2 October 2017

Montgomery Schoenhals
Consolidated Nuclear Security, LLC
USDOE/NNSA Pantex Plant
P.O. Box 30020
Amarillo, TX 79120-0020

Mr. Schoenhals

Attached you will find the final report for Swainson's hawk research we have been conducting at the Pantex Plant and adjacent lands. This final report fulfills our contract obligations under Pantex Purchase Order No. 0000031097. I am sending this letter and report as an electronic copy. Please let me know if you wish to have me send hard copies or any specific data in electronic format.

We have genuinely enjoyed engaging with you and Jim Ray at the Pantex Plant, and conducting this valuable research. As you know from our discussions, we are try to obtain funding to continue data downloads from hawks that are currently radio-tagged. Additionally, we anticipate several papers coming from this important research, and will keep you and Mr. Ray involved as we proceed with these efforts.

Again, thank you for your support with our research efforts. We hope we have the opportunity to work with you and Pantex again.

Sincerely,

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USING GPS TRANSMITTERS TO EXPLORE MOVEMENT ECOLOGY AND TO ASSESS RISK OF THE WIND ENERGY INDUSTRY FOR SWAINSON'S HAWKS

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EXECUTIVE SUMMARY

Swainson's hawks (*Buteo swainsoni*) are a long-distance migratory species that breed in western North America and winter in Argentina. As a grassland species, they can also be found in agricultural settings, such as croplands and pastures. Wind energy is expanding rapidly across the breeding range of the population we chose to study, and we suspect the industry is also expanding in their wintering range and across the migratory pathway. Wind turbines pose a threat to birds, and migratory species may be especially susceptible to turbine-related mortality when these structures are placed in important migratory pathways. The purposes of this long-term study were to examine potential threats that wind energy might pose to Swainson's hawks on the breeding range, wintering range, and during migration, add to the body of ecological knowledge on migration and wintering habits, and describe breeding habits in a portion of their range that is relatively understudied. We trapped hawks within a study area near Amarillo, Texas in 2011 – 2013 and 2016 – 2017. We placed 12 VHF and 37 satellite Platform Transmitter Terminals (PTTs) on 35 adult and 14 juvenile hawks to address various ecological and wind-energy-related questions, and have obtained 5 years of data to date. We assessed home range size on the breeding range and compared methodologies to obtain home range information, including comparing VHF versus GPS transmitter locations and comparing results from Minimum Convex Polygon (MCP), Kernel Density Estimate (KDE), and Brownian Bridge Movement Models (BBMM) home range estimators. For the VHF data collected in 2011 and 2012, mean MCP home range was 130.9 ($\pm$ 128.0) km^2 and mean KDE home range was 140.3 ($\pm$ 186.7) km^2. For the PTT data collected in 2012, mean MCP home range was 206.9 ($\pm$ 573.5) km^2, mean KDE home range was 225.6 ($\pm$ 518.8) km^2, and mean BBMM home range was 101.9 ($\pm$ 151.7) km^2. We conducted a compositional analysis on the KDE home range estimates for PTTs in 2012; available cover types were 50% grassland, 29% dryland crops, 17% irrigated crops, 2% textile

crops, and 2% wind farms; birds used $25 - 99\%$ grassland, $1 - 54\%$ dryland crops, $0 - 37\%$ irrigated crops, $0 - 15\%$ textiles, and $0 - 2\%$ wind farms. Grassland was determined to be used more than other habitats, followed by dryland crops, cotton, irrigated crops, and, last, wind farms. In 2013 and 2014, we monitored nest activity in the study area and found $69 - 84\%$ nest success with an average of 1.4 fledglings per successful nest. We assessed level of risk of existing turbines within home ranges and the potential influence of distance to turbines on nest success and number of young produced; we found that birds were exposed to turbines $0 - 100\%$ of the time (mean $12.8 \pm 24.1\%$), but there was no discernable influence of wind energy presence on productivity. For PTT-equipped birds from 2012-2014, proportion of BBMM that overlapped low-collision-risk buffers averaged $4.9 \pm 8.4\%$, proportion overlapping areas of moderate risk averaged $7.4\% \pm 15.2\%$, and proportion overlapping high risk zones averaged $0.2 \pm 0.5\%$. We examined general migration characteristics, including departure date, length of migration, daily travel rate, and migratory pathway, and found no difference between male and female adults. Average date of departure for spring migration was February 28 (± 8 days) and for fall migration was October 8th (± 5 days). Average length of migration was 48 (± 7) days, average distance traveled was 10,283.2 (± 715.4) km, and average daily travel rate was 218.1 (± 29.3) km/day. We identified three regions of potential conservation importance along the migratory pathway; the Oaxaca region of Mexico, along the pacific coastline of El Salvador, Honduras, and Nicaragua, and along the Isthmus of Panama. We used wind potential as a proxy for windfarm locations across the migration range, and we determined that Swainson's hawks may be selecting for low wind regions over moderate wind regions and were utilizing areas with the highest potential for wind energy construction about as much as available on the landscape. Much of our results are consistent with previous literature, and we suggest that while wind turbines may not

be impacting breeding parameters yet, they may pose a significant risk along the migratory pathway and risk of disrupting breeding and behaviors may increase as turbines become denser on the landscape. We have plans to investigate more ecological questions with the adult dataset, and are only beginning to obtain data on juvenile birds. We will assess velocity and altitude of location points to continue our assessment of the risks the wind energy industry poses, and we will expand our assessment to include risks on the wintering grounds in Argentina and Uruguay. The wind energy industry is rapidly expanding as our global need for energy shifts to renewable resources. Thus, it is important to obtain information about this grassland-obligate species to assess the potential risks from the wind energy industry, as well as to fill in ecological knowledge gaps where possible with this dataset.

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Swainson's hawks (*Buteo swainsoni*) are a migratory species that breeds throughout western North America and winters in the Pampas region of Argentina (Bechard et al. 2010). This long-distance migrant travels over 20,000 km annually between breeding and non-breeding grounds (Schmutz 1996, Bechard et al. 2010). Swainson's hawks are a grassland-obligate species that forages mostly on insects and small mammals (Giovanni et al. 2007, Bechard et al. 2010), and they can be found in agricultural areas, both croplands and pastures, throughout their range. In the 1970s and 80s the species was noted as declining in California (Bloom 1980), Oregon (Littlefield et al. 1984), and Nevada (Herron et al. 1985), but populations appeared stable in other areas. The discovery of mass-mortality on the austral summer range in Argentina, driven by pesticide use on croplands (Goldstein et al. 1999), spurred research and conservation efforts for this species. Most research to date has focused on population monitoring, reproduction, foraging, and habitat on the breeding range, as well as pesticide reduction and protection efforts in Argentina, but much remains to be discovered. In addition, we know very little about the mechanisms of migration, or what these birds do on the non-breeding range during the temporal winter months. To our knowledge, no research exists on fledgling migration or natal fidelity and dispersal, and little is known about non-breeding juvenile birds on the breeding range in North America. In addition to pesticide use, land conversion to intense-agricultural production and new technologies, such as wind energy, may pose threats to this species that have not yet been researched.

The wind energy industry has been growing rapidly in North America, and while it is known that turbines can cause avian mortality, little is known as to the ecological impact the industry will have as more turbine fields are added to landscapes. Raptors appear to be more susceptible to turbine collision than most birds (Kuvlesky et al. 2007), perhaps due to their flight

patterns and aerial-hunting strategies. There is a lack of knowledge as to the impact of turbines on most migratory species, but turbine placement within migratory corridors may pose a comparatively greater hazard than other placement options. Additionally, during migration, birds may be at greatest risk of collision when turbines are placed near stopover sites, roosting locations, or other areas where birds are flying near ground level. There may be additional risks when turbines are placed on ridgelines or coastlines, where birds may use orographic lift to gain altitude. On the breeding and wintering grounds, birds may be at risk of collision while going about their daily activities, or when distracted while responding to a disturbance, fleeing a potential threat, or engaged in territorial displays or skirmishes. Birds may be geographically displaced by turbine presence as an avoidance mechanism. Other than a few mentions of Swainson's hawk mortality within wind farm studies (Erickson et al. 2001, Kolar and Bechard 2016), we know almost nothing about how this industry will impact this grassland-obligate and long-distance migratory raptor species.

The purpose of this long-term and ongoing study is to track movement behaviors of Swainson's hawks to fill in gaps in the ecological knowledge of this species as well as to address the potential effects and risks that wind turbines pose. Here, we present results of several studies that were conducted between 2011 and 2017 on a population of Swainson's hawks breeding in the panhandle of Texas. We present study questions and results as separate sections, but first provide an overview of the study area and general methods applicable to all sections.

STUDY AREA

Our study area was in Armstrong, Carson, and Potter counties, Texas, within the southern high plains ecoregion (Fig. 1). This area was dominated by irrigated and non-irrigated row-cropping systems, cattle grazing pastures, isolated parcels of native grassland, and land enrolled

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in the Conservation Reserve Program (CRP). Common crops grown in the area were corn (*Zea mays*), cotton (*Gossypium hirsutum*), sorghum (*Sorghum bicolor*), and wheat (*Triticum aestivum*). We focused study efforts on and around the Pantex plant, which is a nuclear weapon decommissioning facility for the U. S. Department of Energy and the National Nuclear Security Administration. The area surrounding the plant is a native and semi-native grassland landscape with some active farming and grazing, and bordering properties are a similar mix of land covers. We included areas up to 20 km away from Pantex in the study area to maximize sample size for this study. Wind energy facilities were located within and surrounding the study area and have expanded throughout the years of this study (Fig. 2).

GENERAL METHODS

We monitored activity at nesting locations during the breeding seasons (April – August) of 2011-2017 in the study area. In 2011, 2012, and 2013, we used bal-chatri and dho gaza traps to capture adult Swainson's hawks (Bloom et al. 2007). After capture, we restrained the bird by hand and placed a hood over its head to prevent stress or injury during handling. Each bird was fitted with a silver, uniquely numbered aluminum band issued by U.S. Geological Survey Bird Banding Laboratory on one leg, and with an anodized blue leg band with a silver engraved alphanumeric code on the other; this latter band allowed visual identification of individuals. We also took morphometric measurements to determine gender (using methods suggested by Kochert and Mckinley 2008) and body condition. Finally, we measured mass to ensure VHF and GPS transmitters would weigh no more than 4% of the bird's body weight, as allowed under the banding permit.

In 2011 and 2012, we attached Very High Frequency (VHF) transmitters with Teflon ribbon in a backpack-style harness to adult birds (10 birds in 2011 and 2 birds in 2012; Walker

2013). Each VHF transmitter had a 3 V lithium battery with a 720-day life expectancy. Attempts were made to locate birds daily from the moment of release to the start of fall migration in 2011 and 2012. We initially located birds in a moving vehicle using a roof-mounted omni-directional antenna (Model RA, Communication Specialists, Inc., Orange Co.) attached to a handheld receiver (Model R1000, Communication Specialists, Inc., Orange Co.). Once a bird was detected in an area, we located the bird using a hand-held 2- or 5-element Yagi antenna. We then only recorded a location by GPS if the bird was visually sighted, and we took distance and bearing estimates to later convert our GPS location to the bird's actual location. Results from the VHF component of the study are provided in Walker (2013).

In 2012 and 2013, we used the same attachment method to deploy 24 three-dimensional solar-powered platform transmitter terminals (hereafter PTTs; Solar PTT – 100, Microwave Telemetry, Inc., Columbia, Maryland) among 12 birds in 2012 and 12 birds in 2013 (Walker 2013, Groen 2015). One bird wearing a VHF transmitter was recaptured and given a PTT. The PTTs were programmed to report a GPS location every one to six hours daily (at 0000, 0500, 0700, 0900, 1100, 1200, 1300, 1500, 1700, 1800, 1900, and 2100 local time) until transmissions ended due to malfunction or mortality. We monitored up-to-date bird locations weekly and analyzed data to address various ecological questions using ArcGIS (Esri 2011), the Argos system (Argos 2016), Geospatial Modelling Environment (Beyer 2015), Google Earth (Google Inc. 2017), Program MARK (White and Burnham 1999), and Program R (R Core Team 2016).

DATA MANAGEMENT

Error associated with GPS transmissions from our PTTs was estimated to be about 18 m (Microwave Telemetry, Inc., Columbia, Maryland), however ≤10% of data were prone to additional errors. Significant errors might occur due to battery failure, lack of sufficient satellites

in the area, transmission mistakes, and topography or cloud cover causing bouncing signals. To ensure our dataset contained the highest quality data, we conducted a three-step filtering process before analyses. First, when we received raw data, some locations had clear errors reported, such as "2D fix", "battery drain", or a location that was 0.0000 by 0.0000. These points comprised about 8.3% of total data we received and were removed from the dataset. Next, we displayed data in ArcMap to look for clear outlier points that were likely erroneous. We calculated distance between points and speed to next point (distance/elapsed time) and manually looked at all points with distance >100 km and/or speed >80 km/h. We looked at each potential outlier point in context of previous and subsequent points to determine if the point was implausible. We tried to be conservative about further removal of data, and only removed about 10% of potential outlier points from the working dataset. Implausible locations that were removed made up about 0.1% of the dataset. Finally, when mortality occurred, the transmitter did not always stop sending data right away. In some instances, we continued to receive locational data for days to months after the PTT stopped moving. PTTs were programmed to detect movement and to stop sending data when movement ceased for more than four days, however if the PTT continued to move, such as the carcass was moved by scavengers or the PTT could blow in the wind, then it continued to report data. When our assessment was that a bird had perished or the PTT had otherwise stopped moving, we removed the extra data points as irrelevant for our purposes. We used the remaining data for analyses with the assumption that the dataset contained accurate locational information (± 18 m).

HOME RANGE AND HABITAT SELECTION ON THE BREEDING RANGE WITH WIND ENERGY DEVELOPMENT IN PROGRESS

Habitat selection for Swainson's hawks on the breeding range is likely driven by a combination of prey availability and cover types that facilitate hunting (Bechard 1982). Selection of nesting territory near quality foraging habitat is an important driver of successful reproduction. Groskorth (1995) suggested that Swainson's hawks selected nesting habitat within or near natural grasslands and selected against agriculturally dominated areas. Selection regarding agriculture may be partially driven by the types of crops grown across the Swainson's hawk breeding distribution. For example, in a study in Saskatchewan, Canada (Groskorth 1995) wheat is a major crop that would provide poor foraging habitat for Swainson's hawks that prefer land covers of shorter and patchier vegetation. Woodbridge (1991) estimated that active agriculture (wheat, hayfields, and some row crops) made up about 31% of the foraging radius of radio-marked male Swainson's hawks in northern California, with grasslands, pastures, and juniper scrub occurring in varying amounts depending on nesting site. Gilmer and Stewart (1984) reported that pasture and hayfields made up 75% of land surrounding active nests, with few pairs nesting in areas > 60% intensively managed crops. Our study area consists of a mix of agricultural crops (corn, cotton, sorghum, soybeans, and wheat), CRP grasslands, native grasslands, and urbanized areas, which create a mosaic of land cover types in which Swainson's hawks may choose to forage. We expected to find that Swainson's hawks select for natural grasslands or similarly structured CRP lands, consistent with the findings of Groskorth (1995) and Gilmer and Stewart (1984).

Studying home range sizes and habitat characteristics provides an understanding of preferred habitats, but also allows inferences to be drawn about land-use changes over time, such

as the construction of wind turbines in nesting areas. Home range estimates for Swainson's hawks vary from as small as 0.7 km^2 (Woodbridge 1991) and 2.6 km^2 (Fitzner 1980) to as large as 76.6 km^2 (Babcock 1995) and 87.2 km^2 (Estep 1989). Differences in home range size may be driven by heterogeneity of habitat and prey availability, but our estimation of home ranges sizes is substantively influenced by the methodology used to calculate the estimates (e.g., re-sighting banded birds versus attaching transmitters to birds, level of effort to re-locate birds, and using different models to estimate home range from data). In addition, there may be a difference in home range between males and females; their home ranges may overlap but, combined, may be greater than that of either individual (Boal et al. 2003). We expect male home ranges to be larger than females, because male raptors tend to do the majority of hunting to provision the nest, while females incubate eggs and care for young (Sonerud et al. 2014). When females begin hunting later in the nesting stage, they may also choose to stay closer to the nest than males. Reports from Fitzner (1980), Woodbridge (1991), Babcock (1995) support the hypothesis of male Swainson's hawks using larger areas than females.

Home range sizes have not been estimated for Swainson's hawks nesting on the southern high plains of Texas, nor has anyone attempted to quantify wind turbine presence within the home ranges of this population. We examined Swainson's hawk breeding season home ranges, classified and compared habitat types used in the home ranges, and described home range overlap with wind energy facilities that were in operation in 2012 in the study area.

Methods

Home Range Size

We estimated home range size for adult hawks equipped with VHF transmitters and PTTs for the 2011 and 2012 breeding seasons using locations from the time the transmitter was

deployed to when the bird left for migration (i.e., made a greater than 10km movement away from the breeding range and did not return). We estimated home ranges in two ways. First, we calculated a standard 95% minimum convex polygon (MCP). For each tagged hawk, we first manually removed the 5% of points that were furthest away from the center of the highest density of points, and then used the "Minimum Bounding Geometry" tool in ArcMap 10.3 to create MCP home range polygons. Second, we used a 95% kernel analysis (KDE). We then used the "Adehabitat" package in Program R 3.3.2 to create 95% KDE contours based on all obtained relocation points to estimate home range sizes. We compared home range size estimates calculated from the two different methods, and among all hawks, between hawks equipped with the different style transmitters, and between male and female adults.

Habitat Use

We estimated habitat use only for those hawks with PTT transmitters. This was due to VHF transmitters resulting in too few locations per individual for reliable habitat analysis. We used Google Earth imagery (imagery data from 8 June 2011) to conduct the habitat analysis for the PTT birds. We manually digitized the imagery within the study area into polygons and classified portions as "grass", "irrigated crops", "dryland crops", and "textile". The "grass" category included natural grasslands, pastures, and CRP lands planted with grasses. "Irrigated crops" included corn, wheat, sorghum, alfalfa, and soybean fields that had center-pivot irrigation systems. "Dryland crops" included wheat and sorghum planted in fields with no obvious irrigation system. The "textile" category denotes cotton fields, which are common on the southern high plains of Texas. We ground-truthed random points in areas with accessible roadways to ensure accuracy of land-classification maps. We used the Geospatial Modelling Environment (GME) in conjunction with ArcView 10.1 to estimate "use" versus "available"

habitat. The proportion of PTT locations that occurred within a given cover type was classified as "use", and the proportion of the cover type on the landscape within all combined KDE home range contours was classified as "available". We used Multivariate Analysis of Variance (MANOVA) to compare "use" to "available" cover type proportions to infer selection, and we used a compositional analysis model to rank the cover types in terms of most to least used.

