Modeling Breeding Waterfowl Distribution in the Southern Lakes Region of the Yukon

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ABSTRACT

A need exists for a decision support tool to aid in regional land-use planning in the southern Yukon. As part of an effort encompassing the entire western boreal forest, Ducks Unlimited Canada conducted an earthcover classification and breeding waterfowl surveys in the Southern Lakes region to produce maps of predicted waterfowl distribution for use in such decision support tools. Herein, we used a generalized linear modelling approach to evaluate associations between habitat characteristics and number of breeding pairs at a basin specific level, then produced maps of predicted distribution of dabbling, diving, and all ducks. The best predictors for the number of dabbling ducks pairs were: basin latitude, perimeter, elevation, percent emergent vegetation, the percent dwarf shrub and open deciduous cover within 300m of the basin, and the percent open needle, wood needle, low shrub, and sparse vegetation cover within 30m of the basin. For diving ducks pair numbers the best predictors were: the natural log of basin size, latitude, elevation, the percent sparse vegetation cover within 300m of the basin, the percent mesic dry forb cover within 90m of the basin, and the percent closed needle cover within 30m of the basin. For all waterfowl pairs the best predictors were: the natural log of basin size, latitude, elevation, percent emergent vegetation, the percent dwarf shrub and wood needle cover within 90m of the basin, and the percent mesic dry forb, open deciduous, open needle, low shrub, and sparse vegetation cover within 30m of the basin. Models had r-squared values between 40-47%. We used the model to predict waterfowl breeding distribution for every basin between 2 and 300 ha within the Southern Lakes study area. Predicted number of pairs was higher in the northern portions of the study area, particularly east of Lake Laberge and between Fox and Taye Lakes. We discuss the limitations of this model, how best to interpret the results, and review what can be improved upon for future modelling projects.

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TABLE OF CONTENTS

INTRODUCTION

Currently, understanding of waterfowl habitat requirements in the western boreal forest is limited. This is despite the western boreal forest being second only to the prairie pothole region in terms of continental waterfowl breeding numbers. Populations of several common boreal nesting waterfowl species, such as lesser scaup and scoters, are declining (Austin et al. 2006). At the same time, industrial activities including oil and gas explorations, mines and mineral developments, hydroelectric and other energy resources, timber harvest, and urban developments are expanding. Little is known about the influence of these activities on boreal wetland ecosystems or waterfowl. The western boreal forest has been ranked the third most important waterfowl habitat area at risk out of 26 areas identified in North America (Ducks Unlimited 1994).

In 1997, Ducks Unlimited Canada (DUC) began collecting earthcover, waterbird, and water chemistry data throughout the western boreal forest to address some knowledge gaps. It was believed that these three components, conducted across the western boreal forest, could be used to model distribution of waterbirds, provide an assessment of wetland capability, and an indication of the importance of various wetland habitats to breeding and post-breeding waterbirds.

Similar to the rest of the western boreal forest, there is limited knowledge of waterfowl habitat requirements within the Yukon. Furthermore, outside Old Crow Flats in northern Yukon, there is no large scale waterfowl monitoring program to give a coarse understanding of waterfowl distribution. DUC initiated this project in the southern lakes region of the Yukon to complement work being conducted throughout the western boreal forest and to provide data on waterfowl habitat requirements to be used for regional planning and conservation initiatives in the Yukon. The Southern Lakes project area provides representation for the Boreal Cordillera eco-zone and includes portions of six eco-regions (Ecological Stratification Working Group 1996). An earthcover inventory (Ducks Unlimited Canada et al. 2002) was completed in 2000, a water chemistry inventory (Bell et al. 2003) was completed in 2001, and a 3-year waterbird survey program was completed during 2000 – 2002 (van de Wetering et al. 2001, 2002).

This report describes a model that predicts breeding waterfowl distribution based upon habitat characteristics, as determined from the earthcover inventory, within the

Southern Lakes project area. Considerations required for practical use of this model as a decision support tool, including model assumptions, a guide to interpreting and using model predictions, and a review of problems faced are provided.

PROJECT AREA

The 32,000 km^2 Southern Lakes project area was located in southwest Yukon and extended into northern B.C. (Figure 1) within the Boreal Cordillera eco-zone (Ecological Stratification Working Group 1996). Notable physical features within the project area include the Yukon River, Lake Laberge, Marsh Lake, Tagish Lake, Kusawa Lake and the Coastal Mountains. Two nationally important spring staging areas for Trumpeter Swans (*Cygnus buccinator*) and breeding ducks lie within the region (Nisutlin River Delta National Wildlife Area and Marsh Lake/Lewes River Marsh).

There are two communities (Whitehorse and Carcross) and five First Nation Traditional Territories (Teslin Tlingit Council, Carcross Tagish First Nation, Champagne and Aishihik First Nations, Ta'an Kwatchin Council and the Kwanlin Dun First Nation) within the project area. Over 20,000 people live in Whitehorse making the Southern Lakes area the most heavily populated region of the Yukon. Considerable demands are placed on local land resources from activities such as agricultural and urban developments, commercial timber harvest, domestic and commercial fuel wood harvest, gravel quarries, and tourism and recreational activities. Two hydroelectric dams and associated infrastructure are in the area providing electricity for many Yukon communities.

Habitat in the Southern Lakes project area is diverse, ranging from glacial icepack to forested river valleys. Lower elevations were characterized mainly by fire-influenced open needle-leaf forests, whereas mountain uplands were characterized by dwarf shrub, low shrub, tall shrub, sparse vegetation, rock/gravel, snow, ice and lichen cover types. According to the earthcover inventory (Ducks Unlimited Canada et al. 2002), no habitat class comprised of more than 10% of the total area. The three most extensive vegetation classes were closed needle-leaf (9.9%), open spruce (8.4%), and woodland needlelef/shrub (7.9%) (Ducks Unlimited Canada et al. 2002). Just over four percent of the project area was classified as water (classes included open water, turbid water, emergent vegetation, and aquatic bed), although there were relatively few large, non-forested wetland complexes. Emergent vegetation and aquatic beds were common as rings of vegetation around small basin and lakes, and also as riparian wetlands along rivers.

