Shorebird Responses to Waterfowl-Focused Wetland Conservation in the Canadian Prairies

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Executive Summary

Shorebird populations in Canada have experienced long-term declines, including the threatened Lesser Yellowlegs which relies on wetlands in the Prairie Pothole Region during migration for stopover habitat. To understand how existing Prairie Habitat Joint Venture (PHJV) conservation efforts developed for waterfowl are supporting shorebirds, we evaluated:

1. Where shorebird habitat overlaps with PHJV Target Landscapes.
2. How shorebirds use Ducks Unlimited Canada (DUC) restored and conserved wetlands.

Species distribution models showed that 22 – 36 % of the Prairie Canada is suitable habitat for our focal shorebird species (Lesser Yellowlegs, Greater Yellowlegs, Marbled Godwit, Upland Sandpiper, Willet, Wilson's Phalarope). Further, approximately half of the suitable habitat for migrating Lesser Yellowlegs is within PHJV Target Landscapes, indicating alignment between waterfowl-based conservation priorities and shorebird habitat. Four PHJV Target Landscapes (Alexander Griswold, Big Hay/Bittern, Dana Hills, and Kenilworth) contained the highest proportion suitable habitat for Lesser Yellowlegs, offering opportunities for multi-species conservation benefits.

Simulated wetland restoration (converting 10 acres of cropland to wetland per field) increased habitat suitability for migrating Lesser Yellowlegs by an average 4 % across the PHJV Target Landscapes. Restoration benefits were greatest in Beaverhill, Calgary East, and Calgary West, suggesting these areas may yield higher returns for shorebird conservation investment.

Acoustic monitoring at 131 wetlands in the PHJV Target Landscapes detected use by Lesser Yellowlegs (47 wetlands), Greater Yellowlegs (37), Marbled Godwit (17), Upland Sandpiper (30), Willet (51), and Wilson's Phalarope (48) with similar occupancy at restored and conserved natural wetlands.

Overall, we show that:

- PHJV Target Landscapes contain much of the region's shorebird habitat.
- Small wetland restoration improves habitat suitability for migrating shorebirds.
- DUC wetland projects are used by shorebirds, including Lesser Yellowlegs.
- DUC conservation actions for waterfowl also deliver co-benefits for declining shorebird species.

These findings provide clear evidence that wetland conservation can advance both waterfowl and shorebird objectives, while highlighting priority landscapes where multi-species gains can be maximized.

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Background

Just over a third of migratory bird species in Canada, particularly shorebirds, have experienced sustained declines over recent decades. The *State of Canada's Birds 2024* reported an overall shorebird population decline of over 42 % since 1980, and more recent analyses of migration data indicate negative population trends for most shorebird species regularly occurring in Canada. Environment and Climate Change Canada (ECCC) is responsible for the long-term conservation of these populations.

Lesser Yellowlegs (*Tringa flavipes*) has experienced especially steep declines, with population estimates suggesting reductions of over 70 % since 1970, and the species is currently listed as *Threatened* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Lesser Yellowlegs breed across the Boreal Forest from Alaska through eastern Canada and migrate through the midcontinental flyways to non-breeding areas in interior South America. During migration, individuals rely on inland wetland habitats for stopover, including those found within the Prairie Pothole Region (PPR; McDuffie et al., 2022).

The PPR is an important focus area for waterfowl conservation investment by the Prairie Habitat Joint Venture (PHJV), with extensive habitat protection and restoration implemented to support duck populations within priority waterfowl landscapes. Using Target Landscapes helps direct conservation resources to areas most beneficial for breeding ducks. There is a need to better understand how migrating Lesser Yellowlegs and other shorebirds use habitats within priority waterfowl landscapes in the PPR, particularly in the context of existing wetland conservation investments. This project is intended to address these knowledge gaps by examining the overlap between shorebird habitat suitability and priority waterfowl areas, and to assess shorebird use of restored and conserved wetlands in priority waterfowl areas.

Our objective was to better understand how existing conservation actions focused on waterfowl in the PHJV benefit Lesser Yellowlegs and other shorebirds. Besides Lesser Yellowlegs, we considered five other shorebirds: migratory Greater Yellowlegs (*Tringa melanoleuca*) and breeding populations of Marbled Godwit (*Limosa fedoa*), Upland Sandpiper (*Bartramia longicauda*), Willet (*Tringa semipalmata*) and Wilson's Phalarope (*Phalaropus tricolor*). We used two different approaches to achieve our objective:

1) Using species distribution models, we estimated the amount of suitable habitat for Lesser Yellowlegs and other shorebirds in the Prairies Ecozone, and the amount of suitable habitat that overlaps the PHJV Target Landscapes where conservation investments are highest.
2) Using recordings from Autonomous Recording Units (ARUs) in conserved and restored wetlands within Target Landscapes, we estimated how Lesser Yellowlegs and other shorebirds use restored and natural wetlands, and what factors affect occupancy at wetlands.

We aim to provide guidance on how waterfowl habitat funding can be optimized to deliver important co-benefits for shorebirds.

Methods

Biodiversity Mapping and Assessment Tool (Species Distribution Models)

Our study area was the Prairies Ecozone (Prairie Canada, hereafter), comprising southern Alberta, Saskatchewan and Manitoba (Figure 1). We used species observations to fit species distribution models using publicly available data and data sharing agreements with organizations collecting those data. We downloaded observations from the Global Biodiversity Information Facility using the *rgbif* package (Chamberlain et al., 2024) and data from the North American Breeding Bird Survey (Ziolkowski Jr. et al., 2022). We also included regional datasets from NatureCounts, Alberta Biodiversity Monitoring Institute (public locations), and each province's Conservation Data Centre. All observations minimally required the species observed, spatial coordinates accurate to at least 805 m (resolution of prediction), date, and were observed between 2000 and 2025.

We retrieved observations for migrating Lesser Yellowlegs and Greater Yellowlegs and breeding populations of Marbled Godwit, Upland Sandpiper, Willet and Wilson's Phalarope. We filtered species observations by date for fall migration or breeding period based on eBird season estimates (Sullivan et al., 2009; Table 1; Figure S1).

We fit maximum-entropy (MaxEnt) species distribution models following methods in Paterson et al. (2024). For each species, we used 25 environmental variables within an 805 m x 805 m site that described habitat, soil, elevation and climate predictors (Paterson et al., 2024). Within a species range, we divided the area into 100 blocks and fit five species distribution models using k-fold cross-validation where 80 % of blocks were used for training and 20 % were used for testing (Valavi et al., 2018). We used the mean Area Under the Receiver-Operator Curve (AUC) of the five models on test data per species as an indication of model performance. AUC values vary from 0 (perfectly wrong) to 1.0 (perfect prediction), with 0.5 indicating that predictions are no better than random. We considered model performance adequate for species with a mean AUC value ≥ 0.7. The species distribution models visualize predicted habitat suitability, which ranges from 0 (not at all suitable) to 1 (perfectly suitable).

For each species, we converted the habitat suitability score of each site to a binary prediction (suitable/not suitable) using a threshold that maximized the sum of the specificity (true negative rate) and sensitivity (true positive rate; Florkowski, 2008; Paterson et al., 2024). We used the binary habitat suitability to determine the proportion of predicted suitable habitat in the Prairie Canada and the PHJV Target Landscapes.

We also compared the predicted habitat suitability in PHJV Target Landscapes (n = 1000 random points, area covers ~ 35 % of the Prairie Canada) to random points outside of Target Landscapes (n = 1000). We fit a generalized linear model (GLM; binomial family) comparing the predicted habitat suitability at each site (response) inside or outside Target Landscapes.

Change in habitat suitability after wetland restoration

We calculated the mean change in habitat suitability from wetland restoration to highlight areas where restoration would have the greatest benefit for migrating Lesser Yellowlegs. For each 16 mi^2 square within Prairie Canada, we randomly selected 20 quarter sections to simulate the conversion of 10 acres of annual cropland to wetland and its effect on habitat suitability. Our simulation was based on an average wetland restoration project (10 acres or 4.05 ha, split between multiple wetlands) on a quarter section within Prairie Canada. The resulting habitat suitability predictions were compared to baseline outputs from the original model results. We averaged the difference between the restoration scenario and baseline outputs across the 20 sampled quarter sections for each 16 mi^2 square to represent the average change in habitat suitability from wetland restoration. Change in habitat suitability ranges from -1 to 1, where + 0.05 indicates a predicted average increase of 5 % in habitat suitability.

Field recordings and occupancy in conserved and restored wetlands

We deployed autonomous recording units (ARUs; Song Meter Minis, Wildlife Acoustics) at 131 wetlands across the Aspen Parkland Ecoregion of the Prairies Ecozone in 2022 (59 wetlands) and 2023 (72 wetlands). All sampled sites were within PHJV Target Landscapes and within the typical size range of ditch-plug wetland restorations (restored samples: 0.61 ± 0.06 ha, range 0.06 – 3.16 ha, n = 91; natural samples: 0.55 ± 0.07 ha, range 0.05 – 1.89 ha, n = 40). All wetlands we sampled were Ducks Unlimited Canada habitat projects, were separated by a minimum of 5 km, and included a mix of DUC owned properties and private land with Conservation Easements protecting the wetlands. We programmed the ARUs to take daily recordings between deployment (median = 15 April, range 24 March – 29 April) and 31 July for a total of 22 minutes per day: 5 min at 00:00, 3 min at 02:00, 3 min at sunrise, 5 min at 1 h after sunrise, 3 min at 1 h before sunset and 3 min at 1 h after sunset. We attached the ARUs to steel posts within the open water portion of the southern edge of the wetland.

We processed recordings using the multi-species classifier BirdNET-Analyzer (Kahl et al., 2021) wherein various acoustic features (pitch, frequency, spectral characteristics) are input to a machine learning model to associate acoustic features and bird species vocalizations. We limited species detections to those with high confidence (> 0.75) and cases where a species was detected at a site on at least two unique days. To confirm a species was present at a site and reduce false positives, at least one recording of each species identified with BirdNET-Analyzer at a site was confirmed by manually listening to recordings with the highest detection confidence alongside a spectrogram, using AviaNZ (Marsland et al., 2019) or Raven Lite (K. Lisa Yang Center for Conservation Bioacoustics, 2016).

Using verified detections of wetland birds, we fit a multi-species occupancy model with Just Another Gibbs Sampler (JAGS) and the *jagsUI* (Ken, 2024) package in R (R Core Team, 2025). Multi-species occupancy models are hierarchical models that estimate the latent state of occupancy for each species at each site, while accounting for imperfect detection, including between surveys (Devarajan et al., 2020). We estimated how occupancy probability varied with the effect of wetland type (ditch-plug restored wetlands and natural wetlands), age since restoration in years (only for restored wetlands), the proportion wetland within 1 km surrounding the sampling point, the proportion grassland within 1 km surrounding the sampling point, the first principal component of the WorldClim (Fick and Hijmans, 2017) bioclimatic variables (climate PC1), and a quadratic effect of climate PC1. For each variable affecting occupancy, including the intercept, we assumed coefficients were normally distributed among species.

