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Aransas-Wood Buffalo Whooping Crane Abundance Survey (2011 – 2012)

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Message from the Authors

We have 2 objectives for generating this report. 1) To share information in a timely manner 2) To describe the progression of work involved in building a credible survey program for this population of whooping cranes between 2010 through present (September 2012). All data and conclusions contained in this report are preliminary and subject to revision. The assessment is provided on the condition that neither the U.S. Fish and Wildlife Service nor the United States Government may be held liable for any damages resulting from the authorized or unauthorized use of the assessment.

Introduction and Justification

The Aransas-Wood Buffalo population of Whooping Cranes (*Grus americana*) is the last wild migratory flock of the species. Twice yearly the population makes the >4000 km migration between their nesting territories near Canada's Wood Buffalo National Park and their wintering territories near the Aransas National Wildlife Refuge (NWR), Texas (Figure 1). Historically, whooping cranes existed at low densities throughout their range, until widespread habitat change coupled with unregulated shooting are thought to have caused the long-term population decline (Allen 1952). In 1941, the Aransas-Wood Buffalo population reached approximately 15 individuals, its lowest recorded size (CWS and USFWS 2007). In 1973, with the passage of the Endangered Species Act, the whooping crane was listed as an endangered species. The U.S. Endangered Species Act allows for the development and implementation of species recovery plans including down-listing criteria. According to the International Whooping Crane Recovery Plan, if no other self-sustaining populations can be established, the Aransas-Wood Buffalo population must consist of 1000 individuals and 250 reproductive pairs before the species can be considered for down-listing (CWS and USFWS 2007).

For over 60 years, an annual population "census", obtained through aerial surveys, has been the primary metric with which the U.S. Fish and Wildlife Service (USFWS) has monitored the population's recovery. The importance of these surveys is seemingly self-evident. However, after objective critique it is apparent that, as with all surveys, these surveys are not important in and of themselves. Instead, the value of aerial surveys of whooping cranes lies in their applicability as a tool to measure recovery and bolster conservation efforts. Further, the value of these surveys is directly and positively related to how effectively the data they provide can be used to inform decisions affecting the conservation or management of whooping cranes. Therefore, it is incumbent upon the USFWS to frequently and objectively critique the methods we use to measure the effects of conservation or management actions, especially for endangered species such as whooping cranes. Indeed, it is USFWS policy to use the most appropriate, best available, high quality scientific and scholarly data and information to support the mission of the Department. (Department of the Interior 2011a). Furthermore USFWS policy states that scientists should "welcome constructive criticism of [their] scientific and scholarly activities" (Department of the Interior 2011a).

In 2011, the USFWS conducted an internal review of the all facets of the survey to determine if the wintering whooping crane surveys were meeting their objectives and providing the greatest benefit to species recovery. The review evaluated the survey's design to identify its sources and level of bias (distance between results and truth), factors influencing its level of precision (repeatability of results) as well as data storage and reporting procedures. The review was based on Stehn and Taylor's (2008) description of methods used from 1982-2011, as well as surveys conducted during the 2010-2011 winter by T. Stehn and B. Strobel. From this review, the USFWS identified multiple modifications that would improve the survey's scientific rigor and value. These modifications are being incorporated into an official survey protocol and will receive professional peer review upon completion. In the interim, this document provides an update to the stakeholders interested in the recovery of whooping cranes and the methods used to monitor the Aransas-Wood Buffalo population.

Previous Methods (1950-2011)

Description

In 1950, when whooping crane aerial "census" efforts began, all territories were located on the Blackjack Peninsula (Stehn and Johnson 1985). The survey was coined a "census" as it was assumed that every bird in the population was seen. At that time, a sampling frame was not strictly defined and spatially-explicit search effort was not recorded. However, effort of "census" flights was allocated to areas cranes were either observed previously or where they were haphazardly observed by refuge staff and public. Since 1950, whooping cranes have recolonized several adjacent areas (Figure 1; Stehn and Prieto 2010). Although no formal mechanism existed for expanding the "censused" area, in recent years flights were typically conducted over portions of the Blackjack Peninsula, Lamar Peninsula and Matagorda Island, San Jose Island and Welder Flats/Dewberry Island. Flight paths of the aircraft were spaced approximately 250-800 meters apart. Distances between paths changed between surveys, depending upon the observer's confidence that they detected all individuals on the path. The flight path of the aircraft was deviated, if necessary, to distinguish between adult versus juvenile whooping cranes. Survey duration was typically between 5-6 hours with a rest break between blocks during which surveyors returned to the Aransas County Airport. Survey methods were generally adapted to daily weather conditions, personnel availability, and whooping crane abundance. For example, the type of airplane used, area-specific search effort, altitude and flight speed all varied within and across surveys and years. These "metadata" were infrequently recorded and represent potential sources of survey bias.

Surveys were conducted with 1 observer and the pilot. The observer typically allocated their attention to the side of the plane away from the sun (Stehn and Taylor 2008). Upon detecting a crane, the observer would mark the individual's location on a 1:46,080 DOQQ (1997-2001) or hand drawn line map (1950-1997). Crane groups were marked on the hard copy map based upon the number of white plumaged birds and juvenile birds (e.g., "2+1" indicated 2 white birds and 1 juvenile). White plumaged birds were considered after hatch year birds (hereafter, adults). Each survey map was hand tallied after the completion of the survey and the total number of adults and juveniles on each map were summed. The total number of cranes detected varied among surveys within a year. The variability among surveys was likely caused by immigration and emigration of cranes to and from the surveyed area, difference in detectability, and observer errors. Crane sightings reported by the public led to conclusions of the minimum number of whooping cranes assumed to have been outside of the sampled area. The "peak population size" reported each year was obtained by adding the highest number of cranes detected during a given survey to the number of birds assumed to have been undetected within the surveyed area, or outside of the surveyed area at the time the survey was conducted.

Whooping cranes wintering on and around Aransas NWR, demonstrate territoriality and site fidelity within and across winters (Stehn and Johnson 1985, Bonds 2000). The fidelity of whooping cranes to their wintering territory has been used in conjunction with group structure as a surrogate for individually marked birds. Groups of equal size found in similar areas on subsequent surveys were assumed to be the same individuals. This information was used to identify circumstances where distinct groups, or individuals within groups, were not detected and therefore additional search efforts were conducted (Stehn and Taylor 2008). Group structure and location data was also used to assume mortality of individuals. For example, subsequent observations of a group of 1 adult and 1 chick where previous surveys located a group of 2 adults and 1 chick resulted in the presumption that 1 adult had died.

Review

Prior to 2011-2012 winter surveys were assumed to be "censuses" that documented all individuals in the population (complete enumeration). True population censuses are exceptionally difficult to achieve with natural free ranging populations for two primary reasons. First, most study areas are too large to sample completely within a short enough time frame to ensure no individuals enter or exit the survey area (Morrison et al. 2008, Conroy and Carroll 2009). Second, various circumstances including the behavior of individuals, vegetation density, observer fatigue and field methodology typically result in the probability of detecting individuals that are within the survey area being less than 1 (Krebs 1999, Buckland et al. 2001, Williams et al. 2002, Morrison et al. 2008, Conroy and Carroll 2009). Stehn and Taylor (2008) recognized that these conditions may bias the results from population "census" attempts but did not provide recommendations to address them. The review of the aerial survey methods resulted in the identification of major and minor concerns.

