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Research Papers

Potential Sensitivity of Québec's Breeding Birds to Climate Change

Sensibilité potentielle des oiseaux nicheurs du Québec aux changements climatiques

Jean-Luc DesGranges [1] *and François Morneau* [2]

ABSTRACT. We examined the relationship between climatic factors and the distribution of breeding birds in southern Québec, Canada to identify the species whose distribution renders them potentially sensitive to climate change in the study area. We determined the degree of association between the distribution of 65 breeding bird species (601 presence-absence squares of the Atlas of the Breeding Birds of Québec) and climate variables (212 climatological stations in operation for at least 20 years over the period 1953–1984) by statistically correcting for the effects of several factors that are correlated with bird distribution. Factors considered were the nature and scale of land cover patterns that included vegetation types and landscape characterization, geographical coordinates, and elevation. Canonical Correspondence Analysis (CCA) was used to investigate the effect of climatic variables on breeding bird distribution. Independent variables accounted for a total of 29.1% of the variation in the species matrix. A very large portion of the variance explained by climate variables was shared with spatial variables, reflecting the relationships among latitude, longitude, elevation, and climate. After correcting for the effect of land cover variables, climatic variables still explained 11.4% of the variation in the species matrix, with temperature, i.e., warmer summers and milder winters, having a greater influence than precipitation, i.e., wetter summers. Of the 65 species, 14 appeared to be particularly climate-sensitive. Eight are insectivorous neotropical migrants and six species are at the northern limit of their range in the study area. The opposite is largely true for the eight others; they are practically absent from the southern part of the study area, except for the Dark-eyed Junco (*Junco hyemalis*), which is widespread there. The White-breasted Nuthatch (*Sitta carolinensis*) is the only resident species that seemed responsive to climatic variables, i.e., milder winters. Climate warming is thus likely to induce northward shifts for several neotropical migrant species. Many species that currently breed in the northern portion of eastern United States are likely to move northward into Canada. It is thus crucial that sufficient habitats be preserved in Canada to accommodate these future “climate refugees.” Forests in the study area are under management for lumber and therefore, their conservation should receive particular attention.

RÉSUMÉ. La présente étude vise à examiner les liens entre les conditions climatiques et la distribution des oiseaux nicheurs du Québec (Canada) et à dégager les espèces qui paraissent les plus sensibles au climat, de manière à identifier des indicateurs potentiels des incidences du changement climatique sur les écosystèmes. L'approche méthodologique a consisté à déterminer le degré d'association entre la répartition de 65 espèces d'oiseaux nicheurs (601 parcelles de présence-absence de l'Atlas des oiseaux nicheurs du Québec) et des variables climatiques (212 stations climatologiques en opération au moins 20 ans sur la période 1953-1984) en supprimant statistiquement l'effet du maximum de facteurs qui peuvent l'obscurcir. Les facteurs qui ont été considérés sont la nature de l'affectation du sol et son importance, la description du paysage, les coordonnées géographiques et l'altitude. L'analyse canonique des correspondances (CCA) a été utilisée pour estimer l'effet des variables climatiques sur la répartition des espèces d'oiseaux nicheurs. L'ensemble des variables indépendantes expliquait 29,1 % de la variation de la matrice des espèces. Une

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très grande partie de la variation expliquée par les variables climatiques était partagée avec les variables spatiales traduisant de ce fait l'association entre latitude, longitude, altitude et climat. En supprimant l'effet des variables d'affectation du sol, les variables climatiques expliquaient encore une importante partie de la variation de la matrice des espèces (11,4 %). Une fois supprimé l'effet de l'affectation du sol, les variables décrivant la température (étés plus chauds et hivers moins froids) étaient prédominantes sur celles décrivant les précipitations (étés pluvieux). Lorsqu'on corrigeait pour l’effet des variables d’affectation du sol, la température avait plus d'effet sur la distribution des espèces étudiées que les précipitations. Quatorze (14 des 65) espèces paraissaient plus sensibles que d'autres au climat. La plupart (8) sont des migrateurs néo-tropicaux insectivores. Six de ces espèces atteignent la limite nord de leur aire de reproduction dans la zone d'étude. L'inverse est presque observé pour les huit autres espèces; elles sont pratiquement absentes au sud de la zone d'étude, sauf le Junco ardoisé (*Junco hyemalis*) qui y est répandu. Seule la répartition de la Sittelle à poitrine blanche (*Sitta carolinensis*) semblait réagir davantage aux variables climatiques parmi les espèces résidentes (hivers moins froids). Plusieurs espèces qui nichent actuellement dans la portion nord-est des États-Unis pourraient émigrer vers le nord. Il est donc essentiel que suffisamment d’habitats propices soient protégés au Canada pour héberger ces futurs « réfugiés climatiques ». Comme la forêt mixte est le siège d’une intense exploitation forestière, cela milite en faveur d’une attention accrue vis-à-vis du potentiel de conservation des forêts mixtes exploitées.

Key Words: *bioindicators; breeding bird distribution; climate change; habitat use; sensitivity to climate, Québec*

INTRODUCTION

With the continuous increase in atmospheric CO_2 and other greenhouse gases since the beginning of the industrial era, the world’s climate has already changed and may change quite considerably before the end of the 21st century (IPCC 2007). The long term management of biodiversity, in terms of both species and ecosystems, requires an adequate understanding of the responses of vegetation and animals to climate change (Kappelle et al. 1999). Changes are being seen in a broad range of taxa, from insects to mammals, and on several continents (UNEP and GRID-Arendal 2009). Birds, for example, are likely to react directly to climate changes such as repeated periods of rain, frost, and heat, and indirectly to changes in the environment that influence such features as food availability, habitat structure, and relationships among organisms. Such responses vary according to each species’ physiological tolerance, and most importantly as nestlings (Hayworth and Weathers 1984, Burton 1995, Thomas et al. 2001, Harrison et al. 2003, Huntley et al. 2006, Hitch and Leberg 2007, Devictor et al. 2008, Virkkala et al. 2008). For birds that are long-distance migrants, climate change may advance the phenology of their breeding areas, e.g., leaf flush, flowering, hatching of pest insect eggs, seed production, etc. (Thomas et al. 2001, Bertin 2008), but the timing of some species’ spring migration relies on endogenous rhythms that are not affected by climate change (Gwinner 1996). Thus, several generations may be required for an optimal adjustment of spring migration to the timing of peak food supply and nestling demand. This mismatching would force poorly adapted species to either advance or accelerate their migration so that they reach their breeding grounds earlier to breed at their period of optimal reproduction (Perrins 1970, Both and Visser 2001, Thomas et al. 2001). The adaptation process may also result in a modification in species’ distribution (Gates 1993, Huntley et al. 2006, Anciaes and Peterson 2006). The synergism of a rapid temperature rise and other stresses, in particular habitat destruction, could easily disrupt the connectedness among species and lead to a restructuring of species assemblages, reflecting different responses among species (Root et al. 2003). It could also lead to numerous extirpations and possibly extinctions (Thomas et al. 2004, Jiguet et al. 2006, Schwartz et al. 2006, Sekercioglu et al. 2008, Lawler et al. 2009).

This study examines the associations between climate and the distribution of breeding birds in Québec. Because birds are highly mobile, their adaptation to climate change may be observed more rapidly than in other organisms, and therefore some bird species may serve as early indicators of the effects of climate change on ecosystems and biodiversity. A quantitative approach was used to provide a statistical description of the relationships between species, climate, and habitat. Pairing data on temporal variation in local climates and bird populations was not possible, therefore the study focused entirely on spatial variation in climate, with the assumption that climatic change across space is equivalent to climatic change through time (Pearson and Dawson 2003). The objective of this study was to determine the relationships between certain climate descriptors and the distribution of breeding birds during the breeding season. A better understanding of these relationships will assist in the development and adaptation of tools for monitoring the effects of climate change on ecosystems and biodiversity.

METHODS

Study area

The study area extends from the southern border of Québec (45°N) to 50° 30'N latitude (~ 500,000 km^2; Fig. 1). This area encompasses three main geological regions: the Canadian Shield in the north, the Appalachians in the southeast, and the St. Lawrence Lowlands in between. Elevations range between sea level and approximately 150 m in lowland areas and between 250 m and 750 m on the Shield; however, they are more variable in the Appalachians, ranging from less than 100 m to 1268 m, with 500 m being the average. Six climate types (Litynski 1984) are found in the study area. The inland, and largest portion of the study area, has a continental moderate climate. The St. Lawrence Lowlands and the North Shore and Gaspé coastal areas occur in the continental moderate subhumid and continental subpolar subhumid zones, respectively. Other climate types are found only in small enclaves. Vegetation formations in the study area comprise, from south to north, sugar maple (*Acer saccharum*), balsam fir (*Abies balsamea*), and black spruce (*Picea mariana*) forests. Tundra-type formations are found only at the highest elevations. Most of the populated areas and agricultural lands are in the region dominated by sugar maple stands. The northern third of the study area is characterized by the black spruce-feather moss formation (NRC Atlas of Canada).

Bird, vegetation, and climate data

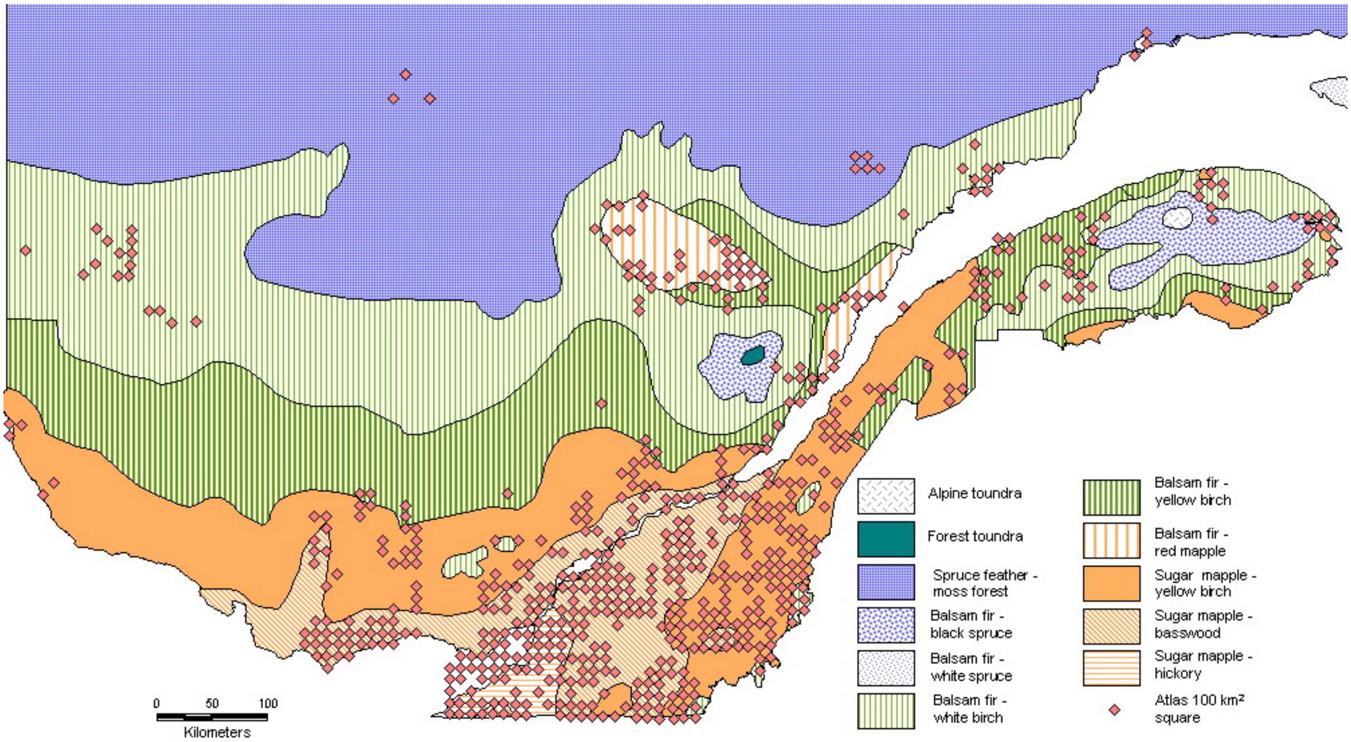
Dependent variable

Given our incomplete knowledge of the local nesting distribution of several of the breeding bird species of southern Québec, we chose to restrict our analysis to an array of candidate species that were found breeding (presence/absence) in at least 25%, but not more than 75%, of a selection of 601 10 km x 10 km squares well surveyed for the *Atlas of the Breeding Birds of Southern Québec* (Gauthier and Aubry 1996). Moreover, to maximize the probability of detecting potential climatic influences, we limited our analysis to a subset of 65 species that were selected on the basis of their expected vulnerability to climate extremes. We hypothesized that bird sensitivity to climate is associated with their life history traits and physical characteristics (Table 1). In order to verify this hypothesis we developed a sensitivity index based on 10 life history traits and physical characteristics, e.g., weight, breeding distribution, migration, foraging, etc; see Appendix 1). Of the 65 species, 18 were predicted to be of limited sensitivity to climate, 27 were predicted to be sensitive, and 20 were predicted to be very sensitive to climate (Appendix II; see Morneau et al. 1998 for details).

Independent variables

Climate data were obtained from Environment Canada's Meteorological Service for the period between 1954 and 1983, thus ending the year before the compiling of data for the *Atlas of the Breeding Birds of Québec* began. During this period, 212 climatological stations were in operation for at least 20 years, mostly in the settled areas of the province. The exhaustive information provided by the stations was used to calculate the values for a series of daily and monthly climatic variables to which birds are likely to be sensitive, such as the frequency of occurrence of a specific temperature in relation to a specific threshold, the number of degree-days in relation to a temperature threshold, the type of precipitation and frequency, etc. Climatic variable selection was based on scientific literature. A variable was selected if significant correlation or association was found between it and any bird species (Table 2). Other climatic variables likely to affect birds, such as wind, insulation, and solar radiation, were measured at too few stations (<10%) to be used in the analyses.

Fig. 1. Layout of the 601 bird atlas squares selected for the analysis according to the major vegetation zones of southern Québec.