In 2001, a wetland chemistry inventory was conducted on a subset of the waterbird survey sample sites in the Southern Lakes project area (Bell et al. 2003). Most of the 99 basins studied were low in phosphorus and either oligotrophic (0-5ug/L) or oligo-mesotrophic (5-10ug/L) with few eutrophic basins (30-100ug/L). Basins were neutral to basic and had low inorganic nitrogen levels. Basin water chemistry was related to bedrock geology, which varied from sandstone and limestone sedimentary rock to tholeitic volcanics and intrusive bedrock. Basins located in limestone were generally rich in phosphorous and chlorophyll-a, and some were saline while basins located in sandstone were generally dilute and nutrient poor. Basin chemistry was also influenced by surficial geology. Alpine basins were generally dilute and nutrient poor whereas basins in lacustrine fine-grained silts and clays had higher solute concentration, pH, and nutrients in comparison to other surficial geological units.

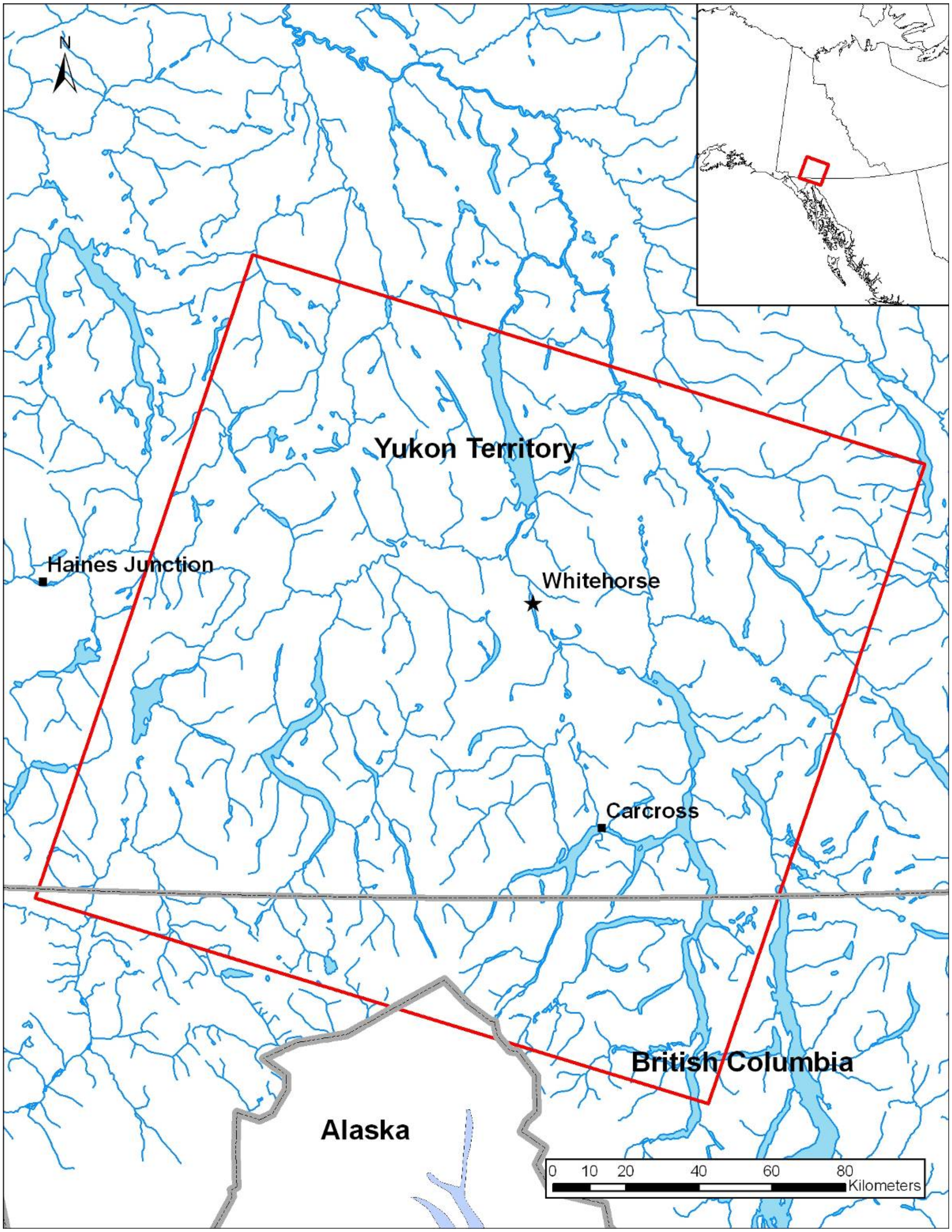

Figure 1: Location of the Southern Lakes project area in Yukon and northern British Columbia.

THE MODEL

Site Selection

We used ArcView software and an unsupervised Landsat Thematic Mapper 7 image to uniquely identify and estimate the size of all basins in the project area. We limited our surveys to distinct permanent waterbodies such as lakes and basins because 1) we could more accurately repeat the same coverage on subsequent surveys, and 2) because waterbirds were most visible on these wetland types despite suspected waterfowl use of other wetland types such as streams and riparian habitat. Basins less than 2.0 ha were excluded to reduce risks of misclassification (e.g., terrain shadow, misclassified single and small clusters of pixel). We then used a random proportional allocation method stratified by eco-district to select specific basins for waterbird surveys. Basins greater than 300 ha were omitted due to survey constraints (e.g., safety concerns). Twenty percent of the basins surveyed in 2000 were randomly selected for repeated surveys in 2001 and 2002 to account for yearly variation in waterfowl abundance.

Waterfowl Data

Waterbird observations were recorded on individual basins (the sampling unit). We navigated to the pre-selected basins using navigation software (Fugawi and ArcView 3.2a software integrated with a Tracking Analyst moving map extension (Environmental Systems Research Institute Inc. 1996)) and a global positioning system.

Survey and safety protocol was modified from a Canadian Wildlife Service application outlined in the Black Duck Joint Venture (1996). We used a Bell 206B helicopter equipped with bubble windows for breeding pair surveys. Surveys were flown about 35 m above ground level at speeds less than 100 km/hr. We adjusted altitude and speed, as required, to improve visibility or to maintain safety. Flight paths varied depending on the size and shape of each wetland basin and the surrounding topography. In general, we flew the inside perimeter of small wetlands, and added a transect down the middle for large wetlands to achieve 100% coverage. Surveys were generally flown early in the morning for better visibility and flying conditions. Each survey crew consisted of a pilot, an observer/navigator seated in the front beside the pilot, and an observer seated in the rear behind the pilot. Both observers were responsible for observations on opposite sides of the aircraft, and each recorded all waterbird sightings using micro-cassette tape recorders. We recorded each waterfowl's species, sex and social status.