Major Concerns

- <u>No Survey Protocol Exist</u> - *Although whooping crane surveys have been conducted for over 60 years a formal protocol including: survey objectives, survey methods, sampling frame, data analysis and reporting procedures was never completed. These components are fundamental to defensible inference from surveys. A new comprehensive survey protocol is currently under development and should be completed by November 2012.*

- <u>Survey Objectives were Undefined</u> - *Post-hoc definitions of survey objectives included (1) recording peak population abundance, (2) enumerating paired adults, (3) calculating annual recruitment, (4) enumerating winter mortalities, and (5) reporting habitat use. The methods employed did not allow each of these objectives to be attained defensibly.*

- <u>Results were Influenced by Observer's Discretion, Judgment and Perception</u> - *Survey methods and subsequent results were dependent upon the observers experience and judgment. As such the methods were not directly repeatable by subsequent observers or on subsequent flights. This flaw is manifested in multiple ways described below.*

    - <u>Lack of Standardization and Randomization</u> - *Inconsistencies in altitude, flight speed, transect location and search effort limited the inference that can be made across surveys. Furthermore, the order with which transects and areas were surveyed was convenience based and did not utilize basic techniques to minimize bias such as systematic or random sampling.*

    - <u>Search Effort was Inconsistent and Unrecorded</u> – *Search effort was inconsistently and disproportionately allocated based upon observers experience (i.e., higher effort was allocated to families with 2 chicks versus those with 1 chick and to predictably occupied territories versus sporadically occupied territories). The absence of search effort data results in post-hoc assumptions regarding the* *validity of "null" detections. In other words, it is unclear if locations where cranes were not recorded were searched.*

  - Inconsistent Incorporation of Ancillary Data – *Reports of birds sighted outside of the surveyed area were incorporated into the data collected from aerial surveys in unclear and inconsistent ways. These practices caused inconsistences among reported datasets and eroded the credibility and value of the dataset.*

- Assumed Individuals Do Not Leave Their Territories – *Much of the interpretation of these data hinge upon the assumption that location (i.e., territory) are defensible surrogates for individually marked birds. In other words, data were interpreted under the assumption that birds did not leave their territories. Therefore, a bird that was presumed to be absent from its territory during multiple surveys was assumed to have died. This assumption of territoriality is unnecessary and untenable given recent data.*

- No Defensible Estimates of Precision or Bias - *Previously employed methods are not based on a statistically defensible sampling design and therefore cannot provide meaningful measures of precision. It is USFWS policy to recognize that uncertainty is inherent in science, and the agency considers data as well as their associated uncertainty in the management and conservation of species and their habitats (Department of the Interior 2011b).*

- Imperfect Detection of Individuals - *Observation specific characteristics (i.e., distance from aircraft, group size, plumage coloration) as well as survey specific characteristics (i.e., type of aircraft, sun angle, observer skill) were suspected to influence the probability of detection but were not addressed prior to interpretation of the data. Several methods exist for determining how aerial survey results are affected by the detectability of wildlife under various characteristics (Pollock and Kendall 1987, Conroy et al. 2008, Green et al. 2008).*

Minor Concerns

- Metadata Were Not Recorded – Attributes such as *survey effort, time, aircraft type, pilot used, and weather conditions are potentially valuable covariates affecting the data collected on a given survey. These and other covariates are stipulated within the protocol to be recorded on all future surveys.*

- Inefficient and Insecure Data Storage Methods – *Once collected and tallied, these data were stored in their original hardcopy form and filed at Aransas NWR. These data were vulnerable to loss through catastrophic events (e.g., fire, hurricane). Presently, all historic data have been captured digitally. The new survey protocol will stipulate data to be stored in digital format and backed-up off-site.*

- Inefficient Use of Spatial Data – *Survey methods collected spatial locations of observed whooping cranes. When analyzed using appropriate statistical techniques these types of data can provide valuable insight into resource use and ecology of species and therefore provide a rigorous mechanism to direct conservation efforts. The survey analysis protocol will incorporate methods to develop resource selection models from these data.*

- Elimination of Unnecessary Mid-survey Breaks – *To minimize the bias caused by the movement of individuals during a survey, the survey duration will be kept to a minimum.*

- Distribution of Non-peer Reviewed Data/Interpretations – *USFWS policy states that employees must "differentiate among facts, personal opinions, assumptions, hypotheses, and professional judgment in reporting the results of scientific and scholarly activities and characterizing associated uncertainties in using those results for decision making, and in representing those results to other scientists, decision makers, and the public"*(Department of the Interior 2011a). *Previous reports of the whooping crane 'census' contained individual assumptions and biases, that did not allow differentiation between data and interpretations. Future reports will clearly differentiate facts from interpretations. Moreover, many facets of this program will rely on the peer review process to ensure that the methods and information reported are credible.*

Improvements in Survey Methods

Developing Survey Protocol

A formal whooping crane survey protocol is in development. This protocol will be submitted for professional peer review to ensure that the methods are appropriate, scientifically defensible and professionally valuable. The survey protocol will describe measurable survey objectives, sampling design, field methods, data management, data analysis, and reporting procedures. Reviewer recommendations will be addressed prior to the finalizing the protocol. Below, we provide a synopsis of the improved survey.

Survey Objectives

1. Provide a scientifically defensible estimate of the annual peak abundance of the Whooping Crane population within the surveyed area, on and around Aransas NWR, with precision enough to detect population declines that will substantially reduce the probability of the population reaching their down-listing goal by 2035 (CWS and USFWS 2007).

2. Calculate the proportion of detected Whooping Crane groups considered "pairs" (i.e., 2 white-plumaged birds) and "recruitive pairs". (i.e., A pair with at least 1 young-of-the-year)This information provides an index for the number of "paired" birds that successfully recruited juvenile birds into the population wintering within the surveyed area.

3. Utilize data collected to meet Objective 1, to provide an estimate of the annual recruitment rate of juvenile whooping cranes that enter into this population wintering within the surveyed area.

4. Create spatially explicit resource selection models to predict abundance of whooping cranes in relation to local characteristics (e.g., vegetation type, patch configuration, water quality, food availability, etc.) for use in conservation planning efforts.

Standardizing Data Collection

<u>Definition of Sampling Frame</u>

A clear definition of the spatial and temporal aspects of a survey (i.e., sampling frame) determine the sampled population and are imperative to defensible inferences from survey data (Jeffers 1980, Scheaffer et al. 1996, Garton et al. 2005, Morrison et al. 2008, Conroy and Carroll 2009). In the recent years before 2011, surveys were typically conducted over portions of the Blackjack Peninsula, Lamar Peninsula, Matagorda Island, San Jose Island and Welder Flats/Dewberry Island where territories were known to occur. The boundaries of these areas are the basis for formally defining the sampling frame. We divided the sampling frame divided into 2 strata: Primary Sampling Frame (PSF) and Secondary Sampling Frame (SSF). Each strata is comprised of several "regions" (Table 1). Regions within the PSF were designated based on recent data indicating that these places are occupied by multiple groups of whooping cranes annually. Regions within the SSF are not used consistently by whooping cranes but have either been occupied periodically in recent years, or appear to have suitable whooping crane habitat and may become occupied consistently if whooping crane populations increase.