The number of squares used in the analyses was based on the number of Atlas squares that could be associated with climatic data, and to determine this we used a 25 km range from the centre of an Atlas square as the maximum distance from a climatological station at which climatic data can be inferred to that square. Theoretically, if the topography remains fairly similar within this 25 km range, a climatological station located in the centre of an Atlas square could be used to infer the climatic data for 13 other squares (see Morneau et al. 1998). In practice, not all squares were adequately covered during the bird atlas field work and not all were located ≤ 25 km from a station; in all there were 601 squares that corresponded to these criteria and 171 climatological stations for which the topography and altitude were similar to the Atlas squares with which they are associated (see Morneau et al. 1998). Most of the squares that were retained occur along a southwest to northeast axis that runs parallel to the St. Lawrence River (Fig. 1).

Other environmental variables used were related to habitat, land use, landscape characteristics, and the spatial distribution of the Atlas squares. The characteristics and area of the habitats (10 classes) in each square were obtained from National Oceanic and Atmospheric Administration (NOAA) satellite images (pixels of 1 km²) of Québec obtained in 1989. FRAGSTATS software (McGarigal and Marks 1994) was used to extract additional information from the NOAA images. Specifically, five variables were selected: number of patches, patch size standard deviation, patch richness, Simpson diversity index, and contagion index. NOAA images were also used to determine the elevation of Atlas squares. Elevation was divided into classes and the area of each class was calculated for each Atlas square. To reduce the number of variables, only three variables were retained: lowest elevation, highest elevation, and mean elevation for each square. Each square's geographic location was described using the latitudinal and longitudinal coordinates of the southwest corner.

Table 1. Scoring system for evaluating bird species sensitivity to climate.

Criteria	Scoring	Comments and assumptions
Migration strategy[†,‡,§]	0 = sedentary (permanent resident) 1 = short-distance migrant (winters no further south than the southern border of the United States) 2 = long-distance migrant	
Spring arrival[†]|	0 = sedentary 1 = early migrant 2 = late migrant	Early migrants are defined as species with a median spring arrival date before 8 May.
Breeding range in Quebec [†,§] (north-south axis)	0 = goes beyond northern boundary of study area 1 = breeds as far north as boreal forest 2 = breeds as far north as mixed forest 3 = only breeds in deciduous forest 99 = coastal species	The scores must be reversed for species found in the north but not in the south of the province (i.e., the southern limit of their range is in the study area). A score of 99 is not included when totalling up the scores for each category.
Breeding range in Quebec[†,§] (east-west axis)	0 = no gradient 1 = gradient not apparent 2 = clear significant gradient found 99 = coastal species	A score of 99 is not included when totalling up the scores for each category
Breeding habitat[†]	0 = forested (trees) 1 = open (fields, shrubs)	Climate variations are less pronounced in forested habitats than in open habitats.
Cavity nester or not[†]	0 = nests in cavities 1 = does not nest in cavities	
Incubation and brooding strategy	0 = both sexes incubate and brood 1 = only female incubates and broods	Species in which both sexes incubate the eggs and brood the young are more able to adapt to changes in the environment.
Maturity at hatching	0 = precocial 1 = semiprecocial or semialtricial 2 = altricial	
Foraging method[†,¶]	0 = does not hawk for insects or feed on the wing 1 = hawks for insects or feeds on the wing	
Average weight[†]	0 = over 100 g 1 = 30.1 to 100 g 2 = 30 g or less	

†Gauthier and Aubry (1996); “sedentary” refers to resident sedentary breeders.
‡National Geographic Society (1987).
§Peterson (1980).
|Cyr and Larivée (1995).
¶Ehrlich et al. (1988).

Table 2. Scoring system for daily and monthly climatic variables affecting bird sensitivity to climate.

Target species	Variable [code]	Justification	Source
	a) Temperature		
Permanent residents	Mean number of degree-days from December to April (in absolute values): - ≤ -15°C [DD-15]; - ≤ -20°C [DD-20]; - ≤ -25°C [DD-25].	In Wisconsin, monthly mortality in the Black-capped Chickadee over three winters was strongly correlated with months in which the minimum daily temperature was < -18°C for 5 days or more.	Brittingham and Temple (1988)
		The average annual number of days ≤ -17.8°C is associated with sex-ratio differences in the winter distribution of the Dark-eyed Junco (*Junco hyemalis*). Males are found further north than females, due to the greater fasting capacity associated with their greater weight.	Ketterson and Nolan (1976)
Permanent residents	Mean annual temperature from December to February [MTDF]	" "	" "
Permanent residents	Mean minimum temperature, January [MMTJ]	Variable associated with the northern limit of the wintering range of many North American species of birds, in particular the winter distribution of the Dark-eyed Junco.	Root (1988*a*), Ketterson and Nolan (1976)
Permanent residents	Variation in mean minimum daily temperatures: mean of temperature variances for all possible three-day chronological sequences, from December to February [VDTF].	The variability in daily temperatures affects birds' metabolism, digestion, and nighttime fat reserves.	Bednekoff et al. (1994)
	b) Precipitation		
Permanent residents	Mean annual snowfall, excluding September to November [MAS]	These variables are associated with the sex differences in winter distribution in the Dark-eyed Junco. Males are found further north than females, because of the greater fasting capacity associated with their greater weight.	Ketterson and Nolan (1976)
Migrants	Temperature		
	Variation in mean minimum daily temperatures: mean of temperature variances for all possible three-day chronological sequences, from May to July [VDTJ]	The variability in daily temperatures affects birds' metabolism, digestion and nighttime fat reserves.	Bednekoff et al. (1994)
	Mean annual number of degree-days ≥ 10°C in May, June and July [DD+10]	Warm temperatures increase insect capture rates; insects fly at temperatures ≥ 10°C.	Rodenhouse (1992)

(con'd)

	Average annual number of frost-free days [FFD]	-	Bock and Lepthien (1974)
	Average annual number of days in June and July with an average temperature < 8°C [AND8]	Cold periods in June or July reduce the number of young produced.	Järvinen (1994)
Migrants	Precipitation		
	Mean annual rainfall, excluding September to November [MAR]		
	Mean annual rainfall in June and July [MARJJ]	Precipitation in summer is linked to mortality of eggs and young.	Rodenhouse (1992)
	Mean snowfall in May and June [MASMJ]	Mean April temperatures and amount of snow are strongly correlated with annual survival rates in one species of sandpiper.	Holland and Yalden (1991)
Migrants	c) Temperature and precipitation		
	Mean number of days in June and July with rainfall ≥ 10 mm and T ≤10°C [MNDR]	Cold rain in summer.	Lustick and Adams (1977), Odum and Pitelka (1939)

To meet the requirements of the statistical analyses, we included only those variables that were as independent as possible. Variable selection was made using the Kendall rank correlation test and was conducted separately for the three groups of variables: climatic, spatial, and vegetation/landscape. Variables representing climate extremes were generally favored. In all, 10 significant climatic variables were retained for the following analyses (Table 3).

Data analysis

Canonical Correspondence Analysis (CCA; Ter Braak 1988) and the method used by Borcard et al. (1992) for partitioning the variance of species abundance were used to determine the effects of climatic variables on the breeding distribution of birds. CCA is a constrained ordination technique that allows identifying which environmental variables, i.e., climatic, land cover, and spatial variables, drive bird species distributions in southern Québec. An inertia value, associated with each dimension, expresses the percentage of the total variance in species distribution attributable to each dimension. The total variation in the species matrix can be divided among eight sources of variation with respect to the three sets of variables taken into account: a) variation due to spatial variables alone, b) variation due to climatic variables alone, c) variation due to land cover variables alone, d) spatial variation shared with climatic variation, e) climatic variation shared with land cover variation, f) spatial variation shared with land cover variation, g) variation shared among all three sets of variables, and h) variation not explained by the independent variables retained.

An initial series of three CCAs were performed (with the CANOCO software package; Ter Braak 1988) on the species matrix, each taking into account only one of the three sets of environmental variables, i.e., climate, land cover, space, in an independent matrix. Environmental variables that were not found to be relevant in the first three CCAs were excluded from subsequent CCAs. A fourth CCA included in a single matrix all the independent variables found to be significant during the first three CCAs (a + b + c + d + e + f + g), allowing the portion of the total variation in the species matrix associated with these variables to be determined (see Morneau et al. 1998 for the combinations of analyses conducted).

Table 3. Independent variables used in the canonical correlation analysis.

Type	Code	Description
Climate	DD-25	Mean annual degree-days from December to April ≤ -25°C
	DD+10	Mean annual of degree-days ≥ +10°C in May, June and July
	MTDF	Mean annual temperature from December to February
	VDTF	Variation in mean minimum daily temperatures from December to February: mean of temperature variances for all possible three-day chronological sequences during these months
	VDTJ	Variation in mean minimum daily temperatures from May to July: mean of temperature variances for all possible three-day chronological sequences during these months
	MAS	Mean annual snowfall, excluding September to November
	MAR	Mean annual rainfall (mm), excluding September to November
	MARJJ	Mean annual rainfall (mm) in June and July
	MASMJ	Mean snowfall in May and June
	MNDR	Mean number of days in June and July with rainfall ≥ 10 mm and mean temperatures ≤ 10°C
Vegetation	HYDR	Area of open water
	BARS	Area of bare soil
	OPLI	Area of open lichen woodland
	CONI	Area of conifer-dominated forest
	DECI	Area of forest dominated by deciduous species
	MIX	Area of mixed forest
	OPEN	Area of open forest
	BURN	Area of burns
	AGRI	Area of agricultural land
	URBA	Area of urban land
	POPU	Degree of urbanization and anthropogenic food supply
Landscape	LR	Number of vegetation categories on square
	CONTAG	Contagion index: this is a calculation of the product of the probability that a biotope patch belongs to category I and the conditional probability that it is adjacent to a patch belonging to category J
Spatial	LATI	Latitude of the southwest corner of the square
	LONGI	Longitude of the southwest corner of the square
	MOALT	Modal altitude; this variable corresponds to the index of the altitude class that is most representative in terms of the area it occupies on the square.

In partial CCA, the coordinates of the species along a canonical axis provide a ranking along a given environmental variable (Legendre and Legendre 1998). A series of six partial CCAs were carried out to determine the percentage of the variation in the species matrix accounted for by each combination of two of the three sets of predictors, one set being the independent variables, the other set being the covariables. These additional analyses served to determine the percentage of variation in the species matrix associated with the covariable matrix and the percentage explained by the independent matrix not already explained by the covariable matrix. Subsequently, a series of linear combinations were calculated using linear algebra to determine the percentage of the variation in the species matrix associated with each potential source of variation (a to g above). The amounts of variation explained by the seven components [a] to [g], as well as the amount of unexplained variation [h], were obtained by subtractions from these results.

RESULTS

Significant independent variables

The results of the CCA carried out with climatic variables showed that all 10 variables were significant. The canonical axes for this CCA account for 21.8% of the variation in the species matrix. Axis 1 accounts for 6/7 of the variation explained by the ten canonical axes, corresponding to the ten variables taken into account. The climatic variables that show the strongest correlation with Axis 1 consist of the mean annual degree-days ≥ 10°C in May, June, and July (DD+10), the mean number of days with rainfall ≥ 10 mm and T ≤ 10° C in June and July (MNDR), and the mean annual temperature from December to February (MTDF; Table 4). Thus, the first axis constitutes a temperature gradient. In comparison, Axis 2 accounts for 1/14 of the variation explained by the canonical axes. Two variables were correlated with this axis: the mean annual rainfall in June and July (MARJJ) and the mean annual rainfall, excluding September to November (MAR). Axis 2 thus represents a gradient of precipitation in the form of rain.

The results of the CCA with land cover variables showed that 9 of the 13 land cover variables were significant (Table 4). This CCA accounts for 14.9% of the variance explained in the species matrix; Axis 1 accounts for 7/10 of the variation explained by the nine canonical axes, corresponding to the nine variables taken into account. Four land cover variables were correlated most strongly with this axis: the area covered by agricultural land (AGRI) and human population (POPU), which were inversely correlated, and the area covered by mixed forest (MIX) and by coniferous forest (CONI), which were positively correlated. Axis 1, therefore, appears to represent a gradient of urbanization or area covered by forest. In comparison, Axis 2 accounts for 1/7 of the explained variance. In particular, two variables were correlated with this axis: area covered by deciduous forests (DECI) and area covered by water (HYDR), both of which were inversely correlated.

All three spatial variables were significant in the CCA carried out with these variables. The canonical axes in this analysis account for 22.7% of the variation in the species matrix. Axis 1 accounts for most of the variation (6/7) explained by the three canonical axes, corresponding to the three variables taken into account. The spatial variable most strongly correlated with this axis was latitude (LATI; Table 4); Axis 1 therefore represents a latitudinal gradient. Axis 2 accounts for 1/10 of the variation explained by the canonical axes. It represents an altitudinal gradient, altitude (MOALT) being the variable most strongly correlated with the axis.

In the fourth CCA, the independent matrix consisted of a combination of climatic, spatial, and land cover variables. The canonical axes were found to be associated with 29.1% of the variation in the species matrix. Axis 1 accounted for 7/10 of the variation in the species matrix explained by the canonical axes, and Axis 2 for 1/10. A strong correlation was found between the climatic variables and Axis 1, indicating that these variables best explain the variation in the species matrix. Axis 1 thus represents a gradient of temperature and precipitation, which is mainly latitudinal and to a lesser degree longitudinal (Table 4). In general, this indicates that the highest values for temperature variables (mainly DD+10 and MTDF) and total rainfall (MAR) were recorded in the southern and western parts of the study area. Conversely, the lowest temperatures (DD-25, MNDR) and the highest snowfall (MAS, MASMJ) were associated with the northernmost and easternmost regions. Mixed and coniferous forests are found in the north and east, whereas agricultural areas, human

Table 4. Correlation coefficients of significant independent variables (p < 0.05), based on results for Axes 1 and 2 of four Canonical Correspondence Analyses (CCA).