We used protocol established by U.S. Fish and Wildlife Service/Canadian Wildlife Service (1987) to estimate indicated breeding pairs for most species. We summed total observed pairs, lone males, males in groups of 2-4 and males in 2:1 male/female groups to estimate indicated breeding pairs for all waterfowl species except ring-necked duck, scaup spp., redhead, and ruddy duck. For these species, we considered observed pairs only as our estimation of indicated breeding pairs.

We flew two breeding pair surveys each year to estimate pair numbers for early and late nesting species. The first survey was flown early to mid-May with a second survey flown in early-June. Indicated breeding pairs were derived from either the first, second, or an average of both surveys depending upon the breeding chronology of the species (Table 1).

Table 1: Breeding pair survey count used for determining indicated breeding pairs for each species.

Species	Breeding Pair Survey Count Used
American wigeon (*Anas americana*)	Average
Barrow's goldeneye (*Bucephala islandica*)	1
Blue-winged teal (*Anas discors*)	2
Bufflehead (*Bucephala albeola*)	1
Canvasback (*Aythya valisineria*)	2
Cinnamon teal (*Anas cyanoptera*)	2
Common goldeneye (*Bucephala clangula*)	1
Common merganser (*Mergus merganser*)	2
Gadwall (*Anas strepera*)	2
Green-winged teal (*Anas crecca*)	Average
Long-tailed duck (*Clangula hyemalis*)	2
Mallard (*Anas platyrhynchos*)	1
Northern pintail (*Anas acuta*)	1
Northern shoveler (*Anas clypeata*)	Average
Red-breasted merganser (*Mergus serrator*)	2
Redhead (*Aythya americana*)	2
Ring-necked duck (*Aythya collaris*)	2
Ruddy duck (*Oxyura jamaicensis*)	2
Scaup (*Aythya marila and Aythya affinis*)	2
Surf scoter (*Melanitta perspicilatta*)	2
Unidentified dabbling duck	Average
Unidentified diving duck	Average
Unidentified duck	Average
White-winged scoter (*Melanitta fusca*)	2

Basin Level Data

Complete survey data (habitat data and waterfowl breeding pair counts) existed for 325 basins. Basin habitat data was based upon data from the earthcover classification. A total of 11 predictors were initially available for inclusion in the model: total basin area, latitude, longitude, elevation, slope, aspect, perimeter, shape, percent aquatic bed, percent emergent vegetation, and percent water. Latitude and longitude were measured in decimal degrees and elevation in metres.

Water classified as clear water or turbid water was combined simply as "water". For compositional data (e.g., percent aquatic bed, percent emergent vegetation, and percent water), complete collinearity would result by including each component as a predictor since the total of all compositions is constrained to sum to 100%. Therefore, percent water was excluded as a predictor.

Since aspect is irrelevant when slope = 0 (i.e., aspect values are treated as missing data when slope = 0), aspect was initially excluded as a predictive variable. If slope was shown to be an important predictor, aspect was considered as a predictor in models using the subset of basins with non-zero slope.

Shape is an index based upon other characteristics of the basin. The shape index was calculated as 0.25 * basin perimeter / sqrt(basin area). Shape is strictly greater than or equal to 1, with values closer to 1 when the basin is more circular and increasing without limit as the shape becomes more irregular.

Basin Buffer Data

Earthcover mapping produced 31 earthcover classes (Ducks Unlimited Canada et al. 2002). Using earthcover classes, 30m, 90m, and 300m buffers around each basin were used to describe adjacent upland habitat for each basin. Some classes were aggregated into biologically meaningful landcover classes (Table 2). Habitat compositions were calculated for these aggregated classes by dividing class area by the total of all classes. Typically, there were high correlations among the component habitat proportions at each buffer scale (e.g., closed needle at 30m, closed needle at 90m, and closed needle at 300m). Therefore, these variables were not to be considered as multiple predictors in the same model.

Due to lack of data (only one basin with non-zero area), we excluded the agriculture class from all models. Deletion of this one habitat was also sufficient to eliminate the issue of complete collinearity for all habitats.

Model Construction

Generalized linear modeling techniques were used to associate year-averaged (2000-2002) indicated breeding pair counts with the landscape composition and basin-specific characteristics. Models were constructed for all duck pairs combined, dabbling duck pairs, and diving duck pairs. A negative binomial distribution was used to characterize the counts – similar to a Poisson distribution but it allows for over-dispersion through estimation of a scaling factor. A log link was specified to linearize the association between the pair counts and predictor variables providing a model with the form:

$$Y = e^{(n+n_1 x_1+\ldots+n_i x_i)}.$$

Table 2: Original landcover classes that were merged into aggregated landcover classes.

Aggregated Landcover Class	**Original Landcover Classes**
Closed Needle	Closed Mixed Needleleaf, Closed Mixed Needleleaf Deciduous
Open Needle	Open Mixed Needleleaf, Open Needleleaf Lichen, Open Spruce, Open Pine
Closed Deciduous	Closed Deciduous
Open Deciduous	Open Deciduous
Closed Mixed	Closed Mixed Wood
Wood Needle	Woodland Shrub, Woodland Other
Tall Shrub	Tall Shrub Open and Closed
Low Shrub	Closed Low Shrub, Open Low Shrub, Open Low Shrub Herb, Open Low Shrub Lichen
Dwarf Shrub	Dwarf Shrub Lichen, Dwarf Shrub Other, Dwarf Shrub Herb
Lichen	Lichen
Mesic Dry Forb	Mesic Dry Forb
Sparse Vegetation	Sparse Vegetation, Rock/Gravel
Urban	Urban
Agriculture	Agriculture

Initially, four sets of models were considered: (i) basin-level predictors, (ii) 30m buffer characteristics, (iii) 90m buffer characteristics, (iv) 300m buffer characteristics. To account for differing basin sizes, the natural log of basin area was included as a predictor in each of the full models. The full models were simplified via a backwards elimination process, progressively removing the independent variables least predictive of the pair counts. A best approximating model was selected as the one yielding the minimum AIC. Successful predictors from each of the model sets were then combined into a multi-scale model, taking care to advance a predictor at only one of the buffer scales (i.e., if open needle was a successful predictor at both the 30m and 300m scales, then open needle would be considered at the scale at which the parameter estimate/standard error ratio was largest). This combined model always included the natural log of basin area as a predictor and was reduced successively to produce a best approximating model.

