Factors influencing presence and detection of breeding shorebirds in the Prairie Pothole Region of North Dakota, South Dakota, and Montana, USA

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Conservation of breeding shorebirds in the Prairie Pothole Region of North America is hindered by lack of information concerning shorebird population size, population trends, and habitat use. Prior to conducting regional surveys in a major segment of the U.S. Prairie Pothole Region, we assessed survey procedures for American Avocet *Recurvirostra americana*, Willet *Tringa semipalmata*, Marbled Godwit *Limosa fedoa*, and Wilson's Phalarope *Phalaropus tricolor*. We used data collected during the 2002 breeding season and information-theoretic methods to assess relationships between shorebird detections and daily timing, seasonal timing, and survey type (roadside vs. off-road) at 1,649 wetlands. We also evaluated daily and seasonal patterns of shorebird detection at 2,100 roadside point counts in 2003. Marbled Godwit presence on wetlands was positively associated with roadside surveys, whereas the number of Wilson's Phalaropes detected was negatively associated with roadside surveys. All species except American Avocet exhibited changes in detection throughout the season for both wetland-based and point-count surveys. All species except Marbled Godwit exhibited changes in detection throughout day-long wetland-based surveys; detection of Wilson's Phalarope varied during morning hours when point counts were conducted. Our results provide guidelines for surveys that will help increase detection of target species, increase consistency and precision of surveys, reduce survey-related biases in detection, and provide baseline information to guide conservation and management of breeding shorebirds in the Prairie Pothole Region.

INTRODUCTION

Providing accurate information on population status and trends is essential to developing shorebird conservation strategies, but survey protocols for many shorebird species are either poorly developed or have not yet been implemented (Brown *et al*. 2000, Howe *et al*. 2000). A variety of survey techniques is currently used to monitor shorebirds in North America, including the North American Breeding Bird Survey and specialized regional surveys (Brown *et al*. 2007, Howe *et al*. 2000, Stanley & Skagen 2007). However, the validity of many of these techniques needs to be determined (Lanctot *et al*. 2008, Oring *et al*. 2000), especially how factors such as roads (Bystrak 1981), seasonal timing (Gratto-Trevor 2006, Redmond *et al*. 1981), and time of day (Robbins 1981) can influence detection of birds. Improved understanding of these factors, along with knowing what fraction of a population is detected on surveys, is critical to developing reliable population estimates for shorebirds (Alldredge *et al.* 2006, Farmer 2008, Lanctot *et al*. 2008, Rosenstock 2002).

The Prairie Pothole Region (PPR) of North America is an important breeding area for many species of shorebirds, including American Avocet *Recurvirostra americana*, Willet *Tringa semipalmata*, Marbled Godwit *Limosa fedoa*, and Wilson's Phalarope *Phalaropus tricolor*. Extensive waterfowl conservation programs in the PPR that conserve wetlands and grasslands offer considerable opportunity to extend conservation benefits to the shorebird species that breed in these habitats (Niemuth *et al*. 2008). To best accomplish this, expanded knowledge of the population status and habitat requirements of key species is needed.

In an effort to develop statistically rigorous surveys, we evaluated survey protocols for American Avocet, Willet, Marbled Godwit, and Wilson's Phalarope. All four species are associated with wetlands and grasslands and all are species of moderate to high conservation concern (Brown *et al*. 2000, Skagen & Thompson 2000). Estimating numbers of breeding pairs and population trends and understanding factors affecting population trends are priority research needs for American Avocet, Willet, and Marbled Godwit (Gratto-Trevor 2000, Lowther *et al*. 2001, Robinson *et al*. 1997). We sampled these four species in June 2001 during a pilot survey of 204 randomly selected wetlands in North Dakota and detected at least one individual of any of the four species on only 35 (17%) of the survey wetlands. Low numbers of shorebirds relative to survey effort suggested the need to consider alternative sampling methods and led to the subsequent evaluation of wetland-based surveys in 2002 and point count surveys in 2003.

We evaluated factors influencing detection of breeding shorebirds using data from wetland-based surveys conducted in 2002 and roadside point-count surveys conducted in 2003. Our primary goal was to evaluate how roadside sampling, daily timing, and seasonal timing influenced the number of breeding shorebirds observed so that future surveys could be designed to maximize detection of target species and increase

