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Homeward bound: annual breeding home range size and overlap in Broad-winged Hawks (*Buteo platypterus*) and the effects of sex, productivity, and ecoregion

Rumbo a casa: tamaño anual y superposición del ámbito hogareño reproductivo de *Buteo platyperus* y los efectos del sexo, la productividad y la ecorregión

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ABSTRACT. Documenting home range size, and identifying the variables influencing it, is key to understanding raptor population ecology and to addressing conservation issues. The Broad-winged Hawk (*Buteo platypterus*, hereafter broadwing) is a small forest buteo that travels over 8,000 km between its breeding range in North America and wintering range in Central and South America. Although conspicuous during migration, its secretive behavior while nesting hinders data collection on behavior and movements during the breeding season. We calculated breeding home ranges of 14 telemetry-tracked broadwings in northeastern USA and analyzed the effects of intrinsic (sex and nest productivity) and extrinsic (ecoregion) variables, using autocorrelated kernel density estimations. Breeding home ranges were 20 times larger in males than in females, in line with the strong division of labor between sexes observed in raptors. Breeding home ranges were larger in the most southerly ecoregion, suggesting that adults may need to move more to find prey for their nestlings or the habitat is less suitable in this ecoregion. We found no effect of nest productivity, although sample size was small. We assessed nest site fidelity and home range overlap across years for five adults. We found annual breeding home ranges overlapped (>0.85 in all cases) and inter-annual nest distances were less than 200 m on average, indicating a strong fidelity to the breeding home range and to the nest site area. To our knowledge, this is the first study using telemetry data to calculate breeding home ranges of this secretive forest raptor. Our findings indicate that broadwing breeding home ranges and nesting locations may remain stable over several years. Understanding and protecting the habitats used by nesting broadwings throughout their breeding range could be important to their long-term conservation.

RESUMEN. Documentar el ámbito hogareño reproductivo e identificar las variables que lo determinan son clave para comprender la ecología de poblaciones de rapaces y abordar cuestiones de conservación. La Aguililla Alas Anchas (*Buteo platypterus*) es una rapaz principalmente de bosque y de tamaño pequeño que viaja más de 8,000 km entre su área de reproducción en América del Norte y su área de invernada en Centro y Sudamérica. Aunque es conspicuo durante la migración, su comportamiento elusivo durante la nidificación dificulta la recopilación de datos sobre su comportamiento y movimientos durante la época reproductiva. En el noreste de los Estados Unidos, estimamos el ámbito hogareño reproductivo de 14 individuos usando datos de telemetría y analizamos los efectos de las variables intrínsecas (sexo y productividad del nido) y extrínsecas (ecorregión), mediante estimaciones de la densidad del Kernel autocorrelacionada. Los ámbitos hogareños reproductivos fueron 20 veces más grandes en los machos que en las hembras, acorde con la fuerte división de tareas entre los sexos observadas en las rapaces. Los ámbitos hogareños durante la reproducción fueron más grandes en la ecorregión más sureña, lo que sugiere que los adultos pueden necesitar desplazarse más para encontrar presas para sus crías o que el hábitat es menos adecuado en esta ecorregión. No encontramos ningún efecto en la productividad de los nidos, aunque el tamaño de la muestra fue pequeño. En cinco individuos adultos evaluamos la fidelidad al sitio de anidación y la superposición de los ámbitos hogareños a lo largo de los años. Encontramos que los ámbitos hogareños anuales se superponían (> 0.85 en todos los casos) y en promedio, las distancias interanuales entre nidos fueron inferiores a 200 m, lo que indica una fuerte fidelidad al ámbito hogareño y al área del sitio de anidación. Hasta donde sabemos, este es el primer estudio que utiliza datos de telemetría para calcular los ámbitos hogareños durante la época reproductiva en esta rapaz de comportamiento elusivo. Nuestros hallazgos indican que los ámbitos hogareños durante la crianza y las ubicaciones de los sitios de anidación de *Buteo platypterus* pueden permanecer estables durante varios años. Comprender y proteger los hábitats utilizados por esta especie de rapaz en toda su área de reproducción podría ser importante para su conservación a largo plazo.