We estimated how detection probability varied through time with a quadratic effect of week. We assumed intercepts, the effect of week, and the quadratic effect of week coefficients were normally distributed among species.

We ran chains for 21,000 iterations with 1000 burn-in iterations, and a thin-rate of 10 (n = 6,000 posterior samples). For all coefficients, we tested for convergence using the Gelman-Rubin Diagnostic ($\hat{R}$) using values > 1.10 indicative of insufficient mixing.

We used the species' coefficient estimates to test how shorebird occupancy was affected by wetland type (restored or natural), wetland size, of the proportion wetland within 1 km, and of the proportion grassland within 1 km.

Results

Biodiversity Mapping and Assessment Tool Analyses

Overall, our species distribution models performed well using AUC as a benchmark (mean ± SE; 0.76 ± 0.02 for the 6 focal species; Table 1). The proportion of open water within the 805 m site, the proportion of settlement within the site, and the maximum patch size of open water had the largest (positive) effects on habitat suitability for migrating Lesser Yellowlegs and Greater Yellowlegs (Figure 2; Table S1; Figure S2).

The species distribution models for migrating Lesser Yellowlegs predicted 26.81 % of Prairie Canada was suitable habitat (Figure 3A). Similarly, 21.9 % of Prairie Canada was predicted suitable habitat for migrating Greater Yellowlegs (Figure 3B). The percentage of predicted suitable habitat for breeding shorebirds ranged from 22.8 – 35.5% (Figure 4). Within Prairie Canada, 51.6 % and 48.2 % of suitable habitat for migrating Lesser Yellowlegs and Greater Yellowlegs, respectively, was predicted to be within the PHJV Target Landscapes (Figure 3). For the breeding shorebirds, 31.7 – 48.8 % of suitable habitat was within PHJV Target Landscapes (Figure 4). Sites in Target Landscapes had higher predicted habitat suitability for migrating Lesser Yellowlegs (0.38 ± 0.01) than those outside (0.25 ± 0.01; $\chi^2 = 39.03$, df = 1, $P < 0.001$; Figure 5).

The PHJV Target Landscapes that had the highest proportions of suitable habitat for migrating Lesser Yellowlegs and Greater Yellowlegs were Alexander Griswold (MB), Big Hay/Bittern (AB), Dana Hills (SK) and Kenilworth (AB; Table 2). These Target Landscapes had 80 – 84 % suitable habitat for Lesser Yellowlegs and 64 – 79 % suitable habitat for

Greater Yellowlegs. There were two PHJV Target Landscapes that had the highest proportion suitable habitat for all breeding shorebirds investigated: Eastern Irrigation District (86 – 100 % suitable habitat) and Jenner Plains (81 – 94 % suitable habitat; Table 2), both in Alberta.

When simulating changes from wetland restoration (10 acres of annual cropland to wetland), we found that the mean change in habitat suitability across all Target Landscapes was 0.04 ± 0.0002. In other words, a 10-acre wetland restoration project would increase habitat suitability for migrating Lesser Yellowlegs by 4 % per quarter section in PHJV Target Landscapes (Figure 6). The Target Landscapes with the highest potential to increase migrating Lesser Yellowlegs habitat suitability were Beaverhill (0.058 ± 0.002), Calgary West (0.056 ± 0.002), and Calgary East (0.054 ± 0.002; Table 3), which are all in Alberta.

Field recordings and occupancy in conserved and restored wetlands

Based on 309,166 minutes of recording at 131 sampled wetlands within the PHJV Target Landscapes, we detected Lesser Yellowlegs at 47 (36 %), Greater Yellowlegs at 37 (28 %), Marbled Godwit at 17 (13 %), Upland Sandpiper at 30 (23 %), Willet at 51 (39 %), and Wilson's Phalarope at 48 (37 %) wetlands (Figure 7, Figure 8).

Our focal shorebird species were detected throughout the recording period from April 1 to July 31, but there were large differences between species (Figure 9). Lesser Yellowlegs were more frequently detected later in the year during fall migration, whereas Greater Yellowlegs were just as likely to be detected using wetlands in spring migration as fall migration. We detected the species that breed in Prairie Canada vocalizing more in May and June.

Shorebird occupancy was similar in restored and natural wetlands, but mean predictions were higher in restored wetlands for all focal species (Figure 10). Lesser Yellowlegs occupancy was 10 % higher (95 % CI on difference: -3 to 23 %) in restored wetlands (45 %) than in natural wetlands (35 %).

Lesser Yellowlegs occupancy increased with the proportion wetland within 1 km and increased weakly with the proportion grassland within 1 km (Figure 11). Occupancy of Lesser Yellowlegs increased with wetland size from 41 % in wetlands that were 0.05 ha to 62 % in wetlands that were 3.16 ha (our largest sampled site). Considering just restored wetlands, occupancy of Lesser Yellowlegs did not change with restoration age between 1 and 18 years post-restoration.

Discussion

We present strong evidence that conservation actions and focal areas designed to benefit waterfowl are benefitting Lesser Yellowlegs and other shorebird species in Prairie Canada.

Species distribution models predict that large proportions of Prairie Canada provide suitable habitat for both migrating and breeding shorebirds, including Lesser Yellowlegs. Over half of the area within PHJV Target Landscapes is predicted to offer suitable stopover habitat for Lesser Yellowlegs during fall migration, suggesting that existing waterfowl conservation investments overlap with shorebird needs. This is unsurprising, given that wetland density is positively associated with waterfowl pair density, which drives where Target Landscapes are located. The influence of open water on habitat suitability and the effects of wetland proportion and wetland size in the occupancy models highlights the importance of maintaining and restoring wetlands in Prairie Canada for migrating shorebirds, such as Lesser Yellowlegs. Our field recordings confirmed that migrating Lesser Yellowlegs regularly use wetlands in PHJV Target Landscapes, particularly during their southward migration. These same wetlands are also used by other migrating and breeding shorebirds.

High overlap between predicted suitable habitat for shorebirds and PHJV Target Landscapes suggests that existing waterfowl conservation investments also provide benefits for both migrating and breeding shorebirds. Several Target Landscapes, like Alexander Griswold, Big Hay/Bittern, Dana Hills, and Kenilworth, contain high proportions of predicted suitable habitat (> 0.75) for migrating Lesser Yellowlegs. In contrast, different PHJV Target Landscapes support large proportions of predicted suitable habitat for the breeding shorebird species included in our analyses. This variation in predicted suitable habitat across landscapes and between species indicates that shorebird conservation gains delivered by waterfowl-focused Target Landscapes are not uniform across Prairie Canada. As a result, these patterns provide an opportunity to strategically identify regions where conservation and restoration efforts could provide the greatest benefits for different shorebirds. For example, the Eastern Irrigation District and the Jenner Plains had low habitat suitability for Lesser Yellowlegs, but very high habitat suitability for breeding Marbled Godwit, Willet, and Wilson's Phalarope.

Within Target Landscapes, Lesser Yellowlegs had similar occupancy in restored and natural wetlands, suggesting that restoration practices by DUC are providing habitat used by shorebirds. Through both targeting and opportunity, DUC focuses on conserving and restoring small wetland basins on the landscape. The vast majority (91 %) of wetlands sampled over 5,198 quarter-sections in the PHJV delivery area are smaller than 1 ha in size, while the mean and median sizes are 0.5 ha and 0.1 ha, respectively (Watmough et al., 2017). Further, small wetlands (≤ 0.1 ha) are most valuable for breeding ducks, as they have been shown to host disproportionately more pairs per area than larger wetlands (≥ 0.5 ha; Bartzen et al., 2017). We detected Lesser Yellowlegs, and other shorebirds, using wetlands as small as 0.05 ha but occupancy increased with wetland size. However, occupancy was high (41%) even at the smallest wetlands we studied. Continued investment in small wetland basins will therefore sustain habitat that is essential not only for breeding ducks but also used by migrating shorebirds, such as Lesser Yellowlegs.

Future Research

Future research could expand on this work by integrating DUC's waterfowl pair predictions at the species level with our species distribution models for Lesser Yellowlegs. Species-specific waterfowl pair abundance estimates could be compared to predicted habitat suitability for Lesser Yellowlegs to evaluate areas of overlap in habitat use. Such analyses could help identify opportunities for multi-species conservation planning, refine habitat prioritization, and assess potential trade-offs or synergies across focal species. Species distribution models are available for the PHJV priority waterfowl species - the seven most abundant duck species in Prairie Canada (Mallard, Gadwall, Blue-winged Teal, Northern Shoveler, Northern Pintail, Canvasback, and Redhead). These waterfowl species have different habitat preferences and distributions that likely affect the amount of overlap between duck and shorebird habitat suitability.

Conclusion

We present strong evidence that current conservation programs in PHJV Target Landscapes designed to benefit waterfowl provide suitable habitat for Lesser Yellowlegs and other shorebirds, and we confirmed shorebirds use both conserved and restored wetlands through field observations. Our findings show that restoring small wetland basins provides dual benefits by supporting breeding ducks while also offering stopover habitat for migrating Lesser Yellowlegs and other shorebirds, underscoring the ecological value of these small basins across taxa. Further, shorebirds' reliance on open-water availability highlights the importance of wetland conservation (i.e., preventing drainage) to support declining populations. Together, these results demonstrate that existing waterfowl conservation investments already contribute to shorebird habitat needs, and that targeted increases in conservation and restoration in key landscapes can amplify multi-species conservation outcomes.

Recommendations

To maximise the benefits of waterfowl conservation in Prairie Canada for shorebirds, including Lesser Yellowlegs, we recommend:

- Conserving wetland habitats in the priority waterfowl areas with the most suitable habitat for Lesser Yellowlegs (Alexander Griswold, Big Hay/Bittern, Dana Hills, and

Kenilworth Target Landscapes; Greater Yellowlegs also have large proportions of suitable habitat in those areas).

