Golden Eagle resource selection during spring, fall, and winter in central Pennsylvania: Implications for wind energy development

A report prepared for the Sierra Club Huplits Wildlife Grant

1 June 2015

by

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Abstract

Across the globe, wind energy is one of the fastest growing alternative energy industries. However, development of wind energy does not come without environmental costs. Many wildlife species are negatively affected by wind energy developments either directly through mortality and injury, or indirectly through habitat modification, destruction, etc. Developing sustainable alternative energy sources is critical to meeting our ever increasing energy needs, while preserving wildlife. This can be done by reducing direct and indirect effects through prevention or mitigation. To address potential effects of wind energy development on Golden Eagles, one of the most at risk species, we modeled resource selection of low flying Golden Eagles during the three seasons during which they are present in central Pennsylvania. Central Pennsylvanina is a well-known important migratory corridor for eagles and other raptors and it has recently come to light that they utilize this same area during winter. We tracked eagles during winter (n=2), fall migration (n=9) and spring migration (n=29) in the study area. We found that during all three seasons, low flying Golden Eagles preferentially selected ridge tops, high elevations, areas with high updraft potential, and forested areas over what was available in the study area. Migratory resource selection was more constrained than during winter, when eagles selected a broader range of elevations. Moreover, we found that eagles flew at lower altitudes during winter and fall than they did during spring and that when in flight they spent a greater proportion of time flying below 150 m (maximum height of a turbine) during winter and fall than during spring. We plotted turbines that were proposed to be sited in the study area and found complete overlap between turbines and high quality eagle resources during each season. This suggests that wind developments in this region would pose a risk to eagles during all seasons during which they are present, but risk to eagles may be higher during fall and winter when eagles generally fly lower and spend more time flying at low altitudes.

Introduction

Sustainable development of wind energy is one of the fastest growing alternative energy industries and may be important for lowering carbon emissions (Wiser and Bolinger 2009, Tabassum-Abbasi et al. 2014). However, wind energy development does not come without environmental costs. From the late 1970s until present, wind turbines have been a known source of mortality for birds, especially in open environments like the Altamont Pass Wind Resource Area (APWRA) (Thelander and Smallwood 2007). More recently it has come to light that other species, especially migratory forest bats, may sustain large scale mortality at some installations, especially those occurring in forested areas (Kunz et al. 2007 and references therein). Importantly, costs to wildlife and the environment from wind turbine developments may be either direct (e.g., mortality, injury) or indirect (e.g., habitat loss, avoidance) (Drewitt and Langston 2006, Pruett et al. 2009). These effects vary regionally and among facilities, where some facilities and some regions show high mortality and others low. Variation within a facility also occurs, where certain turbines cause high mortality and others very low or none (Smallwood et al. 2007, Smallwood and Thelander 2008). Moreover, there is seasonal variation in mortality as well (Pagel et al. 2013). For example, burrowing owl mortality at APWRA is highest during winter when there is an influx of migrant owls (Smallwood et al. 2007). Conversely, vulture mortality is highest near Gibralter, Spain during spring migration (de Lucas et al. 2012) and white-tailed sea eagle (*Hailaeetus albicilla*) mortality is highest in Smöla, Norway during the early breeding season (Nygård et al. 2010). Finally, not all species are equally affected and some species, especially eagles, may have population level effects (Hunt et al. 1999).

Among raptors, Golden Eagles (*Aquila chrysaetos*) have been recognized as one of the species of greatest concern for negative interactions with wind turbines. The concern for Golden Eagle as well as Bald Eagle (*Hailaeetus leucocephalus*) mortality at wind installations prompted the US Fish and Wildlife Service to issue the Eagle Conservation Plan Guidance in 2013 to “help make wind energy facilities compatible with eagle conservation” (USFWS 2013). However, because of the small population size and general lack of understanding of Golden Eagles in the eastern US, take (harm, harass, kill, etc.) of Golden Eagles was not permitted east of 100° W longitude under the plan. Nonetheless, Golden Eagles may be at risk from wind energy in the region (Miller et al. 2014).

Central Pennsylvania is an important concentration area of Golden Eagles during spring and fall migration and there are a considerable number of eagles that spend the winter in this same region (Miller et al. 2010, Katzner et al. 2012*b*). Like much of the rest of the US, Pennsylvania has undergone significant expansion of wind power development in the last decade. The majority of facilities were developed on ridge tops in the Ridge and Valley Physiographic Province and along the escarpment of the Allegheny Plateau in the Allegheny Mountains (Miller et al. 2014). These areas are very important for Golden Eagles during three seasons where the physical features of the landscape – the long, linear ridges and the escarpment– provide updrafts (deflected wind currents) that subsidize flight (Kerlinger 1989). The majority of Golden Eagles that spend the summer in Québec and Labrador migrate through this region twice annually. Based on recent population estimates ~ 90% of Golden Eagles use this important corridor (Dennhardt et al. 2015). Recent research has shown that the central ridges of the Appalachian Mountains are selected for by spring migratory eagles and that there is a large amount of overlap between the areas where wind turbines are placed and where eagles migrate at low altitudes (Miller et al. 2014). However, there is currently no information about risk from wind energy to fall migrant eagles and wintering eagles.

The purpose of this research is to model resource selection of Golden Eagles in central Pennsylvania during the three seasons during which eagles are present in the region – spring, fall, and winter. We tested several hypotheses of resource selection including that eagles selected for areas based on topography or land cover or a combination of the two. We then compared turbine locations in a proposed facility in the study area to resource selection of eagles. By understanding what landscape features are important to eagles we can better understand where wind power development would have minimal effects on Golden Eagles.

Methods

Study Area

The study area is located in central Pennsylvania (Fig. 1a) and includes Huntingdon, Mifflin, and Juniata counties. Several ridges run more-or-less north to south through the study area, with Jacks and Stone Mountains in the center. The ridges are dominated by broadleaf forests with open areas occurring mainly in the valleys.

Study Species

Golden Eagles are among the largest predatory birds in North America. Eagles have been extirpated during the breeding season from the eastern US, though they once bred in the northeast, with only one confirmed historical breeding record in PA (Lee and Spofford 1990). They regularly occur in PA from September through May during fall and spring migration and during winter (Miller et al. 2010, Katzner et al. 2012*b*).

Data Collection

From 2009 – 2015, we captured Golden Eagles during winter in the mid- and southern Appalachians using rocket nets, air cannons, or net launchers. Except for a few very large females, we banded each bird with an aluminum USGS band and collected standard morphometric data. We determined sex based on DNA extracted from blood or feather samples (Fridolfsson and Ellegren 1999) and we estimated age based on molt patterns (Jollie 1947, Bloom and Clark 2001). We fitted each bird with a GSM-GPS telemetry unit (model series CTT-1070-1100, Cellular Tracking Technologies, Somerset, PA) weighing 70 – 100 g (<3% of the body weight). Each unit collected

GPS data including latitude, longitude, ground speed (knots), altitude (m), heading, and fix quality at 15 min or 30-60 s intervals depending on season. We attached the units in a backpack style (Fuller et al. 2005) using non-abrasive Teflon ribbon (Bally Ribbon Mills, Bally, PA) harnesses in either an X or modified X configuration.

