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Modeling waterfowl damage to crops surrounding the Quill lakes in Saskatchewan

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Abstract: Waterfowl using the Central Flyway congregate on staging lakes before fall migration. The Quill lakes area of Saskatchewan Province, Canada, contains many staging lakes, which are surrounded by annual cropland. Crop losses to waterfowl occur every year, but the severity fluctuates greatly from year to year. We obtained historical crop compensation data, waterfowl-staging surveys, harvest chronology, and weather records from various agencies. Using GIS, we referenced all data types to potential claim-land parcels (0.65 km^2 for the damage model and 5 km^2 for the density model). We constructed empirical landscape-level logistic regression models, weighting factors influencing the magnitude of crop loss and density of waterfowl damage claims. Crop type, yield, abundance of waterfowl, and distance to feed stations (where bulk grain is provided to keep waterfowl off the nearby fields) were important to both the magnitude and density of damage. Oats were more susceptible to waterfowl damage than field peas, barley, or spring wheat. The end date of combining crops had a major influence on the magnitude of claims but had little effect on their density of claims. Magnitude was large in years when harvest was protracted and coincident with waterfowl staging. Distance to staging lakes was important to the density model, indicating that areas in close proximity to staging lakes experience chronic losses over time. In high-magnitude years, waterfowl damaged the more productive fields farther from staging lakes. Our results are consistent with the marginal value theorem and central place foraging: the relative benefits to foraging greater distances from a central place increases as resources are depleted near the central place.

Key words: agricultural landscape, crop damage, ducks, geese, human–wildlife conflict, spatial analysis, waterfowl, wildlife damage

Human–wildlife conflicts occur throughout the world but are especially acute and chronic in the agricultural landscape where crop damage by wildlife occurs (Conover 2002). The conversion of natural habitats to agricultural land use has created a shifting mosaic of patchy habitats that vary spatially and temporally and to which wild animals using the landscape must respond. The spatial distribution of damaged crops in a landscape is likely influenced by the spatial configuration of the landscape, as well as the foraging strategy of the damaging animals (Messmer 2000, Conover 2002).

For individuals foraging in habitat patches that vary in quality and quantity, decisions on whether to forage in a particular patch and residence time in a patch both are constrained by many factors, including energy expenditure (Pyke et al. 1977), size and quality of patch (Cowie and Krebs 1979, Stephens and Krebs 1986), resource depletion (Hamilton et al. 1967), predator avoidance (Schultz 1983), and care of young (Rosenberg and McKelvey 1999). The use of a habitat patch by individuals exhibiting central-place foraging behavior, such as staging waterfowl, will also be influenced by the habitat's proximity to the central place (Rosenberg and McKelvey 1999). For gregarious foragers, flock size could influence patch-use decisions, because group feeding increases predator detection, thus affording greater foraging time and less time spent in predator vigilance per individual (Pulliam 1973).

Crop damage by fall staging waterfowl has a well-documented history in the prairie region of North America since cereal grains were first grown. A marked decrease in waterfowl habitat and increase in protein-rich cereal

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grains during the late 1800s and early 1900s, followed by the recovery of waterfowl populations after the drought in the 1930s, created conditions conducive to crop damage by waterfowl throughout the prairies in North America (Knittle and Porter 1988). The onset of significant damage occurred in the 1940s when the practices of swathing grain (i.e., cutting and leaving it in the field to ripen) became widespread (Colls 1951, Bossenmaier and Marshall 1958, Sugden 1976, Knittle and Porter 1988). The practice of swathing grain to dry it before combining is still widespread in the Canadian prairie provinces. With Canada's short growing season, crops often do not mature until the onset of cool weather in the fall when drying conditions are poor. Planting may be delayed in the often wet soils surrounding wetlands, making the effective growing period even shorter. With direct combining, the moisture content is often too high for grain to store well. Chemical dessication was tried, but was not as effective as drying in the swath (Clarke 1981).

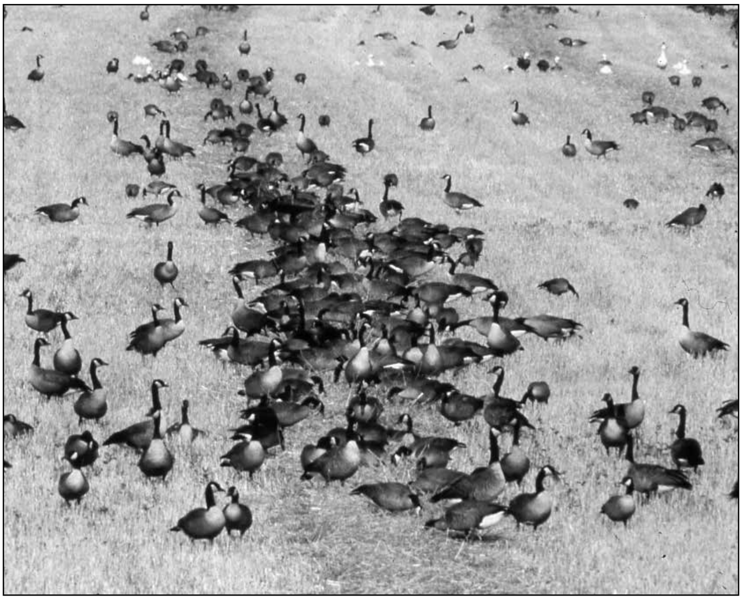

Figure 1. Geese feeding on a swathed lure-crop. *(Photo courtesy Saskatchuan Ministry of Environment)*

Damage to cereal crops during fall migration is caused by several waterfowl species, although most of the damage is attributed to mallards (*Anas platyrhynchos*), northern pintails (*Anas acuta*), and Canada geese (*Branta canadensis*; Sugden 1976). Other damaging species include, greater white-fronted geese (*Anser albifrons*), lesser snow geese (*Chen caerulescens*), Ross's goose (*Chen rossii*), and sandhill cranes (*Grus canadensis*; MacLennan 1973). Sandhill cranes tend to use harvested cereal fields in preference to swathed grain, but will forage on unharvested fields, causing damage through trampling and feeding on swathed grain (Sugden et al. 1988). Crop damage by waterfowl includes consumption, trampling, and fecal contamination (Sugden 1976, Knittle and Porter 1988; Figure 1).