Two commercial wind energy sites were located within the study area during this portion of the study. The "east wind farm" had been in operation since 2006 with 62 turbines (see Fig. 2), and the "west wind farm" began operation in July 2012 with 39 turbines. We drew polygons around existing turbine locations and added a 100-m buffer to define areas as "wind farms" for analysis. Because two birds had home ranges that overlapped wind turbine fields, we included wind farm as a fifth habitat category on the landscape.

Results

We captured and attached VHF transmitters to 12 adult Swainson's hawks (seven male and five female) during the 2011 and 2012 breeding seasons. We captured and equipped 12 adult hawks (eight male and four female) with PTTs in 2012. In 2011, we recorded 233 locations for ten hawks equipped with VHF transmitters, with an average of 23 ($\pm$ 19) locations per hawk (Table 1). In 2012, we recorded 254 locations of eight hawks, six of which were returning birds from the previous year, with an average of 32 ($\pm$ 17) locations per bird (Table 1). We only included birds with $\geq$ 20 locations for analyses. During the 2012 nesting season, we recorded 11,455 GPS locations from the hawks wearing PTTs, with an average of 955 ($\pm$ 321) locations per bird (Table 2).

Mean MCP home range was 130.9 ($\pm$ 128.0) km^2 for the VHF-tagged hawks (Table 1). Male Swainson's hawks averaged 113.1 ($\pm$ 106.0) km^2 and females averaged 145.8 ($\pm$ 152.4)

km^2 (Table 1). Mean KDE home range for the VHF tagged hawks was 140.3 ($\pm$ 186.7) km^2, with

males averaging 103.6 ($\pm$ 178.6) km^2 and females averaging 170.9 ($\pm$ 204.2) km^2 (Table 1). The

VHF home range estimates were counter to the hypothesis that males have larger home ranges

than females. Mean MCP home range for the PTT-equipped birds was 206.9 ($\pm$ 573.5) km^2, with

males averaging 305.9 ($\pm$ 695.1) km^2 and females averaging 8.7 ($\pm$ 3.9) km^2 (Table 2). Mean

95% KDE home range for the PTT-equipped birds was 225.6 ($\pm$ 518.8) km^2, with males

averaging 332.8 ($\pm$ 619.4) km^2 and females averaging 11.3 ($\pm$ 4.7) km^2 (Table 2). The PTT home

range estimates were consistent with the hypothesis of males having larger home ranges than

females.

We combined all KDE home ranges to estimate cover types available for the 12 PTT-

equipped hawks. Availability of cover types were 50% grassland, 29% dryland crops, 17%

irrigated crops, 2% textiles, and 2% wind farms (Table 3). Habitat proportions determined by

ground-truthing at random points on public roadways reflected similar proportions as the

estimate of available habitat with 65% grassland, 28% dryland crops, 8% irrigation, and 7%

textile. Proportions of habitat used by individual birds ranged from 25 – 99% grassland, 1 – 54%

dryland crops, 0 – 37% irrigated crops, 0 – 15% textiles, and 0 – 2% wind farms (Table 3). A

compositional analysis model indicated that grassland was used significantly more than other

habitats, followed by dryland crops, textile crops, irrigated crops, and, last, wind farms (Table 4).

Two hawks had KDE home ranges that overlapped the east and west wind farms in 2012

(Fig. 3). The hawk equipped with PTT 115937 had 74 locations (5.6%) and 25 locations (1.9%)

that fell within the east and west wind farms, respectively. The portion of home range where this

Swainson's hawk might have been at risk of encountering a turbine was 1.7 km^2 (1.6%; Table 3).

The hawk equipped with PTT 115940 had 90 locations (8.1%) within the east wind farm and no

locations within the west wind farm, with an area of 0.1 km^2 (2.4%) of potential collision risk (Table 3).

Discussion

Home Range Estimates

Home range sizes for Swainson's hawks are variable, ranging from the relatively small home ranges reported by Fitzner (1980) in Washington (2.6 – 20.3 km^2, mean: 2.4 km^2) to larger home range reports from Babcock (1995) in California (7.2 – 76.6 km^2, mean: 40.4 km^2). Our results range from comparable to significantly larger home range sizes. The MCP method suggests home ranges from 6.2 – 415.9 km^2 for the hawks equipped with VHF transmitters (Table 1) and 5.4 – 1997.1 km^2 for the PTT-equipped hawks (Table 2), and the KDE method suggests home ranges from 6.2 – 466.6 km^2 (Table 1) and 8.3 – 1694.4 km^2 (Table 2) for the VHF and PTT birds, respectively. The VHF transmitter component of our study implies that home ranges for hawks in our study area may be much larger than previous estimates, with only five of the MCP range sizes and eight of the KDE range sizes falling within the range of previously reported data. However, the higher volume and locational accuracy of our PTT data implies that home ranges of Swainson's hawks in our study area are similar to previous reports, with two exceptions. Two male birds equipped with PTTs had large home range estimates, which might suggest these males were either not associated with a nest and were more nomadic than males holding territories, or they may have been associated with a nest that failed and then stopped maintaining a territory early in the season. If we exclude those birds, the mean MCP home range estimate drops to 10.9 ($\pm$ 6.6) km^2 and the mean KDE estimate drops to 17.9 ($\pm$ 13.5) km^2, with the male birds averaging 12.5 ($\pm$ 7.8) km^2 MCP and 22.2 ($\pm$ 16.0) km^2 KDE. With the outlying birds excluded, our PTT data is consistent with previous reports from other

portions of the Swainson's hawk breeding range (Fitzner 1980, Estep 1989, Woodbridge 1991, Babcock 1995). However, our VHF transmitter data and the data from those outlying birds imply that home range for this species might have been underestimated in previous studies, and larger estimates might be driven by ranging and nomadic behaviors, behavioral plasticity to changing events (such as nest failures), or differences in habitat and prey availability across the breeding range.

The 95% MCP method may be a misleading home range size, as it gives equal weight to all points, but allows the manual removal of 5% of points considered "outliers", which may introduce bias into the analysis. For this study, MCP generally provided a lower and more-conservative estimate of home range size, though some home ranges were estimated as larger than the KDE method (Tables 1 and 2). The MCP method is also crude in methodology as it is meant to draw a simple polygon around all outermost points, which may include areas that were not biologically important or used by the animal. This can be illustrated by our side-by-side comparison of the polygons created from the different home range methodologies employed in this and one later study (below) for the exact same dataset of PTT birds in 2012 (Fig. 4). Large home range estimates may be artifacts of the polygon methodology, including areas that are not necessarily relevant due to the shape of outlying points, while small home range estimates may be biased by removal of 5% of outermost data, as the researcher is making the assumption that those points are not important or relevant to the animal's core-use areas. The 95% KDE method includes all data provided to the model, but draws various home range contours by giving more weight to clusters of points than outlying points; we believe this provides a more-realistic representation of Swainson's hawk home range size in this study. Further, the KDE approach can result in multiple polygons for the same bird due to areas of high use space across areas of little

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or no use; three KDE home ranges (birds 115938, 120332, and 120334) included multiple

polygons while the MCP method only allowed for single polygons (Fig. 4). The KDE method

also produced more-realistic representations of habitat use, with varying polygon shapes where

higher density of data occurred, and allowed the exclusion of areas that were not used or used

with less frequency. For example, the MCP home range estimate of bird 120332 implied that a

great deal of landscape between the study site and an area to the north should be considered

within the 95% home range, while the KDE home range estimate shows that there are three areas

that the bird used, with the in-between landscape being a corridor it might have used to get from

one location to the next (Fig. 4).

Home Ranges of Male and Female Hawks

Previous studies suggested that male Swainson's hawks might maintain larger home

ranges than females (Fitzner 1980, Woodbridge 1991, Babcock 1995), and our PTT data is

consistent with that conclusion. The VHF data did not support that hypothesis, but sample sizes

were small enough that the contrary result may be due to error or a bias in data collection. The

KDE home range of Swainson's hawks equipped with PTTs suggested that males average 22.2

km^2 home ranges (excluding the two males with largest home ranges), while females average

11.3 km^2 home ranges. This likely stems from gender-specific parental roles during the breeding

season that most raptor species exhibit. Females are responsible for most of the incubation and

brooding (Sonerud et al. 2014), which would cause home range estimates to cluster around the

nest site for a large portion of the season. Males are tasked with feeding the female during

incubation and brooding, and, in most species, males continue to hunt for the brood throughout

the entire nesting period (Sonerud et al. 2014). Females begin to hunt after nestlings are old

enough to thermoregulate independently, and thereafter, both adults will take part in feeding

chicks for many, but not all, raptor species (Sonerud et al. 2014). It is possible that females might remain closer to the nest for protection from territory intruders and nest predators, while the males venture further away to expand the hunting effort to provide for a growing brood. This might drive the difference in home range size even after the female begins hunting. Alternatively, the early-nesting period might cause bias toward smaller home ranges for females due to the clustering of points during incubation and brooding, and their home ranges might expand to similar sizes as males during the latter part of the season, when they resume hunting. If a researcher were to observe Swainson's hawk nests daily to separate out when a female is brooding and when she resumes hunting, or use telemetry data to determine when she begins to foray away from the nest, home range calculations might be improved to address the question of whether nesting behaviors are biasing home range estimates or if females continue to maintain smaller home ranges than males after the incubating and brooding period.

Habitat Composition of Home Ranges

Existing descriptions of Swainson's hawk habitat use and selection vary widely, primarily due to the longitudinal and latitudinal span of landscapes they occupy across their breeding range in western North America. The driving factors for habitat selection in this species appear to be prey availability and low vegetation cover (Bechard 1982), but they also appear to have adapted well to the expansion of agriculture across the breeding range (Bechard 1982, Gilmer and Stewart 1984, Schmutz 1987, Nishida et al. 2013). The habitat analysis we conducted suggests that grasslands made up about 50% of home ranges within our study area, passively-managed agricultural areas (dryland crops) made up about 30%, and intensively-managed agricultural areas (irrigated crops and cotton) made up the remaining 20%. There was significant individual variation on proportions of these land covers within individual home ranges, with

grasslands and cotton being used more than their overall availability and dryland crops and irrigated crops being used less. Many birds selected home ranges that had no cotton or irrigated crops, instead favoring areas of grassland and dryland agriculture. This result could be due to increased prey availability in these cover types, increased ability to hunt effectively within these cover types, or, perhaps, due to lower human disturbance on these landscapes. Our results are consistent with previous reports of habitat selection surrounding nesting sites and within home ranges for this species being dominated by grasslands and pastures and with hawks showing reduced use of intensively-managed agricultural fields (Gilmer and Stewart 1984, Woodbridge 1991, Groskorth 1995).

Use of Wind Energy Facilities

Only two hawks in this study had home ranges that overlapped existing wind energy facility areas in 2012. The proportions of home ranges where these hawks were at risk of encountering turbines was 1.6% and 2.4% (Table 3, Fig. 3). This might imply that the birds monitored in this study avoided wind energy areas, but our data are too sparse to draw any conclusion. It is possible that the two birds had established home ranges in those locations prior to construction of wind turbines, and did not relocate after turbine installment. It is also possible that Swainson's hawks generally avoid areas with wind turbines as lower-quality habitat or areas of higher mortality risk, and these two birds happened to get stuck with the lower-quality nesting ranges. Additionally, at the time this study was conducted, relatively few turbines existed on the landscape, which limited the conclusions that could be drawn from the data. Wind farms have subsequently increased in the study area (Fig. 2), and continuation of data collection and analyses through 2013 – 2017 from the PTT-equipped birds will lend a larger dataset with which

to draw conclusions about how wind turbines affect the nesting behaviors and home ranges of Swainson's hawks on the high plains of Texas.

PRODUCTIVITY AND REPRODUCTIVE SUCCESS

Population dynamics are influenced by reproductive potential, and several researchers have tracked nesting parameters for Swainson's hawks. Rodríguez-Estrella (2000) reported high nesting success and 1.3 – 2.0 fledglings per nest at a site in Mexico. Dunkle (1977) found 60% nesting success and 1.2 fledglings per nest in Wyoming. Bednarz (1988) reported 81% nest success and 1.3 –1.9 fledglings per nest in New Mexico. Nishida et al. (2013) reported nesting success of 44 – 58% with 1.4 – 1.8 fledglings per nest in Arizona. Other researchers report similar numbers with the expected variety from temporal and geographic differences among studies. With a large and seemingly stable population of Swainson's hawks in our study area, we anticipated finding similar results from long-term monitoring of nest activity. However, wind turbines were being built within the study area and distribution of sample nests (Fig. 2), so we chose to explore if the presence of these structures influenced productivity in this population. Declines in reproductive parameters due to landscape-level influences might have an impact on local population dynamics, especially as wind energy development expands in the region.

Swainson's hawks have shown relatively positive responses to anthropogenic factors on their nesting ranges, such as following harvesting machines to capture insects in agricultural fields (Littlefield and Johnson 2013) and nesting closer to urban settings than would be expected (Groskorth 1995). Due to their proclivity for insects and rodents as prey (Bechard et al. 2010), agriculture on the breeding and wintering range might actually enhance survival and productivity, and the habit of planting trees at homesteads across the prairie might have increased nesting sites for this species over the last century. However, increasing density of

roadways, power lines, wind turbines, and other mortality hazards may be detrimental to populations by reducing survival of adults and fledglings, by reducing fecundity, and by pushing populations into sub-optimal habitat. White-tailed eagles (*Haliaeetus albicilla*) vacated nesting territories after wind turbine construction in western Norway (Dahl et al. 2012), suggesting that some raptors are highly sensitive to this type of disturbance. Farfán et al. (2009) found decreased abundance of raptors utilizing sites in Spain after turbine construction, also suggesting displacement of multiple species. Madders and Whitfield (2006), however, suggest that for most raptor species, while displacement might occur immediately after construction, the overall effect on landscape usage appears to be negligible. Significant disturbances may be species-specific rather than an overall trend. For raptors nesting near turbines, collision risk may be heightened during the post-fledging period as young raptors are learning to fly and forage and as adults are focused on caring for fledglings (Kolar and Bechard 2016). Barrios and Rodríguez (2004) found relatively high proportions of juvenile raptors when collecting carcasses at a turbine field in Spain, supporting the contention that the post-fledging period and the first year of a raptor's life may be especially risky for collision with wind turbines. If increased mortality risk of juveniles is maintained over time, it may be evolutionarily advantageous for raptors to shift breeding ranges away from established turbine fields. Usgaard et al. (1997) reported finding no Swainson's hawk nests in areas with active wind turbines, even though nesting density was fairly high and stable throughout the study; thus, there is evidence that some displacement effect of wind energy facilities may occur. Kolar and Bechard (2016) explored turbine influences on productivity and, while they found no mortalities of fledglings during the study, three adult Swainson's hawks perished due to turbine collision, which led to two failed nests (the third nest successfully produced one young to independence). Kolar and Bechard (2016) did not, however, find any

correlation with nesting success and density of turbines, nor did they find signs of displacement or disturbance due to the turbines or the human activities required for maintenance of turbine fields. With lack of further evidence of displacement or habituation, there appears to be a gap in knowledge of how Swainson's hawks will be influenced by increasing wind energy development in their breeding range.

Our objectives for this component of our study were to quantify nesting parameters and nesting success for 2013 and 2014, and to assess this in context of distance of each nest to the nearest turbine in the study area. Our hypothesis was that Swainson's hawks would show an inverse relationship, via reduced fecundity, at nests closest to turbine fields. We also utilized PTT data to estimate landscape usage of adult Swainson's hawks during the breeding seasons of 2012-2014 to determine the proportion of home ranges where birds were at risk of encountering wind turbines, because increased risk of mortality for adult hawks would likely influence survival of nestlings.

Methods

In 2013 and 2014, we visually searched the study area for large stick nests in trees during winter, when most trees had bare branches. During the breeding season (mid-April to August) of each year, we monitored nests every 7-10 days to determine activity, success or failure, and, when possible, number of nestlings present and fledglings. When we failed to find activity at a nest site, we checked the nest a minimum of 3 times before declaring it "inactive" for the season. Success was determined when nestlings reached 80% of maturity (i.e., approximately 34 days after hatching for this species), as per Steenhof and Newton (2007). Failure was recorded for any nest that was determined to be active, but activity ceased before nestlings were ever recorded, nestlings disappeared before reaching 80% maturity, or nestling mortality was apparent.

Nestlings were observed, counted, and aged using a photographic guide by Gossett and Makela (2005).

To map nest locations, we took a GPS coordinate from the public roadway and estimated distance and bearing to each nest with a rangefinder and a compass. We displayed the roadway points in ArcMap 10.1 and estimated actual nest location using the "Bearing Distance to Line" and the "Feature Vertices to Points" tools. We obtained wind turbine location data across the United States from the United States Geologic Survey (USGS) tabular dataset DS-817 (i.e., data for all turbines installed and operational by January 2013), and overlaid these data with nest locations to measure distance from nest to nearest wind turbine.

We estimated nest success and reproductive output using "known fate analysis" in Program MARK. We attempted to test nest data against distance to turbine in Program MARK, however perfect fit of the data skewed results, so we instead used linear regression and Poisson distributions in Program R to assess relationships with nest success or number of young and distance to nearest turbine. We used linear models for success versus failure and Poisson models for number of nestlings and number of fledglings. If failed nests or nests with lower number of young were found to have disproportionally smaller distances to nearest turbine, this would suggest that wind energy developments may have a negative influence on Swainson's hawk nesting ecology.

We estimated home range polygons using PTT data during the breeding seasons of 2012, 2013 and 2014 using Brownian Bridge Movement Models (BBMM) with the "BBMM" package of Program R. We chose this method to estimate home ranges, because MCP and KDE methods use points as discrete and independent units of location, while BBMM uses the autocorrelation between points to estimate home ranges that consider how individuals move across time and

space (Horne et al. 2007). In ArcMap 10.1, we created low (3 km), moderate (1.5 km), and high (100 m) risk-zone buffers around turbine locations, and we estimated proportion of area of 95% home range polygons that intersected turbine buffers.

Results

In 2013, we monitored 13 active nests in the study area. Nine of these nests (69%) fledged 13 young (average = 1.44 ± 0.53 fledglings per successful nest; Table 5). In 2014, we monitored 19 active nests of which 16 (84%) successfully fledged 23 young (average = 1.44 ± 0.53 fledglings per successful nest; Table 6). Active nests were 0.37 – 28 km from the nearest wind turbine (Fig. 5). Our models did not indicate any significant relationship between nest success or productivity and distance to nearest turbine (all models had p > 0.05).