Variable	Climatic variables		Habitat & Land use variables		Spatial variables		All variables	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
DD-25	0.399	0.059	-	-	-	-	0.396	0.054
DD+10*	- 0.801	- 0.028	-	-	-	-	- 0.798*	- 0.062
MTDF*	- 0.646	0.172	-	-	-	-	- 0.640*	- 0.184
VDTF	0.021	0.137	-	-	-	-	0.024	- 0.137
VDTJ	0.053	0.267	-	-	-	-	0.059	- 0.255
MAS*	0.541	0.185	-	-	-	-	0.543*	- 0.105
MAR	- 0.466	0.284	-	-	-	-	- 0.459	- 0.281
MARJJ	0.180	0.299	-	-	-	-	0.184	- 0.244
MAS-MJ*	0.515	0.127	-	-	-	-	0.515*	- 0.052
MNDR*	0.786	0.175	-	-	-	-	0.786*	- 0.089
HYDR*	-	-	0.026	0.481	-	-	0.019	0.462*
BARS	-	-	n.s.†	n.s.	-	-	-	-
OPLI	-	-	n.s.	n.s.	-	-	-	-
CONI	-	-	0.420	0.255	-	-	0.415	0.240
DECI*	-	-	- 0.017	- 0.538	-	-	- 0.026	- 0.545*
MIX	-	-	0.499	- 0.024	-	-	0.477	- 0.021
OPEN	-	-	n.s.	n.s.	-	-	-	-
BURN	-	-	n.s.	n.s.	-	-	-	-
AGRI*	-	-	- 0.550	- 0.004	-	-	- 0.522*	0.018
URBA	-	-	- 0.288	0.257	-	-	- 0.279	0.246
POPU	-	-	- 0.414	0.131	-	-	- 0.397	0.145
PSSD	-	-	- 0.159	- 0.026	-	-	- 0.157	- 0.015
CONT-AG	-	-	0.094	- 0.024	-	-	0.097	- 0.033
LATI*	-	-	-	-	0.804	0.326	0.800*	0.313
LONGI*	-	-	-	-	- 0.528	0.183	- 0.526*	0.176
MOAL-T*	-	-	-	-	0.464	- 0.486	0.468	- 0.414*

†n.s. = Not significant, * = p < 0.05

population, and urban areas are concentrated in the south and west. The variables most strongly correlated with Axis 2 were land cover and altitude. Moreover, altitude and the area covered by deciduous forests were negatively correlated with Axis 1 and the area covered by water was positively correlated. High values for deciduous forest area are therefore associated with higher altitudes and high water values with lower altitudes. These two variables seem to be structured by altitude rather than latitude.

Partitioning the variance

The way in which the variation in the species matrix was partitioned suggests that there is a strong association between the three sets of variables (Fig. 2). The variation of the species matrix explained and shared by the three sets of independent variables accounted for 29.1% of the explained variance. A very large portion of the variation explained by climatic variables (5/6) is shared at least partially with spatial variables. Spatial variables accounted for most of the variation in the species matrix, while land cover variables accounted for the least. The fraction of the species-matrix variation not explained by any of the environmental variables used is 70.9%. After correcting for the effect of land cover variables, climatic variables still explain a significant portion (1/9) of the variation in the species matrix. The CCA carried out with climatic variables and correcting for the effect of land cover shows that Axis 1 accounts for 4/5 of the variance explained by the canonical axes. The climatic variables most strongly correlated with this axis are DD+10 (r = - 0.77) and MNDR (r = + 0.68), or the same variables as in the CCA without covariates.

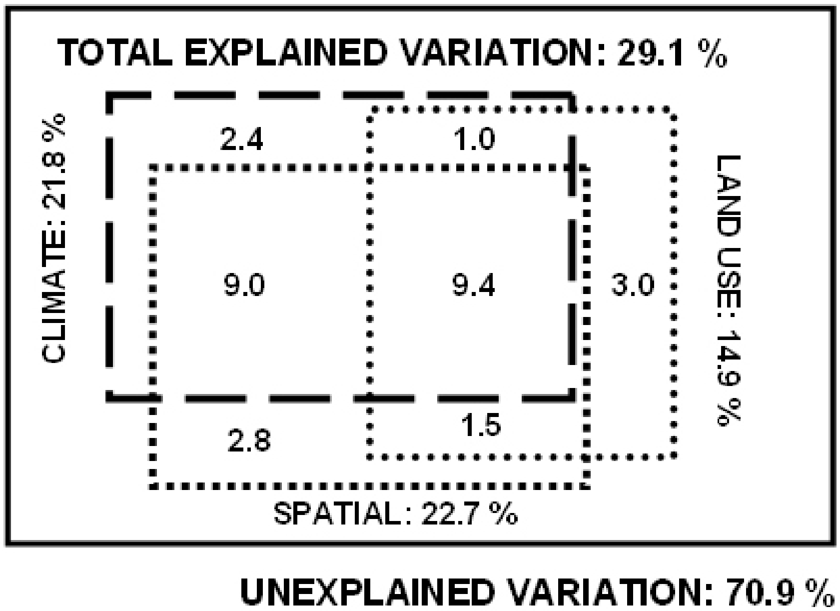
Evaluation of bird species' sensitivity to climate

Table 5 presents the results of the CCAs carried out, firstly with climatic variables and land cover variables without covariates and secondly with climatic variables corrected for the effect of land cover. The results of the CCA using climatic variables without covariates as independent variables reveal the species that appear to be the most sensitive to climate. Table 6 lists the species for which an important part of the variance (> 33%) was accounted for by the first axis. Species are presented in the sensitivity categories identified during the first stage of the study according to physiological and ecological criteria (see Table 1 and Appendix 1). For these species, variation associated with climate was less influenced by land cover variables.

A comparison of the CCA results, using climatic variables and correcting for the effect of land cover (Table 6), with the evaluation of potential climatic sensitivity, and using criteria taken from the literature (Table 1) shows that our qualitative assessments (Appendix II) are generally supported by the quantitative results. Using a threshold of 20% of the variance on Axis 1 (not shown here), 17 of the 18 (94%) species thought not to be sensitive to climate were effectively found to be weakly associated with climatic variables. Similarly, 38 of the 47 (81%) suspected sensitive species were effectively associated with climatic variables.

To identify species that could be used as indicators of climate change, we determined which species were most strongly correlated with climatic variables, not correcting for the effect of land cover. In nature, species evolve in an environment affected both by climatic conditions and habitat; hence the CCA was performed with climatic variables without covariates (Table 5). Out of the 22 species for which the percentage of explained variation was equal to or greater than that of the entire species matrix for all variables, there were 14 species for which 16% or more of the variation could be explained by climate, correcting for the effect of land cover (Table 6). Among these species, six are at the northern limit of their breeding range in the study area. The inverse can be observed for almost all of the remaining species, that is, they are nearly absent from the southern part of the study area, except for the Dark-eyed Junco (*Junco hyemalis*), which is frequent there. Of the 14 species, eight are neotropical migrants, five are short-distance migrants and only one is a year-round resident, the White-breasted Nuthatch (*Sitta carolinensis*; Table 6). The distribution of these species along the first two axes of the CCA with climatic variables shows that six species are correlated above all with the mean annual degree-days ≥ 10°C in May, June, and July (DD+10 in Fig. 3). Five of these are migrants, Great Crested Flycatcher (*Myiarchus crinitus*), House Wren (*Troglodytes aedon*), Eastern Meadowlark (*Sturnella magna*), Warbling Vireo (*Vireo gilvus*), and Baltimore Oriole (*Icterus galbula*), and are likely associated with warm

Fig. 2. Proportion of total variance explained by different groups of environmental variables considered, as indicated by the hierarchical partitioning method.



summers. In contrast, the White-breasted Nuthatch, a resident species, is probably primarily associated with milder winters (MTDF in Fig. 3). The other species, Ruby-crowned Kinglet (*Regulus calendula*), Lincoln's Sparrow (*Melospiza lincolnii*), Swainson's Thrush (*Catharus ustulatus*), Tennessee Warbler (*Oreothlypis peregrina*), Magnolia Warbler (*Dendroica magnolia*), Bay-breasted Warbler (*Dendroica castanea*), Wilson's Warbler (*Wilsonia pusilla*), and Dark-eyed Junco, all boreal forest species, appear to be more correlated with cooler and wetter summers (Fig. 3).

DISCUSSION

The relative importance of the bioclimate envelope

In this study, climatic, spatial, and land cover factors are strongly associated with one another. The portion of variation in the species matrix explained by both climatic variables and habitat variables suggests that climate may indirectly influence bird distribution by affecting vegetation. Although this is a widely accepted hypothesis (Hayworth and Weathers 1984), these links may also reflect the simultaneous influence of climate on vegetation and bird distribution. In either case, the link between climate and bird distribution is clear and most of the explained variation (21.7%) is probably due to climate in some way. Root (1988*b*) found that in winter, both climate and vegetation had an effect on the distribution of certain species of birds. In a Tennessee study using atlas data, Nicholson (1991) was not able to find much of a link between temperature and precipitation and species richness in the squares, whereas habitat variables were found to have a greater effect on determining the number of species. According to Telleria et al. (1992), climate is the ultimate determinant of the theoretical number of species that can occupy a given location, because it may directly affect productivity and it plays an indirect role in other cases. The actual number of species in a given area, therefore, is

Table 5. Percentage of variance in the distribution of breeding bird species explained by climatic and land use variables, based on results for Axes 1 and 2 of three Canonical Correspondence Analyses (CCA).

Potential sensitivity to climate (Appendix II) †	CCA: Climate (21.8%)		CCA: Land use (14.7%)		CCA: Climate holding Land use constant (11.4%)	
Species	Axis 1 (83.9%)	Axis 2 (6.9%)	Axis 1 (71.2%)	Axis 2 (10.4%)	Axis 1 (80.9%)	Axis 2 (5.9%)
Not very sensitive						
Rock Dove (*Columba livia*)	30.8§	0.5	28.3	0.1	8.8	0.6
Common Raven (*Corvus corax*)	32.9	0.0	25.6	0.1	11.6	0.0
Boreal Chickadee (*Poecile hudsonicus*)	29.9	2.1	16.1	0.5	15.4	1.9
White-breasted Nuthatch‡ (*Sitta carolinensis*)	38.9	0.6	15.4	0.2	22.8	1.1
Sensitive						
Great Crested Flycatcher‡ (*Myiarchus crinitus*)	48.8	0.2	21.2	0.3	27.6	0.0
House Wren‡ (*Troglodytes aedon*)	40.2	0.2	24.5	1.3	19.4	0.4
Ruby-crowned Kinglet‡ (*Regulus calendula*)	37.3	0.2	15.7	0.2	22.1	0.0
Swainson’s Thrush‡ (*Catharus ustulatus*)	43.8	0.1	24.3	0.1	21.6	0.1
Wood Thrush (*Hylocichla mustelina*)	31.6	3.5	14.9	4.7	15.6	1.1
Brown Thrasher (*Toxostoma rufum*)	28.7	0.4	13.8	1.2	14.5	0.2
Magnolia Warbler‡ (*Dendroica magnolia*)	35.4	0.1	21.3	0.7	16.7	0.2
Dark-eyed Junco ‡ (*Junco hyemalis*)	35.2	0.0	21.0	0.1	16.1	0.0
Eastern Meadowlark‡ (*Sturnella magna*)	49.9	0.1	29.1	0.4	22.7	0.2

(con'd)

Very sensitive						
Eastern Phoebe (*Sayornis phoebe*)	31.0	1.1	12.5	2.3	18.9	0.0
Warbling Vireo‡ (*Vireo gilvus*)	40.4	0.2	24.1	0.2	18.7	0.1
Philadelphia Vireo (*Vireo philadelphicus*)	25.5	3.5	8.4	2.5	16.3	1.0
Tennessee Warbler‡ (*Oreothlypis peregrina*)	36.3	3.2	15.6	1.1	21.7	1.2
Bay-breasted Warbler‡ (*Dendroica castanea*)	38.1	0.0	13.3	0.1	24.8	0.1
Wilson’s Warbler‡ (*Wilsonia pusilla*)	43.5	0.5	15.5	1.5	28.0	0.0
Indigo Bunting (*Passerina cyanea*)	29.1	2.5	12.1	0.2	17.5	2.1
Lincoln’s Sparrow‡ (*Melospiza lincolnii*)	33.4	1.3	12.5	0.8	20.9	0.1
Baltimore Oriole‡ (*Icterus galbula*)	51.4|	0.3	32.6	1.3	20.8	0.0

† Final Mark: 0: [0%, 25%], 1: [25%, 50%], 2: [50%, 75%], 3: [75%, 100%].
‡ Species for which a substantial part of the variance is accounted for by climate (> 33% in the first column). They constitute the selection of 14 potential bioindicator species that are displayed along the first two axes of the CCA illustrated in Figure 3.
§ In this case, climate alone accounts for 5.6% (i.e., 30.8% of 83.9% of 21.8%) of the variation in presence/absence of Rock Doves.
| For the Baltimore Oriole, climate alone accounts for 25.5%.