- Restoring wetlands within waterfowl Target Landscapes that are predicted to yield the greatest improvements in Lesser Yellowlegs habitat suitability, particularly in the Beaverhill, Calgary East, and Calgary West Target Landscapes.
- Continuing to restore small wetlands (0.1 – 3.1 ha) within all PHJV Target Landscapes, given that shorebirds had similar occupancy in small restored and natural wetlands and we detected all focal species using ARUs.
- Conserving wetland and grassland habitats in the priority waterfowl areas with the most suitable habitat for breeding shorebirds (Eastern Irrigation, Milk River Ridge, and Jenner Plains Target Landscapes for Marbled Godwit, Willet, and Wilson's Phalarope; Alexander Griswold, Killarney, and Coteau South for Upland Sandpiper).
- Prioritize conservation opportunities with more wetland cover (including open water) and those that include larger wetlands, since shorebird species distribution models and occupancy models showed positive associations with the proportion of wetlands in the surrounding landscape and wetland size.

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Tables

Table 1. The observation period and number of observations used for shorebird species distribution models, and the resulting Area Under the Receiver-Operator Curve (AUC) from each species.

Species	Period	Observations dates	Number of observations	AUC
Greater Yellowlegs	Migration	After June 21	5242	0.83
Lesser Yellowlegs	Migration	After June 14	4888	0.81
Marbled Godwit	Breeding	May 31 – June 14	2849	0.73
Upland Sandpiper	Breeding	May 24 – June 28	5522	0.72
Willet	Breeding	June 7 – June 14	2186	0.73
Wilson's Phalarope	Breeding	June 7 – July 5	4322	0.75

Table 2. Proportion of suitable habitat and area (acres) of suitable habitat for six shorebird species in each Prairie Habitat Joint Venture Target Landscape that has at least 80 % of its area in Prairie Canada. Bold values are the target areas with top 3 highest proportions of suitable habitat for each species.

	Lesser Yellowlegs		Greater Yellowlegs		Marbled Godwit		Upland Sandpiper		Willet		Wilson's Phalarope	
Target Landscape	Prop.	Area (acres)	Prop.	Area (acres)	Prop.	Area (acres)	Prop.	Area (acres)	Prop.	Area (acres)	Prop.	Area (acres)
Alexander Griswold	**0.84**	32270.7	**0.76**	29366.3	0.15	5808.7	**0.95**	36788.6	0.69	26462	0.71	27268.7
Kenilworth	**0.80**	371132.6	**0.79**	364891.1	0.01	4641.2	0	0	0.17	79699.9	0.35	162120.5
Big Hay/Bittern	**0.76**	497409.3	0.64	421278.5	0	959.6	0	0	0	2079.2	0.27	179931.0
Dana Hills*	**0.76**	1254928	**0.74**	1224673	0.12	194791.8	0.18	294397.4	0.72	1190848	0.54	894580.5
Calgary East	0.73	213362.2	0.60	175907.7	0.23	66905.8	0.07	20007.7	0.47	137332.9	0.8	234970.5
Derwent*	0.73	132868.1	0.73	133966.1	0	183.0	0	0	0.02	3477.3	0.18	32942.5
Buffalo Lake	0.71	450650.1	0.63	403887.5	0.01	4644.2	0	0	0.01	6245.7	0.35	224524.3
Beaverhill*	0.61	357590.9	0.51	297992.4	0.02	12019.9	0	0	0.07	40066.2	0.26	155089.6
Hillmond	0.60	230702.8	0.59	227811.0	0.01	4177.1	0	0	0.14	54783.9	0.28	107318.6
Calgary West	0.55	346627.4	0.45	279347.5	0.18	112825.7	0.02	11346.5	0.34	212547	0.68	424135.1
Killarney	0.55	258697.6	0.38	179504.4	0.12	58714.9	**0.92**	434042.3	0.47	223020.7	0.62	291014.8
Quill South	0.50	827381.4	0.39	640470.5	0.24	391309.5	0.59	963754.1	0.74	1222060.0	0.49	797218.9
Killarney	0.48	77782.4	0.48	78266.6	0.01	1775.1	0.44	70682.0	0.17	27756.4	0.31	50510.2
Sullivan Lake	0.48	665118.3	0.40	547255.3	0.13	175595.1	0.14	195265.6	0.44	604187.8	0.56	767149.0
Touchwood/Beaver	0.47	982446.0	0.37	758980.8	0.02	44693.0	0.01	15218.1	0.32	671677.2	0.22	455260.3
Thickwood*	0.46	384354.9	0.47	390014.7	0.05	39104.4	0.01	5831.4	0.32	263268.5	0.19	156589.0
Minnedosa Shoal*	0.44	508066.8	0.40	462846.2	0.06	69540.9	0.12	137181.8	0.30	340294.5	0.23	267143.6
Vermillion Viking*	0.43	517007.9	0.35	426724.0	0	1282.9	0	0	0.01	16517.3	0.13	160843.3
Bellshill	0.42	307433.4	0.28	206449.3	0.01	4641.1	0	0	0.03	23525.6	0.15	109786.2
Pheasant Hills	0.41	283099.2	0.32	216251.9	0.01	3526.7	0.12	84641.2	0.37	253923.6	0.26	174251.9
Regina East	0.41	358241.0	0.24	211106.3	0.07	56614.9	0.58	499938.2	0.45	388627.6	0.43	369436.1
Coteau Central	0.40	822981.2	0.20	411650.6	0.30	615316.0	0.72	1491733.0	0.74	1525651	0.67	1391581.0
Wintering Hills	0.40	353631.5	0.30	263063.5	0.61	534127.6	0.61	538448.0	0.70	618135.1	0.73	644377.4
Allan Hills	0.39	399974.4	0.26	271451.2	0.12	117959.6	0.44	451511.7	0.72	742809.5	0.47	476800.2
Tramping Lake East	0.38	509859.0	0.25	328646.9	0.30	404845.7	0.44	583976.6	0.69	917906.3	0.38	512580.4

Bellshill	0.35	82509.9	0.29	68146.5	0.05	10852.4	0	159.6	0.18	42451.9	0.23	53144.7
Cactus Lake	0.35	455984.8	0.25	318805.6	0.23	292904.7	0.40	515780.8	0.62	799572.2	0.40	515780.8
Upper Assiniboine*	0.34	520695.6	0.32	497289.7	0.06	84973.4	0.02	33073.5	0.21	324120.3	0.19	291894.8
Pine Lake	0.31	120697.8	0.28	107411.5	0	960.5	0	160.1	0	1440.7	0.16	60829.2
Coteau South	0.29	525242.3	0.12	223135.9	0.22	398537.0	**0.93**	1666071.0	0.63	1133300.0	0.66	1181515.0
Virden Sask	0.28	122677.5	0.19	86097.9	0	0	0.10	42809.3	0.16	72360.5	0.16	69645.0
Virden	0.27	182521.9	0.16	107875.8	0.19	132597.3	0.79	540984.1	0.44	303400.6	0.38	260699.8
Lightning	0.26	811469.0	0.14	437745.1	0.12	366841.6	0.83	2569812.0	0.47	1454722	0.36	1118931.0
Clear Lake	0.24	40070.7	0.20	32407.7	0.26	42465.3	0.02	3352.5	0.28	46137.1	0.75	122447.0
Coteau North	0.24	102606.4	0.11	46814.2	0.08	33667.7	0.29	127456.3	0.70	303811.0	0.45	194310.8
Eastern Plains	0.24	622412.2	0.15	392470.4	0.47	1210237.0	0.67	1732090.0	0.71	1846741.0	0.64	1662755.0
Eastern Irrigation District (EID)	0.20	93016.1	0.15	69601.7	**1.00**	470373.0	0.86	405261.7	**0.94**	443751.1	**0.86**	402695.7
Lenore/Ponass*	0.17	207011.2	0.14	173024.3	0.05	61249.2	0.01	11995.4	0.14	174478.3	0.06	77970.0
Arrowwood	0.15	84228.2	0.12	63770.5	0.54	292161.5	0.20	106444	0.60	328761.6	0.62	339629.8
Cypress	0.12	10684.3	0.16	14352.1	0.19	16744.1	0.77	69687.3	**0.90**	80850.1	**0.92**	82604.2
Pakowki	0.12	89379.7	0.07	55002.9	0.58	435386.4	0.15	115282.3	0.45	333535.1	0.44	329697.7
Milk River Ridge	0.11	46299.3	0.10	41798.0	**0.76**	308179.7	0.36	147579.0	**0.87**	351585.3	**0.81**	327149.6
Jenner Plains	0.08	17501.1	0.05	10597.0	**0.94**	209691.9	0.86	190745.8	0.85	189300.7	**0.81**	180309.4
Boundary Plateau	0.07	59317.8	0.03	27254.1	0.31	253784.1	0.14	114467.4	0.45	374984.9	0.55	451296.5
Fox Valley	0.07	32995.3	0.02	9770.5	0.25	111959.8	0.53	233529.8	0.31	136946.5	0.34	149920.4

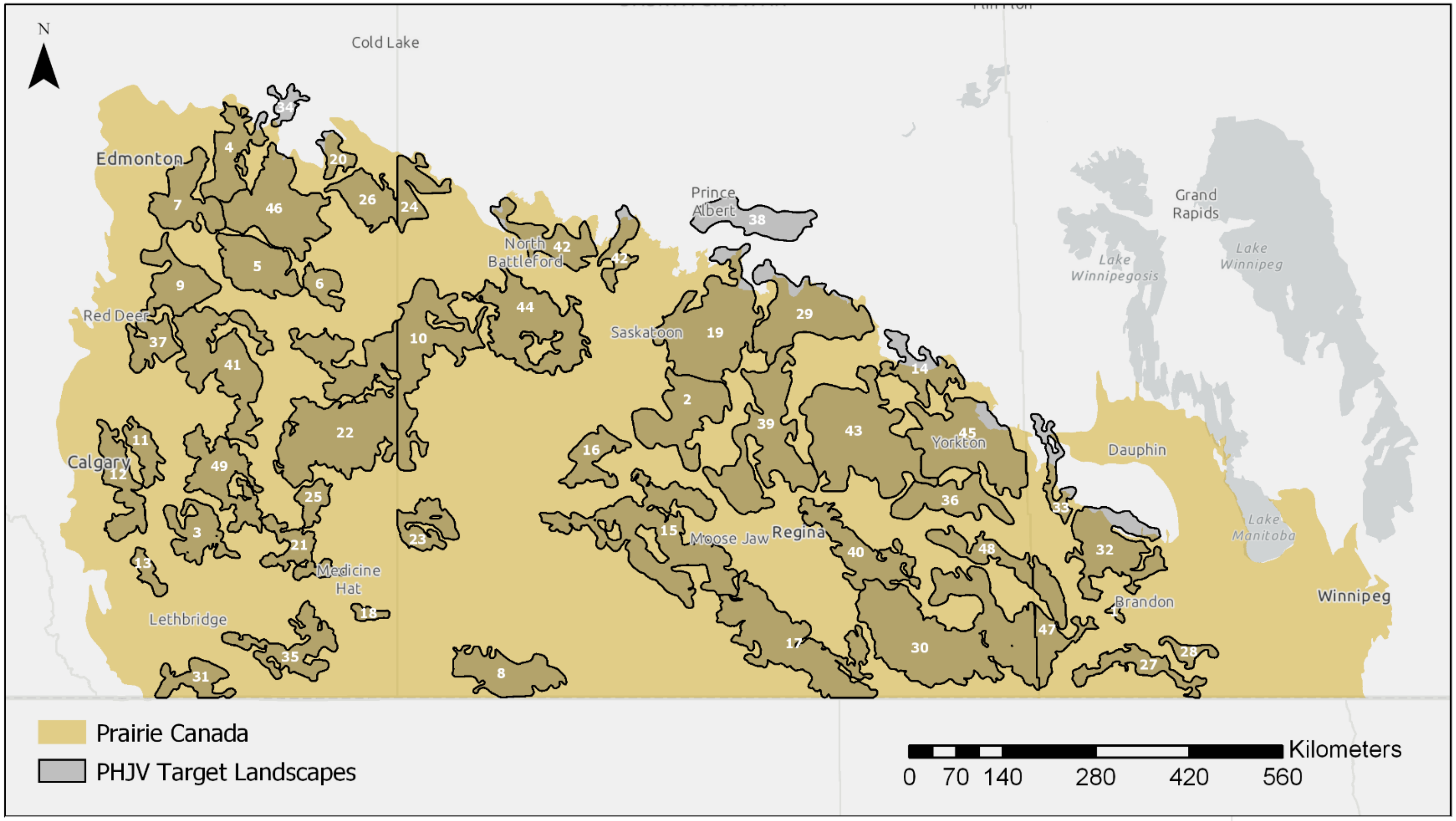
*Target Landscape is not fully inside Prairie Canada; therefore, the full region was not evaluated, and these predictions are minimum estimates.

