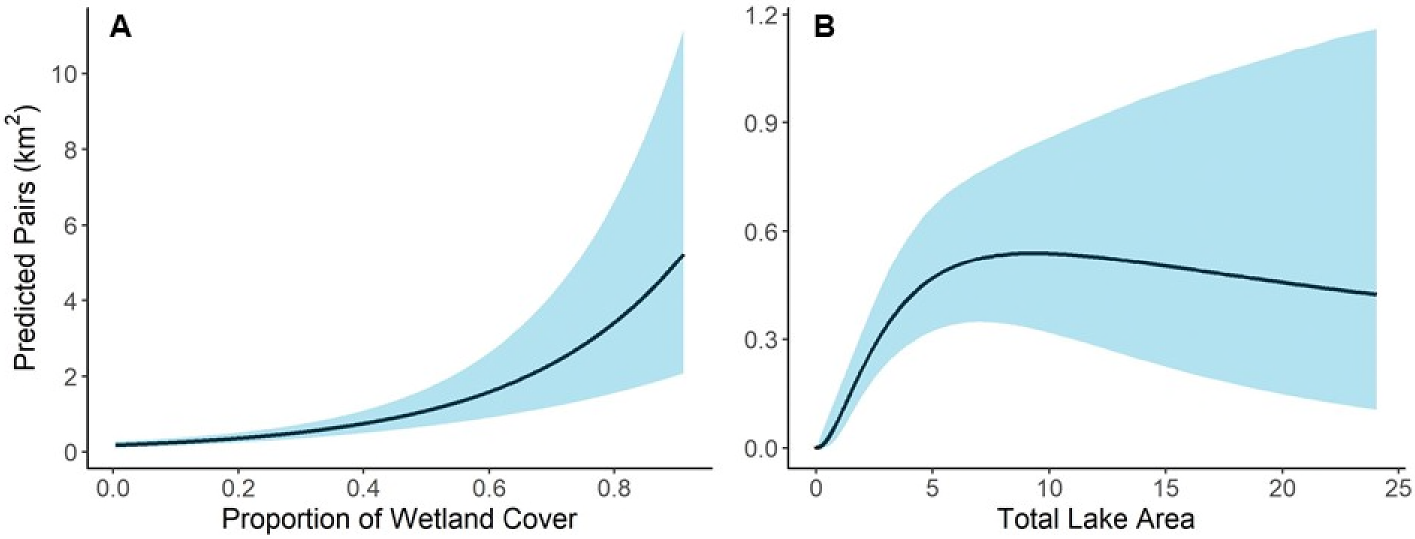

Figure 29. Relationships between the predicted number of Black Scoter (*Melanitta americana*) breeding pairs per square kilometer (± 95 % Bayesian Credible Interval) and (A) the proportion of wetland cover, (B) total lake area. Relationships estimated using the best-approximating habitat model.

