Wetland use by Greater White-fronted Geese and spatial overlap with waterfowl conservation priority areas in Mexico

Jay A. VonBank, Joshua P. Vasquez, Jason P. Loghry, Kevin J. Kraai, Lei Cao, and Bart M. Ballard

ABSTRACT. Greater White-fronted Geese (Anser albifrons frontalis) use both agricultural and wetland habitats throughout winter with changes in use exhibited temporally and in relation to environmental and landscape factors. Currently, an unknown proportion of Greater White-fronted Geese winter in Mexico, largely along the Gulf Coast and in the Central Highlands, where information regarding wintering ecology is largely unknown. Because conservation efforts for waterfowl typically focus on wetland habitats, understanding factors influencing wetland use is imperative to developing informed conservation strategies. During winters, 2016–2018, we used remote sensing to measure characteristics of 91 wetlands used by GPS-tagged Greater White-fronted Geese, and modeled how wetland and landscape variables influenced wetland use and selection. Our top model of wetland use indicated that larger wetlands and wetlands that were closer to other used wetlands were related to increased use. There was an interaction between wetland type and distance to agriculture, indicating that Greater White-fronted Geese exhibited increased use of emergent herbaceous/grass and woody wetland types that were in closer proximity to agriculture. Our wetland-selection model indicated that woody and emergent wetlands that were larger in size were selected at greater rates than available wetlands on the landscape. Additionally, we conducted a spatial comparison of used wetlands in this study with wetlands previously identified as important for waterfowl conservation in Mexico in the literature. Of 91 wetlands used by geese, only 7.7% fell within wetland complexes identified as priority for waterfowl conservation or specific wetlands important to Greater White-fronted Geese by previous research, and all were within the Laguna Madre de Mexico and Rio Grande Delta regions in Tamaulipas. Wetlands in Mexico are being degraded at a rapid rate, and information such as this is important for future management and conservation-planning efforts throughout Mexico for wetland-dependent species such as the Greater White-fronted Goose.

Utilisation des milieux humides par l'Oie rieuse et chevauchement spatial avec les zones prioritaires de conservation de la sauvagine au Mexique

RÉSUMÉ. L'Oie rieuse (Anser albifrons frontalis) fréquente les terres cultivées et les milieux humides tout au long de l'hiver, et utilise différemment ces milieux dans le temps et en fonction de facteurs environnementaux et paysagers. À l'heure actuelle, une proportion inconnue d'Oies rieuses hivernent au Mexique, principalement le long de la côte du golfe du Mexique et dans les Hautes-Terres centrales, où on en connait très peu sur l'écologie de l'hivernage de cette espèce. Comme les efforts de conservation des espèces de sauvagine se concentrent généralement sur les milieux humides, il est impératif de comprendre les facteurs influant sur l'utilisation de ces milieux pour qu'on puisse élaborer des stratégies de conservation éclairées. Au cours des hivers 2016-2018, au moyen de la télédétection, nous avons mesuré les caractéristiques de 91 milieux humides utilisés par des Oies rieuses munies d’un GPS, et avons modélisé l’effet de variables des milieux humides et du paysage sur l’utilisation et la sélection des milieux humides. Notre meilleur modèle d’utilisation des milieux humides a indiqué que les milieux humides plus grands et ceux qui sont plus proches d’autres milieux humides occupés étaient plus susceptibles d’être utilisés. Il y avait une interaction entre le type de milieu humide et la distance aux terres cultivées, ce qui indiquait que les Oies rieuses utilisaient davantage les types de milieux humides avec plantes herbacées émergentes/herbes ou boisés qui se trouvaient à proximité de terres cultivées. Notre modèle de sélection des milieux humides a indiqué que ceux qui étaient boisés ou avec plantes émergentes et de plus grande taille étaient sélectionnés plus souvent que les milieux humides disponibles dans le paysage. De plus, nous avons effectué un comparaison spatiale des milieux humides utilisés dans notre étude avec les milieux humides identifiés précédemment comme importants pour la conservation de la sauvagine au Mexique dans la littérature. Sur les 91 milieux humides utilisés par les oies, seulement 7,7 % se trouvaient dans des complexes de milieux humides identifiés comme prioritaires pour la conservation de la sauvagine ou dans des milieux humides reconnus comme importants pour les Oies rieuses selon des recherches antérieures, et tous se trouvaient dans les régions de la Laguna Madre de Mexico et du delta du Rio Grande à Tamaulipas. La dégradation des milieux humides du Mexique se produit à un rythme rapide, et les informations comme celles que nous présentons sont importantes pour les efforts futurs de gestion et de planification de la conservation dans tout le Mexique pour les espèces qui dépendent de milieux humides comme l'Oie rieuse.

Key Words: GPS transmitters; habitat use; remote sensing; waterfowl; wetland management
INTRODUCTION

Mexico provides important habitat for North American waterfowl throughout the non-breeding period. Eighty percent of North American waterfowl species and as many as 3.7 million waterfowl winter there annually (Saunders and Saunders 1981). Despite Mexico’s importance to waterfowl populations, very limited information exists on general waterfowl ecology, including distributions, abundances, demographics, or habitat requirements for nearly all species that winter there (Pérez-Arteaga and Gaston 2004). Winter-waterfowl population surveys in Mexico beginning in 1936 by the United States Fish and Wildlife Service noted moderate declines and large interannual variability in winter abundance of several waterfowl species (Saunders and Saunders 1981). Unfortunately, surveys in Mexico have remained inconsistent over time, primarily because of lack of funding, and logistical and safety concerns (Central, Mississippi, and Pacific Flyway Councils 2005, unpublished manuscript), and the survey was discontinued in 2006. Because of limited funds, staff, equipment, and to maximize efficiency of counts across all waterfowl species, winter-aerial surveys in Mexico targeted a predetermined set of large, complex wetland systems, which are of known historical importance to waterfowl (Pérez-Arteaga et al. 2005). Whereas targeting specific wetlands may maximize population-assessment efficiency over long time frames, it may overlook important aspects of wetland characteristics for which waterfowl exhibit preferences. Long-term abundance estimates and trends are important components of waterfowl management; however, the investigation and incorporation of biological drivers and requirements of waterfowl habitat use and selection are necessary for successful wetland conservation for waterfowl.