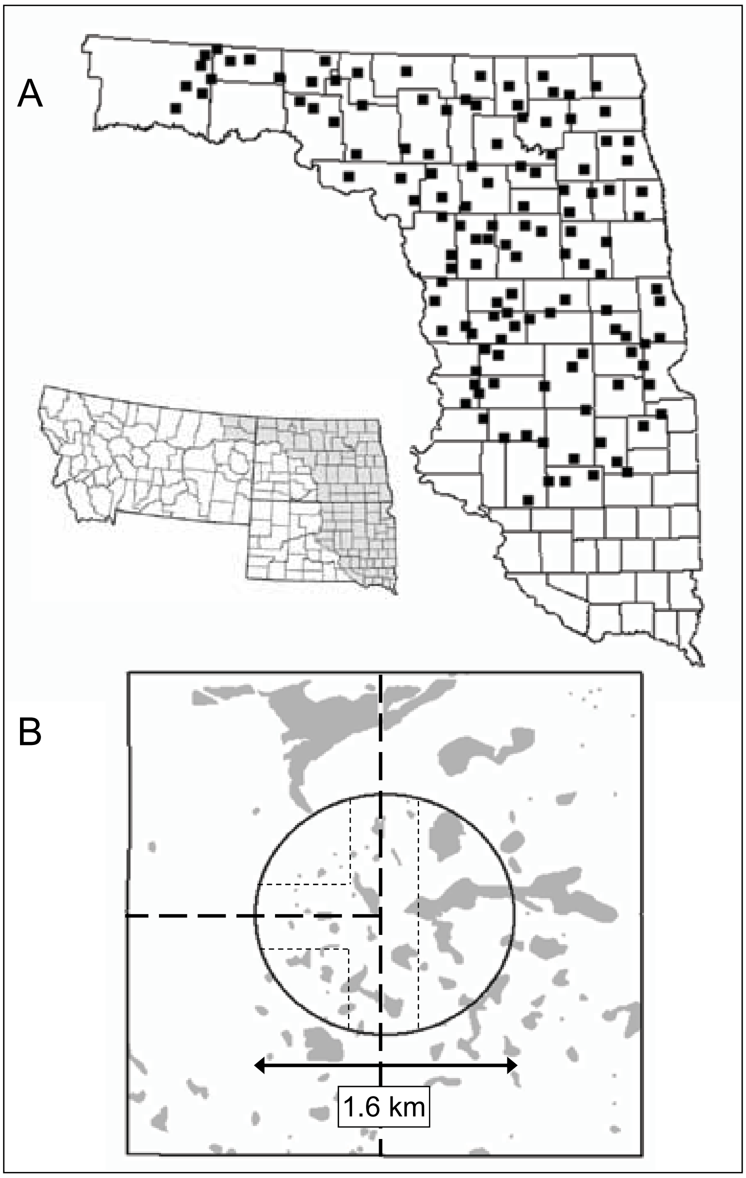

Fig. 1. (A) Location of 118 10-km^2 plots in eastern Montana, North Dakota, and South Dakota (inset) surveyed to assess the effects of habitat and survey characteristics on shorebird detection. **(B)** Wetlands (shaded) within10-km^2 survey plot. Wetlands inside the circle within 220 m (thin dashed lines) of roads (thick dashed line) were surveyed from the road; remaining wetlands within the circle were surveyed on foot.

consistency of survey results. Our secondary goal was to evaluate relationships between shorebird observations and the habitats we surveyed.

METHODS

Study area

The PPR is located in north-central North America where areas of high wetland density intersect with grasslands of the northern Great Plains. "Pothole" wetlands in the PPR were formed by glacial action and consist of wetland types ranging from wet meadows and shallow-water ponds to saline lakes, marshes, and fens (Cowardin *et al.* 1979, Kantrud *et al.* 1989). The mean size of these wetlands is 0.45 ha and their density exceeds 40/km^2 in some areas (Kantrud *et al.* 1989). Because of the small size, high number, annual variation in water levels, and dispersion of wetlands in the PPR, we focused on entire wetlands, rather than just shoreline or shallow-water zones within them. Our study area did not include potholes in Iowa and Minnesota, as the target shorebird species occur less frequently there (Sauer *et al.* 2008).

Wetland-based survey

In 2002, we surveyed wetlands in 118 10-km^2 survey plots (Fig. 1A). Our plots were part of a larger stratified random sample of plots developed for surveying waterfowl and wetlands (Cowardin *et al.* 1995). The sample unit was an individual wetland as mapped by the National Wetlands Inventory (NWI) and uplands within 50 m of the wetland margin. We combined wetlands with >1 wetland zone mapped by the NWI into individual depressional wetland basins following methodology of Cowardin *et al.* (1995).

We selected two samples of wetlands from a 1.6-km diameter circle at the center of each 10-km^2 plot (Fig. 1B). The first sample consisted of wetlands that we surveyed from the road. We included all wetlands within a 220 m radius of, and visible from, improved (gravel or paved) roads that bisected the circle at the center of the plot. We selected 220 m as it was consistent with some existing roadside surveys and would likely reduce undercounting of wetland birds that can occur with wider transects (Arnold 1994, Austin *et al.* 2000). The second sample consisted of the remaining wetlands within the circle, which were approached and surveyed on foot. Where >20 wetlands were available for off-road surveys within a sample plot, 20 wetlands were randomly selected. Wetlands were sampled from 15 May to 25 Jul 2002.

We conducted a complete, instantaneous count of adults of the target species on all wetlands. Wetlands in the roadside portion of the survey were sampled from the road only, using multiple stops as necessary on large wetlands. Wetlands in the off-road portion of the survey were sampled from a vantage point or by walking around their perimeter 25–50 m from shore. Surveyors marked the locations of birds on digital aerial photographs. If a sample wetland extended out of the 10-km^2 plot, it was sampled up to the edge of the plot. The proportion of the wetland that was sufficiently visible to detect shorebirds was estimated for all wetlands; this value was typically 1.0 for off-road surveys, but was less in cases where wetlands extended out of the plot or were inaccessible due to terrain or lack of landowner permission to access the wetland. Time spent surveying birds was recorded at each wetland so survey effort could be accounted for in analysis.

In addition to counting birds, surveyors assessed characteristics likely to affect shorebird use of wetlands, including amount of water present, amount and configuration of emergent vegetation, salinity, width of mudflats, proportion of the wetland surrounded by a vegetative buffer, and whether or not the wetland was an excavated ditch (Table 1; Colwell & Oring 1988, Conway *et al.* 2005, Gratto-Trevor 1999, 2006, Niemuth *et al.* 2006). Emergent vegetation in each wetland was characterized using classes adapted from Stewart & Kantrud (1971; Fig. 2). To ensure that data reflected current water conditions, which are highly variable in the PPR, surveyors estimated the proportion of each wetland covered by water using aerial photographs that included wetland outlines derived from NWI data. Water in each wetland was categorized as fresh, brackish, or saline based on indicator vegetation (Stewart & Kantrud 1971) and presence of salt crust; water was assigned to the fresh category if evidence of elevated salt levels was absent or ambiguous. Perimeter and area of each wetland were acquired from digital NWI data. Wetland-based surveys were conducted from the middle of May to the end of July.