Using PTT data, we estimated BBMM home range for 12 birds with data from 2012, 21 birds with 2013 data, and 12 birds for 2014 (Fig. 6, 7, 8, Table 7). We compared means of overall and gender-specific home ranges with the MCP and KDE data (Table 2; Fig. 4) to show differences in the results of each model. Nine BBMM estimates are larger than KDE estimates with a similar trend for MCP (Table 2). The largest home ranges from this dataset (birds 115937 and 120332) resulted in a more-conservative home range estimate with BBMM. One BBMM model failed to converge on an estimate of home range for the 2012 birds, but we expect a similar result as the rest. Home ranges for the 2013 and 2014 datasets were generally larger than those calculated in 2012 (Figure 7, Table 7). Proportion of BBMM home range where birds had any chance of encountering wind turbines ranged from 0 – 100% with a mean of 12.8% (± 24.1%). Proportion of home ranges that overlapped the low-risk buffer averaged 4.9% (± 8.4%, range 0 – 36%), proportion where there was moderate risk averaged 7.4% (± 15.2%, range 0 – 69%), and proportion where there was highest risk of a bird encountering turbines averaged 0.2%

(± 0.5%, range 0 – 3%; Table 7). Twenty birds had home ranges where there was at no apparent risk of flying near wind turbines (Fig. 7).

Discussion

Productivity and Distance to Turbine

Our reproductive parameters for 2013 and 2014 were similar to previous reports from across the breeding range (Dunkle 1977, Bednarz 1988, Rodríguez-Estrella 2000, Nishida et al. 2013), with 69 – 84% nesting success and 1 – 1.2 fledglings per nest (1.4 per successful nest). Average fledgling numbers were a bit low during this study, but appear to be within the range of reported studies (see Bechard et al. 2010), and may be a result of temporal or geographic variation. While active nests ranged from 0.4 – 28 km from turbine fields, we did not find a relationship with any nesting parameters and distance to turbine. In some regions of the breeding range, Swainson's hawks appear to avoid nesting near wind turbines (Usgaard et al. 1997), while in other regions they seem to co-exist with wind energy facilities (Kolar and Bechard 2016). Our results suggest that Swainson's hawk reproduction was not heavily influenced by turbines in our study site. If we continue monitoring nesting activity into the coming years as turbine density increases on the study site and across the region, we may revisit this analysis to see if there is a lag effect of reduced productivity or nest area occupancy in response to turbine construction. Swainson's hawks are relatively long-lived birds, and short-term nesting failures may not influence immediate responses of range shifting from adults. As new individuals enter the breeding population over time, the younger birds searching for nesting territories may show a different response to turbines and the associated human activity than those adults that had established territories before turbine construction. In addition, at the time of this analysis, there were fewer turbines in operation within the entire study site than there were by 2016 (Fig. 2), and

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we anticipate continuation of wind energy development in the area in the coming years. The increasing density of turbines across the landscape may ultimately have a larger effect on nesting productivity, survival of fledglings and adults, and landscape usage of individual birds than the construction of a few small wind farms.

Turbines within Home Ranges

Our BBMM models produced home ranges similar to the MCP and KDE models for the birds equipped with PTTs in 2012 (Table 2, Fig. 4). Most BBMM estimates were a bit larger than KDE, perhaps because movements were considered just as important as stationary points, resulting in additional areas being classified as home range with the BBMM method. For the largest home ranges, the BBMM models were smaller than KDE and MCP, which may be due to the way BBMM deals with autocorrelation. We modeled points as being correlated when elapsed time was less than 10 hours, with greater elapsed times being considered independent from the previous points. This resulted in the largest home ranges having disconnected and shrunken polygons compared to KDE and MCP estimates (Fig. 4). Because BBMM takes into account the movements of animals across a landscape, rather than treating points as discrete units (Horne et al. 2007), we believe this is the superior methodology for producing home range estimates when animals are equipped with transmitters that provide frequent locational data.

Birds in this study ranged from almost no risk of encountering wind turbines within their 95% BBMM home ranges to a constant level of risk. On average, birds were within 3 km of turbine fields 23% of the time, but spent less than 1% of their time within 100 m of operational turbines. This result indicates that at the time of this study, most of the birds equipped with PTTs were at relatively low risk of mortality due to wind energy development on their breeding areas. However, if Swainson's hawks continue to maintain the same territories year after year, they will

be at higher risk of encountering wind turbines as development increases on the study area. Erickson et al. (2001) and Kolar and Bechard (2016) reported Swainson's hawk mortality due to wind turbine collision; indeed, one of our marked birds was killed by collision with a wind turbine elsewhere during its return to the breeding grounds. Although reports are few, it is apparent that this species is susceptible to risks from the wind energy industry.

GENERAL MIGRATION CHARACTERISTICS AND GENDER-SPECIFIC DIFFERENCES

The migration of Swainson's hawks has been studied by ground observations (Thiollay 1980, Juhant 2010), by mapping leg band recoveries (Houston and Schmutz 1995, Schmutz 1996), and by placing VHF and satellite transmitters onto adult hawks to track movements remotely (Fuller et al. 1998, Kochert et al. 2011). Using evidence provided by these and other studies, researchers believe that the majority of the global Swainson's hawk population travels to Argentina during the temperate winter. There is evidence that the migration occurs across land corridors (Fuller et al. 1998, Kochert et al. 2011), rather than passing over large bodies of water (although some over-water crossings are known to occur, such as Swainson's hawks observed flying over the Caribbean nation of Cuba, Rodríguez-Santana 2010). Research and recorded observations have also provided estimates of departure and arrival, daily travel rates, and other migration characteristics (Fuller et al. 1998, Bechard et al. 2010, Kochert et al. 2011). However, much remains to be described to understand how this species migrates such long distances before we can understand how landscape changes, such as land conversion, climate change, and novel technologies, such as wind energy development, might impact the success and survival of these migrating birds.

Kochert et al. (2011) provided some of the most-detailed descriptions of migration characteristics to date using 46 adult Swainson's hawks tagged with Argos-satellite transmitters, which we will use to make comparisons with our dataset. The transmitters used in that study had lower accuracy than the PTTs in our study (≥ 250 m error radius for Argos PTTs [Argos 2007] compared to an estimated ≤ 18 m error radius for GPS PTTs [Microwave Telemetry, Inc., Columbia, MD, U.S.A.]), which limited the conclusions that could be drawn from their data. Kochert et al. (2011) also obtained a lower amount of total data to analyze, with filtering data to one point per day and three years of total data. In addition, while their study included adult hawks from across much of the breeding range, there were no birds from the southeast portion of the breeding range where our study area is located. For our first analysis of the migration data, we chose to analyze general migration characteristics to not only compare to Kochert et al. (2011), but to also present novel descriptions and analyses to begin filling the knowledge gap. The objectives of this analysis were to determine departure and arrival dates, total transit days, daily rates of travel, and migratory corridors.

Migration characteristics might differ for male and female raptors due to differing roles in parental and post-fledging care on the breeding range, differences in the timing of molt and how that relates to migration, or differences in migration strategies (e.g., faster/slower travel rates, the need to compete for territories upon return, etc.). Martell et al. (2001) provided evidence with satellite telemetry that female osprey (*Pandion haliaetus*) left breeding areas and began migration before fledglings had fully achieved independence, leaving the males to care for the young. In addition, female osprey traveled to more-distant wintering grounds than males, which might drive the earlier departure (Martell et al. 2001). Sharp-shinned (*Accipiter striatus*) and Cooper's hawks (*Accipiter cooperii*) display gender- and age-specific differences in

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migration, with juvenile birds leaving before adults and females leaving before males (DeLong and Hoffman 1999). DeLong and Hoffman (1999) proposed that the reduced hunting skills of juveniles drove the earlier departure for migration as prey availability declined, and that the gender-specific differences may be due to hunting differently sized prey (a hypothesis related to reversed sexual size dimorphism). Variation may also have been driven by differences in the timing of molt, or differences in the rate of migration, with females potentially travelling at a faster rate than males due to their larger size (DeLong and Hoffman 1999). Reports of northern harrier (*Circus hudsonius*) migration imply that females depart earlier than males, but because females are so difficult to distinguish from juvenile birds, Bildstein et al. (1984) argued that juvenile birds may depart before adults, and that previous studies may have been misleading due to not separating female adults from juvenile birds. Mueller and colleagues (2000) reported age- and sex-specific differences in migration timing for ten species of raptors banded in Wisconsin, and found that juveniles departed for migration before adults in northern harriers, red-tailed hawks (*Buteo jamaicensis*), Cooper's hawks, American kestrels (*Falco sparverius*), sharp-shinned hawks, merlins (*Falco columbarius*), and red-shouldered hawks (*Buteo lineatus*), that females departed earlier than males in northern harriers, American kestrels, sharp-shinned hawks, and merlins, and that males departed earlier than females in Cooper's hawks (contrary to the report by DeLong and Hoffman 1999). Peregrine falcons (*Falco peregrinus*), rough-legged hawks (*Buteo lagopus*) and northern goshawks (*Accipiter gentilis*) had roughly equal departure timing among the ages and sexes (Mueller et al. 2000). Within long distance migrant raptor species, such as honey buzzard (*Pernis apivorus*), Montagu's harrier (*Circus pygargus*), osprey, and hobby (*Falco subbuteo*), adults appear to migrate ahead of juveniles (Kjellén 1992). Kjellén (1992, 1994) found that among a variety of raptor species inhabiting Falsterbo, Sweden, females

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generally migrated before males due to differences in the timing of molt, but that females generally had shorter migration distances, wintering further north than males.

Reports to date of Swainson's hawk migration suggest that there may be a difference in the timing of juvenile versus adult migration (Littlefield and Johnson 2013), but there appears to be no difference in the timing of males and females (Bechard et al. 2010, Kochert et al. 2011, Groen 2015). There remains, however, a lack of clarity as to potential sex-specific differences in migration patterns. We used our PTT data to determine if males and females display similar migration characteristics, as suggested by Kochert et al. (2011), or if there are sex-specific differences in migration timing, rate, and number of days in transit that have yet to be described for this species.

Methods

We used PTT data to analyze Swainson's hawk migration characteristics from Fall 2012 to Spring 2015. We determined date of departure for migration as the moment a bird made a >10 km movement in the direction of migration (i.e., south/southeast for fall migration; north/northwest for spring migration) from their breeding or wintering grounds without returning. Prior to fall migration, several birds moved to another location within Texas for a week or more before continuing their southward journey, so for the purposes of this portion of the study, we did not consider this behavior to be migration, and instead labeled it as "staging". For purposes of assessing departure dates and time in transit, we considered migration to begin when these birds left their staging grounds. We determined arrival date as when a bird ceased movement in the direction of migration, which was either an arrival on the wintering grounds (various locations in Argentina) or on the breeding grounds (within or near the study area). We defined number of days in transit for every migration of each bird. We considered points

recorded at night (1700 – 0500) to be "roosting" locations. We chose one roost location per day and measured distance between roost points using the GME software. We determined total migration distance as the sum of distances between roost locations, and calculated rate of travel (kilometers traveled per day) as the total distance divided by the number of days the bird was in transit. We compared departure and arrival dates, number of transit days, and daily travel rate between migrations, between birds, and between male and female hawks. We excluded data from analysis when the PTT stopped transmitting during migration due to mortality or technical failure. To statistically compare data among groups, we first tested data for homogenous variance using Levene's test and for normality using the Shapiro-Wilk test, and then we used Student's T-Test and Analysis of Variance (ANOVA) with alpha = 0.05. Number of transit days were log-transformed to conform to parametric assumptions.

We displayed PTT data reported during migration in ArcGIS 10.1 to determine travel routes and to identify migratory corridors. We visually analyzed routes by individual migration travel, by all migrations for one bird at a time, and by pooling birds to see differences between genders and between spring and fall migrations. Where migratory routes appeared to converge into relatively narrow geographic locations, we measured the perpendicular distance across all points to estimate width of migration corridors. We defined "corridors of potential conservation importance" as locations where the distance across all points was less than 100 km.

Results

Average date of departure was February 28th (± 8 days) for spring migration and October 8th (± 5 days) and for fall migration. Average length of migration was 48 (± 7) days. Among seasons and between males and females, date of departure and number of days in transit were similar and consistent (Fig. 9). We ran ANOVA models to test for seasonal and gender-specific

differences, and found that number of days in transit were similar for seasons and genders. Spring departure dates were similar between genders, but there was a difference between genders for the fall migrations ($F_{1,40} = 7.15$, $p = 0.011$; Table 8). In retrospect, we were concerned that using date of departing staging grounds as equivalent to date of departing breeding grounds might have introduced some bias into the migration departure data, resulting in a significant difference in fall departure dates that may be erroneous. We tested the same models again, but considered the departure dates to be when the birds left the breeding grounds and with correcting the number of transit days to include time spent on staging grounds. With the corrected models, we found no difference in fall or spring migrations for departure date, and for number of transit days there was a significant difference between seasons ($F_{1,73} = 6.71$, $p = 0.012$), but no difference among genders (Table 8). With the corrected dataset, total transit for fall migration averaged 56 ($\pm$ 15) days and spring migration averaged 48 ($\pm$ 14) days, with the largest differences between the original data and the dataset that included "staging" days being in fall 2012 and fall 2013 (Fig. 10). Mean departure date for fall migration was September 30$^{\text{th}}$ ($\pm$ 12 days) in the alternative dataset.

Because gender-specific differences were not found in the first analyses, we pooled data to analyze average daily travel rate. We chose to not include time spent on staging grounds in the calculation of distance or rate, because movement patterns were not linear and often back-tracked during these periods, which would inflate distance traveled. Using the original dataset for departure and arrival dates, we estimated distance traveled as an average of 10,283.2 ($\pm$ 715.4) km (Fig. 11A). Distances did not differ with season and year. Average daily travel rate was also similar between seasons, with an overall mean of 218.1 ($\pm$ 29.3) km/day (Fig. 11B). Finally, we identified three geographic areas where perpendicular distances across all points were < 100 km,

which we considered to be areas of potential conservation importance; the Oaxaca region of Mexico (72 km across), along the pacific coastline of El Salvador, Honduras, and Nicaragua (80 km), and along the Isthmus of Panama (58 km; Fig. 12).

Discussion

Migration Characteristics

Birds from our study area left for spring migration 4 days earlier and left for autumn migration 9 – 16 days later (depending on which dataset you use) than departure dates reported by Kochert et al. (2011). Our birds were in a portion of the breeding range that was not included in the sample of Swainson's hawks in the previous study, so there may be a geographic difference in the migration strategies. The difference in departure for spring migration is likely negligible, as our standard deviations overlap the reported mean date. The difference in the fall migrations is larger, however, and might be attributable to the longer growing season in Texas where prey (rodents and insects) might be available later in the season than more-northerly latitudes. In support of this idea, Kochert and colleagues (2011) reported that the majority of their tagged birds stopped for an average of 12 days prior to the majority of the migration travelling, and many of those stopovers were in the high plains of Texas where prey was likely still abundant at the time. Many of our birds also made movements away from the study area and then stopped for several days, which we classified as "staging" behavior, and this might represent a common migration strategy among birds from all portions of the breeding range. Average number of days in transit for birds in this study was 10-18 days shorter than for migrations reported by Kochert et al. (2011), which may be due to the later departure dates, or may be related to the shorter overall distance that our birds needed to travel between the common wintering grounds in Argentina and the nesting grounds in the southeastern portion of the

breeding range. The average distance traveled during spring migrations reported by Kochert et al. (2011) was similar to our estimates, while their fall migrations were about 800 km longer. This could be related to where birds were located when they began migration. In our migration dataset, many birds went from nesting or staging grounds to the most-distant areas on the wintering grounds before stopping, but prior to spring migration, many birds made slow movements to more-northerly portions of the wintering grounds, which would shorten migration distance. The distances reported by Kochert et al. (2011) are surprisingly similar, however, considering that some birds migrated from Canada to the same general wintering range as our birds from Texas. Kochert et al. (2011) described the pattern of movements on the wintering range as birds arriving in a northern region and moving southward, then moving northward again before departing for spring migration. Because many of the birds in this study did not cease migration until reaching the most southerly region of the wintering range, this could explain the similarity in distances described. Average daily rate of travel in this study was higher than for migrations reported by Kochert et al. (2011), but within the range of travel rates that they calculated (mean = 177, range 136 – 263 km/day), so we consider this to be a similar result. Overall, migration characteristics for Swainson's hawks nesting in Texas were similar to those nesting in other portions of the range, with some dissimilarities that are likely attributable to the differences in latitude.

Gender-Specific Similarities

Migration characteristics were similar between adult male and female Swainson's hawks in our study, which is consistent with the findings of Kochert et al. (2011). Many raptor species have gender- and age-specific differences in migration departure, travel rate, and wintering grounds. For some species, such as the osprey, this difference may be driven by a shift in the

parenting role to the male while the female leaves for migration, and might also be influenced by

females needing to winter in areas further away than the male wintering grounds (Martell et al.

2001). For sharp-shinned hawks, the differences in migration timing may be related to sexual

size dimorphism and the differences in prey availability, or might instead be driven by

differences in molting and how that relates to migration timing (DeLong and Hoffman 1999).

Peregrine falcons, rough-legged hawks, and northern goshawks were reported to have similar

migration departures for adult males and females by Mueller et al. (2000). The similarity of

characteristics for birds in this study suggests that breeding and post-fledging care either does not

influence migration or influences migration in similar ways for males and females. Molt is

relatively poorly understood for this species (see Bechard et al. (2010) for a synopsis of known

molting behaviors), so this also may contribute to the similarity in migration strategies. Finally,

sexual size dimorphism is less-pronounced for this species compared to the accipiters and

falcons, and we do not expect there to be a difference among genders in prey availability that

might drive gender-specific migration strategies in other raptors.

Migratory Corridors

Migration routes for birds in this study funneled from varying starting locations to a fairly

narrow route from Mexico to Argentina, which is consistent with previous reports (Fuller et al.

1998, Bechard et al. 2010, Kochert et al. 2011). We identified three regions where migration

routes narrowed significantly; in the Oaxaca region of Mexico, along the pacific coastline of El

Salvador, Honduras, and Nicaragua, and along the Isthmus of Panama (Fig. 12), which may be

important funneling locations of all migrating Swainson's hawks that do not winter in North

America. This corroborates the corridors identified by Kochert and colleagues (2011), with the

pacific coastline of Central America being an additional corridor that we suggest may be of

importance to the species. Of particular concern is the potential for wind energy conflict in these corridors, as they are relatively narrow and virtually all of the Swainson's hawk population passes through them. If wind energy developments, such as those present and increasing in Oaxaca, result in mortality risk for Swainson's hawks, it could present a substantial conservation concern.

SWAINSON'S HAWK USE OF AREAS OF DIFFERENT WIND POTENTIAL DURING MIGRATION

Migrating birds are subject to a variety of mortality risks when embarking on long-distance migrations, including natural risks they have evolved with, such as inclement weather, starvation, and predation, and man-made risks that are recent introductions on the landscape, such as aircraft, electrocution on power lines, large buildings with deceptive glass, and wind turbines. Osprey, marsh harrier (*Circus aeroginosus*), and Montagu's harrier suffered a six-fold increase in mortality during migration compared to breeding or wintering grounds, which exemplifies the risks raptors undertake during long-distance migration (Klaassen et al. 2014). The increasing types of potential mortality with man-made structures and technology might make migration even more perilous than during historic times.