The declining trend in waterfowl abundance has likely manifested from the rapid and longstanding declines in the number, diversity, and quality of wetlands in Mexico, where up to 50% of wetlands have been degraded or replaced (Mitsch and Gosselink 2007, Mellink et al. 2018). Waterfowl extensively utilize freshwater, brackish, and saltwater wetland resources throughout the Pacific coast, Interior Highlands, and Gulf Coast regions (Baldassarre 2014). Mexico’s wetlands have undergone substantial degradation and replacement throughout the country, but especially in regions important to Central Flyway waterfowl including the Interior Highlands and the Gulf Coast. Hydrology of non-coastal wetlands in Mexico is largely driven by rainfall, evaporation, and water use by humans, and wetland management for waterfowl is essentially non-existent (Mellink et al. 2018). Wetland degradation in the semi-arid Interior Highlands has been the result of agricultural development, sedimentation, and urban development (Mellink et al. 2018). In 1994 Mexico was the last country to join the North American Waterfowl Management Plan, which has since aided in identifying and conserving priority wetlands and habitat vital to wintering waterfowl throughout the country (Environment Canada et al. 2012). To support strategies identifying wetlands and wetland characteristics that are critical to waterfowl in Mexico, conservation planners need relevant biological information on waterfowl habitat preferences and space-use patterns to strengthen conservation initiatives (Medellín et al. 2009, Mellink et al. 2018).

The Greater White-fronted Goose (Anser albifrons frontalis; hereafter White-front) was once the most abundant goose species in Mexico and is currently the most widely distributed species of goose during winter in Mexico (Baldassarre 2014). White-fronts have altered their distribution and abundance in response to large-scale landscape changes in agriculture, e.g., expansion of sorghum acreage and redistribution of rice acreage, and wetland availability, e.g., diking and draining of wetlands (Saunders and Saunders 1981). Currently, White-fronts from the Midcontinent population primarily winter in the south-central USA, but an unknown proportion of White-fronts continue to winter in Mexico annually as evidenced by leg-band recoveries, telemetry, and small-scale surveys (Yépez Rincón 2000, Mireles and Mellink 2017). White-fronts in Mexico winter largely in the states of Tamaulipas and Veracruz along the Gulf Coast of Mexico, and in the Interior Highland states of Zacatecas and Durango (Ely et al. 2013; Fig. 1), and may spend the entire wintering period (October to March) in Mexico (Ely and Dzubin 1994, Yépez Rincón 2003). As many as 180,000 White-fronts have been recorded in Tamaulipas during winter (Yépez Rincón 2003), and the wintering population may constitute as much as 20% of the Midcontinent population in some years (Nieman et al. 1999). Yet, little information regarding their wintering ecology is known (e.g., survival, habitat use), and very few studies focusing on White-front ecology have been conducted in Mexico (Yépez Rincón 2000, Yépez Rincón et al. 2007).

Recent advancements in tracking technologies allow detailed accounts of individual movements and habitat choices throughout longer periods of the annual cycle. Yépez Rincón et al. (2007) used Argos Platform Terminal Transmitters with coarse-data collection (one location every three to seven days) to determine White-front distribution in Mexico. They confirmed that White-fronts primarily winter in the Interior Highlands and northeastern Mexico but suggested that individuals occupy larger ranges throughout winter and that individual distributions vary among years to a greater degree than previously described. Interannual variability in winter distribution of White-fronts may be attributable to changing wetland conditions and distributions as a function of variability in climate (and, therefore, rainfall) from...
arid temperate to tropical climatic zones across the White-front range in Mexico. Given that White-fronts winter across large geographic areas in Mexico, it is imperative to determine habitat requirements and characteristics that influence their distribution at broad and fine spatial scales for future management and conservation planning.

Geese exploit wetland habitat for roosting and foraging, but characteristics of preferred wetlands in Mexico are completely unknown, yet are critical for conservation planning (Anderson et al. 1999). Because conservation efforts for wintering waterfowl typically focus on wetland habitats, understanding what factors influence wetland use by species of interest is imperative to develop informed conservation strategies. The distribution of White-fronts in Mexico extends from arid to tropical climates, highlighting the diversity of wetlands they utilize, and specific characteristics of these wetlands, which may influence the intensity of use by geese (Mireles and Mellink 2017). Quantifying use and selection of wetland characteristics by White-fronts will not only aid in conservation planning for the species but may serve to identify areas that are important to wintering White-fronts and other waterfowl. Our objectives were (1) to determine wetland characteristics that influenced use and selection by White-fronts; and (2) to assess whether wetlands used by White-fronts aligned with specific wetlands and wetland complexes previously identified as important to both White-fronts and waterfowl conservation in Mexico.

METHODS

Goose capture and tracking
From October to February 2016–2018, we captured White-fronts in three ecoregions of Texas (i.e., Lower Gulf Coast, South Texas Brushlands, and Rolling Plains) and fit geese (n = 71) with Global Positioning System (GPS)/Global System for Mobile Communication (GSM) transmitter neck collars (Cellular Tracking Technologies, Rio Grande, New Jersey, USA; Ornitela, Vilnius, Lithuania; USGS Bird Banding Permits #21314; Texas A&M University - Kingsville Institutional Animal Care and Use Committee #2015-09-01B) to after-hatch-year geese, identified by plumage characteristics and cloacal inversion. Transmitters recorded GPS locations every 30 minutes and obtained ± 7.2 and 6.5 m accuracy for Cellular Tracking Technologies and Ornitela devices, respectively. Seven White-fronts migrated from U.S. wintering regions into Mexico, and we identified wetlands used by these individuals during winters 2016–2017 and 2017–2018. We removed GPS locations with a speed > 2.5 km/h because we determined these as flight locations based on a natural break in the density distribution of all GPS locations, leaving only ground locations.

Wetland characteristics
Throughout their wintering range, White-fronts use seasonally flooded agriculture, as well as ephemeral, seasonal, and permanent wetlands during winter for both foraging and roosting (Hobauh 1982, Anderson et al. 1999). To account for the dynamic nature of water availability in arid landscapes and shifting monthly distributions of White-fronts in Mexico (Yépez Rincón et al. 2007), we developed monthly spatially explicit surface-water raster layers using a modified normalized-difference water-extraction index (NDWI; Xu 2006). We downloaded multi-spectral Landsat 8 Operational Land Imager satellite imagery courtesy of the U.S. Geological Survey (https://www.earthexplorer.gov), each month from November to February 2016-2018, for all scenes where White-fronts were present. We included scenes with ≤ 15% cloud cover, where cloud cover did not conceal areas containing goose locations when cloud cover was > 15%, or where multiple images within the same satellite path and month could be mosaicked to produce a cloud-free scene. When cloud-free scenes were not available in a month, we substituted scenes with the date as close as possible to the middle of the month of interest. We used the NDWI model in Erdas Imagine (Hexagon Geospatial) to produce a binary shapefile layer of water and land for each month at 30 m resolution. Wetland features where GPS locations from tagged geese intersected water polygons using ESRI ArcMap (version 10.5) were deemed wetlands used by White-fronts.