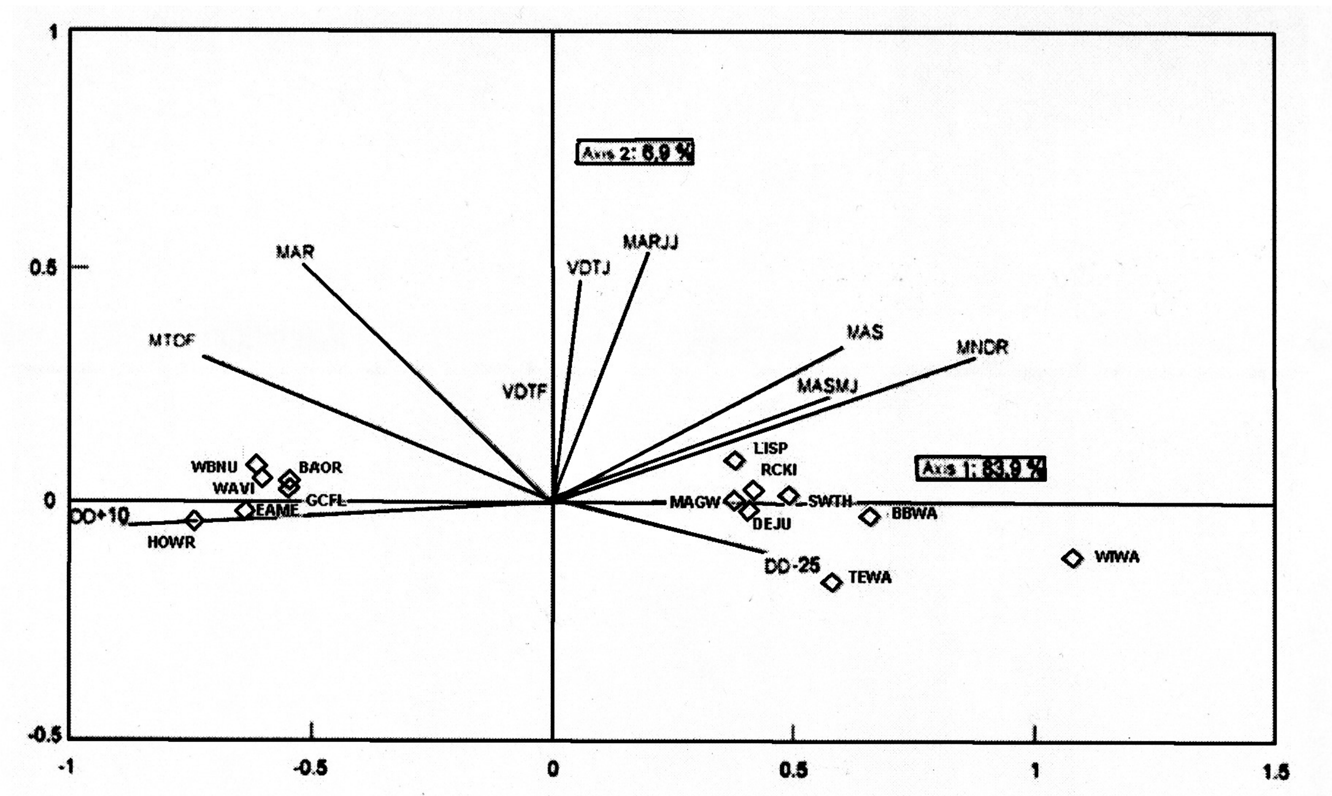
always less than the number that is theoretically possible, i.e., limited by climate alone, because of proximate causes such as habitat components. Consequently, the scale of observation is crucial in separating the effect of climate from that of habitat; too large a scale favors climate over habitat as an explanation of the variation in species richness in a given area (Telleria et al. 1992). To sum up, climate and habitat work together to affect the distribution of bird species. It is already apparent that the scale at which current bioclimatic studies are addressed is of fundamental importance, with effects on the distribution of species being most influential at regional to global scale (Pearson and Dawson 2003). Unfortunately, characterizations of more complex relationships between climate change, land cover change, and Québec bird assemblages are presently limited by a lack of process understanding, data availability at a higher resolution, and inherent climate scenario uncertainties.

Our study’s results suggest that the associations between bird species and climate in the analyses are correct. Nearly 30% in the variation in the distribution of the 65 breeding birds of southern Québec selected for the analysis can be explained by climate, land cover, and spatial variables. The fact that this percentage was not higher may be because of other factors aside from the geographical constraints discussed above, including the accuracy of the Atlas data and the resolution of variables. Because of the limited resolution of the NOAA images (pixels of 1 km^2), the habitat variables used are highly related to the landscape structure variables for most species, which may account for part of the unexplained variation.

Table 6. Species of breeding birds with the highest percentage of variance in distribution explained by climatic variables, based on results for Axis 1 of two Canonical Correspondence Analyses (CCA), according to migration strategy.

Species according to migratory behaviour	CCA response table's variance	
	CCA: climate First canonical axis accounts for 5/6 of the variance (21.8%) captured by the CCA axes	CCA: Climate holding land use constant First canonical axis accounts for 4/5 of the variance (11.4%) captured by the CCA axes
Sedentary species		
White-breasted Nuthatch (*Sitta carolinensis*)	38.9	22.8
Short-distance migrants		
Eastern Meadowlark (*Sturnella magna*)	49.9	22.7
House Wren (*Troglodytes aedon*)	40.2	19.4
Ruby-crowned Kinglet (*Regulus calendula*)	37.3	22.1
Dark-eyed Junco (*Junco hyemalis*)	35.2	16.1
Lincoln's Sparrow (*Melospiza lincolnii*)	33.4	20.9
Neotropical migrants		
Baltimore Oriole (*Icterus galbula*)	51.4	20.8
Great Crested Flycatcher (*Myiarchus crinitus*)	48.8	27.6
Swainson's Thrush (*Catharus ustulatus*)	43.8	21.6
Wilson's Warbler (*Wilsonia pusilla*)	43.5	28.0
Warbling Vireo (*Vireo gilvus*)	40.4	18.7
Bay-breasted Warbler (*Dendroica castanea*)	38.1	24.8
Tennessee Warbler (Oreothlypis peregrina)	36.3	21.7
Magnolia Warbler (*Dendroica magnolia*)	35.4	16.7

Fig. 3. Distribution of 14 potential bird indicator species along the first 2 axes of a Canonical Correspondence Analysis (CCA) with climatic variables. See Table 3 for climatic code definitions. Bird species are: (HOWR) House Wren, (AEME) Eastern Meadowlark, (WBNU) White-breasted Nuthatch, (WAVI) Warbling Vireo, (BAOR) Baltimore Oriole, (GCFL) Great Crested Flycatcher, (LISP) Lincoln Sparrow, (MAGW) Magnolia Warbler, (DEJU) Dark-eyed Junco, (RCKI) Ruby-crowned Kinglet, (SWTH) Swainson’s Trush, (TEWA) Tennessee Warbler, (BBWA) Bay-breasted Warbler, and (WIWA) Wilson’s Warbler. This group of 14 consists of species for which 16% or more of the variation is explained by climate, correcting for the effect of land use.



Similarly, it is important to keep in mind that the relationships documented here describe the link between the distribution of birds and environmental variables at a given point in time, i.e., 1984–89. The actual situation, however, is dynamic. A recent analysis of the Canadian Breeding Bird Survey (BBS) data from 1967 to 2000 (Downes and Collins 2003) has indicated that the populations of the Swainson’s Thrush and Eastern Meadowlark have declined, those of the Magnolia Warbler and Warbling Vireo have increased, while the population of the Winter Wren (*Troglodytes troglodytes*) showed precursory signs of decline. Furthermore, certain thrushes and some warblers have been decreasing in numbers over the last 15 years, whereas others, like the Purple Finch (*Carpodacus purpureus*), House Finch (*Carpodacus mexicanus*), and Northern Cardinal (*Cardinalis cardinalis*) have increased significantly.

Population changes could have been caused by a variety of factors including habitat loss in the winter range, proliferation of bird feeders, etc. Whatever the factors involved, they might either have reduced or increased the climatic effects on breeding birds. Despite these problems, we found significant links between the three types of independent variables and the bird species. Our results show that most of the variation in the species matrix due to climatic variables is shared with the variation due to spatial values. Because geographic coordinates and altitude have a strong influence on climate but not the inverse, it can be concluded that part of the portion of the variation in the species matrix shared by these two variables corresponds to spatially-structured climatic variables (Borcard et al. 1992). Therefore, over 10% of the variation in the distribution of species is probably because of climate alone. Given the difficulty of isolating climatic effects on bird distribution from those of other environmental variables in endothermic vertebrates living in nonextreme conditions (Telleria et al. 1992), this is an important finding. Moreover, Johnson (1994) and Currie (2001) found that the contemporary patterns of bird distribution in the conterminous United States covary strongly with summer temperature and moisture. The portion of the variation in the species matrix supposedly explained strictly by climate (11.4%) may be because of the indirect effects of climate on birds. For example, climate may affect birds by influencing insect development or vegetation, variables that were not measured in this study. This is especially plausible given the fact that the main climatic variable used was the number of degree-days greater than or equal to 10°C. It is well known that higher temperatures favor insect activity and development (Gates 1993). For example, flying insects become more active as the temperature rises, which in turn increases the capture success rate by birds (Rodenhouse 1992). Therefore, it is not surprising to find a link between temperature and distribution in the Great Crested Flycatcher, a species that hawks for insects. Furthermore, climate tends to be most limiting on bird distribution during extreme climatic events (Root 1988*b*); the same is true for dramatic changes in the number of species (Telleria et al. 1992). The use of climatic data measured over a 30-year period in conjunction with the Atlas distribution data (Gauthier and Aubry 1996), which was measured over a shorter period of time, might not have provided a faithful reflection of extreme events in the data set.

Projected climate induced avifaunal change in southern Québec and management

In this study, 14 out of 65 (22%) bird species appear to be sensitive to climate change. Our results show that the White-breasted Nuthatch may be limited by winter temperatures while the Great Crested Flycatcher, House Wren, Eastern Meadowlark, Warbling Vireo, and Baltimore Oriole may be limited by the number of degree-days. The other species, including Wilson's Warbler, the Bay-breasted Warbler, Tennessee Warbler, Lincoln's Sparrow, and Swainson's Thrush, require a cool, wet climate. Matthews et al. (2004) projected dramatic shifts northward in the breeding distribution of several northern U.S. bird species, including most of the species just mentioned, under warming climatic conditions or indirectly through dependence on tree species that themselves are limited by warming conditions such as balsam fir, yellow birch (*Betula alleghaniensis*), sugar maple, red maple (*Acer rubrum*), and striped maple (*Acer pensylvanicum*; McKenney et al. 2007). In the case of neotropical migrants, many species that currently breed in the northern portion of eastern United States are likely to move northward into Canada. This is especially true for those species that are associated with the presence of coniferous trees inside the mixed wood forest of north-eastern North America (Matthews et al. 2004). It is thus crucial that enough habitats will be preserved in Canada to accommodate these future "climate refugees". Since mixed wood forests are often exploited for lumber, additional attention should be placed on their conservation.

From a global warming perspective, birds may be used as early bioindicators of climate change. Birds are highly mobile organisms and can colonize new and suitable areas more quickly than such organisms as trees. They are easy to observe and have generated a large amount of data covering long periods of time. However, it must be remembered, as Morrison (1986) noted, that birds are probably better indicators of secondary changes, i.e., the repercussions brought about by changing conditions, than of primary ones, which act directly on the survival of individuals or the abundance of populations. Although the variables most often taken into account in studies dealing with the links between environmental change and birds are changes in density, abundance, and distribution of avian populations (Temple and Wiens 1989), these may not always be the most appropriate variables. Bird distribution can be an effective indicator of climatic changes only for species that are affected directly by climatic changes. Species that are indirectly affected, that is through habitat or other biotic changes, will react with a delay depending on the speed of the modifications. Therefore, these species are less likely to be effective indicators of climatic changes. Hence, natality, mortality, and dispersal rates, which reflect more directly the bird’s behavioral and physiological responses to environmental change, would be better choices as bioindicator criteria than distributional characteristics. Identifying decline-promoting factors allows scientists to infer mechanisms responsible for observed declines in wild bird populations facing global change, and by doing so allows for a more pre-emptive approach to conservation planning (Jiguet et al. 2007). To the extent that appropriate factors are taken into account, birds are an ideal way of studying the effect of anticipated climate change (Macdonald 1992).

Responses to this article can be read online at:
http://www.ace-eco.org/vol5/iss2/art5/responses/

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LITERATURE CITED

Anciaes, M., and A. T. Peterson. 2006. Climate change effects on neotropical manakin diversity based on ecological niche modelling. *Condor* **108**:778-791.

Bednekoff, P. A., B. Biebach, and J. Krebs. 1994. Great Tit fat reserves under unpredictable temperatures. *Journal of Avian Biology* **25**:156-160.

Bertin, R. I. 2008. Plant phenology and distribution in relation to recent climate change. *Journal of Torrey Botanical Society* **135**:126-146.

Bock, C. E., and L. W. Lepthien. 1974. Winter patterns of bird species diversity and abundance in the United States and southern Canada. *American Birds* **28**:556-562.

Borcard, D., P. Legendre, and P. Drapeau. 1992. Partialling out the spatial component of ecological variation. *Ecology* **73**:1045-1055.

Both, C., and M. E. Visser. 2001. Adjustment to climate change is constrained by arrival date in a long-distance migrant bird. *Nature* **411**:296-298.

Brittingham, M. C., and S. A. Temple. 1988. Impacts of supplemental feeding on survival rates of black-capped chickadees. *Ecology* **69**:581-589.

Burton, J. F. 1995. *Birds and climate change*. Christopher Helm - A & C Black, London, UK.

Currie, D. J. 2001. Projected effects of climate change on patterns of vertebrate and tree species richness in the conterminous United States. *Ecosystems* **4**:216-225.

Cyr, A., and J. Larivée. 1995. *Atlas saisonnier des oiseaux du Québec*. Les Presses de l'Université de Sherbrooke et la Société du Loisir ornithologique de l'Estrie, Sherbrooke, Québec, Canada.

Devictor, V., R. Julliard, D. Couvet, and F. Jiguet. 2008. Birds are tracking climate warming, but not fast enough. *Proceedings of the Royal Society B Biological Sciences* **275**:2743-2748 doi:10.1098/rspb.2008.0878.

Downes, C. M., and B. T. Collins. 2003. The Canadian breeding bird survey, 1967-2000. *Canadian Wildlife Service Progress Notes* **219**:1-39.

Ehrlich, P. R., D. S. Dobkin, and D. Wheye. 1988. *The birder's handbook.* Fireside Book, Simon and Schuster, New York, New York, USA.

Gates, D. M. 1993. *Climate change and its biological consequences.* Sinauer and Associates, Sunderland, England.

Gauthier, J., and Y. Aubry, editors. 1996. *The breeding birds of Québec: atlas of the breeding birds of southern Québec.* Association québécoise des groupes d'ornithologues, Province of Québec Society for the Protection of Birds, Canadian Wildlife Service, Environment Canada, Québec Region, Montreal, Québec, Canada

Gwinner, E. 1996. Circannual clocks in avian reproduction and migration. *Ibis* **138**:47-63.

Harrison, P. A., D. P. Vanhinsbergh, R. J. Fuller, and P. M. Berry. 2003. Modelling climate change impacts on the distribution of breeding birds in Britain and Ireland. *Journal of Nature Conservation* **11**:31-42.

Hayworth, A. M., and W. W. Weathers. 1984. Temperature regulation and climatic adaptation in Black-billed and Yellow-billed Magpies. *Condor* **86**:19-26.