With the abundance of migration data we gathered from adult Swainson's hawks, we explored risks posed by the wind energy industry across the migration range. If turbines are avoided by migrating birds, this could significantly increase the distance traveled or the length of time spent travelling, which might have a detrimental effect. The migratory corridors identified by Kochert et al. (2011) and this study (Fig. 12) may be especially important areas to avoid building in, or to consider siting options of turbines to minimize potential conflict.

We attempted to obtain data on wind turbine locations across the entire global range of Swainson's hawks to assess risk during migration, but were unable to find global data at the time of this study. To assess risk that the wind energy industry poses to migrating Swainson's hawks, we instead used "wind potential" as a proxy for turbine locations. Wind potential is a term used by the wind energy industry to classify geographic locations by their potential for developing wind farms to prioritize expansion into areas that will best support turbine technology. Wind speed data is collected at meteorological stations across the world; most stations measure winds at 80 m above ground, which is an appropriate height for wind turbines that range from 15 to 118 m above ground (Barclay et al. 2007). Wind energy companies and consulting firms use these data to create wind potential maps.

We used wind potential information to classify the Swainson's hawk migration range into categories of high, moderate, and low potential for wind energy development. We then examined migration rates to assess if migrating Swainson's hawks selected for or against areas of low or high wind potential. High wind potential was used in this analysis as regions we considered to have the highest likelihood of having turbines present or constructed in the future. Areas of moderate wind potential might also have turbines, but would be a lower priority for turbine construction as the wind speeds would not be conducive for maximizing electrical output from turbines with the technology being employed in 2014. In addition to a selection analysis of the entire landscape, we examined roosting and mid-day locations to see if Swainson's hawks selected for or against areas of high wind potential while actively migrating or when roosting at night.

Methods

We obtained a map of average wind speeds across North, Central, and South America from Vaisala 3TIER, and used this data to create polygons of wind potential areas in ArcMap 10.1. We classified high wind potential as areas with wind speeds > 6 meters per second (m/sec). Moderate wind potential was areas with wind speeds between 4.2 and 6 m/sec, and low wind potential was areas with wind speeds < 4.2 m/sec. We assessed the landscape Swainson's hawks used during migration for data collected from 2012 to 2015 by creating 50% and 95% dynamic Brownian Bridge movement models (dBBMM) with the "Move" package in Program R for each individual migration of each bird, excluding migrations where mortality or technical failure occurred. Brownian Bridge movement models used in the previous analysis (above) take into account the autocorrelation of points for moving animals, however the variance term calculated is assumed to be homogeneous across all data, which implies that movements between points are similar at all times (Kranstauber et al. 2012). The dynamic version of BBMM was developed to tackle the problem of varying types of movements within data by allowing the variance term to change throughout the dataset (Kranstauber et al. 2012). We chose this model to estimate landscape usage during migration, because the movements of birds during this time period may vary significantly, from small movements at roosts to moderate-distance movements when birds are staging or stopping en route to the long-distance movements that allow a bird to get from Texas to Argentina. We then estimated the proportions of the migration range that were classified as high, moderate, and low wind potential and compared those proportions with the total wind potential map to estimate use versus available. We used Student's T-tests to compare the proportion of each wind potential category that was available on the landscape with the proportion used in the 50% and 95% dBBMM contours.

As a second method to analyze selection for or against areas of high wind potential, we examined roosting and mid-day locations. We classified all locations by the wind potential areas they fell within, and then selected only the locations within high wind potential regions for analysis. We identified roosting locations (between 1700 and 0500, local time) and mid-day locations (between 0700 and 1500), and we then estimated the proportion that these locations made up of the total datasets for each individual migration. We expected to find that birds would select for lower wind potential categories when roosting at night and high wind potential for mid-day migration flights, because the higher wind might aid the efficiency of long-distance migration. We used linear regression models to examine relationships between roosting and mid-day locations.

Results

We estimated wind potential across the entire migration range, and we classified points and dBBMM home range polygons by the wind potential categories they overlapped (Fig. 13). We found that Swainson's hawks appeared to use areas of low wind potential more than expected, and areas of moderate wind potential less than expected (Fig. 14). We found a significant result with lower use of the high wind potential regions at the 50% dBBMM scale, but not at the 95% dBBMM scale ($p = 0.66$, Fig. 14). Compared to results from the low and moderate wind potential areas, we considered the use of high wind potential to be about equivalent to what was available on the landscape, rather than an indication of selection. The proportion of points within the highest-risk areas ranged from 17 to 22%. We compared the number and proportion of locations classified as "roosting" versus "midday" within the high wind potential region, and found no difference for any migration (Fig. 15). A linear regression resulted in a positive correlation between the proportions of roosting locations to the proportions

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of midday locations for each migration, with some variation, but not enough to be considered significant (Fig. 16).

Discussion

Selection of Wind Potential Areas

Our results suggest that Swainson's hawks select for low wind potential areas during migration, select against moderate wind potential areas, and they use high wind potential regions proportional to availability. Selection for low wind areas may be advantageous when birds make stops en route, as these regions might offer more opportunities to rest and forage than areas with higher wind speeds. This species relies heavily on thermal air columns to assist with lift and then soars from thermal to thermal for maximum migration efficiency, and it is possible that low-wind regions offer the best availability of air thermals on the landscape. Because there is no clear selection against high wind potential, it appears that the selection against moderate wind potential may simply be an effect of balancing the selection for low wind regions. Using the regions with highest risk of encountering turbines about as much as available might be driven by where these regions are situated. A large proportion of high wind potential polygons fell in the breeding range and along corridors that hawks consistently traveled through, so there may be no way for these birds to easily avoid those regions. It is also possible that displacement could occur if or when wind turbines are constructed. Using wind potential as a proxy to draw conclusions about migration behaviors is not as informative as knowing the locations of turbines on the landscape, and we hope to improve this analysis in the future after finding turbine locations across the global range using remote sensing techniques (see below).

Roost versus Midday Locations

We found no difference in roosting and midday locations with respect to high wind potential regions, which indicates that birds migrating through areas of high wind speeds were highly likely to also roost within the same regions. This result is likely driven by the large size of many high wind potential polygons on the landscape, where it would be infeasible for a bird to roost in a separate wind potential category from where it was travelling at midday. When in high wind potential regions, a migrating bird may be at essentially no risk of encountering a turbine if flying at heights well above the reach of turbine blades. However, when these birds come to trees or the ground to roost at night, they are flying within high-risk zones if turbines are constructed in their migratory pathway. Our result indicates that $8 - 36\%$ of roost locations are within regions where birds may be facing a high risk of encountering wind turbines, and as turbines become denser on the landscape, this may translate to high mortalities for migrating Swainson's hawks in the future.

PRIORITIES FOR FUTURE RESEARCH TO EXPLORE ECOLOGY OF ADULT AND JUVENILE SWAINSON'S HAWKS

The transmitters we have attached to adult Swainson's hawks have provided a plethora of movement data to answer many questions about the ecology of a long-distance migrant raptor species. With more than 5 years of data on some birds, multiple migratory passages, movement data on both the breeding and wintering range, and the data we are beginning to collect on fledgling birds, we will explore a breadth of topics not previously possible before GPS transmitter technology was miniaturized enough to attach to these birds. The analyses we have conducted are only the beginning of this ongoing project, and we have plans to explore a variety of topics in the upcoming years.

Breeding Range Movements

For Figure 6, we combined all BBMM models to discuss an unanticipated result regarding the movements birds made on and off their nesting ranges. The home ranges estimated for the 2012 data were generally much smaller than those in 2013 and 2014 (see Fig. 7 and Table 7), because 2012 was when we equipped half of the hawks with PTTs on the breeding range. About a quarter of the birds were captured in May, at the beginning of the breeding season, and about a quarter were captured in July, which is towards the end of breeding season. This limited our home range estimate to only what birds did while maintaining a nest up to the point when they left for migration. Upon return the following year, many of these birds did something unexpected. We officially cut off the migration at the point that the bird made its first location in or near the study area, assuming this was the end of the bird's long-distance travels. However, more than half of the birds returning from migration in 2013 and 2014 left the study area within a few days and traveled tens to hundreds of kilometers before returning to breed a week or two later (i.e., 10 birds out of 11 returning in 2013 and 4 birds out of 13 returning in 2014 made these movements). Most of these movements occurred in April, which may explain why we did not see this result in the 2012 dataset where birds were captured in May. This resulted in significantly inflated home range estimates, but brought up a new question: why do these adult birds display ranging behavior prior to nesting? Perhaps the birds make it back to their nest site only to find the nest destroyed or falling apart, and then range to attempt to find a new nesting location. If that were true, however, one would not expect all birds to have high site fidelity from year to year, which is what we have found from banding and monitoring these birds for five years. Perhaps the bird returns to the nest site to wait for the mate from the previous year, and if their mate does not make an appearance, the bird will go ranging in search of a new mate. The ranging

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could also be resource-driven, if, perhaps, the bird arrives from migration early and prey availability is low in the nesting area. These are questions that we would like to explore with this dataset in the future.

Migration

Kochert and colleagues (2011) provided the most detailed descriptions and analyses of the migration of Swainson's hawks to date using transmitters similar to those in this study, however recent advances in technology allow us to obtain data with higher accuracy and precision. This gives us the ability to not only compare migration of birds from the southern high plains to the previously tagged birds using similar analyses, but we also have the daily patterns and the location accuracy to consider novel questions. Using these data, we have addressed migration initiation and duration, similarities between genders, and the pathway birds traveled. However, we have not yet explored stopover or staging behaviors, travel velocity, altitude during travel and rest, or landscape use and selection.

Stopover or Staging Behaviors

Warnock (2010) defined "staging" as a behavior where birds move to a location away from the nesting range and stay for days to weeks building food reserves before making a relatively non-stop migration movement, and he defined "stopovers" as a behavior where birds make multiple stops along the migration pathway for shorter periods of time, presumably to forage en route. The literature on Swainson's hawks is sparse, but there is a controversy as to whether Swainson's hawks stage prior to a long-distance migration or whether they make stopovers to refuel along the way. Smith et al. (1986) suggested that Swainson's hawks do not forage en route, and instead subsist on fat reserves built prior to migration. Bechard et al. (2006) countered that argument with evidence that Swainson's hawks do not build enough fat reserves

during staging periods to be able to complete such a long-distance journey, and therefore must conduct stopover behaviors to forage en route. Kochert et al. (2011) provided further evidence using locational data that Swainson's hawks may have a stop-and-forage migration strategy, rather than staging.

It would appear that the argument is settled with the acquisition of transmitter data, but the locational data we have gathered might suggest otherwise. We have not completed analysis yet, but so far it appears that our data supports the original argument that Swainson's hawks primarily stage prior to migration, and that stops during migration might be due to inclement weather or poor wind conditions, rather than an opportunity to forage. Using the migration data, we are identifying stops of greater than one day along the entire route, and have surprisingly not found the kind of stopover data that Kochert et al. (2011) provided. Instead, the stops prior to migration are the longest and most frequent, and stops along the bulk of the route are uncommon and typically only last 1.5 to 2 days, suggesting that Swainson's hawks may have a staging strategy, and stopovers during migration may be of less ecological importance than their staging grounds. The differences in our datasets may also show a geographic variability or behavioral plasticity in the migration patterns of this species.

Travel Rates

Schmutz (1996), Fuller et al. (1998), and Kochert et al. (2011) provided estimates of travel rate during migration as average distance covered per day, and due to the limitations with their data collection, this may be the most informative estimate they could produce. The PTTs deployed in this study provide hourly locations for most of the day, so we have taken this a step further by calculating travel velocity as distance traveled per hour. Using the velocity data, we have found patterns of high-velocity travel (> 80 kmh^{-1}) in four areas; Texas, Central America

(between Costa Rica and Panama), Bolivia, and Argentina. This pattern may be related to topographical features of the migratory pathway, such as mountain ranges, and in Texas this may be related to high wind speeds. We plan to further explore this data in respect to the landscapes that might drive this result.

Altitude During Travel

To our knowledge, the only altitudinal descriptions of the Swainson's hawk mass migration are anecdotal. Smith (1985) estimated birds flying at 375 to 2650 m above ground level, but suggested that birds could potentially fly far higher in good conditions. Our transmitters provide an estimate of altitude at each reported location ($\pm$ 11 m) so we will calculate above-ground altitude by comparing to an ASTER global landscape elevation model. With this data, we can address questions such as; do birds fly at different altitudes when traversing different topographical features, such as flat grasslands compared to mountain ranges? Does altitude correlate with travel velocity in any meaningful way? Are altitudes relatively stable or do they vary widely from day to day and throughout the route?

Landscape Use and Selection

To our knowledge, no one has described the landscapes used by Swainson's hawks during migration. When actively travelling, the landscape below might be of little consequence as long as air thermals and wind exist. However, these birds only travel diurnally and must roost at night, so they may have selection preferences for resting areas, such as grasslands or areas with trees. Swainson's hawks travel en mass, and we do not know how land use changes might impact their roosting or survivability en route. We also know very little about their stopover/staging behaviors, and if they select for specific habitats for these events, which many be areas to consider for conservation. We plan to explore landscape utilization and selection

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using our location data and remotely sensed landscape classification images across the migration route.

Movements on the Non-breeding Range

Little is known about the ecology of Swainson's hawks on their nonbreeding range, which is thought to be primarily in the Pampas region of Argentina (Bechard et al. 2010). Population declines on the breeding range in North America may be directly related to land conversion and pesticide use due to intensive agricultural practices in Argentina (Goldstein et al. 1999), so understanding the ecology of these long-distance migrants may be important for future conservation management. Swainson's hawks are known to occur in large numbers in crop fields and cattle pastures eating grasshoppers and dragonflies, and we believe that rather than maintaining territories, the birds' movements are nomadic across a general landscape. Kochert et al. (2011) described the movements of tagged birds as a north-to-south and then south-to-north pattern, but we do not know if all birds move about in such a manner or consistency of patterns over time.

With data we have collected at a high spatial accuracy and multiple points per day, we have the ability to observe movement patterns that were not possible before. We can create time-series maps to show how birds move across the landscape. We will create dBBMMs to model use and selection of areas across the non-breeding range. Using land-classification maps, we will describe habitat use and selection, and then we can discuss how land use and land conversion in Argentina may be impacting this species.

Juvenile Ecology

Essentially nothing is known about the behavioral ecology of juvenile Swainson's hawks after they leave the nesting area. As stated above in "General Migration Characteristics and

Gender-Specific Differences", many raptor species show differential migration between juvenile and adult birds, including Osprey, sharp-shipped hawks, Cooper's hawks, northern harriers, red-tailed hawks, American kestrels, merlins, red-shouldered hawks, honey buzzards, Montagu's harriers, and Hobbys (Bildstein et al. 1984, Kjellén 1992, DeLong and Hoffman 1999, Mueller et al. 2000, Martell et al. 2001), with many species showing juvenile departure days or weeks before adults, and other species showing adults beginning migration ahead of juvenile birds. To address questions of age-specific migration strategies and to compare and contrast the migration routes and wintering areas among adults and juveniles, we tagged 5 fledgling hawks with similar transmitters as the adults in 2016 and 9 hawks in 2017. To make these transmitters lighter weight for fledgling birds, we chose solar-powered Argos satellite transmitters, rather than GPS, which gives us a spatial accuracy similar to the transmitters used for previous movement studies of Swainson's hawks (Bechard et al. 2006, Kochert et al. 2011). Juvenile PTTs were scheduled to collect hourly location data for 10 hours, then an off-period of 24 hours to conserve battery life before reporting more data. With the data we are currently collecting, we are able to track these birds through their first migration and their first return to the breeding range. This allows us to see if young birds conduct migration in a similar fashion as adults (similar departure and arrival dates, similar pathway, similar wintering grounds), or if they deviate from adult patterns. We will also be able to see if first-year birds return to their natal range, or if the first-year's return trip is a time for dispersal to a novel portion of the breeding range.

Swainson's hawk populations appear to have high connectivity and genetic exchange in the majority of their range (Hull et al. 2008), but we do not know if adult movements or juvenile dispersal explain that result. Understanding natal dispersal is important for understanding population dynamics at large spatial scales. Schmutz et al. (2006) found a low return rate of

banded juvenile Swainson's hawks; less than 5% were re-sighted throughout the course of their study. These results may indicate high mortality among young hawks or low fidelity to the natal range and a high dispersal rate. Briggs et al. (2012) studied the dispersal differences of birds banded as fledglings that returned to breed within the study area in California, and found dispersal ranging from 0.1 to 46.0 km, and that females had a larger dispersal distance than males. This may indicate that juvenile Swainson's Hawks tend to nest within a finite distance of natal territories, but their study was biased by a limited search area. Woodbridge et al. (1995) stated that two birds banded as fledglings in California were later found as adults in Nevada (565 km from natal territory) and Oregon (160 km from natal territory), but breeding status could not be confirmed. Houston and Schmutz (1995) identified three birds that bred 190 – 310 km from their natal ranges, but also found seven birds breeding within 10 km of their natal sites. Variability in results and low recovery of bands indicates that the question of natal dispersal has yet to be answered for this species.

When juvenile birds return to the breeding range, they are not known to breed their first year (Bechard et al. 2010). Continuous locational data will allow us to discover what juvenile birds do upon return. Do they maintain a territory? Are they nomadic? Do they have a different habitat selection than adult birds? Answers to these questions will add to the body of knowledge of Swainson's hawk natural history and behavioral ecology and may aid conservation efforts in areas with population declines.

PRIORITIES FOR FUTURE RESEARCH TO DETERMINE RISK THE WIND ENERGY INDUSTRY MIGHT POSE TO SWAINSON'S HAWKS

As stated above, the wind energy industry potentially poses a threat to Swainson's hawks. Raptor mortality is commonly found at active wind farms, with the most notable source of

mortality being the Altamont Pass Wind Resource Area, which might kill as many as 1,127 raptors every year (Smallwood and Thelander 2008). Some birds may be more vulnerable to wind turbine mortality than others, such as golden eagles (*Aquila chrysaetos*) and griffon vultures (*Gyps fulvus*) that have flight patterns that put them right in the path of poorly-placed turbines and that have long lifespans, low fecundity, and declining populations due to a wide variety of factors (Barrios and Rodríguez 2004, Smallwood and Thelander 2008). There have been some reports of Swainson's hawk mortality at wind farms (Erickson et al. 2001, Kolar and Bechard 2016), but as most pre- and post-construction research is unpublished (see Kuvlesky et al. 2007), the breadth of knowledge available for this species is poor. Swainson's hawks in our study area occupy grasslands and agricultural fields that are ripe for wind energy contracts, and reports from the wintering range suggest that their habitat preferences are similar in Argentina (Woodbridge et al. 1995*b*). Our wind potential map (Fig. 13) indicates that a large proportion of the breeding and staging areas for this study population are the highest priority for wind farm construction, and almost all of the Argentina region that we chose to classify is either high or moderate wind potential. Similar to our observations on the breeding range, the wind energy industry is rapidly expanding on the wintering range as well (C. Gordon, personal communication). We do not yet know where windfarms have been placed throughout the migratory passageway, but there are several regions of high and moderate wind potential throughout Mexico, Central America, Columbia, Bolivia, and Paraguay that might pose further collision risks to Swainson's hawks. There is a significant gap in knowledge as to how this species will respond to wind turbines, and we hope to continue to provide an extensive examination of possible risk with the PTT data we have obtained.

