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Author(s): David J. Lieske , Bruce Pollard , Mark Gloutney , Randy Milton , Kevin Connor , Randy Dibblee , Glen Parsons and David Howerter

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The Importance of Agricultural Landscapes as Key Nesting Habitats for the American Black Duck in Maritime Canada

DAVID J. LIESKE[1,*], BRUCE POLLARD[2], MARK GLOUTNEY[3], RANDY MILTON[4], KEVIN CONNOR[5], RANDY DIBBLEE[6], GLEN PARSONS[4] AND DAVID HOWERTER[7]

[1]Department of Geography and Environment, Mount Allison University, 144 Main Street, Sackville, New Brunswick, E4L 1A7, Canada

[2]Canadian Wildlife Service, Environmental Stewardship Branch, Environment Canada, 17 Waterfowl Lane, Sackville, New Brunswick, E4L 1G6, Canada

[3]Ducks Unlimited Canada, Box 430, Amherst, Nova Scotia, B4H 3Y4, Canada

[4]Nova Scotia Department of Natural Resources, Wildlife Division, Provincial Building, 136 Exhibition Street, Kentville, Nova Scotia, B4N 4ES, Canada

[5]Fish and Wildlife Branch, New Brunswick Department of Natural Resources, P.O. Box 6000, Fredericton, New Brunswick, E3C 2G6, Canada

[6]Forests, Fish and Wildlife Division, Department of Environment, Energy and Forestry, 183 Upton Road, P.O. Box 2000, Charlottetown, Prince Edward Island, C1A 7N8, Canada

[7]Ducks Unlimited Canada, Institute for Waterfowl and Wetland Research, P.O. Box 1160, Stonewall, Manitoba, R0C 2Z0, Canada

[*]Corresponding author; E-mail: dlieske@mta.ca

Abstract.—Given historical patterns of decline, the American Black Duck (*Anas rubripes*) has long been a species of concern. To support the identification of core Maritime habitat, the distribution of breeding ducks was mapped at the landscape scale through the combination of GIS-based land cover information and five years of intensive aerial surveys (2006-2010). A predictive, mixed effects model was used to generate the maps, based on the weighted average of coefficients for the top 95% of all-possible models (as measured by AIC weights). The results of the averaged mixed model indicated that annual variation (YEAR), availability of surface water (WET_AREA, LAKE_AREA and WET_DIVERSITY) and occurrence of active agricultural landscapes (AG_PROP and ROAD_DENSITY) were strongly associated with the number of breeding pairs. The presence of larger numbers of breeding ducks in agricultural landscapes represents a departure from studies conducted in more intensively utilized regions (e.g. southern Ontario and Quebec), and suggest that the benefits of breeding in Maritime agricultural areas outweigh potential costs. Using 34,659 prediction points, duck distribution was modeled in relatively high and low years (2008 and 2006, respectively), resulting in detailed maps suitable for the identification of priority areas for habitat restoration and enhancement. In order to help refine conservation management plans, future work should more closely examine the impact of different types and combinations of Maritime agricultural production to better understand the way these landscapes attract breeding ducks. *Received 29 August 2011, accepted 12 August 2012.*

Key words.—American Black Duck, GIS, Maritimes, mixed modeling, model averaging, species distribution.

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The American Black Duck (*Anas rubripes*) is a large species of dabbler with a historical record of continent-wide declines (Rusch *et al.* 1989; Longcore *et al.* 2000). A number of factors have been implicated, e.g. loss or deterioration of breeding and wintering habitat (Diefenbach and Owen 1989), hybridization and competitive exclusion by the Mallard (*Anas platyrhynchos*) (Merendino and Ankney 1994) and hunting pressure (Grandy 1983, cited in Bélanger *et al.* 1998). A long-term study of the species' nesting ecology in southern Quebec suggested that the intensification of farming practices and degradation or removal of mainland nesting habitats played an important role in declining duck numbers in the 1970-1980s along the St. Lawrence Valley (Bélanger *et al.* 1998). Findings such as those of Bélanger *et al.* (1998) suggest that effective regional conservation planning requires both an accurate knowledge of landscape condition (e.g. human land use, wetland availability) as well as detailed information about species distribution. Taken together, this information can be used to assess species status and identify optimal habitat for the targeting of conservation and enhancement efforts (Fielding and Haworth 1995; Venier *et al.* 1999; Beissinger *et al.* 2006; Rhodes *et al.* 2006).

When land cover information is combined with species survey data within a geographic information system (GIS) it becomes possible to employ a species distribution modeling (SDM) framework to achieve a number of goals. First, species-habitat associations can be measured and key factors influencing species abundance identified (Guisan and Zimmermann 2000). Second, model predictions can be applied to unsurveyed areas allowing for a more comprehensive, region-wide assessment of species distribution (Austin 2002; Shriner *et al.* 2002). Third, survey data collected over multiple years can be used to model annual variation, thereby providing an accurate picture of the natural range and trajectory of population change. Multi-year studies also allow high quality habitat to be more finely assessed on the basis of consistency of usage (van Horne 1983; Darveau *et al.* 1992).

Previous efforts at modeling the distribution of this species focused on either probability of usage for a small study area (Diefenbach and Owen 1989), or aggregated across wide time spans (Hanson 2001). A goal of the present study was to directly model the number of breeding pairs as a function of time, as well as a number of potentially influential landscape-level factors: wetland availability, diversity and spatial arrangement; topographic complexity; human population density; road density; and the presence of active agriculture.