Although economic losses from waterfowl crop damage are small relative to other natural impacts (e.g., insect or weather damage), the annual cost of compensating landowners for crop damage in Canada can range in the millions of dollars. From 2000 to 2004, annual waterfowl damage compensation ranged from $877,737 to >$5.6 million across the 3 prairie provinces in Canada (Alberta, Manitoba, and Saskatchewan). Waterfowl damage claimed by Saskatchewan producers averaged 61% of the total annual compensation across the 3 provinces (Agricultural and Agri-Food Canada, unpublished data).

Crop damage is not uniformly distributed among farms or years (Sugden 1976). The synchrony of fall waterfowl staging behavior with swathed grain is a prerequisite for damage. Several additional factors may contribute to vulnerability by waterfowl in a particular field, including geographic location, topography, weather, crop type, and method of harvest (Knittle and Porter 1988). Fall precipitation is a principal factor affecting magnitude of damage (Jakimchuk 1969, MacLennan 1976), and crop damage is more severe when harvesting is delayed by inclement weather and when grain remains in swath for long periods (Sugden et al. 1988, Arsenault 1994). Damage is more chronically severe in northern areas where late springs can have an inordinate influence on harvesting date (Jakimchuk 1969).

In response to the waterfowl crop damage issue, an integrated federal-provincial damage prevention and compensation program was established across the Canadian prairies in 1978. In addition to developing a standardized damage compensation system, the program also provided intervention feeding options to waterfowl in the form of lure crops and feeding stations to mitigate crop damage caused by waterfowl (Sugden 1976, Gollop 1988, Poston 1991). Clark et al. (1993) found that number of feeding stations was unrelated to magnitude of damage at a provincial scale.

The objectives of our study were to investigate the relationship between crop damage by waterfowl and various crop production, precipitation, and harvesting factors, and to develop predictive models of waterfowl damage using easily-obtainable data that are applicable at fine and coarse scales (0.65 km^2 and 5 km^2). We demonstrate the utility of combining climate and landscape data with damage records to identify areas with chronic vulnerability to waterfowl damage and relative vulnerability of crop types. We developed the models using data on crop damage, crop production, harvest dates, precipitation, damage mitigation, distance to staging lakes, and fall waterfowl abundance for the Quill lakes area of Saskatchewan, a well-known staging area for fall migrant waterfowl. This region was selected based on the spatial variability of waterfowl damage claims, allowing us to test which factors explain the variability in the damage data in a multivariate model.

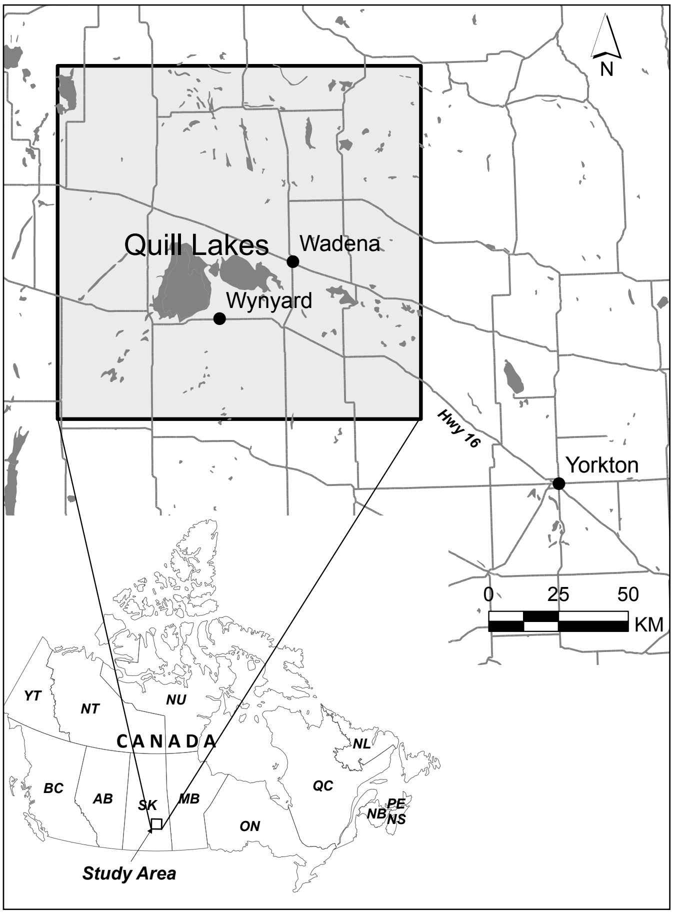

Figure 2. Location of the Quill lakes study area, Saskatchewan, Canada, showing migratory waterfall staging lakes. Approximately 80% of the area is planted to annual crops.