We extracted the underlying elevation of each point from the 10 m national elevation dataset (NED) (Gesch 2007). We estimated altitude above ground level (AGL) by subtracting the NED value from the altitude above sea level (ASL) provided by the GPS. Vertical accuracy of the GPS is within 22.5 m (Lanzone et al. 2012) and horizontal accuracy is within 3 m.

We classified each point as in-flight, perched, or unknown based speed estimated by the GPS. Points with speed >2 knots were considered in-flight, points with speed <1 knot were considered perch, and points in between were considered unknown. From the in-flight points, we divided our dataset into points above and below 150 m AGL. We regarded eagles flying below 150 m AGL to be at relatively higher risk of negative interactions with wind turbines because the maximum height of modern wind turbines is <150 m AGL. Additionally, eagles flying at low altitudes respond similarly to environmental conditions and show stereotyped flight behavior (Katzner et al. 2012*a*, Lanzone et al. 2012).

Environmental data

We selected environmental covariates that we expected to influence behavior of flying Golden Eagles (Miller et al. 2014) during the three seasons that they are present in central PA. We used the 10 m NED to estimate elevation and derived slope, northness (cosine of aspect), and eastness (sine of aspect) from that elevation dataset. We reclassified landform type from ecological land units (Anderson et al. 2006) into four categories: ridgetops, steep slopes, side slopes, and other (footslope, hill/valley, dry flats, wet flats, and open water). Finally, we estimated the maximum updraft (w_o) (Brandes and Ombalski 2004) potentially available for each grid cell. For each of the eight cardinal directions we determined available updrafts:

$$w_o = v \times sin(\theta) \times (cos(\alpha - \beta)) \qquad \text{Eq. 1}$$

where v was a standard wind speed of 10 m s^{-1} and where all angles are in radians and θ is the slope angle, α is the wind direction, and β is the terrain aspect (ArcGIS 10.1, ESRI, Redlands, CA). We then calculated the maximum w_o from the eight resulting datasets and extracted that value for each point.

In addition to topographic variables we included land cover. We reclassified GAP land cover (U.S. Geological Survey 2011) into three categories, forest, open (including grasslands, agriculture, etc.) and other. We then calculated the Euclidean distance to each forest or open cell and used the resultant distance layers as our variables of interest, i.e., distance to forest and distance to open (ArcGIS 10.1, ESRI, Redlands, CA).

Resource selection functions

We modeled resource selection of Golden Eagles using environmental variables that potentially influence flight behavior of Golden Eagles. We utilized a used-available design to estimate the relative probability of use based on what was available across the study area and what was used by eagles flying at low altitudes (Manly 2002).

To estimate available resources we dropped 10,000 random points within the study area. We then grouped a selection of those points with each bird that used the study area during each season. Thus, for each bird within each season we had a selection of available locations (GPS) and a set of used locations (random). For all data, used and available, we extracted the underlying topographic and land cover variables described above.

For all three seasons we separated our data into test and training data by randomly selecting 25% of data points for validation and 75% of data points for training. Using the training data, we calculated a correlation matrix among all variables for each season. We removed one of each set of variables with a Pearson correlation >0.5. We modeled resource selection using logistic generalized estimating equations, which provide a population level estimate of resource selection and are robust to misspecification of the correlation structure (GEE, geepack, (Højsgaard et al. 2005); R 2.13 (R Development Core Team 2011)). We tested autoregressive and independence correlation structures, using the structure and defined each bird as a repeated measure. We ran 8 different models (Table 1) and used a quasi-likelihood under the independence model criterion (QIC) for model selection (Pan 2001). We selected the model with the lowest QIC and highest weight as our top model. We used the top model from each season to create spatially explicit models of resource selection (ArcGIS 10.1, ESRI, Redlands, CA; (Manly 2002)). We then reclassified each model into four classes of increasing relative probability of selection (1-4), where 1 = low selection and 4 = highest selection.

Data Analysis

In addition to modeling resource selection, we examined seasonal differences in flight behavior. We used a linear mixed-effects model (nlme; (Bates et al. 2011) to model seasonal difference in flight altitude ASL, flight altitude AGL, and flight altitude AGL below 150 m. We used individual eagles as a random effect to account for repeated measures. We calculated the means of the proportion of flight locations below 150 m AGL from all flight locations for each eagle. We then used generalized least squares models (gls, (Bates *et al*. 2011) program R, (R Development Core Team 2011)) to model the proportions of low altitude flight locations per season. To examine seasonal differences in flight behavior, we made *post hoc* pairwise comparisons among seasons using Tukey contrasts (glht in Package multcomp; Hothorn et al. 2008).

Finally, we mapped turbines from a proposed facility on Jacks Mountain (oeaaa.faa.gov; Fig. 1-2, Fig. 4). For each turbine, we then extracted the underlying resource selection class for each season to better understand the potential for negative effects on eagles from wind turbines sited in the study area.

Results

We collected a total of 13,133 locations during all seasons from 2009-2015, with 5,484 points during winter, 1,823 during fall migration, and 5,826 during spring migration (Fig. 1). We tracked two eagles during winter (9 Nov – 16 Mar) and collected 985 (17.9%) locations from flying eagles with 632 (11.5% of total; 64.2% of in-flight) locations below 150 m AGL from both eagles. During fall (25 Oct – 27 Dec), we collected 1,320 (72.4%) in-flight locations from 9 birds; 400 (21.9% of total; 30.3% of in-flight) of those locations from 8 (88.9%) eagles were below 150 m AGL. During spring (19 Feb – 30 Apr), we collected 4,498 (77.2%) in-flight locations from 29 eagles with 636 (10.9% of total; 14.1% of in-flight) of those locations from 23 (79.3%) eagles below 150 m AGL.

Flight behavior

Eagles flew at higher altitudes ASL during spring than during the other two seasons (spring vs. fall: $z = 12.27$, $p < 0.001$; spring vs. winter: $z = 8.57$, $p <0.001$; Fig. 3). Flight altitudes during winter were lower than during the fall (winter vs. fall: $z = -3.5$, $p = 0.001$; Fig. 3). Likewise, eagles flew at higher altitudes AGL during spring than during the other two seasons (spring vs. fall: $z = 19.29$, $p < 0.001$; spring vs. winter: $z = 9.8$, $p <0.001$; Fig. 3). Eagles flew at about the same altitudes AGL during winter as during fall (winter vs. fall: $z = -1.68$, $p = 0.2$; Fig. 3). When eagles flew below 150 m AGL, flight altitudes were similar across all seasons (spring vs. fall: $z = -0.74$, $p = 0.74$; spring vs. winter: $z = 1.13$, $p = 0.48$; winter vs. fall: $z = -1.78$, $p = 0.17$; Fig. 3). Eagles spent a greater proportion of time flying below 150 m AGL during winter and fall than during spring (spring vs. fall: $z = -3.0$, $p = 0.014$; winter vs. spring: $z = 2.77$, $p = 0.024$; winter vs. fall: $z = 1.03$, $p = 0.554$; Fig. 3)

Resource selection

During winter, eagle resource selection was influenced by topography, updraft availability and land cover (Table 1). Eagles selected ridgetops and steep slopes and showed no preference for side slopes (Table 2, Fig. 2, Figs. 4-7). They selected areas at higher elevations and areas with relatively higher updraft potential. They avoided open areas and selected forested areas.