We hypothesized six wetland characteristics would influence wetland use and selection that served as explanatory variables (Table 1). To examine factors influencing the intensity of use, we calculated the area of surface water (ha), distance from the wetland centroid to the centroid of the nearest agricultural field used by White-fronts (km), and distance from the wetland centroid to the nearest wetland (centroid) also used by White-fronts (km) for each individual wetland using ArcMap (Table 1). Additionally, we categorized wetlands into four broad wetland classes based on vegetation that dominated the wetland area (e.g., flooded trees) or dominated the perimeter of the wetland (e.g., emergent vegetation) following the Cowardin et al. (1979) wetland classification system using temporally matched satellite imagery (Table 1), because we were unaware of any existing, publicly available wetland information and classification in Mexico. These categories included unconsolidated shore, emergent herbaceous/grass, woody/scrub-shrub, and agricultural wetlands (Table 2). We used the number of GPS locations within each wetland as a proxy for the intensity of use, where more GPS locations represent more time spent on the wetland, which served as our response variable. To account for potential GPS and remote-sensing error, we included all GPS locations within 30 m (one raster pixel) of the wetland boundary as determined by surface water extraction in order to account for normal loaing activities (e.g., resting or foraging on wetland edges), in addition to accounting for GPS error.

Factors influencing wetland selection by White-fronts may be different than factors influencing the intensity that a wetland is used. Estimating resource selection functions with small sample sizes, varying temporal overlap among individuals, and simplistic landscape structure and variation can produce inconsistent estimates of selection (Wisz et al. 2008, Hebblewhite and Haydon 2010, McLoughlin et al. 2010). Because of the small sample size of individual geese (n = 7), especially between years (i.e., three in 2016–2017 and four in 2017–2018), and simplistic landscape structure (because of limited spatial data), we chose to use a conditional logistic regression approach using used and available wetlands as the sampling unit. To select unused (available) wetlands, we determined which wetlands were available to geese by calculating the average total daily movement distances of geese (Mireles and Mellink 2017). Quantifying landscape structure (because of limited spatial data), we chose to use a conditional logistic regression approach using used and available wetlands as the sampling unit. To select unused (available) wetlands, we determined which wetlands were available to geese by calculating the average total daily movement distances of geese (Mireles and Mellink 2017). Quantifying landscape structure (because of limited spatial data), we chose to use a conditional logistic regression approach using used and available wetlands as the sampling unit. To select unused (available) wetlands, we determined which wetlands were available to geese by calculating the average total daily movement distances of geese (Mireles and Mellink 2017). Quantifying
Table 1. Predictor variables, descriptions, and specific hypotheses tested for each variable hypothesized to influence wetland use and selection by Greater White-fronted Geese (Anser albifrons frontalis) in Mexico.

| Predictor Variable and Model | Description                                                                 | Hypothesis                                                                                          |
|-----------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Use Intensity Model          |                                                                             |                                                                                                      |
| Dominant Wetland Type        | Vegetation characteristics that were within or surrounded the wetland by ≥51% of the surface water perimeter and based on | Emergent Herbaceous/Grass wetlands will be used more than others                                      |
| Unconsolidated Shore         | Shoreline or wetland area dominated by gravel, sand, mud, or organic material |                                                                                                      |
| Woody/Scrub-Shrub            | Shoreline or wetland area dominated by woody vegetation, including shrubs, small or large trees |                                                                                                      |
| Emergent Herbaceous/Grass    | Shoreline or wetland area dominated by non-woody, emergent vegetation       |                                                                                                      |
| Agriculture                  | Shoreline or wetland area dominated row crop agriculture                     | Greater use of smaller wetlands relative to all used wetlands                                        |
| Surface Water Area (ha)      | Area of polygons identified as water derived from satellite imagery and a normalized difference water extraction index (NDWI) | Greater use of wetlands that are closer to agriculture used for foraging                             |
| Distance to Agriculture (km) | Distance from the wetland centroid to center of the closest agricultural field that contained GPS locations, indicative of foraging |                                                                                                      |
| Distance to Used Wetland (km)| Distance from the wetland centroid to center of the closest wetland that contained GPS locations (used wetland) | Greater use of wetlands that are closer to other used wetlands                                      |
| Wetland Selection Model      |                                                                             |                                                                                                      |
| Dominant Wetland Type        | Same as use model                                                           | Same as use model                                                                                    |
| Surface Water Area (ha)      | Area of polygons identified as water derived from satellite imagery and an NDWI | Selection for smaller wetlands relative to all available wetlands                                    |
| Landscape Surface Water Area (ha) | Total area of polygons identified as water within a 21 km buffer derived from satellite imagery and NDWI | Selection for wetlands with greater total surface area of water (greater wetland area) within a 21 km buffer |
| Landscape Agricultural Area (ha) | Total area of cells identified as agriculture in the North American Lands Cover Dataset 2015 within a 21 km buffer | Selection for wetlands with greater total agricultural area within a 21 km buffer                  |

Priority wetlands comparison

Several studies and surveys have listed wetlands that are of high conservation priority for waterfowl or are used extensively by White-fronts throughout the Interior Highlands and Gulf Coast regions (Saunders and Saunders 1981, Pérez-Arteaga et al. 2005). Pérez-Arteaga et al. (2005) identified the highest priority wetlands in Mexico for waterfowl conservation based on waterfowl population trends from 10 years of midwinter waterfowl surveys. Saunders and Saunders (1981) summarized wetlands where White-fronts were present in a comprehensive report from 28 years (1937–1964) of aerial and ground surveys. To determine if White-fronts in our study used wetlands of previously determined conservation priority or continued to use wetlands of historical importance to White-fronts, we assembled a list of 31 wetlands or wetland complexes identified by two definitive works on waterfowl distributions and important wetlands in Mexico (Appendix 1). We identified wetlands by following coordinates provided for each wetland in the literature, or by searching and identifying the wetland using the provided wetland name, characteristics, and state through online search engines if no coordinates were provided. Once wetlands were located and identified, we digitized the total wetland boundary or the total wetland complex by using available satellite imagery in ArcMap. We then intersected the final polygons of priority wetlands with the layer of wetlands used by White-fronts in this study to determine if GPS-tagged White-fronts used wetlands identified as priority conservation areas. Finally, we calculated the proportion of priority sites that were used by White-fronts of the total number of used wetlands to investigate how many distinct priority sites were used, and determined the regions where used wetlands were located in relation to priority sites.

Statistical analyses

We used generalized linear mixed-effects models with a Poisson distribution and log-link function in program R (version 3.5.2; R Core Team 2019) using the lme4 package (Bates et al. 2015) to model the effects of predictor variables (i.e., wetland size, wetland classification, distance to the nearest used agricultural field, and distance to the nearest used wetland) and biologically plausible interactions of these variables, in addition to the quadratic effect of each predictor because we anticipated non-linear relationships may exist, on the count of GPS locations within each wetland. Continuous predictor variables were log-transformed, centered, and standardized. We checked for collinearity among predictor variables using Pearson correlation coefficients, and found no
strong correlations among predictors ($r < 0.34$). We removed seven wetlands containing outliers for wetland size, distance to wetland, or distance to used agricultural field. We used the wetland class unconsolidated shore as the reference level for the wetland-classification variable. We combined all wetlands for each month and winter into a single analysis. We included a random intercept for wetland ID because some wetlands were used in several months, by several geese, or in both winters. We detected overdispersion in our initial model runs (i.e., $\phi > 1$; Zuur et al. 2009), so we added an observation-level random effect to account for overdispersion (Harris 2014), which effectively reduced over-dispersion ($\phi = 0.08$). We ran a candidate set of 23 a priori models, including a null model, and used Akaike’s Information Criterion (AIC) model selection to determine the top-ranked model. We considered variables statistically significant if their associated 95% confidence intervals did not overlap zero. We then predicted the effects of significant variables to examine the relationship of predictor variables influencing wetland use.