<u>Survey Logistics</u>

We standardized survey logistics and incorporated randomized sampling into survey protocol, to improve the consistency of survey data and reduce methodological biases We standardized survey altitude and flight speed to 60 meters and 90 knots, respectively, as suggested by Stehn and Taylor (2008). We established transects 1 km apart to provide a uniformly high search effort in each region. Within each region, transects are sequentially numbered from the mainland toward the Gulf of Mexico. On a given survey flight, all transects within a region will be surveyed. The region where each survey starts will be selected at random. Transects within regions will be surveyed chronologically in ascending or descending order, depending on whichever approach is most efficient, safe and logistically beneficial (Figure 2).

To meet the first objective of the survey (i.e., "Provide a scientifically defensible estimate of the annual peak abundance of the Whooping Crane population within the surveyed area.") survey effort will be focused on the period when this peak is most likely to occur. Historically this occurs during the last 2 weeks of November (Figure 3). We recommend that estimates of "peak" whooping crane abundance within the sampling frame should be estimated between 28 November and 26 December annually.

To standardize search effort and increase data collection efficiency each survey will be conducted by 2 observers and a pilot. Although the pilot is not considered an observer in the survey, they are encouraged to communicate their observations. Upon detecting a crane, the observer will determine whether the individual is a juvenile or adult bird based upon its plumage coloration. Then, observers record the bird's location using a touch screen laptop equipped with a wireless GPS, and a GIS displaying 1-meter resolution satellite imagery. At a minimum, data collected on each survey will include the spatial location of cranes, the age class of detected birds (i.e., juvenile, adult or unknown age class) and the track that the aircraft flew.

To avoid inconsistent detection caused by low sun angles, surveys will be conducted between 10:00 and 15:00 hours, or under high overcast conditions. Movement of individual birds during a survey can bias survey results by causing individuals present during the survey to be missed or counted more than once (Granholm 1983). However, without extensive experimentation and individually marked birds, determining the level of bias caused by movement of individuals is difficult. The potential bias caused by the movement of individuals can be reduced by minimizing survey duration. To minimize the duration of each survey, “off-transect” excursions and “rest breaks” will be kept to a minimum.

Addressing Imperfect Detectability

Analysis of Historic Data

We used data collected by T. Stehn and B. Strobel during aerial surveys of whooping cranes during the winter of 2010–2011 to evaluate the feasibility of distance-based sampling methods to account for imperfect detection of whooping crane groups. We followed survey protocols established by Stehn and Taylor (2008) except we collected whooping crane group locations and the aircraft’s flight track with a global positioning system (GPS) unit, and measured distance from detected groups to the transect in a geographic information system (GIS). We used those detections and distances in a conventional distance sampling analysis (Thomas et al. 2010) to estimate encounter rates and model detection probabilities. These analyses revealed three key findings:

- ≈95% of detected whooping crane groups were within 500 meters of the transect; suggesting that line transects could be spaced systematically at 1,000 meter intervals.
- The detection curve estimated from these data indicated that distance sampling was a tractable approach to account for imperfect detectability.
- The survey techniques of Stehn and Taylor (2008) were unlikely to provide a complete census of whooping cranes overwintering around Aransas NWR.

We determined that accounting for imperfect detectability of whooping cranes is necessary to provide an accurate estimate of the population within the surveyed area. However, because the previously employed methodology did not rigorously fit assumptions of conventional distance sampling, the level of precision could that be expected from implementing conventional distance sampling methods for whooping cranes was unclear. Therefore, we implemented a pilot study during the 2011-2012 winter to determine the survey effort required to obtain the desired level of precision.

Experimental Decoy Surveys

Decoys have frequently been used to estimate the bias and precision of aerial surveys for birds (Smith et al. 1995, Butler et al. 2007, Pearse et al. 2007, Butler et al. 2008) including whooping cranes (Howlin et al. 2008). Using decoys as surrogates allowed these researchers to ensure sample sizes are adequate to evaluate each experimental factor. Therefore, we implemented experimental surveys of decoys to understand the factors affecting the detectability of whooping cranes wintering on the Texas coast. We painted sandhill crane (*Grus canidensis*) decoys to resemble adult and juvenile whooping cranes (i.e., painted white or tawny respectively). We conducted aerial surveys of the decoys during September 2011 from an amphibious Kodiak (Quest Aircraft Company, Sandpoint, ID). We deployed the decoys on the Blackjack Peninsula at Aransas NWR at randomly selected locations >1,000 meters apart. Observers on the survey were naïve to the location and arrangement of the crane decoys.

We developed models to evaluate the impact of distance from the transect, group size, observer experience, and sun position on the detection probability of crane groups. We used logistic regression to model decoy group detectability (Hosmer and Lemeshow 2000, SAS Institute 2004). We selected the best model(s) using Akaike's Information Criteria corrected for small sample size (AIC_c, Burnham and Anderson 2002).

We conducted 4 surveys of whooping crane decoys with an average of 104 decoys. Our best model indicated detectability was influenced by group size, distance, and sun position. It indicated detectability was 2.7 times greater when the sun was overhead and 3.9 times greater when the sun was at the observers back than when it was in the observer's eyes. The detectability of whooping crane decoy groups was positively associated with group size and negatively associated with the distance from the observer. These analyses uncovered several potential sources of bias, and helped us develop recommendations for addressing these biases in the survey protocol:

- Detectability of whooping crane decoys was imperfect. - *This result provided further evidence that the method used to survey whooping cranes must account for imperfect detectability.*

- Sun angle influenced detectability of whooping crane decoys. – *Detection probabilities were most predictable under high sun conditions when lighting is even regardless of the direction the observer is facing. When the sun was at low angles, detectability was high on one side of the aircraft but poor on the other.*

- Use of reference marks on the aircraft's struts did not facilitate accurate measurement of distances to whooping crane decoys. - *Although apparently useful in other aerial surveys, in our situation, the sight reference marks on the aircraft struts did not provide distance measures (between the observer and cranes) at the required accuracy. Therefore, we incorporated improved methods to measure distance in the survey protocol.*

- Observer experience was positively associated with correct identification of whooping crane decoys. - *Inexperienced observers will be provided identification training prior to collecting actual survey data. Therefore, an organized training procedure will be incorporated into the protocol to improve the continuity of data collection.*

- Methods produced relatively low bias and high precision. - *When compared to the actual number of whooping crane decoys present in the surveyed area the conventional distance sampling analyses provided accurate estimates. Therefore, we have continued to develop distance sampling methods for aerial whooping crane surveys.*

- Avoid using aircraft equipped with floatation pontoons. - *Use of airplane equipped with floatation pontoons during experimental decoy surveys impeded detection of decoy groups near the transect.*

Application of Methods during Winter 2011-2012

The results presented below are derived from data collected within the PSF (Figure 2) during the winter of 2011-2012 and therefore do not represent the entire Aransas-Wood Buffalo population.

We conducted surveys on 26, 27, 29 January; 2012, 6, 25, 26 February 2012; and 31 March 2012. All regions within the PSF (Figure 2) were surveyed on each survey-day except 26 January, during which only the Blackjack and Lamar-Tatton regions were surveyed before gusty winds resulted in terminating the survey. During the surveys conducted on 26, 27, 29 January, a total of 156 groups of whooping cranes were observed within the PSF on 1,343 km of transect. During the 6 February survey 60 whooping crane groups were detected within the PSF on 588 km of transect. During the 25, 26 February surveys 119 whooping crane groups were observed within the PSF on 1,238 km of transect. During the survey conducted on 31 March, 43 whooping crane groups were detected within the PSF on 556 km of transect.