Table 3. Mean change in suitable habitat for migrating Lesser Yellowlegs after the simulated wetland restoration (10 acres per quarter site) for each PHJV Target Landscape with least 80 % area in Prairie Canada.

Target Landscape	Mean change in habitat suitability	SE
Beaverhill	0.058	0.002
Calgary West	0.056	0.002
Calgary East	0.054	0.002
Big Hay/Bittern	0.053	0.001
Wintering Hills	0.052	0.001
Milk River Ridge	0.052	0.002
Jenner Plains	0.051	0.003
Killarney	0.051	0.001
Coteau Central	0.051	0.001
Coteau North	0.050	0.001
Fox Valley	0.050	0.001
Pine Lake	0.050	0.001
Cypress	0.049	0.002
Quill South	0.048	0.001
Clear Lake	0.047	0.002
Bellshill	0.047	0.001
Buffalo Lake	0.046	0.001
Allan Hills	0.046	0.001
Vermillion Viking	0.046	0.001
Arrowwood	0.046	0.001
Hillmond	0.046	0.001
Kenilworth	0.046	0.001
Regina East	0.046	0.001
Dana Hills	0.045	0.001
Tramping Lake East	0.045	0.001
Eastern Plains	0.045	0.001
Derwent	0.045	0.002
Cactus Lake	0.045	0.001
Thickwood	0.044	0.001
Sullivan Lake	0.044	0.001
Pakowki	0.043	0.001
Alexander Griswold	0.043	0.002
Boundary Plateau	0.042	0.001
Killarney	0.041	0.001
Touchwood/Beaver	0.040	0.001
Coteau South	0.040	0.001
Lenore/Ponass	0.040	0.001
Bellshill	0.039	0.002
Virden	0.038	0.001

Pheasant Hills	0.038	0.001
Lightning	0.037	0.000
Upper Assiniboine	0.037	0.001
Virden Sask	0.033	0.001
Minnedosa Shoal	0.033	0.001

Figures



1 Alexander Griswold	11 Calgary East	21 Eastern Irrigation District (EID)	31 Milk River Ridge	41 Sullivan Lake
2 Allan Hills	12 Calgary West	22 Eastern Plains	32 Minnedosa Shoal	42 Thickwood
3 Arrowwood	13 Clear Lake	23 Fox Valley	33 Minnedosa Shoal	43 Touchwood/Beaver
4 Beaverhill	14 Conjuring Creek	24 Hillmond	34 Owlseye	44 Tramping Lake East
5 Bellshill	15 Coteau Central	25 Jenner Plains	35 Pakowki	45 Upper Assiniboine
6 Bellshill	16 Coteau North	26 Kenilworth	36 Pheasant Hills	46 Vermillion Viking
7 Big Hay/Bittern	17 Coteau South	27 Killarney	37 Pine Lake	47 Virden
8 Boundary Plateau	18 Cypress	28 Killarney	38 Prince Albert	48 Virden Sask
9 Buffalo Lake	19 Dana Hills	29 Lenore/Ponass	39 Quill South	49 Wintering Hills
10 Cactus Lake	20 Derwent	30 Lightning	40 Regina East	

Figure 1. Map of study area showing Prairie Canada in yellow and the Prairie Habitat Joint Venture (PHJV) Target Landscapes in black.

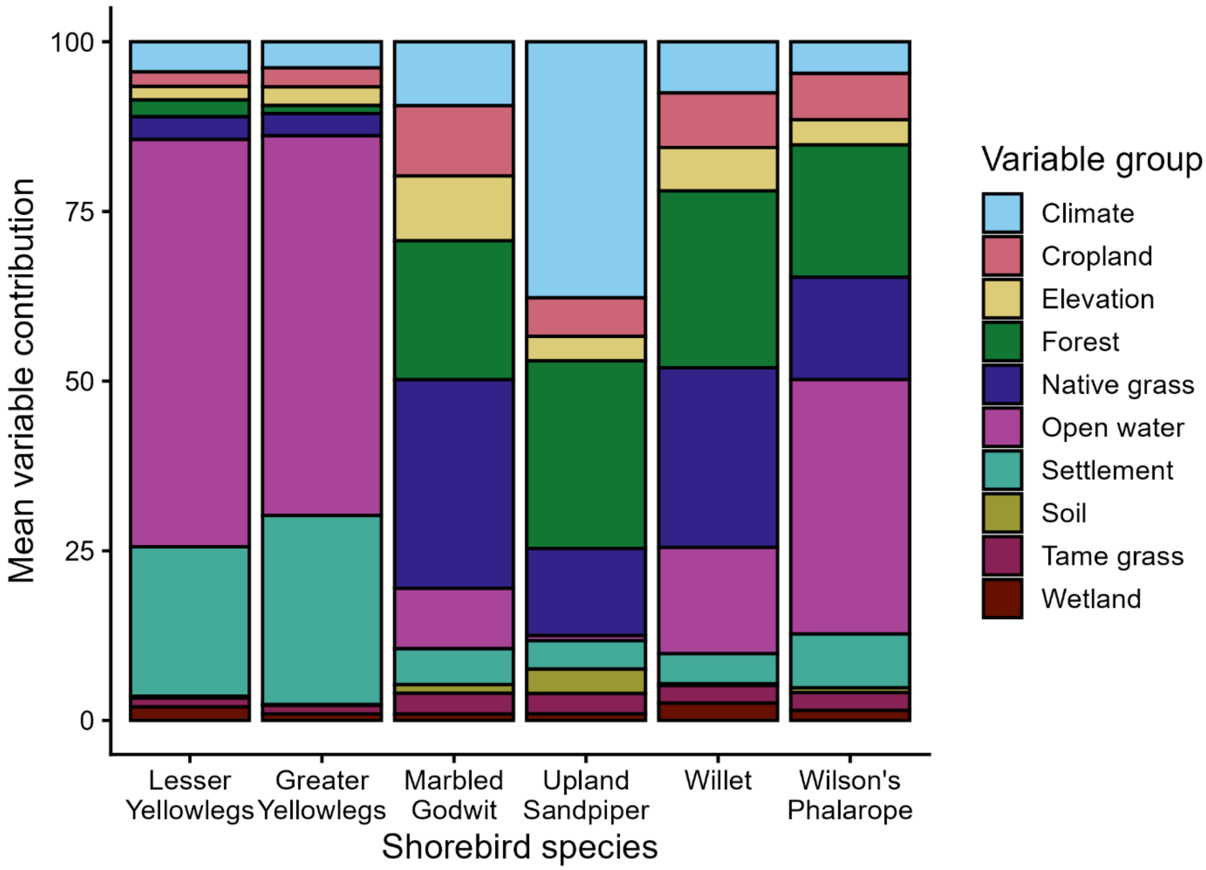


Figure 2. Mean variable contribution (%) from the species distribution models of migrating and breeding shorebirds in Prairie Canada. Variable contribution can indicate either a positive or negative effect on shorebird habitat suitability.