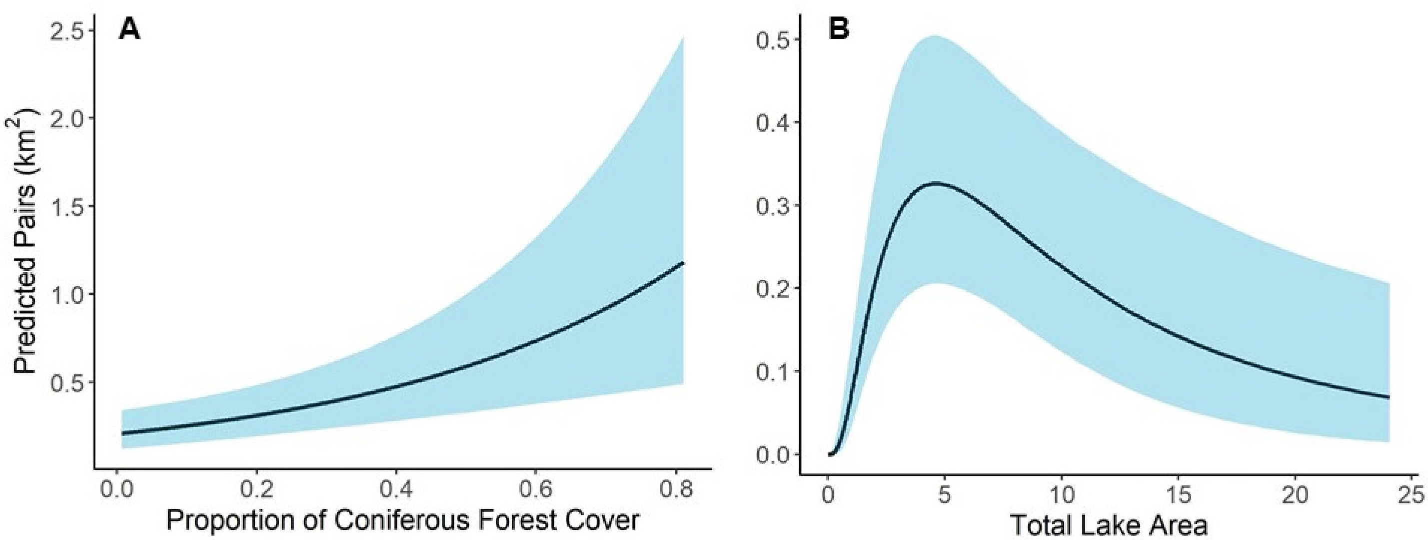

Figure 30. Relationships between the predicted number of Surf Scoter (*Melanitta perspicillata*) breeding pairs per square kilometer (± 95 % Bayesian Credible Interval) and (A) the proportion of coniferous forest, (B) total lake area. Relationships estimated using the best-approximating habitat model.