We used a conditional logistic-regression framework to estimate wetland selection by White-fronts. Because the same used wetland could occur in multiple months, we used month as the strata, and wetland ID, associated to one used wetland and three available wetlands within a 21-km buffer, as the cluster. We used conditional logistic regression in program R (version 3.5.2; R Core Team 2019) using the survival package (Therneau 2022) to model the effects of predictor variables (i.e., wetland size, wetland classification, area of surface water within the 21-km buffer, and agricultural area within the 21-km buffer) and biologically plausible interactions of these variables, in addition to the quadratic effect of each predictor because we anticipated non-linear relationships may exist, to estimate wetland selection. We checked for collinearity among predictor variables using Pearson correlation coefficients and found no strong correlations among predictors ($r < 0.33$). Quadratic effects of surface-water area and agricultural area were run as univariate fixed-effects models and, if not significant, were not included in subsequent models. We removed four used wetlands and their associated available wetlands because their wetland-size calculations were outliers. We ran a candidate set of 26 a priori models and used AIC model selection to determine the top-ranked model. We considered variables statistically significant if their associated 95% confidence intervals did not overlap zero. We then predicted the effects of significant variables to examine relationships of predictor variables influencing wetland selection.

### RESULTS

#### Tracking and wetland characteristics

We tracked seven White-fronts for a total of 313 goose days in Mexico. Three of seven transmitters failed during the winter period, but White-fronts with transmitters that functioned properly stayed in Mexico until the beginning of spring migration in February each year. White-fronts arrived in Mexico earlier in 2016–2017 (median date 10 Nov 2016; range = 7 Nov 2016–11 Dec 2016; $n = 3$) than in 2017–2018 (median date 2 Dec 2017; range = 23 Nov 2017–4 Jan 2018; $n = 4$). We collected GPS information on White-fronts for an average of 31.67 ± 15.45 (SE) days per goose in Mexico in 2016–2017 ($n = 3$), and 54.50 ± 17.17 days per goose in 2017–2018 ($n = 4$). We identified a total of 6865 GPS locations within wetlands from a total of 8218 total GPS locations (excluding flight locations) meaning that White-fronts spent approximately 83.54% of the time within wetlands. White-fronts used a total of 91 unique wetlands over two winter periods (2016–2017 and 2017–2018), using 47 wetlands in Tamaulipas, 31 wetlands in Nuevo León, six wetlands in Zacatecas, six wetlands in Jalisco, and one wetland in Durango. Across all 91 wetlands, mean size was 36.92 ± 14.31 ha, distance to agriculture field used for foraging was 9.11 ± 1.21 km, and distance to other used wetlands was 4.37 ± 0.78 km, but varied based on wetland type (Table 2). Used wetlands in our study contained an average of 75 GPS locations (~1.56 days used), ranging from 1–830 (~30 min–17.29 days).

Our top model of wetland-use intensity included wetland size, wetland type, distance to agriculture, quadratic effect of distance to wetland, and the interaction of wetland type and distance to agriculture. This model accounted for 56.55% of the Akaike weight, and provided the third largest marginal coefficient of determination ($R^2_M = 0.27$; Appendix 2). The model indicated that wetland use by White-fronts was positively related to wetland size ($B = 0.53$; 0.21–0.85 95% confidence interval or CI; Figs. 2, 3). Wetland use initially increased with increased distance between used wetlands up to ~2.10 km, then decreased with increasing distance between used wetlands ($B = -0.19$, -0.36–-0.01 CI; Figs. 2, 3). Wetland use was negatively related to the interaction of wetland type and distance to agriculture, where both emergent herbaceous/grass ($B = -0.69$, -1.34–-0.04 CI) and woody ($B = -1.08$, -1.81–-0.35 CI; Fig. 2) wetland types that were closer to agricultural fields were used more than wetlands of those habitat types that were farther away from agriculture. The confidence intervals of all other variables overlapped zero and were not interpreted (Fig. 2).

| Wetland Type                  | $n$ | Size (ha)  | Distance to Agriculture (km) | Distance to Wetland (km) | Proportion of GPS locations (%) |
|------------------------------|-----|------------|------------------------------|--------------------------|-------------------------------|
| All Wetland Types            | 91  | 36.92 ± 14.32 | 9.11 ± 1.21                  | 4.37 ± 0.78               | -                             |
| Unconsolidated Shore         | 29  | 33.56 ± 22.34 | 10.80 ± 2.31                 | 6.43 ± 1.60               | 19.16                         |
| Woody/Scrub Shrub           | 33  | 9.90 ± 1.71   | 5.69 ± 1.21                   | 2.44 ± 0.30               | 51.39                         |
| Emergent Herb/Grass          | 24  | 117.92 ± 48.30| 11.01 ± 1.69                  | 2.82 ± 0.49               | 26.13                         |
| Agriculture                  | 5   | 24.46 ± 9.91  | 0.48 ± 0.12                   | 10.23 ± 7.83              | 3.32                          |

Table 2. Mean ± standard error, and sample size ($n$) of wetland size, distance to agriculture, and distance to wetlands for each wetland type used by Greater White-fronted Geese (*Anser albifrons frontalis*) in Mexico during winters 2016–2018.
Fig. 2. Mean β coefficient estimates and 95% confidence intervals from the top-ranked linear mixed-effects model of variables influencing wetland use by Greater White-fronted Geese (*Anser albifrons frontalis*) in Mexico. Black colored point estimates are interpreted as statistically significant (do not overlap 0), and gray colored estimates interpreted as non-significant and overlap 0.

The top model of wetland selection included only two variables, the interaction of wetland type and size. Because the interaction of these variables was significant, we do not interpret main effects independently. There was only one competing model within 2 ΔAIC (0.70 ΔAIC), which included the interaction of wetland type with the quadratic effect of wetland size (Appendix 2). We concluded the covariate wetland size$^2$ was likely an uninformative parameter because it increased the best model by one parameter; the log likelihood was not substantially improved; and the confidence intervals of wetland size$^2$ overlapped zero (Arnold et al. 2010). There were no other competing models. The top model showed that White-fronts selected for woody (β = 1.7; 0.62–2.76 CI), emergent (β = 0.58; 0.03–1.13 CI) and agricultural (β = 11.91; 4.41–19.41 CI) wetlands that were larger in size than wetlands of those types that were smaller (Fig. 4). The coefficient estimate for the agriculture and size interaction was quite large because of very few wetlands of this type being either used and available on the landscape, and we, therefore, do not interpret this effect. Relative selection ratios (bound between zero and one) for woody and emergent wetlands increased as wetland size increased, whereas selection for unconsolidated wetlands decreased as size increased (Fig. 4).