Low tides and the exceptional drought conditions occurring through the sampling frame during the 26, 27, 29 January and 6 February surveys resulted in the tidally influenced water receding and leaving exposed mud flats. Concurrently, whooping crane groups were widely and more evenly distributed throughout the sampling frame. Precipitation occurring in February and the typical resurgence of tides resulted in the inundation of most tidally influenced water bodies during the 25, 26 February and 31 March surveys. Potentially in response to prey resources, whooping crane groups appeared to be clustered in the marsh vegetation-communities during latter surveys.

Objective 1: Estimating Annual Peak Abundance within the Surveyed Area

All evidence suggests that, in recent years, observers on aerial surveys were unlikely to detect all whooping cranes within the surveyed area. Distance sampling is a tractable, widespread approach used to correct for the bias that results from imperfect detection (Buckland et al. 2001, Buckland et al. 2004, Thomas et al. 2010). The conventional distance sampling (CDS) methods used to analyze the decoy detection experiment, provided tractable estimates of abundance when applied to actual whooping crane survey data collected during the 2011-2012 winter. However, variance estimates with CDS methodology can be inflated when the population being surveyed is not distributed evenly across transects (i.e., selecting specific habitat types or areas).

Fortunately, recent theoretical advances (i.e., hierarchical distance sampling models, HDS) have resulted in models that explicitly consider relationships between population density and environmental covariates resulting in spatially-explicit models of abundance (Hedley and Buckland 2004, Royle et al. 2004, Chandler et al. 2011, Sillet et al. 2012). Using spatially explicit covariates (i.e., percent coverage of saltmarsh, presence of freshwater, etc.) these models simultaneously estimate the abundance of cranes at a given site as well as the probability that they are detected by the observers.

Disproportion use of particular habitat features occurs frequently when whooping crane groups are associating with vegetation communities or other covariates that are not evenly distributed across the landscape (e.g., transects across coastal marsh versus prairie communities). Under such circumstances, HDS models are attractive because they exploit the relationship among animal abundance and environmental conditions to improve the precision of abundance estimates. During the analysis stage we evaluated the advantages of spatially explicitly models of abundance such as improved precision (Katsanevakis 2007) and inferences about resource use (Royle et al. 2004, Chandler et al. 2011, Sillet et al. 2012) by comparing results from CDS and HDS methods for whooping cranes.

To implement the HDS methods, each transect was divided into 1-km^2 cells. To provide general "habitat" covariates within each 1-km^2 cell, we used the Texas Ecological Systems Classification Project data (TESCP, Texas Parks and Wildlife Department 2012). We pooled vegetation communities recognized in the TESCP dataset into 5 course categories: upland, saltmarsh, shrub dominated saltmarsh, freshwater wetlands and open-water. We tested for correlation among the 6 vegetation community covariates and constructed ecologically meaningful models using uncorrelated covariates (Zar 1999). We used those covariates to develop models representing specific hypothesis about whooping crane habitat use. We analyzed the whooping crane survey data using the "distsamp" function of package "unmarked" in program R (Fiske and Chandler 2011, R Development Core Team 2012), which fit the multinomial-Poisson mixture model of Royle et al. (2004). We selected the best model(s) based on Akaike's Information Criterion (AIC; Anderson and Burnham 2002, Burnham and Anderson 2002, Anderson 2008). We then used the best-supported model (or suite of models, averaged) to estimate the abundance of whooping crane groups present within each 1-km^2 cell. The number of individuals is easily estimated as the estimated number of groups multiplied by mean group size. The average number of cranes per detected group ranged from 2.53-2.56, depending on the survey.

Percent CV was generally negatively related to the survey effort (i.e., precision increased with the number of kilometers of transect flown). Hierarchical distance sampling analyses produced greater precision relative to CDS for all surveys analyzed. However, the magnitude of increase in precision provided by HDS methods was greatest when cranes appeared to be associated with specific vegetation communities (e.g., 25, 26 February 2012). That is, when cranes were more evenly distributed among transects, HDS methods only improved precision marginally. Although HDS methods require slightly more data preparation and are more computationally intensive, we suggest that the increased precision they provide warrants adoption of the technique for the analyses of future survey data. Additionally, HDS methods can yield a better understanding of the ecological processes driving habitat selection by wintering whooping cranes, which in-turn can provide important tools for conservation (See Objective 4 below).

<u>The peak estimated whooping crane abundance within the sampled area occurred on 26, 27, 29 January.</u> During this survey a total of 156 groups of whooping cranes were observed on 1,343 km of transect. The best-supported HDS model from the 26, 27, 29 January data indicated the percent of salt marsh within each grid cell was positively associated with the abundance of whooping crane groups (Figure 5). <u>The model-averaged predictions indicated 96 groups and 254 (12.6% CV) whooping cranes were present within the PSF.</u> This estimate was obtained nearly a month later than the historic data suggest the peak population arrives on the wintering grounds (Figure 3). Therefore, it is possible that some mortalities occurred on the wintering grounds prior to the survey on 26, 27, 29 January 2012. Furthermore, multiple birds were sighted outside

of the PSF throughout the winter. It is not possible to know the exact number of cranes outside of the PSF during the 26, 27, 29 January survey. However it is unlikely that the entire population of whooping cranes was within the PSF during the 26, 27, 29 January survey and therefore the estimated abundance within the PSF is less than the total abundance of this entire population.

Objective 2: Estimating the Number and Reproductive Status of Pairs

The International Recovery Plan for whooping cranes (CWS and USFWS 2007) identified the number of productive pairs as one metric in which down-listing decisions will be based. The International Recovery Plan defines a productive pair as “a pair that nests regularly and has fledged offspring” (CWS and USFWS 2007:xii) and distinguishes productive pairs from breeding pairs which are defined as “a pair that breeds or is intended to breed in the future” (CWS and USFWS 2007:38). Regardless of the subjective nature of such definitions, identification of all productive pairs (i.e., pairs that fledge a chick) on the wintering grounds is impossible since, some juveniles die prior to arriving on the wintering grounds. Furthermore, these definitions hinge upon the positive identification of individual pairs across multiple years, which would be confounded by individual birds changing mates. However, the number of whooping crane “pairs” can be estimated based on the proportion of detected groups that meet this criterion. Also, the number of pairs that recruited a juvenile into the wintering population (i.e., “recruitive pairs”) can be estimated based on the proportion of detected groups containing juveniles. Unlike the previous definitions of “productive pair” and “breeding pair” our definitions of “pair” and “recruitive pair” are less ambiguous and do not require unique identification of cranes or groups of cranes. We calculated these estimates for the population within the PSF for the 2011-2012 winter.

We used data collected on the 26, 27, 29 January surveys to estimate the number of pairs and recruitive pairs in the population. We estimated the number of pairs in the sampled population as the proportion of whooping crane groups comprised of 2 white-plumaged birds. We estimated the number of recruitive pairs in the sampled population as the proportion of the whooping crane groups detected that contained at least 1 young-of-the-year. Whooping cranes typically orient themselves in pair-specific territories which are spatially distinct from adjacent pair’s territories. The segregation of whooping crane pairs into territories typically results in detected groups representing distinct “families”. Occasionally, detected groups of whooping cranes are comprised of more than 4 individuals that likely represent multiple “families” or non-breeding sub-adults. When groups of whooping cranes were detected that were >4 individuals and contained at least 1 juvenile we only considered the data to represent 1 recruitive pair. Furthermore, we were unable to determine the age of all individuals within each group due to their distance from the aircraft, lighting, etc. Therefore we excluded groups from the analysis that had both individuals of undetermined age and no juveniles detected. We estimated the uncertainty (i.e., % CV) associated with the estimated number of pairs and recruitive pairs using conventional parametric bootstraps.