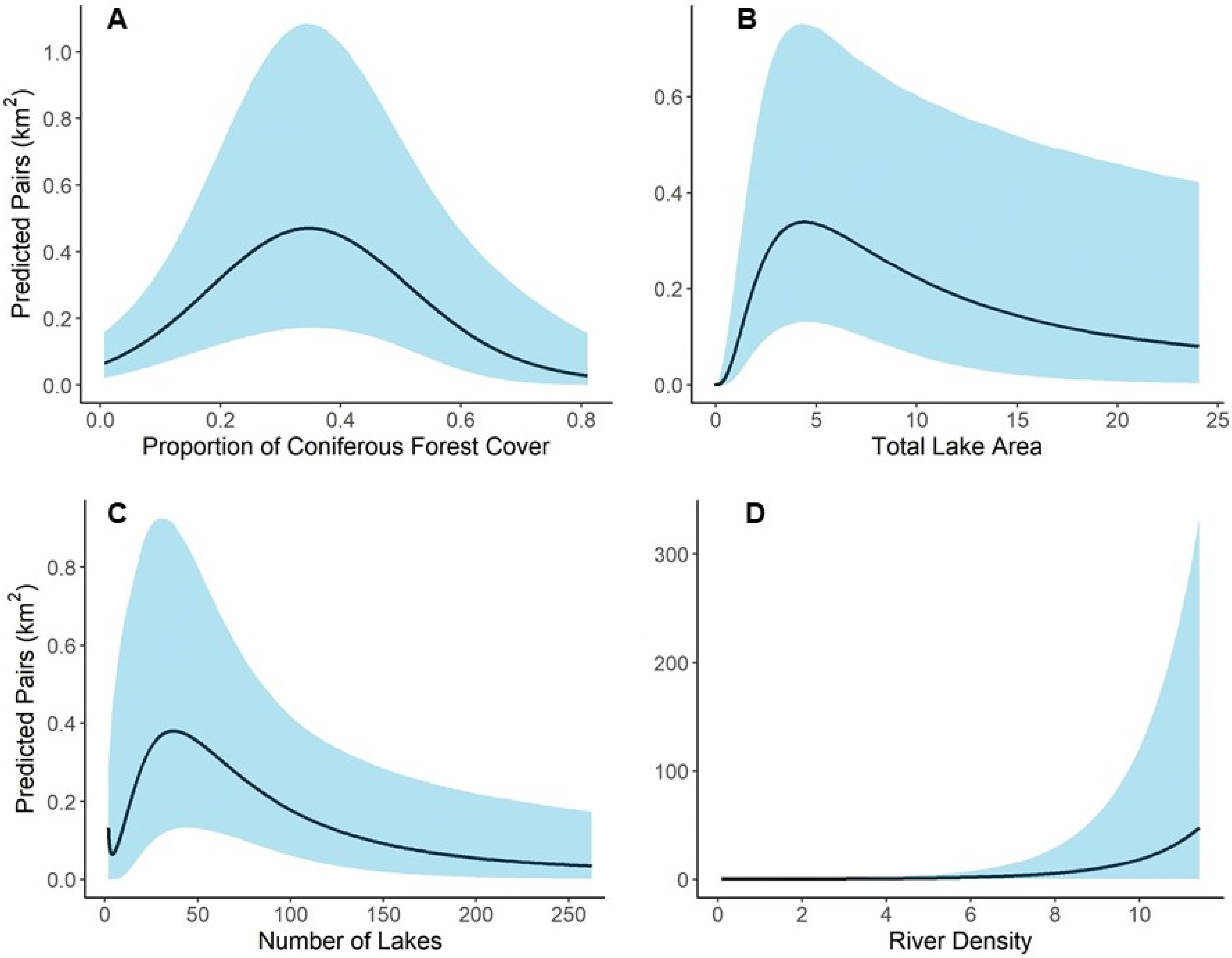

Figure 31. Relationships between the predicted number of White-winged Scoter (*Melanitta deglandi*) breeding pairs per square kilometer (± 95 % Bayesian Credible Interval) and (A) the proportion of coniferous forest, (B) total lake area, (C) the number of lakes on plot, and (D) river density. Relationships estimated using the best-approximating habitat model.

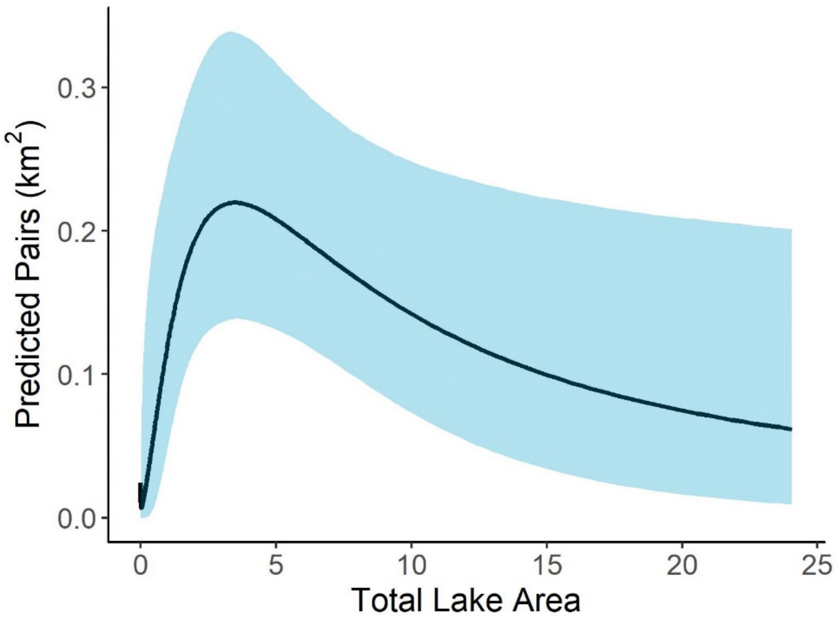

Figure 32. Relationships between the predicted number of Greater Scaup (*Aythya marila*) breeding pairs per square kilometer (± 95 % Bayesian Credible Interval) and total lake area. Relationships estimated using the best-approximating habitat model.