Hitch, A. T., and P. L. Leberg. 2007. Breeding distribution of North American bird species moving north as a result of climate change. *Conservation Biology* **21**:534-539.

Holland, P. K., and D. W. Yalden. 1991. Population dynamics of common sandpipers *Actitis hypoleucos* breeding along an upland river system. *Bird Study* **38**:151-159.

Huntley, B., Y. C. Collingham, R. E. Green, G. M. Hilton, C. Rahbek, and S. G. Willis. 2006. Potential impacts of climatic change upon geographical distributions of birds. *Ibis* **148**:8-28.

Intergovernmental Panel on Climate Change (IPCC). 2007. Summary for Policymakers. *In Climate change 2007: the physical science basis.* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, H. L. Miller, editors. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Järvinen, A. 1994. Global warming and egg size of birds. *Ecography* **17**:108-110.

Jiguet, F., R. Julliard, C. D. Thomas, O. Dehorter, S. E. Newson, and D. Couvet. 2006. Thermal range predicts bird population resilience to extreme high temperatures. *Ecology Letters* **9**:1321-1330.

Jiguet, F., A.-S. Gadot, R. Julliard, S. E. Newson, and D. Couvet. 2007. Climate envelope, life history traits and the resilience of birds facing global change. *Global Change Biology* **13**:1672-1684.

Johnson, N. K. 1994. Pioneering and natural expansion of breeding distributions in western North American birds. *Studies in Avian Biology* **15**:27-44.

Kappelle, M., M. M. I. Van Vuuren, and P. Baas Magret. 1999. Effects of climate change on biodiversity: a review and identification of key research issues. *Biodiversity and Conservation* **8**:1383-1397.

Ketterson, E. D., and V. Nolan Jr. 1976. Geographic variation and its climatic correlates in the sex ratio of eastern-wintering dark-eyed juncos (*Junco hyemalis hyemalis*). *Ecology* **57**:679-693.

Lawler, J. J., S. L. Shafer, D. White, P. Kareiva, E. P. Maurer, A. R. Blaustein, and P. J. Bartlein. 2009. Projected climate-induced faunal change in the Western Hemisphere. *Ecology* **90**:588-597.

Legendre, P., and L. Legendre. 1998. *Numerical Ecology.* Second edition. Elsevier Science BV, Amsterdam, The Netherlands.

Lustick, S., and J. Adams. 1977. Seasonal variation in the effects of wetting on the energetics and survival of starlings (*Sturnus vulgaris*). Comparative Biochemistry and Physiology **56A**:173-177.

Litynski, J. 1984. *Classification numérique des climats mondiaux*. Organisation météorologique mondiale, Programme climatologique mondial, PCM/WCP-63. Genève Suisse.

Macdonald, I. A. W. 1992. Vertebrate populations as indicators of environmental change in Southern Africa. *Transactions Royal Society of South Africa* **48**:87-122.

Matthews, S., R. O'Connor, L. R. Iverson, and A. M. Prasad. 2004. *Atlas of climate change effects in 150 bird species of the Eastern United States.* Gen. Tech. Rep. NE-318, U.S. Department of Agriculture, Forest Service, Northeastern Research Station, Newton Square, Pennsylvania, USA.

McGarigal, K., and B. J. Marks. 1994. *FRAGSTATS. Spatial pattern analysis.* Program for quantifying landscape structure. Version 2.0.

McKenney, D. W., J. H. Pedlar, K. Lawrence, K. Campbell, and M. F. Hutchinson. 2007. Potential impacts of climate change on the distribution of North American trees. *BioScience* **57**:939-948.

Morneau, F., D. Lambert, M. St-Georges, and J.-L. DesGranges. 1998. Évaluation de la vulnérabilité des oiseaux nicheurs du Québec au changement climatique. G.R.E.B.E. for Environment Canada, Québec Region. *Canadian Wildlife Service Technical Report Series* **299**:1-50.

Morrison, M. L. 1986. Bird populations as indicators of environmental change. *Current Ornithology* **3**:429-451.

National Geographic Society. 1987. *Guide d'identification des oiseaux de l'Amérique du Nord*. Éditions Marcel-Broquet, Laprairie, Québec, Canada.

Nicholson, C. P. 1991. Geographic patterns in species occurrence of Tennessee's breeding birds. *Journal of Tennessee Academy of Sciences* **66**:195-199.

Odum, E. P., and F. A. Pitelka. 1939. Storm mortality in a winter Starling roost. *Auk* **56**:451-455.

Pearson, R. G., and T. E. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography* **12**:361-371.

Perrins, C. M. 1970. The timing of birds' breeding seasons. *Ibis* **112**:242-255.

Peterson, R. T. 1980. *Field guide to the birds east of the Rockies*. Houghton Mifflin, Boston, Massachusetts, USA.

Rodenhouse, N. L. 1992. Potential effects of climatic change on a neotropical migrant landbird. *Conservation Biology* **6**:263-272.

Root, T. L. 1988*a*. Environmental factors associated with avian distributional boundaries. *Journal of Biogeography* **15**:489-505.

Root, T. L. 1988*b*. Energy constraints on avian distributions and abundances. *Ecology* **69**:330-339.

Root, T. L., J. T. Price, K. R. Hall, S. S. Schneider, C. Rosenzweig, and J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. *Nature* **421**:57-60.

Schwartz, M. W., L. R. Iverson, A. M. Prasad, S. N. Matthews, and R. J. O'Connor. 2006. Predicting extinctions as a result of climate change. *Ecology* **87**:1611-1615.

Sekercioglu, C. H., S. H. Schneider, J. P. Fay, and S. R. Loarie. 2008. Climate change, elevational range shifts, and bird extinctions. *Conservation Biology* **22**:140-150.

Telleria, J. L., T. Santos, A. Sanchez, and A. Galarza. 1992. Habitat structure predicts bird diversity distribution in Iberian forests better than climate. *Bird Study* **39**:63-68.

Temple, S. A., and J. A. Wiens. 1989. Bird populations and environmental changes: can birds be bio-indicators? *American Birds* **43**:260-270.

Ter Braak, C. J. F. 1988. *CANACO - a fortran program for canonical community ordination.* Microcomputer power, Ithaca, New York, USA.

Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. Ferreire de Siqueira, A. Grainger, L. Hannah, L. Hugues, B. Huntley, A. S. van Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. T. Peterson, O. L. Phillips, and S. E. Williams. 2004. Extinction risk from climate change. *Nature* **427**:145-148.

Thomas, D. W., J. Blondel, P. Perret, M. M. Lambrechts, and J. R. Speakman. 2001.

Energetic and fitness costs of mismatching resource supply and demand in seasonally breeding birds. *Science* **291**:2598-2600.

United Nations Environment Programme (UNEP), and GRID-Arendal. 2009. *Climate in peril: a popular guide to the latest IPCC reports.* UNEP/GRID-Arendal, Nairobi, Kenya and Arendal, Norway.

Virkkala, R., R. K. Heikkinen, N. Leikola, and M. Lueto. 2008. Projected large-scale range reductions of northern-boreal land bird species due to climate change. *Biological Conservation* **141**:1-343-1353.

Appendix 1. Potential climate sensitivity categories and biological characteristics of breeding bird species (see Tables I & 2 for criteria, scoring, and climate change sensitivity index descriptions).

Species		Migration strategy	Spring arrival	Breeding range (Qc)		Breeding habitat	Cavity nester (?)	Incubation & brooding strategy	Maturity at hatching	Foraging method	Average weight
English name	Scientific name			North-South	East-West						
		(†), (§) & (#)	(†) & (¶)	(†) & (#)	(†) & (#)	(†) & (§)	(‡)	(†)	(†)	(†) & (‡‡)	(†)
Red-throated Loon	*Gavia stellata*	1	1	99	99	1	1	0	0	0	0
Common Loon	*Gavia immer*	2	1	1	0	1	1	0	0	0	0
Pied-billed Grebe	*Podilymbus podiceps*	2	1	1	0	1	1	0	0	0	0
Horned Grebe	*Podiceps auritus*	1	1	99	99	1	1	0	0	0	0
Red-necked Grebe	*Podiceps grisegena*	1	1	3	2	1	1	0	0	0	0
Leach's Storm-Petrel	*Oceanodroma leucorhoa*	.	1	99	99	1	0	0	1	0	1
Northern Gannet	*Morus bassanus*	2	1	99	99	1	1	0	2	0	0
Great Cormorant	*Phalacrocorax carbo*	1	1	99	99	1	1	0	2	0	0
Double-crested Cormorant	*Phalacrocorax auritus*	2	1	99	99	1	1	0	2	0	0
American Bittern	*Botaurus lentiginosus*	2	1	1	0	1	1	1	1	0	0
Least Bittern	*Ixobrychus exilis*	2	2	3	0	1	1	0	1	0	1
Great Blue Heron	*Ardea herodias*	2	1	0	0	1	1	0	1	0	0
Great Egret	*Casmerodius albus*	2	1	3	0	1	1	0	1	0	0
Green Heron	*Butorides virescens*	2	1	3	0	0	1	0	1	0	0
Black-crowned Night-Heron	*Nycticorax nycticorax*	2	1	1	0	0	1	0	1	0	0
Brant	*Branta bernicla*	2	1	3	0	1	1	1	0	0	0
Canada Goose	*Branta canadensis*	2	1	0	0	1	1	1	0	0	0
Wood Duck	*Aix sponsa*	2	1	1	0	0	0	1	0	0	0
Green-winged Teal	*Anas crecca*	2	1	0	0	1	1	1	0	0	0
American Black Duck	*Anas rubripes*	1	1	0	0	1	1	1	0	0	0
Mallard	*Anas platyrhynchos*	2	1	1	0	1	1	1	0	0	0
Northern Pintail	*Anas acuta*	2	1	0	0	1	1	1	0	0	0
Blue-winged Teal	*Anas discors*	2	1	1	0	1	1	1	0	0	0
Northern Shoveler	*Anas clypeata*	2	1	1	0	1	1	1	0	0	0
Gadwall	*Anas strepera*	2	1	1	0	1	1	1	0	0	0
American Wigeon	*Anas americana*	2	1	1	0	1	1	1	0	0	0
Redhead	*Aythya americana*	2	1	3	0	1	1	1	0	0	0
Ring-necked Duck	*Aythya collaris*	2	1	1	1	1	1	1	0	0	0
Greater Scaup	*Aythya marila*	1	1	3	1	1	1	1	0	0	0
Lesser Scaup	*Aythya affinis*	2	1	0	0	1	1	1	0	0	0

Common Eider	*Somateria mollissima*	1	1	99	99	1	1	1	0	0	0
Harlequin Duck	*Histrionicus histrionicus*	1	1	0	0	0	1	1	0	0	0
Surf Scoter	*Melanitta perspicillata*	2	1	3	0	0	1	1	0	0	0
Common Goldeneye	*Bucephala clangula*	2	1	1	0	0	0	1	0	0	0
Barrow's Goldeneye	*Bucephala islandica*	0	1	2	0	0	0	1	0	0	0
Bufflehead	*Bucephala albeola*	2	1	2	2	0	0	1	0	0	0
Hooded Merganser	*Lophodytes cucullatus*	1	1	1	0	0	0	1	0	0	0
Common Merganser	*Mergus merganser*	2	1	0	0	0	0	1	0	0	0
Red-breasted Merganser	*Mergus serrator*	2	1	1	0	1	1	1	0	0	0
Ruddy Duck	*Oxyura jamaicensis*	2	1	3	0	1	1	1	0	0	0
Turkey Vulture	*Cathartes aura*	2	1	3	0	0	1	0	1	0	0
Osprey	*Pandion haliaetus*	2	1	0	0	1	1	1	1	0	0
Bald Eagle	*Haliaeetus leucocephalus*	2	1	1	0	0	1	0	1	0	0
Northern Harrier	*Circus cyaneus*	2	1	1	0	1	1	1	1	0	0
Sharp-shinned Hawk	*Accipiter striatus*	2	1	0	0	0	1	1	1	0	0
Cooper's Hawk	*Accipiter cooperii*	2	1	3	0	0	1	1	1	0	0
Northern Goshawk	*Accipiter gentilis*	0	0	1	0	0	1	1	1	0	0
Red-shouldered Hawk	*Buteo lineatus*	2	1	2	0	0	1	1	1	0	0
Broad-winged Hawk	*Buteo platypterus*	2	1	1	0	0	1	1	1	0	0
Red-tailed Hawk	*Buteo jamaicensis*	2	1	1	0	0	1	1	1	0	0
Golden Eagle	*Aquila chrysætos*	2	1	0	0	1	1	1	1	0	0
American Kestrel	*Falco sparverius*	2	1	0	0	1	0	0	1	0	0
Merlin	*Falco columbarius*	2	1	1	0	0	1	1	1	0	0
Peregrine Falcon	*Falco peregrinus*	2	1	0	0	1	1	1	1	0	0
Gray Partridge	*Perdix perdix*	0	0	3	0	1	1	1	0	0	0
Ring-necked Pheasant	*Phasianus colchicus*	0	.	3	0	1	1	1	0	0	0
Spruce Grouse	*Dendragapus canadensis*	0	0	1	0	0	1	1	0	0	0
Willow Ptarmigan	*Lagopus lagopus*	0	0	3	0	1	1	1	0	0	0
Ruffed Grouse	*Bonasa umbellus*	0	0	0	0	0	1	1	0	0	0
Sharp-tailed Grouse	*Tympanuchus phasianellus*	0	0	2	2	1	1	1	0	0	0
Wild Turkey	*Meleagris gallopavo*	0	0	3	0	0	1	1	0	0	0
Yellow Rail	*Coturnicops noveboracensis*	1	2	0	0	1	1	1	0	0	1
Virginia Rail	*Rallus limicola*	2	1	1	0	1	1	0	0	0	1
Sora	*Porzana carolina*	2	1	1	0	1	1	0	0	0	1
Common Moorhen	*Gallinula chloropus*	1	1	3	0	1	1	0	0	0	0
American Coot	*Fulica americana*	1	1	1	0	1	1	0	0	0	0