METHODS

Species Data

Species records consisted of georeferenced observations of individual American Black Ducks, spanning the period 2006-2010. A total of 66, 25 km^2 (5 km × 5 km) survey plots, distributed throughout New Brunswick and Nova Scotia (Fig. 1), were surveyed at least twice in alternate years by the Canadian Wildlife Service and partners in the Black Duck Joint Venture (BDJV). These

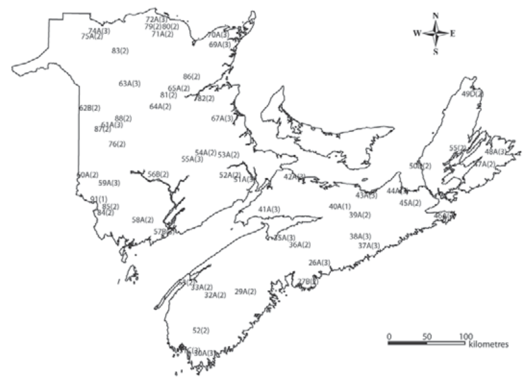

Figure 1. Distribution of 66, 25-km^2 plots sampled by helicopter between 2006 and 2010 in the study region. The extent of the sampled region (including water bodies) is approximately 174, 676 km^2. Each sample plot is indicated by its "plotkey" identifier, and the number of times the plot was sampled is shown in parentheses.

plots were originally selected as part of a regional monitoring scheme initiated in 1985 (Erskine *et al.* 1990), through randomly chosen 1:50,000 map sheets (with replacement) and survey-plots positioned on the basis of perceived habitat quality. Subsequent declines in funding necessitated the selection of a smaller subset of survey plots, eventually leading to the selection reported here. Prince Edward Island was surveyed under an alternative (ground-based) protocol with results that are not discussed.

During the breeding period, individual observations were gathered using a Bell 206L Long Ranger helicopter equipped with bubble windows to enhance visibility. All waterfowl habitats within the 5 km x 5 km sample plots were surveyed, and all ducks observed during the visit recorded. Surveys were flown at 60-100 km/hr, 16-50 m above ground level, but only during favorable conditions (i.e. avoiding high winds and heavy precipitation) in order to reduce weather-induced variation. An experienced navigator/observer sat in the front left seat and an experienced observer was positioned in the rear right behind the pilot. Surveys were scheduled to coincide with the nest initiation to early incubation period (late April through early May). All aquatic habitats within each plot were overflown, with both forward and rear observers recording duck occurrences on 1:50,000 topographic maps. An intercom system with noise-limiting headsets was employed to ensure that duplicate counting did not occur.

All data was digitized and incorporated within a geodatabase, with counts later converted to "indicated breeding pairs (IBP)" in accordance with the Black Duck Joint Venture Strategic Plan (Black Duck Joint Venture Management Board 2008). The conversion of count data to IBPs maximizes the conservation relevance of field-based observations by inferring breeding status from individual observations (e.g. one male and one female "indicates" a single breeding pair).

Habitat and Anthropogenic Data

The physiography of the region is summarized by Erskine (1992) as geologically complex, with distinctly cooler and warmer areas (e.g. Fundy and Atlantic coast vs. upland interior). For the most part low-lying (with only a few summits exceeding 750 m), a combination of land morphology, moisture regime and soil texture in this region interact to support wetlands that cover between 1% and 33% of the provincial land bases (PEI and Nova Scotia, respectively; Zoltai 1988). These systems are widely prioritized for terrestrial conservation planning out of recognition that they play a crucial role in storing water and carbon, supporting biodiversity and provisioning important animal habitat (Mitsch and Gosselink 2007; Zoltai 1988).

A Maritime-wide GIS land cover database (Table 1) was constructed and, similar to Rhodes *et al.* (2006), habitat features were distinguished from anthropogenic ones. For a dabbling duck, wetlands constitute a key habitat resource, but comprehensive inventories of these features are expensive and difficult to obtain at regional scales (Hanson 2001). As part of their wetland conservation mandates, the Nova Scotia and New Brunswick departments of natural resources maintain databases of individually-delineated wetland polygons, based on interpretation of 1:10,000 scale airphoto imagery of wetlands greater than 0.5 ha in size. In addition to geographic delineation, wetlands were also classified by the provincial departments. The Nova Scotia freshwater classification system was very similar to the Circular 39 Classification of Shaw and Fredine (1956, cited in Mitsch and Gosselink 2007), with the addition of a fen class, and included: bog (BG), deep marsh (DM), fen (FE), lakeshore wetland (LW), meadow (ME), seasonally flooded flat (SF), shallow marsh (SM), shrub swamp (SS), wooded swamp (WS) as well as salt marsh and coastal-zone classes. The New Brunswick freshwater classification system (DNR 2006) identified bog, fen, emergent wetland (including wet meadow), shrub wetland and forested wetland (considered to be underrepresented in the provincial wetland inventory).

Extra variables were derived from the wetland databases using geoprocessing tools in ArcGIS 9.3 (Environmental Systems Research Institute 2009) and the spdep package (Bivand 2006) available for the R Statistical Package (R Development Core Team 2011). Two habitat features, total wetland area (WET_AREA, km^2) and shape complexity (perimeter-to-area ratio or PARATIO, Turner *et al.* 2001), were derived from the feature geometry of individual wetland polygons and averaged for each 5 km x 5 km survey plot. The spatial distribution of wetlands within survey plots (e.g. clustered vs. regularly spaced) were also of interest as they might indicate wetland connectedness/degree of isolation, so a standardized nearest neighbor index (RINDEX; de Smith *et al.* 2007) was calculated using the following formula:

$$\frac{NN_O}{NN_E}, \text{ with } NN_E = \frac{1}{2\sqrt{n/area}} \tag{1}$$

where NN_O is the average nearest neighbor distance for all n observations, and NN_E is the expected nearest neighbor distance under conditions of pure randomness. Nearest-neighbor distance calculations were computed using the spdep package (Bivand 2006).