Certain variables were excluded due to data paucity. Additional predictors were excluded due to excessively high parameter estimates, yielding a high likelihood of generating excessively high predicted numbers of pairs.

In order to explore the nature of the effects of the landscape compositions on indicated breeding pairs, exploratory generalized additive models were fit. There were no strongly non-linear patterns and therefore each independent variable was treated as a linear predictor.

RESULTS

All Pairs Model

After a full negative binomial regression model, the effect of percent lichen at the 30m buffer level was deleted. In total, 14 predictor variables were advanced to the combined scales model. Basin level predictors advancing were percent emergent vegetation (basin), elevation, longitude, and latitude. Percent closed needle advanced from the 300m buffer level. Percent wood needle and percent low shrub advanced from the 90m buffer level. Percent tall shrub, percent mesic dry forb, percent open deciduous, percent open needle, and percent sparse vegetation advanced from the 30m buffer level.

The best supported combined scale model had 11 predictor variables (Table 3). Elevation and percent mesic dry forb 30 had a negative effect on pair numbers while all other predictor variables had a positive effect on number of pairs (Table 4). Miaou's R-squared for this model was 40.64%.

Basins with the most predicted pairs of all ducks were concentrated in the northern portion of the study area (Figure 2). Basins north of Fox Lake and east of Taye

Lake were predicted to have relatively high pair numbers. Pair distribution, as expected, is similar to the distribution of dabbling and diving ducks (see below).

Table 3: Results for the combined scales model for all pairs of ducks. The bolded model was used to advance predictor variables to the combined scales model as it had the lowest AIC. Number of variables within the model is represented by k.

Model	**k**	**Log Likelihood**	**AIC**	**AICc**	**Delta AICc**
Full	16	791.245	-1550.49	-1548.72	3.964
Remove Longitude	15	791.245	-1552.49	-1550.94	1.752
Remove Percent Closed Needle 300	14	790.903	-1553.81	-1552.45	0.236
Remove Percent Tall Shrub 30	**13**	**789.929**	**-1553.86**	**-1552.69**	**0**
Remove Percent Mesic Dry Forb 30	12	788.718	-1553.44	-1552.44	0.252
Remove Percent Emergent Vegetation (basin)	11	786.812	-1551.62	-1550.78	1.908
Remove Percent Open Needle 30	10	784.904	-1549.81	-1549.11	3.581
Remove Percent Sparse Vegetation 30	9	784.020	-1550.04	-1549.47	3.220
Remove Open Deciduous 30	8	783.316	-1550.63	-1550.18	2.511
Remove Percent Dwarf Shrub 90	7	779.760	-1545.52	-1545.17	7.522
Remove Percent Wood Needle 90	6	776.820	-1541.64	-1541.38	11.312
Remove Percent Low Shrub 30	5	772.545	-1535.09	-1534.90	17.786
Remove Elevation	4	761.544	-1515.09	-1514.96	37.726
Remove Latitude	3	752.233	-1498.47	-1498.39	54.297
Remove ln(Total basin ha)	2	737.576	-1471.15	-1471.11	81.574

Table 4: Parameter estimates, standard error, and ratio between the effect and standard error for each of the variables in the most supported combined scales model for all pairs of ducks. The ratio of effect to standard error represents the strength of the covariate having a non-zero effect.

Effect	**Estimate**	**Standard Error**	**Effect/Standard Error**
Intercept	-36.0000	8.6923	
ln(Total basin ha)	0.3172	0.0565	5.6112
Latitude	0.5901	0.1434	4.1143
Elevation	-0.0016	0.0004	4.0164
Percent Emergent Vegetation (basin)	1.0221	0.5567	1.8361
Percent Dwarf Shrub 90	3.5937	1.5799	2.2746
Percent Wood Needle 90	2.3143	0.6404	3.6136
Percent Mesic Dry Forb 30	-17.7540	11.5568	1.5362
Percent Open Deciduous 30	6.0540	2.7915	2.1687
Percent Open Needle 30	1.6503	0.6599	2.5007
Percent Low Shrub 30	2.1345	0.6267	3.4058
Percent Sparse Vegetation 30	1.6536	0.6059	2.7293
Dispersion	0.9573	0.1190	