Semipalmated Plover	*Charadrius semipalmatus*	2	2	99	99	1	1	0	0	0	1
Piping Plover	*Charadrius melodus*	2	1	99	99	1	1	0	0	0	1
Killdeer	*Charadrius vociferus*	1	1	1	0	1	1	0	0	0	0
Greater Yellowlegs	*Tringa melanoleuca*	2	2	3	0	1	1	0	0	0	0
Solitary Sandpiper	*Tringa solitaria*	2	2	1	1	0	1	1	0	0	1
Spotted Sandpiper	*Actitis macularia*	2	1	0	0	1	1	0	0	0	1
Upland Sandpiper	*Bartramia longicauda*	2	1	2	0	1	1	0	0	0	0
Least Sandpiper	*Caladris minutilla*	2	2	3	0	1	1	0	0	0	2
Short-billed Dowitcher	*Limnodromus griseus*	2	2	3	0	1	1	0	0	0	0
Common Snipe	*Gallinago gallinago*	2	1	1	0	1	1	1	0	0	0
American Woodcock	*Scolopax minor*	1	1	1	0	0	1	1	0	0	0
Wilson's Phalarope	*Phalaropus tricolor*	2	2	2	0	1	1	1	0	0	1
Little Gull	*Larus minutus*	1	2	2	0	1	1	0	1	0	0
Common Black-headed Gull	*Larus ridibundus*	1	2	99	99	1	1	0	1	0	0
Bonaparte's Gull	*Larus philadelphia*	2	1	3	0	1	1	0	1	0	0
Ring-billed Gull	*Larus delawarensis*	1	1	1	0	1	1	0	1	0	0
Herring Gull	*Larus argentatus*	1	1	1	0	1	1	0	1	0	0
Great Black-backed Gull	*Larus marinus*	1	1	99	99	1	1	0	1	0	0
Black-legged Kittiwake	*Rissa tridactyla*	1	1	99	99	1	1	0	1	0	0
Caspian Tern	*Sterna caspia*	2	1	99	99	1	1	0	1	0	0
Roseate Tern	*Sterna dougallii*	2	2	99	99	1	1	0	1	0	0
Common Tern	*Sterna hirundo*	2	1	1	0	1	1	0	1	0	0
Arctic Tern	*Sterna paradisæa*	2	2	99	99	1	1	0	1	0	0
White-winged Tern	*Chlidonias leucopterus*	2	.	.	0	1	1	0	1	0	1
Black Tern	*Chlidonias niger*	2	1	1	1	1	1	0	1	1	1
Common Murre	*Uria aalge*	1	1	99	99	1	1	0	1	0	0
Thick-billed Murre	*Uria lomvia*	1	1	99	99	1	1	0	1	0	0
Razorbill	*Alca torda*	1	1	99	99	1	0	0	1	0	0
Black Guillemot	*Cepphus grylle*	0	1	99	99	1	0	0	1	0	0
Atlantic Puffin	*Fratercula arctica*	1	1	99	99	1	0	0	1	0	0
Rock Dove	*Columba livia*	0	0	1	0	1	1	0	2	0	0
Mourning Dove	*Zenaida macroura*	2	1	1	0	0	1	0	2	0	0
Black-billed Cuckoo	*Coccyzus erythropthalmus*	2	2	1	1	0	1	0	2	0	1
Yellow-billed Cuckoo	*Coccyzus americanus*	2	2	3	0	0	1	0	2	0	1
Barn Owl	*Tyto alba*	1	.	3	0	0	0	1	1	0	0
Eastern Screech-Owl	*Otus asio*	0	0	3	0	0	0	1	1	0	0

Great Horned Owl	*Bubo virginianus*	0	0	0	0	0	1	1	1	0	0
Northern Hawk Owl	*Surnia ulula*	0	0	2	0	1	0	1	1	0	0
Barred Owl	*Strix varia*	0	0	1	0	0	0	1	1	0	0
Great Gray Owl	*Strix nebulosa*	0	0	3	2	0	1	1	1	0	0
Long-eared Owl	*Asio otus*	1	1	1	0	0	1	1	1	0	0
Short-eared Owl	*Asio flammeus*	2	1	1	0	1	1	1	1	0	0
Boreal Owl	*Ægolius funereus*	0	0	2	0	0	0	1	1	0	0
Northern Saw-whet Owl	*Aegolius acadicus*	1	1	1	0	0	0	1	1	0	1
Common Nighthawk	*Chordeiles minor*	2	1	0	0	1	1	1	1	1	1
Whip-poor-will	*Caprimulgus vociferus*	2	1	2	0	0	1	1	1	1	1
Chimney Swift	*Chaetura pelagica*	2	1	1	0	0	1	0	2	1	2
Ruby-throated Hummingbird	*Archilochus colubris*	2	1	1	0	0	1	1	2	0	2
Belted Kingfisher	*Ceryle alcyon*	2	1	0	0	1	0	0	2	0	0
Red-headed Woodpecker	*Melanerpes erythrocephalus*	1	1	3	0	1	0	0	2	1	1
Yellow-bellied Sapsucker	*Sphyrapicus varius*	2	1	0	0	0	0	0	2	0	1
Downy Woodpecker	*Picoides pubescens*	0	0	0	0	0	0	0	2	0	2
Hairy Woodpecker	*Picoides villosus*	0	0	0	0	0	0	0	2	0	1
Three-toed Woodpecker	*Picoides tridactylus*	0	0	3	0	0	0	0	2	0	1
Black-backed Woodpecker	*Picoides arcticus*	0	0	1	0	1	0	0	2	0	1
Northern Flicker	*Colaptes auratus*	2	1	0	0	1	0	0	2	0	0
Pileated Woodpecker	*Dryocopus pileatus*	0	0	1	0	0	0	0	2	0	0
Olive-sided Flycatcher	*Contopus borealis*	2	2	1	0	0	1	1	2	1	1
Eastern Wood-Pewee	*Contopus virens*	2	2	1	0	0	1	1	2	1	2
Yellow-bellied Flycatcher	*Empidonas flaviventris*	2	2	1	0	0	1	1	2	1	2
Alder Flycatcher	*Empidonax alnorum*	2	2	0	0	1	1	1	2	1	2
Willow Flycatcher	*Empidonax traillii*	2	2	3	2	1	1	1	2	1	2
Least Flycatcher	*Empidonax minimus*	2	1	0	0	0	1	1	2	0	2
Eastern Phoebe	*Sayornis phoebe*	2	1	1	0	0	1	1	2	1	2
Great Crested Flycatcher	*Myiarchus crinitus*	2	1	2	0	0	0	1	2	1	1
Eastern Kingbird	*Tyrannus tyrannus*	2	1	1	0	1	1	1	2	1	1
Horned Lark	*Eremophila alpestris*	1	1	1	0	1	1	1	2	0	1
Purple Martin	*Progne subis*	2	1	3	0	1	0	1	2	1	1
Tree Swallow	*Tachycineta bicolor*	2	1	0	0	1	0	1	2	1	2
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	2	1	3	0	1	0	1	2	1	2
Bank Swallow	*Riparia riparia*	2	1	1	0	1	0	0	2	1	2
Cliff Swallow	*Hirundo pyrrhonota*	2	1	1	0	1	0	0	2	1	2

Barn Swallow	*Hirundo rustica*	2	1	1	0	1	1	1	2	1	2
Gray Jay	*Perisoreus canadensis*	0	0	1	0	0	1	1	2	0	1
Blue Jay	*Cyanocitta cristata*	1	0	1	0	1	1	1	2	0	1
American Crow	*Corvus brachyrhynchos*	1	1	0	0	0	1	0	2	0	0
Common Raven	*Corvus corax*	0	0	0	0	1	1	1	2	0	0
Black-capped Chickadee	*Parus atricapillus*	0	0	0	0	0	0	1	2	0	2
Boreal Chickadee	*Parus hudsonicus*	0	0	1	0	0	0	1	2	0	2
Red-breasted Nuthatch	*Sitta canadensis*	2	0	0	0	0	0	1	2	0	2
White-breasted Nuthatch	*Sitta carolinensis*	0	0	1	0	0	0	1	2	0	2
Brown Creeper	*Certhia americana*	2	1	0	0	0	0	1	2	0	2
Carolina Wren	*Thryothorus ludovicianus*	0	0	3	0	0	0	1	2	0	2
House Wren	*Troglodytes aedon*	2	1	2	0	0	0	1	2	0	2
Winter Wren	*Troglodytes troglodytes*	1	1	0	0	0	0	1	2	0	2
Sedge Wren	*Cistothorus platensis*	2	2	3	0	1	1	1	2	0	2
Marsh Wren	*Cistothorus palustris*	2	2	3	0	1	1	1	2	0	2
Golden-crowned Kinglet	*Regulus satrapa*	1	1	0	1	0	1	1	2	0	2
Ruby-crowned Kinglet	*Regulus calendula*	2	1	0	0	0	1	1	2	0	2
Blue-gray Gnatcatcher	*Polioptila cærulea*	2	2	3	0	0	1	0	2	0	2
Eastern Bluebird	*Sialia sialis*	2	1	1	0	1	0	1	2	1	2
Veery	*Catharus fuscescens*	2	1	1	0	0	1	1	2	0	1
Bicknell's Thrush	*Catharus bicknelli*	2	.	1	1	0	1	1	2	0	1
Swainson's Thrush	*Catharus ustulatus*	2	1	0	0	0	1	1	2	0	1
Hermit Thrush	*Catharus guttatus*	2	1	0	0	0	1	1	2	0	1
Wood Thrush	*Hylocichla mustelina*	2	1	1	0	0	1	1	2	0	1
American Robin	*Turdus migratorius*	2	1	0	0	0	1	1	2	0	1
Gray Catbird	*Dumetella carolinensis*	2	1	1	0	1	1	1	2	0	1
Northern Mockingbird	*Mimus polyglottos*	0	1	1	0	1	1	1	2	0	1
Brown Thrasher	*Toxostoma rufum*	1	1	1	0	1	1	0	2	0	1
American Pipit	*Anthus rubescens*	1	1	3	0	1	1	1	2	0	2
Cedar Waxwing	*Bombycilla cedrorum*	1	2	0	0	1	1	1	2	0	1
Loggerhead Shrike	*Lanius ludovicianus*	2	1	3	0	1	1	1	2	0	1
European Starling	*Sturnus vulgaris*	0	1	1	0	1	0	0	2	0	1
Solitary Vireo	*Vireo solitarius*	2	1	0	0	0	1	0	2	0	2
Yellow-throated Vireo	*Vireo flavifrons*	2	1	3	0	0	1	0	2	0	2
Warbling Vireo	*Vireo gilvus*	2	1	2	1	1	1	0	2	0	2
Philadelphia Vireo	*Vireo philadelphicus*	2	2	1	2	0	1	0	2	0	2
Red-eyed Vireo	*Vireo olivaceus*	2	1	0	0	0	1	1	2	0	2
Brewster's Warbler	*Vermivora chrysoptera X*	2	.	3	0	1	1	1	2	0	.

	pinus										
Golden-winged Warbler	*Vermivora chrysoptera*	2	2	3	0	1	1	1	2	0	2
Tennessee Warbler	*Vermivora peregrina*	2	2	1	1	0	1	1	2	0	2
Orange-crowned Warbler	*Vermivora celata*	2	2	3	0	0	1	1	2	0	2
Nashville Warbler	*Vermivora ruficapilla*	2	2	0	0	0	1	1	2	0	2
Northern Parula	*Parula americana*	2	2	1	0	0	1	1	2	0	2
Yellow Warbler	*Dendroica petechia*	2	2	0	0	1	1	1	2	0	2
Chestnut-sided Warbler	*Dendroica pensylvanica*	2	2	1	0	0	1	1	2	0	2
Magnolia Warbler	*Dendroica magnolia*	2	2	0	0	0	1	1	2	0	2
Cape May Warbler	*Dendroica tigrina*	2	2	1	1	0	1	1	2	0	2
Black-throated Blue Warbler	*Dendroica caerulescens*	2	2	1	0	0	1	1	2	0	2
Yellow-rumped Warbler	*Dendroica coronata*	2	1	0	0	0	1	1	2	0	2
Black-throated Green Warbler	*Dendroica virens*	2	2	0	0	0	1	1	2	0	2
Blackburnian Warbler	*Dendroica fusca*	2	2	1	0	0	1	1	2	0	2
Pine Warbler	*Dendroica pinus*	1	2	3	0	0	1	1	2	0	2
Palm Warbler	*Dendroica palmarum*	2	2	1	0	1	1	0	2	0	2
Bay-breasted Warbler	*Dendroica castanea*	2	2	0	1	0	1	1	2	0	2
Blackpoll Warbler	*Dendroica striata*	2	2	1	2	0	1	1	2	0	2
Cerulean Warbler	*Dendroica cerulea*	2	2	3	0	0	1	1	2	0	2
Black-and-white Warbler	*Mniotilta varia*	2	2	1	0	0	1	1	2	0	2
American Redstart	*Setophaga ruticilla*	2	2	0	0	0	1	1	2	0	2
Ovenbird	*Seiurus aurocapillus*	2	2	0	0	0	1	1	2	0	2
Northern Waterthrush	*Seiurus noveboracensis*	2	2	0	1	0	1	1	2	0	2
Connecticut Warbler	*Oporornis agilis*	2	2	3	1	0	1	.	2	0	2
Mourning Warbler	*Oporornis philadelphia*	2	2	0	0	1	1	1	2	0	2
Common Yellowthroat	*Geothlypis trichas*	2	2	0	0	1	1	1	2	0	2
Wilson's Warbler	*Wilsonia pusilla*	2	2	1	0	1	1	1	2	0	2
Canada Warbler	*Wilsonia canadensis*	2	2	0	1	0	1	1	2	0	2
Scarlet Tanager	*Piranga olivacea*	2	2	1	0	0	1	1	2	0	2
Northern Cardinal	*Cardinalis cardinalis*	0	0	3	2	1	1	1	2	0	1
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	2	1	1	0	0	1	0	2	0	1
Indigo Bunting	*Passerina cyanea*	2	2	2	2	1	1	1	2	0	2
Rufous-sided Towhee	*Pipilo erythrophtalmus*	2	1	3	2	1	1	1	2	0	1
Chipping Sparrow	*Spizella passerina*	2	1	0	0	1	1	1	2	0	2
Clay-colored Sparrow	*Spizella pallida*	2	1	3	0	1	1	1	2	0	2
Field Sparrow	*Spizella pusilla*	2	1	3	0	1	1	1	2	0	2
Vesper Sparrow	*PoAcetes gramineus*	2	1	1	0	1	1	1	2	0	2

