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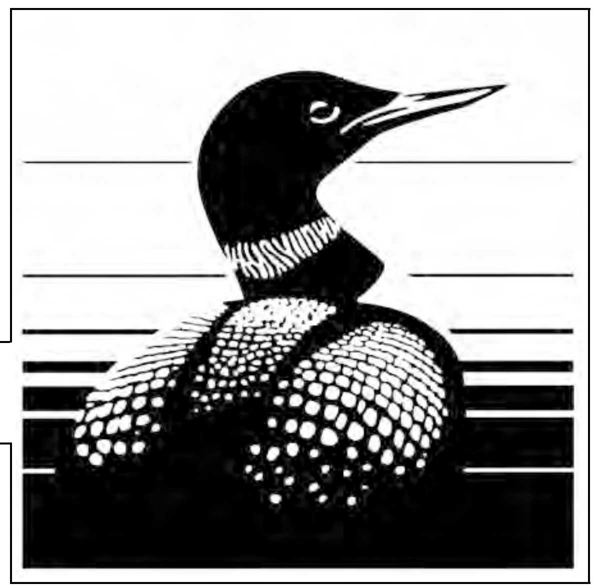
Québec Region, 2001
Canadian Wildlife Service
Environmental Conservation Branch



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For more information on the Black Duck Joint Venture or to download the electronic version of this report, visit the Web site of the Canadian Wildlife Service, Québec Region, at:

www.qc.ec.gc.ca/faune/faune.html

Readers should note that this publication uses the International System of Units: thousands are separated from hundreds by a space (53 833 km²; 1 231 448 pairs), and decimals are separated from units by a comma (9,98 pairs/100 km²; -7,8°C).

Abstract

The Canadian Wildlife Service carried out annual waterfowl breeding pair surveys in southern Québec from 1985 to 1989 under the Black Duck Joint Venture. Since these surveys only cover a small portion of the territory, a methodology was developed to compensate for the gaps in data in nonsurveyed portions of the territory. This allowed a picture of the potential distribution of waterfowl throughout the entire study area, located in the Gouin Reservoir region, to be obtained.

In the helicopter surveys, the occurrence (presence or absence) of the ten most abundant loon and waterfowl species in the study area was recorded. Surveys were carried out in 4 649 sample plots, each 1 km^2 in area. Mean densities of 0,01–0,26 pair/km^2 were recorded in the study area. Subsequently, a Landsat-5 satellite image from August 3, 1990 (image 16-26) of the Gouin Reservoir area was used to obtain an image of the habitats throughout the study area. Using a maximum likelihood classifier, a total of 23 habitat variables in the image were characterized. Habitat descriptors (class, area and frequency) were described for each 1-km^2 unit in the study area.

The relation between waterfowl occurrence data, obtained from the surveys, and habitat data, obtained from the supervised classification, was described using a logistic regression model for each of the ten most abundant loon and waterfowl species. The probability of occurrence of breeding pairs was modelled using independent habitat variables. The parameters from the logistic regression models were then applied to the entire image, in which the habitats had been characterized. This allowed a potential distribution map to be produced for each waterfowl species throughout the study area without the entire area having to be surveyed. Predicted densities for the American Black Duck in the Gouin Reservoir region were particularly high in the southwestern and central western portion of the image. The predicted values were validated with recent data (1996-2000), showing that the models constructed from the 1985-89 survey data reflected fairly well the situation actually observed in 1996-2000.

Lastly, an example of a preliminary impact study (simulation of two proposed routes of a road) is described to illustrate a potential application of the methodology. The potential distribution models allowed the species and numbers of pairs affected by the two routes to be compared, and, from the standpoint of waterfowl conservation, the most important sectors in the area to be protected to be identified.

Résumé

Des inventaires de couples nicheurs de sauvagine ont été réalisés annuellement au Québec méridional par le Service canadien de la faune de 1985 à 1989 dans le cadre du Plan conjoint sur le Canard noir. Comme ces inventaires ne couvraient qu'une portion minime du territoire, une approche méthodologique est proposée afin de combler l'absence de données dans les portions de territoire non inventoriées et ainsi obtenir une image de la répartition potentielle de la sauvagine dans l'ensemble du territoire à l'étude, localisé dans le région du réservoir Gouin.

Dans un premier temps, l'inventaire en hélicoptère de la sauvagine nous a permis de noter la présence ou l'absence des 10 espèces les plus abondantes dans 4 649 unités de 1 km^2. Les densités moyennes observées dans l'aire d'étude variaient de 0,01 à 0,26 couple/km^2. Dans un second temps, nous avons choisi l'image satellite Landsat-5 16-26 du 3 août 1990 (réservoir Gouin) afin d'avoir une image des habitats de l'ensemble du territoire. À l'aide de la classification par maximum de vraisemblance, nous avons caractérisé un total de 23 variables d'habitats présents sur l'image. Les descripteurs d'habitats (classe, superficie, fréquence) ont été décrits pour chaque unité de 1 km^2 du territoire.

La relation entre les données de sauvagine, issues des inventaires, et les habitats, issus de la classification dirigée, a ensuite été décrite à l'aide d'un modèle de régression logistique. Nous avons modélisé la probabilité de présence d'un couple de sauvagine en fonction des variables d'habitats explicatives. Nous avons obtenu un modèle de régression logistique pour chacune des 10 espèces de plongeon ou de sauvagine les plus abondantes. Les paramètres des modèles de régression logistique ont finalement été appliqués à l'ensemble de l'image satellite, dont les habitats avaient été classifiés. Une carte de répartition potentielle a ainsi été produite pour chaque espèce de sauvagine sur l'ensemble du territoire à l'étude, sans pour autant l'avoir inventorié en entier. En ce qui concerne le Canard noir, les densités prédites dans la région du réservoir Gouin sont particulièrement élevées dans le sud-ouest et le centre-ouest de l'image. La validation des données à l'aide de données récentes (1996 à 2000) a permis d'établir que les modèles construits à partir des inventaires de 1985-1989 reflètent assez bien la situation observée en 1996-2000.

Enfin, nous présentons un exemple d'étude d'impact d'avant-projet (simulation de la construction de deux tracés de route), pour illustrer une application possible des modèles construits. Dans cet exemple, les modèles de répartition potentielle permettent de comparer les espèces et le nombre de couples touchés par les différents tracés, en plus d'identifier les secteurs les plus importants à protéger pour assurer la conservation de la sauvagine sur le territoire visé.

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1.0 Introduction

The Canadian Wildlife Service has carried out annual surveys of breeding pairs of waterfowl in southern Québec since 1985 (Bordage and Plante 1997), under the Black Duck Joint Venture (BDJV), a component of the North American Waterfowl Management Plan (NAWMP) (Anonymous 1986, 1994). The primary objective of these surveys is to monitor population trends on a long-term basis to ensure the conservation of waterfowl populations, particularly with respect to the American Black Duck.[1] They also provide a more precise picture of the distribution of waterfowl species in the portions of the Boreal Shield and Atlantic Maritimes ecozones (Wiken 1986) covered by the surveys. The distribution of a number of waterfowl species that breed in Québec is poorly known and, even for the most well-studied species, range maps usually show occurrence but not relative abundance.

Distribution maps showing abundance can be created solely from survey data (Bordage and Grenier 1996). Since the sampling effort deployed is usually low (covering only a few sample plots with large gaps in between), requiring significant interpolation, such maps are generally fairly inaccurate. For example, from 1985 to 1990, the annual sampling effort in the region studied was 5%. To compensate for these gaps, statistical modelling can be used to establish a link between aerial survey data and habitat data obtained from satellite remote sensing (Grenier et al. 1994). The results of the models are then applied to all the portions of the study area that were not surveyed but where habitat information was obtained. The final result is a map of potential waterfowl distribution that imitates the results of exhaustive surveys.

This report presents results on the Common Loon and the nine most abundant waterfowl species recorded in the Gouin Reservoir region during the breeding season, based on aerial surveys carried out between 1985 and 1989 and a Landsat-TM image from August 3, 1990. A synthesis map showing species richness (loons, ducks and geese) was also produced. These maps, which allow the most important areas of habitat for birds to be identified, are a first step in ensuring the conservation of the Common Loon and the main waterfowl species in the region, and in preserving the habitats in the study area used by these species during the breeding season. Lastly, an

[1] For the scientifc names of the bird species cited in the report, see Table 3.

example of a preliminary impact study is presented to illustrate a potential application of the model.

2.0 Study area

The 25 301-km^2 study area is in the Gouin Reservoir region of southwestern Québec (Figure 1). Aerial surveys carried out under the BDJV to monitor population trends did not include Gouin Reservoir itself, because of the low American Black Duck density expected in this habitat. Although the reservoir was included in the characterization of habitats using the satellite image, it was not included in the models, making the total area modelled 19 131 km^2. The total area covered in the distribution maps was 18 611 km^2, however, due to an additional 520 km^2 that was excluded because of the high proportion of the CLOUD and UNCLASS classes (see section 3.3). The study area makes up part of the larger Boreal Shield ecozone and the smaller Rupert river Plateau ecoregion in the northwest and the South Laurentian ecoregion (Groupe de travail sur la stratification écologique 1995). The landscape is hilly with heights ranging from 300 m to 600 m above sea level. The vegetation communities are black spruce–moss in the north and balsam fir–white birch in the south (Thibault 1985).

3.0 Methods

3.1 Waterfowl surveys

The study area was divided into 1 000 square plots, each 10 km $\times$ 10 km in size, using the Universal Transverse Mercator (UTM) grid system. A random sampling plan was used to select fifty plots for each survey year, representing an annual surveying effort of 5%. Figure 2 shows the locations of the plots surveyed from 1985 to 1989.

The plots selected were divided up among three survey teams operating separately from Chibougamau, Lebel sur Quévillon and Roberval. Each team consisted, along with the helicopter pilot, of three people. The first person, the navigator-compiler, sat beside the pilot in the front of the aircraft (a Bell 206B Jet Ranger helicopter), and showed the pilot where to go according to the flight plan. This person also recorded on a transparency, superimposed on a 1:50 000-scale topographic map of the plot, all observations made by the two observers seated in the rear, on either side of the aircraft. Observations comprised the following: species, number, sex and location (± 100 m) of loons, geese and ducks; notes on the route; survey date and starting and stopping time; observation conditions (wind, temperature, precipitation, etc.); and habitat conditions (presence of ice, growth of vegetation, etc.). The helicopter was equipped with bubble windows in the rear to improve observers' field of vision, as well as floats and an extended fuel tank.

The flight plan entailed overflying all aquatic habitats in each plot so that birds along the shoreline could be observed. Flight speeds ranged from 80 km/h to 150 km/h and flight altitudes, from 20 m to 50 m, depending on the configuration of the aquatic habitats and the surrounding relief. Each plot was surveyed three times, on three different days, by the same team.

Surveys were only carried out during suitable weather and were postponed during winds of over 40 km/h, excessive turbulence, heavy precipitation or reduced visibility. Surveys were conducted during the daytime, avoiding as much as possible the hour after sunrise and the hour before sunset because of the poor lighting conditions (yellowish or blinding light or heavy shadows on the banks). All information gathered was compiled in georeferenced databases (location accuracy of 1 ha).

The optimum period for determining the number of breeding pairs is from around the end of laying to the beginning of incubation, after any migrants have passed through and before the paired males have left their mates. The exact period is difficult to predict, however, due to the absence of data on regional waterfowl breeding phenology. Consequently, the starting date for the surveys was adapted to local spring conditions.

Only breeding evidence indicating that breeding pairs were observed near the nest (indicated breeding pair records) was retained. For the purposes of this study, breeding evidence consisted of any isolated record (at least 10 m from other individuals of the same species) of one or two individuals of either sex displaying breeding behaviour. Such behaviour included: (1) not flushing or only flushing when the helicopter was nearby (migrants usually fly away well before the arrival of the helicopter); (2) flushing, but returning quickly to where they had been before the aircraft came; (3) swimming in all directions but remaining close to the place they were first seen; (4) swimming away from the place where they were first seen but returning soon after the helicopter left.

The choice of criteria for evidence of an indicated breeding pair was based on the need to simplify procedures as much as possible and to obtain evidence that was as representative as possible of birds actually nesting in the habitat where they were observed, to facilitate the characterization of breeding habitat. For example, although many studies assume that groups of three to five males represent three to five breeding pairs, this requires that sex be determined. In addition, such males, which have left paired females, could be using habitat that does not necessarily correspond to actual breeding habitat.

The basic unit used in the study to determine the relation between the survey data and habitat characterization data was one square kilometre (km^2). In the databank created (SAS file; SAS Institute Inc. 1996), each line corresponded to each 1-km^2 surveyed; variables (or fields) comprised location (UTM coordinates of the southwest corner of each 1-km^2 plot), date and the number of pairs per species observed in the unit.

3.2 Survey of habitats

Habitat characterization entailed identifying as many habitat classes as possible, as accurately as possible (taking account of the huge area involved), in order to establish a link between habitat and the occurrence of loon and waterfowl. Landsat-5 satellite images obtained with the Thematic Mapper sensor were selected since they have already been used successfully in a number of wildlife habitat characterization studies (Marsh and Ommanney 1991, Homer et al. 1993). In addition, they are a very good value, given the resolution (pixel size: 30 m) and coverage (roughly 25 000 km^2) obtained. The satellite has a 16-day orbit, which limits the number of images available per year. Since the best representation possible of habitats, and particularly vegetation, is required, only images acquired in summer can be used. Late summer, when maximum growth occurs, is preferable since it is easier to distinguish between habitats (Polson and Campbell 1987, Perras et al. 1988). These factors limited the choice of images. The characteristics of image 16-26, selected to represent the study area, are described in Table 1. Readers should note that the image was resampled to a pixel size of 25 m to meet study requirements, particularly to facilitate the division of the image into 1 km² units.

To refine the study methodology and find an optimal combination of spectral bands, a pilot project was carried out using an adjacent image covering the Lebel sur Quévillon area (image 17-26; Daoust et al. 1992). After the biomass index was determined using the TM3 and TM4 bands, water bodies and beds of aquatic vegetation were classified using a parallelepiped classifier. Subsequently, for the remaining unclassified areas, spectral bands TM2, TM3, TM4, TM5 and TM7 were combined using principal components analysis and then classified using a maximum likelihood classifier using predefined training areas selected from aerial photographs and forest maps. This method requires a number of processing steps as well as a thorough knowledge of the region, given the emphasis on wetland habitats. A second test involved the image actually used in the study (Gouin Reservoir; image 16-26). A colour composite image (spectral bands TM3, TM4 and TM5) enhanced by linear stretching was classified (Beaubien 1987, Grenier et al. 1994). The maximum likelihood classifier used on the composite provided good results. It should be noted, however, that a large number of training areas were established using aerial photographs and forest maps, and the composite provided better results for heavy forested areas, as was the case for the actual study. This type of image (a colour composite consisting of spectral bands TM3, TM4 and TM5 enhanced with linear stretching) was chosen for two reasons: first, it is more economical (three spectral bands instead of seven) and, second, increasing the number of training areas rather than carrying out several processing steps improves the validation process. Image processing involved the following steps, which were performed using PCI software (PCI Geomatics, Ontario, Canada) on image 16-26 of the Gouin Reservoir:

Step 1. Reference document search. To facilitate image analysis, particularly the choice of training areas, additional data were essential. The following documents were used to identify habitats on the images: 1:50 000-scale topographic maps (National Topographical Data Base, Natural Resources Canada); black and white aerial photographs at a scale of 1:15 000 and 1:20 000 (Canadian Wildlife Service, Québec Region); forest and ecoforest maps at a scale of 1:20 000 (Service de l’inventaire forestier, Québec Department of Natural Resources); and observations made during the aerial surveys. The date of the aerial photos and year of the maps had to be as close as possible to the date of the image. The quality of the information used to identify habitats influences the accuracy of supervised classification enormously.

Step 2. Selection of training areas. A colour composite image displaying spectral bands TM4, TM5 and TM3 (Table 1) in red, green and blue respectively, and enhanced by linear stretching, is commonly used to differentiate among forest habitats. Therefore, it seemed appropriate for this study, which involved identifying the heavily forested habitat in the Gouin Reservoir area. Since the study focused on aquatic habitats, linear stretching was performed on the entire histogram (histogram stretch) to avoid saturating the colours of the water and wetlands. Training areas selected had to meet a number of criteria. The sampled area must be homogenous and be a respectable size (minimum 3 pixels $\times$ 3 pixels). There must be a sufficient number of training areas representing each class and they must be distributed over the entire image. The more extensive the sampling of each class, the better the identification of the class. Given the relation sought between habitats and waterfowl, special attention was paid to aquatic and riparian habitats and water bodies. Furthermore, a distinction was made between deep and shallow water in the classification. Similar distinctions were made for several other habitats: for example, between recent cutovers and regenerating areas to better determine the potential impact of such modifications on wildlife.

Step 3. Calculation of spectral signatures. For each habitat class, the statistics defining training areas were calculated. Spectral bands TM4, TM5 and TM3 were used to generate the signatures.

Step 4. Verification of signatures. Class differentiation by spectral signatures can be assessed using a divergence matrix. If there is a significant spectral overlap between two classes, the signatures can be pooled; if the two classes do, indeed, need to be kept separate, larger or different samples (training areas) can be used.

Step 5. Classification. A maximum likelihood classifier was used for TM4, TM5 and TM3 (the bands used to generate the spectral signatures). The result was a thematic image containing the classes defined by spectral signatures (each class is coded with a numeric value). Maximum likelihood classifiers employ the Gaussian threshold defined in each signature file to determine if a given pixel falls within the class or not. The threshold corresponds to the radius (in standard deviation units) of a hyperellipse surrounding the mean of the class in feature space. If the pixel falls within the hyperellipse, it is assigned to the class. Classes can be assigned a different weight, which resolves the problem of overlap between classes by favouring one class over another. Pixels that are not associated with any classes are coded as «unclassified» and assigned a zero value. In using this algorithm, it is assumed that the classes have a Gaussian (normal) distribution and that signatures have been properly selected.

Step 6. Verification of results. Although the reference documents used to identify habitats can also be employed to validate the resulting classes visually, this process is long and subjective. In this study, a confusion matrix (also known as a classification error matrix or contingency table) was used instead. The matrix was based on the training areas used to generate the spectral signatures (Story and Congalton 1986). For each pixel in the training areas, the table compares the classification obtained in the image analysis with the classification determined from the reference documents. The two classifications are cross-tabulated in the table, allowing classification accuracy to be validated. Readers should note, however, that validation is based on the same training areas used for classification, resulting in a favourable bias towards validation. For each class, the percentage of correct identifications (columns) and correct designations (rows) are obtained. If the results are unsatisfactory, steps 2 to 6 are repeated.

Step 7. Smoothing. The thematic image was smoothed to replace small islands of pixels with the adjacent themes. A modal filter was used since it allows the same grey level values to be retained. A 3 pixels $\times$ 3 pixels window was defined so that only the smallest islands were eliminated.

Step 8. Calculation of areas. The area of each habitat class in each 1-km^2 unit was calculated, based on the UTM projection.

Step 9. Transformation of water bodies into polygons. In this study, it was important to determine whether the total area of water in each 1-km^2 unit represented one large lake (> 100 ha) or several small lakes (< 5 ha). Therefore, water bodies had to be recognizable as distinct entities. Classes associated with water (DEEPWAT and SHALLWAT[1]) were combined in a single class (water) which was then transformed into

[1] Because of the small area associated with the TURBWAT class and potential confusion with the SHALLWAT class, the TURBWAT class was combined with SHALLWAT in the habitat classifications.

polygons. This allowed the area of each water body to be calculated. In the study, four classes representing the water body size were retained (WATER0, WATER5, WATER10 and WATER100). To eliminate bodies of water that were not lakes, polygons defined as “WATER” with an area of less than 1 ha were eliminated. Lastly, the area occupied by each water class in each 1-km^2 unit was compiled.