Of the 96 whooping crane groups estimated to be present during the 26, 27, 29 January survey, 50 groups (12.9 % CV) were paired adults without juvenile and 25 groups (17.7 % CV) were recruitive pairs. It is possible that differences in the rate at which we can identify adults and juveniles may bias the estimates number of pairs or the number of recruitive pairs. However, preliminary analyses of the data collected during the experimental surveys of decoys did not suggest significant differences in detection probabilities of white and tawny colored decoys.

Objective 3: Estimating the Annual Winter Recruitment Rate

We indexed annual winter recruitment as the ratio of juveniles to adults during the peak population period (late-November through late-December). We used the multiple samples with replacement ratio estimator where each survey represents a sample (Skalski et al. 2005). Analyses of previously collected data suggested that the variance of estimated juvenile to adult ratios is low (Figure 4). This will allow adequate power to meet objective 3 prior to having adequate power to meet objective 1. The juvenile to adult ratio estimated from 1980-2011 ranges by nearly an order of magnitude (≈0.025-≈0.25). The juvenile to adult ratio for 2011 was 0.15 (95% CI, 0.136-0.174), which is similar to those calculated over the past 30 years. This metric may provide a valuable index to reproduction. Analyses investigating this are on-going.

Objective 4: Resource Selection Models for Whooping Crane Conservation

Hierarchical distance sampling methods capitalize on the relationship between whooping crane groups and spatially-explicit variables (e.g., vegetation communities, prey resources, human disturbances, etc.) to improve the precision of population abundance estimates. However, the resource selection models that HDS methods use to improve abundance estimates, may be more important to the conservation of whooping cranes than the abundance estimates themselves (i.e., Objective 1). Understanding the habitat characteristics whooping cranes prefer and the distribution of those characteristics on the landscape can provide a valuable tool to guide land protection and habitat conservation efforts. The resource selection models developed for the analysis of the 2011-2012 winter's data utilized course vegetation community covariates. In the future models could be developed to describe complex population-level patterns in habitat selection that will refine our understanding of whooping crane ecology, habitat management and conservation. For example, models could be developed to explore interactions of vegetation communities and management actions (e.g., comparing whooping crane abundances within burned uplands, grazed uplands and unperturbed uplands), inter-annual interactions between weather patterns and vegetation communities (e.g., comparing whooping crane abundances within burned uplands during high precipitation years versus low precipitation years). Furthermore, if measured covariates are available across a wide area, well developed models can be spatially extrapolated (extended beyond the boundaries of the sampling frame) to provide a quantitative means of prioritizing habitat conservation efforts. A further extension of these models could include temporal extrapolation of the resource selection models (e.g., evaluating where high quality whooping crane habitat will be under various sea-level rise scenarios) to forecast future habitat use and population distribution.

To demonstrate the potential application of these models we conducted a spatial extrapolation of the "best-supported" models from the surveys conducted on 26, 27, 29 January and 25, 26 February 2012. We created an arbitrary prediction grid in ArcMap covering approximately 4,500 km^2 around Aransas NWR. We used the TCES vegetation data and the "predict" function in package "unmarked" to estimate the local abundance of whooping cranes groups within each 1-km^2 cell. We then displayed the values predicted by "best-supported" model(s) from 26, 27, 29 January 2012 (Figure 5) and 25, 26 February 2012 (Figure 6) as quantities within the cells. Direct conclusions from such extrapolated models are unfounded, and the extrapolated predicted values cannot be interpreted as the current or future abundance of whooping crane groups. Instead, the extrapolated predicted values are useful as an index of the relative probability of use by whooping crane groups.

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Table 1. Survey regions within the sampling frame designated by the wintering whooping crane survey protocol

REGION	ACRONYM	HECTARES	STRATUM
Blackjack Peninsula	BJ	9855	Primary
Lamar Peninsula / Tatton	LT	7073	Primary
Matagorda Island, Central	MIC	9016	Primary
Matagorda Island, West Marsh	WM	6729	Primary
San Jose Island	SJ	11548	Primary
Welder Flats/Dewberry Island	WF	12936	Primary
Guadalupe Delta	GD	6915	Secondary
Holiday Beach	HB	3053	Secondary
Matagorda Island, North	MIN	5757	Secondary
Mission Bay	MB	2578	Secondary
Port Bay	PB	5314	Secondary
Powderhorn Lake	PL	7046	Secondary
	TOTAL	57158	Primary
	TOTAL	30663	Secondary