A

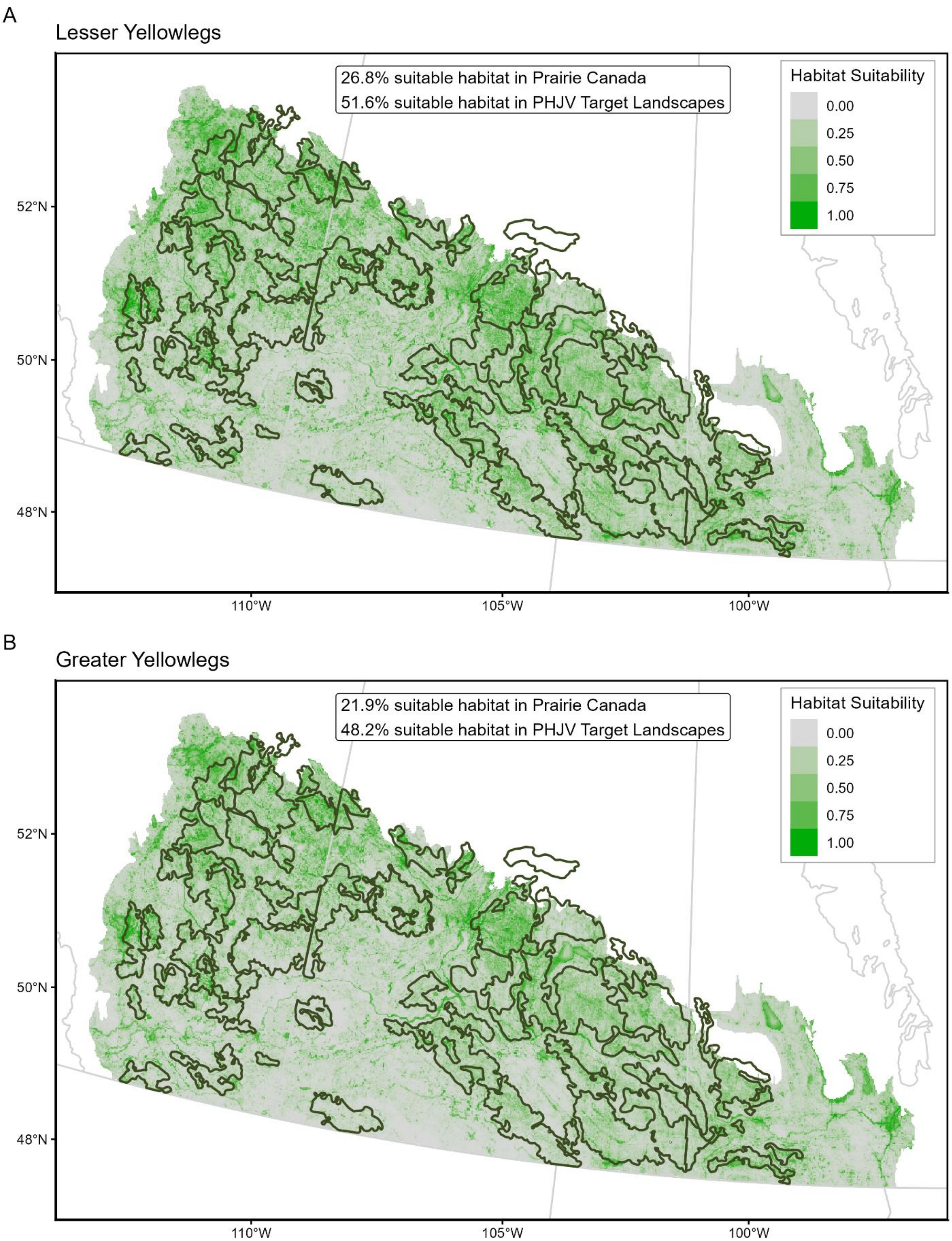


Figure 3. Predicted habitat suitability for migrating (A) Lesser Yellowlegs and (B) Greater Yellowlegs in Prairie Canada using species distribution models.

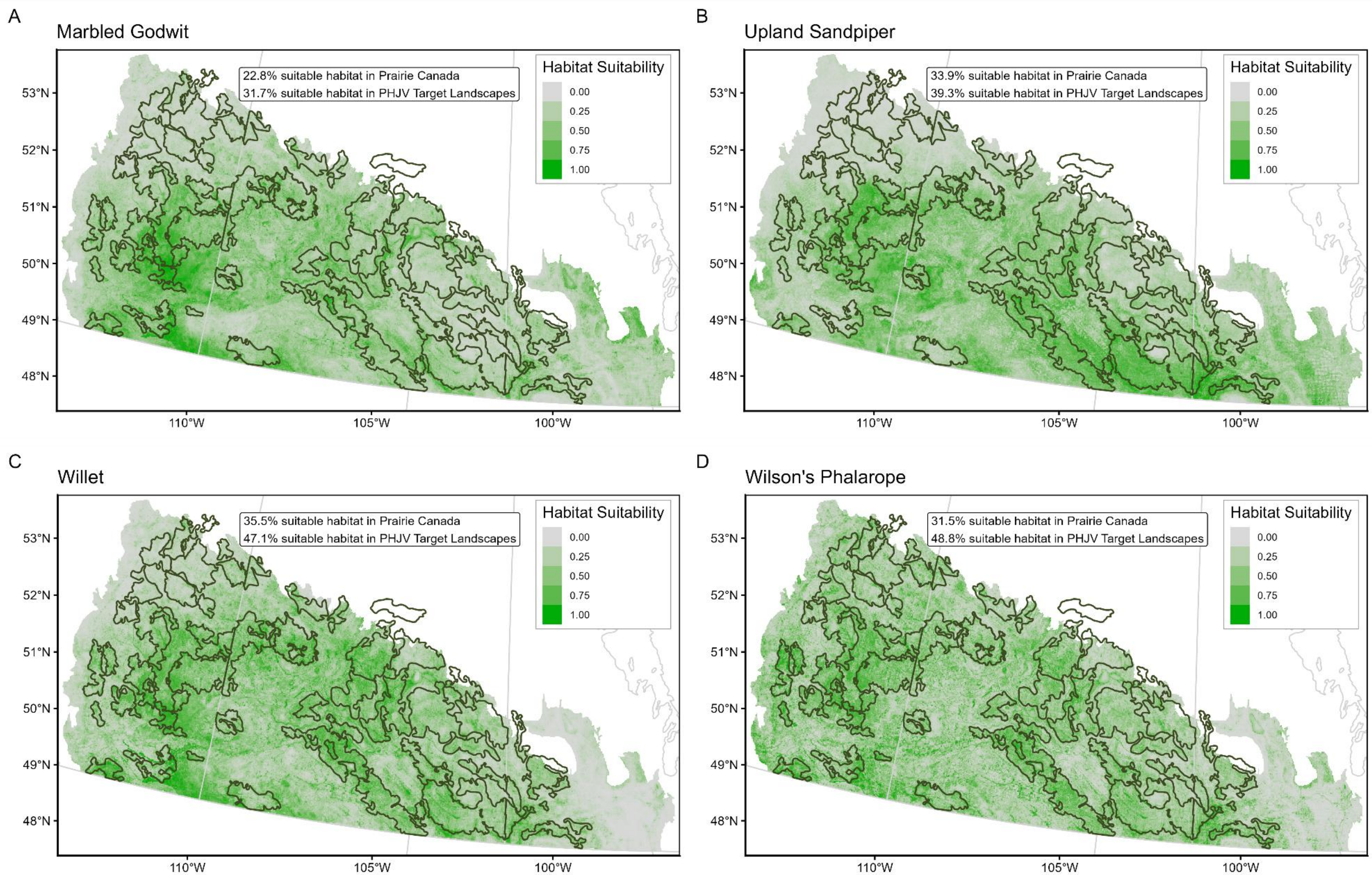


Figure 4. Predicted habitat suitability for breeding (A) Marbled Godwit and (B) Upland Sandpiper, (C) Willet, and (D) Wilson's Phalarope in Prairie Canada using species distribution models.

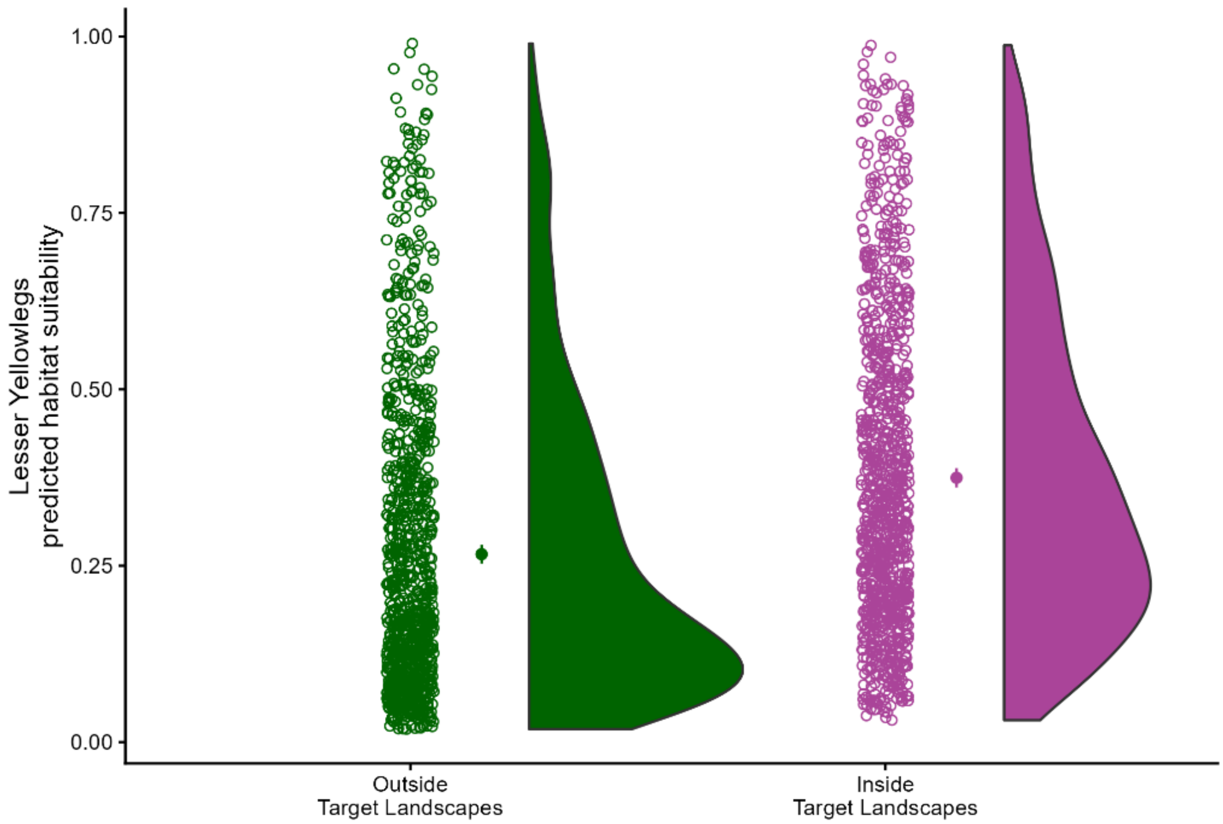


Figure 5. The predicted habitat suitability for migrating Lesser Yellowlegs with species distribution models at randomly selected locations inside PHJV Target Landscapes (n = 1000) and outside Target Landscapes (n = 1000) in Prairie Canada. Hollow points are individual sites, filled points are group means and vertical lines are 95 % confidence intervals of group means. Filled curves are the density distributions of each category.