Step 10. Transfer of files to database. The results were converted into SAS format (SAS Institute 1996) so they could be merged with the waterfowl survey data. The result was a SAS file in which each line corresponds to a 1-km^2 plot in the image and in which the variables (columns) identify the characteristics of the habitats found (area of classes in ha) and the number of pairs of loon or waterfowl observed per species in the surveyed units.

3.3 Modelling

The basic unit used in modelling was the 1-km^2 plot. Only units surveyed by helicopter in which the proportion of clouds to the total area did not exceed 20% and in which the proportion of clouds and unclassified habitats did not exceed 50% were retained. Out of the total area surveyed in the territory covered by image 16-26 (4 751 km^2), 4 649 units were used in the models.

The maximum number of pairs per year and per unit observed in any of the three yearly surveys of each 1-km^2 unit was used in the analyses for the models. In 94% of the units surveyed, the density of American Black Ducks, the most abundant species, was 0 or 1 nesting pair only. Consequently, the pair density information in each unit was summarized as presence or absence of a pair.

Along with the habitat data and results from the waterfowl surveys, the models also took account of the survey year (in the form of a categoric variable) and UTM coordinates.

The relations between survey and habitat data were described using a logistic regression model. This involved modelling the probability of occurrence of pairs (at least one pair) as a function of habitat variables. If Y denotes the presence (Y= 1) or absence (Y= 0) of a pair and x_1, x_2, ... represent habitat variables (independent variables), the model can be described as:

$$p = P(Y = 1 | x_1, x_2, ...) = \frac{\exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ...)}{1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + ...)} \quad ,$$

where $\beta_0, \beta_1, \beta_2, ...$ are the model parameters. These parameters were estimated using the maximum likelihood method. The logistic regression model can be written more simply as:

$$\operatorname{logit}(p) = \log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ...$$

For example, for a single independent variable, the model describes a linear relation between the logit transform for the probability of occurrence of the pair and the independent variable.

The modelling involved the following steps, using SAS software (SAS Institute Inc. 1996):

Step 1. Transformation of variables. The distribution of each independent variable was analyzed. Most of the habitat variables had a highly asymmetrical distribution, with the larger areas less frequent in distribution.

The relation between waterfowl pair occurrence and habitats was analyzed separately for each independent variable using a graph of $\operatorname{logit}(p)$ as a function of the variable in question. This involved creating area classes for the variable and calculating the proportion of occurrence of pairs observed (p) in each class. If the model is appropriate, the graph of $\operatorname{logit}(p) = \log(p/(1-p))$ as a function of the midpoint for each class (in this case, the mean area for the class was used) should be roughly a straight line.

When the univariate analysis revealed a curvilinear (i.e., nonlinear) relation between $\operatorname{logit}(p)$ and the habitat variables, the latter were transformed using a square-root transformation to create a more linear relation, and the prefix "SQ" was added to the name of the habitat class (e.g., SQBOG instead of BOG). Habitat variables showing a stepped trend for $\operatorname{logit}(p)$ (one level for area class 0 and another level for area class > 0) were transformed into binary variables (presence or absence of habitat in the 1-km^2 unit) and the suffix "01" was added to the class name (e.g., BOG01).[1] Variables

[1] To respect the eight-character limit for variable names in SAS, some names had to be shortened; for example, SOFTWOOD transformed into a binary variable = SOFTWO01.

UTMEAST and UTMNORTH were also transformed into binary variables, dividing the image into four quadrants of roughly equal area (UTMEAST < 500 000 or UTMEAST ≥ 500 000 and UTMNORTH < 5 400 000 or UTMNORTH ≥ 5 400 000).

Step 2. Univariate analysis. A test of goodness of fit (INSIGHT: Analyze: Fit(x,y)) was carried out, taking into account one independent variable at a time (the test was done with and without the survey year). Only variables for which $P < 0,25$ were retained.

Step 3. Selection of independent variables. Given the large number of variables resulting from step 2 potentially linked to the occurrence of nesting pairs, we used a stepwise regression method for each year separately. The upper and lower thresholds were set at 0,15 and variables not selected by the model for at least one of the five years were discarded (PROC LOGISTIC).

Step 4. Preliminary model. A full model including year data was fitted with the independent variables retained; variables that were not found to be significant (greater than the threshold of 0,25) were deleted.

Step 5. Interactions between water-related variables. From a biological point of view, the total area of shallow water, turbid water[1] and deep water can be expected to have a different effect on the probability of occurrence of nesting pairs depending on whether this area consists of small or large lakes within each 1-km^2 plot. This information was not readily available, however. In statistical terms, this situation could result in an interaction effect between the area of water and the areas of the different classes of lakes. We tested each interaction by adding them to the model one by one, retaining the variables used previously. Significant interactions ($P < 0,15$) were added to the model and we removed from the full model all variables (including interactions) over the 0,15 threshold.

Step 6. Interactions with the year. To determine if the relation between pair occurrence and habitat varied from year to year, the interactions between each habitat variable and the survey year were tested one by one. Only those found to be significant (0,10 threshold) individually and then overall were retained.

[1] The class TURBWAT was retained in the model even though it was merged with SHALLWAT in the habitat classification.

Step 7. Final model. Lastly, the full model was constructed using all the variables retained in step 6. The options CTABLE (with critical value = density [occurrence] observed by species) and LACKFIT were used to test the goodness of fit of the model (Hosmer-Lemeshow test and Somers' D test), while options DFBETAS, DIFCHISQF and CBAR in OUTPUT were used to test the influence of extreme values on the model results.

3.4 Creation of potential distribution maps

Once a logistic regression model was obtained for each species, the only step left was to produce the map of potential distribution. Basically, this involved applying model parameters to the entire satellite image.

Step 1. Transformation of variables. The variables in the file containing habitat variables for all the 1-km^2 units in image 16-26 were transformed as required (see step 1 in section 3.3) and a new file containing only the variables selected by the model was generated.

Step 2. Calculation of predicted values (probability of occurrence = pair density per km^2). This value was obtained by using parameters (coefficients) of the model for each species and each year. A code for missing data was used for units in which the area with cloud cover exceeded 20 ha and units in which the area of cloud cover and unclassified pixels exceeded 50 ha.

Step 3. Verification of relations between years. Using INSIGHT: Multivariate: Matrix CORR for each species, we constructed a correlation matrix between the values predicted for each year. In the case of values with a strong correlation ($r > 0,8$) between years, the mean (1985-89) of the values predicted for each unit was calculated.

Step 4. Calculation of value of potential. Five scores for potential were awarded to the values predicted for each species (a score of 1 was given for the lowest potential and 5 for the highest):

Score of 1: Predicted value < observed density of occurrence × 0,5;

Score of 2: Predicted value ≥ observed density × 0,5 and < observed density;

Score of 3: Predicted value ≥ observed density and < 2 × observed density;

Score of 4: Predicted value ≥ 2 × observed density and < 3 × observed density;

Score of 5: Predicted value $\geq 3 \times$ observed density.

In terms of species richness, scores for potential were awarded as follows:

Score of 1: None of the 10 most abundant waterfowl species had a predicted value greater than the observed density of the species;

Score of 2: 1-3 waterfowl species had a predicted value greater than the observed density of the species;

Score of 3: 4-6 species had a predicted value greater than the observed density of the species;

Score of 4: 7-8 species had a predicted value greater than the observed density of the species;

Score of 5: 9-10 species had a predicted value greater than the observed density of the species.

Step 5. Production of potential distribution maps. Distribution maps were produced using the PCI software package (PCI Geomatics, Ontario, Canada).

3.5 Validation

A common practice in modelling is to randomly exclude a portion of the data during modelling to be used as a sample for validation. However, since densities of occurrence were low in this study, all the data available were used for the models to maximize the goodness of fit. Instead, data from BDJV helicopter surveys in 1996-2000 were used to validate the models (Bordage 2000). In the 1996-2000 surveys, ten plots of 5 km $\times$ 5 km in the study area were surveyed by helicopter, using a technique similar to that described in section 3.1. The helicopter was equipped with skis rather than floats, however, and only one survey of each plot was done per year. These plots were surveyed twice or three times over five years. Some of the plots were only partially included in the study area and two surveyed units (2 km^2) were located in units coded for missing data because of excessive cloud cover or unclassified habitats (see section 3.4); therefore, the total area available for validation was 198 km^2.

3.6 Simulation

Various types of disturbances play a key role in the ecology of the Boreal Shield ecozone. Some, such as logging and hydroelectric development (reservoirs), are anthropogenic in nature, while others, such as fire and insect epidemics, are natural in origin, although they may be influenced by human activities. The objective of this exercise was to simulate a preliminary study in the environmental impact assessment process. The simulation involved the analysis of two proposed routes for a road to be constructed in the study area. Readers should note that the simulation was extremely simplified and the conclusions reached were purely fictitious and highly simplistic compared to the much more complex issues involved in an actual project of this type. However, an evaluation of the simulation should provide an idea of possibilities and potential applications of the method described in this report.

The simulation consisted of the following scenario. Two routes for a highway construction project undergo a pre-project environmental assessment process. Both routes cross the study area from north to south; the estimated right of way is 1000 m (total width). The centre of the first highway corresponds to UTM 435 000 mE and the second, UTM 455 000 mE. The total area covered by the highway is 167 km^2 in both cases. An overview of the area under study can be found in Figure 3.

4.0 Results

4.1 Waterfowl surveys

Aerial surveys were carried out in a total of 53 plots in the study area from 1985 to 1989 (Figure 2). Of these, 41 lay completely within the study area (100 km^2), while 12 were only partially included (areas ranging from 2 km^2 to 50 km^2). Three plots were surveyed during two of the five survey years. As Figure 2 shows, the distribution of plots provided good coverage of all the study area. Table 2 describes the survey conditions from 1985 to 1989.

Mean pair density (1985-89) of the ten most abundant species of loon and waterfowl in the Gouin Reservoir region is shown in Table 3 (in decreasing order of abundance in the 4 649 km^2 used for modelling). The density of occurrence corresponds to the density calculated after the transformation of observed values into values for presence/absence per km^2.

4.2 Survey of habitats

The classification of the image resulted in the identification of 19 habitat classes, including three involving water: shallow water [SHALLWAT], deep water [DEEPWAT], and water heavily laden with sediment [TURBWAT]. TURBWAT was combined with SHALLWAT in the area calculations. In turn, four classes representing the area of water bodies (WATER0, WATER5, WATER10, WATER100) were generated, bringing to 23 the number of habitat variables available for modelling. Descriptions of the classes and the area occupied by each class in the image are provided in Table 4.

To assess classification accuracy, a confusion matrix was prepared (Table 5). The rate of correct classifications (overall accuracy), based on the total number of pixels correctly classified (along the diagonal), was 92,5%. This high rate is the result of correct classifications for all habitats, except for the classes MARSH and BURN, which had identification (producer's accuracy) and designation (user's accuracy) rates below 65%.

In the classification, the MARSH class, as identified in the reference documents, was erroneously assigned to several other habitat classes in the image, resulting in a rate of correct identification (producer's accuracy) of only 23% (Figure 4 and Table 5; columns in confusion matrix). The MARSH class, as shown on the image, was assigned to 63% (user's accuracy) of the marshes identified in the reference documents (Figure 5 and Table 5; lines in confusion matrix). This means that marshes in the satellite image were difficult to identify, although pixels in the image that were classified as marsh were generally correctly identified. Consequently, the class was underrepresented in the classified image.

The situation was the opposite for the BURN class. This class was fairly well identified in the image (60% of pixels correctly identified or producer's accuracy of 60%), but was assigned to several other classes in the classified image (31% of pixels correctly designated or user's accuracy of 31%), mainly MARSH (marshes and alder swamps) and BARESOIL (bare soil, recent clearcuts and roads). Consequently, the BURN class was overrepresented in the classified image.

The resulting classified image illustrates the striking differences in landscape in the Gouin Reservoir region (Figure 3). Hardwoods (balsam fir with white birch) are concentrated in the southern part of the study area, particularly in the southeast, while the rest consists mainly of softwoods (black spruce with moss). Bogs are visible in the central western portion of the image, while recent extensive clearcuts (easily locatable by the bare soil [BARESOIL]) occur in the northern, central and southeastern parts of the study area. Excluding the Gouin Reservoir itself, the northern part of the image is characterized by the presence of many large lakes (over 100 ha). Two transmission lines are barely visible in the western part of the image. The white diagonal line through the top third of the image is the result of a satellite sensor malfunction (unclassified pixels). A similar effect can be seen south and west of the reservoir, where soft lines of unclassified pixels are visible.

4.3 Modelling

Table 6 shows the various descriptors and parameters used in the models for each of the ten species evaluated. Table 7 provides values for some of the parameters and tests of goodness of fit. To make it easier to interpret these tables, but without going into an in-depth description of the models used for all the species, a brief interpretation of the American Black Duck model is given as an example. The full models for other species can be interpreted in a similar way.

First, the correlation between the occurrence of American Black Duck breeding pairs and the various variables representing lake size—SQWATER0 (lakes less than 5 ha in area), SQWATER5 (lakes between 5 ha and 10 ha in area) and SQWATE10 (lakes between 10 ha and 100 ha in area)—tends to be weaker as the total area of deep water increases (negative interaction; Table 6). The smaller the area of deep water, the stronger the positive correlation between the probability of occurrence of a pair and the area representing small lakes. Similarly, the greater the area of deep water, the stronger the negative correlation between the probability of occurrence and the area representing lakes over 100 ha. Secondly, the area forested in HARDWOOD (hardwoods) is negatively correlated with pair occurrence, while the variables SOMERE01 (cutovers with some regeneration) and BOG01 (bogs) are positively associated. Given the presence of similar habitat, the probability of occurrence of a pair is higher in the western part of the image than the eastern part and is lowest in the southeastern part. Lastly, parameters associated with the interaction RWATER0*YEAR show that the probability of observing a pair is more strongly correlated with the size of small lakes in 1988 and 1989 than in the years 1985 to 1987.

The Hosmer-Lemeshow test indicates a good fit (P = 0,41; Table 7) for the American Black Duck model. Similar results were obtained with the Somers' D test (0,61; the maximum value for the test is 1,00, indicating a maximum association between calculated probabilities and observed values). According to a contingency table with a cutoff point of 0,175 (observed density of American Black Ducks, see Table 3), the total overall accuracy rate (rate of correct classifications) is 73%. The model predicted that pairs will occur in 74% of units where a pair was observed and will be absent in 72% of the units where no pairs were observed.

4.4 Potential distribution maps

To limit the number of figures, all potential distribution maps were created using the mean value for the five years of probability of occurrence data, despite the fact that the correlation matrix for three species (Common Loon, Canada Goose and Bufflehead) showed correlation coefficients below the arbitrarily selected threshold of 0,8 (Table 8). All correlations were significantly different from 0 (P < 0,001), which was not surprising, given the large sample size (n = 18 611). In addition, the year-by-year comparisons (involving years with the greatest differences) showed that no year was systematically different from the others, except for 1987, which showed up in only one comparison. Figures 6 to 15 illustrate the potential distribution of each of the ten most abundant species of loon and waterfowl in the Gouin Reservoir region during the breeding season.

Predicted densities of American Black Ducks were particularly high in the southwestern and central-western portions of the study area, both in hardwood and softwood habitats (Figure 6). This species was poorly represented, however, in the upper (northern) third of the image, which is dominated by large lakes.

The distribution of the Common Merganser was fairly homogenous (Figure 7); the only variables used in the predictive model involved water bodies, except for UTMNOR01 and the survey year. This species' predilection for rivers can also be seen in the configuration of sectors with the highest probability of occurrence. The northwestern part of the study area seems to be less frequented by the species.

The potential distribution of the Common Goldeneye in the study area (Figure 8) resembled that of the American Black Duck. In addition, the areas east and southeast of Gouin Reservoir seem to have good potential as breeding habitat for this species.

The probability of occurrence (moderate to very high) of the Ring-necked Duck appears to be distributed uniformly throughout the study area (Figure 9). The predictive model for this species makes use of a number of habitat variables involving bogs, marshland, softwoods and young hardwoods (SQBOG, SQMARSH, SOFTWOOD, YOUNHARD), as well as variables associated with water bodies (Table 6). The northwest sector appears to be the only one with less favourable breeding habitat for the species.

Contrary to the American Black Duck, the areas favoured by the Common Loon are limited mainly to the large lakes in the region according to the model (Figure 10).

The Canada Goose was present chiefly in the northern part of the study area, particularly in boggy areas and areas with bare soil (Figure 11). This is the species with the greatest number of units in the study area predicted to have very high potential.

The Mallard had a similar distribution to the Ring-necked Duck, with perhaps a little higher probability of occurrence in some disturbed areas, particularly in the central-northern portion of the study area (Figure 12). Readers should also note that, unlike the other species, the Mallard has a low, rather than very low, potential distribution in most of the study area.

The potential distribution of the Green-winged Teal in the study area appears to be strongly associated with disturbed areas (Figure 13); this observation was expected given the predictive model for the species (Table 6), in which the variables SOMEREG, MARSH and YOUNHARD are positive.

The distribution map for the Bufflehead shows some areas with high and very high potential (Figure 14), which appear to correspond to bogs, marshes and alder swamps.

The Hooded Merganser had a fairly homogenous distribution in the study area (Figure 15); however, the species appears to be more abundant in the northeast, while the northwest portion has very low densities. According to the predictive model for the species (Table 6), terrestrial habitats sought by the species comprise defoliated or diseased softwoods, bare soil and recently logged areas alongside aquatic habitats.

Figure 16 shows the richness of loon and waterfowl species in the study area, expressed as classes of numbers of target species. It shows species richness in this huge area at a glance. The potential number of species per km^2 appears to be fairly homogenous over the entire study area, except in the northwest portion, where species richness is significantly lower.

4.5 Validation

The models, which were based on 1985-89 survey data, predicted the situation observed in 1996-2000 fairly accurately. The overall classification accuracy ranged from 53% to 84% (Table 9). Depending on the species, in 1996-2000, pairs were observed in 0–83% of the units where the probability of occurrence was greater than or equal to the densities recorded in 1985-89 (see Table 3). Similarly, in 1996-2000, no pairs were observed in 48–86% of the units where the probability of occurrence was less than the densities recorded in 1985-89. Comparison with the values obtained in Table 7 show that the classification rates obtained with reference data (Table 9) were similar for most species.

Table 10 provides even more detailed information on validation, by examining the distribution of pairs recorded in 1996-2000 according to habitat potential class as predicted by the models constructed with 1985-89 survey data.

For example, according to the 1985-89 model (line D) for the American Black Duck, the 198 units (of 1 km^2 each) used to validate the model were assigned to potential classes as follows: 88 units had very low potential (44%), 53 units had low potential (27%), 34 units had moderate potential (17%), 19 units had high potential (10%) and, lastly, 4 units had very high potential (2%). During the actual surveys in 1996-2000, at least one pair of American Black Ducks was recorded in 52 out of the 198 units (26%). A closer look at the distribution of the pairs actually observed (row P) shows that 7 pairs were recorded in units with very low potential (14%), 13 pairs in units with low potential (25%), 15 pairs in units with moderate potential (29%), 13 pairs in units with high potential (25%) and, lastly, 4 pairs in units with very high potential (8%).

Examining both axes of the table is essential. An examination of the rows shows that units with records of American Black Duck pairs tend to be distributed among the classes with the highest potential (row P), while units where no pairs were observed tend to be those with the lowest potential (row A). An examination of the columns shows that: (1) units with very low potential consist mainly of units where no American Black Ducks were observed; (2) the distribution of units is, according to the model (row D), similar for absences (A) and presences (P) of pairs in classes with low potential; and (3) classes of moderate, high and very high potential mainly consist of units with records.