Wind Potential Analyses

To date, we have analyzed how the wind energy industry is expanding in and around the study area (Fig. 2), the proportion of breeding home ranges where Swainson's hawks were at risk of encountering wind turbines (Fig. 3, 7, 8, and Table 7), how nesting success does not appear to be influenced by distance to turbines (Fig. 5), and the proportion of individual migration pathways where birds might be at risk of encountering windfarms (Fig. 13 and 14). Using the wind potential regions, we have several more steps to take before finalizing an assessment of the migration pathway. We recently began two projects to further this research involving travel rates and altitude during flight.

Preliminary results suggest that Swainson's hawks travel at about 32 km/h when actively migrating, and while we found some significant differences in travel rate among the wind potential regions that the trajectories passed through, we did not find that birds were travelling faster through high wind regions than other areas (Fig. 17). This is potentially important for two reasons. Part of this analysis was meant to explain the apparent selection for low wind areas, as we hypothesized that if birds are travelling faster through moderate and high wind potential regions, this would result in fewer points in our dataset and might skew data to the appearance of selection against those regions. The velocity data we have analyzed so far does not support that hypothesis, which means the apparent selection for low wind areas has merit, and we should investigate why that might occur. The other reason why the velocity data might be important is that if birds are not flying quickly through high wind potential regions, then there is no indication that they can effectively avoid encountering windfarms by reducing their time spent in those areas. Alternative routes and other displacement actions may be the strategy to reduce risk if birds cannot utilize high speeds.

In another preliminary analysis, we used ASTER digital elevation models to convert the reported altitude data to above-ground height, and the migration data appears to range from 0 to 9833 m, with an average of 176 m above ground. We compared the wind potential map to altitude data, and preliminary results suggest that Swainson's hawks were flying at above-ground heights that could put them at risk of turbine collision (defined as $0 - 200$ m above ground) 61% of the time. When we narrowed the data to only points within high wind potential regions, 63% of points were at heights that could put birds at risk. Ninety-four percent of roosting-time points were within the risk zone, which makes sense as Swainson's hawks go to trees or the ground to roost at night during migration. Entering and leaving roost sites that are within the high wind potential regions may be the time of greatest risk for these birds. During diurnal hours, they were flying at heights that put them at risk nearly half of the time. We will continue to work with this dataset to tease out errors and produce reliable estimates before finalizing our conclusions, but so far it appears that a large proportion of points were within a high-risk zone for our study birds.

Analyses Using Turbine Locations

As stated above, the wind potential map can only yield a portion of the complete picture of risk for Swainson's hawks. The ideal analysis will involve knowing the actual locations of wind turbines throughout the global range, from Texas to Argentina. We are currently exploring ways to obtain this information using remote sensing imagery from ArcMap, Google Earth, and possibly Landsat 8. The information exists in imagery form, so the key is finding a method of visually locating turbines over a large geographic area in a manner than is time efficient and reveals accurate information for the relevant time period.

Once we obtain or develop a map of global turbine locations relevant to Swainson's hawks, we will run a series of spatial analyses to better understand the risk that the study birds

may have been encountering during data collection. We will place risk buffers around turbine points, similar to the study above, to assess number of hawk locations that fell within risk zones and what proportion of those points were also at above-ground heights that would make turbine encounters potentially dangerous. We will use the dBBMM migration contours to assess proportion of migration pathways occupied by turbine buffers, similar to the study above on the breeding range. We will also create home range estimates for the wintering range to assess risk of the expanding wind energy industry in Argentina, and we can look for signs of displacement and avoidance of turbine fields when the birds were not holding specific territories. Last, we want to compare final locations of PTTs that have gone offline to windfarm locations to see if collision with a turbine is a possible cause of death for any of the birds in this study. Once we have all of this information compiled, we hope to be able to draw holistic conclusions about how Swainson's hawks might be impacted as wind turbines increase on the landscapes they occupy.

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Figure 1. Study area within Armstrong, Carson, and Potter counties, Texas. The grey polygon

shows the general area where nests were monitored and birds were trapped from 2011 to 2017.

The Pantex plant was the focus of the study and is highlighted in this map as a cross-hatched

polygon.
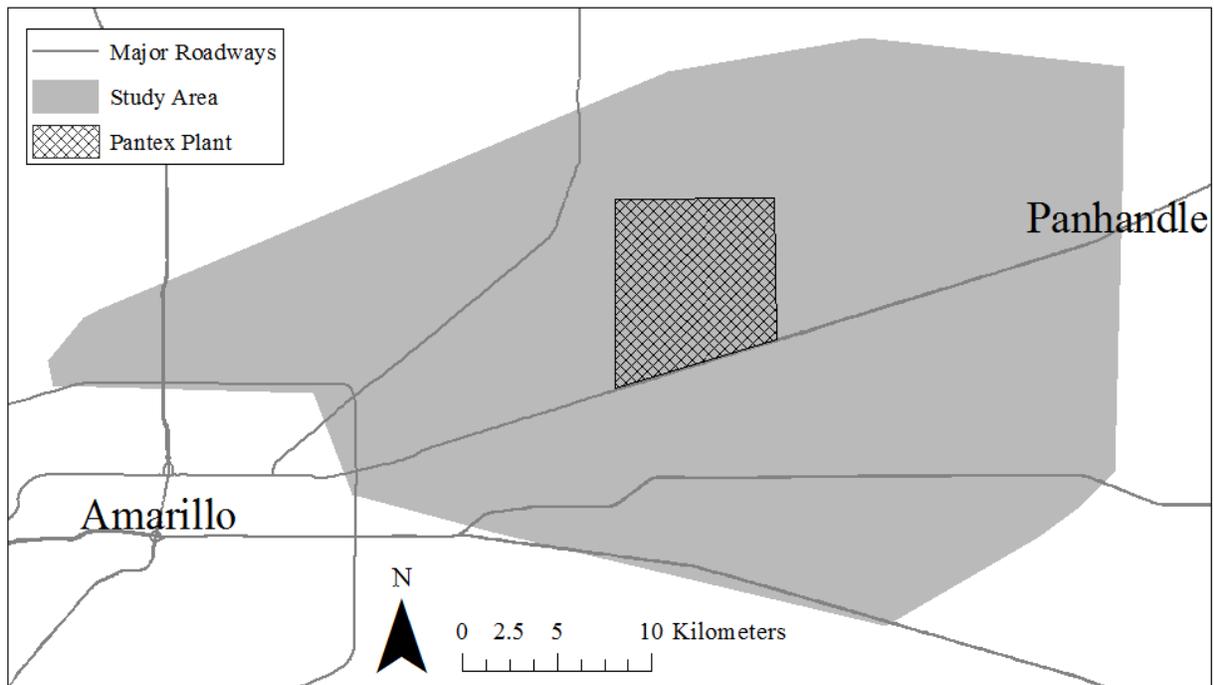
Figure 2. Wind energy development in and around the study area rapidly grew throughout the duration of this study. We obtained turbine locations from Google Earth satellite imagery from 31 Jan 2012 and 8 Feb 2016 (western portion of maps) and from 1 May 2012 and 16 Aug 2016 (eastern portion of maps). The top map represents the turbines that were in operation since the beginning of the study, April 2011, and the bottom map shows how many turbines were in operation five years later.
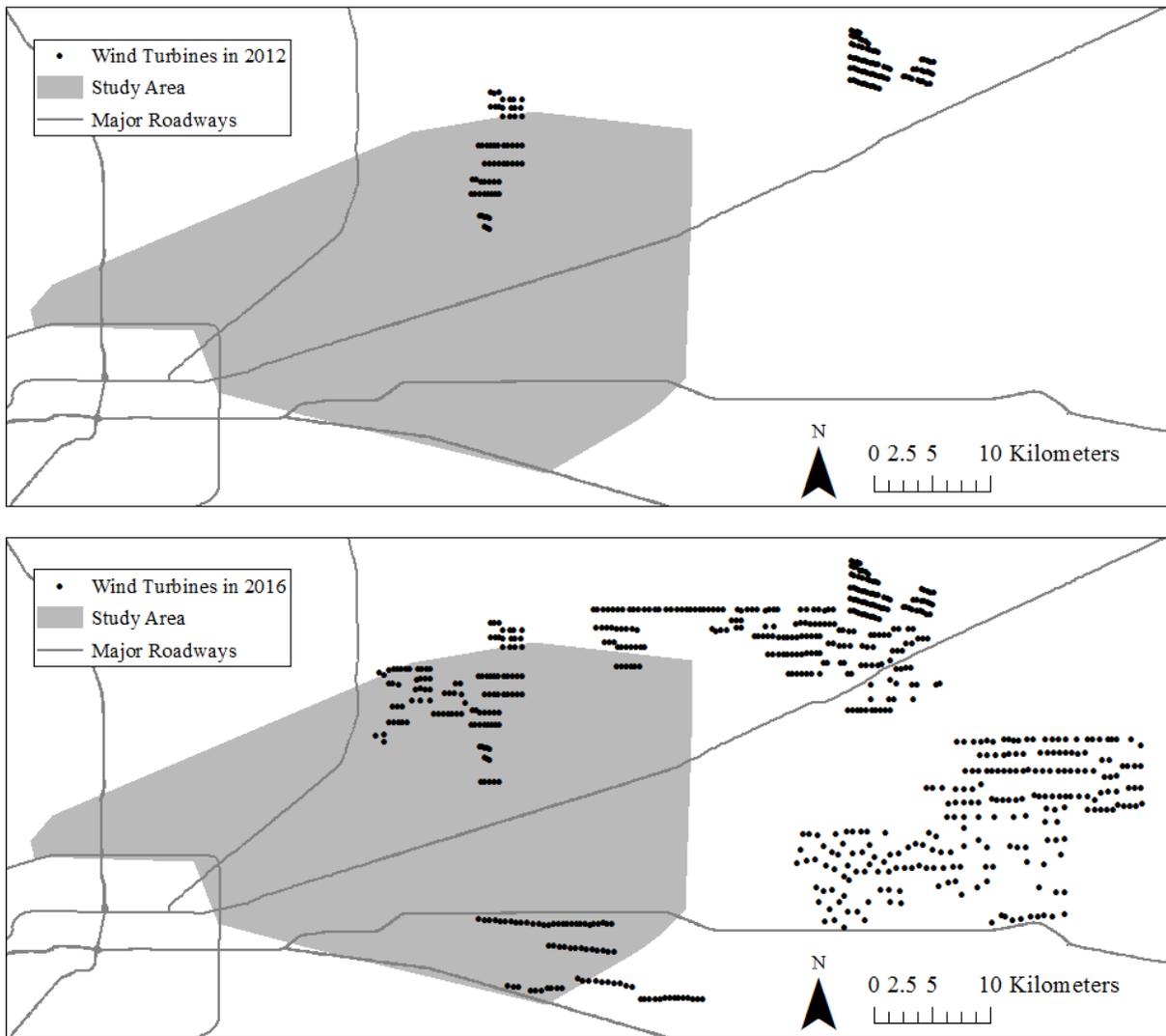
Table 1. Home range size estimates (km^2) of Swainson's hawks equipped with Very High Frequency (VHF) transmitters using the Minimum Convex Polygon (MCP) and the Kernel Density Estimate (KDE) methods. The bird ID column indicates alpha code of leg band on each hawk. Means are presented with standard deviations.

		2011 Breeding Season		
Bird ID	Sex	# Locations	95% MCP	95% KDE
NZ	F	40	91.0	72.7
PE	M	20	51.6	36.8
PW	F	54	86.5	38.1
RK	M	43	8.4	6.7
WINK	F	40	6.2	6.2
		2012 Breeding Season		
NZ	F	33	45.3	45.6
PS	M	60	232.2	39.5
PU	M	23	223.0	422.1
PW	F	31	415.9	466.6
PX	F	21	229.6	396.4
RK	M	54	50.6	13.0
Mean			130.9	140.3
Std. Dev.			128.0	186.7

Table 2. Home range size estimates (km^2) of Swainson's hawks equipped with GPS Platform Transmitter Terminals (PTTs) during the 2012 breeding season using the Minimum Convex Polygon (MCP), Kernel Density Estimate (KDE), and Brownian Bridge Movement Model (BBMM) methods. The bird ID column indicates numeric code of PTT. Means are presented with standard deviations. Dashes indicate one model that was unable to produce a viable home range estimate.

Bird ID	Sex	# Locations	95% MCP	95% KDE	95% BBMM
115937	M	1375	375.7	834.4	407.3
115938	F	1510	14.0	17.5	52.7
115939	M	1275	25.8	40.5	105.1
115940	M	1131	8.5	12.0	18.9
120328	M	936	6.1	8.3	12.6
120329	F	982	5.4	7.1	15.0
120330	F	463	9.3	12.5	21.8
120331	F	853	6.0	8.3	20.4
120332	M	541	1997.1	1694.4	400.7
120333	M	707	8.6	16.7	23.2
120334	M	880	18.2	44.5	--
120335	M	802	7.5	11.2	42.9
Mean			206.9	225.6	101.9
Std. Dev.			573.5	518.8	151.7

Table 3. Compositional analysis of proportion of available habitat within the combined area of all 95% Kernel Density Estimate (KDE) home ranges compared to proportion of habitat used within each individual KDE by Swainson's hawks wearing GPS Platform Transmitter Terminals (PTTs) in 2012. The bird ID column indicates numeric code of the PTT. Numbers are percentage of habitat and means are presented with standard deviations.

Habitat Available to All Birds					
Bird ID	Grassland	Dryland Crops	Irrigated Crops	Textile	Wind Farms
All	50.1	29.0	17.3	1.8	1.8
Habitat Utilized by Each Bird					
115937	25.1	27.5	37.4	8.5	1.6
115938	38.7	41.9	17.0	2.4	0.0
115939	91.2	6.2	2.5	0.0	0.0
115940	63.2	3.8	27.8	2.8	2.4
120328	98.4	1.1	0.5	0.0	0.0
120329	76.2	23.9	0.0	0.0	0.0
120330	60.6	39.0	0.0	0.4	0.0
120331	56.6	31.7	0.0	11.8	0.0
120332	45.2	53.9	0.9	0.0	0.0
120333	77.5	16.1	6.4	0.0	0.0
120334	56.4	27.7	0.4	15.6	0.0
120335	99.0	1.0	0.0	0.0	0.0

Mean	65.7	22.8	7.7	3.5	0.3
St. Dev.	23.5	17.4	12.8	5.4	0.8

Table 4. Simplified ranking matrix of compositional analysis model results comparing proportion of habitat used with available habitat within 95% Kernel Density Estimate (KDE) home ranges for 12 Swainson's hawks equipped with GPS Platform Transmitter Terminals (PTTs). Symbol within each cell indicates if the habitat type in the column header was used more than (+), less than (-), or equal to (0) the habitat type in the row. A triple sign indicates a significant deviation from random ($p < 0.05$). Ranking shows the order in which habitats were most (rank of 1) to least (rank of 5) used compared to what was available on the landscape.

	Habitat Type				
Habitat Type	Grassland	Dryland Crops	Irrigated Crops	Textile	Wind Farm
Grassland	0	-	- - -	- - -	- - -
Dryland Crops	+	0	- - -	-	- - -
Irrigated Crops	+ + +	+ + +	0	+	-
Textile	+ + +	+	-	0	- - -
Wind Farm	+ + +	+ + +	+	+ + +	0
Ranking	1	2	4	3	5

Figure 3. The home ranges of two Swainson's hawks overlapped wind farms in the study area. The polygons represent the 95% Kernel Density Estimate (KDE) home ranges based on GPS Platform Transmitter Terminals (PTT) locations. The east wind farm is represented by black triangles with a white line bounding the wind farm edges, and the west wind farm is black circles with a hatched line surrounding the field. The Pantex Plant, which was the focal point of the study, is symbolized with a hatched polygon, and lines in the background show roadways in this portion of the study area.
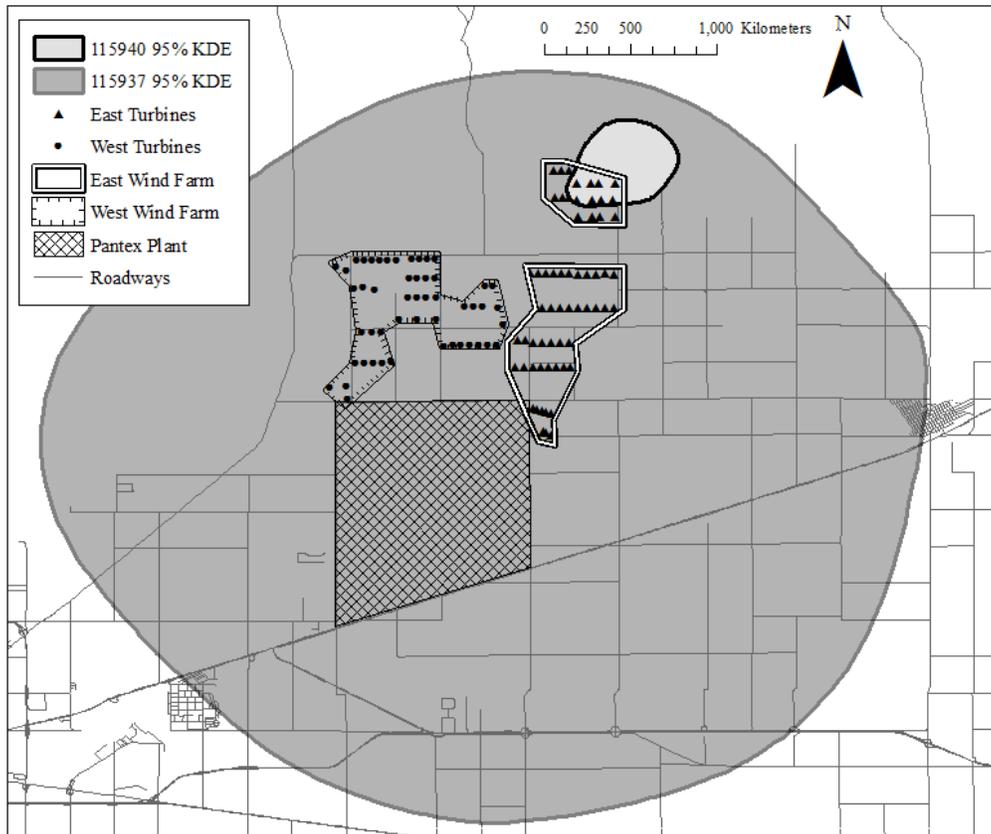
Figure 4. Comparison of Minimum Convex Polygon (MCP; left), Kernel Density Estimate (KDE; middle), and Brownian Bridge Movement Model (BBMM; right) methods used to estimate home range size for Swainson's hawks equipped with GPS Platform Transmitter Terminals (PTTs) during the breeding season of 2012. Home ranges were estimated with identical datasets. The inset map indicates where these polygons are located within the state of Texas.
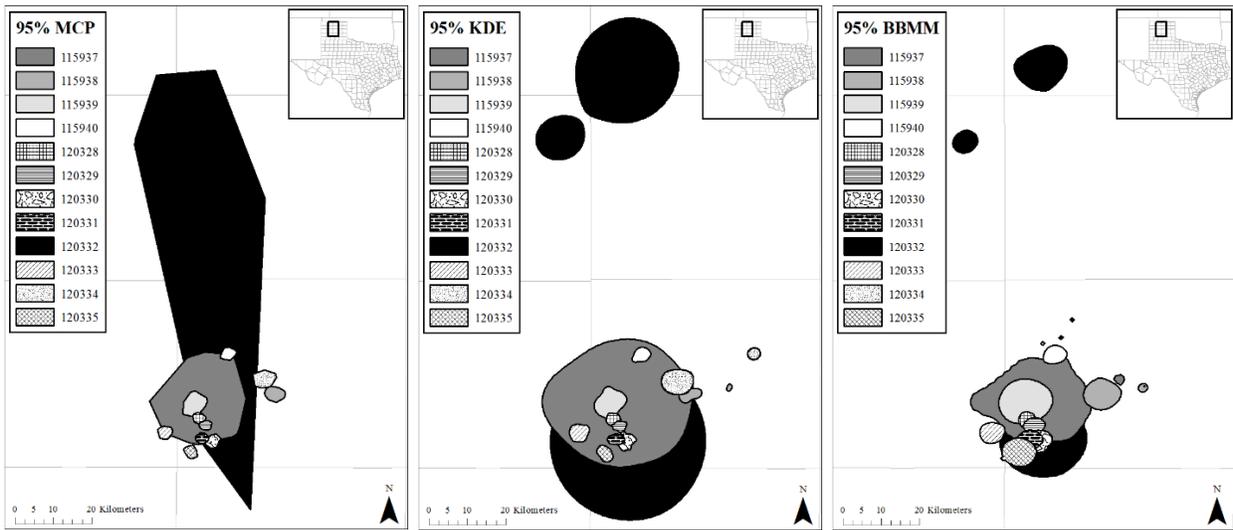
Table 5. Nest success and number of young produced at active Swainson's hawk nests within the study area near Amarillo, TX in 2013. A "1" indicates a successful nest, and a "0" indicates a nest failure. Nests are named as a letter that indicates if the nest was in the general study area (A) or on Pantex Plant property (P) and a unique number. Means are presented with standard deviation.