Fig. 3. Predicted Global Positioning System location count (i.e., a proxy for wetland use; ± 95% confidence interval) for A) distance to other used wetlands, and B) wetland size, from a generalized linear mixed-effects model evaluating effects of wetland characteristics on use by Greater White-fronted Geese (White-front; *Anser albifrons frontalis*) in Mexico during winters 2016–2018.

Fig. 4. (A) Mean β coefficient estimates and 95% confidence intervals from the top-ranked conditional logistic regression model of variables influencing wetland selection by Greater White-fronted Geese (*Anser albifrons frontalis*) in Mexico. Black colored point estimates are interpreted as statistically significant (do not overlap 0), and gray colored estimates interpreted as non-significant and overlap 0 and (B) predicted relative selection ratio for wetland habitat type and size interaction.
**Comparison with priority wetlands**

We identified 31 priority wetlands in Mexico that we used in our spatial analysis, nine of which were outlined as important to White-fronts by Saunders and Saunders (1981), nine outlined as the highest priority wetlands or wetland complexes for waterfowl conservation by Pérez-Arteaga et al. (2005) throughout the Interior Highlands and eastern Gulf Coast of Mexico, and 13 that were identified in both studies (Fig. 5, Appendix 1). Priority sites were located across 16 different Mexican states; 23 wetlands were located in the Interior Highlands; eight were along the Gulf Coast; and one was in northcentral Mexico (Coahuila; Fig. 5).

**DISCUSSION**

This is the first study to investigate wetland characteristics influencing use and selection by Greater White-fronted Geese in Mexico. Through the use of tracking-technology, we show that White-fronts used and selected for wetlands based on wetland-specific and spatial characteristics. Further, our sample of GPS-tagged White-fronts rarely used historically important wetlands for White-fronts, or specific wetlands identified as priority wetlands for waterfowl conservation in Mexico. Whereas the use of non-traditional wetlands is likely driven by water availability in this arid landscape, it highlights both the adaptability of White-fronts and the importance of maintaining a variety of wetland ecosystems that are or may become important in highly variable climates. These results suggest that additional information on waterfowl habitat requirements and distributions in Mexico is likely needed to ensure the development of optimal, fully informed conservation and management strategies.

White-fronts used woody and emergent herbaceous/grass wetland types when those wetlands were in close proximity to agricultural fields, and selected for these wetland types when wetland size was larger than the average available wetland. White-fronts forage heavily on agricultural waste grains throughout their winter range in the United States, primarily relying on rice, corn, and sorghum, and likely feed on these same grains in Mexico (Baldassarre 2014). Whereas the specific crop types, quantity, and quality of waste grains that geese used in our study are unknown, using wetlands that are closer to high-energy food sources such as waste grain likely reduces energetic costs of traveling between roosting and foraging locations (Ackerman et al. 2006, VonBank 2020). White-fronts did not select areas with greater total area of cultivated crops within the average daily movement distances, which may suggest wetlands in close proximity to specific crops used for foraging are more important than total crop area. Emergent herbaceous wetlands provide food in the form of rhizomes, tubers, and seeds of natural vegetation such as *Sagittaria* spp. and *Echinochloa* spp., and Anderson et al. (1999) showed that White-front abundance in wetlands along the Texas coast was greatest on densely vegetated wetlands, specifically lacustrine littoral wetlands with aquatic-bed floating and rooted vascular vegetation. Furthermore, they found that geese primarily fed in vegetated wetlands including scrub-shrub and emergent persistent, while roosting primarily in wetlands dominated by open water (Anderson et al. 1999). Woody wetlands provide cover from aerial predators, as well as thermal refugia for waterfowl (Ringelman et al. 1989). Use and selection of wetlands we classified as woody may be the result of manmade wetlands developed by dams that flooded forested areas. Anecdotally, many wetlands used by White-fronts in our study appeared to be manmade stock ponds (either dammed or dug-out style) used for agriculture or livestock watering, which is consistent with wetland use by White-fronts in arid regions of Texas where natural wetlands and precipitation are limited (J. VonBank, unpublished data).

White-fronts used larger wetlands at a greater rate than smaller wetlands, and wetlands that were in close proximity to other used wetlands. Additionally, White-fronts selected woody and emergent wetlands that were larger in size than other available wetlands of these types on the landscape. Used wetlands were still generally small in size (average size = 36.2 ha, range = 10.0–111.6 ha).
ha; Table 2), compared to wetlands identified as conservation priority areas. White-fronts used wetlands that were closer to other wetlands that were also used at greater rates than those that were more isolated. Wetland complexes provide a diversity of wetland types and are better able to satisfy the array of physiological requirements of waterbirds than a single wetland (Brown and Dinsmore 1986). White-fronts did not select for wetlands with greater total area of wetlands within 21 km, suggesting wetland selection occurs on a smaller scale, and quality of wetlands in close proximity to other used wetlands is likely an important driver of use. Thus, wetlands in close proximity likely provide geese with alternative wetlands in case of disturbance, while providing a diversity of wetland characteristics and configurations to satisfy a suite of daily activities (e.g., foraging, loafing, roosting).

Wetland drainage throughout Mexico has substantially altered the availability of natural wetlands that have been replaced by large reservoirs used for human and agricultural practices (Mellink et al. 2018). However, small wetlands and wetlands in close proximity to one another are important to White-fronts, and likely other waterfowl species as well, especially in arid environments where wetlands and wetland resources are limited and highly dependent on rainfall events (Palacio-Núñez et al. 2008). Future wetland conservation strategies in Mexico should incorporate the inclusion of small wetlands with large wetland complexes, especially where wetland densities are high and wetlands are in close proximity (Brown and Dinsmore 1986).

White-fronts used wetlands in both the Interior Highlands and Gulf Coast regions in Mexico, exhibiting use of varying wetland types across ecosystems. Ely and Dzubin (1994) tracked radio-marked White-fronts from the Pacific population to several large freshwater lagoons in the Northern Interior Highlands of Chihuahua and in coastal salt marshes on the coast of Sinaloa, but unfortunately do not describe wetland characteristics or goose abundances relative to wetland type. White-fronts using the Pacific coast of Mexico and the northern Interior Highlands interchanged and moved between these regions frequently, often being present in both regions during the same winter (Ely and Dzubin 1994). Likewise, White-fronts in the Midcontinent USA frequently moved long distances among ecologically distinct regions during winter (VonBank et al. 2021). Given the large geographic extent used by White-fronts throughout the winter period, seemingly high exchange rates among the Interior Highlands and the Gulf Coast, and unrecognized areas of importance in northern Mexico, we recommend that resource managers consider this connectivity when developing strategies for wetland management and conservation for waterfowl in Mexico (Pérez-Arteaga and Gaston 2004). Further studies using tracking devices deployed on White-fronts in multiple regions of Mexico would further inform rates and direction of landscape connectivity during the non-breeding period (VonBank et al. 2021).