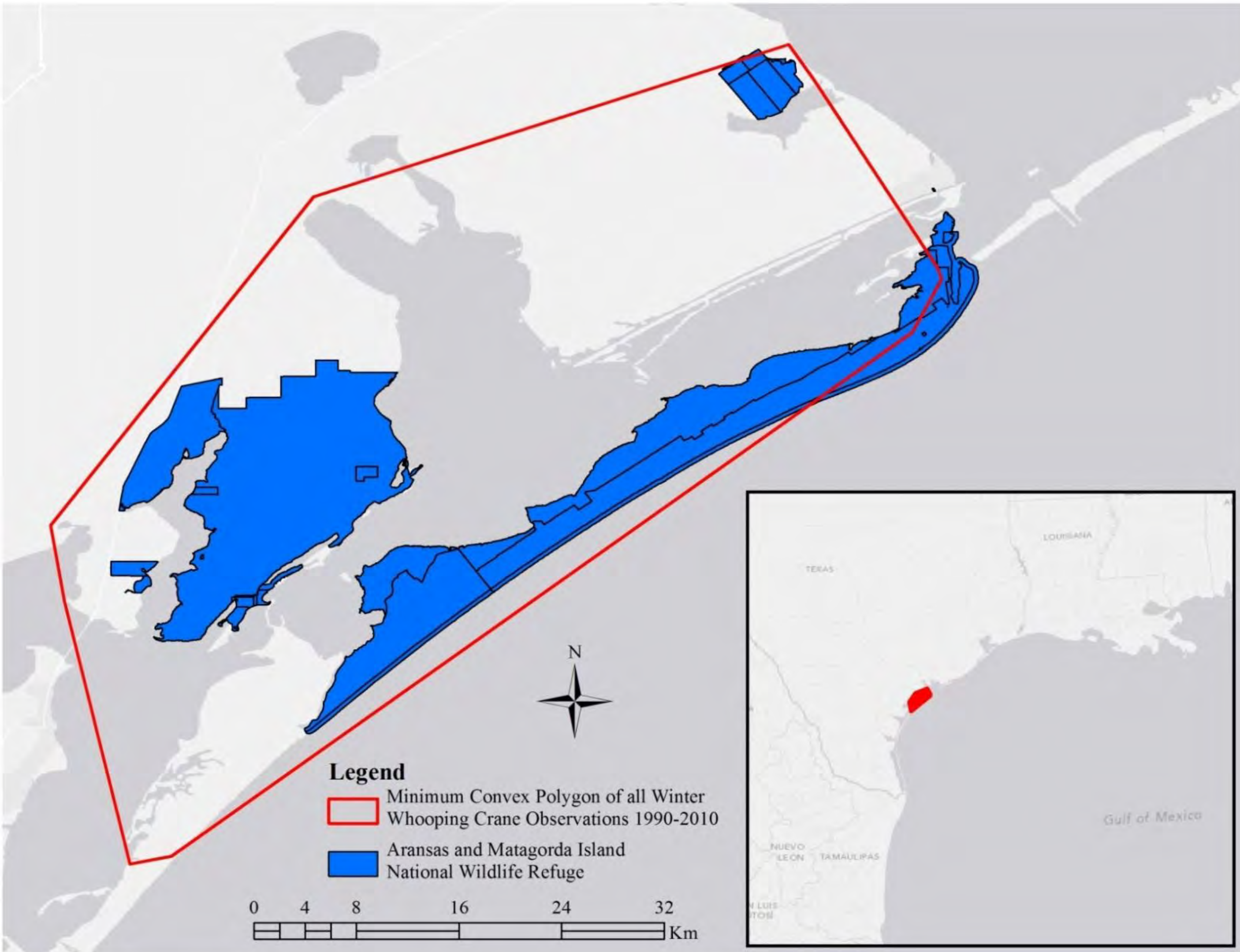

Figure 1. Aransas National Wildlife Refuge and surrounding areas inhabited by wintering Whooping Cranes. Aransas, Calhoun, Refugio Counties, Texas.

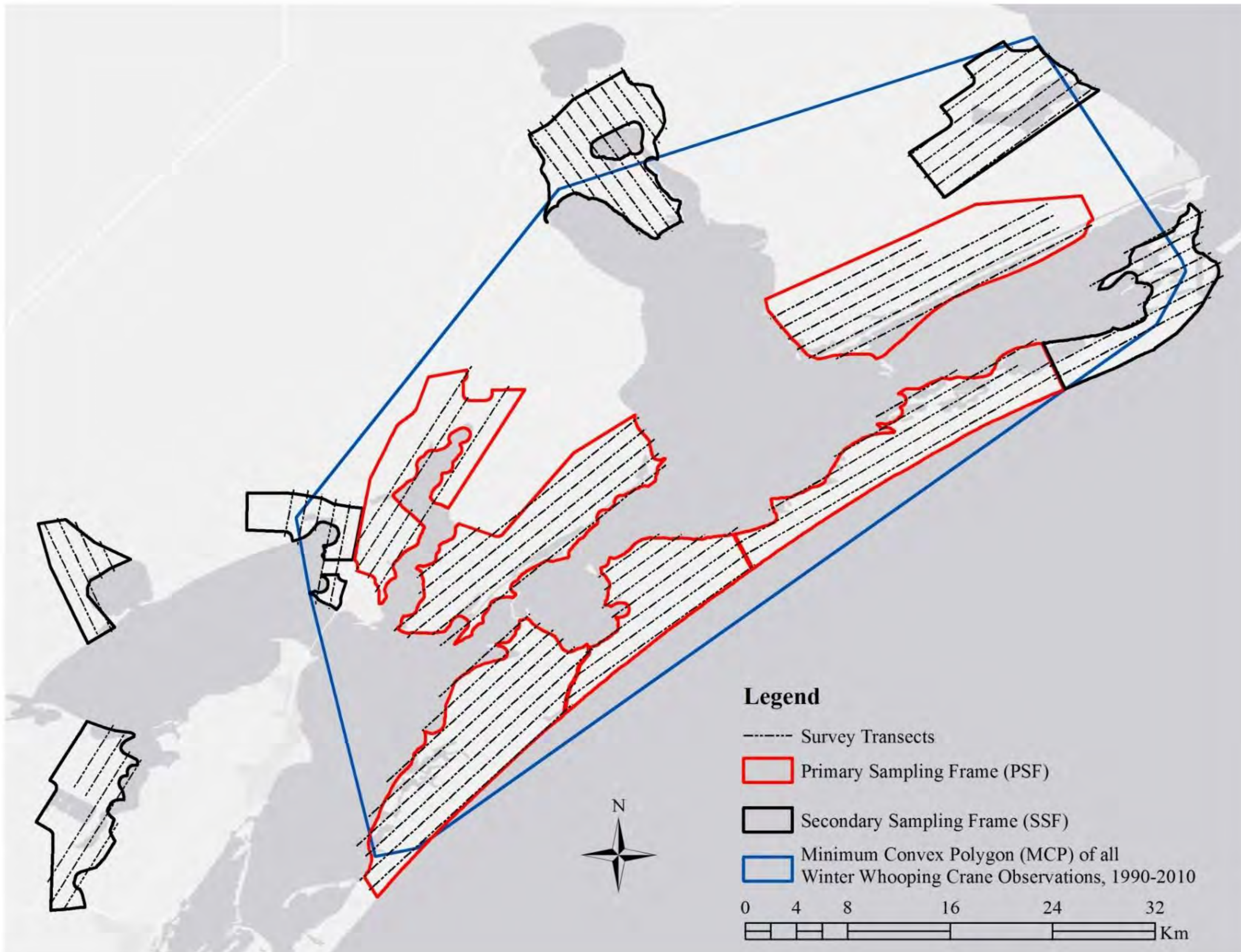

Figure 2. Sampling frames and transects delineated for conducting aerial surveys of whooping cranes wintering along the Texas coast.