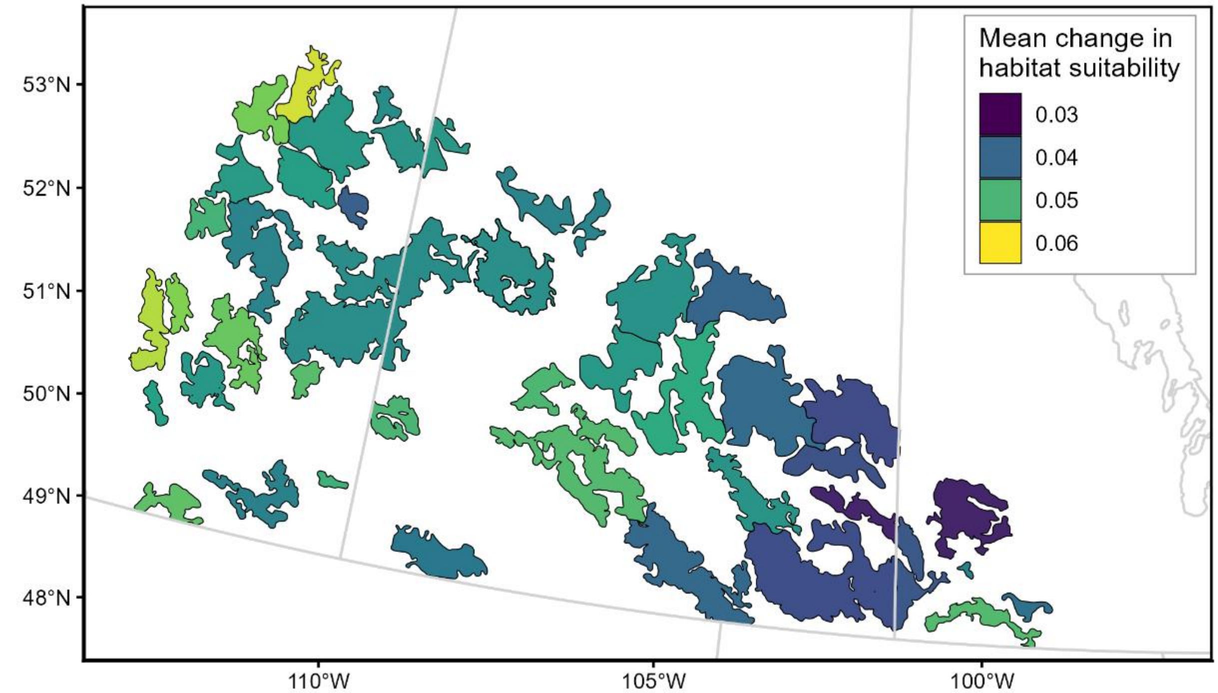


Figure 6. Mean change in habitat suitability for migrating Lesser Yellowlegs from restoring 10 acres of annual cropland to wetland per quarter section in each Prairie Habitat Joint Venture Target Landscape with at least 80 % area in Prairie Canada.

A Lesser Yellowlegs

B Greater Yellowlegs

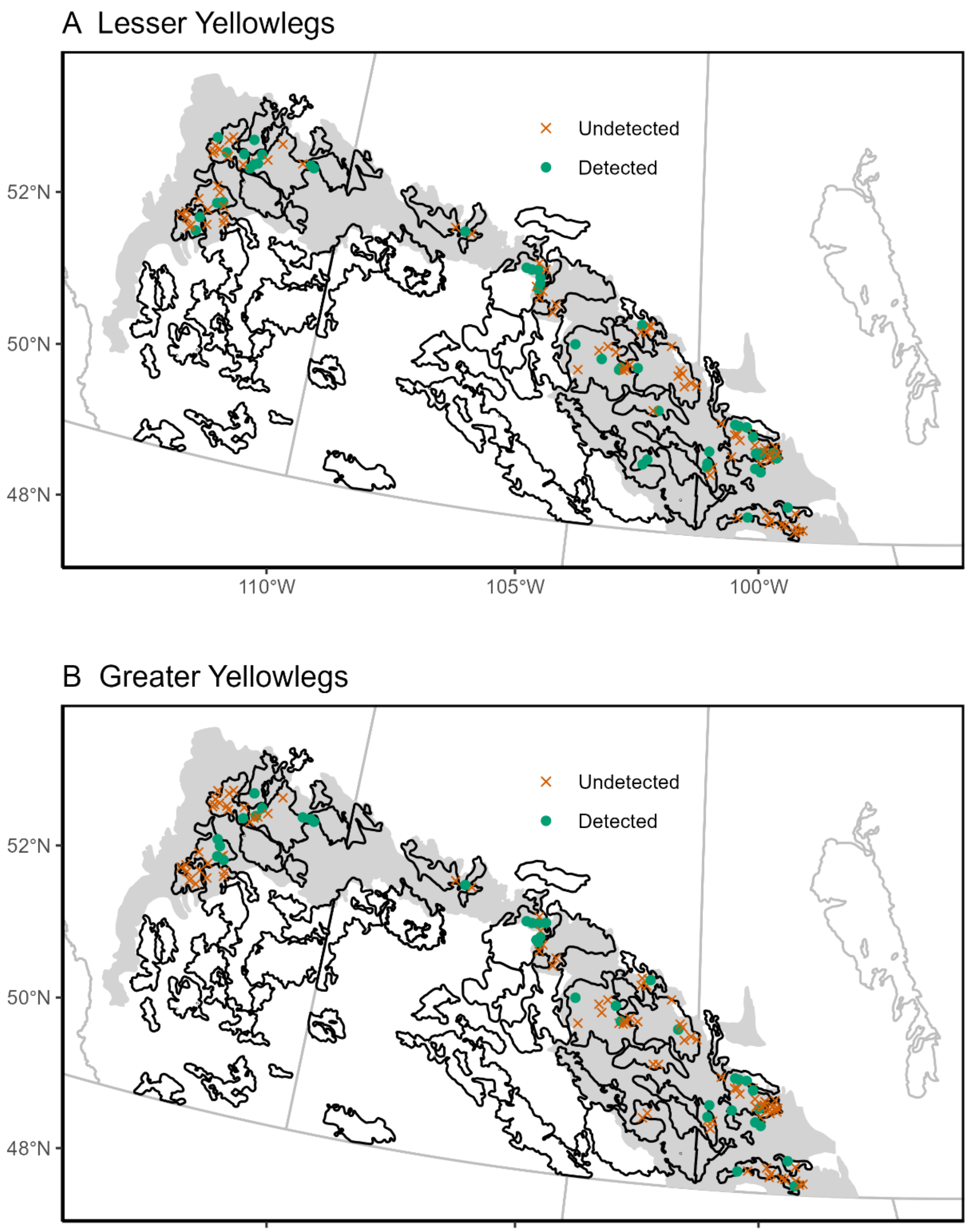


Figure 7. Wetlands within Prairie Habitat Joint Venture Target Landscapes (black outlines) where we detected (A) Lesser Yellowlegs, and (B) Greater Yellowlegs using Autonomous Recording Units at 131 wetlands in the Aspen Parklands Ecoregion (grey background) deployed between March 30 and July 31 in 2022 and 2023.

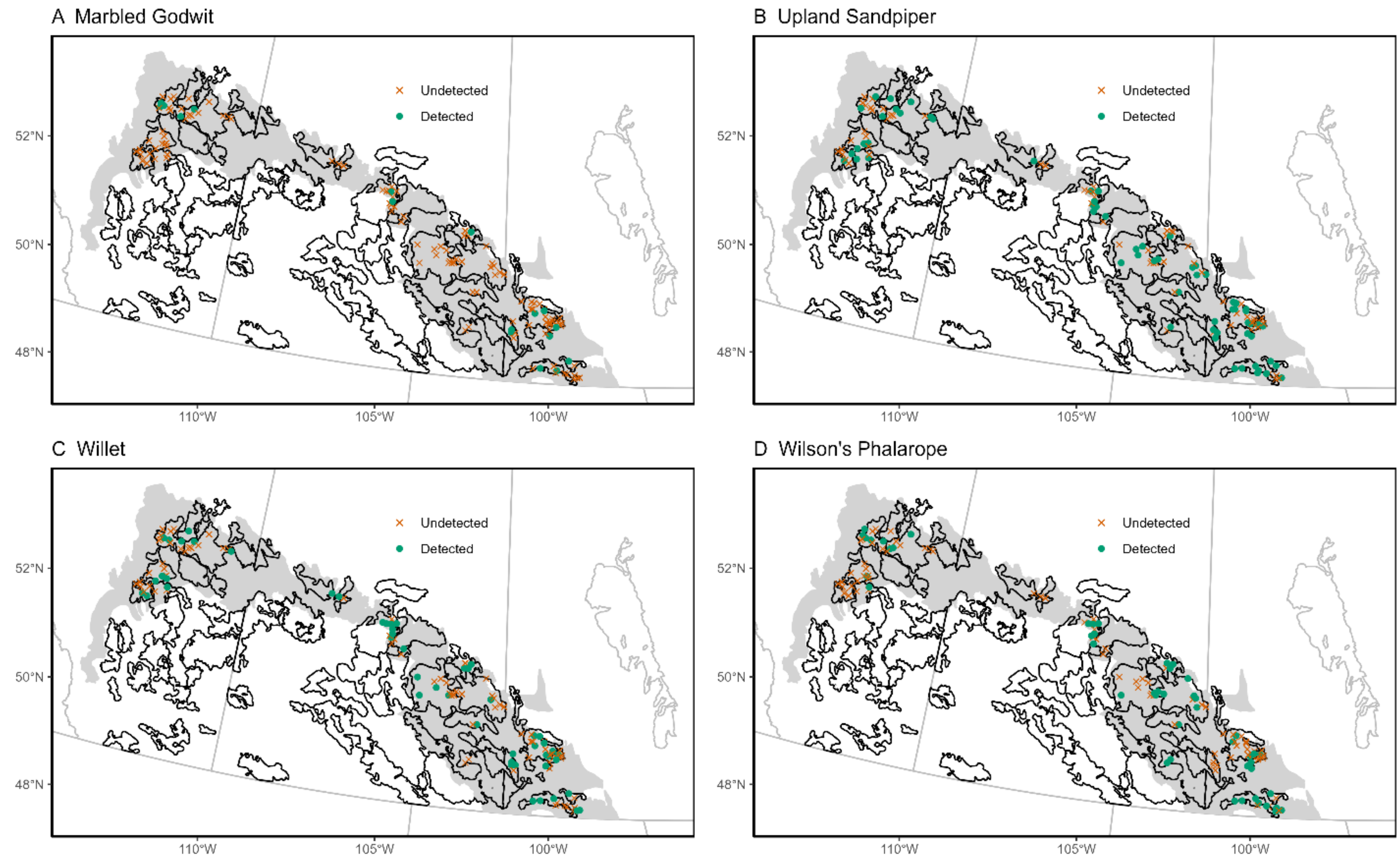


Figure 8. Wetlands within Prairie Habitat Joint Venture Target Landscapes (black outlines) where we detected (A) Marbled Godwit, (B) Upland Sandpiper, (C) Willet, and (D) Wilson's Phalarope using Autonomous Recording Units at 131 wetlands in the Aspen Parklands ecoregion (grey background) deployed between March 30 and July 31 in 2022 and 2023.