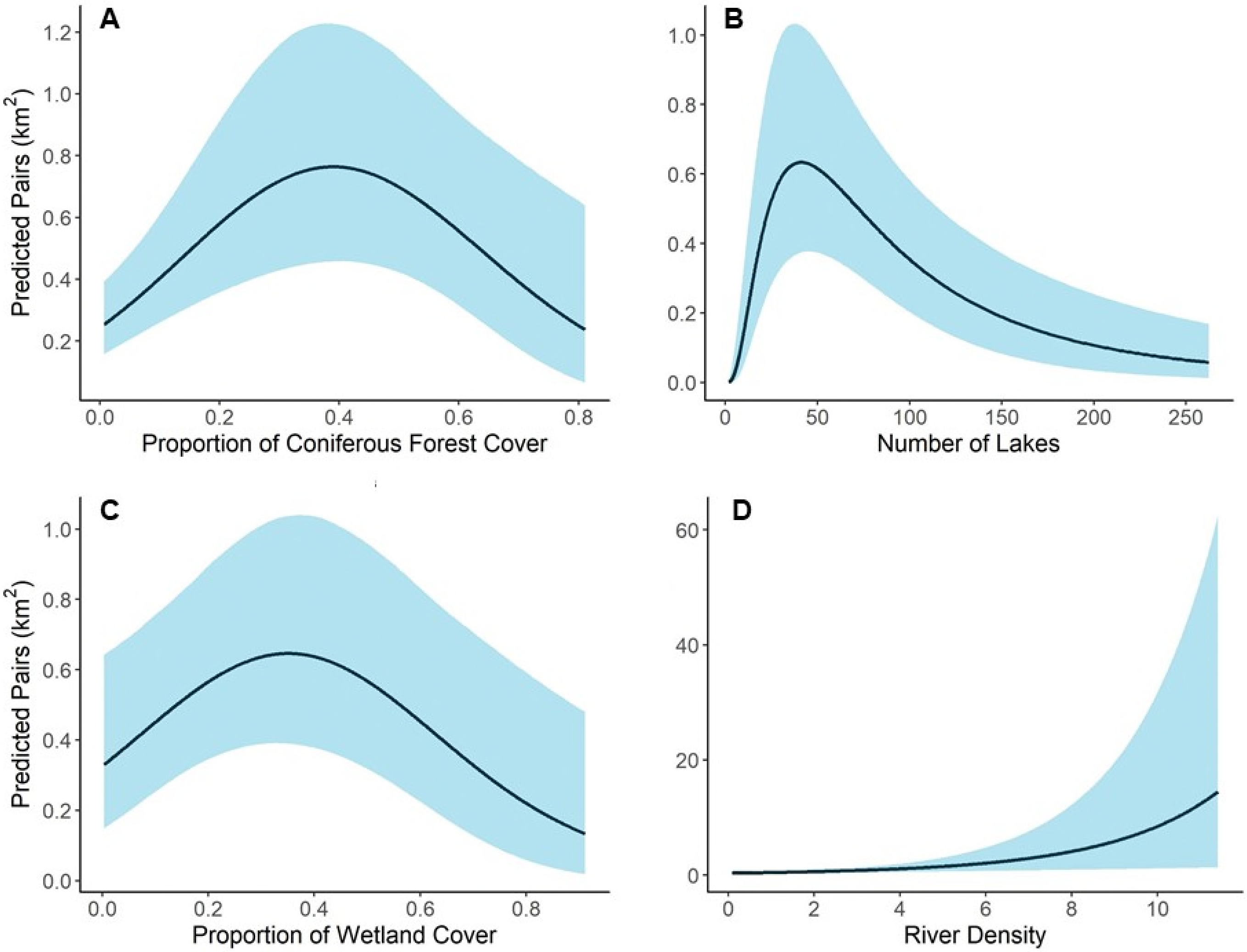

Figure 33. Relationships between the predicted number of Lesser Scaup (*Aythya affinis*) breeding pairs per square kilometer (± 95 % Bayesian Credible Interval) and (A) the proportion of coniferous forest, (B) the number of lakes on plot, (C) the proportion of wetland cover, and (D) river density. Relationships estimated using the best-approximating habitat model.