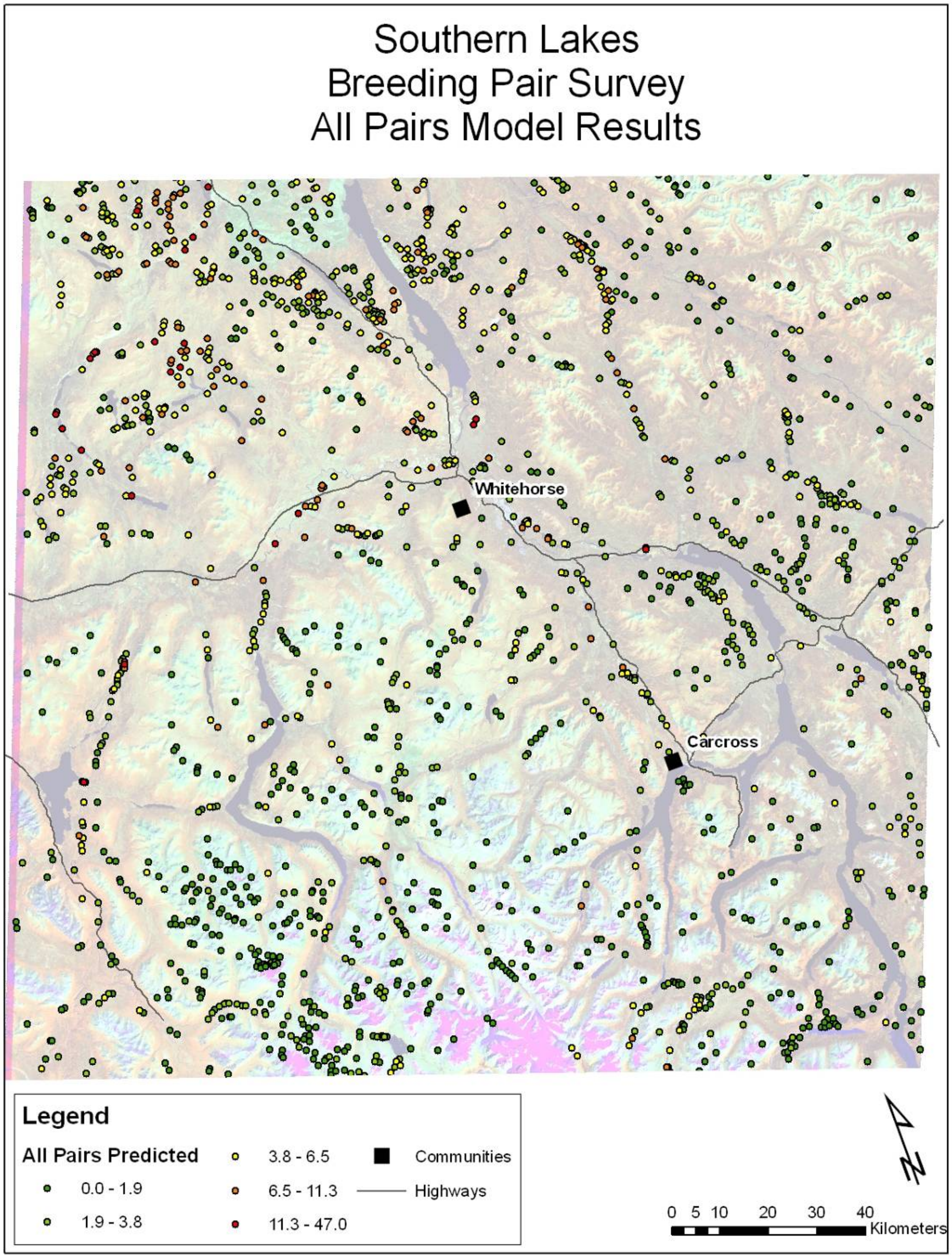

Figure 2: Predicted duck pair distribution (all species) within the Southern Lake project area.

Dabbling Duck Model

After an initial full negative binomial regression model at least one variable was deleted at each of the three buffer levels, 30m, 90m, and 300m. These variables included percent lichen at all three buffer levels, percent open deciduous and percent closed deciduous at both the 30m and 90m buffer levels, and percent urban and percent mesic dry forb at the 30m buffer level.

A total of 16 predictor variables were advanced to the combined scales model. Basin-level predictors advancing included latitude, percent emergent vegetation (basin), longitude, elevation, and perimeter. Percent dwarf shrub advanced from the 300m buffer model). Predictor variables advancing from the 90m buffer model included percent tall shrub and percent closed needle. Predictor variables advancing from the 30m buffer model included percent open needle, percent low shrub, and percent sparse vegetation.

The best supported combined scale model had 10 predictor variables (Table 5). All variables had a positive effect (i.e., a greater value = more pairs) with the exception of elevation which had a negative effect (Table 6). Miaou's R-squared for this model was 43.93%.

Dabbling duck pair numbers were predicted to be low, less than half a pair per basin on about a third of the basins (Figure 3). No single area has numerous basins with high predicted dabbling duck pair numbers with the possible exception of the Takhini River valley. One basin was predicted to have 159 pairs however only 16 other basins had pair numbers predicted to exceed 10 pairs.

Table 5: Results for the combined scales model for predicting dabbling duck pair distribution. The bolded model was used to advance predictor variables to the combined scales model as it had the lowest AIC. Number of variables within the model is represented by k.

Model	k	Log Likelihood	AIC	AICc	Delta AICc
Full	17	-26.592	87.184	89.177	7.257
Remove Longitude	16	-26.612	85.223	86.990	5.069
Remove Percent Tall Shrub 90	15	-26.936	83.873	85.426	3.506
Remove Percent Closed Needle 90	14	-27.324	82.648	84.003	2.083
Remove ln(Total basin ha)	13	-27.772	81.544	82.715	0.795
Remove Percent Closed Deciduous 300	**12**	**-28.460**	**80.920**	**81.920**	**0**
Remove Percent Emergent Vegetation (basin)	11	-29.972	81.943	82.786	0.866
Remove Percent Open Deciduous 300	10	-31.741	83.482	84.183	2.262
Remove Latitude	9	-34.726	87.451	88.023	6.102
Remove Percent Open Needle 30	8	-37.931	91.861	92.317	10.397
Remove Percent Sparse Vegetation 30	7	-39.736	93.472	93.826	11.905
Remove Percent Low Shrub 30	6	-41.054	94.108	94.372	12.452
Remove Percent Wood Needle 30	5	-46.297	102.594	102.782	20.861
Remove Percent Dwarf Shrub 300	4	-49.557	107.115	107.240	25.319
Remove Elevation	3	-56.682	119.365	119.440	37.519
Remove Perimeter	2	-67.176	138.352	138.389	56.469

Table 6: Parameter estimates, standard error, and ratio between the effect and standard error for each of the variables in the most supported combined scales model for predicting dabbling duck pair distribution. The ratio of effect to standard error represents the strength of the covariate having a non-zero effect.