We used linear models (Neter *et al*. 1989) and information-theoretic approaches (Burnham & Anderson 2002) to relate shorebird observations to landscape characteristics, wetland characteristics, and survey methodology. Habitat characteristics influence presence of breeding shorebirds (Gratto-Trevor 1999, Niemuth *et al*. 2008, Ryan & Renken 1987, Ryan *et al*. 1984) and can differ between roadside and off-road sites (Niemuth *et al*. 2007). Therefore, we included wetland and landscape habitat characteristics in models to account for additional variation in shorebird presence and detection and help isolate roadside effects. The area surveyed for each wetland was calculated by multiplying the mapped area of the wetland by the proportion of the wetland estimated to be visible and the proportion of the mapped wetland estimated to be covered by water. We also included the area surveyed as a quadratic term, as we hypothesized that shorebirds might require a wetland of minimum size but be less likely to be

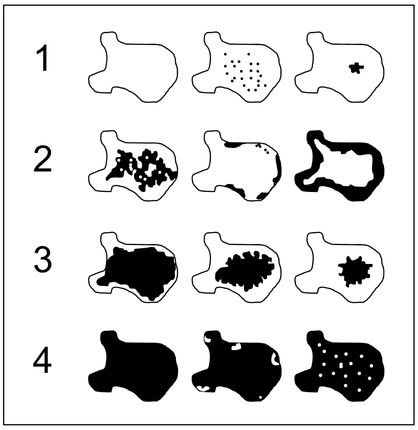

Fig. 2. Example cover type categories used to characterize wetland vegetation, adapted from Stewart & Kantrud (1971). White areas represent emergent vegetation; black areas represent open water or bare soil. Cover type 1 had closed stands of tall (>25 cm) emergent vegetation with open water or bare soil covering <5% of wetland area. Cover type 2 had open water or bare soil covering 5–95% of wetland area, with scattered patches or diffuse open stands of emergent vegetation >25 cm tall. Cover type 3 had central expanses of open water or bare soil covering 5–95% of wetland area, surrounded by peripheral bands of emergent vegetation averaging 1.8 m wide. Cover type 4 had open water or bare soil covering >95% of wetland area. This cover type also included small ponds with emergent vegetation restricted to margins <2 m wide.

Table 1. Predictor variables included in analysis of shorebird presence and number on wetlands in the Prairie Pothole Region of North Dakota, South Dakota, and Montana during the summer of 2002.

Class	Name	Description
Landscape	Easting	UTM coordinate indicating east–west position.
	Northing	UTM coordinate indicating north–south position.
	Grassland (%)	Percent of buffer within 800 m of survey point comprised of mix of native grass, forb, or scattered low shrub species on untilled prairie; typically grazed or hayed annually.
	Wetland (%)	Percent of buffer within 800 m of survey point comprised of temporary, seasonal, semipermanent, and permanent wetlands derived from NWI data.
	Wetland number (n)	Number of disjunct NWI wetlands within 800 m of survey point, regardless of wetland water regime.
	Wetland variety (n)	Number of different NWI water regimes for wetlands within 800-m buffer.
Wetland	Cover class	Categorical variables characterizing emergent vegetation in wetland (Fig. 2). Wetlands with cover class 3 were used as the reference category in analysis.
	Proportion full	Proportion of mapped wetland visually estimated to be covered by water on day of survey.
	Salinity	Categorical variables where wetlands were classified as fresh, brackish, or saline based on indicator vegetation (Stewart & Kantrud 1971) and presence of salt crust. Unknown cases were assigned to the fresh category. Freshwater wetlands were used as the reference category.
	Area surveyed (ha)	Mapped area of each wetland multiplied by the proportion of the wetland estimated as sufficiently visible to detect shorebirds and the proportion of the mapped wetland estimated to be covered by water. Also included in candidate models as a squared term (Area surveyed^2) to accommodate anticipated nonlinear response.
	Ditch	Categorical variable indicating if wetland was an excavated ditch. Non-ditch wetlands were used as the reference category.
	Vegetation buffer (%)	Estimated percentage of shoreline with an upland vegetation buffer ≥25 m wide, excluding woody vegetation >2 m tall.
	Mud flat (m)	Estimated width of widest area of unvegetated shoreline/mudflat present on wetland when surveyed.
Survey	Date	Julian date of survey. Also considered as a squared term (Date^2) to test for a quadratic function.
	Time	Time of day of survey, measured as minutes past sunrise. Also considered as a squared term (Time^2) to test for a quadratic function.
	Road	Categorical variable indicating if wetland was surveyed from road or by walking in. Off-road wetlands were used as the reference category.

found on large wetlands, which would be dominated by large expanses of deep water. Wetlands were included in analysis only if >25% of the mapped wetland was surveyed. Survey effort per wetland was calculated by dividing the number of minutes spent surveying each wetland by the mapped area of each wetland. Because wetland perimeter can be a better predictor of shorebird presence than wetland area (Niemuth *et al*. 2006), we first evaluated models using surveyed area and then perimeter of the wetland to determine which was a better predictor of shorebird presence. We used geographic information system software to determine the Universal Transverse Mercator (UTM) coordinate for each shorebird observation on the aerial photographs. We also recorded the UTM coordinate for a random point along the shoreline of each wetland. We used UTM coordinates as the center of sample windows for quantification of landscape characteristics for each bird observation and wetland. UTM coordinates were also included in models to help account for spatial autocorrelation and patterns of species distributions.

We calculated the number of wetlands, the number of different wetland water regimes, and the percentage of the landscape covered by grasslands or wetlands (Table 1) within 800 m of each random point or point where a shorebird was observed. We found little published information quantifying the scale(s) at which shorebirds perceive landscapes, so we chose an 800-m radius to summarize landscape data, as it was likely to identify a "larger wetland complex" (Skagen & Knopf 1994 p. 103) and was consistent with results of habitat selection analyses for migrant (Niemuth *et al*. 2006) and breeding (Niemuth *et al.* 2008) shorebirds in the PPR. Landscape characteristics were calculated from landcover derived from Thematic Mapper satellite images (30-m resolution) acquired from May 1992 to Sep 1996. Individual images were classified, upland landcover classes were resampled to 2.02-ha minimum mapping unit, and NWI data were integrated into the grid with a 0.09-ha minimum size of individual wetlands. User's accuracy for all images exceeded 80% (C.R. Loesch, USFWS, unpubl. data).