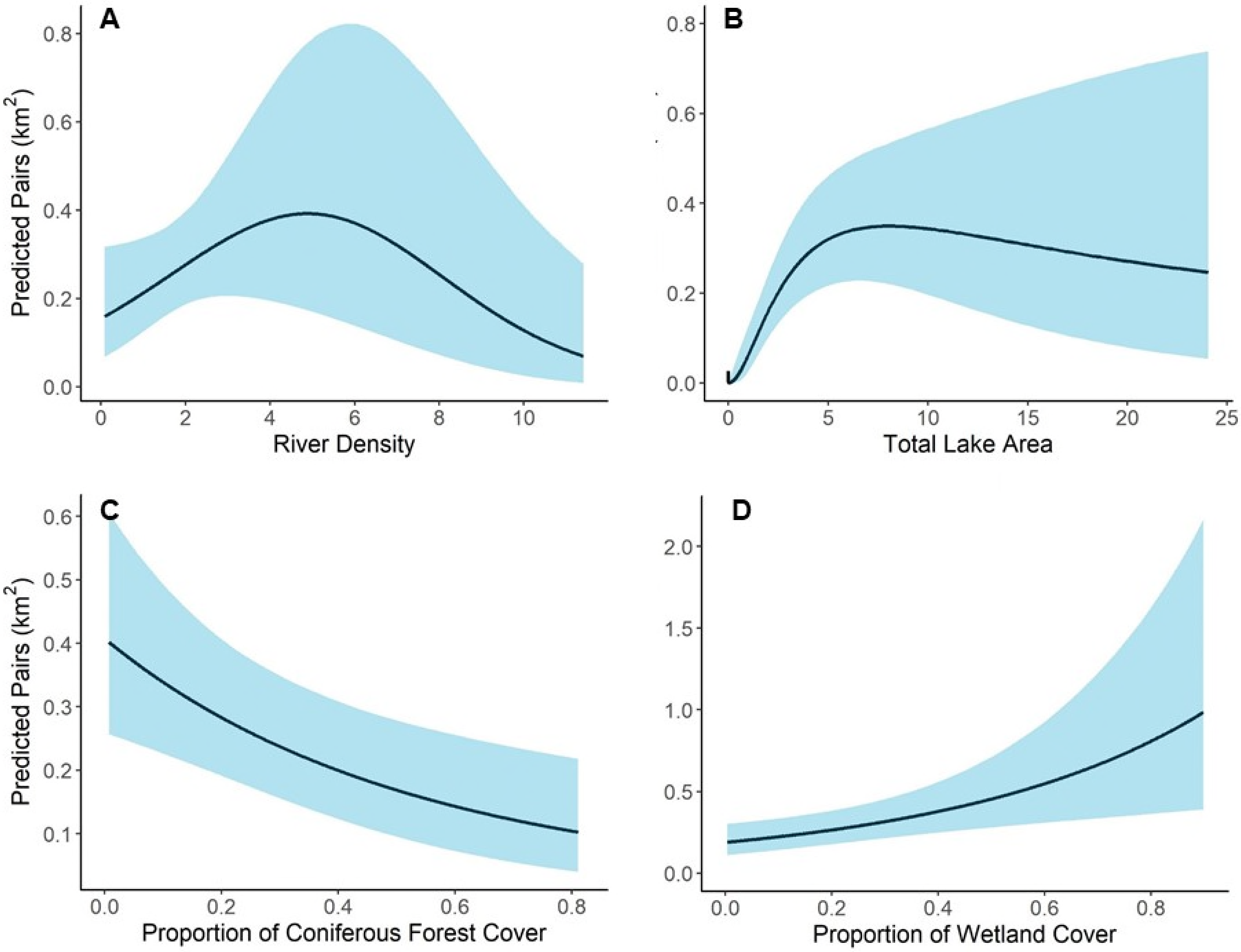

Figure 34. Relationships between the predicted number of Long-tailed Duck (*Clangula hyemalis*) breeding pairs per square kilometer (± 95 % Bayesian Credible Interval) and (A) river density, (B) total lake area, (C) the proportion of coniferous forest, and (D) the proportion of wetland cover. Relationships estimated using the best-approximating habitat model.