Effect	**Estimate**	**Standard Error**	**Effect/Standard Error**
Intercept	-30.39972	12.07145	
Latitude	0.46034	0.19897	2.31362
Perimeter	0.00007	0.00002	3.77352
Elevation	-0.00278	0.00061	4.53643
Percent Emergent Vegetation (basin)	1.27785	0.75586	1.69059
Percent Dwarf Shrub 300	5.71492	1.89961	3.00848
Percent Open Deciduous 300	5.16763	2.86525	1.80355
Percent Open Needle 30	4.50396	1.40976	3.19485
Percent Wood Needle 30	6.18498	1.55168	3.98598
Percent Low Shrub 30	4.37329	1.29639	3.37344
Percent Sparse Vegetation 30	4.71952	1.29641	3.64047
Dispersion	1.72044	0.27476	

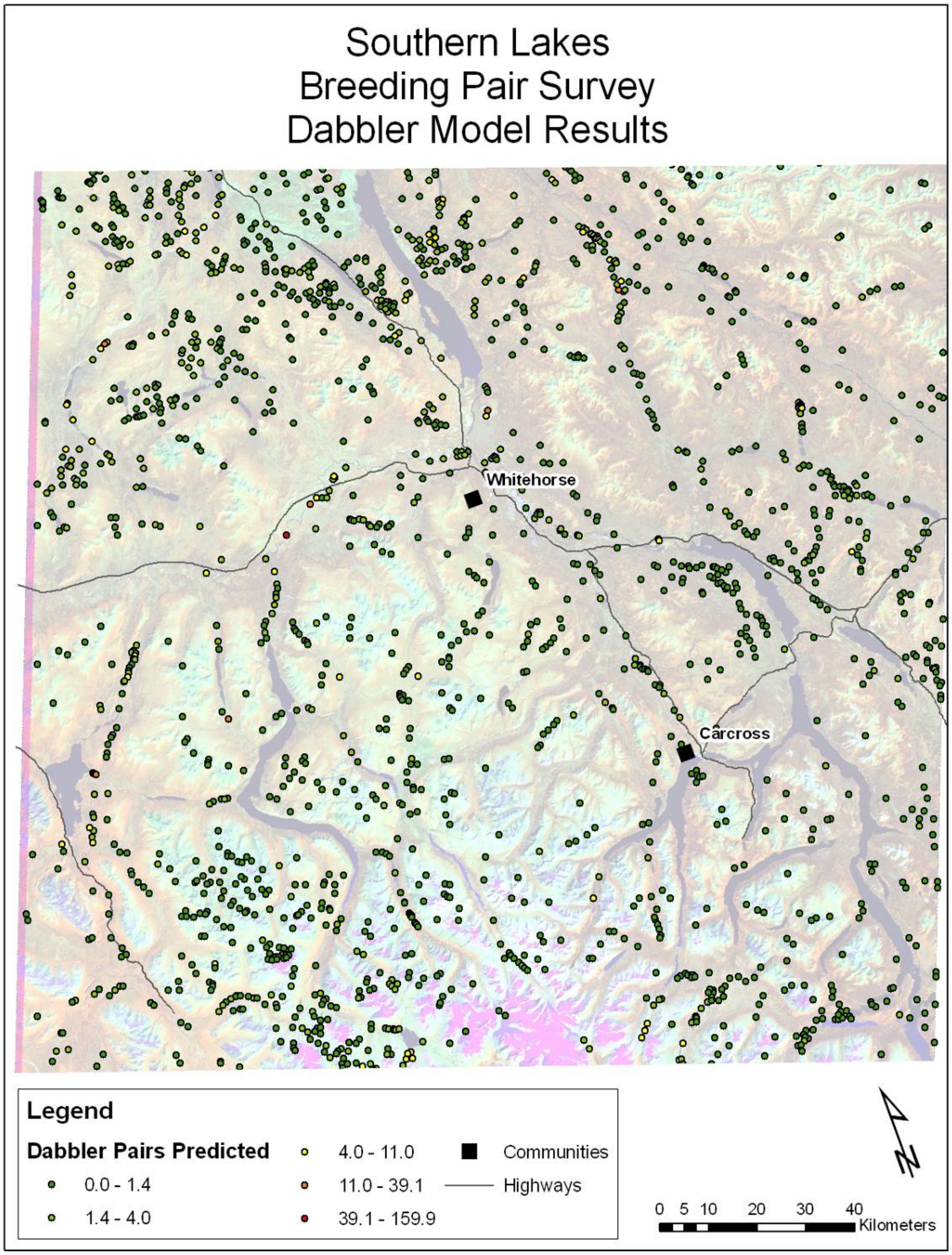

Figure 3: Predicted dabbling duck pair distribution within the Southern Lake project area.

Diving Duck Model

After a full negative binomial regression model, the effects of percent lichen at all three buffer levels plus percent mesic dry forb at the 30m buffer level were deleted. Ten predictor variables were advanced to the combined scales model. Basin level predictors advancing were basin size, percent emergent vegetation (basin), slope, elevation, and latitude. Advancing from the 300m buffer level were percent sparse vegetation and percent wood needle. Only percent mesic dry forb advanced from the 90m buffer level. Percent dwarf shrub and percent closed needle advanced from the 30m buffer level.

The best supported combined scale model had six predictor variables (Table 7). Latitude and basin size had a positive effect on pair numbers while all other predictor variables had a negative effect on number of pairs (Table 8). Miaou's R-squared for this model was 46.86%.

Diving duck pairs were predicted to have a similar distribution as all duck pairs (Figure 4). Highest pair numbers were predicted for the northern portions of the study area, particularly east of Lake Laberge and between Taye Lake and Fox Lake. Basins in the southern portions of the study area had lower predicted diving duck pair numbers than the north but areas east of Dezadeash Lake, along the South Klondike Highway, and on the west side of Marsh Lake had mid-high pair estimates. The range of predicted diving duck pairs was smaller than that of dabbling ducks with a maximum of 12 pairs predicted for a basin.

Table 7: Results for the combined scales model for diving duck pairs. The bolded model was used to advance predictor variables to the combined scales model as it had the lowest AIC. Number of variables within the model is represented by k.

Model	k	Log Likelihood	AIC	AICc	Delta AICc
Full	12	94.864	-165.729	-164.729	5.876
Remove Percent Wood Needle 300	11	94.790	-167.581	-166.737	3.867
Remove Percent Dwarf Shrub 30	10	94.620	-169.239	-168.539	2.066
Remove Percent Emergent Vegetation (basin)	9	94.313	-170.625	-170.054	0.551
Remove Slope	**8**	**93.530**	**-171.060**	**-170.605**	**0**
Remove Percent Mesic Dry Forb 90	7	91.480	-168.961	-168.607	1.997
Remove Percent Sparse Vegetation 300	6	88.317	-164.634	-164.370	6.234
Remove Elevation	5	80.463	-150.926	-150.738	19.867
Remove Percent Closed Needle 30	4	71.389	-134.778	-134.653	35.951
Remove Latitude	3	57.641	-109.281	-109.206	61.398
Remove ln(Total basin ha)	2	43.306	-82.6118	-82.5746	88.300

Table 8: Parameter estimates, standard error, and ratio between the effect and standard error for each of the variables in the most supported combined scales model for diving duck pairs. The ratio of effect to standard error represents the strength of the covariate having a non-zero effect.