The importance of wetlands identified as priority conservation areas in previous literature (Pérez-Arteaga et al. 2005) should not be diminished by the lack of use by White-fronts in this study, because they were derived by the large abundances of many waterfowl species over a longer period of time, and our sample size of White-fronts that migrated to Mexico is small. For example, Lago Cuitzeo has wintered more than 135,000 waterfowl; Lago Babicora annually winters up to 4% of the continental Lesser Snow Goose (Anser caerulescens); and 3.2% of the Midcontinent Sandhill Crane (Antigone canadensis) populations, and the wetlands Cabadas, Languillo, and Laguna de Bustillos support up to 7.7% of the entire Mexican Duck (Anas diazi) population combined (Pérez-Arteaga et al. 2002). White-fronts in this study instead used undesignated, relatively small wetlands primarily located in northeastern Mexico, in the states of Nuevo León and Tamaulipas. Similarly, Ely et al. (2013) used band recoveries and neckband re-sightings from 1949–2008 to show that Tamaulipas was the predominant wintering state for Midcontinent White-fronts (except those from interior Alaska, which winter in Durango and Zacatecas) in Mexico. The Midcontinent population of White-fronts has undergone a substantial winter distribution shift over the last two decades in the United States, moving northeastward away from primary historical wintering grounds along the Gulf Coast of Texas and Louisiana into the Mississippi Alluvial Valley of Arkansas. Whereas no such research has investigated whether winter distribution has shifted from historical distributions in Mexico, it is likely that the continental shift has altered historical distributions there as well, as Tamaulipas and Nuevo Leon received the greatest wetland use and are the two most northeastern states in Mexico. Yépez Rincón et al. (2007) investigated home range and geographic range size of White-fronts in Mexico, and found that the overall area encompassed by Argos-tagged White-fronts was more than 248,000 km², substantially larger than reported in Saunders and Saunders (1981), and with most individuals wintering in Nuevo Leon and Tamaulipas. Yépez Rincón et al. (2007) also reported that interannual range size varied considerably, likely dependent on wetland distribution in these drought-prone regions. Aerial and ground surveys of the Interior Highlalnds from 1998–2002 identified 156 wetlands containing White-fronts, none of which held more than 5500 White-fronts, and the greatest number during all winters was an estimated 27,700 individuals across the entire Interior Highlalnds (M. J. Ochoa, A. L. Terrazas, R. C. Drewien, and M. A. Spindler, unpublished manuscript). Therefore, historical wetlands identified as important to White-fronts by Saunders and Saunders (1981) may no longer support large numbers during winter because of a continuing distribution shift, ultimately the result of wetland loss, changing agricultural practices, and variable water availability.

Our study was limited by the complete lack of spatial data associated with wetlands and agriculture throughout Mexico, including both broad-scale distributions and fine-scale wetland characteristics. In the United States, the National Wetlands Inventory, although quite dated, provides detailed information on wetland form and function for wetlands throughout the country (Cowardin et al. 1979). Data such as these would benefit this and future studies to ascertain correct and detailed wetland classifications to better inform our models of the specific characteristics influencing wetland use by waterfowl. Anderson et al. (1999) used the National Wetlands Inventory to investigate wetland use by White-fronts in coastal Texas, and this dataset allowed the incorporation of detailed wetland type as well as modifier variables from Cowardin et al. (1979), such as wetland alteration, water regime, and soil type, which were important...
predictors of goose density. Additionally, information on the spatial availability of wetlands would allow more robust resource-selection analyses to further home conservation planning and management efforts for waterfowl in Mexico. Additional tracking studies or additional tagged White-fronts that migrate to Mexico would also strengthen future analyses, because more individuals would likely provide further information on wetland characteristics and areas that are important to the remaining White-fronts wintering there. However, waterfowl research in Mexico has remained difficult in recent years because of logistical and safety concerns, and future research of waterfowl habitat requirements may depend on opportunistic movements of tagged individuals into Mexico (Webb 2006). We suggest that results presented in this study be used as baseline information regarding wetland use by White-fronts, and that future studies develop and include high resolution spatial data combined with detailed information on wetland form and function to further examine wetland characteristics influencing use by waterfowl in Mexico.

Responses to this article can be read online at: https://www.ace-eco.org/issues/responses.php/2204

Acknowledgments:
This is publication number 21-109 of the Caesar Kleberg Wildlife Research Institute. We thank the Editor, Subject Editor, and two anonymous reviewers for their suggestions, which improved the quality of this manuscript.

LITERATURE CITED
Ackerman, J. T., J. Y. Takekawa, D. L. Orthmeyer, J. P. Fleskes, J. L. Yee, and K. L. Kruse. 2006. Spatial use by wintering Greater White-fronted Goose relative to a decade of habitat change in California’s Central Valley. Journal of Wildlife Management 70(4):965-976. https://doi.org/10.2193/0022-541X(2006)70[965:SUBWGW]2.0.CO;2

Anderson, J. T., G. T. Muehl, and T. C. Tacha. 1999. Wetland use by wintering geese in the Gulf Coast Plains and rice prairie region of Texas, USA. Wildfowl 50:45-56. https://doi.org/10.2307/3672557

Baldassarre, G. A. 2014. Ducks, geese, and swans of North America. Johns Hopkins University Press. Baltimore, Maryland, USA.

Bates, D., M. Mächler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67:1-48. https://doi.org/10.18637/jss.v067.i01

Brown, M., and J. J. Dinsmore. 1986. Implications of marsh size and isolation for marsh bird management. Journal of Wildlife Management 50(3):392-397. https://doi.org/10.2307/3801093

Commission for Environmental Cooperation. 2020. 2015 land cover of North America at 30 meters. North American Land Change Monitoring System, Edition 2.0, Commission for Environmental Cooperation, Montréal, Québec, Canada. http://ssig.conabio.gob.mx/apollo/us/nalcms/

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Department of the Interior, U.S. Fish and Wildlife Service, Washington, D.C., USA. https://doi.org/10.5962/bhl.title.4108

Ely, C. R., D. J. Nieman, R. T. Alisauskas, J. A. Schmutz, and J. E. Hines. 2013. Geographic variation in migration chronology and winter distribution of Midcontinent Greater White-fronted Geese. Journal of Wildlife Management 77(6):1182-1191. https://doi.org/10.1002/jwmg.573

Ely, C. R., and J. Y. Takekawa. 1996. Geographic variation in migratory behavior of Greater White-fronted Geese (Anser albifrons). Auk 113(40):889-901. https://doi.org/10.2307/4088866

Environment Canada, U.S. Department of the Interior, and Secretariat of Environment and Natural Resources, Mexico. 2012. North American waterfowl management plan 2012: people conserving waterfowl and wetlands. Environment Canada, Ottawa, Canada, U.S. Department of the Interior, Washington, D.C., USA, and Secretariat of Environment and Natural Resources, Mexico City, Mexico.