During fall, resource selection was influenced by topography, updraft potential, and forest cover (Table 1). Eagles primarily selected ridgetops during low altitude flight (Table 2, Fig. 2, Figs. 4-7). In contrast, they showed no preference for the other land form types. Similar to winter they selected areas with relatively higher updraft potential and areas at higher elevations. While open cover did not influence selection (Table 1), forest cover was preferentially selected.

During spring, eagle resource selection was influenced only by topography and updraft potential (Table 1). As during fall, eagles preferentially selected ridgetops and showed no preference for steep slopes or side slopes (Table 2, Fig. 2, Figs. 4-7). Again, they selected areas with higher updraft potential and areas at higher elevations.

While eagles showed some seasonal differences in flight behavior (e.g., flight altitudes, proportion of low altitude flight), resource selection of updraft potential was fairly similar across all seasons (Table 2. Fig. 2, Figs. 4-7). Moreover, during all seasons eagles selected ridgetops during low altitude flights. There were some differences however. Eagles selected broader resources during winter compared to the other seasons (Table 1, Table 2, Fig 2, Fig. 4). In particular, during winter eagles were more influenced by land cover, and generally selected areas at lower elevations than during the other two seasons. During all seasons, eagles flew almost exclusively over or very near forests (Fig. 7).

We mapped 20 wind turbines that were proposed on Jacks Mountain (Fig. 1-3). During winter, 6 turbines fell in class 3 and 14 turbines were sited in the highest selection class (Fig. 3). During fall, 8 turbines fell in class 3 and 12 turbines were sited in class 4. During spring, only one turbine fell in class 3, while 19 were sited in class 4.

Discussion

To our knowledge the models that we generated are the first cross-seasonal models of resource selection of flying birds These models estimate resource selection by low-flying Golden Eagles across the three seasons that they are present in this region. In addition, we characterized flight behavior during that same time period. This allows us to not only understand where eagles are flying, but how flight behavior varies seasonally. Together, the two provide important insights into risk of the negative effects of wind energy across spatial and temporal scales. This includes not only the potential for direct effects such as collision risk during specific seasons, but also for provides a means to directly measure the potential for indirect effects such as habitat loss. Thus, our results provide an important step forward to identifying eagle-safe avenues for wind-energy development in an important wintering and migratory area.

Flight behavior

Our results suggest that eagles fly differently depending on the time of the year, which has direct implications for when eagles would be most at risk from wind energy development. We found variation in the amount of time eagles spend flying at low altitudes. Not surprisingly, eagles spent far less time flying than perching or roosting during winter than during either migration period. However, during winter when eagles did fly, they spent a much higher proportion of time flying at low altitudes (<150 m AGL) than during spring or fall. Because of inherent differences in behavior between sedentary and migratory periods, the variation that we show would be expected. Migratory eagles pass through the region heading north and would only stop to roost for the night or possibly to hunt. Conversely, during winter eagles spend most of their time in a relatively small area (Watson et al. 2010, Miller 2012).

Interestingly however, during fall eagles spent just over twice as much time flying at low altitudes compared to spring. Eagles are heavy bodied birds with high wing loading that they rely greatly on updrafts to subsidize flight. They preferentially use thermal updrafts (Duerr et al. 2012) and fly higher when using thermals compared to other updrafts like orographic updrafts (deflected wind currents) (Lanzone et al. 2012). Importantly, orographic updrafts are only available at relatively low altitudes, unlike thermal updrafts, which can support flight at altitudes > 2000 m ASL in the eastern US (Hertenstein 2005). Thus, the differences between the two migratory periods were likely driven by factors that influence thermal development (Miller et al. *in press*, Duerr et al. 2014). For instance, the sun's angle of incidence is higher during spring migration than during fall migration. The spring migration period (19 Feb – 30 Apr) overlapped and followed the spring equinox when days are getting longer and thermal strength higher. In contrast, the fall migration period (25 Oct – 27 Dec) occurred over a month after the fall equinox, when days are getting shorter and thermal strength is weaker and potentially unavailable.

Resource selection

The long-linear ridges of central Pennsylvania concentrate migrating raptors, including eagles (Kerlinger 1989). Because of this phenomenon, several hawk watch sites were located along the ridgetops in the region. At ridgetop hawk count sites on Stone Mountain and Jacks Mountain, Golden Eagles have been documented from the first week of Sep. to the last week of Dec. and along Tussey Mountain during fall from the first week of Oct. to the last week of Dec. and during spring from the last week of Feb. to the first week of May (hawkcount.org). Each year an average of 98 eagles and a maximum of 145 were counted during fall passing by Stone Mountain and 40 were counted on average each fall with a maximum of 141 at Jacks Mountain. During spring, Tussey Mountain counted on average 184 each spring with a maximum of 239 counted in s single spring. Importantly, many more eagles than are reported pass through the region each year (Dennhardt et al. 2015). Even so, the number of eagles observed during migration suggests that there is a strong potential in this region for negative effects of wind energy on eagles. While it has been well known for more than a decade that large numbers of eagles pass through the region on migration, until recently eagles were not known to winter in large numbers in this region. Telemetry data and camera trapping data show that many eagles are present throughout the winter in the study area (Jachowski et al. 2015).

We found that Golden Eagles preferentially selected ridgetops, areas with high potential updrafts, and areas that were at higher elevation than what is available across the study area. These environmental characteristics were important to eagles across all seasons.

During winter and fall, eagles specifically selected forested areas. This may be because there are important resources that are associated with forest cover, such as food, perches, and roost sites. Eagles are energy-limited migrants during fall (Duerr et al. 2014). Because of this, they spend increased time in stopover compared to spring. The stronger influence of forest may be a result of eagles spending increased time feeding, increased time in stopover, or other activities that either save energy or increase energy intake. Conversely, during spring, there was limited influence of land cover on resource selection (other factors had a greater effect). In contrast to fall migrants, there is a mix of energy- and time-limited individuals, where early migrants – those that are more likely to use orographic updrafts due to timing of migration – tend to be adults and those individuals are time-limited. As a time-limited migrant, individuals attempt to reach the breeding grounds in as little time as possible. Thus they spend less time in stopover than energy-limited migrants (Miller et al. *in press*) and possibly less time feeding.

Implications for wind energy development

Presence of a species does not equate to risk. Overlap between animal resources and the locations where development occurs increases the risk for negative interactions, either directly or indirectly. Understanding which resources animals select and when they select those resources is critical for understanding the risk to and effects on wildlife from anthropogenic induced changes to landscape.

Wind energy development in Pennsylvania primarily occurs along high elevation ridgetops (Miller et al. 2014) that are typically heavily forested. This type of development causes substantial changes to those environs and fragments previously intact forested regions, which may have important ecological consequences especially in the face of other changes (Mantyka-pringle et al. 2012).

Proposed wind turbines that were sited in the study area were located along the summit of Jacks Mountain (Fig. 3). An additional project has been proposed in similar settings further down Jacks Mountain and along the summit of Stone Mountain. We found that turbines sited along Jacks Mountain occurred in the two highest quality resource classes of Golden Eagles and none were cited in areas that were not strongly selected by eagles. This suggests that turbines sited on Jacks Mountain and probably on ridgetops in this region would have some negative effects on both migratory and wintering Golden Eagles.