Figures 17 to 20 show validation data at a glance for the four most abundant species according to the 1985-89 surveys. In the case of the American Black Duck, as shown in Figure 17, units with records in 1996-2000 surveys (present) tend to be distributed along a curve that peaks at the moderate potential class, while the distribution of units without records (absent) is centred on the class with very low potential compared with the distribution predicted by the model (predicted). Table 10 and Figure 17 show that the observed distribution of units with and without records differs somewhat from the predicted distribution and that the differences observed are in the direction required to validate the model. Indeed, higher percentages than expected of units with records are found in classes with high potential and units without records in classes with low potential. More specifically, 82% of units with no records are in classes with very low or low potential, while 62% of records are in classes with moderate, high or very high potential.

A similar analysis shows that the model appears to be appropriate for all the abundant species, comprising the American Black Duck (Figure 17), Common Merganser (Figure 18), Common Goldeneye (Figure 19) and Ring-necked Duck (Figure 20).

For the Common Merganser, 83% of the units with records obtained in 1996-2000 were in classes with higher potential (moderate to very high), while 48% of the units with no records were found in classes with lower potential (low and very low). Readers should note that, according to the 1985-89 models, 48% of the 198 units had moderate potential, which is why this class had so many presences and absences.

In the case of the Common Goldeneye, 81% of the units with absences in 1996-2000 were in the low and very low potential classes. Inversely, 67% of the presences occurred in units with higher potential (moderate to very high), which is in the desired direction in terms of validating the model.

Like the Common Goldeneye model, the 1985-89 Ring-necked Duck model predicts fewer and fewer units as unit potential increases in the 198 units validated. A total of 67% of units with records for the species in 1996-2000 were in classes of higher potential (moderate to very high); 81% of units with no records in 1996-2000 were in classes of lower potential (low and very low).

The goodness of fit of the model appeared to be equally good for two species observed in greater numbers in 1996-2000 than in 1985-1989: the Canada Goose and the Green-winged Teal (Table 10). A total of 47% of the records for the Canada Goose in 1996-2000 were in units with moderate to very high potential, while 69% of the units without records were classified as having low to very low potential. For the Green-winged Teal, 50% of 1996-2000 records were in units with moderate to very high potential and 86% of units without records were classified as having low or very low potential (Table 10).

Table 11 and Figure 21 illustrate the results of the validation from the standpoint of species richness. They show that: (1) units where no species were observed are mainly associated with very low (no species) or low (1-3 species) species richness; (2) units where one to three species were recorded are mainly associated with classes of low (1-3 species) and moderate (4-6 species) species richness; (3) units with four to six species are mainly found in classes of high (7-8 species) and very high (9-10 species) species richness; and (4) no unit contained more than 6 species, while the models predicted that 30 units had the potential to attract over 6 species of loon and waterfowl.

A second validation exercise compared American Black Duck densities in the 198 units as predicted by the 1985-89 model with the actual densities observed in 1996-2000. Again, the model appears to be adequate (Figure 22). Although the densities observed in 1996-2000 (0,26 pair/km^2; Table 10) were much higher than those recorded in 1985-89 (0,175 pair/km^2; Table 3), this element should not be overemphasized. The main point of the exercise was the distribution of records (rather than density), which corresponded fairly well to the model's predictions (Figure 22).

4.6 Simulation

Figure 3 does not reveal, at least at first glance, any significant differences in the habitats traversed by the two proposed routes. According to Table 12, however, there are some minor difference between the routes. The second route traverses a larger area of softwoods, while the first route contains a greater number of disturbed habitats, including bare soil, open softwoods, windthrows and burns. The first route crosses more areas of water, but this difference is minor. An examination of the lake classes, however, shows more significant differences between the routes, with the second one involving fewer large lakes, and more smaller ones.

According to Table 13, the second route has greater potential for frequentation by nine out of the ten species modelled; only the Canada Goose would be slightly more abundant along the first route. In all, the first route would support 100 pairs of Common Loons, Canada Geese and ducks, compared with 117 pairs for the second route. The greatest difference is for the American Black Duck (31 pairs on the first route versus 38 pairs on the second). A more in-depth analysis would allow the sections of the route with the greatest habitat potential to be identified. Although the first route supports fewer pairs overall, Table 13 shows that, in many cases, it has the maximum potential for supporting pairs of a species. Similarly, the data show that two 1-km^2 units along the first route have sufficient potential to support one pair of each of the ten species in question (analysis of species richness), while no units in the second route have the potential to support maximum species richness.

5.0 Discussion

The confusion matrix (Table 5) shows that the classification of habitats in the thematic image was fairly accurate for most habitat types retained. The difficulties with the MARSH and BURN classes show the inherent problems in classifying some habitats. Observations made during the aerial surveys to verify the classification of certain sectors showed that the results of some types of logging methods—for example, very dense herbaceous and shrub vegetation interspersed with large wheel ruts filled with water—could easily be confused with marshes. Similarly, some windthrows could resemble burns, with the only difference being the absence of charred bark or timber. The satellite sensor interprets the resulting landscape—in the second example, an opening in the forest with abundant shrubs interspersed with dead timber—but cannot identify the cause (a fire or the wind). Therefore, caution must be used not only in analyzing classification accuracy but also in assigning names to classes. We decided to call these two classes burns and windfalls but perhaps they should have been combined under a class for disturbed forest. Satellite remote sensing describes the landscape as it appears, perhaps approximating how the landscape appears overall to ducks, geese and loons.

Although the validation data show that, in general, the modelling was adequate, the models appear to have overestimated species richness to a certain extent. This does not necessarily signify a weakness in the models. Indeed, in theory, a habitat could potentially support a large number of species but in reality contain a smaller number because it was not filled to carrying capacity or competition mechanisms prevented some species from occurring together in the same 100-ha unit.

The maps of potential distribution and species richness illustrate the use of a huge area by waterfowl. The distribution of habitats and wildlife using them is the first step in the process of managing and developing habitat for waterfowl conservation. Although the tool is fairly coarse and its accuracy varies from species to species, it provides a good idea of the sites of ecological interest in a region. Once this first step has been completed, ground truthing, which is much more efficient, can be used to validate the results. This allows conservation plans to be formulated for huge, relatively inaccessible and poorly known territories. To meet specific needs or to improve the goodness of fit of predictive models, additional habitat variables applicable to large areas can be added. For example, the following variables would be of particular interest in waterfowl conservation: elevation of lakes or territory surveyed; area or length of rivers and streams (watercourses less than 30 m wide cannot be detected by the Landsat TM-5 satellite); and shoreline length or shoreline development index for water bodies. Lastly, a landscape analysis, which involves the study of the configuration of different habitats and of relief, is a promising research avenue in evaluating wildlife habitat.

6.0 Conclusion

The potential distribution and species richness maps obtained in the project allow the identification of areas with large concentrations of wildlife as well as less frequented sectors in a huge, inaccessible territory. The combination of aerial waterfowl surveys and satellite remote sensing paves the way for wildlife and habitat conservation projects in these environments that are crucial for many species of aquatic birds.

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Figure 1. Study area, Gouin Reservoir region, Québec

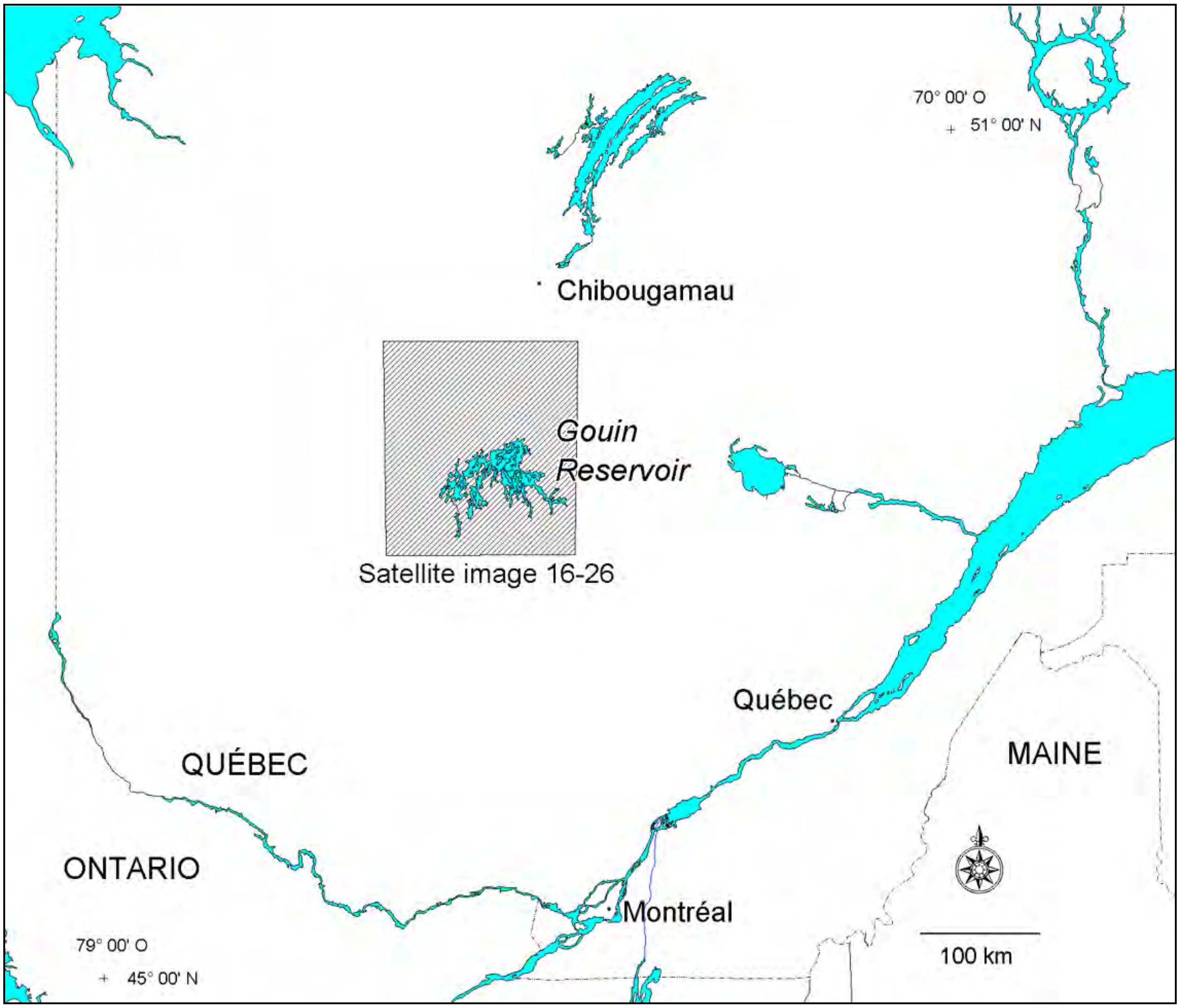

Figure 2. Location of plots surveyed in aerial surveys from 1985 to 1989

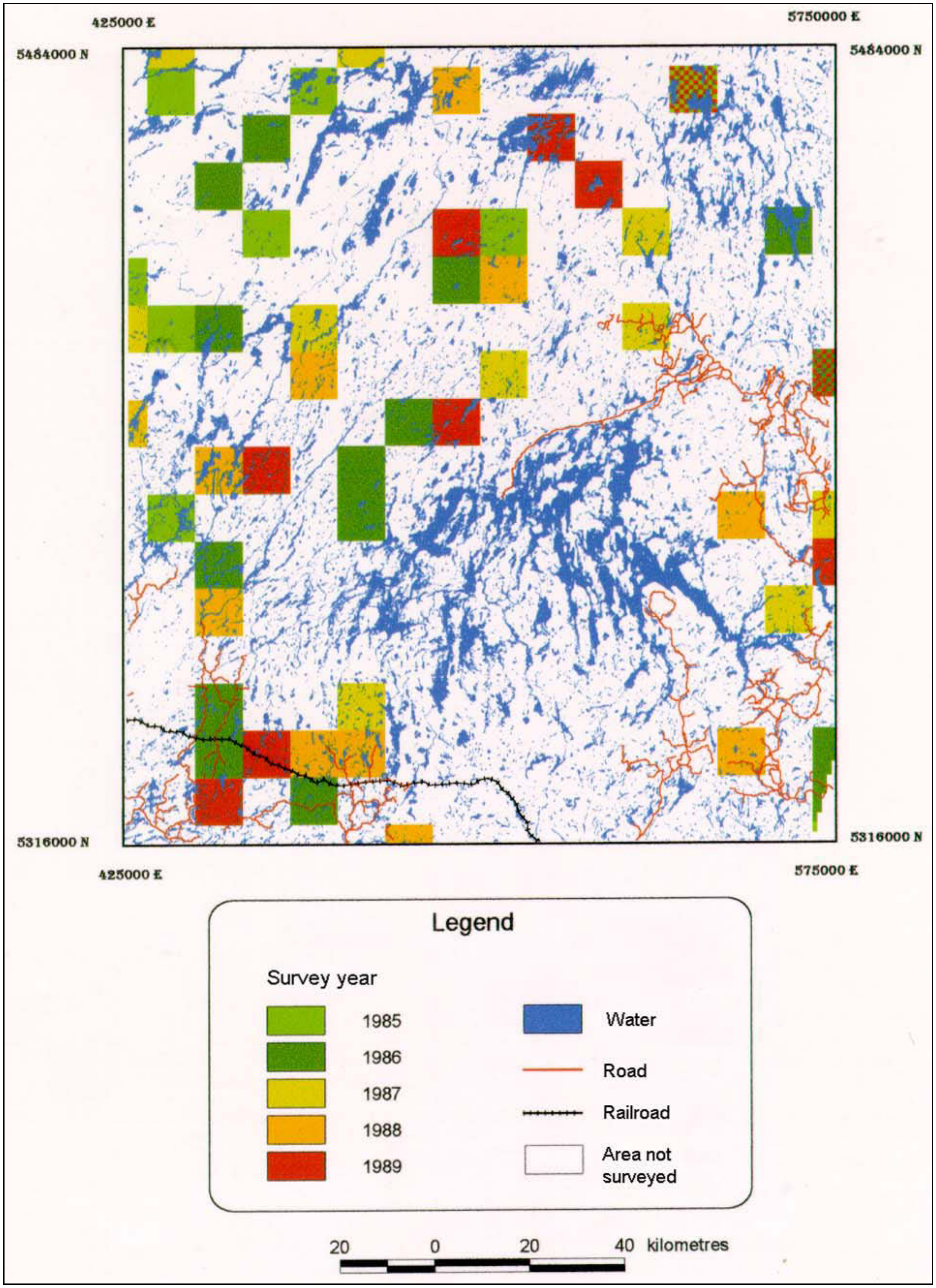

Figure 3. Classified image of habitats in the Gouin Reservoir region, Québec (Landsat TM-5 image 16-26, 3 August 1990)

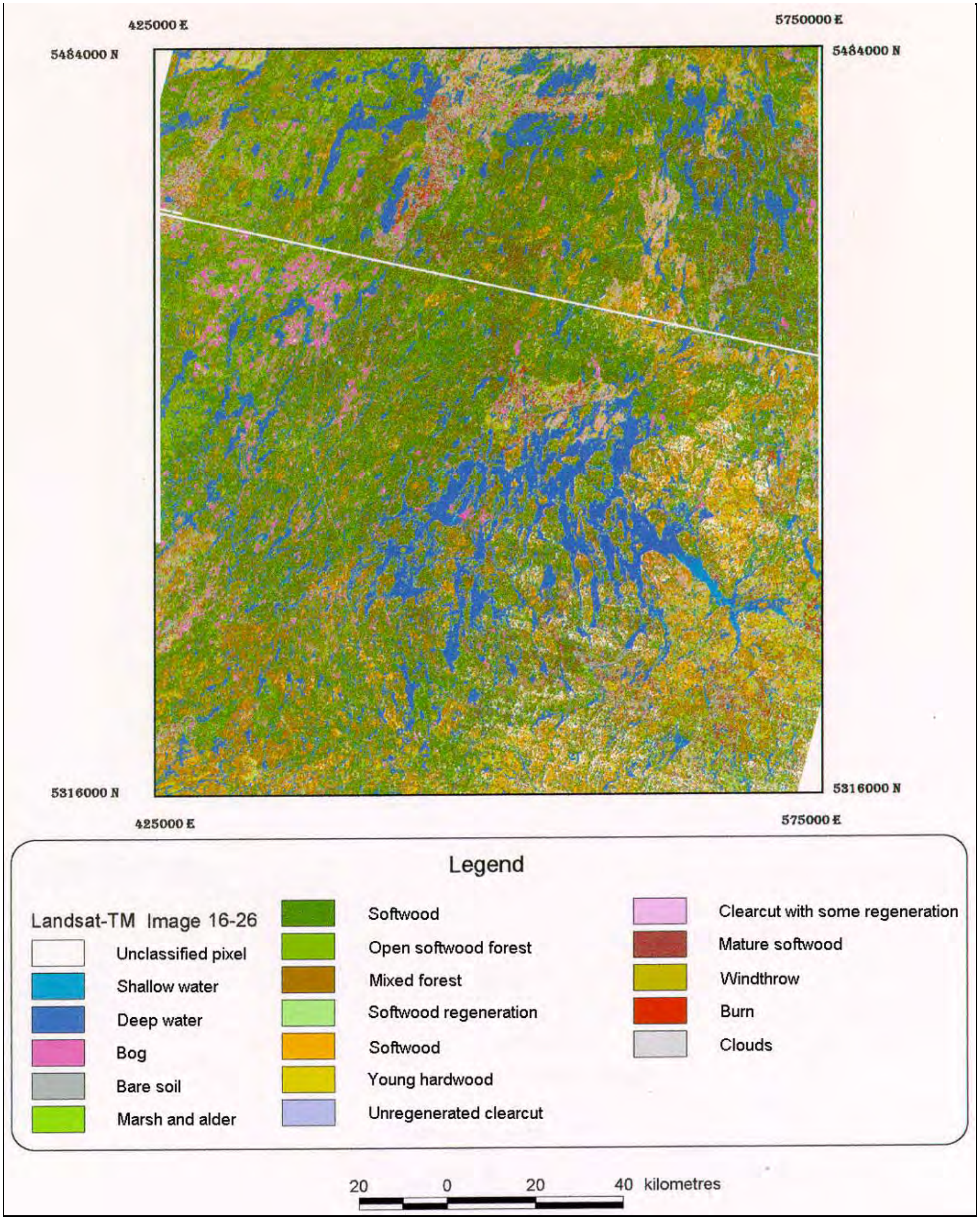

Figure 4. Distribution (%) of MARSH and BURN classes, as identified from reference documents, among all classes identified in the image (taken from confusion matrix in Table 5)

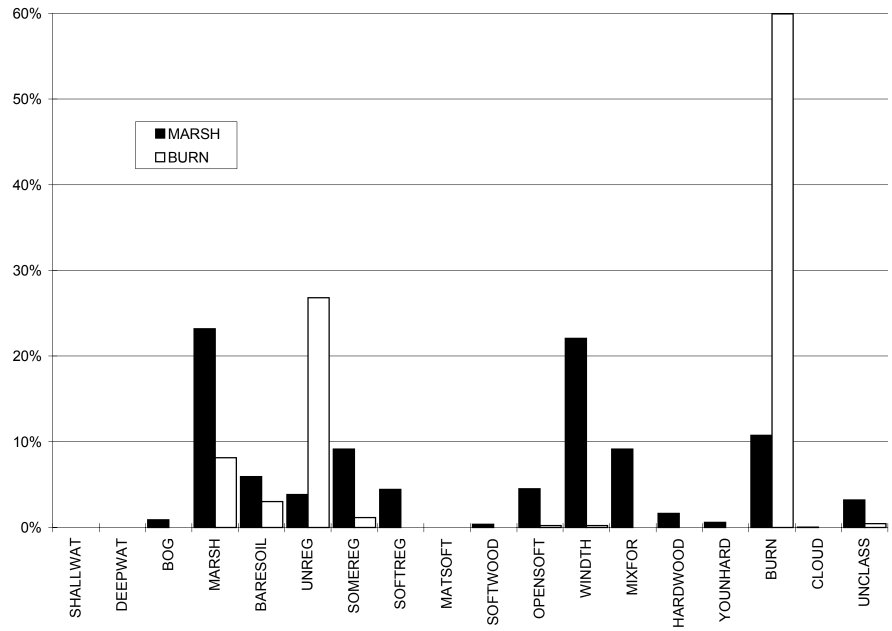

Figure 5. Distribution (%) of MARSH and BURN classes, as identified on the image, among all classes identified from reference documents (taken from confusion matrix in Table 5)