Harris, X. A. 2014. Using observation-level random effects to model overdispersion in count data in ecology and evolution. PeerJ 2:e616. https://doi.org/10.7717/peerj.616

Hebblewhite, M., and D. T. Haydon. 2010. Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. Philosophical Transactions of the Royal Society of London B: Biological Sciences 365:2303-2312. https://doi.org/10.1098/rstb.2010.0087

Hoben, G. C. 1982. Wintering ecology of geese in the rice prairie area of southeast Texas. Dissertation. Texas A&M University, College Station, Texas, USA.

McCoughlin, P. D., D. W. Morris, D. Fortin, E. Vander Waland, and A. L. Contasti. 2010. Considering ecological dynamics in resource selection functions. Journal of Animal Ecology 79:4-12. https://doi.org/10.1111/j.1365-2656.2009.01613.x

Medellin, R. A., A. Abreu-Grobois, M. C. Arizmendi, E. Mellink, E. Ruelas E. Santana, J. Urbán, and E. E. Iñigo-Eliás. 2009. Conservación de especies migratorias y poblaciones transfronterizas. Pages 459-515 in José Sarukhán, editor. Capital natural de México, volumen II: estado de conservación y tendencias de cambio. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Mexico City, Mexico.

Mellink, E., J. Luévano, and M. E. Riojas-López. 2018. Half a century of changes in waterbird populations in a semiarid wetland system. Wetlands Ecology and Management 26:1047-1060. https://doi.org/10.1007/s11273-018-9630-y

Mireles, C., and E. Mellink. 2017. Use of Laguna de Busillos, Chihuahua, by waterbirds during the 2011–2012 wintering season. American Midland Naturalist 178(1):82-96. https://doi.org/10.1674/0003-0031-178.1.82

Mitsch, W. J., and J. G. Gosselink. 2007. Wetlands. Wiley, New York, New York, USA.
Nieman, D., K. Warner, W. Eldridge, and J. Haskins. 1999. White-fronted goose in Mexico. Ducks Unlimited de Mexico. Autumn 21:10-16.

Palacio-Núñez, J., D. Jiménez-García, G. Olmos-Oropeza, and J. Enríquez-Fernández. 2008. Distribución y solapamiento espacial de las aves acuáticas y ribereñas en un humedal de zonas semiáridas del NE de México. Acta zoológica mexicana 24 (2):125-41.

Pérez-Arteaga, A. and K. J. Gaston. 2004. Wildfowl population trends in Mexico, 1961-2000: a basis for conservation planning. Biological Conservation 115(3):343-355. https://doi.org/10.1016/S0006-3207(03)00088-0

Pérez-Arteaga, A., K. J. Gaston, and M. Kershaw. 2002. Undesignated sites in Mexico qualifying as wetlands of international importance. Biological Conservation 107(1):47-57. https://doi.org/10.1016/S0006-3207(02)00043-5

Pérez-Arteaga, A., S. F. Jackson, E. Carrera, and K. J. Gaston. 2005. Priority sites for wildfowl conservation in Mexico. Animal Conservation 8(1):41-50. https://doi.org/10.1017/S1367943004001817

Ringelman, J. K., W. R. Eddleman, and H. W. Miller. 1989. High plains reservoirs and sloughs. Pages 311-340 in L. M. Smith, R. L. Peterson, and R. M. Kaminski editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock, Texas, USA.

Saunders, G. B., and D. C. Saunders. 1981. Waterfowl and their wintering grounds in Mexico, 1937–64. Volume 138. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C., USA.

Therneau, T. 2022. survival: Survival Analysis: a package for survival analysis in R. Version 3.3-1. https://CRAN.R-project.org/package=survival

VanBank, J. A. 2020. Migration, movement, and winter ecology of Midcontinent Greater White-fronted Geese. Dissertation. Texas A&M University - Kingsville, Kingsville, Texas, USA.

VanBank, J. A., M. D. Weegman, P. T. Link, S. A. Cunningham, K. J. Kraai, D. P. Collins, and B. M. Ballard. 2021. Winter fidelity, movements, and energy expenditure of Midcontinent Greater White-fronted Geese. Movement Ecology 9(1):1-15. https://doi.org/10.1186/s40462-020-00236-4

Webb, D. D. 2006. Temporal and spatial distribution on interior Alaska White-fronted Geese (Anser albinforks frontalis) during fall migration and winter staging. Thesis. University of Alaska Fairbanks, Fairbanks, Alaska, USA.

Wisz, M. S., R. J. Hijmans, J. Li, A. T. Peterson, C. H. Graham, A. Guisan, and NCEAS Predicting Species Distributions Working Group. 2008. Effects of sample size on the performance of species distribution models. Diversity & Distributions 14 (5):763-773. https://doi.org/10.1111/j.1472-4442.2008.00482.x

Xu, H. 2006. Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing 27:3025-3033. https://doi.org/10.1080/01431160600589179

Yépez Rincón, F. D. 2000. Winter ecology of the White-fronted Goose in the central region of Tamaulipas, Mexico. Thesis. Universidad Autónoma de Tamaulipas, Tamaulipas, Mexico.

Yépez Rincón, F. D. 2003. History and current trends of waste sorghum production and wintering geese in Mexico. Thesis. State University of New York, College of Environmental Sciences and Forestry, Syracuse, New York, USA.

Yépez Rincón, F. D., D. F. Lozano García, D. Webb, and M. Spindler. 2007. Variación especial y temporal del territorio invernal del ganso frente blanca Anser albilfrons en México. In D. F. L. García, S. C. González, and E. T. Garza, editors. SELPER en el Manejo de Recursos para el Desarrollo Sustentable, Capítulo México, Monterrey, Mexico.

Zuur, A., E. N. Ieno, N. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer, New York, New York, USA. https://doi.org/10.1007/978-0-387-87458-6
Appendix 1

Wetland name, location information, citation in which the wetland or wetland complex was identified as a conservation priority area in Mexico, and whether the wetland or wetland complex was used by GPS-tagged Greater White-fronted Geese during winters 2016–2018.