As with other developments located in the ridge and valley region of Pennsylvania, there are few options for micro-site adjustments that could reduce negative interactions with eagles (Miller et al. 2014). This is because wind turbine resources in the region are restricted to the high elevation ridgetops – the same resources that eagles selected. At a minimum, wind turbines developed in this study area would pose a risk to eagles through habitat loss – removal of forest and ever-present disturbance of ridgetop habitat. Because eagles fly along these same areas, there is a potential for risk of collision, and also for avoidance of developed areas. The consequences of the former are clear – loss of individuals from the population. However, the costs and consequences of the latter are less clear and more difficult to measure. Avoidance behavior during migration could result in increased energetic costs because eagles may need to use powered flight to avoid the area. This would have the potential to decrease fitness if such behaviors occurred over a broad scale. Estimating the costs of increased energy use by eagles and the threshold (number of turbines located along ridgetops) at which profound decreases in fitness occur is something that should be explored. This is becoming increasingly important as cumulative effects grow due to the expansion of wind energy development in this important migratory corridor.

Our analysis of seasonal variation in flight behavior suggests that there is temporal variation in risk, where eagles migrating during fall and eagles wintering in the region are at relatively higher risk of negative effects of wind turbines. This does, however, provide temporal focus for mitigating the negative effects of wind energy on eagles. Our results suggest that mitigation during fall and winter would be most important for eagles. Delving deeper into how variable conditions (e.g., wind speed and direction) affect movement and flight would move potential mitigation measures beyond entire seasons or months to specific days or hours and provide a viable mitigation option to reduce potential mortality. Regardless, such mitigation does not address the potential for habitat loss or other effects on fitness. Such effects are becoming increasingly important to understand as turbine build-out continues and cumulative impacts increase.

Acknowledgements

Funding for this analysis was provided by the Sierra Club Huplits Wildlife Grant. Telemetry data was funded by PA SWG grants T-12 and T47-R-1, US DoE grant DE-EE0003538, NASA Climate and Biological Response Grant #NNX11AP61G, Charles A. and Anne Morrow Lindbergh Foundation. Use of Golden Eagles for this research was approved by the West Virginia University Institutional Animal Care and Use Committee (IACUC) protocol #11-0304. We thank many people for their assistance with field work and data collection.

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Table 1. Model selection tables and variable estimates for resource selection functions of Golden Eagles (2009-2015).

Winter

ID	Intercept	Ridgetop	Steep Slopes	Side Slopes	Elevation (km)	Northness	Eastness	Updraft Potential ($m\ s^{-1}$)	Distance to Forest (m)	Distance to Open (m)	Eastness* Updraft Potential	Northness* Updraft Potential	qLik	QIC	Δ QIC	Weight
7	***-3.06***	***0.78***	***0.61***	***0.20***	***2.36***			***0.47***	***-0.0035***	***0.0010***			***-777***	***1578***	***0.00***	***0.88***
1	**-2.98**	**0.89**	**0.61**	**0.19**	**2.13**	**0.32**	**-0.15**	**0.45**	**-0.0034**	**0.0012**	**0.09**	**-0.17**	**-772**	**1582**	**4.11**	**0.11**
6	**-3.10**	**0.85**	**0.68**	**0.19**	**3.02**			**0.47**	**-0.0043**				**-782**	**1587**	**9.64**	**0.01**
2	-3.05	0.88	0.67	0.19	2.27	-0.03	0.09	0.47	-0.0036	0.0011			-776	1593	14.95	0.00
5	-3.34	0.84	0.64	0.28	3.28			0.49					-785	1594	15.81	0.00
4	-3.28	0.84	0.57	0.28	3.18	0.32	-0.19	0.48			0.09	-0.15	-781	1599	21.18	0.00
3	-3.34	0.85	0.63	0.28	3.28	0.00	0.03	0.49					-785	1609	31.32	0.00
9	-0.95								-0.0121	0.0017			-891	1806	228.18	0.00
8	-0.79												-951	1934	356.46	0.00

Fall

ID	Intercept	Ridgetop	Steep Slopes	Side Slopes	Elevation (km)	Northness	Eastness	Updraft Potential ($m\ s^{-1}$)	Distance to Forest (m)	Distance to Open (m)	Eastness* Updraft Potential	Northness* Updraft Potential	qLik	QIC	Δ QIC	Weight
5	***-7.19***	***0.78***	***0.71***	***0.58***	***7.65***			***0.29***					***-1555***	***3172***	***0.00***	***0.85***
6	**-7.22**	**0.78**	**0.72**	**0.56**	**7.56**			**0.29**		**0.0003**			**-1554**	**3176**	**3.83**	**0.13**
7	**-7.21**	**0.78**	**0.72**	**0.56**	**7.55**			**0.29**	**-0.0001**	**0.0003**			**-1554**	**3181**	**8.61**	**0.01**
4	**-7.17**	**0.80**	**0.73**	**0.61**	**7.52**	**-0.10**	**-0.36**	**0.29**			**0.15**	**-0.02**	**-1546**	**3182**	**9.58**	**0.01**
3	-7.21	0.78	0.72	0.59	7.63	-0.19	0.02	0.30					-1552	3186	14.20	0.00
1	-7.20	0.81	0.73	0.59	7.39	-0.11	-0.36	0.28	-0.0001	0.0004	0.15	-0.02	-1545	3187	15.36	0.00
2	-7.24	0.79	0.72	0.57	7.50	-0.20	0.04	0.30	-0.0002	0.0004			-1550	3192	20.21	0.00
9	-3.15								-0.0110	0.0013			-1867	3782	609.82	0.00
8	-3.04												-1936	3914	742.46	0.00

Spring

ID	Intercept	Ridgetop	Steep Slopes	Side Slopes	Elevation (km)	Northness	Eastness	Updraft Potential ($m\ s^{-1}$)	Distance to Forest (m)	Distance to Open (m)	Eastness* Updraft Potential	Northness* Updraft Potential	qLik	QIC	Δ QIC	Weight
6	***-8.63***	***1.13***	***0.68***	***0.64***	***9.68***			***0.49***	***-0.0028***				***-784***	***1634***	***0.00***	***0.54***
5	**-8.72**	**1.16**	**0.71**	**0.67**	**9.77**			**0.50**					**-784**	**1634**	**0.30**	**0.46**
7	**-8.65**	**1.14**	**0.68**	**0.64**	**9.66**			**0.49**	**-0.0026**	**0.0001**			**-784**	**1644**	**10.80**	**0.00**
4	-8.67	1.19	0.74	0.68	9.68	-0.28	0.04	0.48			-0.05	0.14	-780	1694	60.70	0.00
3	-8.66	1.15	0.70	0.65	9.68	0.11	-0.12	0.49					-782	1697	63.10	0.00
1	-8.58	1.17	0.72	0.65	9.58	-0.28	0.05	0.47	-0.0028	0.0000	-0.05	0.14	-779	1702	68.10	0.00
2	-8.58	1.12	0.67	0.62	9.59	0.11	-0.12	0.49	-0.0026	0.0000			-781	1706	72.50	0.00
9	-2.83								-0.0342	0.0012			-1085	2221	587.60	0.00
8	-2.81												-1153	2345	711.80	0.00

Table 2. Model variables, estimates, 95% confidence intervals, standard errors, Wald statistics and p values of resource selection functions of Golden Eagles during winter, fall and spring (2009-2015) in central Pennsylvania.