Similar to Hanson (2001, Appendix B) wetland diversity was assessed as the sum of the following differen-

Table 1. Candidate landscape-level predictor variables.

Variable	Description
AG_PROP	Proportion of landscape under active agricultural production.
ELEV_SD	Standard deviation of average elevation (in meters) obtained from a 75m × 75m resolution DEM.
WET_DIVERSITY	Wetland diversity score (derived using criteria of Hanson 2001).
LAKE_AREA	Total area of lake polygons (km^2), obtained from NTDB of NRCAN (htwtp://ftp2.cits.rncan.gc.ca/pub/bndt/).
PARATIO	Average perimeter-to-area ratio of wetland polygons.
POP_DENSITY	Average human population density from a 2.5 arc-minute resolution grid (Center for International Earth Science Information Network *et al.*, 2005).
RINDEX	Standardized nearest-neighbour index applied to the distribution of wetland polygons (with 1 = approximately random, < 0.5 = clustered, > 1.5 = dispersed).
RIV_DENSITY	Average river density (length per km^2, using a 10km search radius and a 1km resolution); obtained from NTDB of NRCAN (http://ftp2.cits.rncan.gc.ca/pub/bndt/).
ROAD_DENSITY	Average road density/km^2 (using a 10km search radius and a 1km resolution); obtained from NTDB of NRCAN (http://ftp2.cits.rncan.gc.ca/pub/bndt/).
YEAR	Year in which the survey was conducted (2006 through 2010).
WET_AREA	Total area of non-lake wetlands (km^2), based on New Brunswick and Nova Scotia provincial wetland databases.

tially weighted criteria: type of dominant wetland, with seasonally-flooded flats and deep and shallow marshes ranked higher than regions of open water; level of vegetation cover; degree of "interspersion", as indexed by shape complexity (perimeter-to-area ratio); degree of "juxtaposition", as indicated by how evenly distributed the wetlands were in the plot (RINDEX values); and the number of wetland types. The sum of the ranks determined the value of the variable WET_DIVERSITY.

Other GIS-derived habitat variables included: the standard deviation of elevation (ELEV_SD), total lake area (LAKE_AREA, km^2), and mean river density (RIV_DENSITY). ELEV_SD was based on a 75 m x 75m resolution DEM, and used to measure the topographic complexity of each sample plot. LAKE_AREA, like WET_AREA, was derived from the feature geometry of individual lake polygons using ArcGIS 9.3 (Environmental Systems Research Institute 2009). RIV_DENSITY was calculated as the feature length per km^2, using a 10 km-radius and a 1 km resolution (Environmental Systems Research Institute 2009).

Three anthropogenic variables with the potential to capture the impact of human activity at the landscape scale were used. The first, mean population density (POP_DENSITY) was derived from a 2.5 arc-minute human population density grid obtained from the Center for International Earth Science Information Network *et al.* (2005). As discussed by Forman and Alexander (1998), roads can act as a net negative disturbance directly through increased runoff, sedimentation and air pollution, as well as indirectly through facilitation of human access. We used the same geoprocessing tool as used for RIV_DENSITY to produce the second anthropogenic variable, ROAD_DENSITY.

Lastly, AG_PROP was defined as the proportion of each plot under active agricultural production (e.g. cereal crops, orchards, blueberries). We did not distinguish agricultural units on the basis of long-term production or use of a rotation plan. Inactive lands were included if they were classified as having the potential to be readily brought back into use. Using these criteria, active agricultural polygons were flagged and coded using a dummy variable and the proportional contribution (by area) of each plot was calculated.

All predictor variables were inspected for collinearity, with the highest correlation being between POP_DENSITY and ROAD_DENSITY (Pearson's r = 0.50). To simplify the comparison of their relative impact, habitat and anthropogenic variables were standardized prior to modeling.

Statistical Modeling

Modeling framework- The relationship between indicated number of breeding pairs (IBP), landscape-level variables and survey year (2006 to 2010) was investigated using a generalized linear mixed model, Poisson regression (GLMM, see Bolker *et al.* 2008; Zuur *et al.* 2009). A random-effect term was used to model the effect of individual plots, which were sampled at least twice during the survey period. This permitted plot-specific effects (e.g. differences in wetland productivity) to be distinguished from those related to year, land cover and habitat configuration. All temporal and landscape-level habitat variables were treated as fixed effects. Following the all combinations model inspection (see *Final model construction*), the residuals of the final model were evaluated for spatial autocorrelation, using a maximum distance band of 100 km.

Data management and storage was achieved using Microsoft Access (Microsoft Corporation 2002) while geoprocessing was achieved using ArcGIS 9.3 (Environmental Systems Research Institute 2009) and the Python 2.6.5 scripting language (Python Software Foundation 2010). Ultimately, analyses were conducted using the *R* Statistical Package (R Core Development Team 2009) as well as the lmer library of Bates and Maechler (2010).

Final model construction- Proceeding with a varying intercept term to capture the effect of sample plot, an all-combination algorithm (available from D. Lieske) was used to: create a model for every combination of predictor variables; rank each model on the basis of AIC values; and store the estimated coefficients. The method of Gray *et al.* (2010) was adopted to calculate the weighted average of the coefficients for the top 95% of models, which were sorted and weighted by AIC weights, W_i, (Burnham and Anderson 2002). This approach offers three useful advantages: it is objective; it explicitly incorporates uncertainty about the best combination of predictor variables, eliminating the need to choose which variables will be retained or discarded; and it uses AIC information to place greater weight on the coefficients estimated from the most parsimonious models, and less weight on those derived from less parsimonious models—out to the 95th percentile of weights.