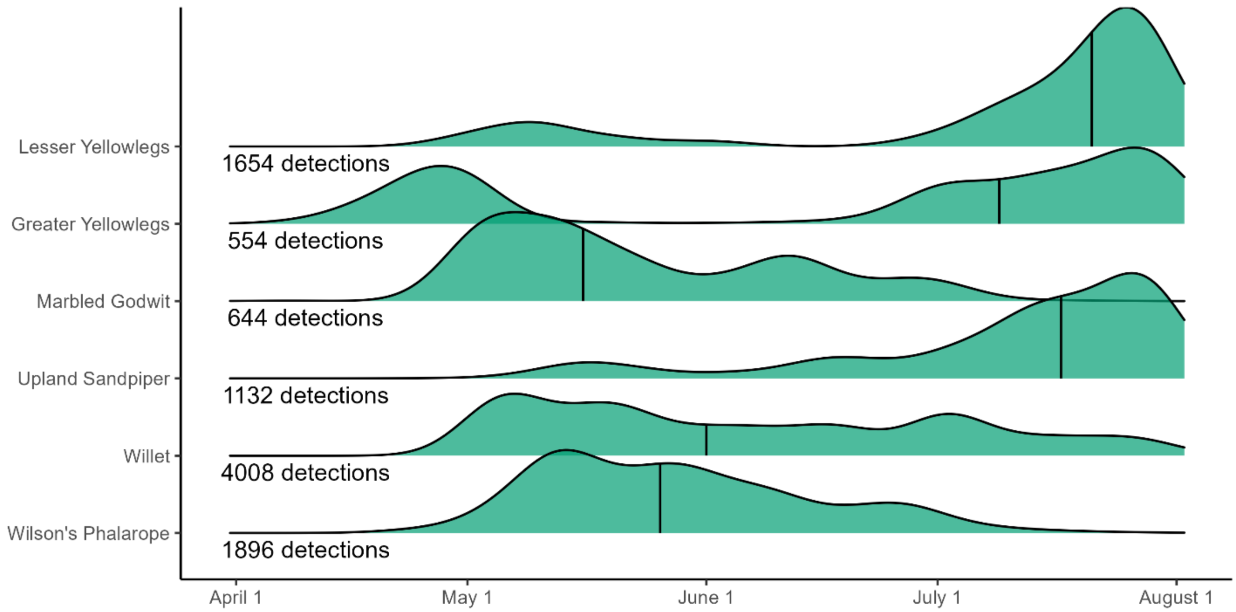


Figure 9. The distribution of shorebird detections using Autonomous Recording Units at 131 wetlands in Prairie Habitat Joint Venture Target Landscapes. Black vertical lines represent the median day of the year when each species was detected.

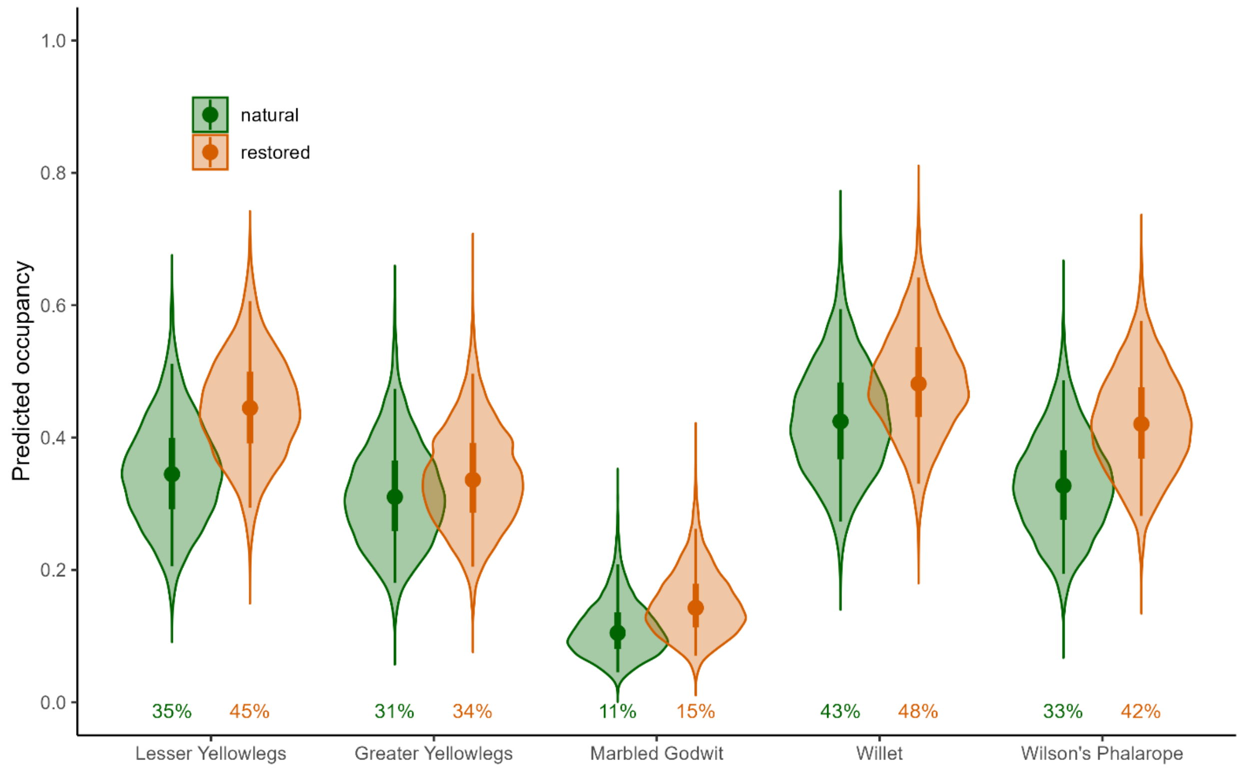


Figure 10. The predicted occupancy (posterior distribution from 6000 samples) for shorebirds at natural and restored wetlands in the Prairie Habitat Joint Venture Target Landscapes using a multi-species occupancy model. The coloured points represent mean estimates, thick lines represent the central 50 %, the thin lines represent 95 % credible intervals, and coloured bubbles represent the density distribution. There are no estimates for Upland Sandpiper because the model was only based on wetland bird species.

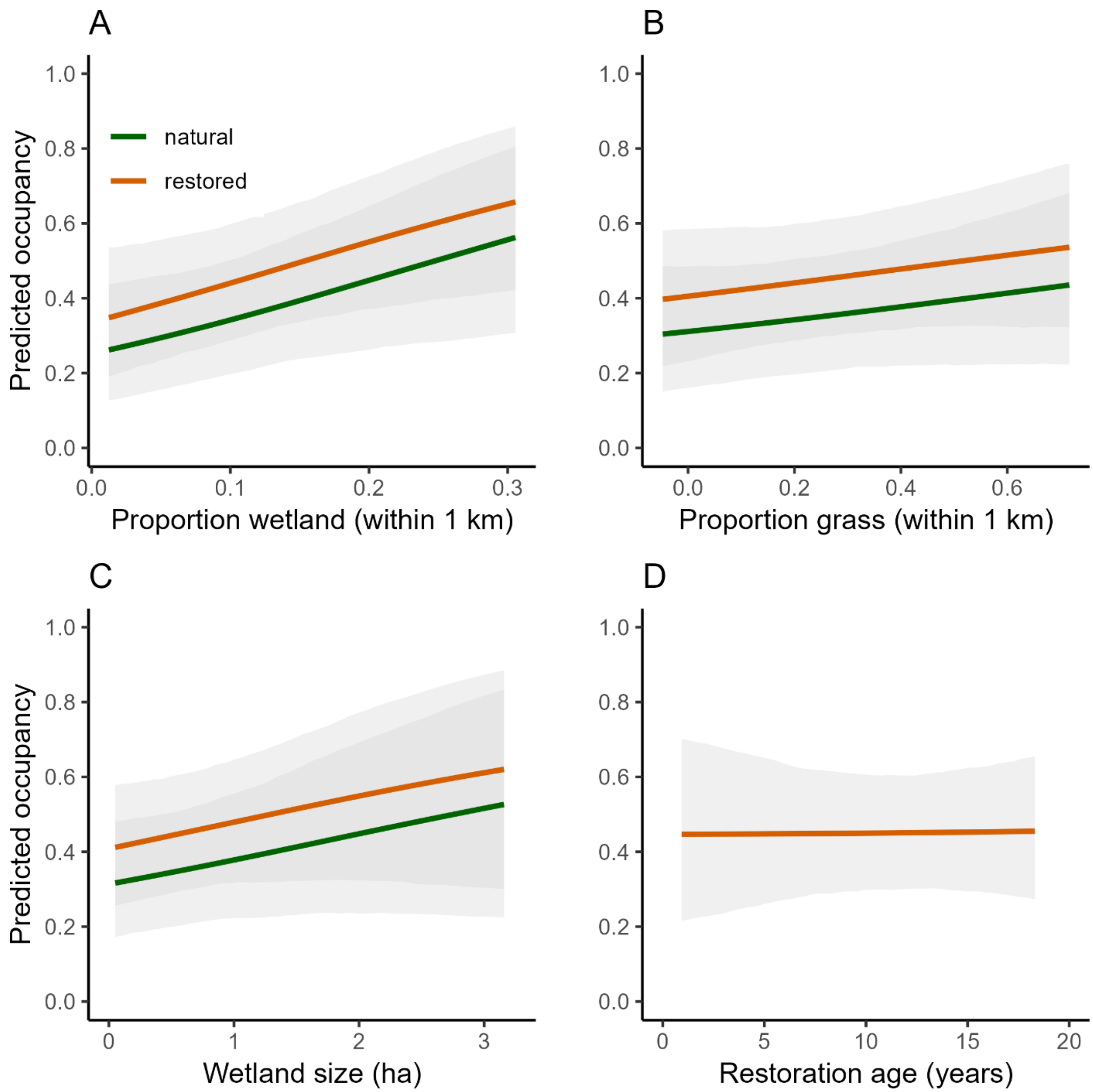


Figure 11. The predicted effects of (A) proportion wetland (within 1 km), (B) proportion grass (within 1 km), (C) wetland size, and (D) restoration age on Lesser Yellowlegs occupancy probability in Prairie Habitat Joint Venture Target Landscape wetlands using a multi-species occupancy model. Solid lines are model predictions, and grey ribbons represent 95 % credible intervals. The modelled effects of each variable assumed other covariates were constant at their mean value from sampled wetlands; predictions are bound by the observed range in covariates from our sample.

Supplementary Tables and Figures

Table S1. Mean variable importance for each species distribution model for six shorebird species. Bolded values are the three most important variables of for each species. The relationships between variables and habitat suitability can be positive or negative.