Winter

Variable*	Estimate	Lower CI	Upper CI	SE	Wald	p
Intercept	-3.060	-3.203	-2.915	0.073	1737.2	<0.0001
Ridgetops	0.847	0.814	0.880	0.017	2492.0	<0.0001
Steep Slopes	0.682	0.504	0.860	0.091	56.6	<0.0001
Side Slopes	0.188	-0.020	0.396	0.106	3.1	0.08
Maximum Updraft Potential	0.467	0.334	0.600	0.068	47.3	<0.0001
Elevation (km)	2.360	2.332	2.392	0.015	23579.6	<0.0001
Distance to Open Cover (m)	0.001	0.001	0.001	0.000	236.4	<0.0001
Distance to Forest Cover (m)	-0.004	-0.004	-0.003	0.001	49.0	<0.0001

Fall

Variable*	Estimate	Lower CI	Upper CI	SE	Wald	p
Intercept	-8.629	-10.779	-6.480	1.097	61.85	<0.0001
Ridgetops	1.134	0.615	1.650	0.265	18.33	<0.0001
Steep Slopes	0.683	-0.052	1.420	0.375	3.32	0.07
Side Slopes	0.640	0.067	1.210	0.292	4.79	0.03
Maximum Updraft Potential	0.492	0.361	0.623	0.067	54.34	<0.0001
Elevation (km)	9.678	7.208	12.100	1.260	58.98	<0.0001
Distance to Forest Cover (m)	-0.003	-0.005	0.000	0.001	3.97	0.05

Spring

Variable*	Estimate	Lower CI	Upper CI	SE	Wald	p
Intercept	-8.719	-8.638	-5.746	1.078	65.37	<0.0001
Ridgetops	1.162	0.317	1.233	0.264	19.35	<0.0001
Steep Slopes	0.709	0.297	1.132	0.374	3.59	0.06
Side Slopes	0.671	0.170	0.983	0.288	5.43	0.02
Maximum Updraft Potential	0.497	0.172	0.411	0.066	57.57	<0.0001
Elevation (km)	9.765	5.013	10.285	1.252	60.85	<0.0001

*Reference category is "Other" land form types

Figures

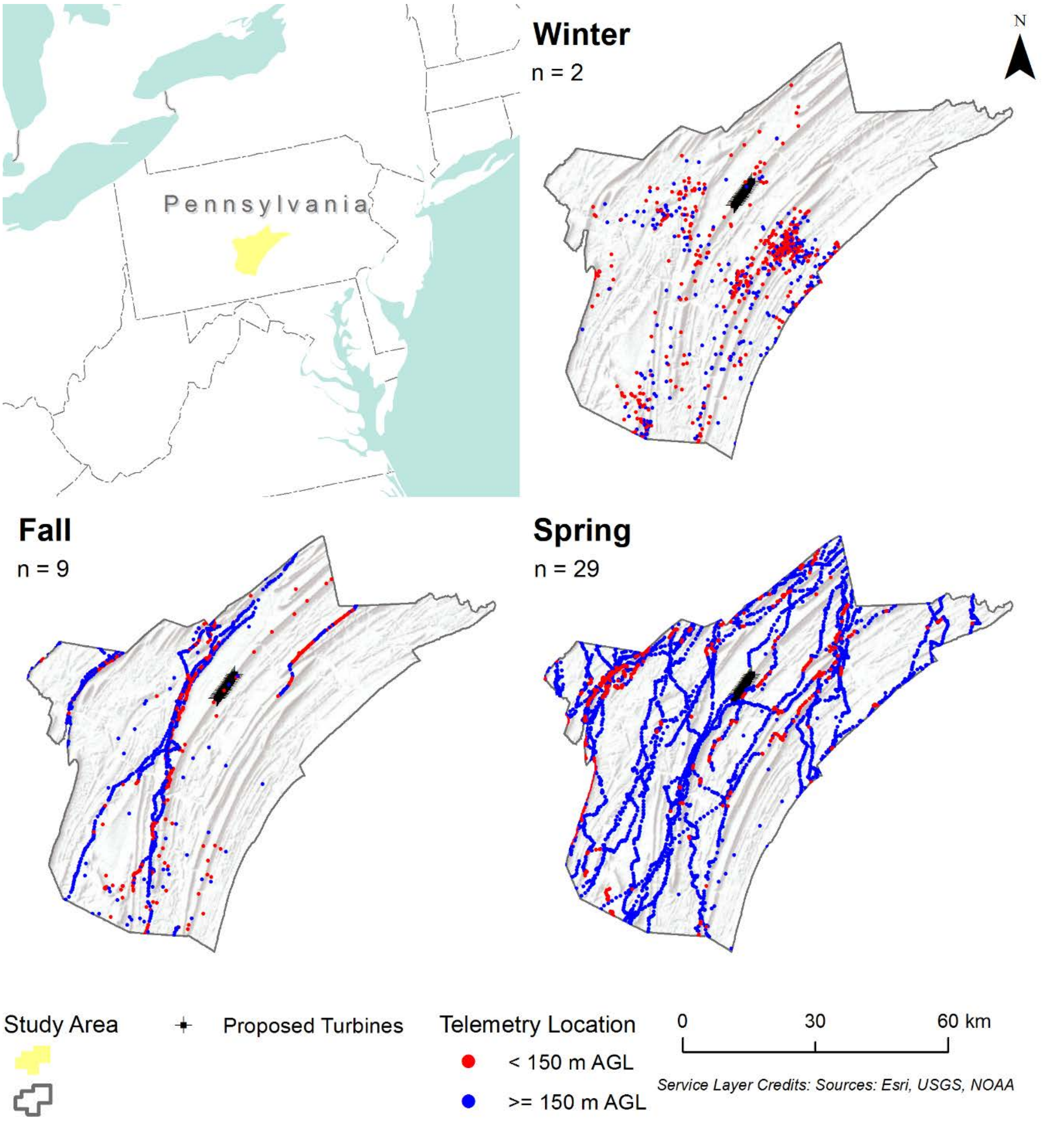

Fig. 1. Overview of study area (top left) and in-flight telemetry locations of Golden Eagles collected within the study area for winter and fall and spring migration. Sample size indicated the number of birds tracked during each season. Red dots represent locations of eagles flying below 150 m above ground level (AGL), which is the maximum height of current generation wind turbines. Blue dots represent locations of eagles flying above 150 m AGL. Data were collected from 2009 – 2015.