Apparent (optimistic) prediction error for the resulting averaged model, using all the available data, was assessed using the root mean squared error (RMSE, de Smith *et al.* 2009):

$$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y-\hat{y})^2} \qquad (2)$$

where n is the sample size, y is the known number of IBPs, and $\hat{y}$ is the predicted number of IBPs based on the final model.

A more stringent test of prediction error was also employed, using ten bootstrapped sets of randomly chosen training (75%) and testing data (25%) (see Verbyla and Litvaitis 1989). An important advantage of bootstrapping is its allowance for large sets of training and testing data, making it easier to calculate accuracy statistics such as RMSE (Vaughan and Ormerod 2005).

RESULTS

Species Data

The distribution of plot-level abundances is indicated in Fig. 2. The median abundance was 11.0 pairs per 25 km^2, with a 25th per-

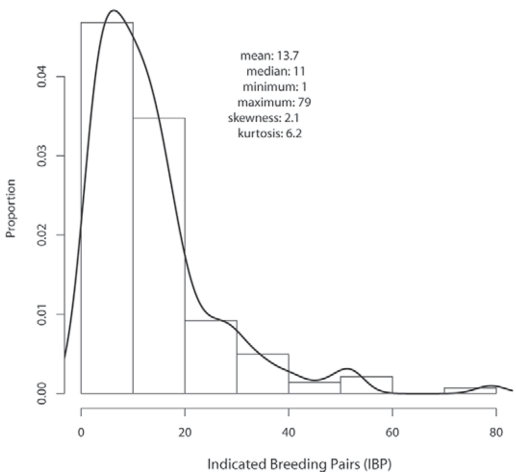

Figure 2. Distribution of the plot-level abundances (indicated breeding pairs, or IBP) of the American Black Duck.

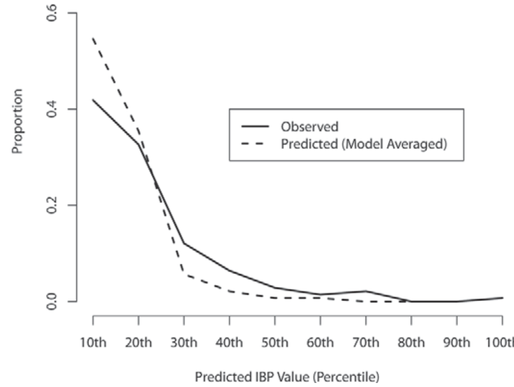

Figure 3. Assessment of agreement between actual and predicted numbers of indicated breeding pairs (IBP) based on the averaged model.

centile of 5.5 and a 75th percentile of 17.0. As typical with abundance data, the distribution was highly positively skewed (> 2.0) with high of 79 IBP for plot 42A in 2007 (Fig. 1).

Model Construction

Using all combinations of landscape-scale predictor variables (Table 1), the relative importance of agricultural production (AG_PROP), availability of surface water (WET_AREA, LAKE_AREA, RIV_DENSITY), wetland diversity (WET_DIVERSITY), average wetland shape (PARATIO), human population (POP_DENSITY, ROAD_DENSITY), topographic complexity (ELEV_SD) and the spatial distribution of wetlands (RINDEX) was assessed. Sorted by lowest AIC values, the first 308 models accounted for 95% of the AIC weights. Evaluation of model fit (concordance between predicted and observed predictions) indicated that the averaged model overpredicted the occurrence of low-IBP landscapes, and slightly underpredicted the number of mid-density ones (Fig. 3). Based on all available data the optimistic RMSE estimate was 10.6 IBP, which was consistent with the estimate based on ten sets of training data (mean: 10.2, range: 7.1 to 15.4).

The coefficients for the AIC-weighted average model, when sorted from lowest to highest, revealed that YEAR was particularly strongly associated with the number of breeding pairs (Fig. 4). Relative to 2006, 2009 and 2010 were years of significantly lower densities of breeding Black Ducks, whereas 2007 and 2008 were years of greater density (Fig. 5). LAKE_AREA, WET_AREA and WET_DIVERSITY were all positively related to IBP numbers. Of the anthropogenic variables, IBP were positively related to landscapes with a greater proportion of active

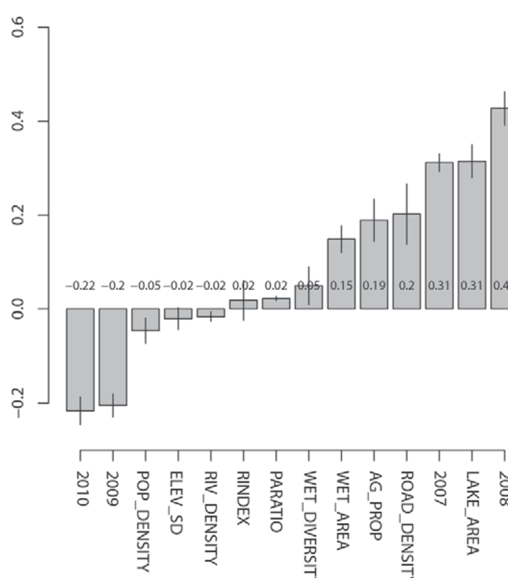

Figure 4. Variable importance, as determined by standardized regression coefficients (sorted from negative to positive, with their values printed). Confidence intervals (95%) are also presented, based on the resampled training data.