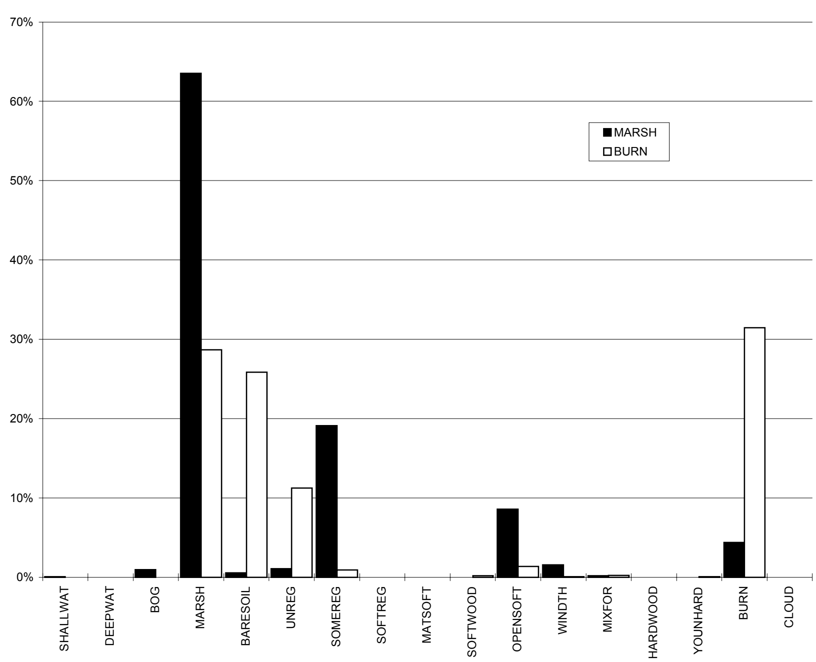

Figure 6. Potential distribution of the American Black Duck during the breeding season in the Gouin Reservoir region, Québec

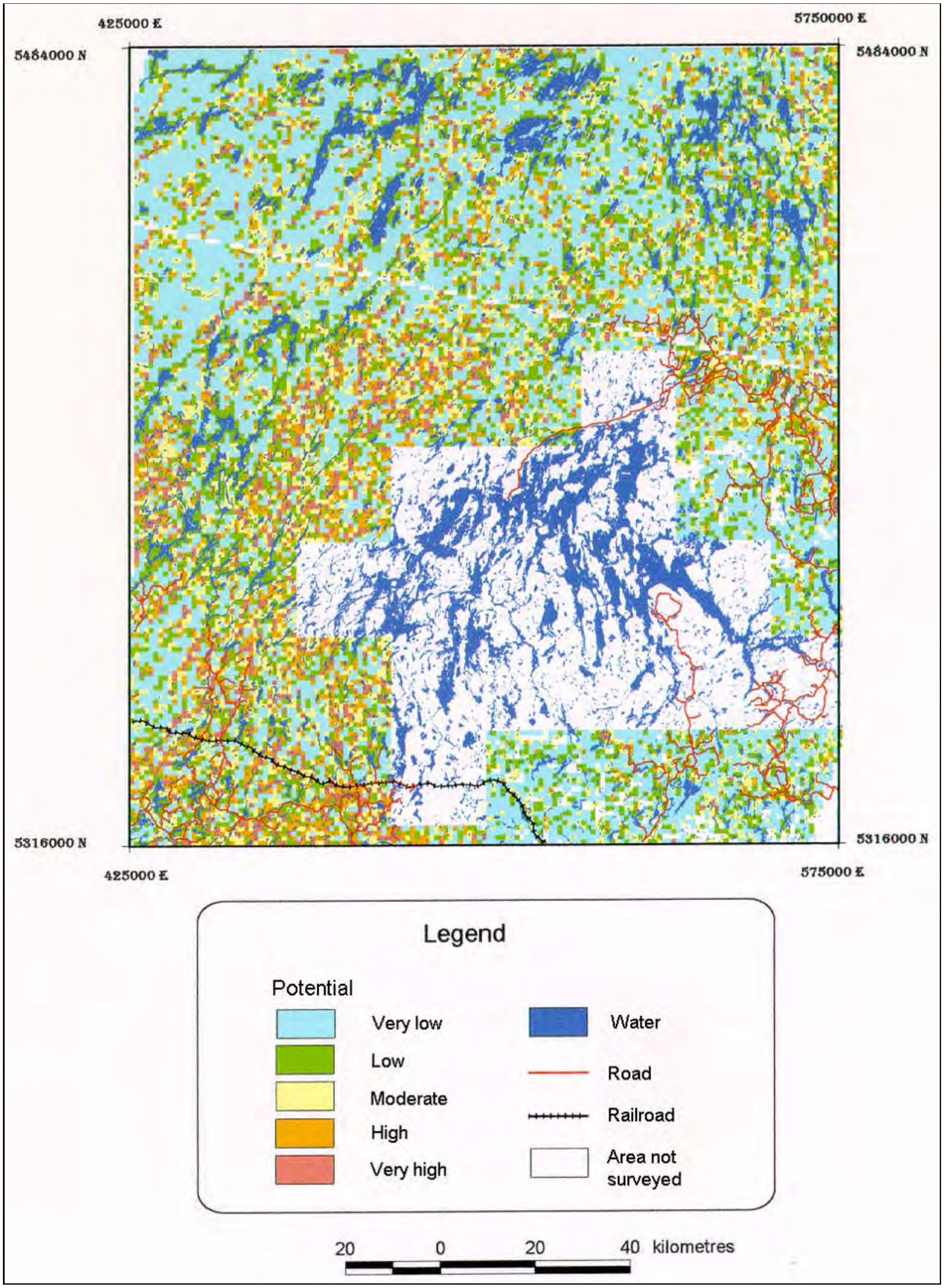

Figure 7. Potential distribution of the Common Merganser during the breeding season in the Gouin Reservoir region, Québec

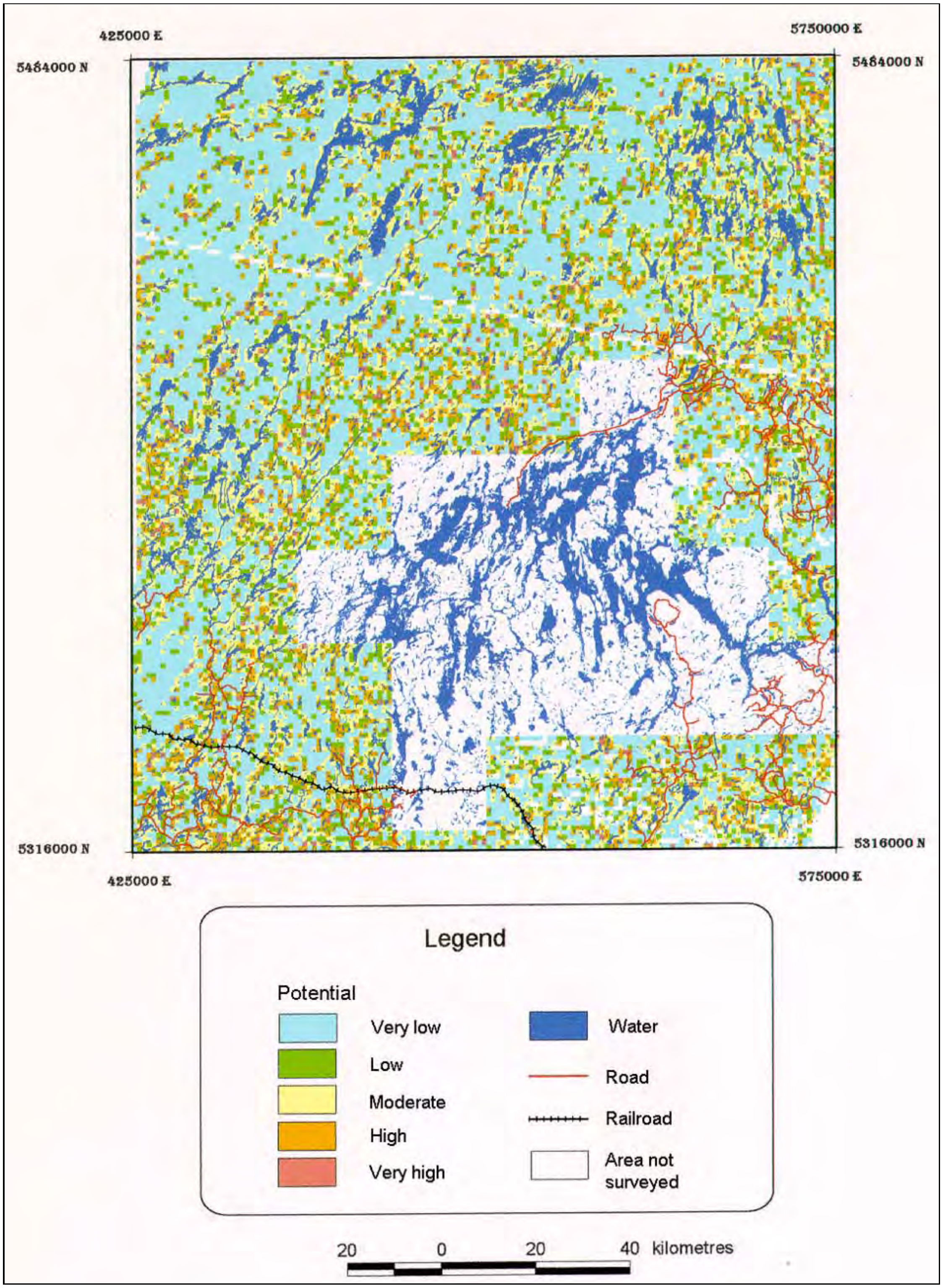

Figure 8. Potential distribution of the Common Goldeneye during the breeding season in the Gouin Reservoir region, Québec

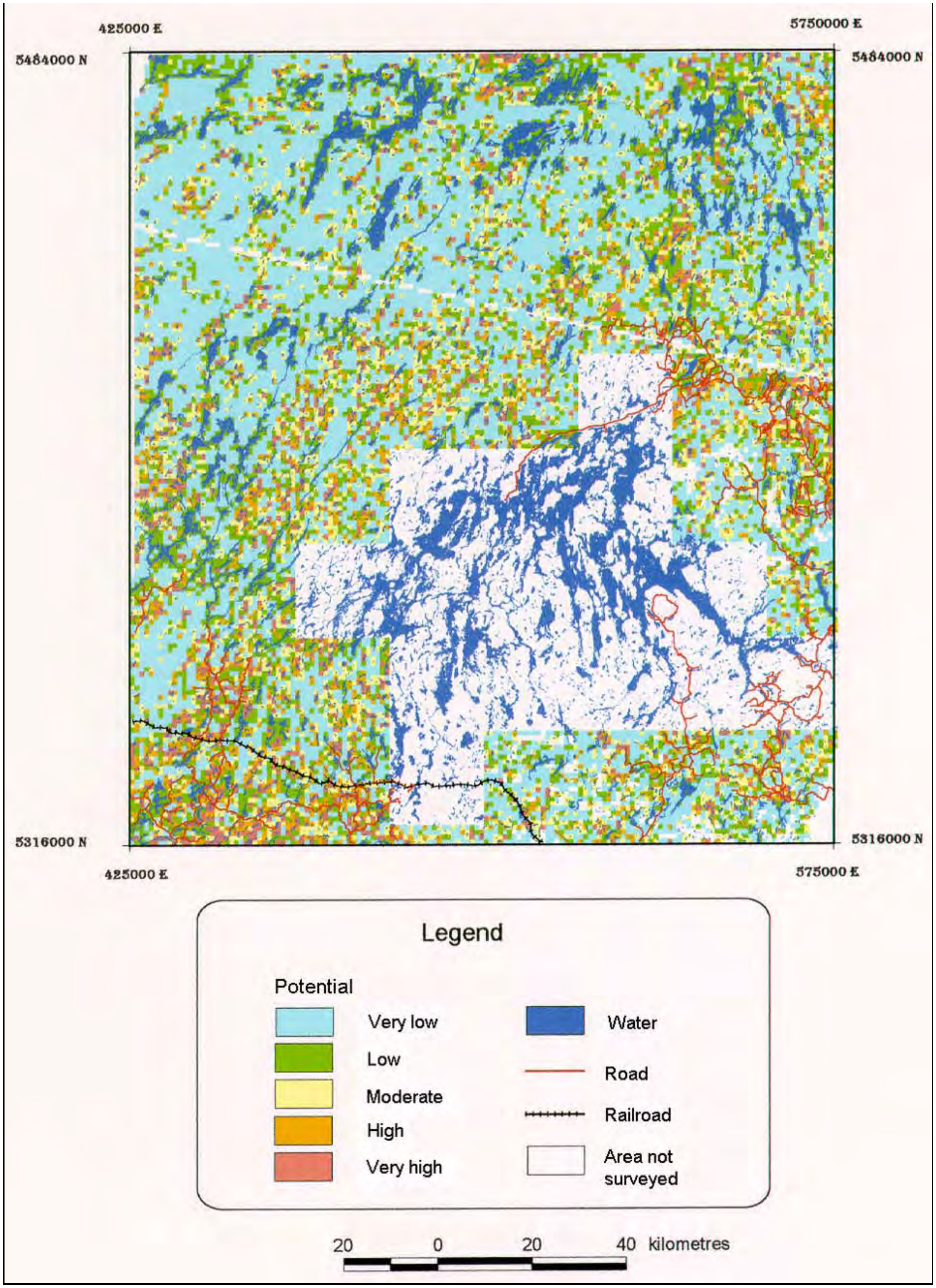

Figure 9. Potential distribution of the Ring-necked Duck during the breeding season in the Gouin Reservoir region, Québec

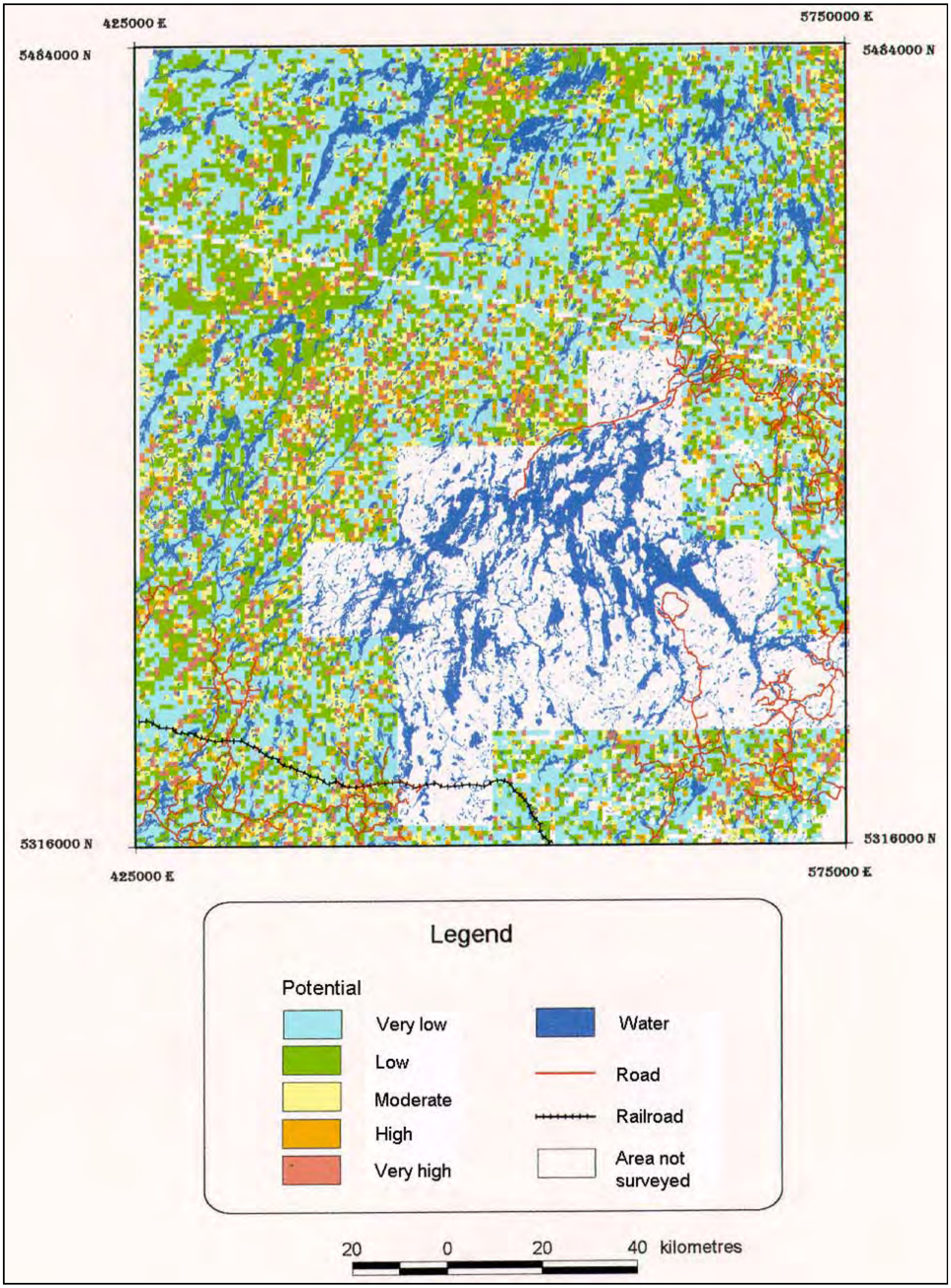

Figure 10. Potential distribution of the Common Loon during the breeding season in the Gouin Reservoir region, Québec