Study area

Our study area was 14,889 km^2 and centered on the Quill lakes region of central Saskatchewan (52° 05′ 29″ N, 104° 08′ 32″ W), approximately 175 km east of Saskatoon (Figure 2). The Quill lakes exist in the prairie ecozone and form part of the northern extent of the Great Plains ecological region of North America. The prairie ecozone is characterized by flat and gently rolling plains with limited forest cover. The climate is sub-humid to semi-arid with short, hot summers and long, cold winters (Agriculture and Agri-Food Canada 1998). The prairie ecozone contains >60% of Canada's cropland and 80% of the rangeland and pasture. Agriculture is the dominant economic activity in the prairie ecozone.

The Quill lakes are located in the aspen parkland ecoregion of the prairie ecozone (Ecological Stratification Working Group 1996). Aspen parkland consists of groves of trembling aspen (*Populus tremuloides)* and balsam poplar *(P. balsamifera)*, interspersed with prairie grasslands, lakes, potholes, shallow open water marshes, and grassy wetlands. The Quill lakes provide critical habitat of international importance for waterfowl. It is designated as a Ramsar Convention wetland, a Saskatchewan heritage marsh, a western hemisphere shorebird reserve, and an important birding area of Canada. The wetlands are of national importance for staging waterfowl (Poston et al. 1990). The study area is dominated by agricultural activity. In 2001, approximately 78% of the land in the study area was cropland, 15% pasture, and 7% other (forest, wetland, riparian, homesteads, etc.). Of the cropland, 54% was grain, 23% oilseed, 10% pulses, and 13% hay, alfalfa, or flax (Census of Agriculture 2001). In more recent years, there has been a reduction in the area seeded to cereals (spring wheat in particular) and increases in the area seeded to oilseeds (mainly canola [*Brassica napus* L.]) and pulses (mainly peas), changing the nature of waterfowl damage (Statistics Canada 2014).

Methods

Geographical and time scale of analysis

In the nineteenth century, the Dominion Land Survey partitioned most of western Canada into 1-square-mile sections (259 ha) for agriculture (McKercher and Wolfe 1992). We used the quarter section (65 ha) as a unit of analysis for the magnitude of damage model because this metric is used for administration of waterfowl damage claims. The study area (approximately 1.5 million ha) consisted of 22,907, 65-ha units; the center point of each was derived for spatial analyses using a Geographic Information System (GIS; ArcGIS 9.2, ESRI Inc., Redlands Calif., 2006). Each damage claim was ascribed to a point at the center of the 65-ha unit. We used a 5-km radius circular moving cell scale for the density of damage model.

For univariate analyses, we used the time frame of 1980 to 1997. This was the full range of years for which crop compensation data were available, and there was more likelihood of low and high damage years when we used the full time range. Univariate analyses allowed us to determine the strength and form of the relationship between a broad suite of explanatory variables and the damage estimates derived from the compensation data. Those variables having the strongest relationship (without auto-correlation) with estimated crop damage were included in a multivariate model. We had fewer years of data for 2 additional explanatory variables that had been mentioned in previous studies: harvest chronology and waterfowl numbers. To include these variables the multivariate models covered only 8 years (1987 to 1994).

Estimates of crop damage

Data on damage to wheat, barley, oats, and field peas were obtained from Saskatchewan Ministry of Environment and imported into ArcGIS. Data on actual losses of crops to waterfowl do not exist; estimated losses are based on damage claims approved for affected producers. Each quarter section field reported to have been damaged by waterfowl is inspected by a Saskatchewan Crop Insurance Corporation (Prince Albert, Saskatchewan, Canada), the insurance adjustor that visually estimates yield loss. Because estimates vary across insurance adjustors, these estimates should be considered in relative rather than absolute terms. Magnitude of damage (yield loss in kg/ha[1]) and density of damage (claims per 5-km radius circular moving cell) were the dependent variables in separate multivariate models. ArcGIS was used to apply a quadratic kernel method with a circular moving cell of 5-km radius to calculate the spatial density of damage claims across the study area. The density at each output raster cell was calculated by adding the values of all the kernel surfaces where they overlay the raster cell center.

Waterfowl abundance

Saskatchewan Ministry of Environment provided fall staging waterfowl counts from aerial surveys conducted on 9 staging lakes in the study area for the study period, excluding 1988, 1989, 1992, and 1993. Using linear interpolation, we replaced the missing abundance values with estimates computed from the mean of nearby temporal values (Figure 3). Although the abundance estimates (NOBDS; see tables for acronyms) are not an accurate count of all staging waterfowl that could cause damage in the study area, they include the vast majority of staging waterfowl.

Harvest and staging chronology

Harvest chronology data were obtained from Saskatchewan Agriculture and Food and Rural Service. These data were available at the crop district scale, which approximate the census agricultural regions defined by Statistics Canada. We ascribed each damage point to one of 4 crop districts that intersect with our study area.

Using the harvest chronology dataset, we derived 5 variables to describe harvest chronology, including Julian date of the last day of harvest (ENDCOMB), Julian date of last day of combining minus Julian date of first day of swathing (HARDAYS), and departure from the mean number of days of harvest across study years (DEPMEAN). We also calculated the number of days from beginning of swathing to end of combining that coincided with waterfowl staging (WFDAYS [difference in days after August 10 between first swathing and last day of harvest]) as a measure of the length of time that crops are vulnerable to damage. Adult waterfowl molt from late July to mid-August, and the young of the year fledge at the same time. Staging behavior begins in early August (M. Gollop, Saskatchewan Ministry of Environment, personal communication). Crops swathed prior to August 10 are not vulnerable to waterfowl unless they are adjacent to wetland habitat that waterfowl can access by walking. We, thus, ascribed WFDAYS as the difference in days on or after August 10 when crops were first swathed and the last day of harvest each year.