Effect	Estimate	Standard Error	Effect/Standard Error
Intercept	-46.9934	8.2221	
ln(Total basin ha)	0.2894	0.5296	5.4556
Latitude	0.7968	0.1357	5.8699
Elevation	-0.0012	0.0004	3.3527
Percent Sparse Vegetation 300	-1.3209	0.5076	2.6023
Percent Mesic Dry Forb 90	-18.9438	10.4738	1.8087
Percent Closed Needle 30	-5.0882	1.0480	4.8515
Dispersion	0.7220	0.1142	

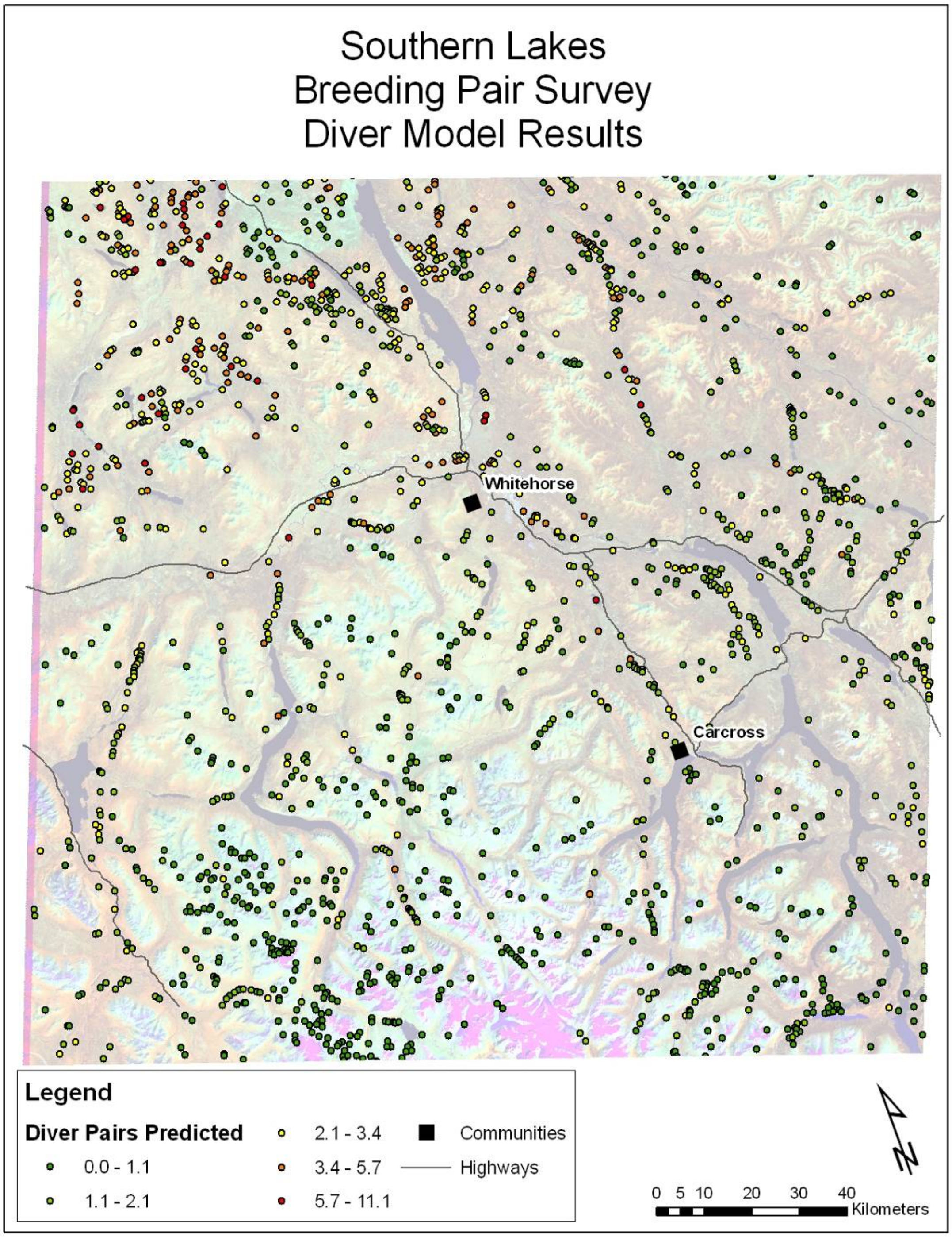

Figure 4: Predicted diving duck pair distribution within the Southern Lake project area.

MODEL ASSUMPTIONS

We made many assumptions in making predictions of waterfowl distribution within the Southern Lake project area. Explicitly stating assumptions allows for a clearer understanding of the model results and the limitations associated with using the model. Assumptions were made at all stages of the project including data collection, data analysis, and model interpretation.

Assumptions regarding data collection influence the quality of the data we collected and then used in creation of the model. We assumed that there was negligible difference between observers in their ability to detect, identify, and determine social status of ducks. We assumed that all species of ducks had an equal probability of detection and that this probability was high, which has been subsequently confirmed in other parts of the western boreal forest (Ducks Unlimited Canada unpublished data). We assumed that basin characteristics did not impact the ability of the observer to detect or identify waterfowl and that all basins were surveyed equally well. This assumption is likely violated as some basins were treed right to shore thereby altering the height of the helicopter during surveys while other basins had large areas of emergent vegetation that made detection of waterfowl difficult. The rate at which birds were identified as “unidentified duck/diver” was assumed to be stable. This assumption is likely violated as weather and observer ability can impact identification accuracy. There was a difference in survey timing between the first year and the last two years due to a high proportion of basins being ice covered during early surveys in the first year. We assume that any difference in the number of birds observed between years is a true year effect not due to differences in survey timing. However, there may be an underestimate in the number of pairs for some species, particularly those species that have their counts averaged over the two surveys. Observations of zero birds on a basin were assumed to imply limited value of the basin for waterfowl regardless of whether the zero observation was recorded at an open water or ice-covered basin.