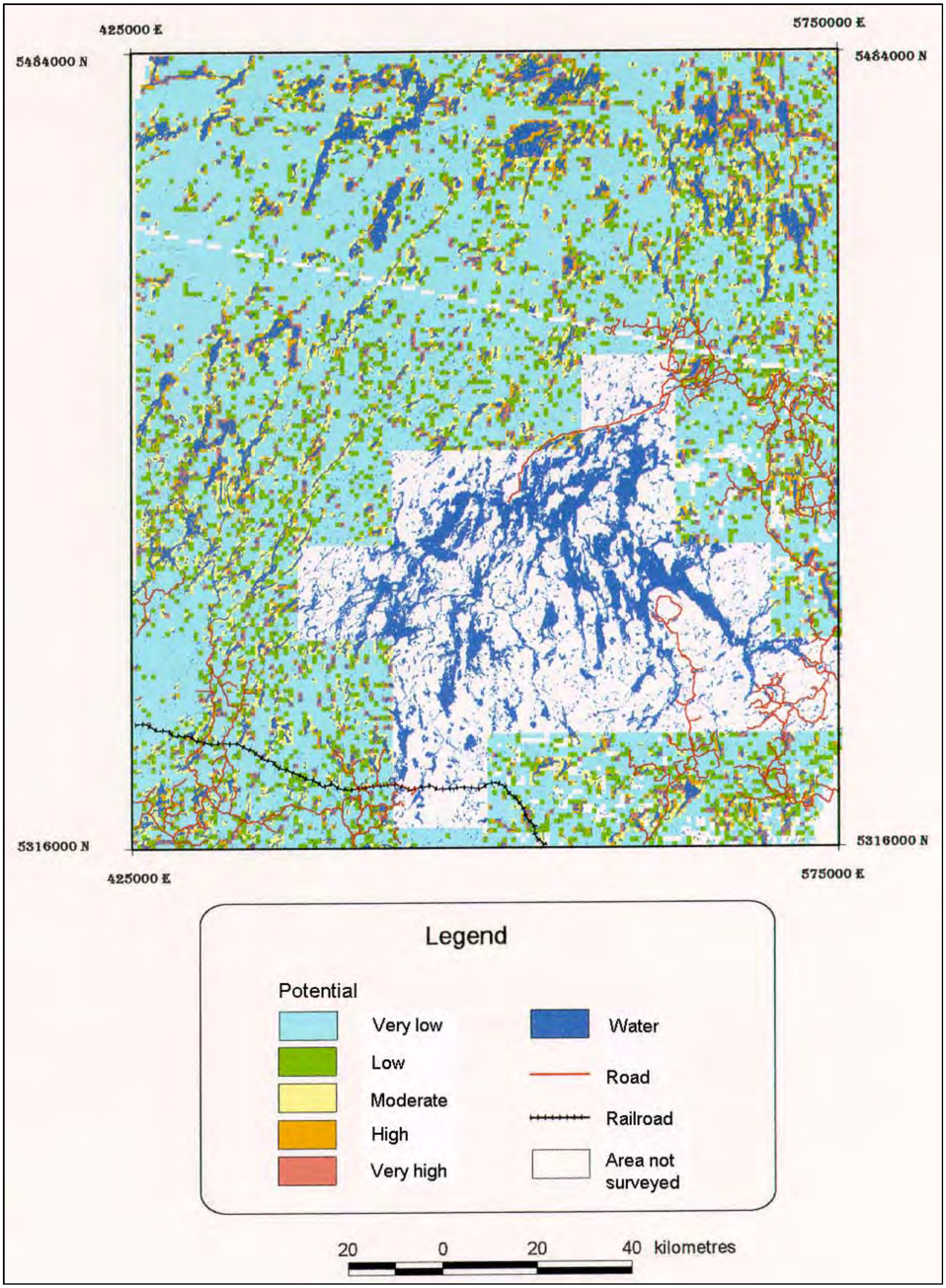

Figure 11. Potential distribution of the Canada Goose during the breeding season in the Gouin Reservoir region, Québec

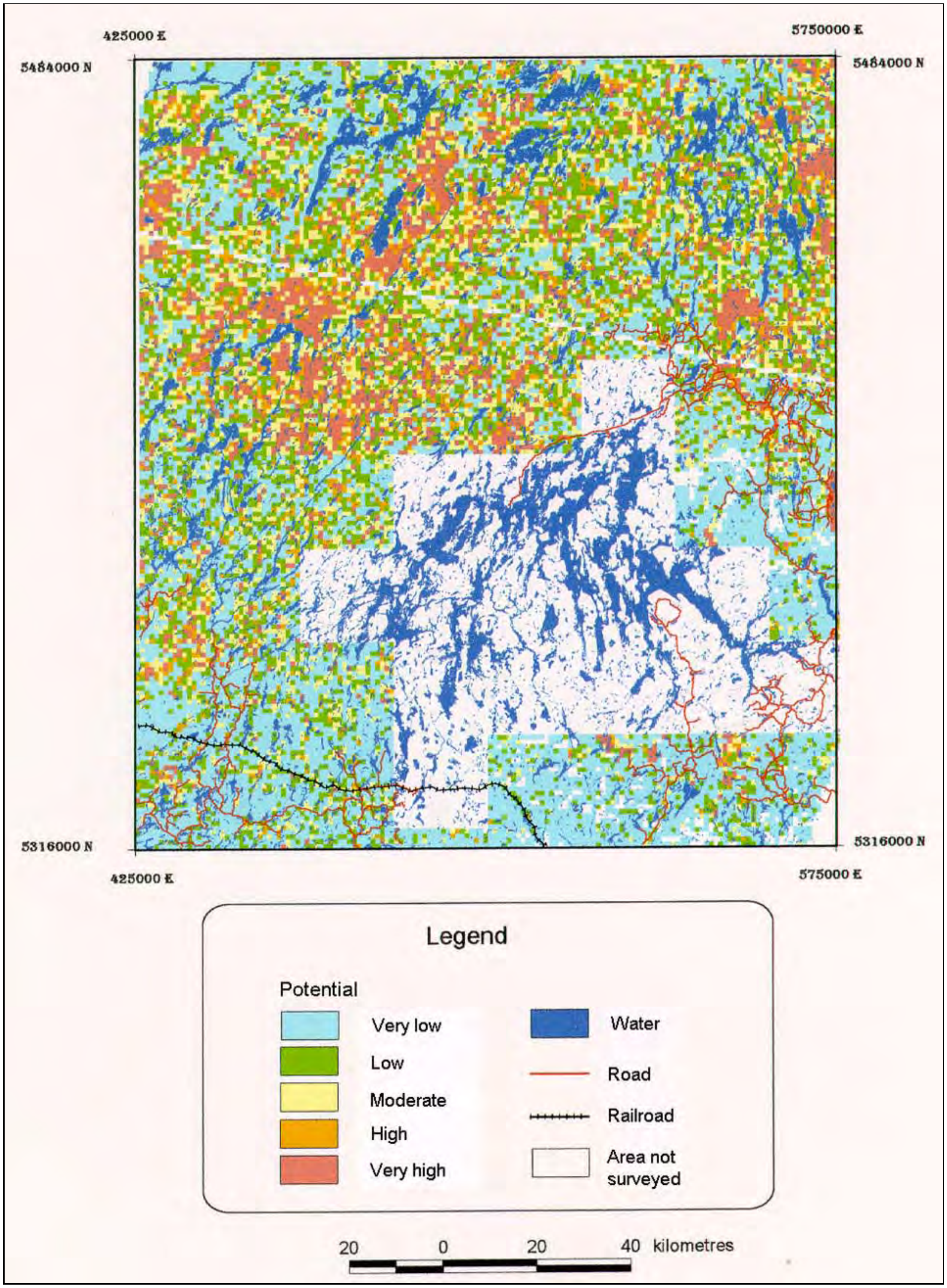

Figure 12. Potential distribution of the Mallard during the breeding season in the Gouin Reservoir region, Québec

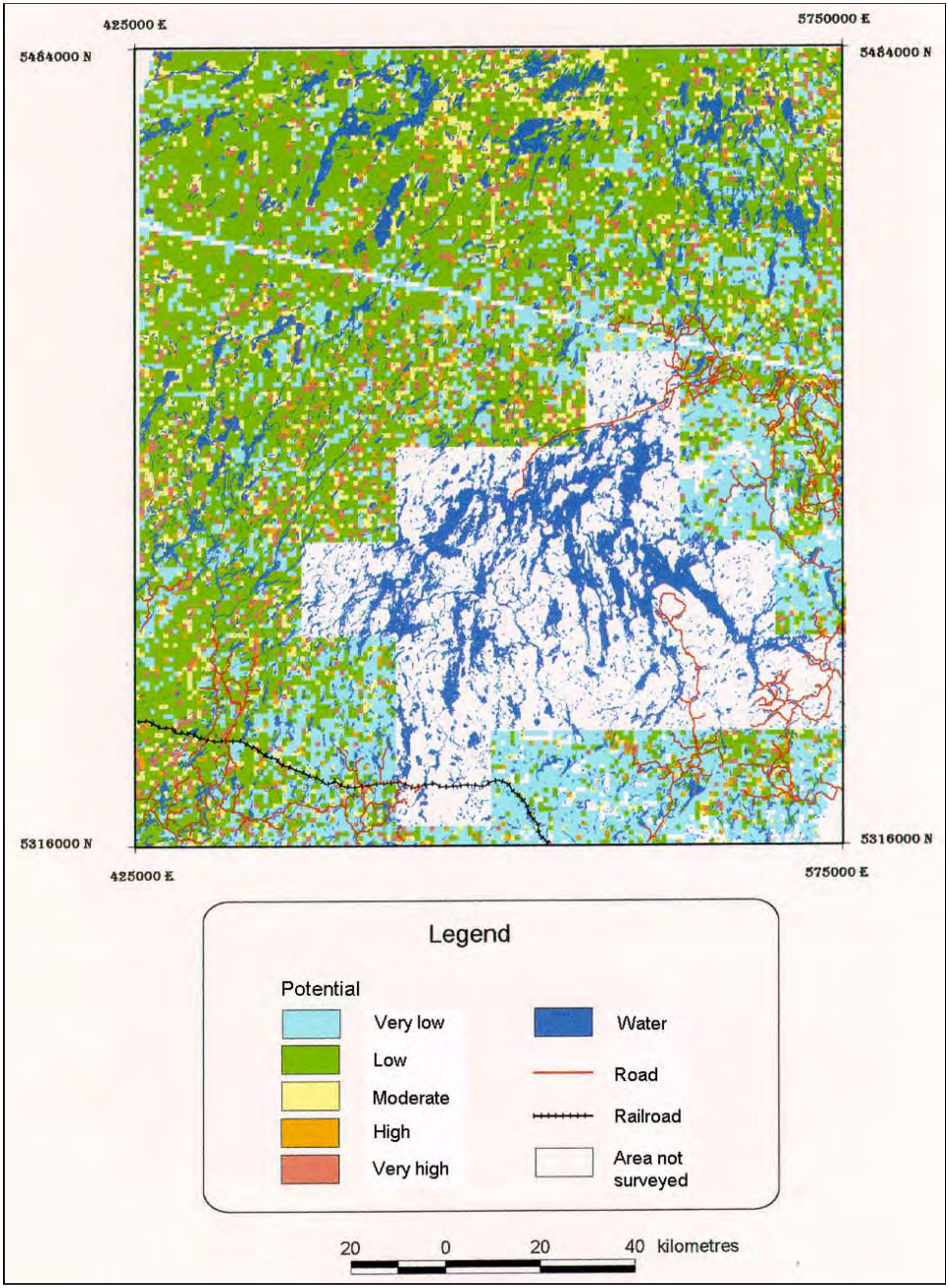

Figure 13. Potential distribution of the Green-winged Teal during the breeding season in the Gouin Reservoir region, Québec

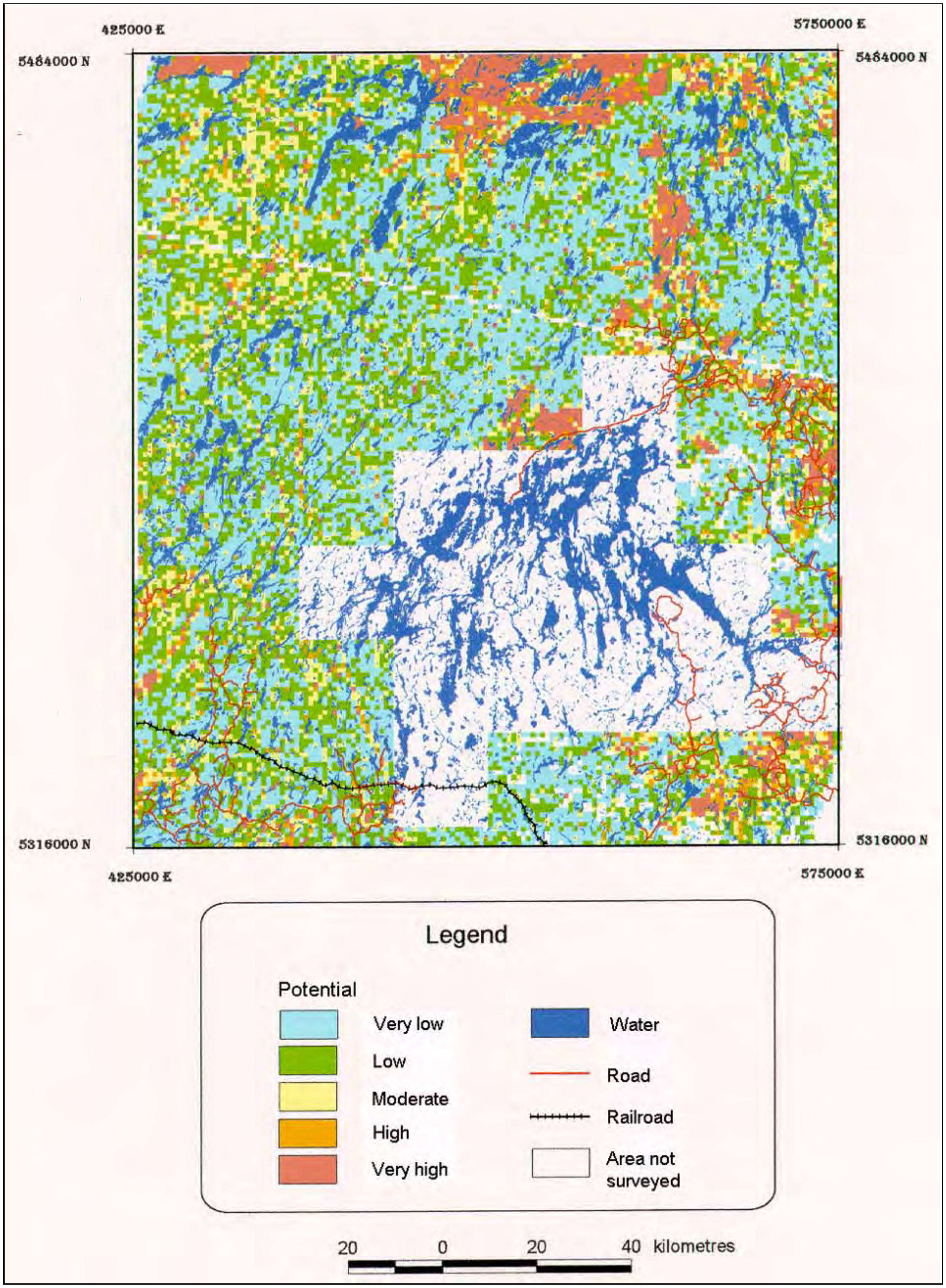

Figure 14. Potential distribution of the Bufflehead during the breeding season in the Gouin Reservoir region, Québec

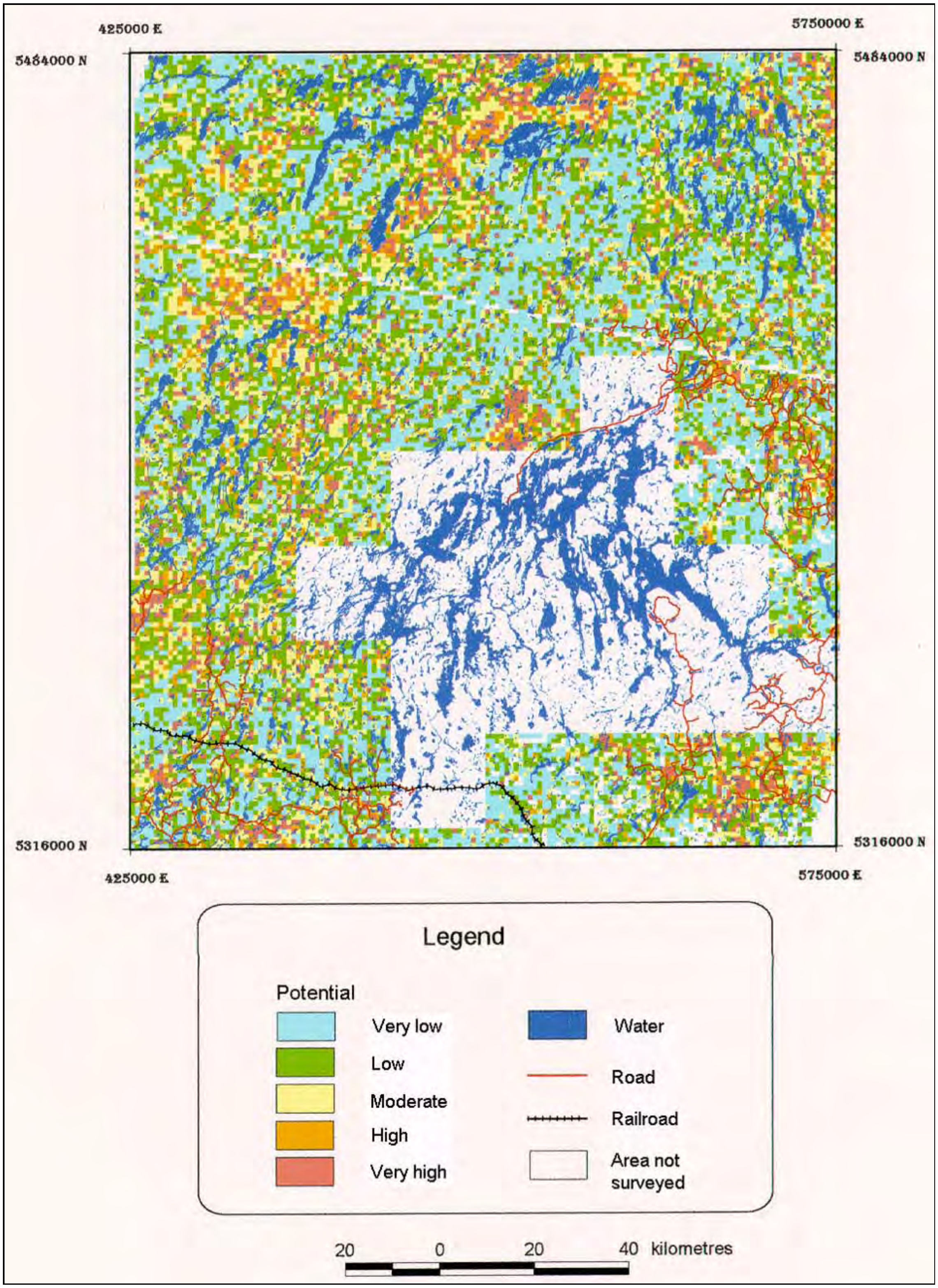

Figure 15. Potential distribution of the Hooded Merganser during the breeding season in the Gouin Reservoir region, Québec

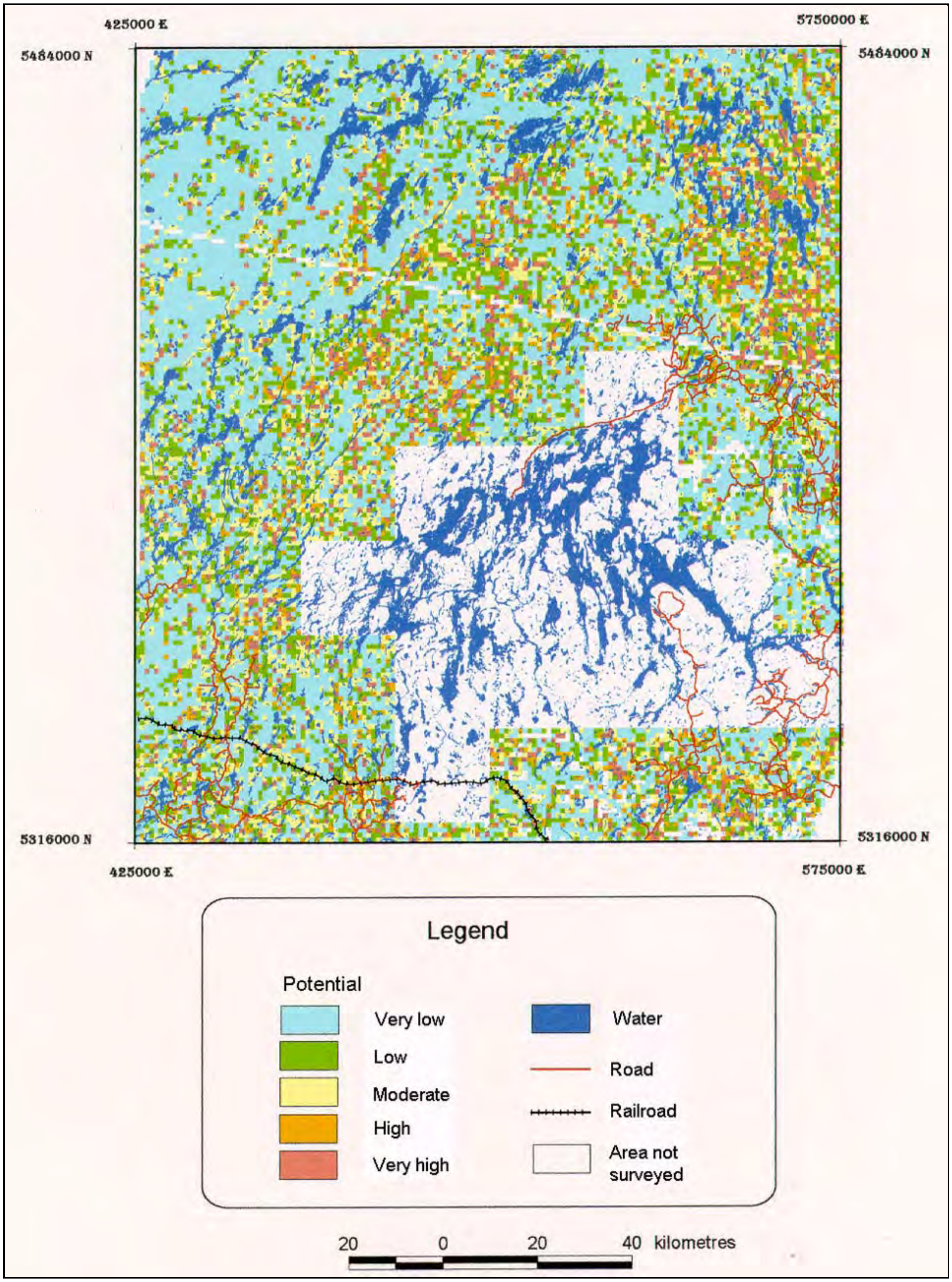

Figure 16. Species richness (loon and waterfowl) during the breeding season in the Gouin Reservoir region, Québec