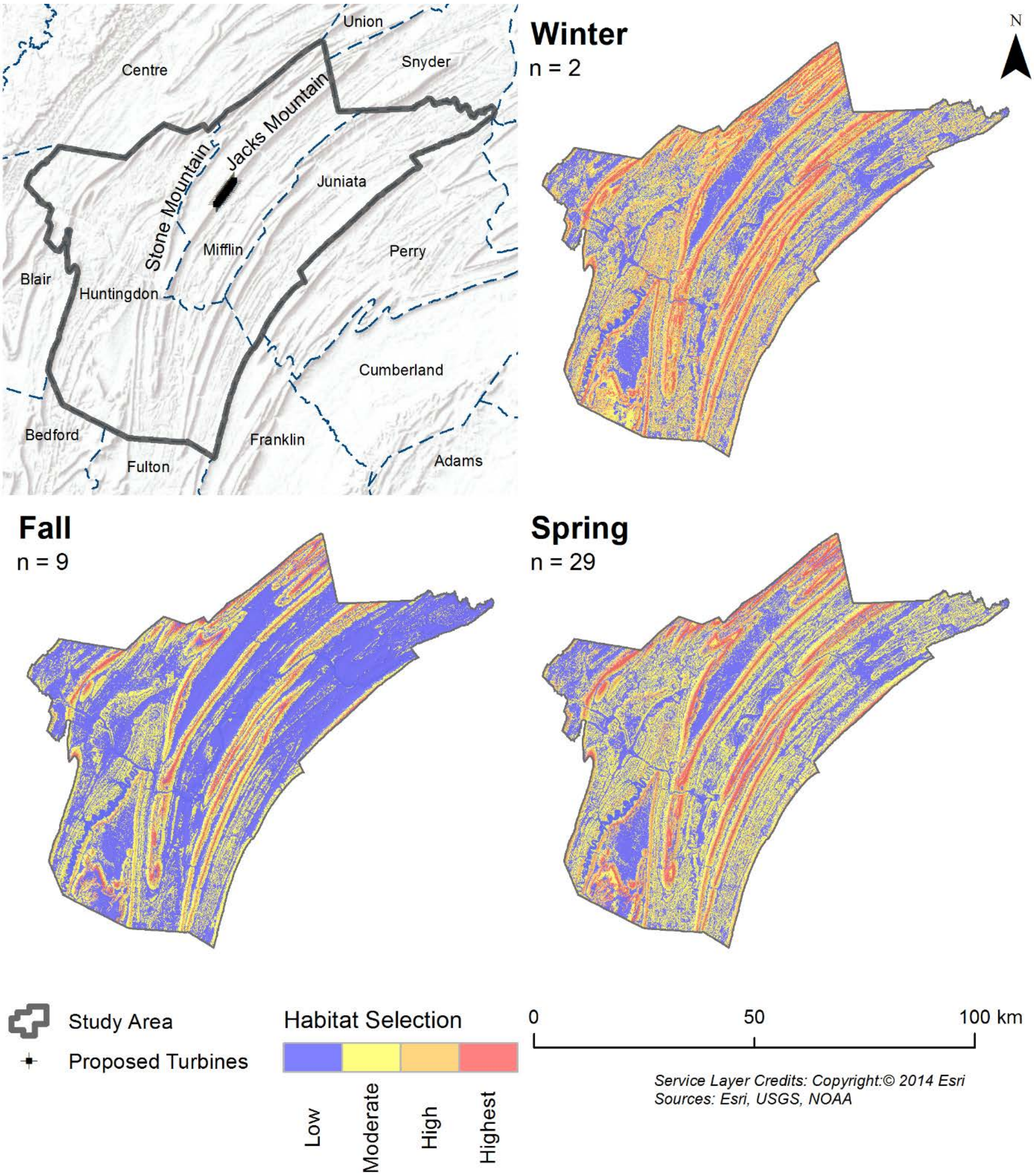

Fig. 2. Overview of study area (top left) and resource selection function models of Golden Eagles flying below 150 m above ground level during winter and fall and spring migration. Sample size indicates the number of birds tracked through the study area during each season (2009-2015).

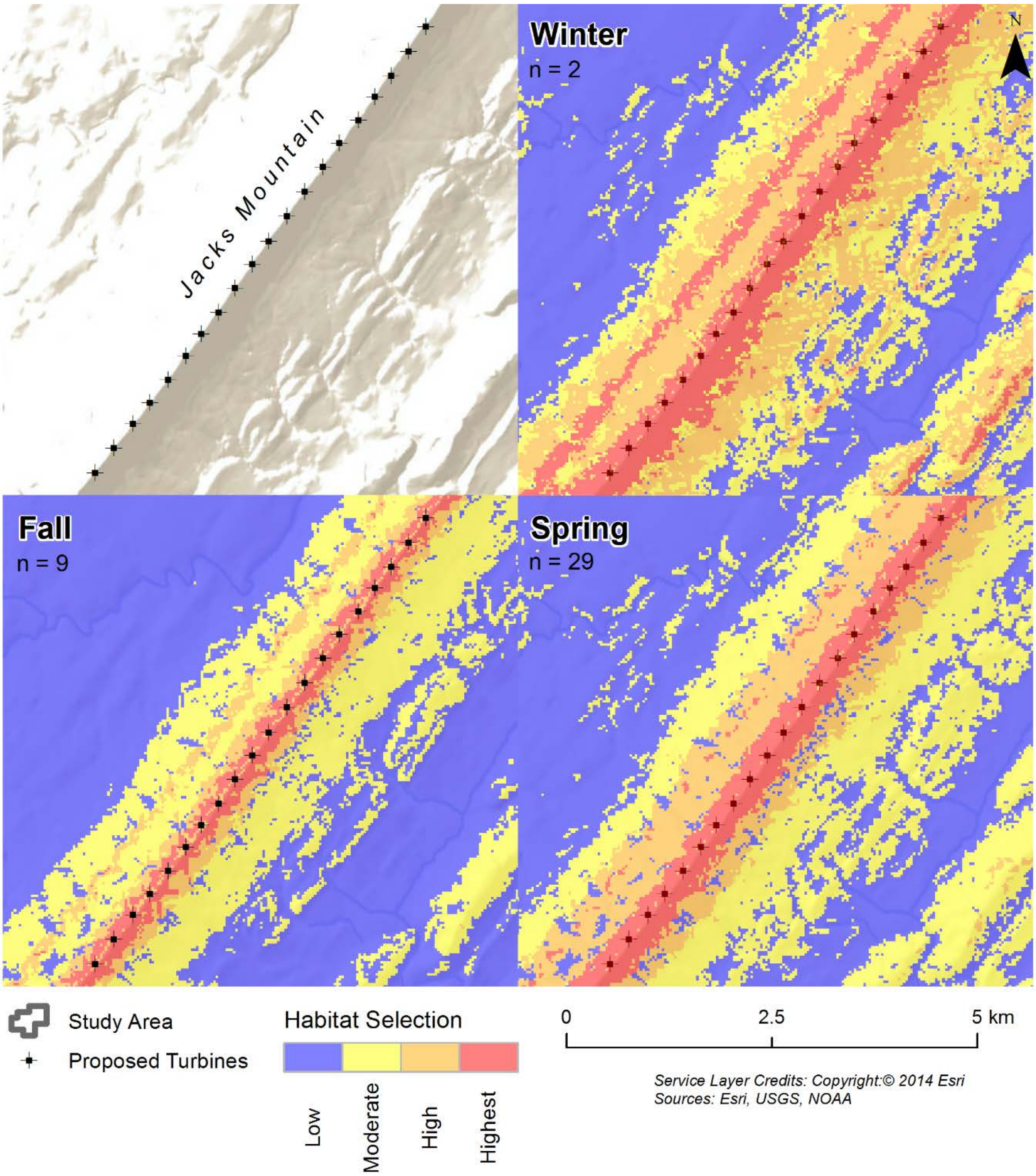

Fig. 3. Close up of proposed wind turbines on Jacks Mountain and resource selection models of Golden Eagles flying below 150 m above ground level during winter and fall and spring migration. Sample size indicates the number of birds tracked through the study area during each season (2009-2015).