Key Words: *breeding biology; Buteo platypterus; forest raptor; home range; Neotropical; nest site fidelity; telemetry*

INTRODUCTION

Space-use movements and patterns are key aspects of the ecology, distribution, and population dynamics of many species (Nathan et al. 2008, Morales et al. 2010, Powell and Mitchell 2012). In fact, understanding animal movements can inform a wide array of topics, including animal physiology, the spread of diseases, and gene flow, and it can help us better address management and conservation issues (Nathan et al. 2008). Among the many

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concepts available to describe animal movements and space use, home range (i.e., the areas that are usually traversed while foraging and breeding; Burt 1943) has probably been the most widely used, because it can account for habitat features (Spencer 2012) that ultimately affect the biological effectiveness of individuals and, thus, the viability of populations (Börger et al. 2008, Powell and Mitchell 2012, Van Moorter et al. 2016, Tapia and Zuberogoitia 2018). For instance, it is generally accepted that individuals tend to use smaller home ranges in more suitable habitats (Newton 1979, Corriale et al. 2013). Because space–use patterns are a key aspect of the ecology and distribution of species, identifying factors associated with variation in size of territories and home ranges is key to understanding population ecology and to addressing conservation issues.

In raptors, there has been extensive research on the factors determining home ranges (general review in Peery 2000, but see also Mirski et al. 2021, Spatz et al. 2022). In general, raptors are limited by suitable conditions in their breeding areas, with specific extrinsic requirements that affect the size and shape of their home ranges, such as the availability of nest sites (Negro et al. 2007), prey type (Peery 2000) and abundance (Martínez-Miranzo et al. 2019), weather conditions (Mirski et al. 2021), presence of intra- and interspecific competitors (Gargett 1990, Ottaviani et al. 2006), and even human disturbance (Tapia and Zuberogoitia 2018, Mirski et al. 2021). For example, range sizes of raptors are bigger when prey are scarce (Kenward 1982, Miller et al. 2017) and when human settlements are far away, in some species (Mirski et al. 2021), but other factors such as habitat heterogeneity and vegetation cover may also play a key role in range size at a macroscale level (Campioni et al. 2013, Tapia and Zuberogoitia 2018, Mirski et al. 2021).

On the other hand, intrinsic factors such as sex (Mirski et al. 2021, Spatz et al. 2022), age (Harestad and Bunnell 1979, Miller et al. 2017), or reproductive status (Pfeiffer and Meyburg 2015) can also play a key role determining the size of breeding home ranges. During the breeding season, many raptor species have separate and specialized reproductive roles between sexes, with females mainly incubating the eggs, and males providing prey to both female and nestlings (Schmutz et al. 2014). This usually results in smaller home ranges for females when compared with those of males (Pfeiffer and Meyburg 2015, Hernández-Pliego et al. 2017, Mirski et al. 2021). Lastly, reproductive parameters (i.e., breeding success and productivity) can influence home range in raptors (Pfeiffer and Meyburg 2015, Moser and Garton 2019). In habitats with poor quality resources (e.g., low prey availability), males need to move greater distances to find food, and lower food availability could impact the breeding performance of the pair (i.e., nestlings being more vulnerable to predators), leading to lower productivity but larger ranges (Pfeiffer and Meyburg 2015). Also, when nests fail during the breeding season, females may abandon the nest or the breeding territory, moving greater distances and increasing their home range size (Moser and Garton 2019, Spatz et al. 2022).

The Broad-winged Hawk (*Buteo platypterus*, hereafter broadwing) is a small buteo that breeds in deciduous or mixed-deciduous forests of northeastern and northcentral North America (Goodrich et al. 2020) and migrates each winter to Central and South America (Haines et al. 2003, Goodrich et al. 2020, McCabe et al. 2020). Despite its abundance during migration, broadwings are showing declines at 15% of 53 migration watch sites in the eastern USA, notably in the Piedmont plateau east of the Appalachians (Oleyar et al. 2021). Moreover, its breeding range has declined by 16% in Pennsylvania since the 1980s (Goodrich 2012). Although some information has documented wintering areas and range size of broadwings (Haines et al. 2003, McCabe et al. 2020, Cuadros et al. 2021), similar attention has not been given to breeding home ranges. Their secretive behavior while nesting makes it challenging to understand the broadwings' habitat needs (Goodrich et al. 2020), a key factor necessary for effective conservation measures (Goldsmith 2012).