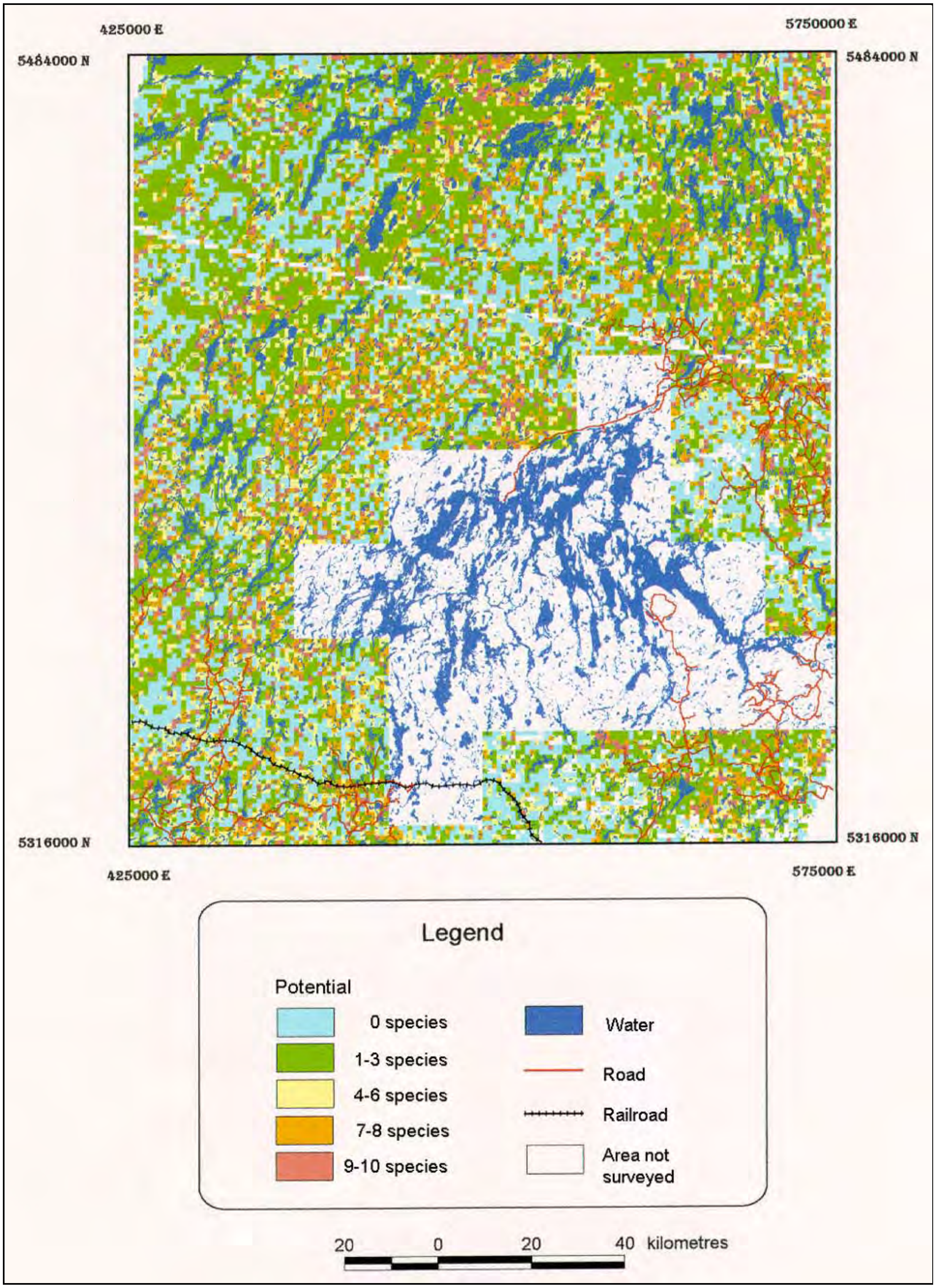

Figure 17. Distribution (%) of 1-km^2 units according to whether American Black Duck pairs were observed (present) or not (absent) in different potential classes as predicted by model based on 1985-89 survey data, from a sample of 198 km^2 overflown during aerial surveys from 1996 to 2000

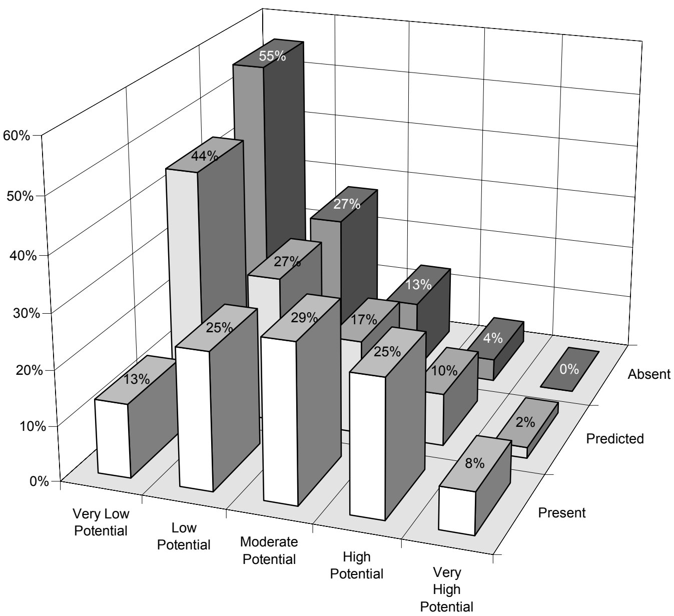

Figure 18. Distribution (%) of 1-km^2 units according to whether Common Merganser pairs were observed (present) or not (absent) in different potential classes as predicted by model based on 1985-89 survey data, from a sample of 198 km^2 overflown during aerial surveys from 1996 to 2000

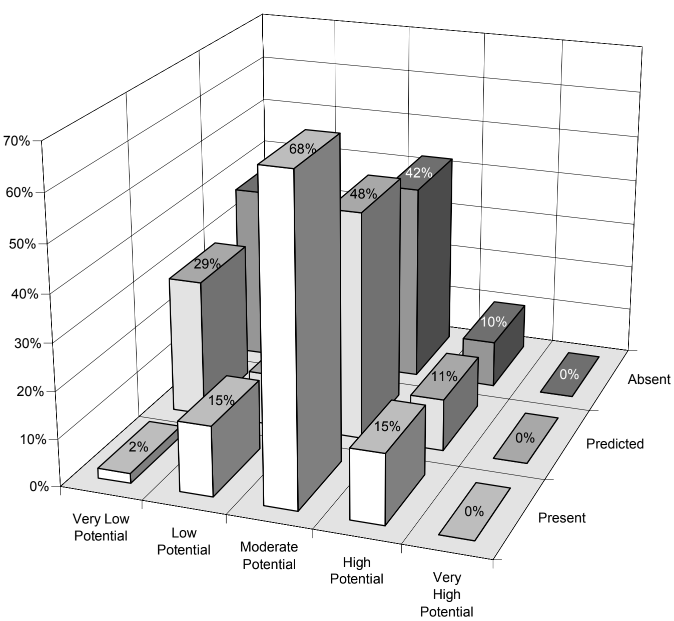

Figure 19. Distribution (%) of 1-km^2 units according to whether Common Goldeneye pairs were observed (present) or not (absent) in different potential classes as predicted by model based on 1985-89 survey data,from a sample of 198 km^2 overflown during aerial surveys from 1996 to 2000

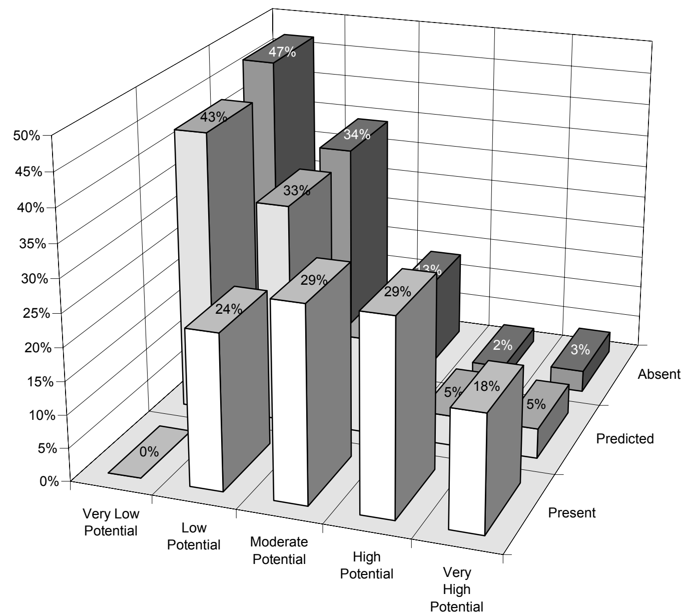

Figure 20. Distribution (%) of 1-km^2 units according to whether Ring-necked Duck pairs were observed (present) or not (absent) in different potential classes as predicted by model based on 1985-89 survey data, from a sample of 198 km^2 overflown during aerial surveys from 1996 to 2000

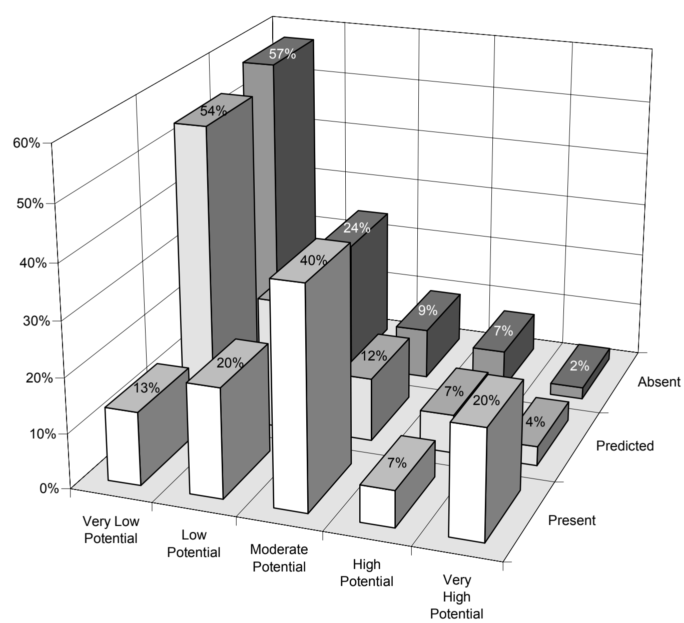

Figure 21. Distribution (%) of 1-km^2 units according to number of species observed in different species richness potential classes (predictions), from a sample of 198 km^2 overflown during aerial surveys from 1996 to 2000

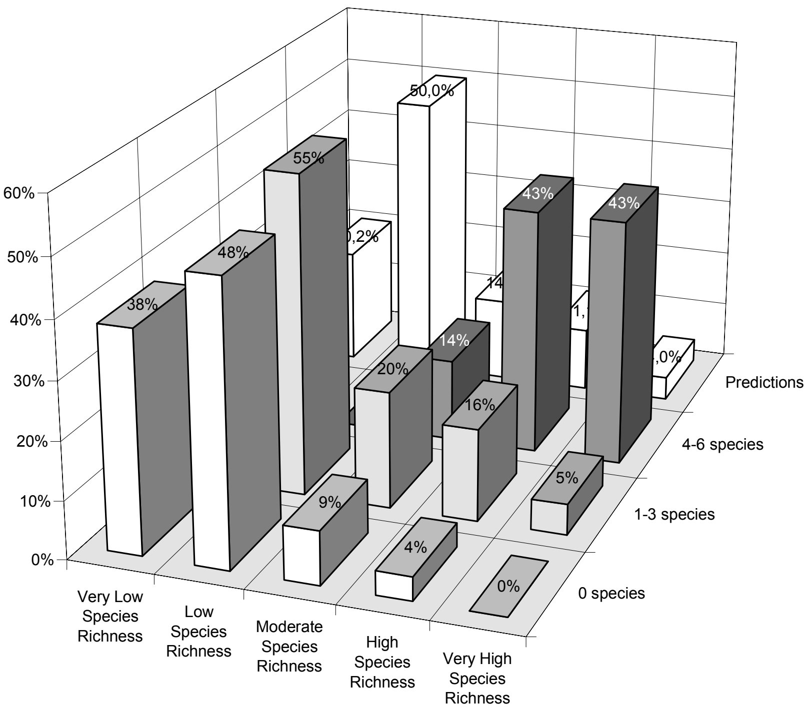

Figure 22. Comparison of American Black Duck density (pairs/km^2) predicted by model based on 1985-89 data with density (pairs/km^2) observed in 1996-2000, from a sample of 198 km^2

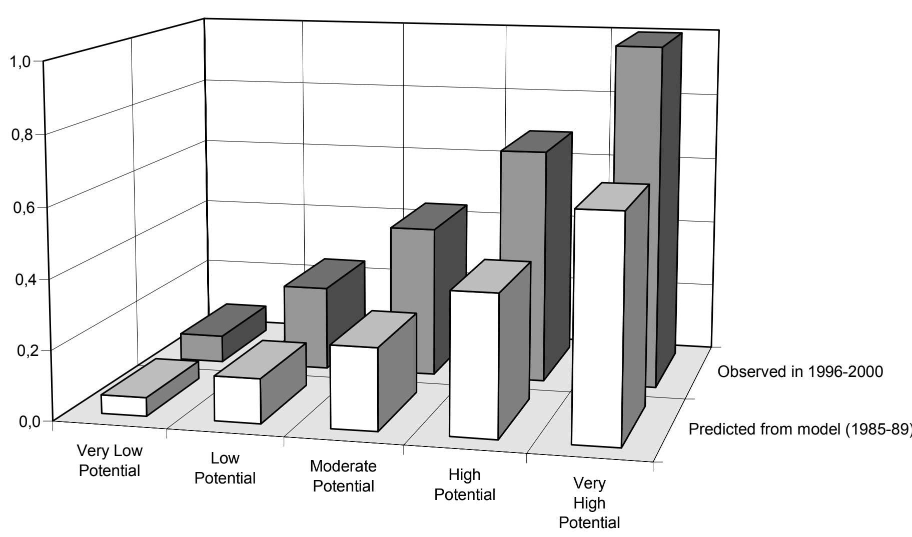

Table 1. Landsat-TM image acquisition parameters

Parameter	Gouin Reservoir image
Track	16
Frame	26
Date	3 August 1990
Pixel size	25 m (resampled)
Geometric correction to correspond to UTM grid (zone 18)	Algorithm corrected (cubic convolution)
Scene size	6000 columns × 6720 rows
Spectral bands	TM1 0,45 to 0,52 μm TM2 0,52 to 0,60 μm TM3 0,63 to 0,69 μm TM4 0,76 to 0,90 μm TM5 1,55 to 1,75 μm TM6 10,4 to 12,5 μm TM7 2,10 to 2,35 μm

Table 2. Survey conditions, 1985-89

Year	Period (dd/mm)	Length (days) [a]	Temperature (°C) [b]	Duration (min) [c]
1985	11/05-26/05	9 (4-14)	9 (–2-22)	38 (17-67)
1986	12/05-27/05	9 (6-14)	15 (–2-27)	37 (15-63)
1987	05/05-20/05	10 (7-14)	7 (–5-22)	43 (16-71)
1988	10/05-24/05	8 (3-12)	10 (–10-31)	46 (21-82)
1989	09/05-24/05	9 (6-13)	15 (–6-27)	50 (22-84)

[a] Number of days between the first and third overflight of a plot: mean (minimum-maximum).

[b] Air temperature recorded from helicopter during surveys: mean (minimum-maximum).

[c] Duration of survey of a plot (100 km^2): mean (minimum-maximum).

Table 3. Mean pair densities (1985-89) obtained during helicopter surveys (in decreasing order of abundance); density of occurrence corresponds to the number of pairs recorded after transformation of data into presence/absence data.

Species	Code	Observed density/ km^2 ± SD	Density of occurrence/ km^2 ± SD
American Black Duck (*Anas rubripes*)	ABDU	0,263 ± 0,0099	0,175 ± 0,0058
Common Merganser (*Mergus merganser*)	COME	0,190 ± 0,0078	0,142 ± 0,0051
Common Goldeneye (*Bucephala clangula*)	COGO	0,162 ± 0,0082	0,109 ± 0,0046
Ring-necked Duck (*Aythya collaris*)	RNDU	0,097 ± 0,0058	0,072 ± 0,0038
Common Loon (*Gavia immer*)	COLO	0,058 ± 0,0041	0,048 ± 0,0031
Canada Goose (*Branta canadensis*)	CAGO	0,044 ± 0,0042	0,032 ± 0,0026
Mallard (*Anas platyrhynchos*)	MALL	0,015 ± 0,0023	0,011 ± 0,0016
Green-winged Teal (*Anas crecca*)	AGWT	0,012 ± 0,0017	0,011 ± 0,0015
Bufflehead (*Bucephala albeola*)	BUFF	0,011 ± 0,0017	0,009 ± 0,0014
Hooded Merganser (*Lophodytes cucullatus*)	HOME	0,008 ± 0,0014	0,008 ± 0,0013

Table 4. Classification of Landsat-TM 16-26 image

Class (code)	Description	Area (ha)	Proportion (%)
BARESOIL	Bare soil; recent clearcutting; road	80 170	3,2
BOG	Bog	97 972	3,9
BURN	Burn; herbaceous vegetation; can include cutting with protection of regeneration (careful logging)	30 731	1,2
CLOUD	Clouds	449	0,0
DEEPWAT	Deep water	252 363	10,0
HARDWOOD	Hardwoods	79 853	3,2
MARSH	Marsh and alder swamp	73 452	2,9
MATSOFT	Mature softwood (also corresponds to defoliated or diseased softwoods)	92 998	3,7
MIXFOR	Mixed forest	288 823	11,4
OPENSOFT	Open softwood forest (density C-D)	195 835	7,7
SHALLWAT	Shallow water (also contains TURBWAT in calculations)	128 955	5,1
SOFTREG	Softwood regeneration resulting from logging 10 to 15 years before	24 128	1,0
SOFTWOOD	Pure softwood (density A-C; height 2-4; at least 50 years old)	695 703	27,5
SOMEREG	Clearcut with some regeneration (shrubs)	55 815	2,2
TURBWAT	Water with suspended sediments. Included in SHALLWAT.	-----	-----
UNCLASS	Unclassified pixels (ecotone) and edges of image	316 786	12,5
UNREG	Unregenerated clearcut (very wet); can include cutting with protection of regeneration	26 281	1,0
YOUNHARD	Young hardwoods (less than 10 years old). May include alder swamps	13 782	0,5
WINDTH	Open softwood forest (density D; softwood regeneration or open softwood forest resulting from windthrow 5 to 15 years before)	76 370	3,0
	TOTAL =	**2 530 466**	**100,0**
WATER0	Bodies of water > 1 ha and <= 5 ha	12 825	3,4
WATER5	Bodies of water > 5 ha and <= 10 ha	11 874	3,1
WATER10	Bodies of water > 10 ha and <= 100 ha	66 650	17,5
WATER100	Bodies of water > 100 ha	288 458	75,9
	TOTAL WATER (lake classes) =	379 807 [a]	100,0

[a] The difference between the total value for all lake classes (379 807 ha) and the total of SHALLWAT + DEEPWAT (381 318 ha) is due to the presence of bodies of water of less than 1 ha.