APPENDIX

Table A.1 Nest initiation dates estimated for scoters in Québec and Labrador from back-dating age of broods observed.

Area	Species	Nest Initiation ± sd (*n*)
Labrador	SUSC	1 June ±14 (12)
Québec	Scoter	28 May ±7 (10)
Québec	SUSC	27 May ±6 (7)
Québec	BLSC	26 May ±9 (7)

Table A.2 Sources of satellite transmitted data used in determining the arrival and departure dates of scoters tagged in eastern North America.

Principal Investigators		Species	
	BLSC	SUSC	WWSC
S. Gilliland & C. Lepage	40	26	17
P. Loring	3	0	0
M. Perry	12	9	0
P. Wilson	x	0	1
L. Savoy	x	2[1]	16
A. Wells-Berlin	x	12[2]	1
Unidentified	x	4	0

1 Data from 2 transmitters provided by BOEM project
2 Data from 8 transmitters provided by BOEM project

Table A.3 Arrival and departure dates for Black Scoters (*Melanitta americana*) tagged in eastern North America estimated from satellite telemetry.

Area	Sex	Arrival	Departure	*n*
Manitoba	F	5 Jun ±3	26 Jul ±3	5
Manitoba	M	5 Jun ±6	21 Jun ±12	8
Labrador	F	8 Jun	NA	1
Northwest Territories	F	11 Jun ±6	14 Aug ±18	9
Northwest Territories	M	30 May	26 Jun	1
Nunavut	F	16 Jun ±12	4 Aug ±10	5
Nunavut	M	7 Jun ±5	3 Jul	2
Ontario	F	27 May ±8	NA	2
Quebec	F	9 Jun ±14	30 Jul ±11	10
Quebec	M	1 Jun ±8	23 Jun ±2	3
Overall	F	11 Jun ±10	4 Aug ±15	27
Overall	M	3 Jun ±7	24 Jun ±11	9

Table A.4 Arrival and departure dates for Surf Scoters (*Melanitta perspicillata*) tagged in eastern North America estimated from satellite telemetry.

Area	Sex	Arrival	Departure	*n*
Manitoba	F	1 Jun ± 7	24 Jul ± 3	3
Manitoba	M	26 May ±12	14 Jun	2
Labrador	F	30 May ±6	26 Jul ± 13	8
Northwest Territories	F	10 Jun	20 Jul	1
Nunavut	F	1 Jun	20 Jul	1
Ontario	F	30 May	6 Jul	1
Quebec	F	29 May ± 5	18 Jul ± 16	16
Quebec	M	22 May ± 4	15 Jun ±9	3
Overall	F	30 May ± 5	21 Jul ± 11	30
Overall	M	24 May ± 7	15 Jun ± 7	5

Table A.5 Arrival and departure dates for White-winged Scoters (Melanitta fusca) tagged in eastern North America estimated from satellite telemetry.

Area	Sex	Arrival	Departure	*n*
Manitoba	F	14 Jun ±11	2 Aug ±21	6
Manitoba	M	1 Jun ±0	20 Jun ±2	2
Northwest Territories	F	11 Jun ±9	22 Jul ±33	12
Northwest Territories	M	2 Jun	16 Jun	1
Nunavut	F	13 Jun ±3	28 Jul ±26	2
Ontario	M	11 Jun	03 Jul	1
Quebec	F	10 Jun ±10	24 Jul ±19	3
Quebec	M	7 Jun	NA	1
Saskatchewan	F	19 Jun ±0	2 Jul	2
Saskatchewan	M	4 Jun	29 Jun	1
Overall	F	12 Jun ±9	24 Jul ±27	25
Overall	M	4 Jun ±4	23 Jun ±6	6

Table A.6 Average length-of-stay on the breeding site by species and sex of scoters estimated from satellite telemetry for scoters tagged in eastern North America.