Because birds were detected on only a few wetlands and in low numbers, we first used logistic regression to evaluate the effects of landscape characteristics, wetland characteristics, and sampling methodology on presence of birds on survey wetlands (Table 1). We evaluated predictive models using the area under curve (AUC) of receiver operating characteristics plots. AUC values of 0.5 represent random performance, values of 0.5–0.7 are interpreted as low accuracy; values of 0.7–0.9 are considered useful, and values of 0.9–1.0 indicate high accuracy (Swets 1988). Shorebirds likely used sites where we did not observe them, so our determination of use and non-use contains error. On wetlands where shorebirds were observed, we used Poisson regression to relate landscape characteristics, wetland characteristics, and sampling methodology to the number of birds (Table 1). In both cases we assumed that birds select habitat in a hierarchical manner and developed models accordingly, first incorporating landscape-level habitat variables followed by wetland characteristics. Because of limited *a priori* knowledge of expected relationships, we only assessed main effects and did not consider interactions between variables. After habitat relationships were identified, we then added to models and assessed factors associated with sampling such as time of day and season (Gratto-Trevor 2001, 2006, Jones *et al.* 2008; Table 1). We used Akaike's Information Criterion corrected for small sample size (AICc) to select the model best fitting the data (Burnham & Anderson 2002).

After we identified models best explaining presence or number of shorebirds of each species as a function of landscape characteristics, wetland characteristics, and timing, we added a variable indicating if birds were sampled from the road or off the road (Table 1). We then calculated AIC weights (w_i; Burnham & Anderson 2002) to assess the weight of evidence for a roadside effect. Our aim was not to develop comprehensive models of shorebird habitat selection and test their predictive power, but to use the modeling process to evaluate survey methods. Highly correlated variables (Spearman's r > 0.6) were not evaluated simultaneously in models, but we evaluated alternative models using different combinations of correlated variables. Because little information exists regarding detection of breeding shorebirds and their response to habitat characteristics and sampling methods, we consider our analyses exploratory. We used Number Cruncher Statistical System 2007, version 7.1.20 (NCSS, Kayesville, Utah) for all statistical analyses.

Point-count survey

In 2003, we surveyed six roadside survey routes in south-central North Dakota, targeting areas with a range of wetland densities and a variety of land uses (Fig. 3A). Routes were not randomly selected, as the goal of the study was to assess factors associated with shorebird observations from roads over a range of habitat and sampling conditions, not to make inferences about populations. Each route had 50 survey stops for a total of 300. Stops were 0.8 km apart, except in 16 cases where stops were placed 1.6 (n = 14) or 2.4 (n = 2) km apart because of the presence of dwellings or lack of wetlands adjacent to the stop. We sampled the area within 400 m of each stop, which could include multiple wetlands as well as uplands, where Marbled Godwits and Willets also forage and nest (Fig. 3B).

Sampling procedures closely followed Breeding Bird Survey methods (Bystrak 1981): all target species heard at a stop or seen within 400 m were recorded during a 3-minute period, with surveys starting 0.5 hour before sunrise and continuing until the route was finished, but ending by 10h00. Each route was run once a week from 12 May to 27 Jun 2003, usually by the same observer. Surveys were conducted by two people following identical procedures.

Willets and Marbled Godwits, which are less associated with wetlands than American Avocets and Wilson's Phalaropes, were assigned to one of four general habitat/behavior classes describing where they were first observed: wetland, upland, flying, and unknown. Birds observed in wetlands, sheetwater, or wet meadows were assigned to the wetland category, and birds observed in uplands were assigned to the upland category. Birds first observed flying were assigned to the flying category, and unseen birds heard vocalizing were assigned to the unknown category.

We used repeated measures analysis of variance to test for changes in the number of shorebirds detected and the number of stops at which shorebirds were detected each week. We evaluated the association between time of day and shorebird detection by examining the relationship between the total number of birds detected at each stop number for all routes and weeks. We used linear regression to compare support for the following three models: 1) null model of no influence of daily timing during the 4.5-hour daily survey period; 2) number of birds detected was linearly related to stop number, which we used as a surrogate for time of day; and 3) number of birds detected was non-linearly related to stop number,