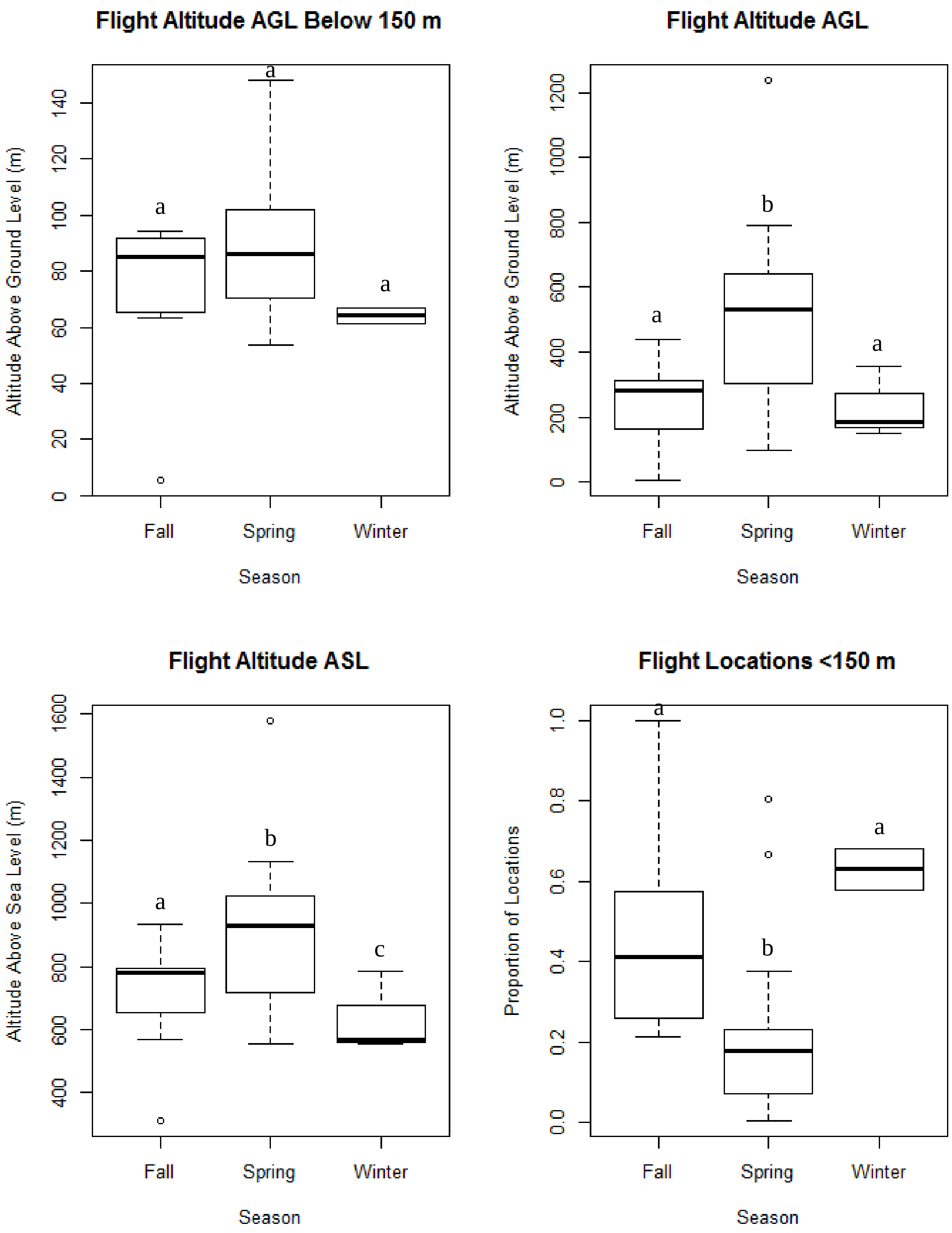

Fig. 4. Boxplots showing range (whiskers), interquartile range (box), and median (dark line) for means per bird per season of flight altitude (m) below 150 m above ground level (AGL), flight altitude AGL (m), flight altitude above mean sea level (m), and the proportion of flight locations below 150 m AGL. Different letters indicated significant differences.

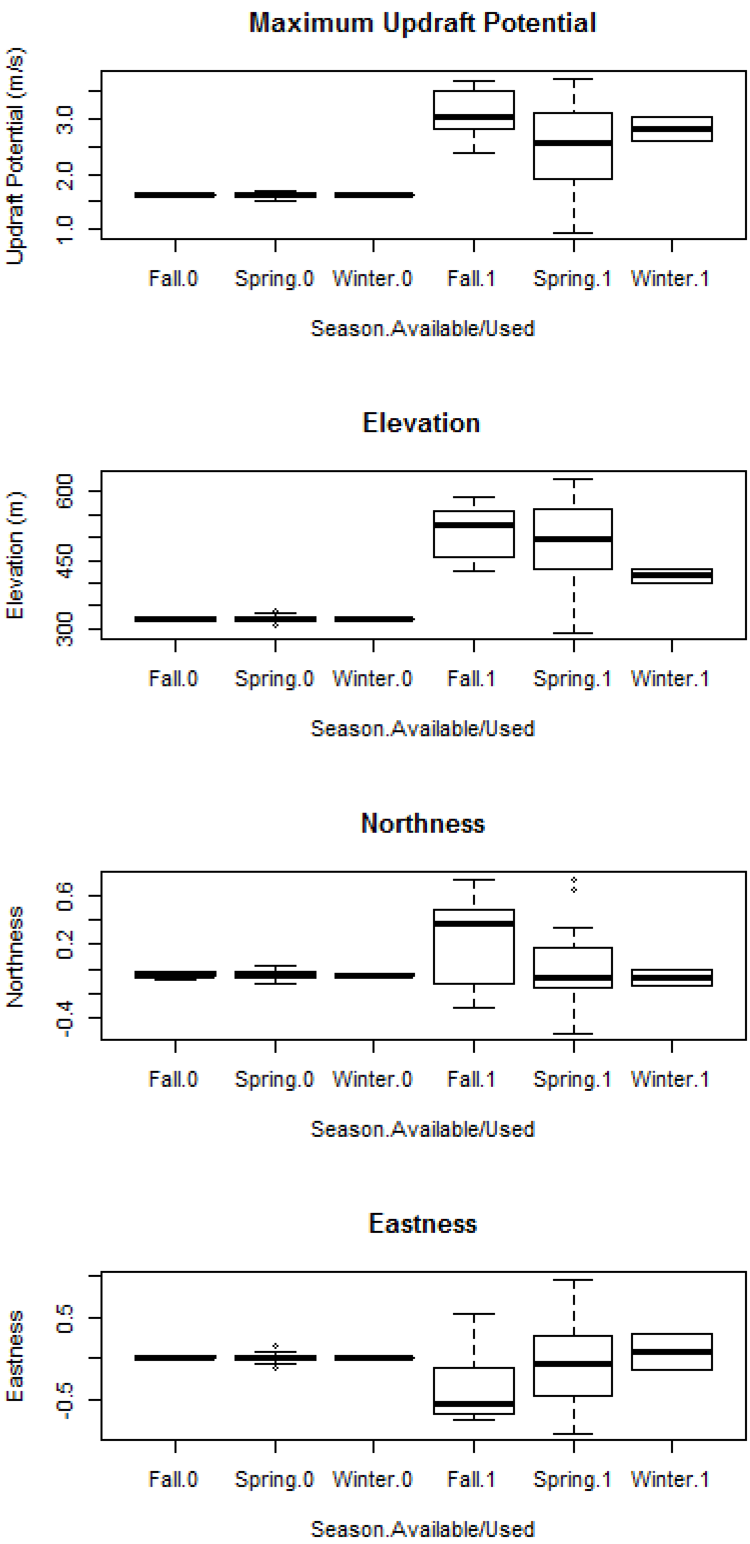

Fig. 5. Boxplots showing range (whiskers), interquartile range (box), and median (dark line) for random locations (0 = available) and means per bird (1 = used) per season for topographic variables used in resource selection functions. These include maximum updraft potential (m s^{-1}), elevation (m), northness (cosine of aspect), and eastness (sine of aspect). When medians of random (available) locations differ from used locations, then there is selection for that variable. For example, updraft potential used by eagles was much higher than the median available across the landscape, thus eagles were selecting for areas with higher potential updrafts.