Nest	Success	Number of Nestlings	Number of Fledglings
A001	1	2	1
A005	0	2	0
P013	1	2	2
P028	1	2	1
A038	1	2	2
A039	0	1	0
A048	0	0	0
A052	0	0	0
A057	1	1	1
A059	1	1	1
A060	1	2	1
A062	1	2	2
A067	1	2	2
Mean	69%	1.46	1.00
St. Dev.	48%	0.78	0.82

Mean per successful nest	1.78	1.44
St. Dev.	0.44	0.53

Table 6. Nest success and number of young produced at active Swainson's hawk nests within the

study area near Amarillo, TX in 2014. A "1" indicates a successful nest, and a "0" indicates a

nest failure. Nests are named as a letter that indicates if the nest was in the general study area (A)

or on Pantex Plant property (P) and a unique number. Means are presented with standard

deviation.

Nest	Success	Number of Nestlings	Number of Fledglings
A002	1	2	2
A003	1	1	1
A004	1	1	1
A005	1	1	1
A010	1	2	1
A011	1	2	2
A021	0	0	0
A023	1	2	2
P025	1	1	1
P027	0	3	0
P028	1	2	1
A030	1	1	1
A031	1	2	2
A033	1	1	1
A034	0	1	0
A035	1	2	2
A036	1	3	3

A037	1	1	1
A075	1	1	1
Mean	84%	1.53	1.21
St. Dev.	37%	0.77	0.79
Mean per successful nest		1.56	1.44
St. Dev.		0.63	0.63

Figure 5. Distance to nearest wind turbine for active Swainson's hawk nests in the study area near Amarillo, TX in 2014. Gray bars indicate nests with successful fledging of young, and black bars indicate nests that failed to produce any young.
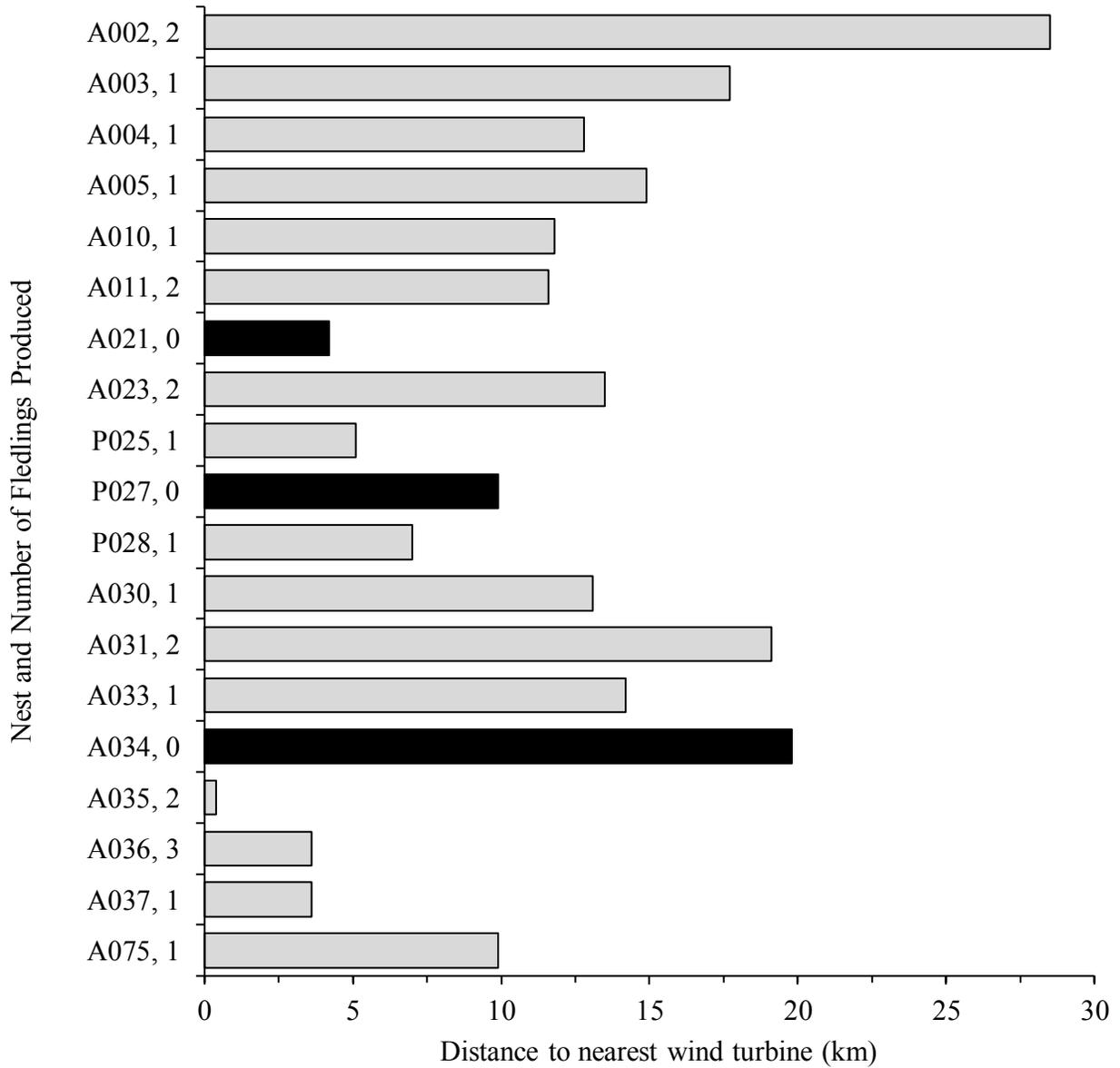
Figure 6. Combined Swainson's hawk home ranges on the breeding range from 2012 – 2014. Swainson's hawks were equipped with GPS Platform Transmitter Terminals (PTTs), and we estimated home range using Brownian Bridge Movement Models (BBMM).
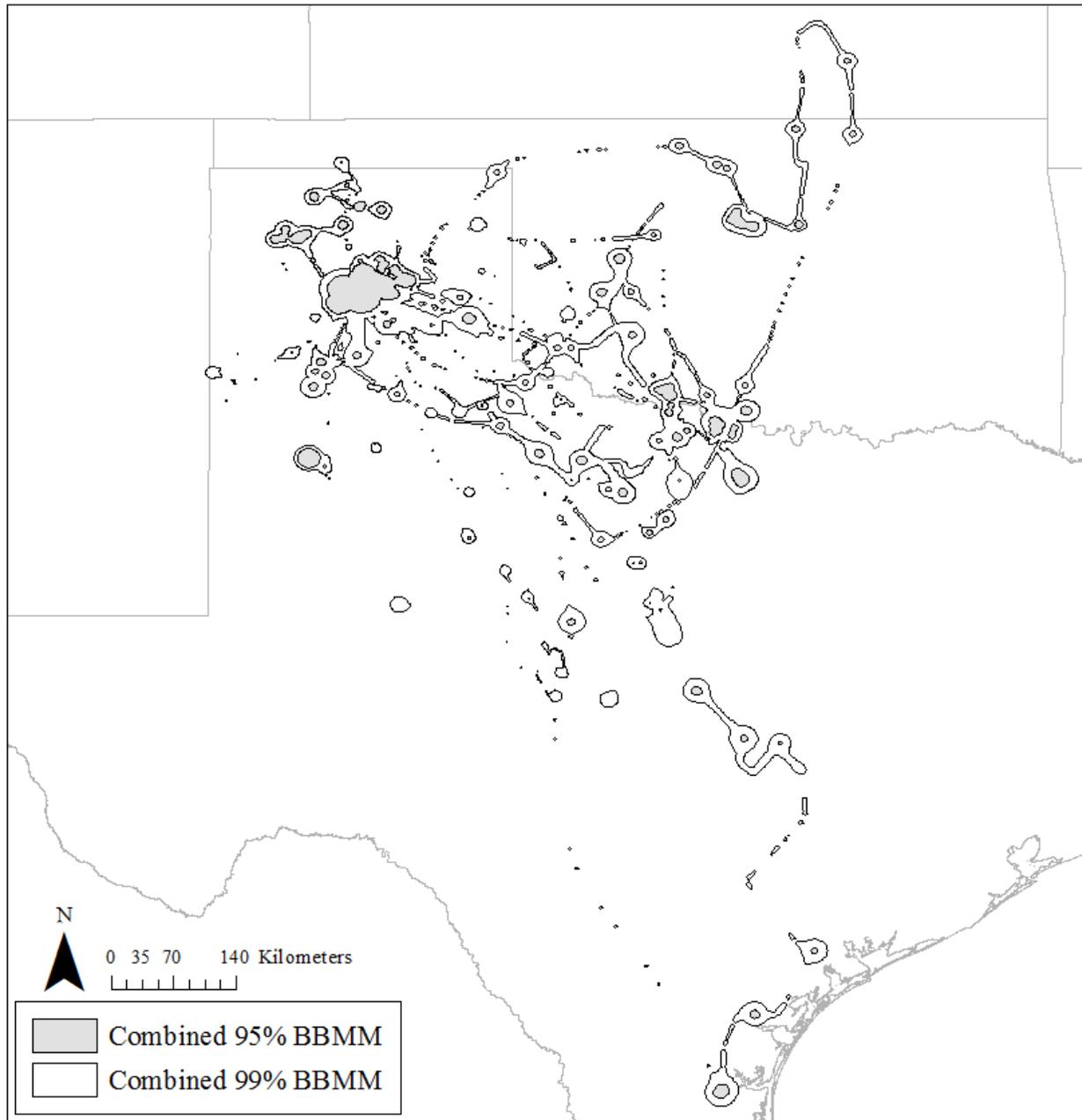
Figure 7. Home range of nesting Swainson's hawks overlapping 3 km buffers around wind turbines in the study area near Amarillo, TX. Swainson's hawks were equipped with GPS Platform Transmitter Terminals (PTTs), and data were analyzed for the 2012, 2013, and 2014 breeding seasons to determine 95% home range using Brownian Bridge Movement Models (BBMM). Bars show total home range, with proportion that overlapped turbine buffers in black and proportion with no risk of encountering wind turbines in gray.
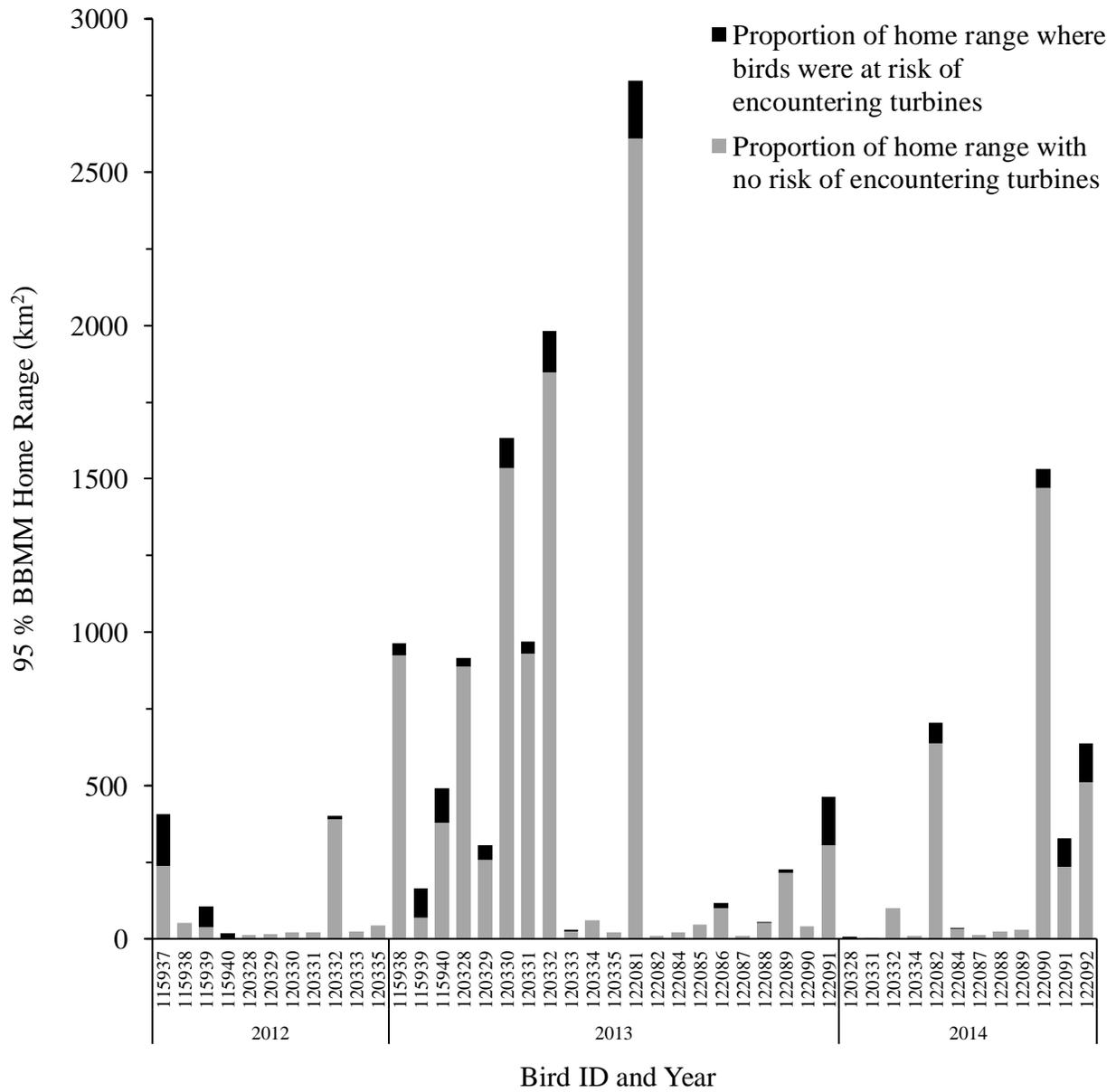
Figure 8. Example of Swainson's hawk home ranges occurring in areas with active wind turbines. Swainson's hawks were equipped with GPS Platform Transmitter Terminals (PTTs) to collect information about home range size and interactions with wind turbines and we estimated home range with Brownian Bridge Movement Models (BBMM). We placed 3 km, 1.5 km, and 100 m buffers around locations of wind turbines to indicate areas of low, moderate, and high risk of encountering spinning turbine blades. Inset map indicates where in Texas home ranges and turbines were located.
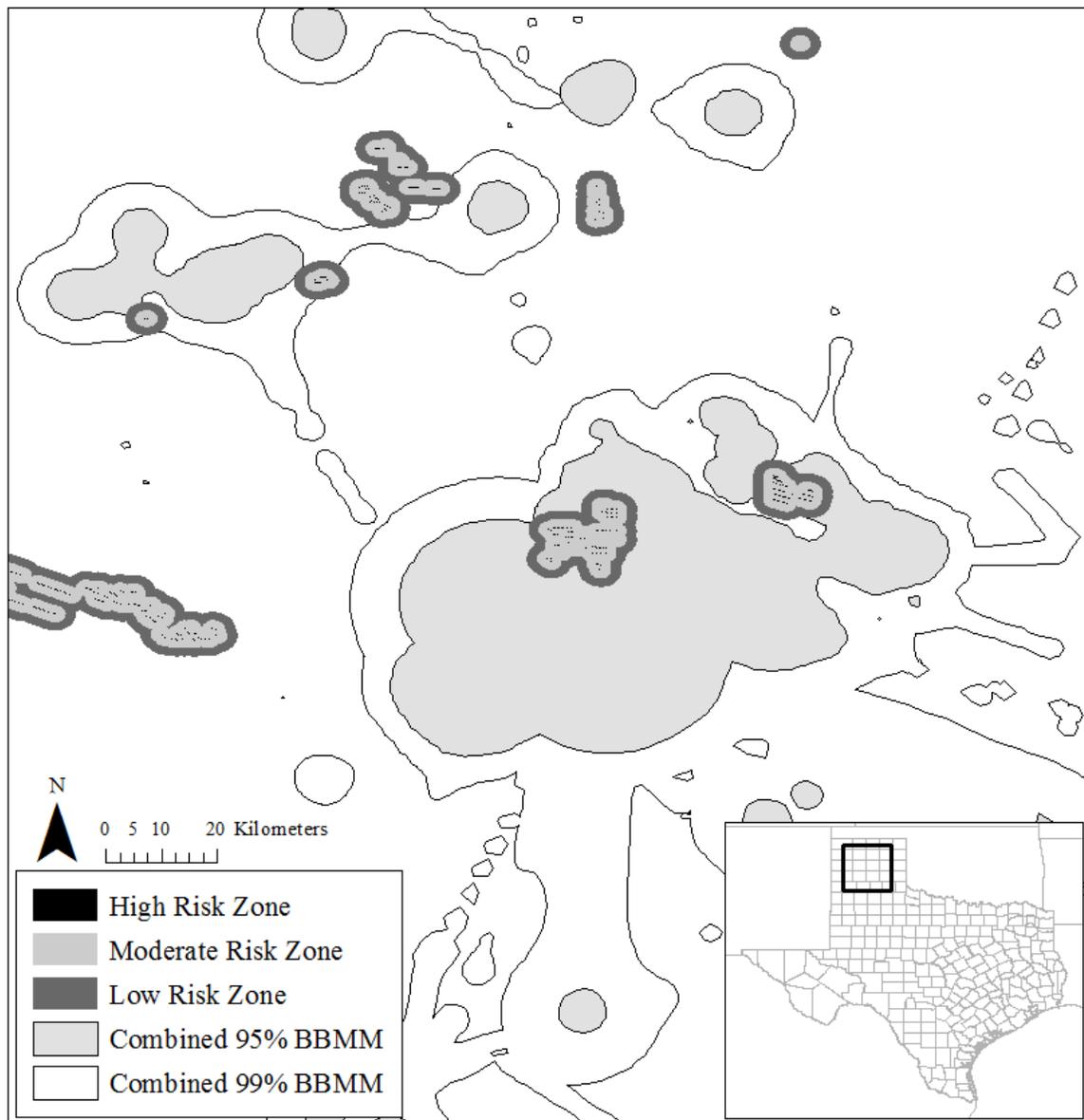
Table 7. Proportion of home range where birds were at varying levels of risk of encountering wind turbines. Swainson's hawks were equipped with GPS Platform Transmitter Terminals (PTTs), and data was analyzed for the 2012, 2013, and 2014 breeding seasons to determine 95% home range using Brownian Bridge Movement Models (BBMM). We placed buffers around turbine locations at 3 km (low risk), 1.5 km (moderate risk), and 100 m (high risk) and determined proportion of home ranges where birds were within risk zones. Only birds that had any chance of encountering turbines are included in this table. Means are presented with standard deviation.