We made few assumptions during the analysis due to the methods chosen. Generalized linear models do not assume linearity between the predictors and the dependent variable or constancy of variance in the response. The most predominant assumption made was that the data followed a negative binomial distribution, a distribution commonly used to approximate count data. This assumption was supported given the non-zero values for the dispersion parameter (Table 4, 6, and 8). We also did not model any interactions among predictor variables.

INTERPRETING MODEL RESULTS

The results of this model can be used for regional land-use planning, as a flagging tool for environmental assessment, and other regional scale processes. However, there are limitations to how this model can be used. This section details how the model results can be used to best avoid using the model out of context.

Although the model predicts exact numbers of waterfowl for each basin, the predictions should be viewed on a relative scale. For example, a basin predicted to have six or seven pairs has a higher value to waterfowl than a basin with only one or two pairs predicted. To aid in regional planning, groupings of basins with higher predicted relative values should be interpreted as more important than lone basins with high predicted pair estimates. Relative values need to be used due to the model's limited ability to predict precise pair numbers and to avoid any bias inherent in pair estimates.

The model's limited predictive ability is evident in the r-squared value (maximum r^2=0.47). Despite accounting for nearly half of all variability, confident predictions of accurate pair abundance (close to actual truth) cannot be made with the current model although comparisons of relative abundance can be made. The variability in parameter estimates (Table 8, 14, and 20) also limits the ability to make accurate pair predictions. For basins with an extreme measure for one or more variables, the likelihood of high uncertainty in the pair estimate increases. The quality of predictions deteriorates when we extrapolate outside the ranges we observed for the predictor variables. Although the range of pair predictions can be large, relative values can be compared across basins.

Bias of pair estimates can be caused by a systemic under- or over-estimation of the number of pairs on a basin. In many instances these biases go undetected. For the Southern Lakes study area, no independent estimate of pair abundance exists that can be compared to the predicted pair abundance. Therefore, we cannot determine if the model is predicting realistic pair abundances, however it is valid to compare the relative value of one basin to another basin despite this limitation. Additionally, the model, as structured mathematically, cannot predict a basin to have zero pairs although functional zeroes are estimated through infinitesimally small positive values.

The data used in the creation of this model was from the late 1990's (earthcover data) and the early 2000's (waterfowl survey data). In localized areas of the study region, the earthcover class may have changed, or may change in the future, due to natural succession, forest fire, receding snow lines, or anthropogenic impacts. Ducks Unlimited Canada et al. (2002) documented that over 95,000ha (2.5%) of the study area changed earthcover classification between 1987 and 1999. Changes in earthcover may lead to a discrepancy between the predicted value of a basin to waterfowl and the current or future value of that basin.

LESSONS LEARNED

A number of issues influenced the quality and delivery of the final products. The final products will be useful as a tool to support regional land-use planning and other conservation processes but improvements can be made. We need to identify where this project was limited and learn from this to improve future projects. Improvements can be made to project design, survey methods, sample size, addition of data sources, and model building.

This project was a partnership between Ducks Unlimited Canada and the Canadian Wildlife Service among other groups. Ensuring a clear understanding between partners regarding the final products, timelines for completion, delays in completion, and data limitations at the onset and throughout the project will minimize the delays faced in this project. Future projects should be designed with a detailed proposal outlining the goals of the project, the deliverables to be provided, the role of all partners within the project, interim goals to be achieved, and a timeline for completion. The project design should also incorporate adaptive management to allow the project to evolve as new information is acquired and/or unforeseen complications arise.

As noted above, survey timing differed between the first year and the last two years of the project. Given the investment in time and money to conduct surveys it is a priority to ensure surveys are conducted at the best possible times to maximize the value of the data collected. When baseline data is limited as in this situation, conducting a trial survey prior to commencement of the larger project to determine local breeding timing may be a worthwhile venture.

A model can only be as good as the input data. Having a large enough sample size to detect a trend is one way to ensure good data. The lack of species-specific models in this report is due to the lack of statistical power given the sample size and underlying waterfowl densities. Most species had an underlying density of no more than one pair per 10 basins. Conducting a power analysis for a range of underlying pair densities shows that upwards of 1,000 basins need to be sampled to detect a 10% change in pair numbers given a 10% change within the range of a predictor variable at an underlying pair density of one pair per two basins (Table 9). For example, if a predictor such as percent open deciduous ranges from 0%-20% then a change of 2% represents 10% of the range. Over 1000 basins would need to be surveyed to have statistical power to conduct species-specific models. Only three species, mallard, Barrow's goldeneye, and scaup, had a high enough pair density that the current sample size provided enough statistical power to detect a 10% change in pair numbers with a 10% change within the range of a predictor variable.

Table 9: Results of a power analysis to determine the sample size of basins needed to detect a 10% change in pair numbers given a 10% change within the range of a predictor variable for four estimates of underlying waterfowl pair densities. Sample size is considered sufficient if statistical power exceeds 0.80.

Underlying Pair Density	**Number of Basins**	**Statistical Power**
One pair per 10 basins	100	0.19
	300	0.35
	1000	0.74
One pair per two basins	100	0.37
	300	0.76
	1000	> 0.99
One pair per basin	100	0.7
	300	0.97
	1000	> 0.99
Four pairs per basin	100	0.97
	300	> 0.99
	1000	> 0.99

Collection of other data that is believed to be a factor in influencing waterfowl distribution can improve the performance of a model. Initially, this project planned on using water chemistry data (Bell et al. 2003) from basins surveyed for waterfowl pair abundance. However, only 99 basins with waterfowl survey data had water chemistry data. Given the low r-squared value of the current model and the low statistical power due to the low underlying waterfowl densities, a further decrease in sample size was deemed unacceptable. Future studies should ensure a power analysis is done with all possible datasets prior to project commencement or at least all data types should be collected for all survey units (e.g. water chemistry data).

Given the data we had available, a method for increasing the model's predictive ability may have been to examine interaction effects between some variables. We did not examine interaction effects because we had no *a priori* prediction of what set of variables may be interacting and we did not want to partake in a data mining exercise. Future projects should, if interaction effects are to be used, list out a set of biologically defensible interaction effects to include in the model before model selection takes place. Using an *a priori* set of models and interaction effects minimizes data mining and the opportunity for spurious results.

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