We tested whether the mean length of harvest after waterfowl arrived (August 10) was different between years of high damage and low damage. For univariate analyses, we classified data into high and low damage years using the median sum of yield lost per year as the threshold between high and low damage years, because the data followed a continuous log normal distribution.

Weather

To test if precipitation during the harvest season has better explanatory power for waterfowl damage than crop harvest chronology data, we obtained precipitation data from 13 weather stations (Environment Canada, unpublished data) within and near the study area and calculated cumulative precipitation from the earliest date of swathing (August 1) to the latest date of harvesting (October 24) during the study period (CUMPPTE). The closest active weather station was determined for each 65-ha unit in each year of the study, and cumulative precipitation was calculated for each damage point during each year of the study.

Distance to staging lakes and mitigation techniques

We used the Canada Land Inventory digital map of staging lakes within and surrounding the study area (Poston et al. 1990) to measure the Euclidean distance from the center point of each 65-ha unit in which damage was reported to the edge of the nearest staging lake within and surrounding the study area (DISLAKE). Lure crops and feeding stations are used by Saskatchewan Ministry of Environment to mitigate damage caused by waterfowl (Gollop 1988). Eight feeding stations and 6 lure crops occurred in the study area. Using GIS, we measured the Euclidean distance from the center of each quarter section in which damage was reported to the nearest active lure crop (DISLC) and feeding station (DISFS) during each year of the study. We also tested for differences in mean distance to staging lakes between high damage years and low damage years.

Model construction and validation

For each model (magnitude and density of damage), we used scatter plots to investigate the relationship between each dependent variable (kg/ha^{-1} of yield loss or number of claims per 5-km radius circular moving cell) and each independent variable to determine whether the relationship was linear or nonlinear. We used logistic regression as a modeling approach to determine the relative importance of the independent variables, including crop type (CRPTYP), yield (YIELD), crop area (AREA), harvest chronology, proximity to mitigation efforts, and proximity to staging lakes, in explaining the variability in magnitude and density of damage and also to calculate the probability for magnitude and density of damage across the study area. We also included the following interactions in the models: yield and crop area; waterfowl abundance and last date of harvest; waterfowl abundance and cumulative precipitation; and waterfowl abundance and distance to feeding stations.

Logistic regression was chosen because

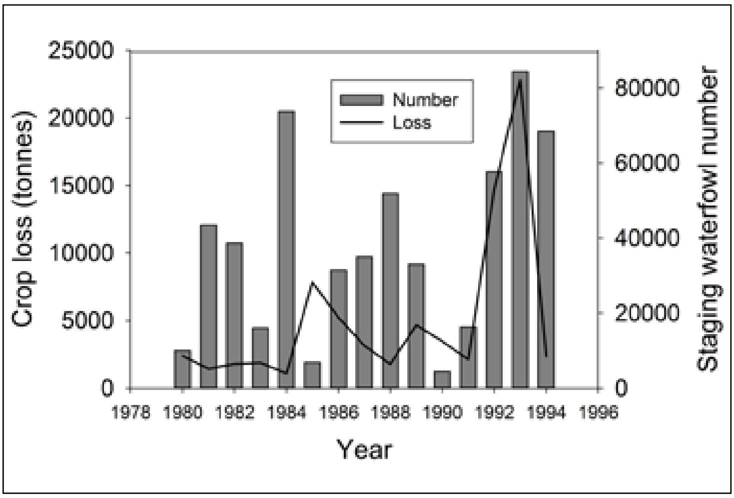

Figure 3. Crop losses summed for wheat, barley, oats, and field peas (tonnes) to waterfowl from the Quill lakes region, and estimated number of staging waterfowl from aerial survey of nine of the Quill lakes (1980 to1984). Source: Saskatchewan Ministry of Environment.

of the nonlinear relationship between the dependent variable and independent variables, and for its ability to incorporate categorical variables. Because logistic regression requires a binary dependent variable (Tabachnick and Fidell 1996), Jenks's (1967) methods was applied in ArcGIS to determine natural breaks in the dependent variables to identify low, moderate, and high magnitude (or density) of crop damage and retained only the data representing low and high damage (or density) for the multivariate analysis. We conducted model evaluations using tests for goodness-of-model-fit and prediction accuracy. For overall measure of goodness of fit, we calculated a pseudo R^2 measure, i. e, Nagelkerke R^2 (Nagelkerke 1991).

Spearman rank correlation was calculated to investigate the relationship among pairs of independent variables. There was high correlation among all pairs of harvest chronology variables ($R^2 > 0.60$), and, thus, we retained only one of the 4 variables for the models. We created a set of models with all variables and only 1 harvest chronology variable at a time to test which of the harvest chronology variables was most important to the model, and retained this variable in the final model. Statistical tests were executed on SPSS 13.0 (Statistical Package for the Social Sciences 2004) with an alpha level of 0.05, unless otherwise stated. Where post hoc tests were required, we used a Bonferroni adjustments procedure to evaluate differences among specific means (Zar 1996).

We used natural logarithm to transform all variables to normalize the distribution of the data, converted all noncategorical variables to z-score to standardize the data, and included interaction terms in the initial models. The forward stepwise design of logistic regression was employed for the models.

The resulting explanatory logistic regression models were used to generate probability surface maps for magnitude and density of damage. Coefficients from the best-fit logistic models were used to calculate a probability value for each pixel using an inverse distance weighting technique in ArcGIS.