Savannah Sparrow	*Passerculus sandwichensis*	2	1	1	0	1	1	1	2	0	2
Grasshopper Sparrow	*Ammodramus savannarum*	2	2	3	0	1	1	1	2	0	2
Henslow's Sparrow	*Ammodramus henslowii*	1	.	3	0	1	1	1	2	0	2
Le Conte's Sparrow	*Ammodramus leconteii*	1	2	1	1	1	1	1	2	0	2
Sharp-tailed Sparrow	*Ammodramus caudacutus*	1	2	2	2	1	1	1	2	0	2
Fox Sparrow	*Passerella iliaca*	2	1	2	2	0	1	1	2	0	1
Song Sparrow	*Melospiza melodia*	2	1	0	0	1	1	1	2	0	2
Lincoln's Sparrow	*Melospiza lincolnii*	2	1	1	1	1	1	1	2	0	2
Swamp Sparrow	*Melospiza georgiana*	2	1	0	0	1	1	1	2	0	2
White-throated Sparrow	*Zonotrichia albicollis*	2	1	0	0	0	1	1	2	0	2
White-crowned Sparrow	*Zonotrichia leucophrys*	2	1	3	0	1	1	1	2	0	2
Dark-eyed Junco	*Junco hyemalis*	1	1	0	0	0	1	1	2	0	2
Bobolink	*Dolichonyx oryzivorus*	2	1	1	0	1	1	1	2	0	1
Red-winged Blackbird	*Agelaius phoeniceus*	2	1	1	0	1	1	1	2	0	1
Eastern Meadowlark	*Sturnella magna*	1	1	2	0	1	1	1	2	0	1
Western Meadowlark	*Sturnella neglecta*	2	1	.	.	1	1	1	2	0	1
Rusty Blackbird	*Euphagus carolinus*	1	1	1	0	1	1	1	2	0	1
Common Grackle	*Quiscalus quiscula*	1	1	0	0	1	1	1	2	0	1
Brown-headed Cowbird	*Molothrus ater*	2	1	1	0	1	1	1	2	0	1
Northern Oriole	*Icterus galbula*	2	2	2	0	1	1	1	2	0	1
Pine Grosbeak	*Pinicola enucleator*	0	0	1	2	0	1	1	2	0	1
Purple Finch	*Carpodacus purpureus*	1	1	0	0	0	1	1	2	0	2
House Finch	*Carpodacus mexicanus*	0	0	3	0	1	1	1	2	0	2
Red Crossbill	*Loxia curvirostra*	0	0	1	0	0	1	1	2	0	1
White-winged Crossbill	*Loxia leucoptera*	0	0	1	0	0	1	1	2	0	2
Common Redpoll	*Carduelis flammea*	1	0	3	0	1	1	1	2	0	2
Pine Siskin	*Carduelis pinus*	1	0	0	0	0	1	1	2	0	2
American Goldfinch	*Carduelis tristis*	2	1	1	0	1	1	1	2	0	2
Evening Grosbeak	*Coccothraustes vespertinus*	0	0	0	1	0	1	1	2	0	1
House Sparrow	*Passer domesticus*	0	0	1	0	1	0	1	2	0	2

† Gauthier and Aubry (1996); "sedentary" refers to resident sedentary breeders.

§ National Geographic Society (1987).

¶ Cyr and Larivée (1995).

Peterson (1980).

‡ Ehrlich et al. (1988).

Appendix 2. Potential sensitivity of breeding bird species to climate change.

English Name‡	Scientific Name	Climate Sensitivity Index (†) Sum	Maximum	Weighted (max =17)	Class	Atlas squares with the species Number (max= 1077)	Constancy	Percent of Observations (§)	Final Mark
Red-throated Loon	*Gavia stellata*	4	12	6	1	5	0,5%	0	0
COMMON LOON	*Gavia immer*	6	17	6	1	527	48,9%	3	1
Pied-billed Grebe	*Podilymbus podiceps*	6	17	6	1	138	12,8%	1	0
Horned Grebe	*Podiceps auritus*	4	12	6	1	0	0,0%	0	0
Red-necked Grebe	*Podiceps grisegena*	9	17	9	2	4	0,4%	0	0
Leach's Storm-Petrel	*Oceanodroma leucorhoa*	4	10	7	2	0	0,0%	0	0
Northern Gannet	*Morus bassanus*	7	12	10	2	1	0,1%	0	0
Great Cormorant	*Phalacrocorax carbo*	6	12	9	2	4	0,4%	0	0
Double-crested Cormorant	*Phalacrocorax auritus*	7	12	10	2	102	9,5%	0	0
AMERICAN BITTERN	*BOTAURUS LENTIGINOSUS*	8	17	8	2	412	38,3%	2	1
Least Bittern	*Ixobrychus exilis*	11	17	11	3	38	3,5%	0	0
GREAT BLUE HERON	*ARDEA HERODIAS*	6	17	6	1	601	55,8%	3	2
Great Egret	*Casmerodius albus*	9	17	9	2	3	0,3%	0	0
Green Heron	*Butorides virescens*	8	17	8	2	177	16,4%	1	0
Black-crowned Night-Heron	*Nycticorax nycticorax*	6	17	6	1	109	10,1%	1	0
Brant	*Branta bernicla*	9	17	9	2	0	0,0%	0	0
Canada Goose	*Branta canadensis*	6	17	6	1	83	7,7%	0	0
WOOD DUCK	*AIX SPONSA*	5	17	5	1	270	25,1%	2	1
Green-winged Teal	*Anas crecca*	6	17	6	1	157	14,6%	1	0
AMERICAN BLACK DUCK	*ANAS RUBRIPES*	5	17	5	1	661	61,4%	3	2
MALLARD	*ANAS PLATYRHYNCHOS*	7	17	7	2	450	41,8%	3	1
Northern Pintail	*Anas acuta*	6	17	6	1	135	12,5%	1	0
Blue-winged Teal	*Anas discors*	7	17	7	2	204	18,9%	1	0
Northern Shoveler	*Anas clypeata*	7	17	7	2	67	6,2%	0	0
Gadwall	*Anas strepera*	7	17	7	2	61	5,7%	0	0
American Wigeon	*Anas americana*	7	17	7	2	91	8,4%	0	0
Redhead	*Aythya americana*	9	17	9	2	11	1,0%	0	0
Ring-necked Duck	*Aythya collaris*	8	17	8	2	247	22,9%	2	0
Greater Scaup	*Aythya marila*	9	17	9	2	3	0,3%	0	0
Lesser Scaup	*Aythya affinis*	6	17	6	1	13	1,2%	0	0
Common Eider	*Somateria mollissima*	5	12	7	2	36	3,3%	0	0
Harlequin Duck	*Histrionicus histrionicus*	4	17	4	1	3	0,3%	0	0
Surf Scoter	*Melanitta perspicillata*	8	17	8	2	3	0,3%	0	0
COMMON GOLDENEYE	*BUCEPHALA CLANGULA*	5	17	5	1	323	30,0%	2	1
Barrow's Goldeneye	*Bucephala islandica*	4	17	4	1	1	0,1%	0	0

Bufflehead	*Bucephala albeola*	8	17	8	2	4	0,4%	0	0
Hooded Merganser	*Lophodytes cucullatus*	4	17	4	1	198	18,4%	1	0
Common Merganser	*Mergus merganser*	4	17	4	1	398	37,0%	2	1
Red-breasted Merganser	*Mergus serrator*	7	17	7	2	75	7,0%	0	0
Ruddy Duck	*Oxyura jamaicensis*	9	17	9	2	8	0,7%	0	0
Turkey Vulture	*Cathartes aura*	8	17	8	2	137	12,7%	1	0
Osprey	*Pandion haliaetus*	7	17	7	2	361	33,5%	2	1
Bald Eagle	*Haliaeetus leucocephalus*	6	17	6	1	33	3,1%	0	0
Northern Harrier	*Circus cyaneus*	8	17	8	2	622	57,8%	3	2
Sharp-shinned Hawk	*Accipiter striatus*	6	17	6	1	412	38,3%	2	1
Cooper's Hawk	*Accipiter cooperii*	9	17	9	2	38	3,5%	0	0
Northern Goshawk	*Accipiter gentilis*	4	17	4	1	161	14,9%	1	0
Red-shouldered Hawk	*Buteo lineatus*	8	17	8	2	190	17,6%	1	0
Broad-winged Hawk	*Buteo platypterus*	7	17	7	2	698	64,8%	3	2
Red-tailed Hawk	*Buteo jamaicensis*	7	17	7	2	459	42,6%	3	1
Golden Eagle	*Aquila chrysætos*	7	17	7	2	6	0,6%	0	0
American Kestrel	*Falco sparverius*	5	17	5	1	794	73,7%	3	2
Merlin	*Falco columbarius*	7	17	7	2	212	19,7%	1	0
Peregrine Falcon	*Falco peregrinus*	7	17	7	2	23	2,1%	0	0
Gray Partridge	*Perdix perdix*	6	17	6	1	77	7,1%	0	0
Ring-necked Pheasant	*Phasianus colchicus*	6	15	7	2	13	1,2%	0	0
Spruce Grouse	*Dendragapus canadensis*	3	17	3	1	106	9,8%	0	0
Willow Ptarmigan	*Lagopus lagopus*	6	17	6	1	0	0,0%	0	0
Ruffed Grouse	*Bonasa umbellus*	2	17	2	1	845	78,5%	3	3
Sharp-tailed Grouse	*Tympanuchus phasianellus*	7	17	7	2	4	0,4%	0	0
Wild Turkey	*Meleagris gallopavo*	5	17	5	1	14	1,3%	0	0
Yellow Rail	*Coturnicops noveboracensis*	7	17	7	2	10	0,9%	0	0
Virginia Rail	*Rallus limicola*	7	17	7	2	120	11,1%	1	0
Sora	*Porzana carolina*	7	17	7	2	108	10,0%	0	0
Common Moorhen	*Gallinula chloropus*	7	17	7	2	60	5,6%	0	0
American Coot	*Fulica americana*	5	17	5	1	27	2,5%	0	0
Semipalmated Plover	*Charadrius semipalmatus*	7	12	10	2	1	0,1%	0	0
Piping Plover	*Charadrius melodus*	6	12	9	2	0	0,0%	0	0
Killdeer	*Charadrius vociferus*	5	17	5	1	823	76,4%	3	3
Greater Yellowlegs	*Tringa melanoleuca*	9	17	9	2	42	3,9%	0	0
Solitary Sandpiper	*Tringa solitaria*	9	17	9	2	69	6,4%	0	0
Spotted Sandpiper	*Actitis macularia*	6	17	6	1	936	86,9%	3	3
Upland Sandpiper	*Bartramia longicauda*	7	17	7	2	248	23,0%	2	0
Least Sandpiper	*Caladris minutilla*	11	17	11	3	6	0,6%	0	0
Short-billed Dowitcher	*Limnodromus griseus*	9	17	9	2	0	0,0%	0	0
Common Snipe	*Gallinago gallinago*	7	17	7	2	732	68,0%	3	2

AMERICAN WOODCOCK	*SCOLOPAX MINOR*	5	17	5	1	546	50,7%	3	2
Wilson's Phalarope	*Phalaropus tricolor*	10	17	10	2	13	1,2%	0	0
Little Gull	*Larus minutus*	8	17	8	2	4	0,4%	0	0
Common Black-headed Gull	*Larus ridibundus*	6	12	9	2	1	0,1%	0	0
Bonaparte's Gull	*Larus philadelphia*	9	17	9	2	10	0,9%	0	0
Ring-billed Gull	*Larus delawarensis*	6	17	6	1	267	24,8%	2	0
HERRING GULL	*LARUS ARGENTATUS*	6	17	6	1	348	32,3%	2	1
Great Black-backed Gull	*Larus marinus*	5	12	7	2	92	8,5%	0	0
Black-legged Kittiwake	*Rissa tridactyla*	5	12	7	2	19	1,8%	0	0
Caspian Tern	*Sterna caspia*	6	12	9	2	2	0,2%	0	0
Roseate Tern	*Sterna dougallii*	7	12	10	2	0	0,0%	0	0
Common Tern	*Sterna hirundo*	7	17	7	2	119	11,0%	1	0
Arctic Tern	*Sterna paradisæa*	7	12	10	2	5	0,5%	0	0
White-winged Tern	*Chlidonias leucopterus*	6	12	9	2	1	0,1%	0	0
Black Tern	*Chlidonias niger*	10	17	10	2	58	5,4%	0	0
Common Murre	*Uria aalge*	5	12	7	2	4	0,4%	0	0
Thick-billed Murre	*Uria lomvia*	5	12	7	2	0	0,0%	0	0
Razorbill	*Alca torda*	4	12	6	1	4	0,4%	0	0
Black Guillemot	*Cepphus grylle*	3	12	4	1	29	2,7%	0	0
Atlantic Puffin	*Fratercula arctica*	4	12	6	1	2	0,2%	0	0
ROCK DOVE	*COLUMBA LIVIA*	5	17	5	1	545	50,6%	3	2
MOURNING DOVE	*ZENAIDA MACROURA*	7	17	7	2	604	56,1%	3	2
Black-billed Cuckoo	*Coccyzus erythropthalmus*	10	17	10	2	235	21,8%	1	0
Yellow-billed Cuckoo	*Coccyzus americanus*	11	17	11	3	12	1,1%	0	0
Barn Owl	*Tyto alba*	6	15	7	2	1	0,1%	0	0
Eastern Screech-Owl	*Otus asio*	5	17	5	1	35	3,2%	0	0
GREAT HORNED OWL	*Bubo virginianus*	3	17	3	1	337	31,3%	2	1
Northern Hawk Owl	*Surnia ulula*	5	17	5	1	0	0,0%	0	0
Barred Owl	*Strix varia*	3	17	3	1	257	23,9%	2	0
Great Gray Owl	*Strix nebulosa*	8	17	8	2	2	0,2%	0	0
Long-eared Owl	*Asio otus*	6	17	6	1	36	3,3%	0	0
Short-eared Owl	*Asio flammeus*	8	17	8	2	63	5,8%	0	0
Boreal Owl	*Ægolius funereus*	4	17	4	1	11	1,0%	0	0
Northern Saw-whet Owl	*Aegolius acadicus*	6	17	6	1	155	14,4%	1	0
COMMON NIGHTHAWK	*CHORDEILES MINOR*	9	17	9	2	318	29,5%	2	1
Whip-poor-will	*Caprimulgus vociferus*	10	17	10	2	146	13,6%	1	0
CHIMNEY SWIFT	*CHAETURA PELAGICA*	10	17	10	2	566	52,6%	3	2
RUBY-THROATED HUMMINGBIRD	*ARCHILOCHUS COLUBRIS*	10	17	10	2	762	70,8%	3	2
Belted Kingfisher	*Ceryle alcyon*	6	17	6	1	918	85,2%	3	3
Red-headed Woodpecker	*Melanerpes erythrocephalus*	10	17	10	2	24	2,2%	0	0