Year	Bird ID	Home Range (km^2)	% Low Risk	% Moderate Risk	% High Risk	% Total Risk
2012	115937	407.3	14.8	24.9	0.8	41.3
	115939	105.1	21.4	40.2	1.3	64.2
	115940	18.9	36.5	53.4	2.6	95.1
	120332	400.7	2.1	0.5	0.0	2.6
2013	115938	963.9	2.6	1.5	0.0	4.1
	115939	163.9	18.8	37.0	1.2	58.3
	115940	490.4	8.3	13.4	0.5	22.7
	120328	914.9	2.3	0.8	0.0	3.1
	120329	305.6	8.7	6.2	0.2	15.3
	120330	1633.8	2.3	3.5	0.1	6.0
	120331	970.1	3.0	1.1	0.0	4.1
	120332	1982.8	2.3	4.2	0.1	6.8
	120333	28.6	0.0	12.2	1.4	13.6
	122081	2796.9	3.0	3.4	0.1	6.7

	122086	117.7	12.9	1.0	0.0	13.9
	122088	53.3	2.3	0.0	0.0	2.3
	122089	225.3	2.2	1.6	0.0	3.8
	122091	462.6	14.3	18.8	0.5	34.1
2014	120328	6.6	29.8	69.2	0.5	100.0
	122082	704.3	4.8	4.4	0.1	9.4
	122084	31.5	1.3	0.0	0.0	1.3
	122090	1532.0	2.2	1.7	0.0	4.1
	122091	328.2	12.5	15.3	0.4	28.7
	122092	637.3	6.6	12.5	0.4	19.9
Mean		636.7	9.0	13.6	0.4	23.4
St. Dev.		714.4	9.6	18.6	0.6	28.7

Figure 9. (A) Swainson's hawk migration initiation date and (B) number of days in transit. Adult Swainson's hawks were equipped with GPS Platform Transmitter Terminals (PTTs) to monitor their migration characteristics. Dates are in Julian date format. Error bars represent standard deviation.
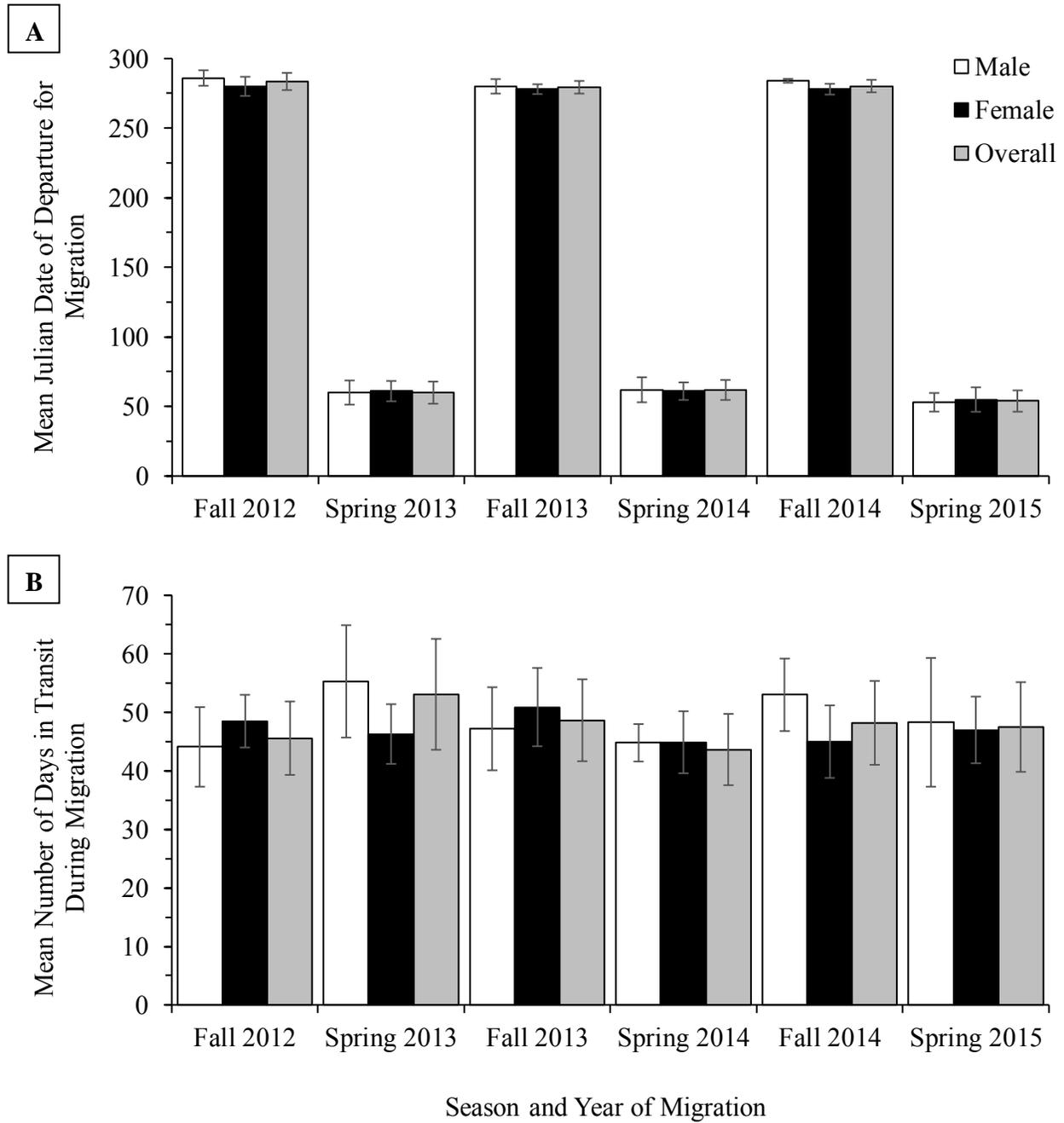
Table 8. Analysis of Variance (ANOVA) results for models testing pooled migration data and between-sex effects. Swainson's hawks were equipped with GPS Platform Transmitter Terminals (PTTs) to monitor migration characteristics to produce the data for these models. Results are presented as degrees of freedom (df), means squared (MS), the statistic value (F) and the significance value (*p*). Models are described as "dataset: tested factor(s)".

Migration Initiation Date				
Model	df	MS	F	*p*
Fall migration: Sex	1	179.76	7.15	0.011
Fall, excluding staging behavior: Sex	1	75.45	0.52	0.475
Spring migration: Sex	1	2.42	0.04	0.851
Spring, excluding staging behavior: Sex	1	10.86	0.17	0.680

Number of Days in Transit				
All migration data: Sex	1	43.02	0.84	0.364
All migration data: Season	1	1.99	1.71	0.144
All migration data: Season * Sex	1	145.30	2.82	0.097
Migration, including staging behavior: Sex	1	50.72	0.34	0.560
Migration, including staging behavior: Season	1	993.39	6.71	0.012
Migration, including staging behavior: Season * Sex	1	79.81	0.54	0.465

Figure 10. Comparing the number of days adult Swainson's hawks equipped with GPS Platform

Transmitter Terminals (PTTs) spent migrating using two datasets that included and excluded