To determine whether year was a confounding factor in the model, we used time series analysis to investigate whether damage was auto-correlated temporally. Damage was not auto-correlated temporally, and year is likely to be important to the magnitude of

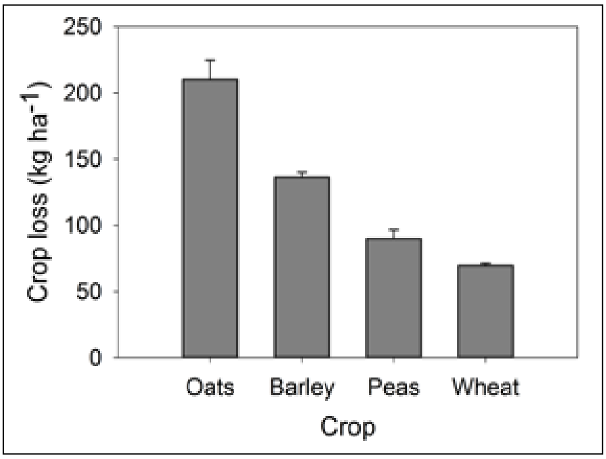

Figure 4. Mean crop losses (kg/ha^{-1}) to waterfowl 1980 to 1997 for 4 crop types in the Quill lakes area of Saskatchewan estimated from wildlife compensation claims. Values are means with standard error. (Source: Saskatchewan Ministry of Environment)

damage only through its association with annual events that impact the length or timing of harvest relative to staging waterfowl activities (e.g., precipitation), and may actually mask the relative importance of other variables. We, therefore, removed year as a factor in subsequent models.

Model validation was performed using k-fold cross validation (Boyce et al. 2002). We partitioned the damage data randomly into 5 equal sets (Huberty 1994). Magnitude and density of damage models were constructed using 80% of the data; the remaining 20% were set aside for model evaluation.

Table 1. Results of logistic regression models of magnitude and density of crop damage by wildlife in the Quill lakes region of Saskatchewan, Canada.

Model	Term	Coefficient	S.E.	Wald	*P*
Magnitude	Intercept	-6.27	0.41	238.70	<0.001
	CRPTYP[a]			41.13	<0.001
	YIELD	1.31	0.26	24.42	<0.001
	AREA	2.76	0.34	65.82	<0.001
	NOBDS	0.66	0.14	23.32	<0.001
	DISFS	-0.40	0.12	11.58	0.001
	ENDCOMB	1.14	0.15	59.19	<0.001
	YIELD*AREA	-0.93	0.25	13.34	<0.001
Density	Intercept	-1.43	0.11	162.04	<0.001
	CRPTYP			21.42	<0.001
	YIELD	-0.48	0.08	36.28	<0.001
	NOBDS	-0.28	0.09	10.47	0.001
	DISFS	-1.39	0.09	229.28	<0.001
	DISLAKE	-0.78	0.08	88.04	<0.001
	YIELD*AREA	-0.18	0.08	5.70	0.017
	NOBDS*ENDCOMB	-0.40	0.08	22.38	<0.001
	NOBDS*CUMPPTE	0.34	0.09	15.67	<0.001
	NOBDS*DISFS	-0.29	0.09	10.92	0.001

[a] CRPTYP = crop type; AREA = area seeded; NOBDS = number of waterfowl; DISFS = distance to feeding station; ENDCOMB = end of combining; DISLAKE = distance to staging lake; CUMPPTE = cumulative precipitation.

Results

From 1980 to 1997, 6,353 damage claims occurred in the study area. The annual harvest for wheat, barley, oats, and field peas in the study area ranged from 1,180 to 23,000 tonnes. Based on the median value of 4,100 kg/ha^{-1} yield loss, we classified 13 years of the study as low magnitude of damage and 5 study years as high magnitude of damage for univariate analyses. Sample size for the multivariate model (1987 to 1994) was 3,097 damage claims. Losses for the shorter time frame ranges from 1,096 to 22,816 tonnes (Figure 3).

Univariate analyses

We found a significant difference between the number of claims made during high damage years and the number of claims filed in low damage years ($t = 5.25$, df = 16, $P < 0.01$). Mean distance to lakes in high damage years was greater than in low damage years ($t = 4.9$, df = 16, $P < 0.001$). In years of high damage, waterfowl damaged crops on fields that were on average 849 m further away from staging lakes than in years of low damage. The mean yield loss differed among crop types (ANOVA, df = 3, $P < 0.001$; Figure 4). Damage to oats was significantly greater than all other crop types (Bonferroni post hoc test, $P < 0.001$); damage to barley was significantly greater than to field peas and wheat (Bonferroni post hoc test, $P < 0.001$), and damage to field peas was significantly greater than damage to wheat (Bonferroni post hoc test, $P < 0.05$). There was a significant difference in mean length of harvest between high damage years and low damage years ($t = 37.8$, df = 16, $P < 0.001$). In years of high damage, mean harvest length was 57 days after waterfowl arrived, and in low damage years, mean harvest length was 49 days after waterfowl arrived. There was a significant difference in mean cumulative precipitation between high damage low damage years ($t = 26.7$, df = 16, $P < 0.001$). In years of high