The objective of this paper is to describe breeding home ranges (hereafter BHRs) of the broadwing and to examine its fidelity to the range and nest area across different years using telemetry data. We aim to analyze the effects of intrinsic (sex and nest productivity) and extrinsic (ecoregion) parameters on the size of BHRs. We hypothesize that: (1) the BHRs of breeding females will be smaller than those of males due to the sex role specialization (Mirski et al. 2021), (2) the BHRs of successful and more productive seasons will be smaller than those of unsuccessful and less productive seasons (Pfeiffer and Meyburg 2015, Moser and Garton 2019), and (3) individuals breeding in more diverse forest types (which have more wetlands and a greater proportion of evergreen forest and conifer species; Bailey et al. 1994, Perry 1994, Herlihy et al. 2008) will have smaller BHRs as prey density and diversity is expected to be higher (Perry 1994).

METHODS

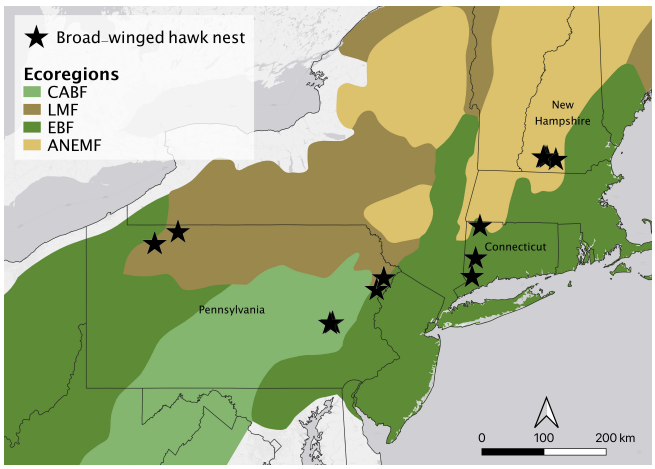
Study Area

Research was conducted in four ecoregions in Pennsylvania, Connecticut, and New Hampshire, USA (U.S. Forest Service; Bailey et al. 1994, Fig. 1). The Central Appalachian Broadleaf Forest (hereafter CABF) is dominated by mixed deciduous forests with interspersed small stands of eastern hemlock (*Tsuga canadensis*) or white pine (*Pinus strobus*). The Laurentian Mixed Forest (hereafter LMF) is a transitional forest between deciduous hardwoods and needleleaf spruce and pines, with a greater evergreen component when compared with the CABF. The Eastern Broadleaf Forest (EBF) is characterized by diverse deciduous forest with mixed oak species and widespread dominants including American beech (*Fagus grandifolia*) and yellow poplar (*Liriodendron tulipifera*) with occasional pockets of eastern hemlock (*Tsuga canadensis*) (Bailey et al. 1994). Lastly, the Adirondack–New England Mixed Forest (hereafter ANEMF), is more similar to boreal forests than the other ecoregions, being heavily dominated by evergreen trees, including species of spruce, pine, and hemlock with mixed stands of hardwoods. Both LMF and ANEMF are characterized by higher abundance of forested wetlands than CABF, with the EBF ecoregion—particularly the glaciated sections in the north—also showing more wetlands compared with the CABF (Tiner 1990, Bailey et al. 1994, Herlihy et al. 2008).

Capture and Telemetry

Adult broadwings were captured and equipped with satellite and GPS-GSM transmitters during the nestling phase of the nest cycle from mid-June to mid-July 2015–2021. We used mist nets, and a mechanical Great Horned Owl (*Bubo virginianus*) with playback calls as a lure (Jacobs 1996, McCloskey and Dewey 1999) to trap adults near the nest when nestlings were at least 1–2 wks old

Fig. 1. Map of the study area showing the four ecoregions in northeastern USA where the Broad-winged Hawks (*Buteo platypterus*) were monitored during the breeding season from 2015–2021. CABF = Central Appalachian Broadleaf Forest; LMF = Laurentian Mixed Forest; EBF = Eastern Broadleaf Forest; ANEMF = Adirondack -New England Mixed Forest.