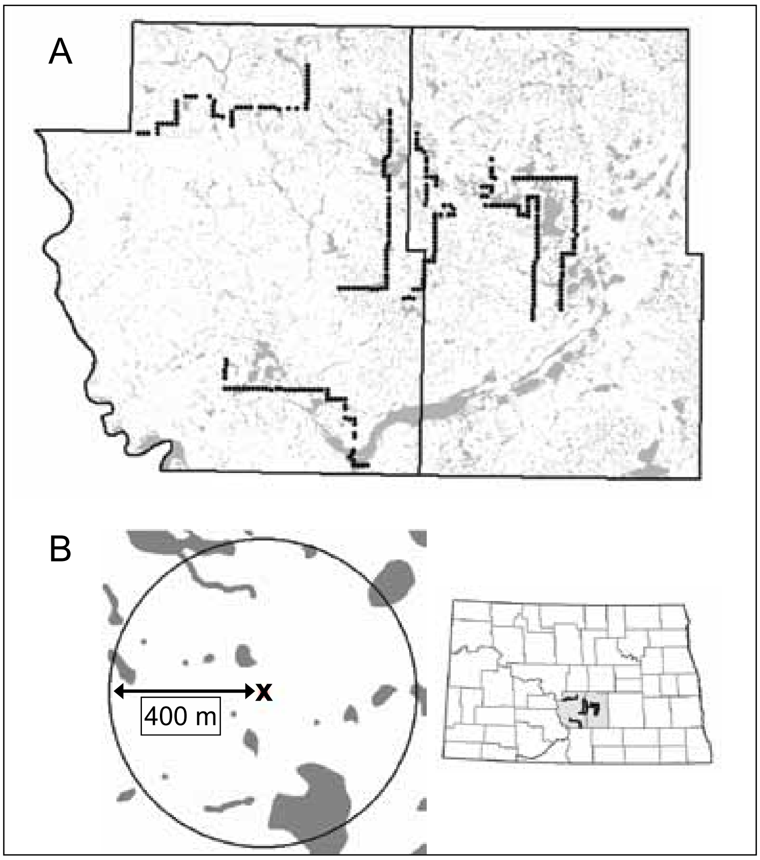

Fig. 3. (A) Location of stops (black dots) along six survey routes and wetlands (shaded) in Burleigh and Kidder counties, North Dakota, used in 2003 surveys of breeding shorebirds. **(B)** Wetlands (shaded) within in landscape surrounding shorebird survey stop (**X**).

which we assessed by adding a quadratic term to the model. Stop number ranged from 1–50, with stop 1 occurring one-half hour before sunrise and stop 50 occurring approximately 4 hours past sunrise. We used AICc to determine which of the three models best fitted the data, again using w_i to assess the weight of evidence for a time-of-day effect in point-count samples.

We evaluated changes in habitat and behavior through the study period by calculating the correlation between week number and the proportion of total birds and stops at which birds were seen in each of the four habitat/behavior classes. Changes in flock size throughout the survey period were evaluated by calculating the correlation between week number and the mean number of birds at a stop when at least one individual was present.

RESULTS

Wetland-based survey

Standing water was present in 782 of 1,649 wetlands surveyed; the remainder were dry or dominated by moist soil. The number of birds observed (number of wetlands on which they were detected) was American Avocets 95 (22); Willet 71 (45); Marbled Godwit 46 (29); and Wilson's Phalarope 393 (64). Survey time per hectare was greater for the 724 wetlands that were sampled off-road than for the 925 wetlands sampled from roadsides (mean = 21.9 vs. 14.9 minutes; $P < 0.001$). Wetlands were surveyed from 15 May to 25 Jul 2002 with a median date of 21 Jun. Observation times ranged from 07h13 to 17h43 with a median time of 11h59.

Models indicated that detection and number of birds were strongly influenced by habitat characteristics with additional influence of daily and seasonal timing of sampling and the area of wetland sampled (Tables 2 & 3). Presence of Marbled Godwits was positively associated with roadside surveys (Table 2) and number of Wilson's Phalaropes detected on wetlands was negatively associated with roadside surveys (Table 3). Number of Willets was positively associated with roadside surveys, although the weight of evidence was relatively low. Logistic regression models were good predictors of shorebird presence on wetlands, with AUC values ranging from 0.75 to 0.86 (Table 2). Pseudo-R^2 values for Poisson regression models predicting number of individuals ranged from 0.44 to 0.88 (Table 3)

Shorebirds were more likely to be observed at medium to large wetlands containing brackish or saline water, with little emergent vegetation, surrounded by a vegetative buffer. Area surveyed and perimeter for each wetland were highly correlated ($r = 0.89$); perimeter and area surveyed were stronger correlates of presence and bird numbers, respectively, for three of the four species (Tables 2 & 3). Landscape characteristics also influenced presence of all four species, with birds more likely to be observed in areas with more grassland, wetlands, and a variety of wetland water regimes (Table 2). The number of birds observed was generally influenced by wetland characteristics, although numbers of Willets and Wilson's Phalaropes were also positively related to the variety of wetland water regimes in the landscape (Table 3).

Point-count survey

The six survey routes were run weekly for seven weeks, beginning on 12 May and ending on 27 Jun 2003 for a total of 2,100 counts. The number of birds observed (number of counts on which they were detected) was American Avocet 269 (92); Willet 417 (309); Marbled Godwit 715 (379); and Wilson's Phalarope 1,019 (250).

The number of stops at which Willets were detected and the number of Willets detected varied among weeks ($P = 0.006$ and 0.004, respectively), with lowest detection in the middle of the survey period (Fig. 4). The number of stops at which Marbled Godwits were detected varied among weeks ($P = 0.007$), but the pattern of higher detection earlier and later in the survey period was not as pronounced as with Willets (Fig. 4). The number of Marbled Godwits detected did not vary among weeks ($P = 0.41$), although variance increased later in the season (Fig. 4). The number of stops at which American Avocets were detected and the number of American Avocets detected did not vary among weeks ($P = 0.80$ and 0.44, respectively). The number of stops at which Wilson's Phalaropes were detected and the number of Wilson's Phalaropes varied among weeks ($P = 0.04$ and 0.02, respectively). Number of stops at which Wilson's Phalaropes were detected was lowest at the beginning and end of the survey period (Fig. 4). Number of Wilson's Phalaropes detected followed a similar pattern, but with more variation, part of which might have been caused by high numbers of migrants observed during the second week of the survey period (Fig. 4).

Detection of Willets, Marbled Godwits, and American

Avocets did not change with stop number (Table 4), indicating that time of day did not influence detection. However, detection of Wilson's Phalaropes increased with stop number (Table 4), as Wilson's Phalaropes were less likely to be detected early in the daily survey period (Fig. 5).

Willets and Marbled Godwits were found in all four habitat/behavior classes, but the habitat in which birds were first observed changed over time. For example, the proportion of Willets observed in uplands (individuals and stops) decreased throughout the survey period, ranging from 15% and 17%, respectively, in Week 1 to 0% in Week 7 (Table 5). Patterns for Marbled Godwits were similar (Table 5), although a third or more of all Marbled Godwit detections (stops and individuals) were in uplands the first week, and declined thereafter.