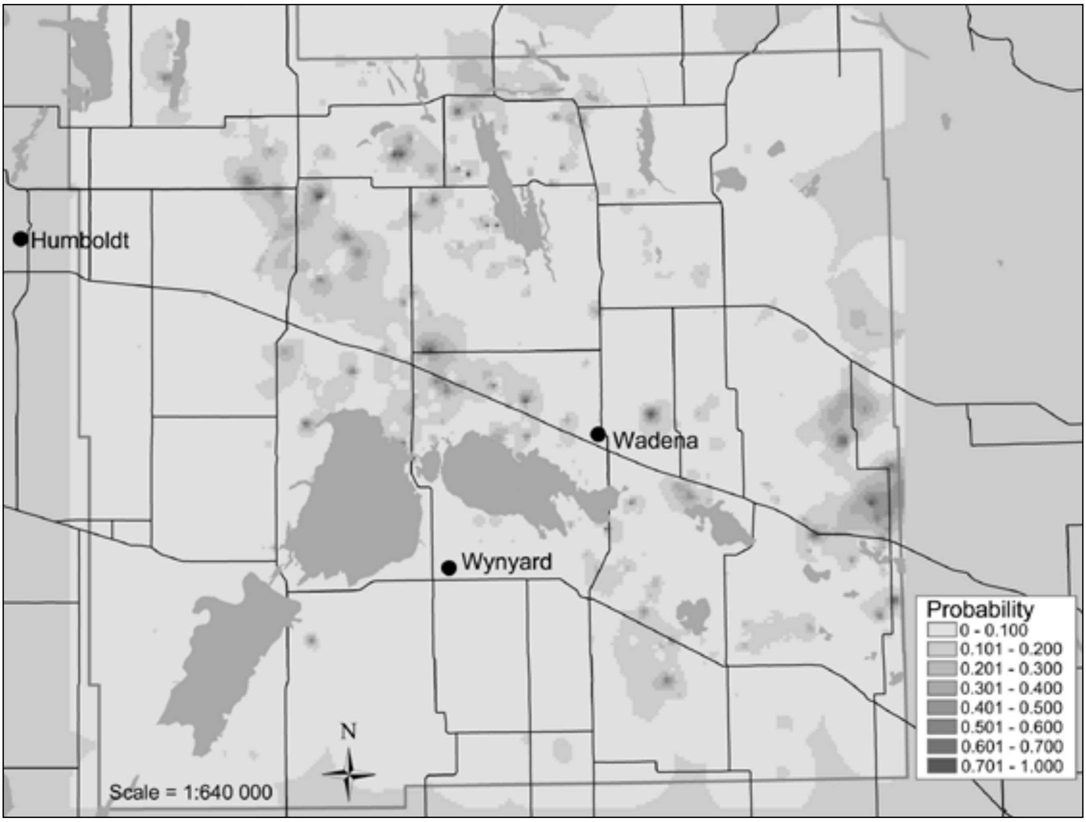

Figure 5. Probability plot of the magnitude of crop damage due to waterfowl in the Quill lakes region of Saskatchewan, Canada. Probabilities are the output from a logistic regression model of magnitude of damage relating crop losses from wildlife compensation to explanatory variables. Note that greatest yield losses occur in the more productive uplands, surrounded by, but at some distance from, the lakes.

damage, mean cumulative precipitation was 1,511 mm, and in low damage years, mean cumulative precipitation was 1,218 mm. The magnitude of damage was highest in the latter 6 years of the study, when the 4 highest damage years occurred (Figure 3). Two of the 4 highest cumulative precipitation levels occurred then, but magnitude of damage and cumulative precipitation throughout the study were not related ($R^2 = 0.01$, $P > 0.05$).

Logistic regression models

Julian date at the end of combining (ENDCOMB) was the harvest chronology variable that contributed the most to the magnitude of damage model (Wald statistic [the ratio of the coefficient to its standard error, squared]) 36.02; $P < 0.01$). Subsequent models were developed using ENDCOMB; other harvest chronology variables were omitted. The logistic regression model was significant ($P < 0.001$, -2 Log Likelihood (-2LL) = 641.42, Nagelkerke $R^2 = 0.47$). Overall classification rate was 94.6%. Based on the relative size of the Wald statistic the most important variables to the model were acres seeded, harvest completion date, and crop type (Table 1). The Wald statistic for waterfowl abundance and yield were intermediate, and distance to feeding stations and the interaction between yield and crop area, though significant, had relatively small contributions to the model. Distance to lure crops, distance to staging lakes, cumulative precipitation, and other interaction terms did not contribute significantly to the model. Based on the interpolated probability surface of the model coefficients, the areas predicted to experience chronic high damage were clustered among 3 primary staging lakes (Figure 5).

No harvest chronology variable contributed significantly to the density of damage model. Consequently, we eliminated all harvest chronology variables from the model. The logistic regression model was significant (*P*