Table 5. Confusion matrix (CD = correct designation for class obtained through image analysis or user's accuracy [supervised classification]; CI = correct identification of class obtained from reference documents or producer's accuracy)

	BURN	WINDTH	SHALL WAT	DEEPWAT	SOFT WOOD	YOUN HARD	MARSH	MIXFOR	UNREG	CLOUD	SOME REG	SOFT REG	SOFT WOOD	MATSOFT	OPENSOFT	BARE SOIL	BOG	TOTAL	CD
BURN	**516**	1	0	0	0	1	470	4	184	0	15	0	3	0	22	424	0	1 640	31 %
WINDTH	2	**4 173**	0	0	65	0	963	151	0	0	9	1	0	0	1	0	0	5 365	78 %
SHALLWAT	0	0	**6 215**	324	0	0	0	0	0	0	0	0	0	16	0	0	0	6 555	95 %
DEEPWAT	0	0	277	**12 824**	0	0	0	0	0	0	0	0	0	0	0	0	0	13 101	98 %
SOFTWOOD	0	77	0	0	**8 584**	0	73	74	0	0	18	98	0	0	0	0	0	8 924	96 %
YOUNHARD	0	0	0	0	0	**2 884**	27	0	12	0	27	113	0	0	0	9	1	3 073	94 %
MARSH	70	25	1	0	0	0	**1 013**	3	17	0	305	0	0	0	137	9	15	1 595	64 %
MIXFOR	0	44	0	0	8	0	400	**10 561**	0	0	0	0	85	0	21	0	0	11 119	95 %
UNREG	231	0	0	0	0	44	169	0	**1 663**	0	63	0	0	0	0	14	0	2 184	76 %
CLOUD	0	0	0	0	0	0	2	0	0	**306**	0	0	0	0	0	5	0	313	98 %
SOMEREG	10	1	0	0	64	78	399	0	18	0	**3 082**	147	0	0	0	3	12	3 814	81 %
SOFTREG	0	0	0	0	78	26	195	0	0	0	4	**5 389**	0	0	0	0	0	5 692	95 %
SOFTWOOD	0	0	7	0	0	0	17	2	0	0	0	0	**21 177**	0	3	0	0	21 206	100 %
MATSOFT	0	0	61	0	0	0	0	0	0	0	0	0	126	**2 542**	0	0	0	2 729	93 %
OPENSOFT	2	5	2	0	0	0	198	122	0	0	0	0	306	0	**7 288**	0	0	7 923	92 %
BARESOIL	26	9	1	0	0	0	259	7	8	0	26	0	0	0	1	**5 572**	176	6 085	92 %
BOG	0	7	9	0	76	3	40	28	0	0	83	0	0	0	0	702	**11 111**	12 059	92 %
UNCLASS	4	5	533	0	135	64	141	230	1	7	2	32	518	86	89	257	62	2 166	
TOTAL	861	4 347	7 106	13 148	9 010	3 100	4 366	11 182	1 903	313	3 634	5 780	22 215	2 644	7 562	6 995	11 377	115 543	
CI	60 %	96 %	87 %	98 %	95 %	93 %	23 %	94 %	87 %	98 %	85 %	93 %	95 %	96 %	96 %	80 %	98 %		

Table 6. Descriptors and parameters retained to predict density of aquatic birds per km^2 (in decreasing order of abundance; for species codes, see Table 3 and for habitat codes, Table 4 [SQ precedes variables transformed by a square root transformation; the suffix 01 was added to variables transformed into binary variables])

Species Code	Descriptors and parameters retained
ABDU	-3,1291 + YEAR + 1,5856 SQWATER0 + 1,2403 SQWATER5 + 0,5113 SQWATE10 + 0,0168 WATER100 + 0,2744 SQDEEPWA - 0,1798 SQWATER0*SQDEEPWA - 0,2381 SQWATER5*SQDEEPWA - 0,0699 SQWATE10*SQDEEPWA - 0,0053 WATER100*SQDEEPWA - 0,0225 HARDWOOD + 0,2546 SOMERE01+ 0,5705 BOG01 - 1,0281 UTMEAST01 - 0,0842 UTMNOR01 + 0,6565 UTMEAST01*UTMNOR01 + SQWATER0*YEAR *where* YEAR : 1985 = -0,4530 ; 1986 = -0,7175 ; 1987 = -0,0303 ; 1988 = -0,2973 ; 1989 = 0,0000 *and* SQWATER0*YEAR : 1985 = -0,3067 SQWATER0 ; 1986 = -0,2712 SQWATER0 ; 1987 = -0,5156 SQWATER0 ; 1988 = 0,0355 SQWATER0 ; 1989 = 0,0000 SQWATER0
COME	-3,1888 + YEAR + 0,5006 WATER0 + 1,1441 SQWATER5 + 0,5210 SQWATE10 + 0,3246 SQWAT100 + 0,5007 SQDEEPWA - 0,0941 WATER0*SQDEEPWA - 0,2473 SQWATER5*SQDEEPWA - 0,0782 SQWATE10*SQDEEPWA - 0,0708 SQWAT100*SQDEEPWA + 0,1231 UTMNOR01 + SQWAT100*YEAR *where* YEAR : 1985 = -0,7927 ; 1986 = -0,8970 ; 1987 = -0,5348 ; 1988 = -0,6170 ; 1989 = 0,0000 *and* SQWAT100*YEAR : 1985 = 0,0914 SQWAT100 ; 1986 = -0,0014 SQWAT100 ; 1987 = 0,0429 SQWAT100 ; 1988 = 0,0833 SQWAT100 ; 1989 = 0,0000 SQWAT100
COGO	-3,6680 + YEAR + 0,7504 WATER0 + 1,1891 SQWATER5 + 0,6401 SQWATE10 + 0,1504 SQDEEPWA + 0,1090 SHALLWAT - 0,1261 WATER0*SQDEEPWA - 0,2153 SQWATER5*SQDEEPWA - 0,0521 SQWATE10*SQDEEPWA - 0,1087 SQUNCLAS + 0,0349 SOMEREG + 0,1810 SQMIXFOR *where* YEAR : 1985 = -0,4171 ; 1986 = -0,6753 ; 1987 = -0,1472 ; 1988 = -0,0900 ; 1989 = 0,0000
RNDU	-4,3605 + YEAR + 0,7679 WATER0 + 0,7235 WATER5 + 0,6092 SQWATE10 + 0,2505 SQTURBWA - 0,1489 SHALLWAT + 0,0027 SQDEEPWA - 0,0984 WATER0*SQDEEPWA - 0,1309 WATER5*SQDEEPWA - 0,0770 SQWATE10*SQDEEPWA + 0,4237 WATER0*SHALLWAT - 0,1159 WATER0*SQTURBWA - 0,1088 WATER5*SQTURBWA + 0,1632 SQBOG + 0,2395 SQMARSH + 0,0125 SOFTWOOD + 0,0489 YOUNHARD + SOFTWOOD*YEAR *where* YEAR : 1985 = -1,0226 ; 1986 = -0,5404 ; 1987 = -0,2973 ; 1988 = -0,0683 ; 1989 = 0,0000 *and* SOFTWOOD*YEAR : 1985 = -0,0006 SOFTWOOD ; 1986 = 0,0070 SOFTWOOD ; 1987 = -0,0004 SOFTWOOD ; 1988 = -0,0270 SOFTWOOD ; 1989 = 0,0000 SOFTWOOD

COLO	-4,1832 + YEAR + 0,1086 WATER10 + 0,6337 SQWAT100 + 0,3234 SQTURBWA + 0,3260 UTMEAST01 + 0,3275 WATER5 - 0,2842 SHALLW01 + 0,2337 SHALLW01*WATER0 + 0,0592 SHALLW01*SQWAT100 - 0,0739 SQDEEPWA*WATER5 - 0,0501 SQDEEPWA*SQWAT100 - 0,0080 BARESOIL + WATER10*YEAR + SQWAT100*YEAR + SQTURBWA*YEAR *where* YEAR : 1985 = -0,6656 ; 1986 = -0,8124 ; 1987 = -0,6554 ; 1988 = -0,5482 ; 1989 = 0,0000 *and* WATER10*YEAR : 1985 = 0,0050 WATER10 ; 1986 = 0,0030 WATER10 ; 1987 = -0,0235 WATER10 ; 1988 = -0,0038 WATER10 ; 1989 = 0,0000 WATER10 SQWAT100*YEAR : 1985 = -0,1827 SQWAT100 ; 1986 = 0,0783 SQWAT100 ; 1987 = -0,1515 SQWAT100 ; 1988 = 0,0847 SQWAT100 ; 1989 = 0,0000 SQWAT100 SQTURBWA*YEAR : 1985 = 0,1296 SQTURBWA ; 1986 = -0,2959 SQTURBWA ; 1987 = -0,1799 SQTURBWA ; 1988 = -0,2979 SQTURBWA ; 1989 = 0,0000 SQTURBWA
CAGO	-7,4302 + YEAR + 0,8120 SQWATER0 + 0,2501 WATER5 + 0,0631 WATER10 + 0,7048 TURBWA01 + 0,0305 SOFTWOOD + 0,4015 BURN01 - 0,0163 DEEPWAT*WATER5 + 0,0016 DEEPWAT + 0,6484 SQBARESO + 0,0610 BOG + 0,7611 UTMNOR01 + SQBARESO*YEAR + WATER10*YEAR *where* YEAR : 1985 = -0,8092 ; 1986 = -0,3655 ; 1987 = -0,9819 ; 1988 = 1,0959 ; 1989 = 0,0000 *and* SQBARESO*YEAR : 1985 = 0,0158 SQBARESO ; 1986 = 0,0861 SQBARESO ; 1987 = -0,2415 SQBARESO ; 1988 = -0,5625 SQBARESO ; 1989 = 0,0000 SQBARESO WATER10*YEAR : 1985 = 0,0156 WATER10 ; 1986 = -0,0261 WATER10 ; 1987 = 0,0211 WATER10 ; 1988 = -0,0937 WATER10 ; 1989 = 0,0000 WATER10
MALL	-3,8534 + YEAR + 0,3010 WATER0 + 0,7484 WATER5 + 0,4073 SQTURBWA - 0,3476 SQNONCLA - 0,0735 SQDEEPWA - 0,1424 SQDEEPWA*WATER5 - 0,1297 SQTURBWA*WATER5 *where* YEAR : 1985 = -1,2084 ; 1986 = -0,5590 ; 1987 = -0,5881 ; 1988 = -0,0894 ; 1989 = 0,0000
AGWT	-5,6627 + YEAR + 0,1810 WATER5 + 0,3655 SQWATER0 + 0,2909 SQSOMERE + 0,5000 SQMARSH + 0,3543 SQYOUNHA - 0,0591 BARESOIL *where* YEAR : 1985 = -0,2116 ; 1986 = -1,4081 ; 1987 = -0,5400 ; 1988 = -0,1773 ; 1989 = 0,0000
BUFF	-6,9827 + YEAR + 0,3016 WATER0 + 0,2111 SQBOG + 0,5281 SQMARSH - 0,0535 WATER100 + 0,3244 SQDEEPWA + 0,3839 SQTURBWA + SQMARSH*YEAR *where* YEAR : 1985 = -1,9994 ; 1986 = -2,5651 ; 1987 = 1,8621 ; 1988 = 0,5617 ; 1989 = 0,0000 *and* SQMARSH*YEAR : 1985 = 0,1790 SQMARSH ; 1986 = 0,8084 SQMARSH ; 1987 = -0,2576 SQMARSH ; 1988 = -0,4109 SQMARSH ; 1989 = 0,0000 SQMARSH
HOME	-7,0720 + YEAR + 0,2875 SQMATSOF + 1,4910 BARESO01 - 0,0299 WATER10 - 0,1645 WATER100 + 0,9501 SQTURBWA + 0,7749 SQDEEPWA - 0,1294 SQTURBWA*WATER10 *where* YEAR : 1985 = -1,5507 ; 1986 = -1,7813 ; 1987 = -0,7064 ; 1988 = -0,7556 ; 1989 = 0,0000

Table 7. Evaluation of models retained (Table 6) to predict densities of aquatic birds per km^2 (in decreasing order of abundance)

Species	Hosmer-Lemeshow (P)	Somers' D	Classification accuracy (%) [a]		
			Overall [b]	Presence	Absence
American Black Duck	0,41	0,61	73	74	72
Common Merganser	0,13	0,56	65	81	63
Common Goldeneye	0,11	0,61	74	72	74
Ring-necked Duck	0,01	0,63	75	71	75
Common Loon	0,06	0,74	79	80	79
Canada Goose	0,97	0,65	72	74	72
Mallard	0,67	0,55	73	58	74
Green-winged Teal	1,00	0,58	78	58	78
Bufflehead	0,77	0,70	74	73	74
Hooded Merganser	0,62	0,72	75	71	75

[a] According to a contingency table for which the cutoff point is equal to the density of occurrence of the species (Table 2).

[b] For the American Black Duck (ABDU), the model predicts exactly what was observed (presence or absence) in 73% of cases, predicting that a pair was present (% sensitivity) in 74% of the units where a pair was observed and that a pair was absent (% specificity) in 72% of the units where no pairs were observed.

Table 8. Weakest correlations (r) obtained for year-by-year comparisons of probabilities of occurrence in each 1-km^2 unit for each species modelled (in decreasing order of abundance)

Species	Weakest correlation obtained (r)	Years compared
American Black Duck	0,948	1987 vs. 1988
Common Merganser	0,938	1985 vs. 1986
Common Goldeneye	0,993	1986 vs. 1989
Ring-necked Duck	0,845	1986 vs. 1988
Common Loon	0,790	1985 vs. 1988
Canada Goose	0,588	1985 vs. 1988
Mallard	0,996	1985 vs. 1989
Green-winged Teal	0,986	1986 vs. 1989
Bufflehead	0,294	1986 vs. 1988
Hooded Merganser	0,996	1986 vs. 1989

Table 9. Validation of models to predict the presence and absence of pairs of loon and waterfowl according to survey data obtained from 1996 to 2000 in 198 1-km^2 units (in decreasing order of abundance)

Species	Classification accuracy (%) [a]		
	Overall [b]	Presence	Absence
American Black Duck	78	60	84
Common Merganser	56	83	48
Common Goldeneye	81	76	81
Ring-necked Duck	80	67	81
Common Loon	53	0	53
Canada Goose	67	47	69
Mallard	82	82	50
Green-winged Teal	84	50	86
Bufflehead	72	0	72
Hooded Merganser	75	33	75

[a] According to a contingency table for which the cutoff point is equal to the density of occurrence of the species (Table 2).

[b] For the American Black Duck (ABDU), the model predicts exactly what was observed (presence or absence) in 78% of cases, predicting that a pair was present (% sensitivity) in 60% of the units where a pair was observed and that a pair was absent (% specificity) in 84% of the units where no pairs were observed.

Table 10. Distribution of 1-km^2 units depending on whether a loon or waterfowl pair was observed (presence [P]) or not (absence [A]) according to potential class determined by model (prediction [D]) from a sample of 198 km^2 surveyed from 1996 to 2000 (for species codes, see Table 3)

Species code	Observed density Total number of units with records (presence) 1996-2000 (pairs/km^2)		Distribution of 1-km^2 units				
			Very low potential n (%)	Low potential n (%)	Moderate potential n (%)	High potential n (%)	Very high potential n (%)
ABDU	52 (0,26)	P [a]	7 (13,5)	13 (25,0)	15 (28,8)	13 (25,0)	4 (7,7)
		D	88 (44,4)	53 (26,8)	34 (17,2)	19 (9,6)	4 (2,0)
		A	81 (55,5)	40 (27,4)	19 (13,0)	6 (4,1)	0 (0,0)
COME	47 (0,24)	P	1 (2,1)	7 (14,9)	32 (68,1)	7 (14,9)	0 (0,0)
		D	58 (29,3)	22 (11,1)	96 (48,5)	22 (11,1)	0 (0,0)
		A	57 (37,7)	15 (9,9)	64 (42,4)	15 (9,9)	0 (0,0)
COGO	17 (0,09)	P	0 (0,0)	4 (23,5)	5 (29,4)	5 (29,4)	3 (17,6)
		D	85 (42,9)	66 (33,3)	29 (14,6)	9 (4,5)	9 (4,5)
		A	85 (47,0)	62 (34,3)	24 (13,3)	4 (2,2)	6 (3,3)
RNDU	15 (0,08)	P	2 (13,3)	3 (20,0)	6 (40,0)	1 (6,7)	3 (20,0)
		D	107 (54,0)	47 (23,7)	23 (11,6)	14 (7,1)	7 (3,5)
		A	105 (57,4)	44 (24,0)	17 (9,3)	13 (7,1)	4 (2,2)
COLO	0 (0,00)	P	0 (0,0)	0 (0,0)	0 (0,0)	0 (0,0)	0 (0,0)
		D	81 (40,9)	23 (11,6)	48 (24,2)	38 (19,2)	8 (4,0)
		A	81 (40,9)	23 (11,6)	48 (24,2)	38 (19,2)	8 (4,0)
CAGO	19 (0,10)	P	4 (21,1)	6 (31,6)	5 (26,3)	0 (0,0)	4 (21,1)
		D	84 (42,4)	49 (24,7)	32 (16,2)	9 (4,5)	24 (12,1)
		A	80 (44,7)	43 (24,0)	27 (15,1)	9 (5,0)	20 (11,2)
MALL	2 (0,01)	P	1 (50,0)	0 (0,0)	1 (50,0)	0 (0,0)	0 (0,0)
		D	58 (29,3)	104 (52,5)	24 (12,1)	4 (2,0)	8 (4,0)
		A	57 (29,1)	104 (53,1)	23 (11,7)	4 (2,0)	8 (4,1)
AGWT	10 (0,05)	P	0 (0,0)	5 (50,0)	3 (30,0)	0 (0,0)	2 (20,0)
		D	117 (59,1)	50 (25,3)	20 (10,1)	5 (2,5)	6 (3,0)
		A	117 (62,2)	45 (23,9)	17 (9,0)	5 (2,7)	4 (2,1)
BUFF	1 (0,01)	P	1 (100,0)	0 (0,0)	0 (0,0)	0 (0,0)	0 (0,0)
		D	85 (42,9)	58 (29,3)	28 (14,1)	12 (6,1)	15 (7,6)
		A	84 (42,6)	58 (29,4)	28 (14,2)	12 (6,1)	15 (7,6)
HOME	3 (0,02)	P	1 (33,3)	1 (33,3)	1 (33,3)	0 (0,0)	0 (0,0)
		D	111 (56,1)	38 (19,2)	25 (12,6)	8 (4,0)	16 (8,1)
		A	110 (56,4)	37 (19,0)	24 (12,3)	8 (4,1)	16 (8,2)

[a] P = Proportion of units where a pair was observed in 1996-2000;
D = Distribution of 198 units in potential classes as predicted by models using 1985-89 survey data;
A = Proportion of units where no pair was observed in 1996-2000.
The total of each line (P, D or A) is 100%.