(McCabe et al. 2020). Sex of individuals was determined based on nesting behavior and morphometrics (Mosher and Matray 1974, Bordner et al. 2022). All birds received a U.S. Geological Survey aluminum leg band and color leg bands for individual identification. We attached solar-powered ARGOS satellite 9.5 g platform transmitter terminals (Microwave Telemetry, Inc., Columbia, Maryland, USA) and 9 g GPS-GSM solar transmitters (Cellular Tracking Technologies, Rio Grande, New Jersey, USA) using the backpack harness method (Steenhof et al. 2006) and 4–6 mm Teflon ribbon (Bally Ribbon Mills, Bally, Pennsylvania, USA) or spectra. We deployed transmitters on individuals with a body mass of more than 380 g to ensure the combined tag and harness weight (approximately 11.5 g) did not exceed 3% of the bird's mass (Murray and Fuller 2000, Barron et al. 2010).

For this study, we analyzed tracking data from broadwings during the entire breeding season (April–August). Broadwings are said to establish nest sites quickly after returning from spring migration (Fitch 1974). For individuals with multiple years of tracking data, we defined the start of the breeding season (after first year of tracking) as the day when the farthest northern location was found, and after which all posterior locations were non-directional, and no further migration movements occurred (McCabe et al. 2020). In most cases, this methodology was also confirmed by visual inspection of adults at the nest sites. For satellite telemetry data, we filtered breeding locations to include only the most accurate location classes of 3, 2, and 1 (<250 m, <500 m, and <1500 m error, respectively; Argos System 2017).

Nest Monitoring and Determination of Reproductive Parameters

During the breeding season, we visited nests twice a week to confirm occupancy and document the nesting stage. At the end of the breeding season, we checked all active nests and assessed nest success and productivity (i.e., number of nestlings fledged). A nest was deemed successful if at least one nestling fledged (Steenhof and Newton 2007).

Statistical Analyses

We calculated BHRs (95% estimator) and core BHRs (50% estimator) (Powell and Mitchell 2012) for nesting broadwings using autocorrelated kernel density estimation (AKDE; Fleming et al. 2015) in the "ctmm" package (Calabrese et al. 2016) in R Studio (R Core Team 2022). This package models the autocorrelation structure of tracking data by using Ornstein-Uhlenbeck Foraging (OUF) or Ornstein-Uhlenbeck (OU) models, and therefore performs more accurate predictions of the home range than traditional kernel density estimation (KDE) methods (Calabrese et al. 2016, 2021), which usually underestimate the home range areas (Fleming et al. 2015).

For individuals that nested in consecutive years, we calculated the inter-nest distances and used the function "overlap" in the "ctmm" package to examine the fidelity to the nest site and range. With this function, we analyzed the proportion of area used from one year that matched the area used from the previous year. To account for the effect of the intrinsic and extrinsic variables on the BHRs, we compared home range size by sex and then we removed the males from the analysis and compared the home range size of females by ecoregion, body mass, and nest productivity. For these analyses, we used generalized linear mixed models (GLMM) using the "lme4" package (Bates et al. 2014), with bird ID as a random factor, and we performed a backward stepwise model selection process, considering a variable as significant if $P < 0.05$ (Crawley 2015). To test the effect of ecoregion on BHRs, we performed a post hoc Tukey Honest Significant Differences test with the "emmeans" package (Lenth et al. 2018; Table 1).

Table 1. Results from the Tukey's Honest Significant Differences (HSD) test to test the post hoc differences in breeding home ranges (BHRs) of Broad-winged Hawks (*Buteo platypterus*) between ecoregions (Central Appalachian Broadleaf Forest [CABF]; n = 4); Laurentian Mixed Forest [LMF]; n = 7); Eastern Broadleaf Forest [EBF]; n = 4; Adirondack - New England Mixed Forest [ANEMF]; n = 3) in northeastern USA in 2015–2022.