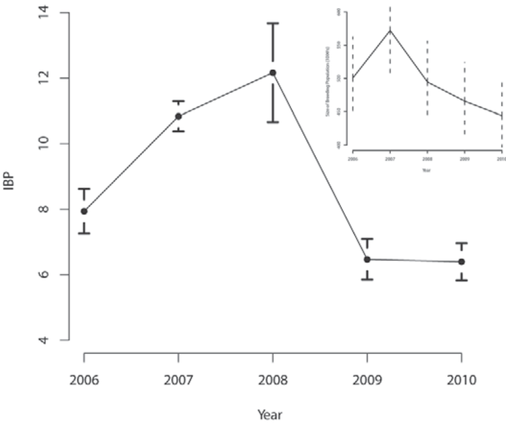

Figure 5. Annual variation in duck abundance (indicated breeding pairs, or IBP), with 95% confidence intervals (based on the resampled training data). The inset figure shows the corresponding breeding population estimate for the same time period (in thousands of Black Ducks, with 90% CI) based on the composite estimate provided by the USFWS (Zimpfer *et al.* 2010).

agriculture (AG_PROP, Fig. 6) and ROAD_DENSITY, but negatively to higher human population densities (POP_DENSITY). The coefficients for PARATIO (+ve), ELEV_SD (-ve), and RIV_DENSITY (-ve) were only marginally significant, while RINDEX and ELEV_SD were indistinguishable from zero.

Mean inter-plot distances were 27.5 km ± 1.2 km (SE), and given the range of documented territory sizes (0.16 to 3.8 ha, Seymour and Titman 1978; 119 ha, Longcore

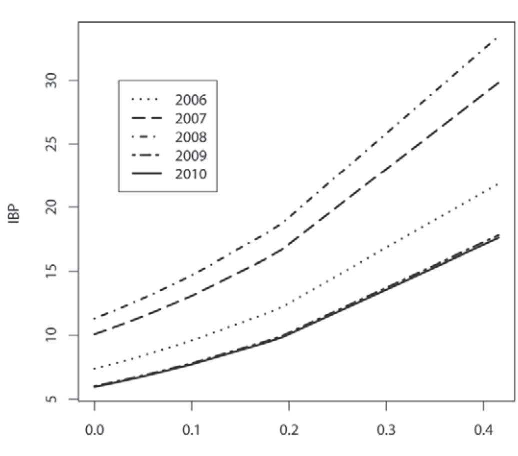

Figure 6. Annual variation in duck abundance (indicated breeding pairs, or IBP), as a function of the proportion of active agriculture (AG_PROP).

and Owen 1982) it seemed implausible that social dynamics, intraspecific competition, and spacing behavior ('inherently' induced spatial autocorrelation, in the sense of Fortin and Dale 2005) would transfer across plots. This notion was confirmed by a post-hoc examination of the residuals from the final model, with a resulting Moran's *I* value of -0.10 (P > 0.90) confirming that spatial autocorrelation was not operating and that habitat factors and yearly effects were sufficient to account for habitat usage.

Distribution Maps

Predicted abundance distribution was generated for 34,659 5km × 5km grid cells evenly distributed throughout New Brunswick and Nova Scotia, with the same landscape-level predictors calculated for each as for the original plots used to build the final model. Inverse-distance weighting (IDW) was then applied to the prediction points to perform a simple spatial interpolation. To visualize temporal differences in distribution, predicted IBP were generated for 2006 and 2008, IDW smoothed, and then mapped as in Figs. 7a and 7b, respectively.

DISCUSSION

Over the five-year time period of this study the indicated number of breeding pairs (for plots with average land cover characteristics) varied between 6.4 IBP ± 0.3 SE and 12.2 IBP ± 0.80 SE. There was an initial rise then fall in breeding numbers, which was a similar pattern to that reported for a continental assessment (Fig. 5, inset map; Zimpfer *et al.* 2010). While the time series available for this study was not particularly long, it does suggest that twofold changes in average breeding numbers are within the recent record, and provides a context for interpreting the importance of future population changes.

The years 2007-2008 stood out as relatively high periods of duck abundance, and a comparison of the distribution maps for 2006 and 2008 show the latter period to have been accompanied by a more diffuse distribution throughout the region and a higher