| Wetland or Wetland Complex Name | Region a | State                | Latitude   | Longitude   | Citation                                         | Used by GPS GWFG |
|---------------------------------|----------|----------------------|------------|-------------|-------------------------------------------------|------------------|
| Rio Grande Delta                | EGC      | Tamaulipas           | 25°81' N   | 97°81' W    | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | Yes               |
| Laguna Madre de Mexico          | EGC      | Tamaulipas           | 24°63' N   | 97°80' W    | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | Yes               |
| Laguna de Alvarado              | EGC      | Veracruz             | 18°62' N   | 95°76' W    | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | No                |
| Tamesí River and Pánuco River Deltas (Tampico Lagoons) | EGC      | Tamaulipas, Veracruz | 22°25' N   | 97°87' W    | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | No                |
| Tabasco Lagoons                 | EGC      | Tabasco              | 18°25' N   | 92°67' W    | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | No                |
| Laguna Tantiahua                | EGC      | Veracruz             | 21°62' N   | 97°56' W    | Saunders and Saunders 1981                       | No                |
| Laguna de Babícora              | IH       | Chihuahua            | 29°23' N   | 108°25' W   | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | No                |
| Laguna de Los Mexicanos         | IH       | Chihuahua            | 28°10' N   | 106°90' W   | Pérez-Arteaga et al.2005                         | No                |
| Laguna de Santiaguillo          | IH       | Durango              | 24°48' N   | 104°78' W   | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | No                |
| Ascensión                       | IH       | Chihuahua            | 31°05' N   | 107°55' W   | Pérez-Arteaga et al.2005                         | No                |
| Laguna de Bustillos             | IH       | Chihuahua            | 28°48' N   | 106°74' W   | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | No                |
| El Soldadito                    | IH       | Zacatecas            | 22°38' N   | 102°02' W   | Pérez-Arteaga et al.2005                         | No                |
| Languillo                       | IH       | Jalisco, Aguascalientes | 21°74' N   | 102°10' W   | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | Yes, 10-km buffer|
| Atotonilco El Alto, East Chapala and Lago de Chapala | IH | Jalisco, Michoacán | 20°43' N | 102°77' W | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | No                |
|                                 | IH       | Jalisco, Michoacán   | 20°20' N   | 102°30' W   | Saunders and Saunders 1981, Pérez-Arteaga et al.2005 | No                |
| Location                        | Code | Region          | Lat/Long         | Authors                         | Notes  |
|--------------------------------|------|-----------------|------------------|--------------------------------|--------|
| Cabadas                        | IH   | Michoacán, Jalisco, Guanajuato | 20°25' N 101°92' W | Pérez-Arteaga et al. 2005 | No     |
| Irapuato                       | IH   | Guanajuato      | 20°60' N 101°78' W | Saunders and Saunders 1981, Pérez-Arteaga et al. 2005 | No     |
| Presa Solís                    | IH   | Guanajuato      | 20°08' N 100°46' W | Pérez-Arteaga et al. 2005 | No     |
| Zacapu                         | IH   | Michoacán       | 19°92' N 101°63' W | Pérez-Arteaga et al. 2005 | No     |
| Lago de Pátzcuaro              | IH   | Michoacán       | 19°55' N 101°61' W | Pérez-Arteaga et al. 2005 | No     |
| Lago de Cuitzeo                | IH   | Michoacán       | 19°95' N 101°07' W | Saunders and Saunders 1981, Pérez-Arteaga et al. 2005 | No     |
| Lerma                          | IH   | Morelos, Mexico, Mexico City | 19°20' N 99°40' W | Pérez-Arteaga et al. 2005 | No     |
| Moreno                         | IH   | Jalisco         | 21°15' N 101°93' W | Saunders and Saunders 1981, Pérez-Arteaga et al. 2005 | No     |
| Presa Francisco I. Madero       | IH   | Chihuahua       | 28°11' N 105°69' W | Saunders and Saunders 1981 | No     |
| Lago Toronto                   | IH   | Chihuahua       | 27°51' N 105°54' W | Saunders and Saunders 1981 | No     |
| Presa Lázaro Cárdenas (El Palmito) | IH  | Durango        | 25°58' N 105°03' W | Saunders and Saunders 1981 | No     |
| Laguna de Zapotlán             | IH   | Jalisco         | 19°76' N 103°48' W | Saunders and Saunders 1981 | No     |
| Laguna de Yuriria              | IH   | Guanajuato      | 20°26' N 101°09' W | Saunders and Saunders 1981 | No     |
| Lagunas Oriental (llanos de San Juan, Puebla) | IH  | Puebla       | 19°28' N 97°61' W | Saunders and Saunders 1981 | No     |
| Leon                           | IH   | Guanajuato, San Luis Potosí, Zacatecas | 20°97' N 101°57' W | Pérez-Arteaga et al. 2005 | No     |
| Villa de Cos                   | IH   | Guanajuato      | 23°27' N 102°21' W | Saunders and Saunders 1981 | No     |
| Lago Don Martin                | NC   | Coahuila        | 27°48' N 100°68' W | Saunders and Saunders 1981 | No     |

*EGC = Eastern Gulf Coast, IH = Interior Highlands, NC= North Central*
Appendix 2

Top five models for wetland use intensity and wetland selection by GPS-tagged Greater White-fronted Geese in Mexico during winters 2016–2018.

Table A2.1. Top five linear mixed-effects models ranked by Akaike’s Information Criterion (AIC), differences in AIC from the top model (ΔAIC), model degrees of freedom (df), model weight (\(w_i\)), and marginal coefficient of determination (\(R^2_M\)) of factors influencing wetland use by Greater White-fronted Geese (Anser albifrons frontalis) in Mexico during winters 2016–2018.

| Rank | Model                                                                 | AIC   | ΔAIC  | df  | \(w_i\) | \(R^2_M\) |
|------|-----------------------------------------------------------------------|-------|-------|-----|---------|----------|
| 1    | Size + Habitat + Dist_Ag + Dist_Wetland + Dist_Wetland² + Dist_Ag*Habitat | 1076.75 | -     | 13  | 0.59    | 0.27     |
| 2    | Size + Habitat + Dist_Ag + Dist_Wetland + Dist_Ag*Habitat             | 1078.74 | 1.99  | 12  | 0.22    | 0.24     |
| 3    | Size + Size² + Habitat + Dist_Ag + Dist_Ag² + Dist_Wetland + Dist_Wetland² + Dist_Ag*Habitat | 1079.96 | 3.21  | 15  | 0.12    | 0.27     |
| 4    | Size + Habitat + Dist_Ag + Dist_Wetland + Size*Dist_Wetland          | 1082.45 | 5.70  | 10  | 0.03    | 0.18     |
| 5    | Size + Dist_Ag                                                        | 1083.02 | 6.27  | 5   | 0.03    | 0.08     |

Table A2.2. Top five conditional logistic regression models ranked by Akaike’s Information Criterion (AIC), differences in AIC from the top model (ΔAIC), and model degrees of freedom (df), factors influencing wetland selection by Greater White-fronted Geese (Anser albifrons frontalis) in Mexico during winters 2016–2018.

| Rank | Model                              | AIC   | ΔAIC  | df |
|------|------------------------------------|-------|-------|----|
| 1    | Habitat*Size                        | 1099.9 | 0     | 7  |
| 2    | Habitat*Size²                       | 1100.6 | 0.7   | 8  |
| 3    | Habitat*Size + Wetland Area + Ag. Area | 1103.8 | 3.9   | 9  |
| 4    | Size²                               | 1106.7 | 6.8   | 2  |
| 5    | Habitat*Wetland Area + Size + Ag. Area | 1107.2 | 7.3   | 9  |