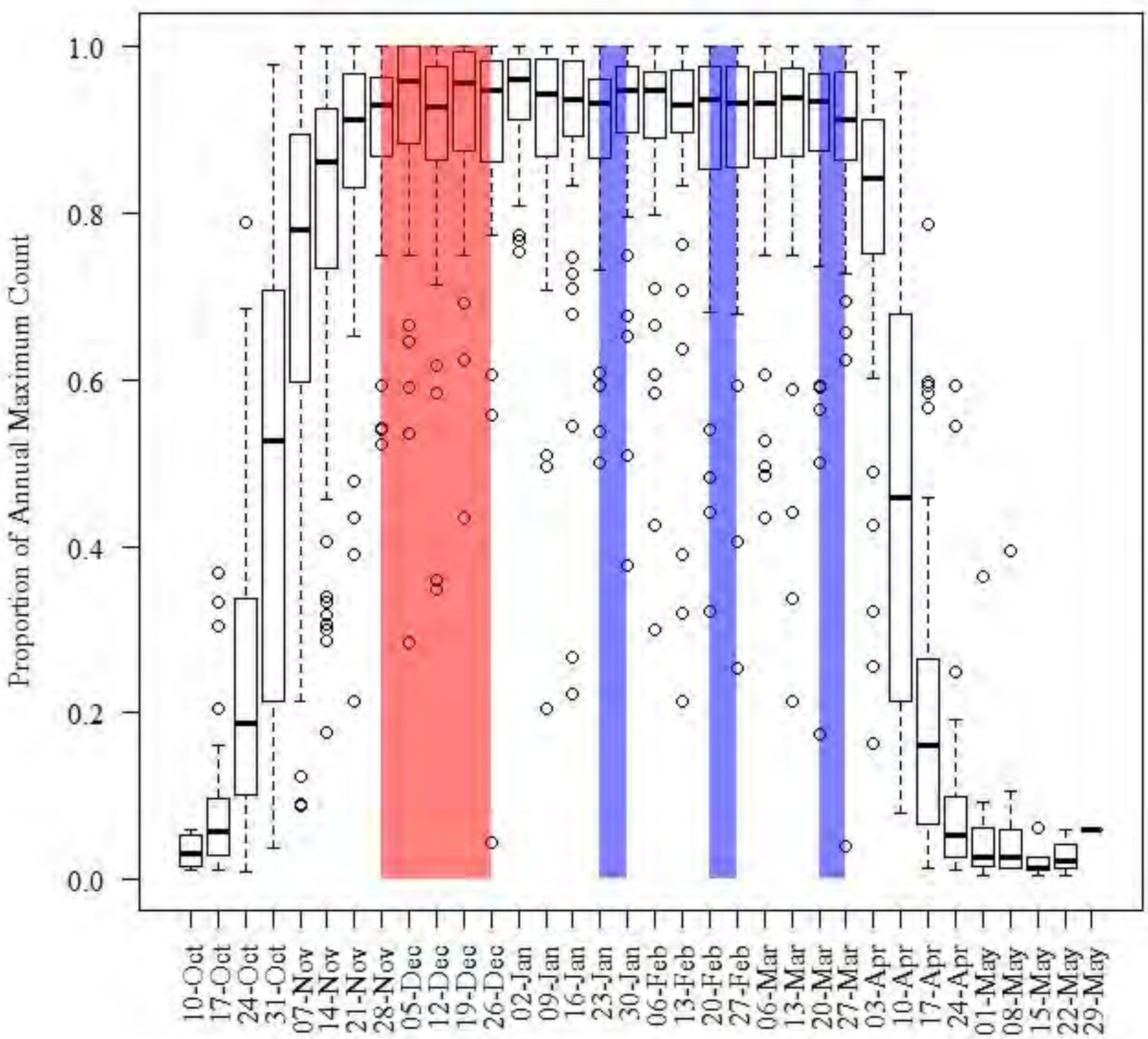

Figure 3. Box and whisker plots describing the chronology of whooping crane arrivals and departures on the Texas coast. Data come from periodic aerial surveys, centered at Aransas NWR, conducted during the winters of 1950-2011,. Solid black lines represent the median proportion of the annual maximum count by date. Boxes contain the .25 and .75 quantiles of data, while the lines span the entire dataset while excluding outliers (black circles). The red box represents the time of year during which effort should be exerted to obtain data to estimate the peak abundance, age ratios and proportion of recruitive pairs of whooping cranes in the sampling frame (Objectives 1-3). Blue boxes represent areas within which additional survey effort could be exerted to obtain resource selection data during the winter (Objective 4).

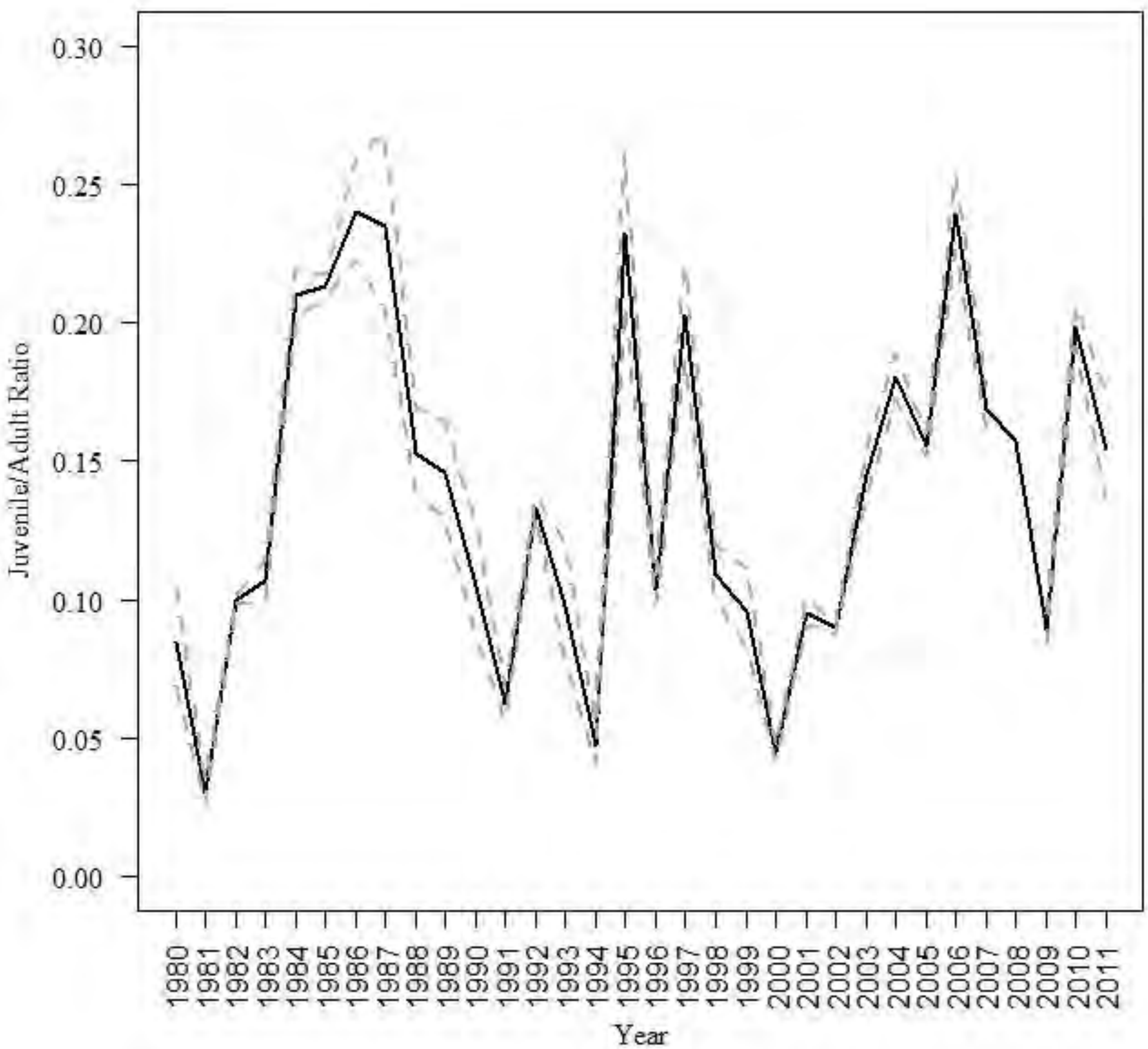

Figure 4. Ratio of juvenile to adult whooping cranes (solid black line) and the 95% confidence interval (dashed gray lines) estimated annually from aerial surveys conducted during November and December from 1980-2010. Data from presented from 2011 were collected during January 2012**.**