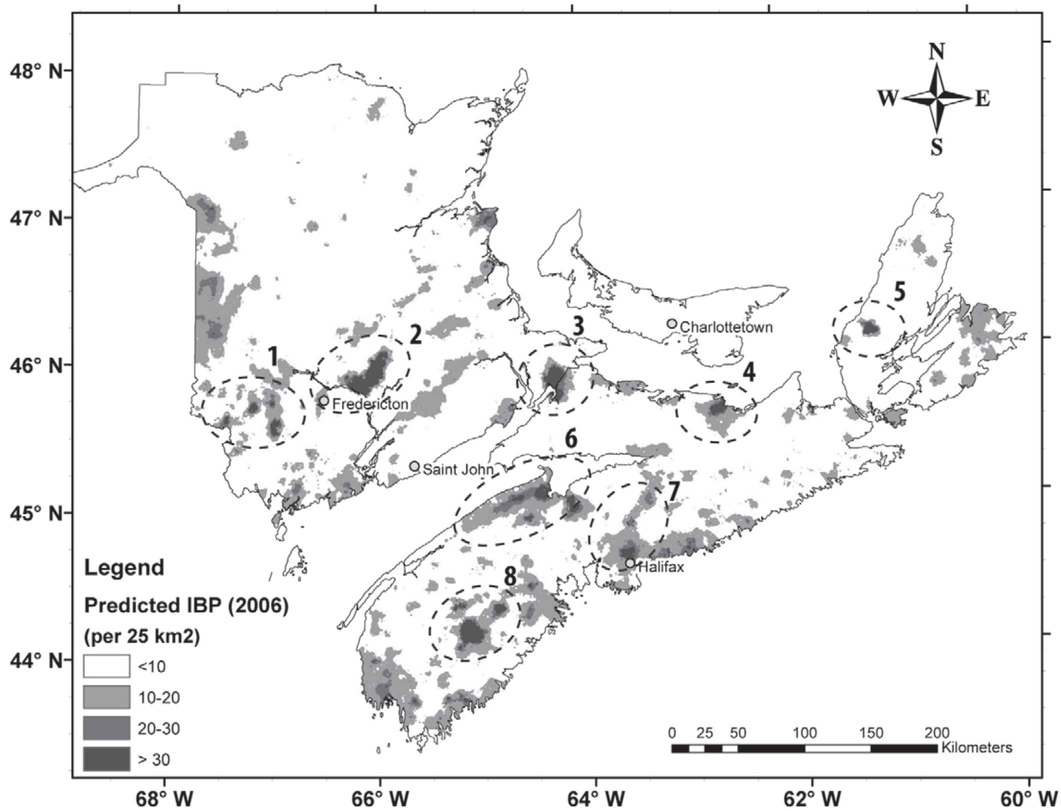

Figure 7a. Distribution map of the expected numbers of American Black Duck pairs breeding in 2006, broken into one of four classes. The largest core areas were identified as 1 = "Lake Magaguadavic", 2 = "Grand Lake", 3 = "Chignecto Isthmus", 4 = "Pictou", 5 = "Lake Ainslie", 6 = "Annapolis Valley", 7 = "Shubenacadie/Bedford", and 8 = "South-west Nova Scotia". See text for more details.

use of more peripheral areas (Figs. 7a,b). High quality breeding habitat was more isolated in 2006, allowing the delineation of a number of core areas (e.g. Annapolis Valley, Chignecto Isthmus). These "hotspots" all shared the common properties of abundant surface water and higher levels of agricultural activity. The "agricultural" effect, in particular, manifested as an approximately threefold increase in the number of breeding pairs for landscape plots varying from 0 to about 41% agricultural use.

The positive association between agriculture and breeding activity in Maritime Canada contrasts notably with the negative effects reported for dabbling ducks breeding in North Dakota (Artmann *et al.* 2001) and southern Quebec (Maisonneuve *et al.* 2006). In both these cases, duck presence was negatively associated with higher proportions of cropland production. For instance, in the North Dakota study, occupancy of artificial nesting structures was four times more likely for Mallards (*Anas platyrhynchos*) in non-cropland sites. However, consideration of the proportion of cropland agriculture in North Dakota (69%, Artmann *et al.* 2001) and southern Quebec (48%, Maisonneuve *et al.* 2006) suggest that the intensity of agricultural production is quite high relative to the Maritimes. Are the negative effects of North Dakota/southern Quebec agriculture merely the result of more severe landscape fragmentation? Bélanger and Grenier (2002) argue that a 50% proportion of landscape conversion can be considered an important threshold value for the occurrence of fragmentation effects such as nest predation (Maisonneuve *et al.* 2000). If this fragmentation threshold level is valid, North

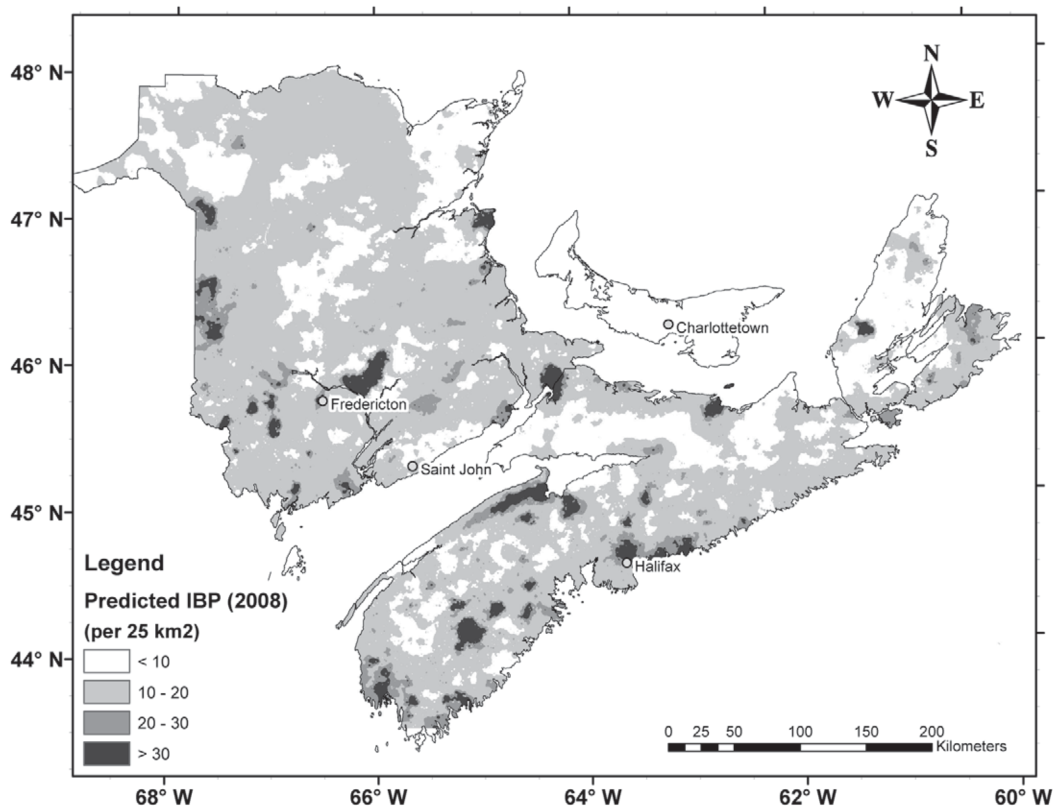

Figure 7b. Distribution map of the expected numbers of American Black Duck pairs breeding in 2008, broken into one of four classes.

Dakota wetlands are severely affected, while those in southern Quebec are at or near the tipping point. In Maritime Canada this level of fragmentation occurs in less than 1% of prediction plots, and suggests that Maritime landscapes may contain a sufficiently high mixture of forested wetland within agricultural landscapes to offset negative impacts.