days spent on the staging grounds. Error bars represent standard deviation.
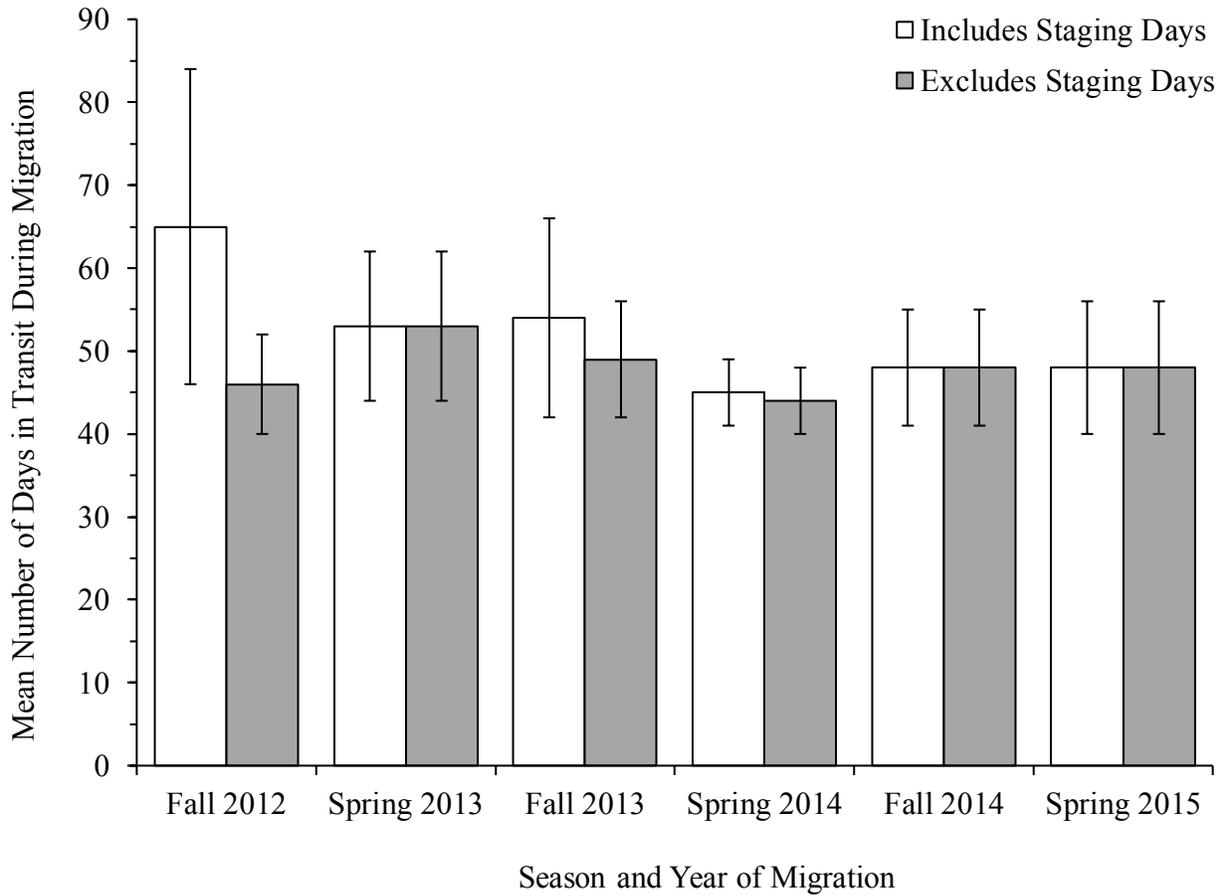
Figure 11. (A) Total distance (km) covered by migrating Swainson's hawks equipped with GPS Platform Transmitter Terminals (PTTs) and (B) daily rate of travel (km/day) during migration. Travel rate was calculated as the total distance divided by the number of days in transit. Error bars represent standard deviation.
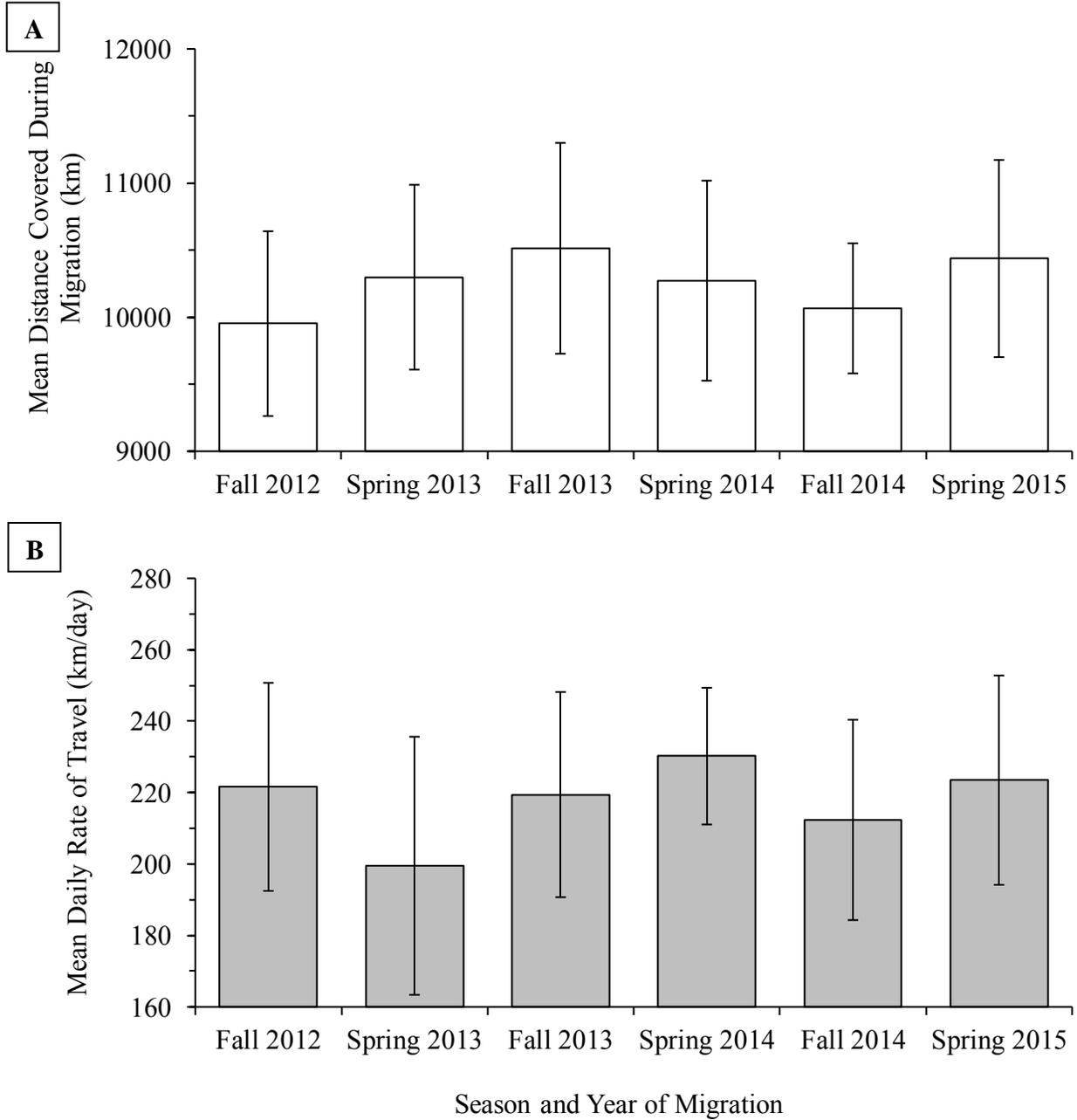
Figure 12. Migration routes for 24 Swainson's hawks equipped with GPS Platform Transmitter Terminals (PTTs) from Fall 2012 to Spring 2015, with circles indicating areas where routes converged with a perpendicular distance ≤ 80 km, which we defined as important migratory corridors for this species.
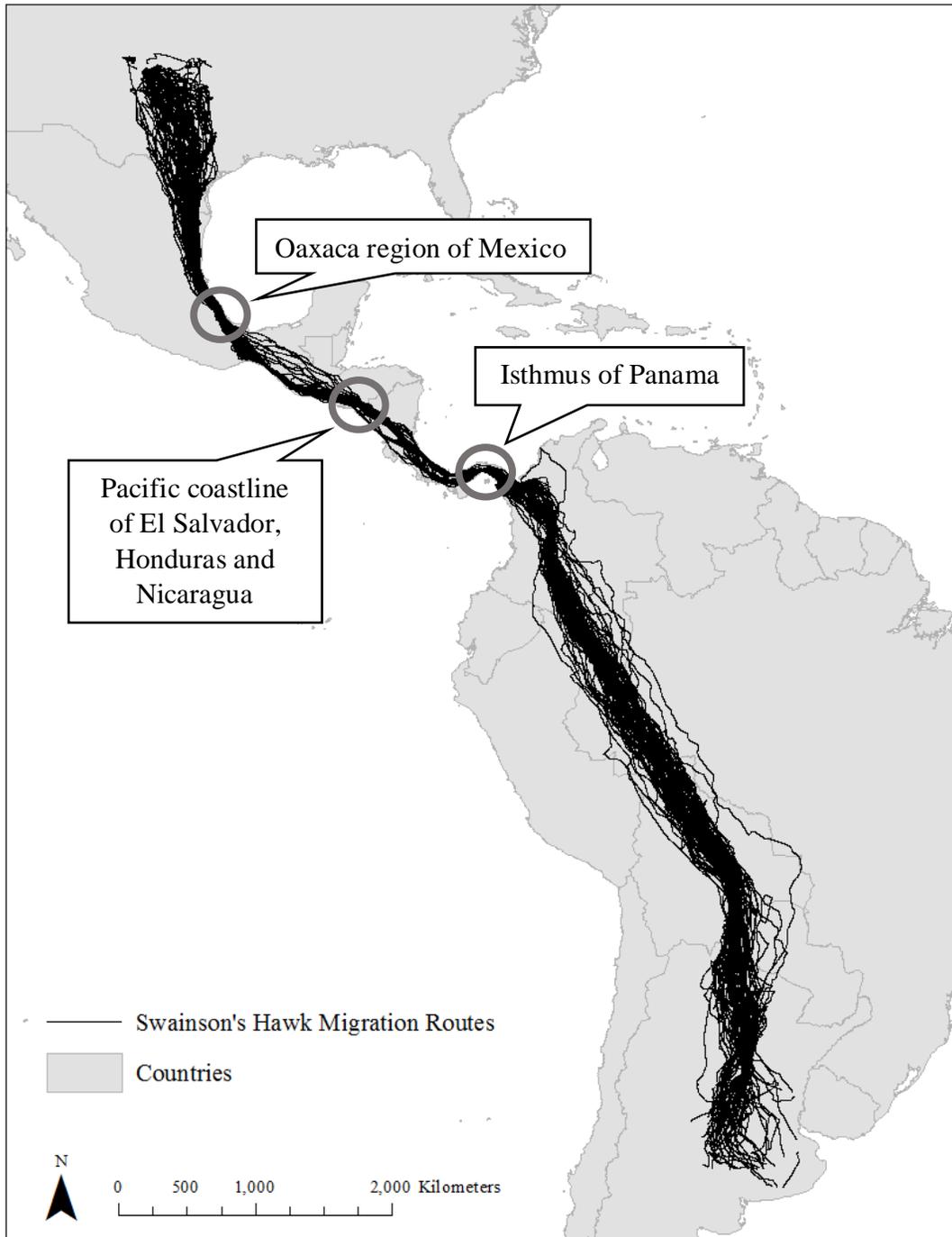
Figure 13. (A) Regions of the Swainson's hawk migration range classified by their potential for wind energy development and (B) location points obtained from GPS Platform Transmitter Terminals (PTTs) equipped on adult Swainson's hawks classified by the wind potential areas each point was within. High wind potential (areas most likely to see construction of wind energy turbines) was defined as areas with average wind speeds > 6 m/sec, moderate wind potential was areas with wind speeds between 4.2 and 6 m/sec, and low wind potential was areas with wind speeds < 4.2 m/sec.
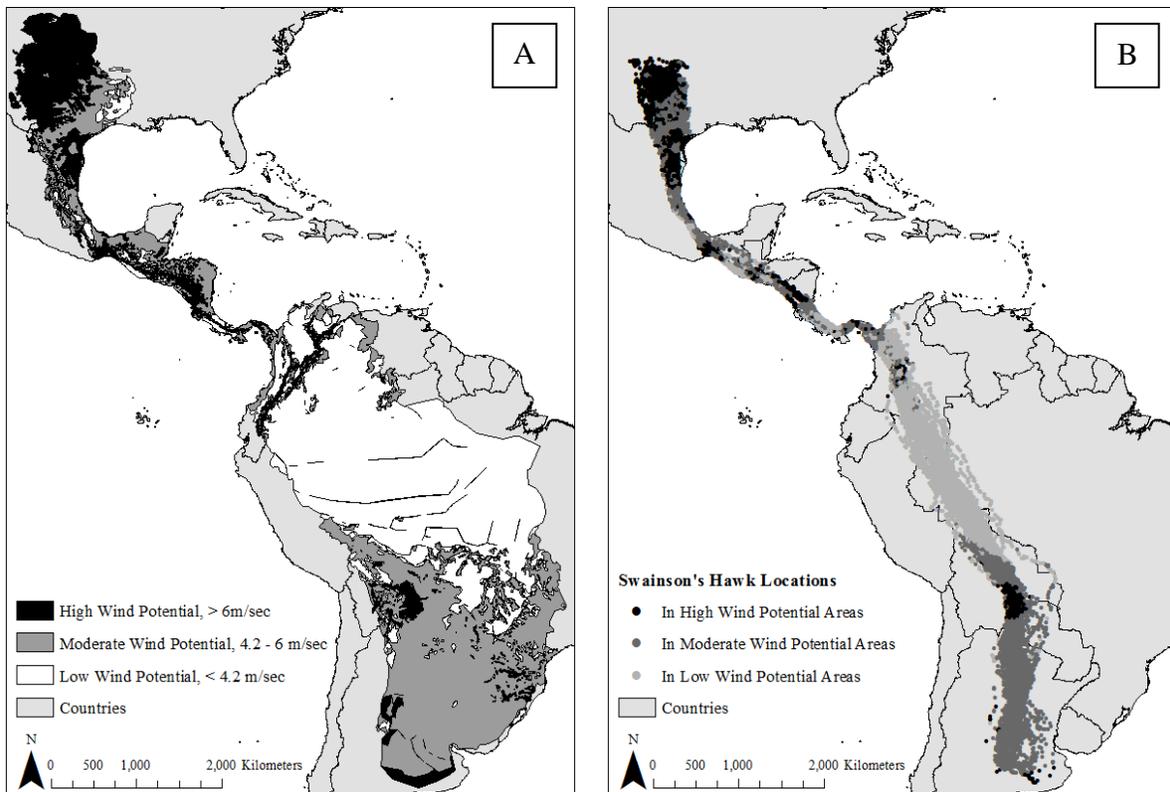
Figure 14. Proportion of the landscape classified by the potential for wind energy development that was utilized by migrating Swainson's hawks compared to the proportion of wind potential areas available across the entire migration range. Swainson's hawks were equipped with GPS Platform Transmitter Terminals (PTTs), and we used 50% and 95% dynamic Brownian Bridge Movement Models (dBBMM) to create maps of landscape usage from the location points. High wind potential (areas most likely to see construction of wind energy turbines) were areas with average wind speeds > 6 m/sec, moderate wind potential was areas with wind speeds between 4.2 and 6 m/sec, and low wind potential was areas with wind speeds < 4.2 m/sec. We used Student's T-test (t) to make comparisons of use versus available and significance (p) was set at 0.05 for the analysis. Statistics from pair-wise comparisons are listed above each pair of bars.
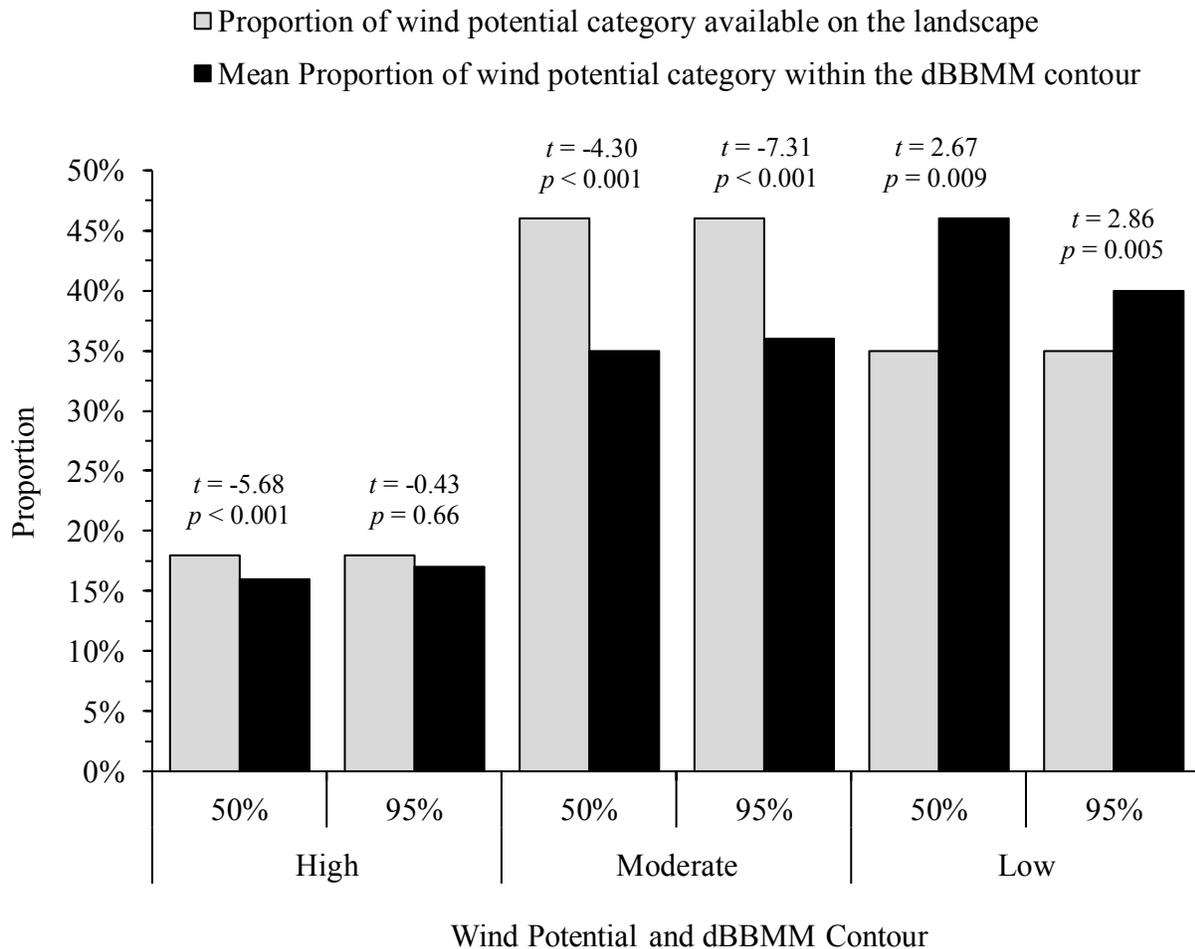
Figure 15. Comparison of number of roosting and mid-day locations and proportions of total locations that fell within the high wind potential regions for each migration. Swainson's hawks were equipped with GPS Platform Transmitter Terminals (PTTs), which allowed us to pinpoint roosting and mid-day locations. High wind potential areas represent locations where average wind speeds were > 6 m/sec, which are locations that are most likely to experience development from the wind energy industry. Error bars represent standard deviation.
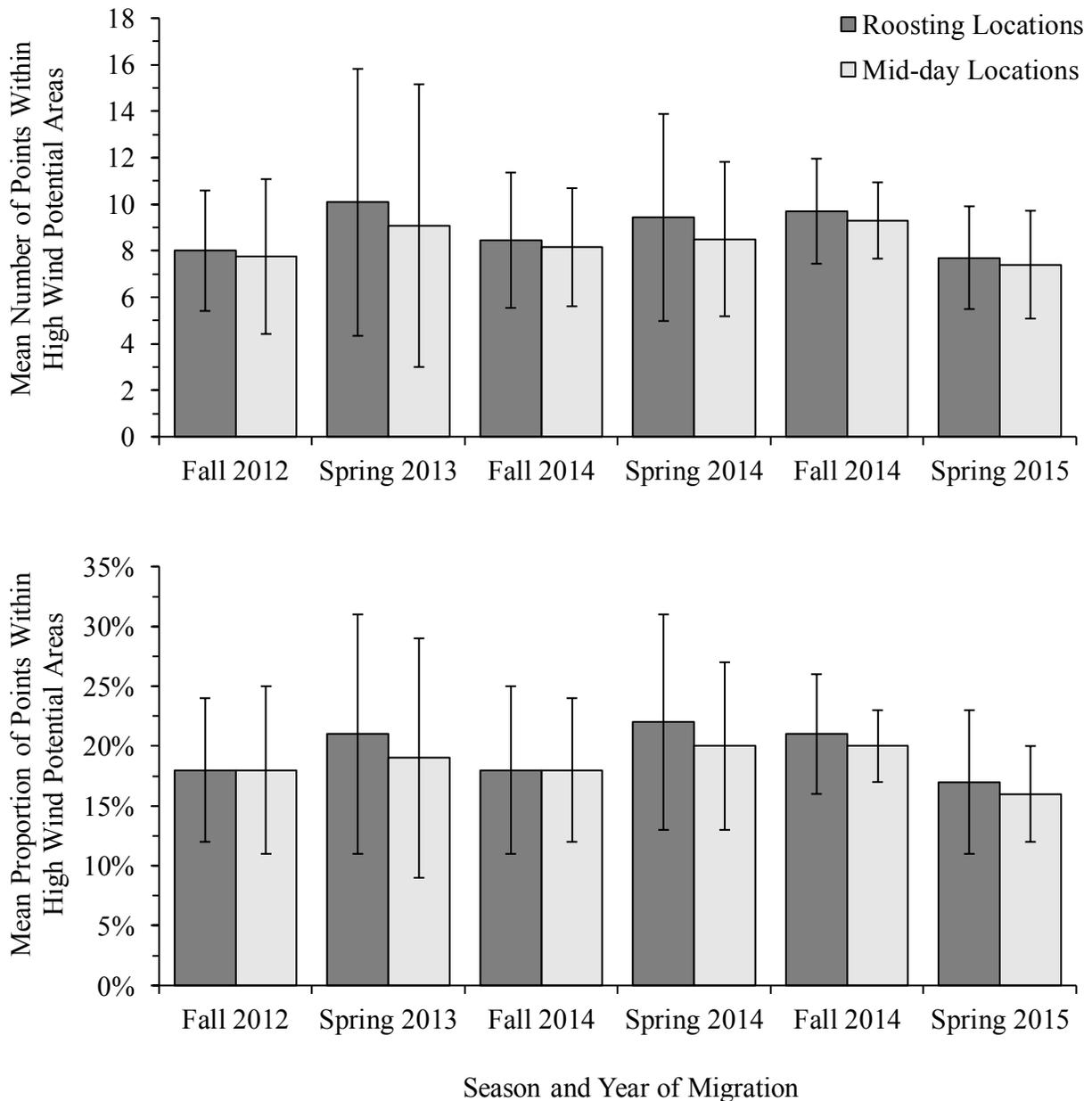
Figure 16. Comparison of the proportion of roost and midday locations that occurred in the high wind potential regions of individual migrations for Swainson's hawks equipped with GPS Platform Transmitter Terminals (PTTs). High wind potential areas are regions that are most likely to see construction of wind energy turbines and are defined by average wind speeds > 6 m/sec. Points represent one migration and the proportion of roost locations and mid-day locations for that dataset. Equation and fit of the trend line are provided on the graph.


$y = 0.7298x + 0.0597$
$R^2 = 0.4594$
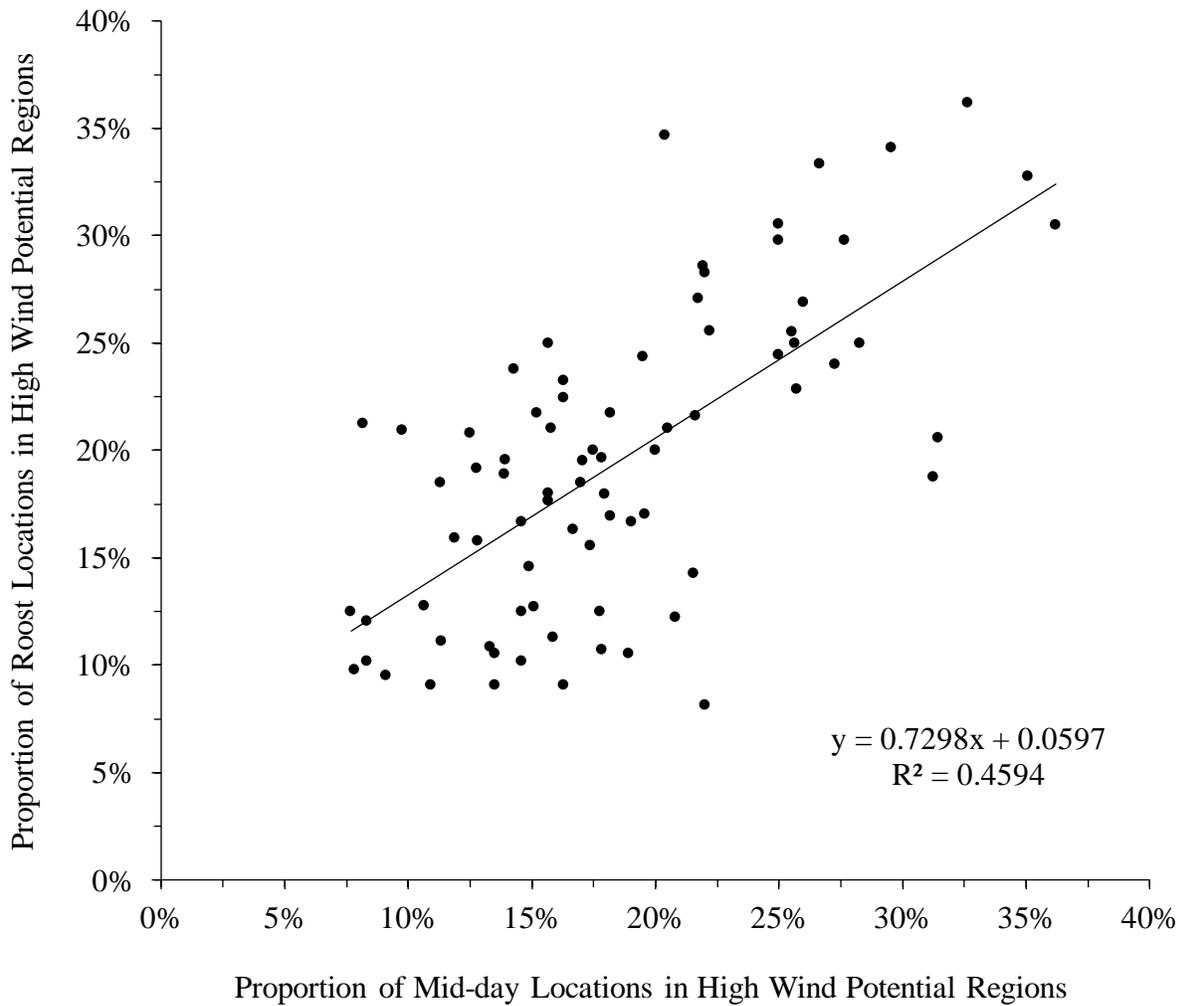
Figure 17. Velocity (km/h) of travel for migrating Swainson's hawks when trajectories were greater than 25 km. An interactive model with wind and season as predictive factors was used to obtain these means, and lines at equal level above bars show similarity of means as indicated by a *post hoc* Tukey's HSD. Means are back-transformed from a natural-log transformation and error bars represent back-transformed 95% confidence intervals.