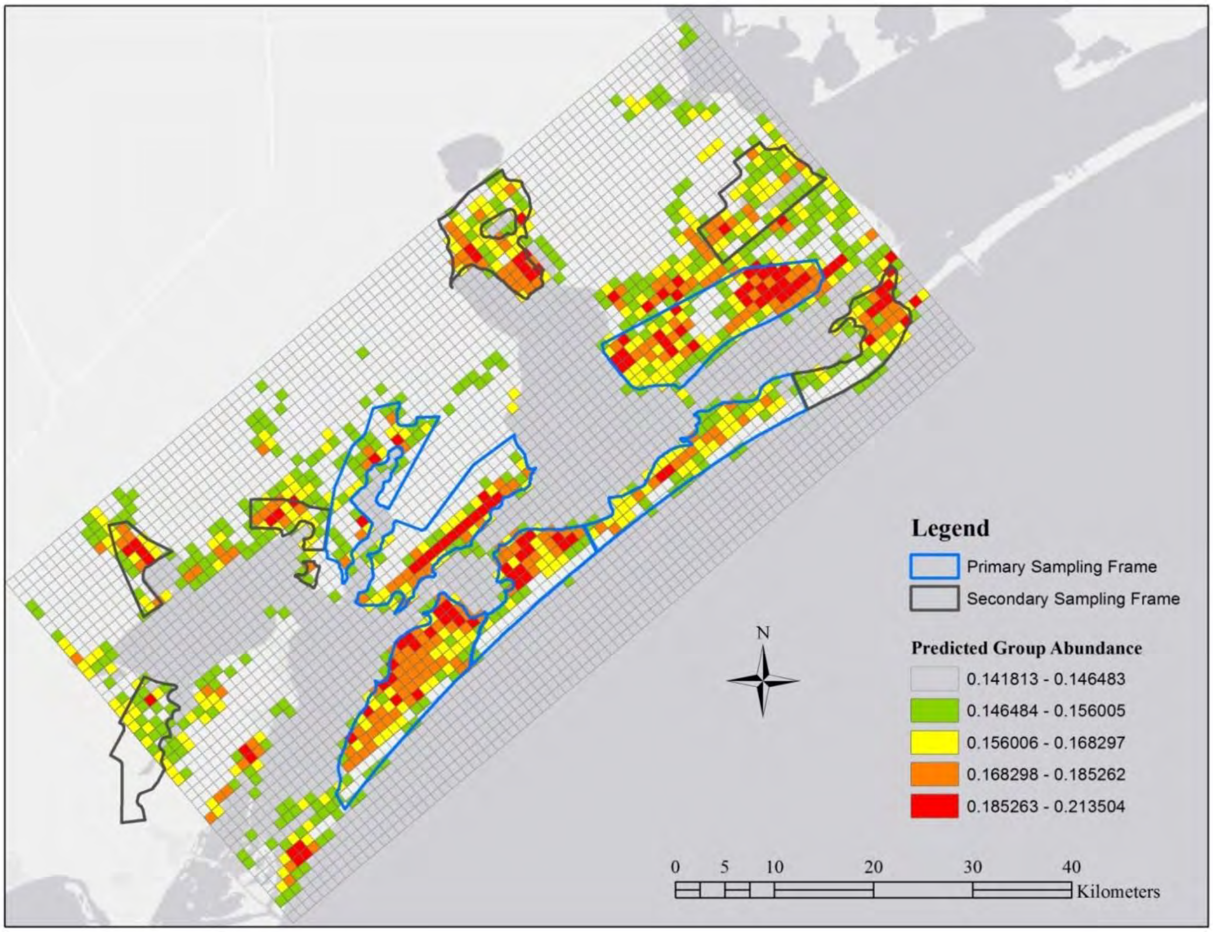

Figure 5. Predicted abundance of whooping crane groups extrapolated from the hierarchical distance sampling model "best-supported" by AICc. Data were collected from fixed-wing aerial surveys within the primary sampling frame 26, 27, 29 January 2012. Percent of salt marsh within each grid cell was positively associated with the abundance of whooping crane groups. Cell color illustrates the predicted likelihood of a cell being occupied by a group of cranes.

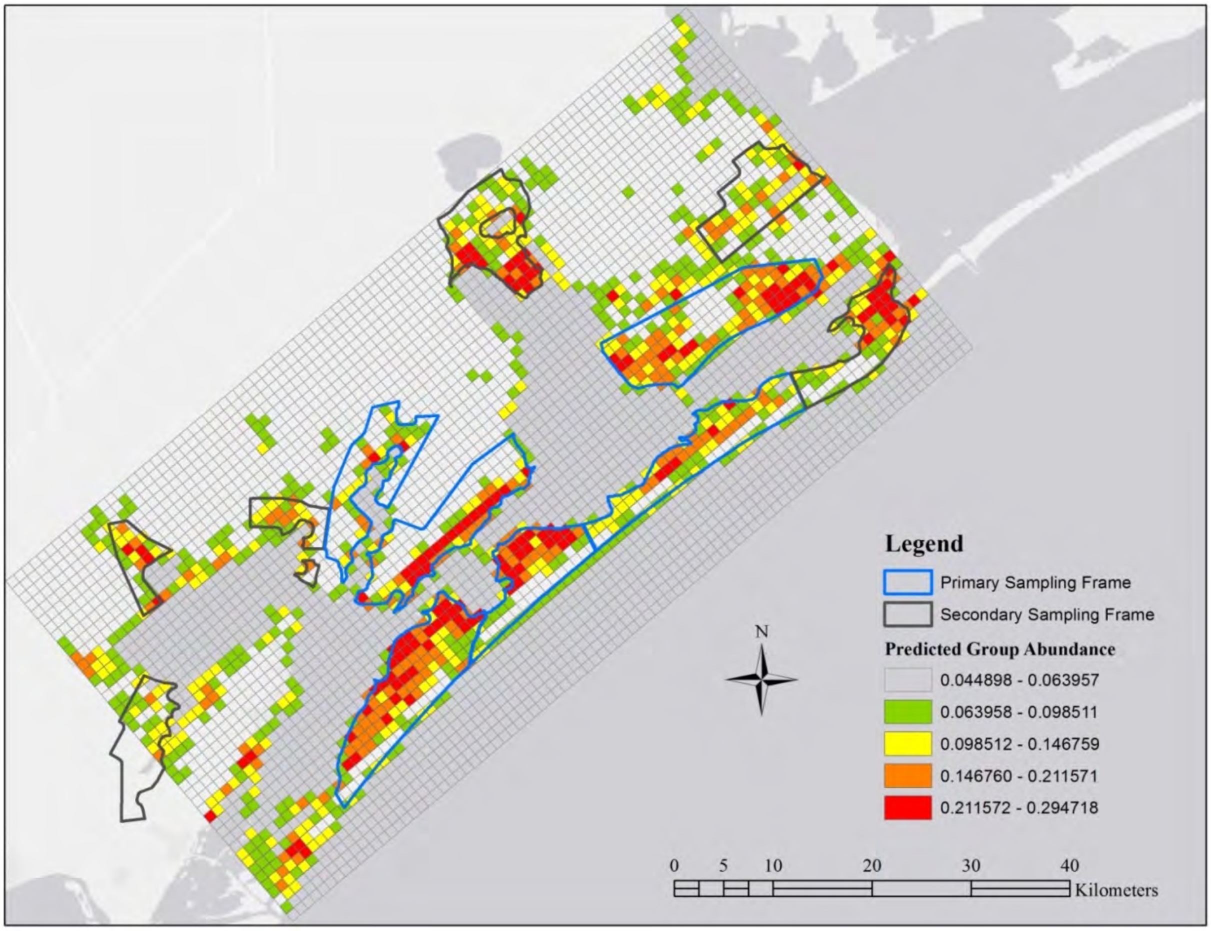

Figure 6. Predicted abundance of whooping crane groups extrapolated from the hierarchical distance sampling model "best-supported" by AICc. Data were collected from fixed-wing aerial surveys within the primary sampling frame 25, 26 February 2012.

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