Research suggests that agricultural land uses can be unequal in their effects. For example, Maisonneuve *et al.* (2006) reported that breeding densities were over four times higher in traditional dairy farm landscapes than cropland-dominated areas, with overall densities comparable to forested landscapes. In a study by Merendino and Ankney (1994), wetlands with fewer breeding Black Ducks tended to be deficient in the calcium, carbohydrate and protein rich plants and invertebrates necessary for reproduction, maintenance and growth. The positive response of breeding ducks to Maritime agricultural landscapes suggests that such landscapes may either be situated in nutrient-rich areas, or may themselves be acting as important sources of limiting nutrients. A key unanswered question is how nutrient availability responds to Maritime agricultural activity, and whether particular land practices are more or less beneficial.

Overall, the beneficial effect of Maritime agricultural landscapes extends beyond the support of larger numbers of breeding pairs. Using stable isotope analysis, Ashley *et al.* 2010 reported that 32% of hunter-shot, hatch-year birds of Maritime origin originated in agricultural areas. Given that approximately 5.5% of the prediction cells in this study had 17.8% or more of the landscape classed as active agriculture, the contribution of agriculturally-influenced vs. non-agriculturally influenced landscapes to maritime Black Duck productivity can be estimated as:

$$\frac{32\%/5.5\%}{68\%/94.5\%} = 8.1 \times \text{more productive.} \quad (3)$$

The estimate will vary depending upon the choice of the percentage of agricultural activity used to define an "agriculturally-influenced" Maritime landscape (at the 5-km × 5-km scale).

Qualitatively, ideal Maritime habitat for this species could be described as landscapes with drainage systems capable of supporting substantive and diverse wetlands, with lower human population densities, but higher levels of active agriculture. Future work should confirm whether the increased usage of more agriculturally-influenced landscapes is matched by a corresponding increase (or no change) in nest success, average brood sizes, and survival. Numerical response (in the form of increased IBP) could mask possible negative effects on these vital rates, a point made by van Horne (1983). Future work should also more closely examine the impact of different types and/or combinations of Maritime agricultural production as it would support decision- making about priorities for habitat restoration and enhancement, and help refine the delivery of conservation plans in Maritime Canada.

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Literature Cited

Artmann, M. J., I. J. Ball and T. W. Arnold. 2001. Influence of perennial upland cover on occupancy of nesting structures by Mallards in northeastern North Dakota. Wildlife Society Bulletin 29: 232-238.

Ashley, P., K. A. Hobson, S. L. Van Wilgenburg, N. North and S. A. Petrie. 2010. Linking Canadian harvested juvenile American Black Ducks to their natal areas using stable isotope (δD, δ13C, and δ15N) methods. Avian Conservation and Ecology 5: 7. http://www.ace-eco.org/vol5/iss2/art7, accessed December 2010.

Austin, M. P. 2002. Spatial prediction of species distribution: An interface between ecological theory and statistical modelling. Ecological Modelling 157: 101-118.

Bates, D. and M. Maechler. 2010. Linear mixed-effects models using S4 classes. http://lme4.r-forge.r-project.org, accessed August 2011.

Beissinger, S. R., J. R. Walters, D. G. Catanzaro, K. G. Smith, J. H. Dunning, S. M. Haig, B. R. Noon and B. M. Stith. 2006. Modeling approaches in avian conservation and the role of field biologists. Ornithological Monographs 56.

Bélanger, L. and M. Grenier. 2002. Agriculture intensification and forest fragmentation in the St. Lawrence valley, Québec. Landscape Ecology 17: 495-507.

Bélanger, L., A. Reed and J-L. DesGranges. 1998. Reproductive variables of American black ducks along the St. Lawrence estuary, 1963-1991. Canadian Journal of Zoology 76: 1165-1173.

Bivand, R. S. 2006. Implementing spatial data analysis software tools in R. Geographical Analysis 38: 23-40.

Black Duck Joint Venture Management Board. 2008. Black Duck Joint Venture Strategic Plan 2008-2013. U.S. Fish and Wildlife Service, Laurel, Maryland; Canadian Wildlife Service, Ottawa, Ontario.

Bolker, B. M., M. E. Brooks, C. J. Clark, S. W. Geange, J. R. Poulsen, M. N. H. Stevens and J-S. S. White. 2008. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in Ecology and Evolution 24: 127-135.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodal inference: a practical information-theoretic approach, 2nd Edition. Springer Verlag, New York, New York.

Center for International Earth Science Information Network (CIESIN), International Food Policy Research Institute (IFPRI), and Centro Internacional de Agricultura Tropical (CIAT). 2005. Global Rural-Urban Mapping Project (GRUMP), Alpha Version: Population Density Grids. Palisades, New York: Socioeconomic Data and Applications Center (SEDAC), Columbia University. http://sedac.ciesin.columbia.edu/gpw, accessed January 2012.

Darveau, M., J. L. DesGranges and G. Gauthier. 1992. Habitat use by three breeding insectivorous birds in declining maple forests. Condor 94: 72-82.

de Smith, M. J., M. F. Goodchild and P. A. Longley. 2007. Geospatial analysis: A comprehensive guide to principles, techniques and software tools. Matador Press, Leicester, U.K.

Diefenbach, D. R. and R. B. Owen, Jr. 1989. A model of habitat use by breeding American Black Ducks. Journal of Wildlife Management 53: 383-389.

Environmental Systems Research Institute. 2009. ArcGIS version 9.3. Environmental Systems Research Institute, Redlands, California.

Erskine, A. J. 1992. Atlas of breeding birds of the maritime provinces. Nova Scotia. Government and Nimbus Publishing, Ltd, Halifax, Nova Scotia.