Ecoregions	Estimate	SE	df	t.ratio	*p* value
CABF - EBF	4.7297	1.24	5.15	3.824	0.0401*
CABF - LMF	1.5391	1.18	3.44	1.305	0.6118
CABF - ANEMF	4.7488	1.33	7.37	3.569	0.0335*
EBF - LMF	-3.1906	1.12	5.57	-2.860	0.1081
EBF - ANEMF	0.0191	1.27	10.79	0.015	1.0000
LMF - ANEMF	3.6097	1.19	13.62	2.699	0.0538

RESULTS

We tracked 11 adult females and three adult males across a total of 22 reproductive seasons, within four ecoregions in northeastern USA (Table 2). None of the tagged males and females were paired with another tagged bird during our study. Of the 22 nests monitored, 16 were successful, two failed, and we were unable to confirm if young fledged at four nests. Of the 16 successful nests, nine nests fledged two young each, five nests fledged one young each, and two nests fledged three young each (Table 2).

Table 2. Home range size, nest success, and productivity for 22 Broad-winged Hawk (*Buteo platypterus*) breeding seasons in eastern North America. Ecoregions: CABF = Central Appalachian Broadleaf Forest; LMF = Laurentian Mixed Forest; EBF = Eastern Broadleaf Forest; ANEMF = Adirondack New England Mixed Forest. Home ranges: BHR (95 %) = breeding home range size (km²); Core (50 %) = core home range (km²). Missing values are indicated by NA.

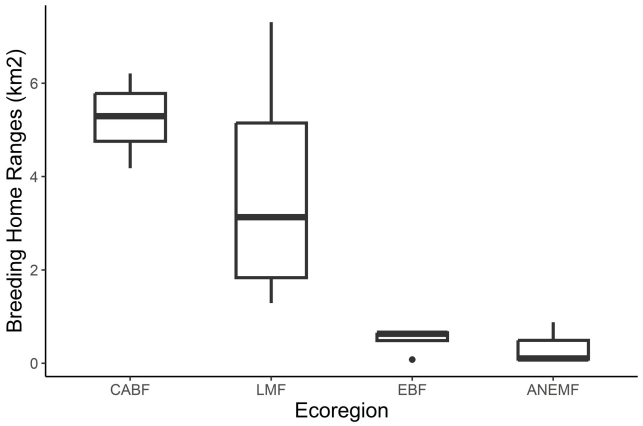
Ecoregion	ID	Year	Sex	Tagged days	BHR (95 %)	Core (50 %)	Success	Productivity
CABFC	146902	2015	Female	54	4.950	0.869	1	1
CABFC	146907	2016	Female	37	4.180	0.726	1	2
CABFC		2017	Female	98	6.210	1.030	1	2
CABFC		2018	Female	121	5.640	0.704	1	3
CABFC	179255	2019	Male	62	46.090	7.630	1	3
LMF	146905	2015	Female	31	4.570	0.793	1	2
LMF		2016	Female	89	7.310	0.966	1	1
LMF		2017	Female	58	1.990	0.386	NA	NA
LMF	161202	2016	Female	69	5.730	0.742	0	0
LMF	146909A	2016	Female	39	1.680	0.286	1	1
LMF		2017	Female	91	1.290	0.236	NA	NA
LMF		2018	Female	119	3.130	0.464	1	2
EBF	146904	2015	Female	32	0.640	0.130	1	2
EBF		2016	Female	96	0.624	0.116	1	2
EBF	18074	2022	Female	38	0.690	0.120	1	2
EBF	17423	2022	Female	77	0.078	0.015	1	2
EBF	16949	2021	Male	35	77.180	10.760	NA	NA
ANEMF	146909B	2021	Female	47	0.878	0.144	1	2
ANEMF	17373	2022	Female	33	0.076	0.016	0	0
ANEMF	14513	2022	Female	38	0.103	0.015	1	1
ANEMF	175124	2021	Male	81	37.420	3.920	1	1
ANEMF		2022	Male	112	80.080	6.960	NA	NA