Flock size increased throughout the survey period for Marbled Godwit ($r = 0.89$, $P = 0.007$) and decreased throughout the survey period for Wilson's Phalarope ($r = –0.82$, $P = 0.02$). Mean flock size increased throughout the survey period for American Avocet ($r = 0.50$, $P = 0.25$), although the trend was not statistically significant due to having just five degrees of freedom. Willet showed no trends in flock size through the survey period ($r = –0.14$, $P = 0.76$).

DISCUSSION

Our results identified several factors that can be controlled to reduce variation in detection during surveys of shorebirds breeding in the PPR. Both wetland-based and point-count surveys exhibited changes in detection during the breeding season for all species except American Avocet, indicating that surveys should take place during a fairly narrow window each year to avoid variation in detection that would occur during an extended survey period (see also Gratto-Trevor 1999, Jones *et al.* 2008, Redmond *et al.* 1981). Results from 2003 indicate that the number of stops on which Willets and Marbled Godwits were detected would be maximized if surveys take place in early May, whereas detection of Wilson's Phalaropes would be maximized in late May and early June.

Table 2. Parameter estimates for variables included in logistic regression models best describing detections of four shorebird species in 1,649 wetlands without considering roadside sampling in the U.S. Prairie Pothole Region; receiver operating characteristics area under curve value (AUC) for best model; parameter estimate for categorical variable indicating roadside sampling when added to best model; odds ratio indicating how much more likely or unlikely it was for a bird to be detected from the road compared to off the road; Akaike difference for best model (Δ_B) and best model with addition of a variable denoting roadside sampling (Δ_R); and Akaike weight for best model (w_B) and best model with addition of variable denoting roadside sampling (w_R).

Species	Best model	AUC	Road	Odds	Δ_B	Δ_R	w_B	w_R
American Avocet	–17.98 + (0.47 * Wetland variety) + (.013 * Proportion full) + (0.0007 * Perimeter) – (0.00000004 * Perimeter^2) – (8.9 * Cover class 1) + (1.3 * Cover Class 4) + (1.3 * Brackish water) + (4.2 * Salt water) + (0.06 * Time) – (0.00008 * Time^2)	0.76	0.007	1.007	0.0	2.1	0.74	0.26
Willet	–31.8 – (0.0000056 * Easting) + (0.011 * Grassland%) + (0.003 * Wetland%) + (0.012 * Proportion full) + (0.024 * Hectares surveyed) – (0.00003 * Hectares surveyed^2) + (0.01 * Vegetation buffer) – (10.9 * Cover class 1) – (1.3 * Cover class 2) + (0.2 * Cover class 4) + (0.01 * Mudflat) + (1.1 * Brackish water) – (10.0 * Ditch) + (0.33 * Date) – (0.001 * Date^2) + (0.03 * Time) – (0.00003 * (Time^2)	0.86	–0.16	0.85	0.0	1.8	0.71	0.29
Marbled Godwit	–1.6 + (0.04 * Grassland%) + (0.04 * Wetland%) + (0.01 * Proportion full) + (0.0002 * Perimeter) – (0.000000001 * Perimeter^2) + (0.02 * Vegetation buffer) + (1.8 * Cover class 4) + (0.03 * Mudflat) + (1.15 * Brackish water) – (0.03 * Date)	0.75	0.9	2.5	1.7	0.0	0.30	0.70
Wilson's Phalarope	–57.6 – (0.00001 * Easting) + (0.02 * Grassland) + (0.004 * Wetland%) + (0.009 * Proportion full) + (0.00003 * Perimeter) + (0.02 * Vegetation buffer) – (2.7 * Cover class 1) – (0.9 * Cover class 2) – (0.01 * Cover class 4) + (0.02 * Mudflat) + (0.9 * Brackish water) + (0.6 * Date) – (0.002 * Date^2) + (0.02 * Time) – (0.0003 * Time^2)	0.83	0.15	1.17	0.0	1.9	0.70	0.28

Table 3. Parameter estimates for variables included in Poisson regression models best describing number of individuals in wetlands containing ≥1 individual of the target species without considering roadside sampling in the U.S. Prairie Pothole Region; pseudo R^2 value for best model; parameter estimate for categorical variable indicating roadside sampling when added to best model; Akaike difference for best model (Δ_B) and best model with addition of indicator variable denoting roadside sampling (Δ_R); and Akaike weight for best model (w_B) and best model with addition of indicator variable denoting roadside sampling (w_R).

Species	Best model	R^2	Road	Δ_B	Δ_R	w_B	w_R
American Avocet	0.06 + (0.0088 * Hectares Surveyed) + (0.42 * Cover Class 4) + (0.35 * Brackish water) + (1.9 * Salt water)	0.88	–0.32	0.0	2.7	0.79	0.21
Willet	–2.95 + (0.48 * Wetland variety) + (0.01 * Date)	0.44	0.3	0.0	0.4	0.55	0.45
Marbled Godwit	0.24 + (0.0008 * Hectares Surveyed) + (1.7 Salt water)	0.67	–0.1	0.0	2.4	0.77	0.23
Wilson's Phalarope	27.3 + (0.000001 * North) – (0.37 * Wetland variety) + (.006 * Proportion full) + (0.00001 * Perimeter) – (2.1E9 * Perimeter2) – (1.1 * Cover class 1) – (0.3 * Cover class 4) + (0.4 * Brackish water) + (3.3 * Salt Water) – (0.3 * Date) + (0.0009 * Date^2) + (0.02 * Time) – (0.00002 * Time^2)	0.68	–0.6	19.8	0.0	0.01	0.99

More Avocets and Marbled Godwits were observed later in the year, but precision of counts was lower than earlier in the year, which is likely a result of detecting few, large flocks of non-breeding birds or failed breeders.