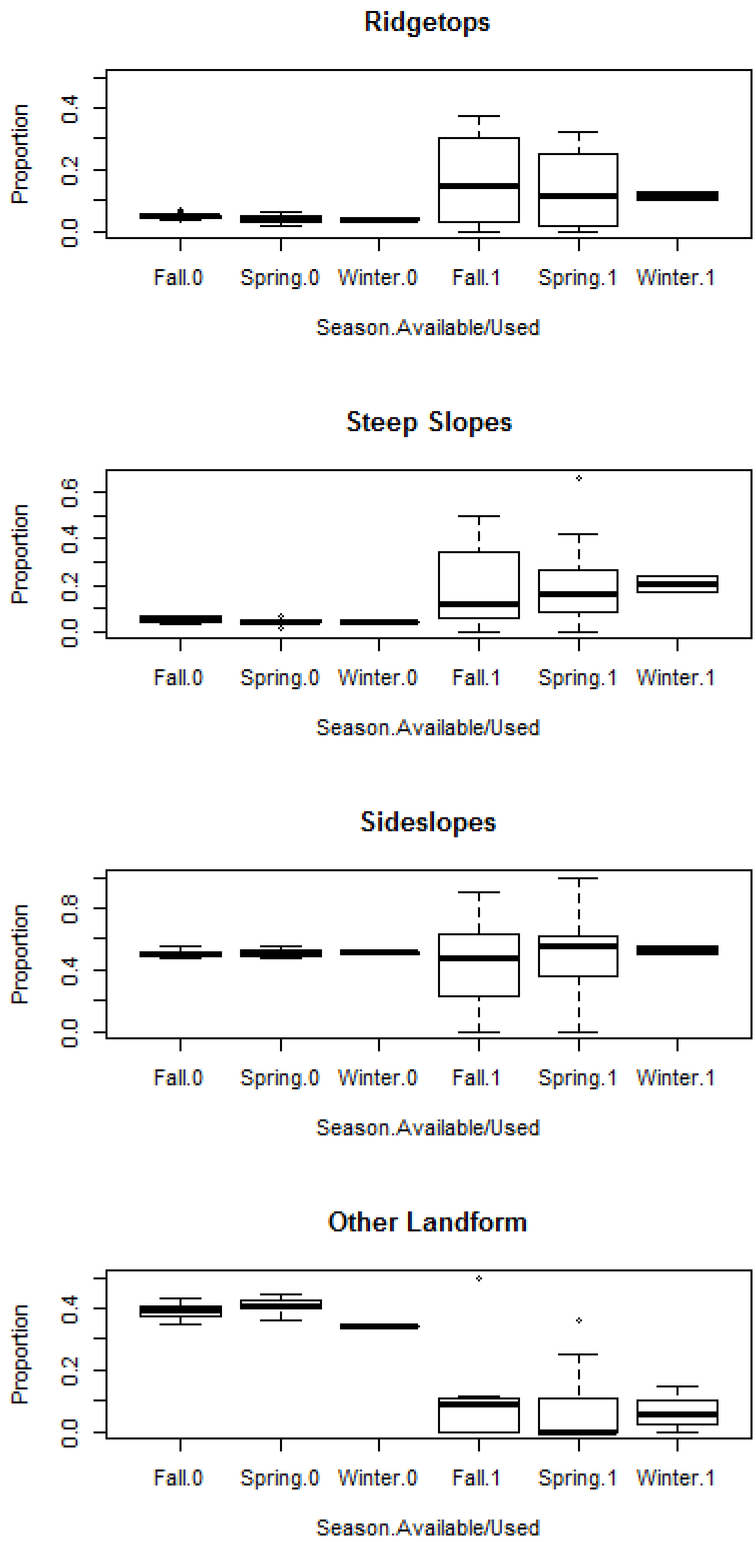

Fig. 6. Boxplots showing range (whiskers), interquartile range (box), and median (dark line) for random locations (0 = available) and mean proportion per bird (1 = used) per season for landform types used in resource selection functions. These include ridgetops, steep slopes, side slopes, and other landform types. When random (available) locations are proportionally higher than used locations, then there is selection against that variable. Conversely, when available locations are proportionally lower than used locations there is selection for that variable. Eagles selected for ridgetops and steep slopes, especially during winter. There was no difference between the availability of side slopes and use of side slopes, and there was strong selection against other landform types, which includes valleys and open water among others.

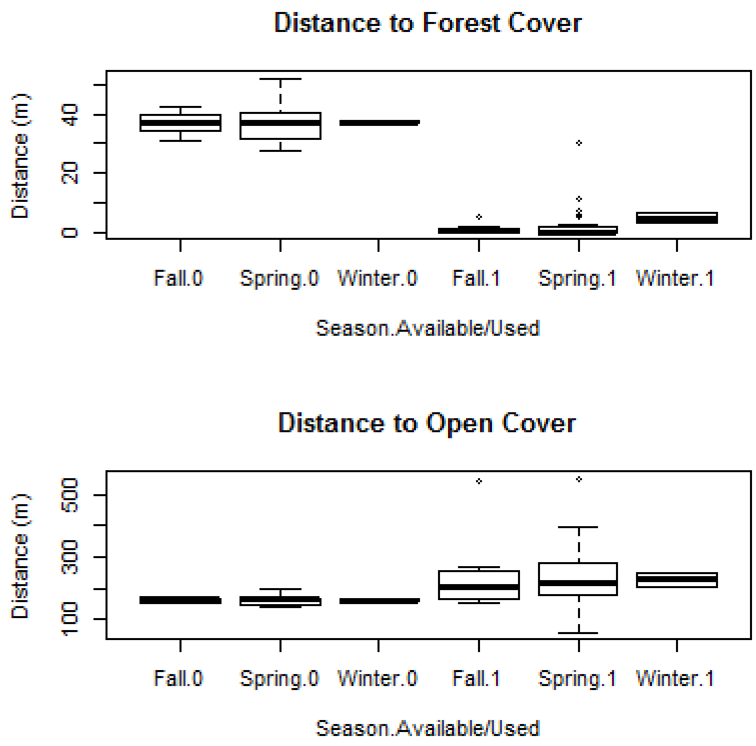

Fig. 7. Boxplots showing range (whiskers), interquartile range (box), and median (dark line) for random locations (0 = available) and means per bird (1 = used) per season for land cover variables used in resource selection functions, namely distance to forest (m) and distance to open cover (m). Eagles showed stronger selection for areas near forests (distance near 0) compared to what was available across the landscape and showed little selection for areas away from open cover.