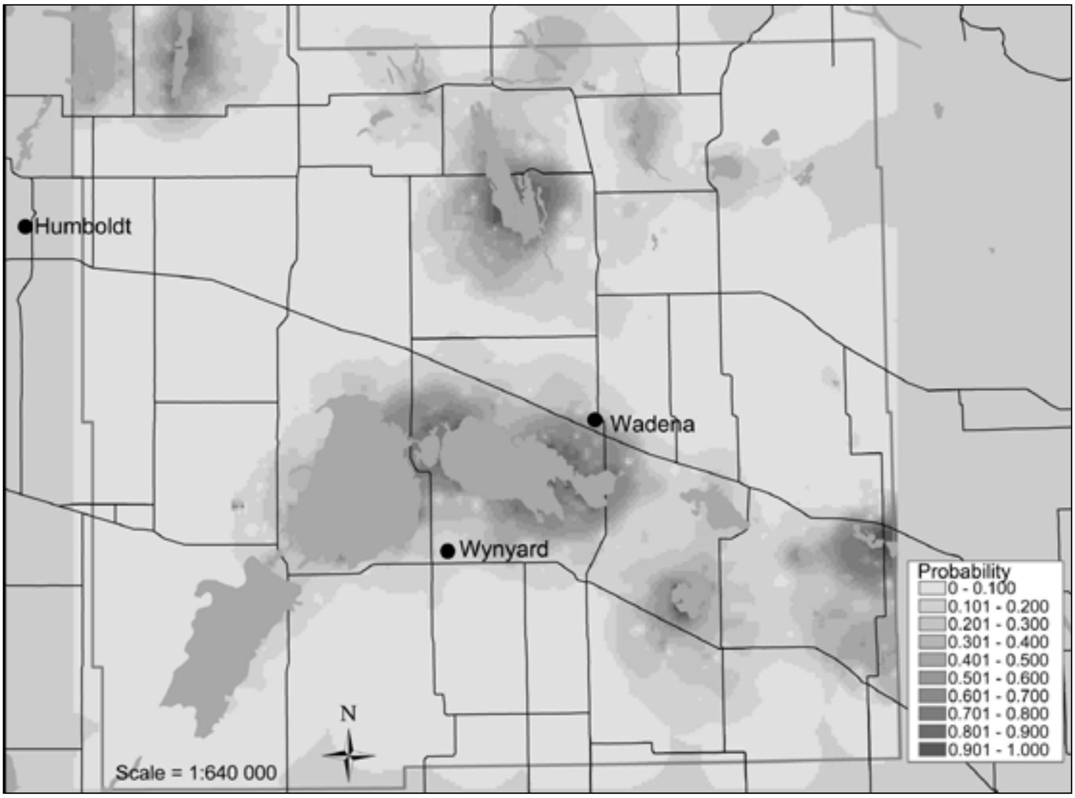

Figure 6. Probability plot of the density of crop damage claims due to waterfowl in the Quill lakes region of Saskatchewan, Canada. Probabilities based on a logistic regression model relating the density of claims to explanatory variables. Note that a claim is more likely to occur close to the staging lakes.

< 0.001, -2LL = 1141.12, Nagelkerke $R^2 = 0.53$). The overall classification rate was 84%. Based on the relative size of the Wald statistic, the most important variables to the model were distance to feed station and distance to staging lakes (Table 2). Crop yield, crop type, and the interaction between waterfowl abundance and last harvest day were moderately important. The interaction between waterfowl abundance and cumulative precipitation, the interaction between waterfowl abundance and distance to feed stations, and cumulative precipitation, though significant, were less important. Acres seeded, harvest completion date, and other interaction terms did not contribute significantly to the model. Based on the interpolated probability surface of the model coefficients, the areas predicted to experience chronic high density of damage occur in proximity to staging lakes (Figure 6). All logistic regression crop type models for magnitude of damage were significant ($P < 0.001$). Crop area was the variable consistently retained among crop type models (Table 2). All logistic regression crop type models for density of damage were significant except for the oats model ($P < 0.05$). Distance to feeding station was the variable consistently retained among crop type models (Table 2).

Model validation showed that the predictive power of the magnitude and density models was relatively high. Based on a k-fold cross validation of predicted versus observed in 7 bins (random selections of the data), we found the Rs = 0.64 for magnitude of damage model and Rs = 0.8218 for density of damage model.

Discussion

Our research demonstrates that the magnitude of crop damage by waterfowl varies spatially and temporally in the Quill lakes region of Saskatchewan; damage follows a patchy distribution across the landscape and is greater in magnitude during years when harvest is protracted. Five variables were important to both the magnitude of damage

Table 2. Results of logistic regression models of magnitude and density of waterfowl damage to 4 crops grown in the Quill lakes region of Saskatchewan, Canada.

Model	-2LL[a]	R^2	Term	Coefficient	S.E.	Wald	*P*
Magnitude							
Oats	29.46	0.49	Intercept	-15.85	5.26	9.1	0.003
			AREA	3.2	1.13	8.09	0.004
Barley	340.19	0.48	Intercept	-228.69	32.41	49.79	0.000
			YIELD	0.7	0.31	5.11	0.024
			AREA	2.43	0.32	59.26	0.000
			NOBDS	1.58	0.4	15.32	0.000
			DISFS	-0.37	0.17	4.75	0.029
			ENDCOMB	35.29	5.6	39.720	0.000
Field peas	50.49	0.45	Intercept	-347.3	138.32	6.3	0.01
			AREA	2.29	1.12	4.19	0.04
			DISFS	-1.27	0.62	4.12	0.04
			ENDCOMB	61.2	24.88	6.05	0.01
Wheat	274.50	0.36	Intercept	-156.12	52.28	8.97	0.003
			YIELD	1.22	0.41	8.85	0.003
			AREA	3.67	0.70	27.47	<0.001
			CUMPPTE	3.35	0.90	14.00	<0.001
			DISLAKE	-0.49	0.14	11.96	0.001
			ENDCOMB	19.6	9.65	4.12	0.042
Density							
Oats			Model				0.012
Barley	571.57	0.59	Intercept	26.5	3.17	69.75	<0.001
			YIELD	-0.6	0.26	7.05	0.008
			NOBDS	-0.7	0.26	15.32	<0.001
			DISFS	-1.55	0.14	125.740	<0.001
			DISLAKE	-0.4	0.08	25.210	<0.001
Field peas	25.37	0.63	Intercept	36.89	11.74	9.88	0.002
			DISFS	-4.46	1.39	10.33	0.001
			DISLAKE	-0.62	0.05	143.2	<0.001
Wheat	777.73	0.54	Intercept	18.16	1.53	141.61	<0.001
			YIELD	-0.85	0.16	29.81	<0.001
			AREA	0.54	0.16	11.13	0.001
			DISFS	-1.38	0.12	141.98	<0.001
			DISLAKE	-0.77	0.07	122.86	<0.001

[a] -2 log likelihood, (-2LL) used in hypothesis tests for mixed models.

and density of damage models: crop type; yield; abundance of waterfowl; distance to feed stations; and the interaction between yield and crop area. (As a reminder, the magnitude of damage model deals with average crop loss per claim, whereas, the density model deals with the number of claims per unit area.)