Breeding home ranges (95% estimator) were more than 20 times larger ($\chi^2 = 15.39$; $P < 0.001$) in males (60.19 ± 21.61 km²; n = four breeding seasons) than in females (2.77 ± 2.45 km²; $n = 18$). A similar difference was found with core range sizes (50% estimator), which averaged 0.43 ± 0.36 km² in females and 7.32 ± 2.81 km² in males, 17% larger. We found no relationship between BHR and nest productivity ($\chi^2 = 0.28$; $P = 0.60$, $n = 18$) (Table 1).

We found a significant difference in BHRs and the ecoregions where the broadwings nested in ($\chi^2 = 25.52$; $P < 0.001$, $n = 18$ reproductive seasons; Table 1, Fig. 2). Female broadwings nesting in the CABF ecoregion had the largest BHRs (5.25 ± 0.88 km², n = four reproductive seasons), being significantly larger than those nesting in EBF (0.51 ± 0.29 km²; $P = 0.04$) and in ANEMF (0.35 ± 0.46 km², n = three reproductive seasons; $P = 0.03$). Female broadwings nesting in the LMF ecoregion (3.67 ± 2.28 km², n = seven reproductive seasons), had larger BHRs than those nesting in the ANEMF ecoregion, although the difference was marginally significant (Table 1).

Breeding home ranges (95% estimator) of individuals nesting in the same territory in consecutive years overlapped by 0.92 ± 0.04; (n = five individuals, Fig. 3). Also, on average, interannual nest distances were = 194.7 ± 326.1 m ($n = 5$), including a female that re-nested in the same tree in two consecutive years.

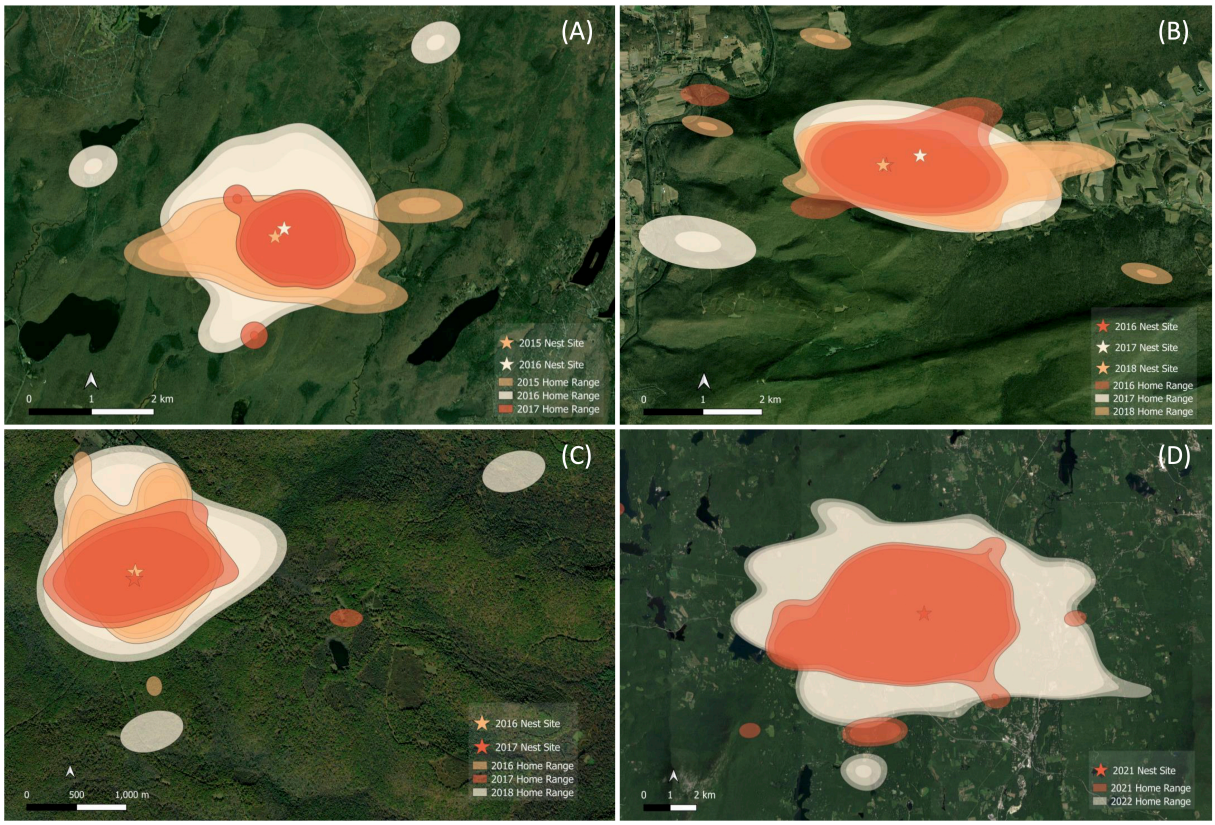
Fig. 2. Breeding home ranges of 11 female Broad-winged Hawks ($n = 18$ reproductive attempts) nesting in four ecoregions (Central Appalachian Broadleaf Forest [CABF]; n = 4); Laurentian Mixed Forest [LMF]; $n = 7$); Eastern Broadleaf Forest [EBF]; $n = 4$; Adirondack - New England Mixed Forest [ANEMF]; $n = 3$) of northeastern USA in 2015–2022.