If more than one survey is conducted annually to ensure high detection of multiple species, we recommend recording all species observed during each of the sample periods. Repeated surveys will best accommodate all species and increase the likelihood of recording presence at a survey point, which is particularly important when assessing habitat use. The time periods we suggest are consistent with the window between observations of species arriving in spring and egg laying (Kantrud & Higgins 1992, Ryan *et al.* 1984) before detection declines during the incubation period (Results; Gratto-Trevor 2006). Visibility of adult Marbled Godwits and Willets increases after eggs hatch, providing another window of improved detection, but detection will likely vary among years depending on nesting success, water conditions, availability of brood habitat, vegetation height, and flocking behavior (Gratto-Trevor 2006, Ryan *et al.* 1984). Varying patterns of detection among species might also be related to behavior, as Wilson's Phalarope provides uniparental care and the other species provide biparental care.

The reduced number of stops at which American Avocets, Willets, and Marbled Godwits were observed later in the season indicates that birds were concentrating at fewer sites. Not only was variance higher, but shorebird locations at that time might not reflect nesting habitat preferences. The movement

Table 4. Akaike differences (Δ_{AIC}) and weights (w_i) for models assessing the relationship between time of day and number of stops at which shorebirds were detected for null model of no relationship (Null), model where number of stops at which birds were detected was linearly related to stop number (Stop, which ranged from 1–50 and which we use as an index to time of day), and model where number of stops at which birds were detected was related to stop number as a quadratic (Stop + Stop^2). Model with greatest weight for each species is highlighted in bold type.

Species	Model	Δ_{AIC}	W_i
American Avocet	**Null**	**0.0**	**0.48**
	Stop	0.7	0.34
	Stop + Stop^2	2.0	0.18
Willet	**Null**	**0.0**	**0.53**
	Stop	1.7	0.22
	Stop + Stop^2	1.5	0.25
Marbled Godwit	**Null**	**0.0**	**0.65**
	Stop	2.1	0.23
	Stop + Stop^2	3.3	0.12
Wilson's Phalarope	Null	5.6	0.04
	Stop	**0.0**	**0.73**
	Stop + Stop^2	2.3	0.23

Table 5. Correlation coefficients (P-value) for changes in proportions of detections of Willets and Marbled Godwits over the 7-week survey period.

		Upland	Wetland	Flying	Unknown
Willet	Stops	–0.75 (0.05)	0.57 (0.18)	0.50 (0.25)	–0.93 (0.003)
	Birds	–0.85 (0.01)	0.74 (0.06)	0.43 (0.34)	–0.65 (0.12)
Marbled Godwit	Stops	–0.57 (0.18)	0.64 (0.12)	0.79 (0.04)	–0.18 (0.70)
	Birds	–0.11 (0.82)	0.67 (0.10)	0.04 (0.94)	–0.75 (0.05)

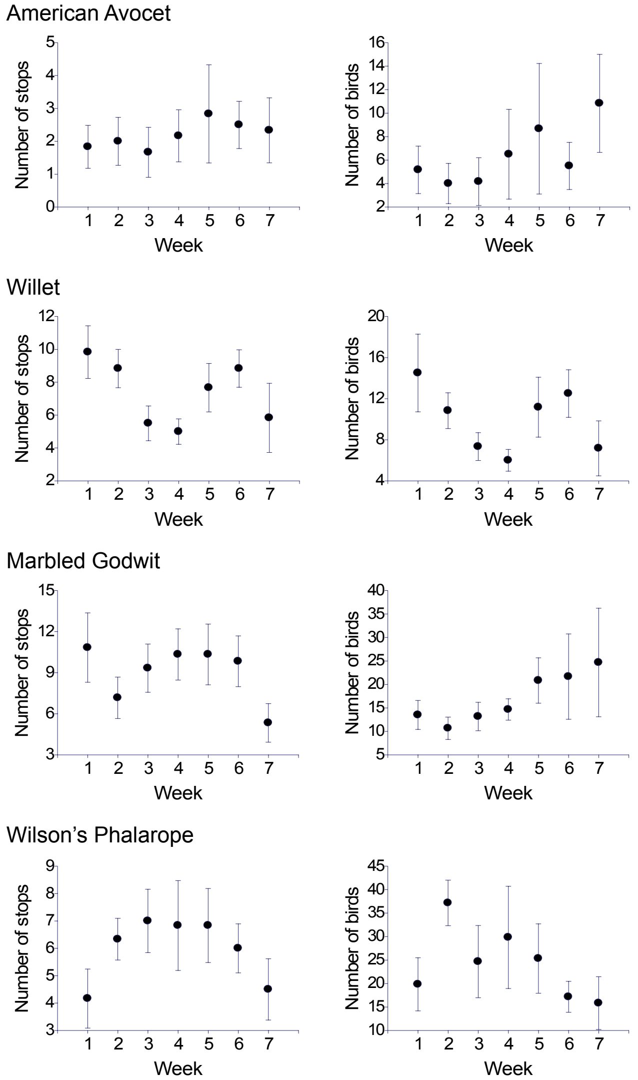

Fig. 4. Mean number (±SE) of stops on which birds were detected and mean number of birds detected for six 50-stop survey routes during seven-week sample period in central North Dakota.

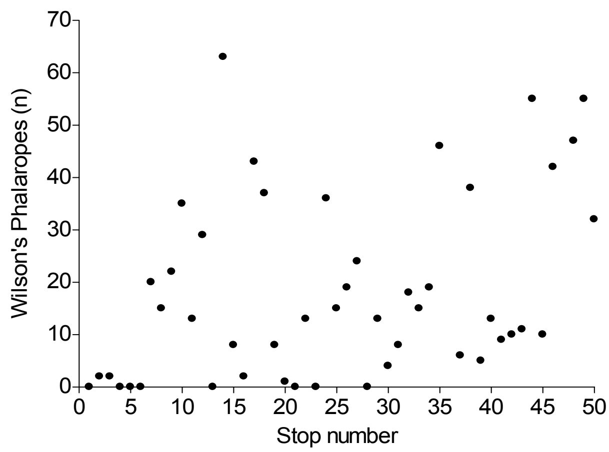

Fig. 5. Total number of Wilson's Phalaropes detected at each stop in relation to stop number, which we use as an index to time of day, during point counts conducted on six 50-stop survey routes during seven-week sample period in central North Dakota.

from uplands to wetlands and increased flock size that we observed as the season progressed may reflect failed breeding attempts and aggregation by failed, post- and/or non-breeders foraging in wetlands (see Robinson & Oring 1997). Both patterns suggest that early surveys will be better for detecting breeding birds on their breeding territories.