Sex	Species		
	BLSC	SUSC	WWSC
Female	47 days ±18 (60)	49 days ±14 (48)	43 days ±27 (34)
Male	18 days ±9 (22)	25 days ±15 (10)	24 days ±10 (8)

Table A.7 Complete model set used to determine habitat selection preferences for scoters (*Melanitta* spp.), scaup (*Aythya* spp.) and Long-tailed Ducks (*Clangula hyemalis*).

Model	Variables included
64	NLake + Area + SDI + River + Wetlands + Conif
63	NLake + Area + SDI + River + Wetlands + Conif + Conif^2
62	NLake + Area + SDI + River + Wetlands + Conif + Wetlands^2
61	NLake + Area + SDI + River + Wetlands + Conif + River^2
60	NLake + Area + SDI + River + Wetlands + Conif + SDI^2
59	NLake + Area + SDI + River + Wetlands + Conif + Area^2
58	NLake + Area + SDI + River + Wetlands + Conif + NLake^2
57	NLake + Area + SDI + River + Wetlands + Conif + Wetlands^2 + Conif^2
56	NLake + Area + SDI + River + Wetlands + Conif + River^2 + Conif^2
55	NLake + Area + SDI + River + Wetlands + Conif + River^2 + Wetlands^2
54	NLake + Area + SDI + River + Wetlands + Conif + SDI^2 + Conif^2
53	NLake + Area + SDI + River + Wetlands + Conif + SDI^2 + Wetlands^2
52	NLake + Area + SDI + River + Wetlands + Conif + SDI^2 + River^2
51	NLake + Area + SDI + River + Wetlands + Conif + Area^2 + Conif^2
50	NLake + Area + SDI + River + Wetlands + Conif + Area^2 + Wetlands^2
49	NLake + Area + SDI + River + Wetlands + Conif + Area^2 + River^2
48	NLake + Area + SDI + River + Wetlands + Conif + Area^2 + SDI^2
47	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Conif^2
46	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Wetlands^2
45	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + River^2
44	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + SDI^2
43	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2
42	NLake + Area + SDI + River + Wetlands + Conif + River^2 + Wetlands^2 + Conif^2
41	NLake + Area + SDI + River + Wetlands + Conif + SDI^2 + Wetlands^2 + Conif^2
40	NLake + Area + SDI + River + Wetlands + Conif + SDI^2 + River^2 + Conif^2
39	NLake + Area + SDI + River + Wetlands + Conif + SDI^2 + River^2 + Wetlands^2
38	NLake + Area + SDI + River + Wetlands + Conif + Area^2 + Wetlands^2 + Conif^2
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24	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + River^2
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11	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + River^2 + Wetlands^2
10	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + SDI^2 + Conif^2
9	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + SDI^2 + Wetlands^2

8	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + SDI^2 + River^2
7	NLake + Area + SDI + River + Wetlands + Conif + Area^2 + SDI^2 + River^2 + Wetlands^2 + Conif^2
6	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + SDI^2 + River^2 + Wetlands^2 + Conif^2
5	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + River^2 + Wetlands^2 + Conif^2
4	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + SDI^2 + Wetlands^2 + Conif^2
3	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + SDI^2 + River^2 + Conif^2
2	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + SDI^2 + River^2 + Wetlands^2
1	NLake + Area + SDI + River + Wetlands + Conif + NLake^2 + Area^2 + SDI^2 + River^2 + Wetlands^2 + Conif^2

NLake = number of lakes (log scale); Area = total lake area (log scale); SDI = shoreline index; River = river density; Wetlands = the proportion of wetland cover on the plot; Conif = proportion of coniferous forest cover on the plot