DISCUSSION

Our findings demonstrate that the size of breeding home ranges in broadwings is influenced by both intrinsic and extrinsic factors, as found in some other raptors (Mirski et al. 2021, Spatz et al. 2022). In addition, BHRs of broadwings nesting in northeastern USA were larger than the ranges found for the Puerto Rican Broadwing (*Buteo platypterus brunnescens*; Delannoy and Tossas 2000, Vilella and Hengstenberg 2006). Smaller home ranges of the island subspecies may be attributed to the habitat type (i.e., tropical forest) and higher densities of suitable prey on the island (Miller et al. 2017). In northern latitudes, compared with tropical latitudes, forests can be less diverse in both tree species and vertebrates, requiring raptors to expand their range to meet the energetic requirements necessary for survival and breeding (Titus and Mosher 1981, Peery 2000, Miller et al. 2017).

Fig. 3. Annual breeding home ranges and nest sites of three telemetry-tracked adult females (A, B, and C) and one adult male (D) Broad-winged Hawk (*Buteo platypterus*) nesting in northeastern USA between 2015–2022.



The Effect of the Intrinsic and Extrinsic Variables on the Breeding Home Ranges

Our findings support our prediction that BHRs of males are bigger than those of females, which is in accordance with other raptor studies (Vilella and Hengstenberg 2006, Moss et al. 2014, Pfeiffer and Meyburg 2015, Hernández-Pliego et al. 2017, Moser and Garton 2019, Mirski et al. 2021). This difference is likely due to the strong division of roles between sexes that is shown by broadwings (Matray 1974, Lyons and Mosher 1987; Hawk Mountain Sanctuary, *unpublished data*). Our results thus indicate that space use is a sex-related behavior (Mirski et al. 2021). Female raptors often show small home ranges (Cardador et al. 2009, Arroyo et al. 2014), especially during breeding season, when they are attached to the nest, whereas males often range farther and explore higher risk habitats and open spaces (Preston 1990). Although breeding success can be correlated with the range size in birds (especially for the male parent; Pfeiffer and Meyburg 2015), broadwing productivity was not related to female range size in this study. As we did not have many males for our analyses, we cannot examine this hypothesis.