Yellow-bellied Sapsucker	*Sphyrapicus varius*	6	17	6	1	797	74,0%	3	2
Downy Woodpecker	*Picoides pubescens*	4	17	4	1	852	79,1%	3	3
Hairy Woodpecker	*Picoides villosus*	3	17	3	1	824	76,5%	3	3
Three-toed Woodpecker	*Picoides tridactylus*	6	17	6	1	39	3,6%	0	0
Black-backed Woodpecker	*Picoides arcticus*	5	17	5	1	243	22,6%	2	0
Northern Flicker	*Colaptes auratus*	6	17	6	1	1064	98,8%	3	3
Pileated Woodpecker	*Dryocopus pileatus*	3	17	3	1	411	38,2%	2	1
Olive-sided Flycatcher	*Contopus borealis*	11	17	11	3	517	48,0%	3	1
Eastern Wood-Pewee	*Contopus virens*	12	17	12	3	739	68,6%	3	2
Yellow-bellied Flycatcher	*Empidonas flaviventris*	12	17	12	3	410	38,1%	2	1
Alder Flycatcher	*Empidonax alnorum*	12	17	12	3	960	89,1%	3	3
Willow Flycatcher	*Empidonax traillii*	17	17	17	3	98	9,1%	0	0
Least Flycatcher	*Empidonax minimus*	9	17	9	2	983	91,3%	3	3
Eastern Phoebe	*Sayornis phoebe*	11	17	11	3	533	49,5%	3	1
Great Crested Flycatcher	*Myiarchus crinitus*	10	17	10	2	550	51,1%	3	2
Eastern Kingbird	*Tyrannus tyrannus*	11	17	11	3	887	82,4%	3	3
Horned Lark	*Eremophila alpestris*	9	17	9	2	351	32,6%	2	1
Purple Martin	*Progne subis*	12	17	12	3	157	14,6%	1	0
Tree Swallow	*Tachycineta bicolor*	10	17	10	2	1060	98,4%	3	3
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	13	17	13	3	180	16,7%	1	0
Bank Swallow	*Riparia riparia*	10	17	10	2	748	69,5%	3	2
Cliff Swallow	*Hirundo pyrrhonota*	10	17	10	2	590	54,8%	3	2
Barn Swallow	*Hirundo rustica*	12	17	12	3	983	91,3%	3	3
Gray Jay	*Perisoreus canadensis*	6	17	6	1	304	28,2%	2	1
Blue Jay	*Cyanocitta cristata*	8	17	8	2	891	82,7%	3	3
American Crow	*Corvus brachyrhynchos*	5	17	5	1	966	89,7%	3	3
Common Raven	*Corvus corax*	5	17	5	1	722	67,0%	3	2
Black-capped Chickadee	*Parus atricapillus*	5	17	5	1	1007	93,5%	3	3
Boreal Chickadee	*Parus hudsonicus*	6	17	6	1	450	41,8%	3	1
Red-breasted Nuthatch	*Sitta canadensis*	7	17	7	2	837	77,7%	3	3
White-breasted Nuthatch	*Sitta carolinensis*	6	17	6	1	459	42,6%	3	1
Brown Creeper	*Certhia americana*	8	17	8	2	398	37,0%	2	1
Carolina Wren	*Thryothorus ludovicianus*	8	17	8	2	4	0,4%	0	0
House Wren	*Troglodytes aedon*	10	17	10	2	325	30,2%	2	1
Winter Wren	*Troglodytes troglodytes*	7	17	7	2	900	83,6%	3	3
Sedge Wren	*Cistothorus platensis*	14	17	14	3	22	2,0%	0	0
Marsh Wren	*Cistothorus palustris*	14	17	14	3	68	6,3%	0	0
Golden-crowned Kinglet	*Regulus satrapa*	9	17	9	2	650	60,4%	3	2
Ruby-crowned Kinglet	*Regulus calendula*	9	17	9	2	819	76,0%	3	3
Blue-gray Gnatcatcher	*Polioptila cærulea*	12	17	12	3	12	1,1%	0	0

Eastern Bluebird	*Sialia sialis*	11	17	11	3	336	31,2%	2	1
Veery	*Catharus fuscescens*	9	17	9	2	920	85,4%	3	3
Bicknell's Thrush	*Catharus bicknelli*	9	15	10	2	0	0,0%	0	0
Swainson's Thrush	*Catharus ustulatus*	8	17	8	2	794	73,7%	3	2
Hermit Thrush	*Catharus guttatus*	8	17	8	2	931	86,4%	3	3
Wood Thrush	*Hylocichla mustelina*	9	17	9	2	534	49,6%	3	1
American Robin	*Turdus migratorius*	8	17	8	2	1073	99,6%	3	3
Gray Catbird	*Dumetella carolinensis*	10	17	10	2	667	61,9%	3	2
Northern Mockingbird	*Mimus polyglottos*	8	17	8	2	151	14,0%	1	0
Brown Thrasher	*Toxostoma rufum*	8	17	8	2	410	38,1%	2	1
American Pipit	*Anthus rubescens*	12	17	12	3	2	0,2%	0	0
Cedar Waxwing	*Bombycilla cedrorum*	9	17	9	2	1043	96,8%	3	3
Loggerhead Shrike	*Lanius ludovicianus*	12	17	12	3	27	2,5%	0	0
European Starling	*Sturnus vulgaris*	6	17	6	1	836	77,6%	3	3
Solitary Vireo	*Vireo solitarius*	8	17	8	2	590	54,8%	3	2
Yellow-throated Vireo	*Vireo flavifrons*	11	17	11	3	56	5,2%	0	0
Warbling Vireo	*Vireo gilvus*	12	17	12	3	444	41,2%	3	1
Philadelphia Vireo	*Vireo philadelphicus*	12	17	12	3	549	51,0%	3	2
Red-eyed Vireo	*Vireo olivaceus*	9	17	9	2	1011	93,9%	3	3
Brewster's Warbler	*Vermivora chrysoptera X pinus*	10	13	13	3	5	0,5%	0	0
Golden-winged Warbler	*Vermivora chrysoptera*	14	17	14	3	29	2,7%	0	0
Tennessee Warbler	*Vermivora peregrina*	12	17	12	3	669	62,1%	3	2
Orange-crowned Warbler	*Vermivora celata*	13	17	13	3	8	0,7%	0	0
Nashville Warbler	*Vermivora ruficapilla*	10	17	10	2	915	85,0%	3	3
Northern Parula	*Parula americana*	11	17	11	3	379	35,2%	2	1
Yellow Warbler	*Dendroica petechia*	11	17	11	3	831	77,2%	3	3
Chestnut-sided Warbler	*Dendroica pensylvanica*	11	17	11	3	892	82,8%	3	3
Magnolia Warbler	*Dendroica magnolia*	10	17	10	2	880	81,7%	3	3
Cape May Warbler	*Dendroica tigrina*	12	17	12	3	408	37,9%	2	1
Black-throated Blue Warbler	*Dendroica caerulescens*	11	17	11	3	692	64,3%	3	2
Yellow-rumped Warbler	*Dendroica coronata*	9	17	9	2	973	90,3%	3	3
Black-throated Green Warbler	*Dendroica virens*	10	17	10	2	824	76,5%	3	3
Blackburnian Warbler	*Dendroica fusca*	11	17	11	3	749	69,5%	3	2
Pine Warbler	*Dendroica pinus*	12	17	12	3	87	8,1%	0	0
Palm Warbler	*Dendroica palmarum*	11	17	11	3	45	4,2%	0	0
Bay-breasted Warbler	*Dendroica castanea*	11	17	11	3	590	54,8%	3	2
Blackpoll Warbler	*Dendroica striata*	13	17	13	3	247	22,9%	2	0
Cerulean Warbler	*Dendroica cerulea*	13	17	13	3	6	0,6%	0	0
Black-and-white Warbler	*Mniotilta varia*	11	17	11	3	880	81,7%	3	3

American Redstart	*Setophaga ruticilla*	10	17	10	2	1014	94,2%	3	3
Ovenbird	*Seiurus aurocapillus*	10	17	10	2	960	89,1%	3	3
NORTHERN WATERTHRUSH	*SEIURUS NOVEBORACENSIS*	11	17	11	3	791	73,4%	3	2
Connecticut Warbler	*Oporornis agilis*	13	16	14	3	14	1,3%	0	0
Mourning Warbler	*Oporornis philadelphia*	11	17	11	3	854	79,3%	3	3
Common Yellowthroat	*Geothlypis trichas*	11	17	11	3	1053	97,8%	3	3
WILSON'S WARBLER	*WILSONIA PUSILLA*	12	17	12	3	355	33,0%	2	1
CANADA WARBLER	*WILSONIA CANADENSIS*	11	17	11	3	779	72,3%	3	2
SCARLET TANAGER	*PIRANGA OLIVACEA*	11	17	11	3	563	52,3%	3	2
Northern Cardinal	*Cardinalis cardinalis*	11	17	11	3	81	7,5%	0	0
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	8	17	8	2	908	84,3%	3	3
INDIGO BUNTING	*PASSERINA CYANEA*	15	17	15	3	314	29,2%	2	1
Rufous-sided Towhee	*Pipilo erythrophtalmus*	14	17	14	3	53	4,9%	0	0
Chipping Sparrow	*Spizella passerina*	10	17	10	2	997	92,6%	3	3
Clay-colored Sparrow	*Spizella pallida*	13	17	13	3	24	2,2%	0	0
Field Sparrow	*Spizella pusilla*	13	17	13	3	117	10,9%	1	0
VESPER SPARROW	*POACETES GRAMINEUS*	11	17	11	3	324	30,1%	2	1
SAVANNAH SPARROW	*PASSERCULUS SANDWICHENSIS*	11	17	11	3	799	74,2%	3	2
Grasshopper Sparrow	*Ammodramus savannarum*	14	17	14	3	18	1,7%	0	0
Henslow's Sparrow	*Ammodramus henslowii*	11	15	12	3	2	0,2%	0	0
Le Conte's Sparrow	*Ammodramus leconteii*	12	17	12	3	13	1,2%	0	0
Sharp-tailed Sparrow	*Ammodramus caudacutus*	14	17	14	3	18	1,7%	0	0
Fox Sparrow	*Passerella iliaca*	12	17	12	3	188	17,5%	1	0
Song Sparrow	*Melospiza melodia*	10	17	10	2	987	91,6%	3	3
LINCOLN'S SPARROW	*MELOSPIZA LINCOLNII*	12	17	12	3	652	60,5%	3	2
Swamp Sparrow	*Melospiza georgiana*	10	17	10	2	845	78,5%	3	3
White-throated Sparrow	*Zonotrichia albicollis*	9	17	9	2	1072	99,5%	3	3
White-crowned Sparrow	*Zonotrichia leucophrys*	13	17	13	3	4	0,4%	0	0
Dark-eyed Junco	*Junco hyemalis*	8	17	8	2	833	77,3%	3	3
BOBOLINK	*DOLICHONYX ORYZIVORUS*	10	17	10	2	698	64,8%	3	2
Red-winged Blackbird	*Agelaius phoeniceus*	10	17	10	2	975	90,5%	3	3
EASTERN MEADOWLARK	*STURNELLA MAGNA*	10	17	10	2	442	41,0%	3	1
Western Meadowlark	*Sturnella neglecta*	9	12	13	3	3	0,3%	0	0
RUSTY BLACKBIRD	*EUPHAGUS CAROLINUS*	9	17	9	2	318	29,5%	2	1
Common Grackle	*Quiscalus quiscula*	8	17	8	2	985	91,5%	3	3
BROWN-HEADED COWBIRD	*MOLOTHRUS ATER*	10	17	10	2	769	71,4%	3	2
NORTHERN ORIOLE	*ICTERUS GALBULA*	12	17	12	3	525	48,7%	3	1
Pine Grosbeak	*Pinicola enucleator*	8	17	8	2	161	14,9%	1	0
Purple Finch	*Carpodacus purpureus*	8	17	8	2	988	91,7%	3	3
House Finch	*Carpodacus mexicanus*	10	17	10	2	108	10,0%	0	0
Red Crossbill	*Loxia curvirostra*	6	17	6	1	48	4,5%	0	0

WHITE-WINGED CROSSBILL	*LOXIA LEUCOPTERA*	7	17	7	2	329	30,5%	2	1
Common Redpoll	*Carduelis flammea*	11	17	11	3	4	0,4%	0	0
PINE SISKIN	*CARDUELIS PINUS*	7	17	7	2	686	63,7%	3	2
American Goldfinch	*Carduelis tristis*	11	17	11	3	884	82,1%	3	3
EVENING GROSBEAK	*COCCOTHRAUSTES VESPERTINUS*	6	17	6	1	751	69,7%	3	2
HOUSE SPARROW	*PASSER DOMESTICUS*	7	17	7	2	691	64,2%	3	2

† To ensure that species with a relatively wide range of sensitivity to climate change were selected, 3 sensitivity classes were created (with the maximum sensitivity being 17): 0-6; 7-10 and 11-17. These 3 classes contained 60, 119 and 63 species respectively.

§ Final Mark: 0: [0%, 25%], 1: [25%, 50%], 2: [50%, 75%], 3: [75%, 100%].

‡ Selected species are in small capitals.