Distance to staging lakes was important to the density model, indicating that areas in close proximity to staging lakes experience predictable chronic losses. During high damage years, however, when crops are in swath for a longer period coinciding with staging behavior, waterfowl damaged fields that were farther from staging lakes. Our results are consistent with the marginal value theorem and central place foraging: the relative benefits to foraging greater distances from a central place increase as resources are depleted near the central place (Charnov 1976, Orians and Pearson 1979, Schoener 1979).

We found that oats were more susceptible to waterfowl damage than were field peas, barley, or spring wheat, and that field peas and barley were more susceptible than was wheat. Other researchers did not investigate damage to oats, but Arsenault (1993), Clark et al. (1986), and MacLennan (1973) reported barley to be more vulnerable than other crops. Growing crops less preferred by waterfowl has some potential to mitigate damage. For example canola is considered to be less susceptible to crop damage than cereals (Paynter and Stephen 1964). Growing earlier-maturing crops, such as winter wheat, may also reduce crop damage. However, commodity prices are likely a more important determinant of crop type grown each year than the desire to avoid waterfowl damage.

Commodity prices drove considerable changes in the suite of annual crops grown in the Quill lakes part of Saskatchewan after the period covered by our study (Statistics Canada 2014) that may have affected waterfowl damage. Crop diversification involved a large decrease in the area planted to spring wheat and an increase in peas (starting about 1994), canola (starting about 2000), and winter wheat (post 2005). With the exception of an increase in peas, these changes have likely reduced waterfowl damage to crops. Prices for both wheat and canola have increased in recent years, but producers in this region of Saskatchewan may have chosen canola because of its lesser susceptibility to waterfowl damage.

Crop area was the most important determinant of the magnitude of damage, but it was important only to damage density through its interaction with yield. Both area seeded and yield affect the mass of crop, and, therefore, have a combined influence on potential food availability for waterfowl. In contrast, Clark et al. (1993) reported that crop damage was unrelated to crop area or yield at a provincial scale.

Unlike Clark et al. (1993) and MacLennan (1973), we found that abundance of waterfowl was important in explaining waterfowl damage. Abundance of waterfowl made a significant contribution to four of our 9 significant multivariate models, and the interaction of waterfowl abundance with harvest chronology, cumulative precipitation, and distance to feed station were important to the density of claims. This difference may be explained by the use of spring breeding survey data as a surrogate for fall waterfowl abundance by Clark et al. (1993) and MacLennan (1973). Although most of the ducks that damage crops during fall breed on the Prairie Potholes, there is also a northward fall migration into Saskatchewan taken by ducks that produced offspring in North and South Dakota (Gilmer et al. 1977, Dieter and Anderson 2009). Thus, use of spring waterfowl survey data likely underestimates the actual use of fall crops by waterfowl in the Canadian prairies.

Distance to the nearest feeding station was important to the density and magnitude models. This result is best explained by site selection of feeding stations; waterfowl damage managers established the feeding stations in locations with high damage density along the shores of staging lakes in the study area. Distance to lure crop, however, was not a significant factor in either model. Burgess (1973) reported that feeding stations are: more cost effective; relatively easier to operate than lure crops; attract ducks continuously and consistently over time; and provide more control of duck movement.

Among the suite of harvest chronology factors, the end date of combining had a major influence on the magnitude of claims but had little effect on the density of claims. End date of combining captures the effects of delay in harvest due to late maturity and wet weather during the harvest period. Our results also indicate that cumulative precipitation during the harvest season is not a good surrogate for harvest chronology. Although fall precipitation is a contributing factor to a later harvest, precipitation during spring and temperature during the growing season also contribute to delay in harvest.

Management implications

Our models highlight areas vulnerable to chronic waterfowl damage and show where to focus mitigative efforts. Distance from staging lakes influences the density of damage claims, and the type of crop influences both the magnitude and density of damage. Crops palatable to waterfowl that are grown in close proximity to staging lakes are more vulnerable to waterfowl damage, and larger fields are more vulnerable than smaller fields. Planting less palatable crops, such as canola (Paynter and Stephen 1964) in proximity to staging lakes would reduce the risk of damage.

We showed that when harvest chronology is delayed, damage by waterfowl increases. Measures that could result in earlier harvests include straight combining (Sugden et al. 1988, Clark et al. 1993) and planting earlier maturing cereals, such as winter wheat.

Managing access of hunters to harvested fields can also reduce damage to swathed fields awaiting harvest. Waterfowl prefer gleaning grain from harvested fields, so, posting no-hunting signs around harvested fields to discourage hunters could result in a reduction of movement of waterfowl to swathed fields (M. Gollop, Saskatchewan Ministry of Environment, personal communication). For example, Sugden et al. (1988) recommended that sandhill cranes using harvested fields should not be disturbed by hunters while nearby fields are in swath. Given that waterfowl prefer to feed in areas that provide a good vantage point (Hochbaum et al. 1954), presumably to enhance predator detection, producers could consider leaving some narrow rows of standing grain in a swathed field to provide a visual barrier to feeding waterfowl and, thus, deter flocks from field feeding.

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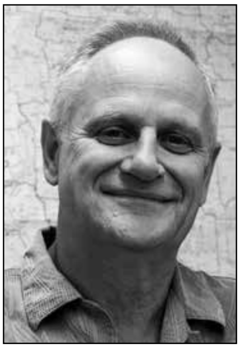

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