Breeding home ranges of broadwings in CABF ecoregion were larger than BHRs in EBF and ANEMF ecoregions, and BHRs in LMF were intermediate in size when compared with CABF and the other three ecoregions. The greater diversity of forest trees, particularly evergreen species, and abundance of wetlands found in EBF, LMF, and NEMF, may be one of the possible reasons why we observed smaller home ranges for broadwings nesting in these three ecoregions. As a generalist predator, broadwings feed mainly on small mammals but also on birds, reptiles, and amphibians, which can be associated with wetlands (McCabe et al. 2019, Goodrich et al. 2020). By contrast, the forest in CABF is mostly dry, mixed deciduous and may have lower prey abundance than the other forest types, thus broadwings could have to move farther to find adequate prey to feed their nestlings. This is in line with the hypothesis that raptors increase their foraging range when preferred habitats or prey are scarce or deficient (Kenward 1982, Santangeli et al. 2012, Miller et al. 2017, Tucker et al. 2019, Mirski et al. 2021). As the LMF is a transitional ecoregion between CABF and the other two ecoregions (EBF and ANEMF), it seems logical that it shares some characteristics of both forest types (i.e., intermediate diversity and abundance of species) and, thus, BHRs of LMF fall in between the sizes of BHRs from birds nesting in CABF and the other two ecoregions. Prey availability surveys within the BHRs would aid in confirming the link between habitat type and prey abundance and diversity. Finally, more northern forest types (i.e., EBF, LMF, NEMF) may also have higher densities of broadwings, leading to greater competition, which also can reduce range size (Peery 2000).

Overlap of Breeding Home Ranges and Nest-site Fidelity

Our study confirms that broadwings show strong interannual breeding range overlap and nest area fidelity. The high overlapping values for the five adults that bred during consecutive years, and the relatively short distances between nests of

consecutive years, suggest that broadwings often reuse the same breeding area for several years in northeastern forests. A breeding pair in the Adirondack Mountains (New York, USA) nested approximately 400 m away from its previous year's nest (Matray 1974), and two additional banded birds were re-trapped on the same breeding area during two consecutive years (Matray 1976). In Puerto Rico, re-occupancy (the use of traditional territories or nests by different pairs; Delannoy and Tossas 2000) was documented for the subspecies *B. p. brunnescens*, indicating that areas of extremely high quality of resources remain valued even after individual turnover occurs.

High nesting range and site fidelity coupled with high re-occupancy could make broadwing populations highly vulnerable to habitat alteration and destruction (Titus and Mosher 1981, Goodrich et al. 2020). Forest fragmentation is rapidly altering previously forested landscapes across many regions of the eastern USA (Hall et al. 2002, Wickham et al. 2007, Drummond and Loveland 2010). These changes can have negative effects on the abundance and diversity of some of the preferred prey of broadwings, such as the eastern chipmunk (*Tamias striatus*; Nupp and Swihart 1998), or bird and amphibian species (Robinson et al. 1995, Cushman 2006), and may increase interactions with possible nest predators (e.g., Great Horned Owl, *Bubo virginianus*, Red-tailed Hawk, *Buteo jamaicensis*, and raccoon, *Procyon lotor*), both factors potentially affecting their long-term conservation. Thus, identifying size and attributes of the broadwing breeding range, and the factors affecting it, is critical to conserving their populations for the long term.

CONCLUSION

In this study, we showed that both intrinsic and extrinsic drivers shaped space use in the broadwing during the reproductive season, providing vital knowledge on the movement ecology and space use of this elusive raptor. The study of other variables (not covered by this study) affecting BHRs, such as body mass (Ottaviani et al. 2006), the degree of anthropic disturbance (Tapia and Zuberogoitia 2018, Mirski et al. 2021), or the presence of competitors including other broadwing pairs (Ottaviani et al. 2006) may aid in clarifying the links between landscape quality, biodiversity, and viability of populations (Börger et al. 2008, Powell and Mitchell 2012, Van Moorter et al. 2016, Tapia and Zuberogoitia 2018). Also, our findings indicate that broadwing BHRs may remain stable over several years. The knowledge and protection of nesting areas may be key for broadwing long-term conservation (Goldsmith 2012, McCabe et al. 2019).

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Data Availability:

The data on the home ranges and the different variables used will be available from the authors, as well as the code used for the analysis. Trapping, handling, and processing of birds were under permits from the Pennsylvania Game Commission (Permit #32125, L. Goodrich) and the US Geological Survey Bird Banding Laboratory (Permit #22749, L. Goodrich).

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