Erskine, A. J., M. C. Bateman, R. I. Goudie and G. R. Parker. 1990. Aerial surveys for breeding waterfowl, Atlantic Region, 1985-1989. Technical Report No. 85. Canadian Wildlife Service, Atlantic Region, Sackville, New Brunswick.

Fielding, A. H. and P. F. Haworth. 1995. Testing the generality of bird-habitat models. Conservation Biology 9: 1466-1481.

Forman, R. T. and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29: 207-231.

Fortin, M-J. and M. Dale. 2005. Spatial analysis: A guide for ecologists. Cambridge University Press, New York, New York.

Gray, T. N. E., C. Phan and B. Long. 2010. Modelling species distribution at multiple spatial scales: gibbon habitat preference in a fragmented landscape. Animal Conservation 13: 324-332.

Guisan, A. and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135: 147-186.

Hanson, A. R. 2001. Modelling the spatial and temporal variation in density of breeding black ducks at landscape and regional levels. Unpublished Ph.D. Thesis, University of Western Ontario, London, Ontario.

Longcore, J. R., D. G. Mcauley, G. R. Hepp and J. M. Rhymer. 2000. American Black Duck (*Anas rubripes*). The Birds of North America Online (A. Poole, Ed.). Cornell Lab of Ornithology, Ithaca, New York. http://bna.birds.cornell.edu.bnaproxy.birds.cornell.edu/bna/species/481doi:10.2173/bna.481, accessed August 2011.

Longcore, J. R. and R. B. Owen Jr. 1982. Breeding habitat selection and home range of radio-marked Black Ducks (*Anas rubripes*) in Maine. Canadian Journal of Zoology 60: 241-248.

Maisonneuve, C., L. Bélanger, D. Bordage, J. Benoît, M. Grenier, J. Beaulieu, S. Gabor and B. Filion. 2006. American Black Duck and Mallard breeding distribution and habitat relationships along a forest-agriculture gradient in southern Québec. Journal of Wildlife Management 70: 450-459.

Maisonneuve, C., R. McNicoll and A. Desrosiers. 2000. Comparative productivity of American Black Ducks and Mallards nesting in agricultural landscapes of southern Quebec. Waterbirds 23: 378-387.

Merendino, M. T. and C. D. Ankney. 1994. Habitat use by Mallards and American Black Ducks breeding in central Ontario. Condor 96: 411-421.

Microsoft Corporation. 2002. Microsoft Access. Microsoft Corporation, Redmond, Washington.

Mitsch, W. J. and J. G. Gosselink. 2007. Wetlands. John Wiley & Sons, Inc., Hoboken, New Jersey.

Python Software Foundation, 2010. Python 2.6.5. http://www.python.org, accessed August 2010.

Rhodes, J. R., T. Wiegand, C. A. McAlpine, J. Callaghan, D. Lunney, M. Bowen and H. Possingham. 2006. Modeling species' distributions to improve conservation in semiurban landscapes: koala case study. Conservation Biology 20: 449-459.

R Development Core Team. 2011. R: A language and environment for statistical computing, version 2.14.1. R Foundation for Statistical Computing, Vienna, Austria. http://www.r-project.org, accessed January 2012.

Rusch, D. H., C. Ankney, B. H. Davison, J. R. Longcore, F. Montalbano III, J. K. Ringelman and V. D. Stotts. 1989. Population ecology and harvest of the American Black Duck: A review. Wildlife Society Bulletin 17: 379-406.

Seymour, N. R. and R. D. Titman. 1978. Changes in activity patterns, agonistic behavior, and territoriality of black ducks (*Anas rubripes*) during the breeding season in a Nova Scotia tidal marsh. Canadian Journal of Zoology 56: 1773-1785.

Shriner, S. A., T. R. Simons and G. L. Farnsworth. 2002. A GIS-based habitat model for Wood Thrush, *Hylocichla mustelina*, in Great Smoky Mountains National Park. Pages 529-535 *in* Predicting species occurrences: issues of accuracy and scale (J. M. Scott, P. J. Heglund, M. L. Morrison, J. B. Haufler, M. G. Raphael, W. A. Wall and F. B. Samson, Eds.). Island Press, Washington, D.C.

Turner, M. G., R. H. Gardner and R. V. O'Neill. 2001. Landscape ecology in theory and practice: pattern and process. Springer-Verlag, New York, New York.

van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47: 893-901.

Vaughn, I. P. and S. J. Ormerod. 2005. The continuing challenges of testing species distribution models. Journal of Applied Ecology 42: 720-730.

Venier, L. A., D. W. McKenney, Y. Wang and J. Kee. 1999. Models of large-scale breeding-bird distribution as a function of macro-climate in Ontario, Canada. Journal of Biogeography 26: 315-328.

Verbyla, D. L. and J. Litvaitis. 1989. Resampling methods for evaluating classification accuracy of wildlife habitat models. Environmental Management 13: 783-787.

Zimpfer, N. L., W. E. Rhodes, E. D. Silverman, G. S. Zimmerman and M. D. Koneff. 2010. Trends in ducks breeding populations, 1955-2010. USFWS, Division of Migratory Bird Management. http://www.fws.gov/migratorybirds/NewReportsPublications/PopulationStatus/Trends/TrendReport2010.pdf, accessed August 2011.

Zoltai, S.C. 1988. Wetland environments and classification. Pages 3-26 *in* Wetlands of Canada (National Wetlands Working Group and Canadian Committee on Ecological Land Classification). Sustainable Development Branch, Environment Canada, Ontario and Polyscience Publications Inc., Montreal, Quebec.

Zuur, A., E. N. Ieno, N. J. Walker, A. A. Savaliev and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer, New York, New York.