Variable	Lesser Yellowlegs	Greater Yellowlegs	Marbled Godwit	Upland Sandpiper	Willet	Wilson's Phalarope
Climate pc1	1.44	1.60	4.98	4.88	2.56	0.94
Climate pc2	0.66	0.67	1.65	**17.17**	2.18	0.77
Climate pc3	1.12	0.62	1.04	4.28	0.65	0.45
Climate pc4	1.23	0.95	1.76	11.40	2.16	2.51
Elevation mean	0.93	2.05	2.91	2.09	5.18	2.48
Elevation standard deviation	1.06	0.69	6.64	1.52	1.21	1.24
Max. patch size forest	0.93	0.59	2.36	0.36	0.09	3.52
Max. patch size native grass	1.35	1.09	**16.63**	9.47	**19.12**	**11.49**
Max. patch size open water	**16.51**	**14.88**	7.24	0.17	4.21	**26.31**
Max. patch size tame grass	0.38	0.12	1.08	1.97	1.15	1.18
Proportion cropland (805 m)	1.72	2.41	8.41	4.08	7.70	5.23
Proportion cropland (10 km)	0.42	0.40	1.94	1.59	0.32	1.59
Proportion forest (805 m)	1.18	0.27	5.57	**14.97**	9.54	6.63
Proportion forest (10 km)	0.38	0.33	**12.53**	**12.34**	**16.45**	9.34
Proportion native grass (805 m)	1.16	1.67	1.77	0.75	3.43	2.51
Proportion native grass (10 km)	0.85	0.53	**12.34**	2.59	3.90	1.07
Proportion open water (805 m)	**42.91**	**40.39**	1.09	0.42	**10.04**	**10.61**
Proportion open water (10 km)	0.59	0.67	0.57	0.16	1.41	0.58
Proportion settlement (805 m)	**20.99**	**26.71**	3.41	3.20	4.09	7.38
Proportion settlement (10 km)	1.03	1.12	1.88	0.99	0.33	0.54
Proportion tame grass (805 m)	0.79	0.64	0.51	0.33	0.88	0.91
Proportion tame grass (10 km)	0.12	0.48	1.46	0.69	0.57	0.54
Proportion wetland (805 m)	1.36	0.60	0.15	0.76	0.28	0.85
Proportion wetland (10 km)	0.63	0.36	0.81	0.21	2.28	0.62
Soil texture	0.28	0.15	1.26	3.60	0.27	0.71

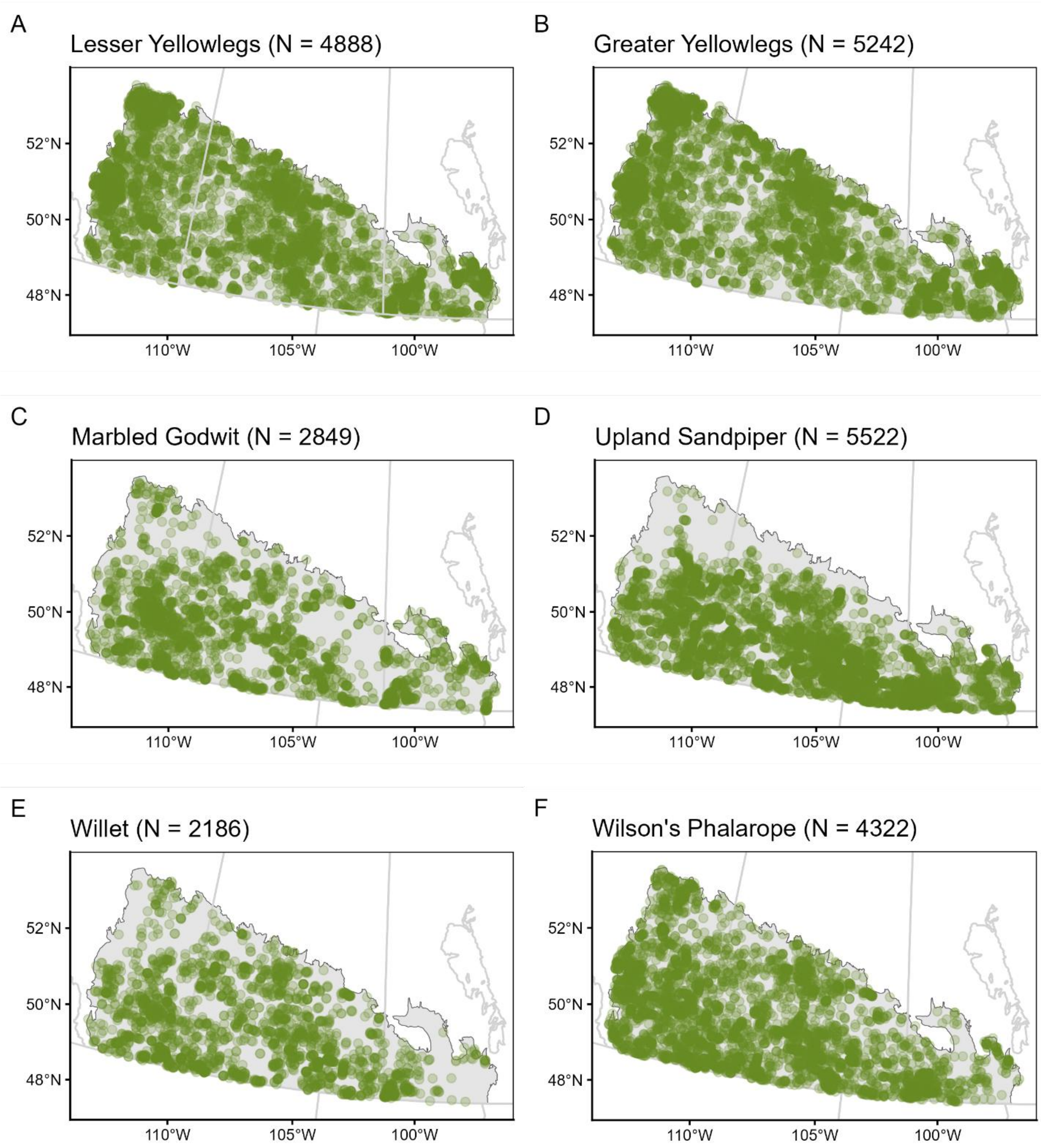


Figure S1. Observations of migrating Greater Yellowlegs (A) and Lesser Yellowlegs (B), and breeding Marbled Godwit (C), Upland Sandpiper (D), Willet (E), and Wilson's Phalarope (F) in Prairie Canada. Hollow green points are individual observations, and the Prairie Ecozone is outlined in black. Observations were downloaded from GBIF and from data sharing agreements. Migratory and breeding date range was informed by eBird estimates.

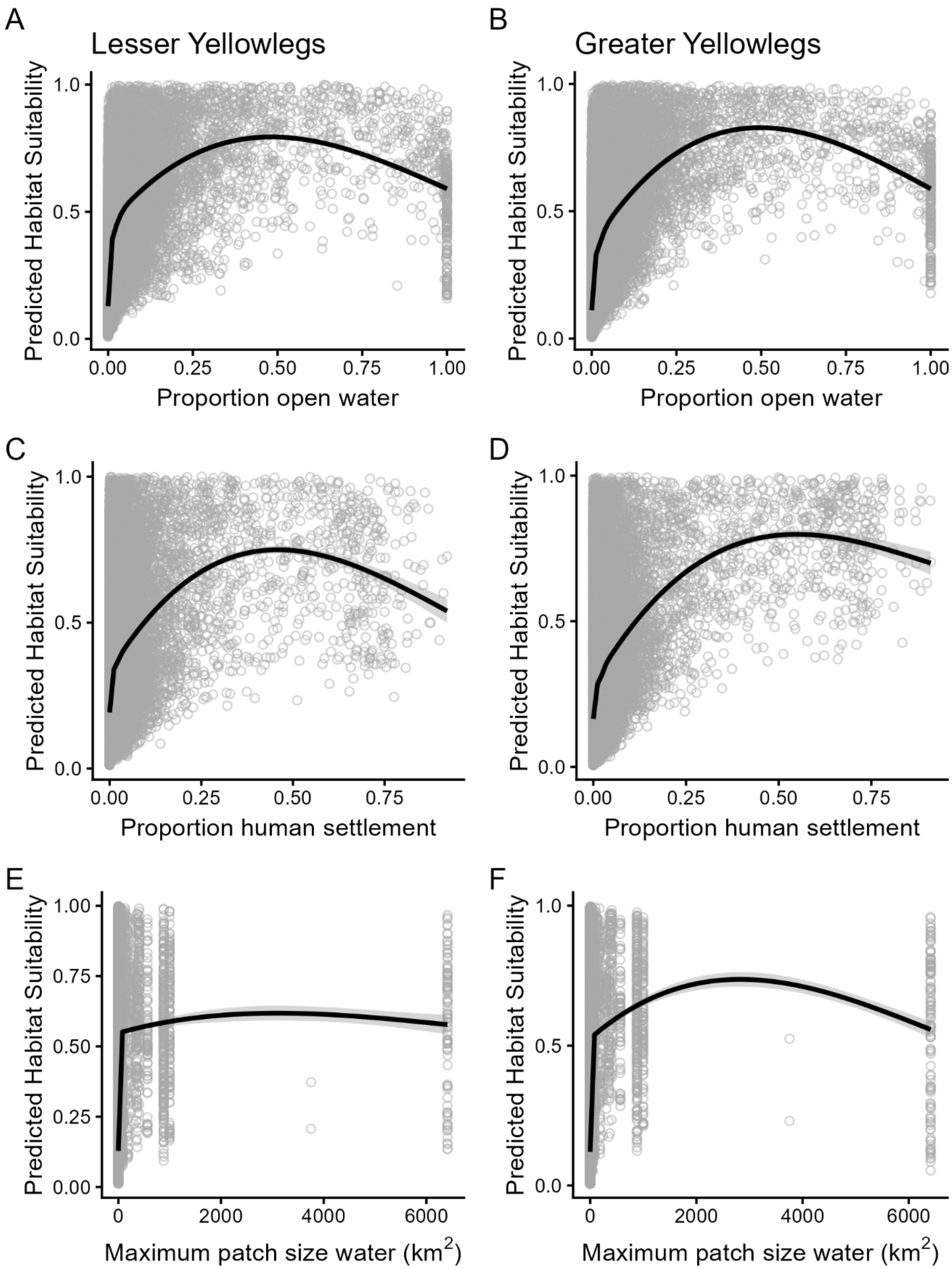


Figure S2. The effect of the three most important variables (proportion of open water, proportion of human settlement and maximum patch size of open water) on the predicted habitat suitability for migrating Lesser Yellowlegs (A, C, E) and Greater Yellowlegs (B, D, F) in Prairie Canada. Gray points are a random selection of 50,000 sites (805 m x 805 m), black lines are predictions from General Additive Models, and ribbons are 95 % confidence intervals.