Shorebird surveys also should be conducted within consistent and narrow daily time frames. Wetland-based sampling indicated changes in detection throughout the day for all species when sampling occurred from early morning to early evening. Point-count data indicate that, except for Wilson's Phalarope, there was little variation in detection during the four-hour period in which point counts were conducted from 0.5 hour before sunrise to approximately 3.5 hours after sunrise. Inconsistent results between the two assessments may be a consequence of the shorter daily observation periods used on point counts in 2003 or possibly by daily patterns in wetland use that would be evident in the wetland-based survey but not on the point counts, which included both wetlands and uplands. Activities causing such patterns could include foraging in wetlands or nest building and territory maintenance on uplands. We recommend surveying in morning to avoid high winds that often develop later in the day, but not surveying before sunrise to avoid the period of reduced detection of Wilson's Phalarope that occurred during that time.

The wetland-based surveys suggest that detection of shorebird presence on wetlands did not differ between roadside and off-road surveys except for Marbled Godwit, which were more likely to be observed from roadside surveys. Increased detection of Marbled Godwit on roadside surveys is likely attributable to the birds' use of gravel roads that often split wetlands, have little traffic to disturb birds or vegetation to obscure visibility, and provide attractive loafing sites. The same factors likely contribute to increased numbers of Willets on roadside surveys, although the weight of evidence was not as strong. On the other hand, number of Wilson's Phalaropes detected on wetlands was lower on roadside surveys. This difference is likely caused in part by the small size and consequent difficulty of observing Wilson's Phalaropes relative to the other species, as well as the tendency of Wilson's Phalaropes to use wetlands and uplands with denser and taller vegetation (Results; see also Colwell & Oring 1990). Roadside bias in our study could take two forms: actual use might have differed between roadside and off-road surveys, or observations could have been lower at roadside sample points because birds were not as readily detected. Our study was not designed to distinguish between these two types, although it is likely that the Marbled Godwit and Wilson's Phalarope examples above illustrate these two forms of bias. The number of wetlands on which we detected birds was relatively small, and it could be argued that we had low power to detect roadside bias, most notably an avoidance of roads. However, if birds were actively avoiding roadsides, we likely would have detected at least an apparent avoidance of roads as time spent surveying was significantly greater off-road. In addition, the opportunity to flush birds was greater at off-road wetlands, which likely explains the increased numbers of Wilson's Phalaropes observed at off-road wetlands.

Roadside surveys will increase sample size and ease of sampling, and can serve as permanent transects that are not subject to vagaries of permission to gain access. Roadside sampling has some drawbacks, though, in that differential presence or detection of species such as Marbled Godwit and Wilson's Phalarope must be considered. Also, roadside bias might differ on roads more heavily traveled than the little-used secondary roads we sampled. We did not compare roadside and off-road point counts, but suspect that roadside bias will not be as strong in uplands as we documented in the wetland-based surveys where roads bisecting wetlands provide attractive loafing sites.

Point counts provide several advantages over wetland-based surveys. First, many birds, especially Willets and Marbled Godwits, are found in uplands, particularly early in the breeding season, and these species likely would be overlooked by wetland-based samples. Sampling uplands as well as wetlands is especially important as use of wetlands varies with water conditions (Ryan *et al.* 1984). Second, wetland-based surveys employ differing areas of sample units, which complicates detection (Results, above) and analyses of survey data (Johnson 2001). Finally, because point counts encompass grasslands as well as wetlands, changes in detection throughout the day caused by daily patterns in habitat use would be minimized. However, there may be cases where wetland-based surveys are preferable, such as the assessment of wetland-specific management or habitat characteristics. As with all data collection efforts, the question to be answered should drive survey development.

Our analysis modeled detection rates of shorebirds relative to timing and roadside sampling and did not consider the proportion of the population detected (Alldredge *et al.* 2006, Rosenstock 2002). Correcting for detection is appealing and theoretically sound, but is often difficult to implement in practice (Johnson 2008). Some studies of breeding shorebirds suggest that differences between apparent and adjusted detection are not large (Andres 2006, Jones *et al.* 2008, Stanley & Skagen 2007), but the proportion of the population detected should be assessed for the species, habitats, and areas we considered.

In addition to providing guidance for development of surveys for breeding shorebirds, our analyses provide information regarding habitat selection by American Avocets, Willets, Marbled Godwits, and Wilson's Phalaropes. This information can help guide conservation and management of these species at both the local and landscape scales in the PPR, and may be useful in assessing landscape-level effects of disturbances such as wind, oil, and gas development (Burton 2007). Correlations with landscape composition such as amount of grassland and wetland in the area provide guidance for siting projects, and correlations with local habitat features provide guidance for project design and management actions. For example, probability of use of wetlands by breeding shorebirds generally increased as the wetland perimeter and proportion of the wetland surrounded by a grass buffer increased, which can be considered in wetland creation and restoration projects. In addition to the attraction to grass in the landscape, shorebirds were more likely to be present when wetlands contained water (Gratto-Trevor 2006), when water was brackish or saline, and when multiple wetland water regimes were present, reinforcing the importance of conserving grassland and wetland complexes for shorebirds (Colwell & Oring 1990, Niemuth *et al.* 2006).

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