Table 11. Distribution of 1-km^2 units by class of potential species richness (prediction), according to the number of species observed during surveys in 1996-2000 with a sample of 198 km^2

Number of species observed	**Distribution of 1-km^2 units**				
	Very low species richness n (%)	**Low species richness** n (%)	**Moderate species richness** n (%)	**High species richness** n (%)	**Very high species richness** n (%)
0	**37 (18,7)** [a]	47 (23,7)	9 (4,5)	4 (2,0)	0 (0,0)
1-3	3 (1,5)	**52 (26,3)**	19 (9,6)	15 (7,6)	5 (2,5)
4-6	0 (0,0)	0 (0,0)	**1 (0,5)**	3 (1,5)	3 (1,5)
7-8	0 (0,0)	0 (0,0)	0 (0,0)	**0 (0,0)**	0 (0,0)
9-10	0 (0,0)	0 (0,0)	0 (0,0)	0 (0,0)	**0 (0,0)**
Prediction	40 (20,2)	99 (50,0)	29 (14,6)	22 (11,1)	8 (4,0)

[a] Figures in bold-faced type correspond to the correct observations in relation to predictions made by models based on 1985-89 survey data (last line).

Table 12. Coverage of each habitat class (%) in two proposed routes for a road with a length of 167 km and right of way (width) of 1 km (habitat classes are listed in decreasing order of area occupied in route 1)

Habitat	Route 1 (UTMEAST = 435 000 m)	Route 2 (UTMEAST = 455 000 m)
SOFTWOOD	26,9	36,7
OPENSOFT	13,3	15,1
MIXFOR	13,1	14,3
DEEPWAT	10,3	8,9
UNCLASS	6,2	6,1
BARESOIL	6,1	2,1
BOG	5,2	5,4
WINDTH	4,6	2,3
MARSH	2,8	2,7
HARDWOOD	2,5	1,7
BURN	1,6	0,2
TURBWAT	1,6	1,2
SOMEREG	1,6	1,2
MATSOFT	1,5	1,5
YOUNHARD	0,9	0,2
SOFTREG	0,9	0,2
UNREG	0,7	0,1
SHALLWAT	0,1	0,1
TOTAL	100, 0	100,0
Proportion of water	12,0	10,2
WATER100	74,0	55,6
WATER10	20,3	34,0
WATER0	3,7	7,3
WATER5	2,0	3,1
TOTAL	100,0	100,0

Table 13. Simulation of a proposed road construction project, comparing two proposed routes, each 167 km long and with a right of way (width) of 1 km. The values shown were calculated based on the probabilities of occurrence predicted by the models (mean of five years) (species in decreasing order of abundance).

	Route 1 (UTMEAST = 435 000 m)			**Route 2 (UTMEAST = 455 000 m)**		
	Min.-Max.	**Mean ± SD**	**Total**	**Min.-Max.**	**Mean ± SD**	**Total**
American Black Duck	0,015-0,785	0,185 ± 0,013	30,9	0,030-0,698	0,225 ± 0,013	37,6
Common Merganser	0,024-0,550	0,133 ± 0,009	22,2	0,024-0,424	0,153 ± 0,009	25,5
Common Goldeneye	0,012-0,728	0,120 ± 0,009	17,7	0,017-0,442	0,122 ± 0,008	20,4
Ring-necked Duck	0,011-0,454	0,058 ± 0,005	9,7	0,008-0,367	0,079 ± 0,006	13,2
Common Loon	0,006-0,452	0,044 ± 0,005	7,3	0,009-0,797	0,049 ± 0,007	8,1
Canada Goose	0,002-0,551	0,038 ± 0,005	6,4	0,001-0,288	0,035 ± 0,003	5,8
Mallard	0,001-0,064	0,011 ± 0,001	1,8	0,001-0,067	0,013 ± 0,001	2,1
Green-winged Teal	0,001-0,064	0,008 ± 0,001	1,3	0,002-0,031	0,009 ± 0,000	1,5
Bufflehead	0,000-0,083	0,010 ± 0,001	1,7	0,001-0,076	0,012 ± 0,001	1,9
Hooded Merganser	0,000-0,078	0,006 ± 0,001	1,0	0,000-0,046	0,008 ± 0,001	1,3
Total (pairs)			**100,0**			**117,0**

Appendix 1. Standard error, chi-square and observed threshold (probability > chi-square) of parameters used in models (species codes are listed in Table 3 and habitat codes in Table 4; species in decreasing order of abundance)

Species code	Descriptors	Estimated parameters	Standard error	Chi-square	Observed threshold
ABDU	INTERCEPT	-3,1291	0,2291	186,47	0,0001
	YEAR 1985	-0,4530	0,1948	5,41	0,0201
	YEAR 1986	-0,7175	0,1685	18,13	0,0001
	YEAR 1987	-0,0303	0,1792	0,03	0,8658
	YEAR 1988	-0,2973	0,1716	3,00	0,0832
	YEAR 1989	0,0000	- [a]	- [a]	- [a]
	SQWATER0	1,5856	0,1758	81,33	0,0001
	SQWATER5	1,2403	0,1723	51,81	0,0001
	SQWATE10	0,5113	0,0853	35,96	0,0001
	WATER100	0,0168	0,0207	0,66	0,4181
	SQDEEPWA	0,2744	0,0856	10,28	0,0013
	SQWATER0*SQDEEPWA	-0,1798	0,0459	15,37	0,0001
	SQWATER5*SQDEEPWA	-0,2381	0,0590	16,30	0,0001
	SQWATE10*SQDEEPWA	-0,0699	0,0172	16,59	0,0001
	WATER100*SQDEEPWA	-0,0053	0,0021	6,73	0,0095
	HARDWOOD	-0,0225	0,0078	8,40	0,0038
	SOMERE01	0,2546	0,1227	4,30	0,0381
	BOG01	0,5705	0,1639	12,11	0,0005
	UTMEAST01	-1,0281	0,1963	27,43	0,0001
	UTMNOR01	-0,0842	0,1119	0,57	0,4518
	UTMEAST01*UTMNOR01	0,6565	0,2309	8,09	0,0045
	SQWATER0*YEAR 1985	-0,3067	0,2207	1,93	0,1647
	SQWATER0*YEAR 1986	-0,2712	0,1773	2,34	0,1260
	SQWATER0*YEAR 1987	-0,5156	0,1976	6,81	0,0091
	SQWATER0*YEAR 1988	0,0355	0,1930	0,03	0,8539
	SQWATER0*YEAR 1989	0,0000	- [a]	- [a]	- [a]
COME	INTERCEPT	-3,1888	0,1707	348,85	0,0001
	YEAR 1985	-0,7927	0,1970	16,19	0,0001
	YEAR 1986	-0,8970	0,1566	32,80	0,0001
	YEAR 1987	-0,5348	0,1707	9,82	0,0017
	YEAR 1988	-0,6170	0,1651	13,96	0,0002
	YEAR 1989	0,0000	- [a]	- [a]	- [a]
	WATER0	0,5006	0,0833	36,09	0,0001
	SQWATER5	1,1441	0,1907	36,00	0,0001
	SQWATE10	0,5210	0,0945	30,39	0,0001
	SQWAT100	0,3246	0,0818	15,75	0,0001
	SQDEEPWA	0,5007	0,0978	26,19	0,0001
	WATER0*SQDEEPWA	-0,0941	0,0278	11,49	0,0007
	SQWATER5*SQDEEPWA	-0,2473	0,0620	15,92	0,0001
	SQWATE10*SQDEEPWA	-0,0782	0,0177	19,55	0,0001
	SQWAT100*SQDEEPWA	-0,0708	0,0087	67,09	0,0001
	UTMNOR01	0,1231	0,0990	1,54	0,2140
	SQWAT100*YEAR 1985	0,0914	0,0456	4,01	0,0453
	SQWAT100*YEAR 1986	-0,0014	0,0468	0,00	0,9756
	SQWAT100*YEAR 1987	0,0429	0,0497	0,74	0,3883
	SQWAT100*YEAR 1988	0,0833	0,0440	3,59	0,0581
	SQWAT100*YEAR 1989	0,0000	- [a]	- [a]	- [a]
COGO	INTERCEPT	-3,6680	0,2421	229,56	0,0001
	YEAR 1985	-0,4171	0,1790	5,43	0,0198
	YEAR 1986	-0,6753	0,1520	19,73	0,0001
	YEAR 1987	-0,1472	0,1621	0,82	0,3640
	YEAR 1988	-0,0900	0,1514	0,35	0,5525

	YEAR 1989	0,0000	-[a]	-[a]	-[a]
	WATER0	0,7504	0,0770	95,04	0,0001
	SQWATER5	1,1891	0,1852	41,21	0,0001
	SQWATE10	0,6401	0,0807	62,90	0,0001
	SQDEEPWA	0,1504	0,0304	24,52	0,0001
	SHALLWAT	0,1090	0,0422	6,67	0,0098
	WATER0*SQDEEPWA	-0,1261	0,0283	19,91	0,0001
	SQWATER5*SQDEEPWA	-0,2153	0,0664	10,51	0,0012
	SQWATE10*SQDEEPWA	-0,0521	0,0171	9,24	0,0024
	SQUNCLAS	-0,1087	0,0554	3,85	0,0497
	SOMEREG	0,0349	0,0089	15,44	0,0001
	SQMIXFOR	0,1810	0,0328	30,49	0,0001
RNDU	INTERCEPT	-4,3605	0,3571	149,10	0,0001
	YEAR 1985	-1,0226	0,5549	3,40	0,0654
	YEAR 1986	-0,5404	0,3669	2,17	0,1408
	YEAR 1987	-0,2973	0,3722	0,64	0,4244
	YEAR 1988	-0,0683	0,3534	0,04	0,8467
	YEAR 1989	0,0000	-[a]	-[a]	-[a]
	WATER0	0,7679	0,0915	70,49	0,0001
	WATER5	0,7235	0,0973	55,33	0,0001
	SQWATE10	0,6092	0,1145	28,32	0,0001
	SQTURBWA	0,2505	0,1278	3,84	0,0501
	SHALLWAT	-0,1489	0,1560	0,91	0,3398
	SQDEEPWA	0,0027	0,0603	0,00	0,9638
	WATER0*SQDEEPWA	-0,0984	0,0374	6,94	0,0084
	WATER5*SQDEEPWA	-0,1309	0,0315	17,31	0,0001
	SQWATE10*SQDEEPWA	-0,0770	0,0277	7,72	0,0055
	WATER0*SHALLWAT	0,4237	0,1496	8,02	0,0046
	WATER0*SQTURBWA	-0,1159	0,0644	3,24	0,0718
	WATER5*SQTURBWA	-0,1088	0,0428	6,46	0,0110
	SQBOG	0,1632	0,0460	12,57	0,0004
	SQMARSH	0,2395	0,0744	10,37	0,0013
	SOFTWOOD	0,0125	0,0066	3,59	0,0582
	YOUNHARD	0,0489	0,0222	4,84	0,0279
	SOFTWOOD*YEAR 1985	-0,0006	0,0135	0,00	0,9628
	SOFTWOOD*YEAR 1986	0,0070	0,0088	0,64	0,4232
	SOFTWOOD*YEAR 1987	-0,0004	0,0096	0,00	0,9652
	SOFTWOOD*YEAR 1988	-0,0270	0,0103	6,90	0,0086
	SOFTWOOD*YEAR 1989	0,0000	-[a]	-[a]	-[a]
COLO	INTERCEPT	-4,1832	0,2854	214,79	0,0001
	YEAR 1985	-0,6656	0,4668	2,03	0,1539
	YEAR 1986	-0,8124	0,4073	3,98	0,0461
	YEAR 1987	-0,6554	0,4529	2,09	0,1478
	YEAR 1988	-0,5482	0,4136	1,76	0,1851
	YEAR 1989	0,0000	-[a]	-[a]	-[a]
	WATER5	0,3275	0,1442	5,16	0,0231
	WATER10	0,1086	0,0178	37,14	0,0001
	SQWAT100	0,6337	0,1075	34,73	0,0001
	SQTURBWA	0,3234	0,1590	4,14	0,0419
	UTMEAST01	0,3260	0,1768	3,40	0,0651
	SHALLW01	-0,2842	0,3036	0,88	0,3492
	WATER0*SHALLW01	0,2337	0,1048	4,97	0,0258
	SQWAT100*SHALLW01	0,0592	0,0547	1,17	0,2792
	WATER5*SQDEEPWA	-0,0739	0,0454	2,65	0,1037
	SQWAT100*SQDEEPWA	-0,0501	0,0107	21,81	0,0001
	BARESOIL	-0,0080	0,0222	0,13	0,7184
	WATER10*YEAR 1985	0,0050	0,0275	0,03	0,8569
	WATER10*YEAR 1986	0,0030	0,0230	0,02	0,8975
	WATER10*YEAR 1987	-0,0235	0,0269	0,76	0,3821
	WATER10*YEAR 1988	-0,0038	0,0231	0,03	0,8692
	WATER10*YEAR 1989	0,0000	-[a]	-[a]	-[a]

	SQWAT100*YEAR 1985	-0,1827	0,1248	2,14	0,1432
	SQWAT100*YEAR 1986	0,0783	0,0879	0,80	0,3725
	SQWAT100*YEAR 1987	-0,1515	0,1416	1,15	0,2844
	SQWAT100*YEAR 1988	0,0847	0,0955	0,79	0,3749
	SQWAT100*YEAR 1989	0,0000	-[a]	-[a]	-[a]
	SQTURBWA*YEAR 1985	0,1296	0,2949	0,19	0,6603
	SQTURBWA*YEAR 1986	-0,2959	0,2532	1,37	0,2427
	SQTURBWA*YEAR 1987	-0,1799	0,3012	0,36	0,5504
	SQTURBWA*YEAR 1988	-0,2979	0,2548	1,37	0,2422
	SQTURBWA*YEAR 1989	0,0000	-[a]	-[a]	-[a]
CAGO	INTERCEPT	-7,4302	0,6045	151,06	0,0001
	YEAR 1985	-0,8092	0,5958	1,84	0,1744
	YEAR 1986	-0,3655	0,5084	0,52	0,4721
	YEAR 1987	-0,9819	0,6282	2,44	0,1180
	YEAR 1988	1,0959	0,4734	5,36	0,0206
	YEAR 1989	0,0000	-[a]	-[a]	-[a]
	SQWATER0	0,8120	0,1259	41,57	0,0001
	WATER5	0,2501	0,0879	8,10	0,0044
	WATER10	0,0631	0,0228	7,66	0,0057
	TURBWA01	0,7048	0,2401	8,62	0,0033
	SOFTWOOD	0,0305	0,0066	21,26	0,0001
	BURN01	0,4015	0,2045	3,85	0,0496
	DEEPWAT*WATER5	-0,0163	0,0109	2,25	0,1340
	DEEPWAT	0,0016	0,0119	0,02	0,8935
	SQBARESO	0,6484	0,1992	10,60	0,0011
	BOG	0,0610	0,0075	67,00	0,0001
	UTMNOR01	0,7611	0,2087	13,30	0,0003
	SQBARESO*YEAR 1985	0,0158	0,2946	0,00	0,9572
	SQBARESO*YEAR 1986	0,0861	0,2830	0,09	0,7610
	SQBARESO*YEAR 1987	-0,2415	0,2789	0,75	0,3864
	SQBARESO*YEAR 1988	-0,5625	0,2507	5,04	0,0248
	SQBARESO*YEAR 1989	0,0000	-[a]	-[a]	-[a]
	WATER10*YEAR 1985	0,0156	0,0300	0,27	0,6028
	WATER10*YEAR 1986	-0,0261	0,0308	0,72	0,3966
	WATER10*YEAR 1987	0,0211	0,0321	0,43	0,5118
	WATER10*YEAR 1988	-0,0937	0,0430	4,75	0,0292
	WATER10*YEAR 1989	0,0000	-[a]	-[a]	-[a]
MALL	INTERCEPT	-3,8534	0,5202	54,88	0,0001
	YEAR 1985	-1,2084	0,5736	4,44	0,0351
	YEAR 1986	-0,5590	0,3875	2,08	0,1492
	YEAR 1987	-0,5881	0,4676	1,58	0,2085
	YEAR 1988	-0,0894	0,3817	0,05	0,8148
	YEAR 1989	0,0000	-[a]	-[a]	-[a]
	WATER0	0,3010	0,0838	12,91	0,0003
	WATER5	0,7484	0,1985	14,21	0,0002
	SQTURBWA	0,4073	0,2007	4,12	0,0424
	SQNONCLA	-0,3476	0,1586	4,80	0,0284
	SQDEEPWA	-0,0735	0,0930	0,62	0,4293
	SQDEEPWA*WATER5	-0,1424	0,0653	4,76	0,0292
	SQTURBWA*WATER5	-0,1297	0,0852	2,32	0,1279
AGWT	INTERCEPT	-5,6627	0,4177	183,78	0,0001
	YEAR 1985	-0,2116	0,4705	0,20	0,6529
	YEAR 1986	-1,4081	0,5870	5,76	0,0164
	YEAR 1987	-0,5400	0,4530	1,42	0,2333
	YEAR 1988	-0,1773	0,4267	0,17	0,6778
	YEAR 1989	0,0000	-[a]	-[a]	-[a]
	SQWATER0	0,3655	0,2155	2,88	0,0898
	WATER5	0,1810	0,0500	13,11	0,0003
	SQSOMERE	0,2909	0,1059	7,54	0,0060

	SQMARSH	0,5000	0,1633	9,38	0,0022
	SQYOUNHA	0,3543	0,1378	6,61	0,0101
	BARESOIL	-0,0591	0,0394	2,24	0,1342
BUFF	INTERCEPT	-6,9827	0,8637	65,36	0,0001
	YEAR 1985	-1,9994	2,2406	0,80	0,3722
	YEAR 1986	-2,5651	1,4032	3,34	0,0675
	YEAR 1987	1,8621	0,8627	4,66	0,0309
	YEAR 1988	0,5617	1,0481	0,29	0,5920
	YEAR 1989	0,0000	-[a]	-[a]	-[a]
	WATER0	0,3016	0,0823	13,44	0,0002
	WATER100	-0,0535	0,0183	8,55	0,0035
	SQDEEPWA	0,3244	0,1168	7,72	0,0055
	SQTURBWA	0,3839	0,2277	2,84	0,0918
	SQBOG	0,2111	0,0866	5,94	0,0148
	SQMARSH	0,5281	0,4129	1,64	0,2010
	MARSH*YEAR 1985	0,1790	1,0030	0,03	0,8583
	MARSH*YEAR 1986	0,8084	0,5677	2,03	0,1544
	MARSH*YEAR 1987	-0,2576	0,4449	0,34	0,5626
	MARSH*YEAR 1988	-0,4109	0,5548	0,55	0,4589
	MARSH*YEAR 1989	0,0000	-[a]	-[a]	-[a]
HOME	INTERCEPT	-7,0720	1,1214	39,77	0,0001
	YEAR 1985	-1,5507	0,7617	4,14	0,0418
	YEAR 1986	-1,7813	0,5705	9,75	0,0018
	YEAR 1987	-0,7064	0,4962	2,03	0,1545
	YEAR 1988	-0,7556	0,4482	2,84	0,0918
	YEAR 1989	0,0000	-[a]	-[a]	-[a]
	WATER10	-0,0299	0,0655	0,21	0,6481
	WATER100	-0,1645	0,0357	21,29	0,0001
	SQTURBWA	0,9501	0,3943	5,81	0,0160
	SQDEEPWA	0,7749	0,2140	13,12	0,0003
	SQMATSOF	0,2875	0,1133	6,44	0,0112
	BARESO01	1,4910	1,0234	2,12	0,1451
	SQTURBWA*WATER10	-0,1294	0,0660	3,84	0,0500

[a] Not applicable.

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