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BROAD-WINGED HAWK (*BUTEO PLATYPTERUS BRUNNESCENS*) MOVEMENTS AND HABITAT USE IN A MOIST LIMESTONE FOREST OF PUERTO RICO

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Resumen. – Patrones de movimiento y uso de hábitat del Guaraguao de Bosque (*Buteo platypterus brunnescens*) en bosque húmedo de caliza de Puerto Rico. – El Guaraguao de Bosque(*Buteo platypterus brunnescens*) es una subespecie endémica de los bosques montanos de Puerto Rico listada como en peligro de extinción. Durante 2001 y 2002 estudiamos el Guaraguao de Bosque en la Reserva Forestal de Río Abajo y áreas aledañas en el norte de Puerto Rico. Capturamos adultos y juveniles utilizando trampas bal-chatri y dho-ghaza, y volantones a mano en el nido. Tomamos medidas morfométricas y marcamos con radios a ocho Guaraguaos de Bosque. Obtuvimos 884 localizaciones de individuos marcados con radios, y demarcamos los territorios de parejas de Guaraguao de Bosque no marcadas a través de observación directa. Promediamos 105 (10–277) localizaciones por individuo durante el estudio y 3,5 localizaciones por semana. Los radiotransmisores duraron entre 31 y 464 días, con un promedio de 218 días. El ámbito doméstico anual (95% kernel) promedio de los adultos fue de 213,1 ha (62,9–446,1 ha) y el de los juveniles 130,7 ha (48,2–250,9 ha). Documentamos Guaraguaos de Bosque perchados en 16 especies de árboles a una altura promedio de 10,4 m. Las especies utilizadas más frecuentemente como perchas fueron *Hibiscus elatus* y *Tectona grandis*. Los Guaraguaos de Bosque marcados con radios no usaron los hábitats en proporción a su disponibilidad ($P < 0{,}001$), seleccionando cuatro de seis hábitat en el área de estudio. Los hábitat seleccionados fueron bosque estacionalmente siempre-verde, bosque montano, matorral montano, y bosque en regeneración. Encontramos 3 áreas en la periferia del Bosque de Rió Abajo usadas frecuentemente por el Guaraguao de Bosque que deben recibir protección o ser consideradas para adquisición. Los juveniles del Guaraguao de Bosque manifestaron un grado altamente reducido de dispersión en comparación con la subespecie continental. Sugerimos que este patrón es resultado de un proceso de adaptación a condiciones insulares.

Abstract. – The Broad-winged Hawk (*Buteo platypterus brunnescens*) is an endemic, non-migratory subspecies of the highly migratory nominate form. Broad-winged Hawks inhabit the interior montane forests of Puerto Rico and are listed as endangered. We studied the Broad-winged Hawk in Rio Abajo Forest and surrounding lands during 2001 and 2002. Adult and juvenile Broad-winged Hawks were trapped using a modified bal-chatri trap and a dho-gaza net. Nestlings were taken by hand from the nest. We collected morphometric measurements and radio-tagged eight Broad-winged Hawks. We obtained 884 locations from radio-tagged hawks and mapped territories of unmarked Broad-winged Hawk breeding pairs by direct observation from limestone hilltops. Telemetry locations per hawk averaged 105 (10–277) overall, with an average of 3.5 locations per bird per week. Transmitter life ranged from 31 to 464 days and averaged 218 days. Adult annual home range (95% kernel) averaged 213.1 ha, and ranged from 62.9–446.1 ha.

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Juvenile annual home range averaged 130.7 ha, and ranged from 48.2–250.9 ha. We recorded Broad-winged Hawks perched in 16 different tree species at an average height of 10.4 m. Tree species most frequently used as perches were *Hibiscus elatus* and *Tectona grandis*. Analysis indicated disproportional use of habitat by Broad-winged Hawks ($P < 0.001$). In our study area radio-tagged Broad-winged Hawks selected four of six available habitat associations. These included seasonal evergreen forest, montane forest, montane evergreen shrub, and regenerating forest. We identified three areas of high Broad-winged Hawk use in the periphery of Rio Abajo Forest that should be considered for protection or acquisition. We documented reduced dispersal by Broad-winged Hawk juveniles and suggest this is an adaptive response to insular conditions. *Accepted 20 June 2006*.

Key words: Broad-wing, *Buteo platypterus brunnescens*, dispersal, endangered, hawk, homerange, habitat use, island, karst forest, movements, Puerto Rico.

INTRODUCTION

Home range and movements of raptors are influenced by multiple factors including food availability (Marquiss & Newton 1981, Village 1982), age or gender (Harestad & Bunnell 1979, Kennedy *et al.* 1994), time of year (Village 1982), and trophic status (Schoener 1968). These factors influence how an individual raptor perceives a particular habitat and its trajectory across habitats in ways that maximize its survival (Newton 1979, Weidensaul 2000). However, landscape features such as the spatial distribution of habitats and barriers to dispersal may affect raptor movements and home range sizes (Bissonette 1997).

Published information exists on juvenile dispersal of various raptor species (González *et al.* 1989, Walls & Kenward 1995, Ellsworth & Belthoff 1999, Lahaye *et al.* 2001). The dynamics of juvenile dispersal may depend on various factors including the capability to acquire food resources in natal areas and the ability to compete for dispersal areas (Mañosa *et al.* 1998, Ellsworth & Belthoff 1999). In general, juvenile raptors tend to exhibit nomadic behavior (González *et al.* 1989) within several weeks of independence and may settle into areas generally not occupied by adult conspecifics (Ferrer 1993, Mañosa *et al.* 1998, Ellsworth & Belthoff 1999). Body condition of juveniles has been associated with long-distance dispersal (Ferrer 1993, Mulder 1995, Walls *et al.* 1999). Moreover, while there are costs associated with early and late dispersal (Horn 1983), some juvenile birds are philopatric and may return to the vicinity of their natal areas to breed once sexually mature (Newton 1979).

The Broad-winged Hawk (*Buteo platypterus brunnescens*) is an endemic island raptor of upland montane forests of Puerto Rico. The Broad-winged Hawk subspecies is listed as endangered (Federal Register 1994) by the Puerto Rico Department of Natural and Environmental Resources and the U.S. Fish and Wildlife Service. The Broad-winged Hawk in Puerto Rico is non-migratory and exhibits a limited geographic range with all known populations restricted to montane forests (Delannoy 1997). This insular subspecies is smaller and darker than its North American counterpart *Buteo platypterus platypterus*, but larger than the Lesser Antillean subspecies (Raffaele 1989, Goodrich *et al.* 1996).

The current known range of the Broad-winged Hawk in Puerto Rico is largely limited to public lands (Delannoy & Tossas 2000). At present, no available information exists on home range and movement patterns, habitat use, and juvenile dispersal for any subspecies of Broad-winged Hawk in the Caribbean region. This information is important for conservation and management of the Broad-winged Hawk in Puerto Rico. Here we report

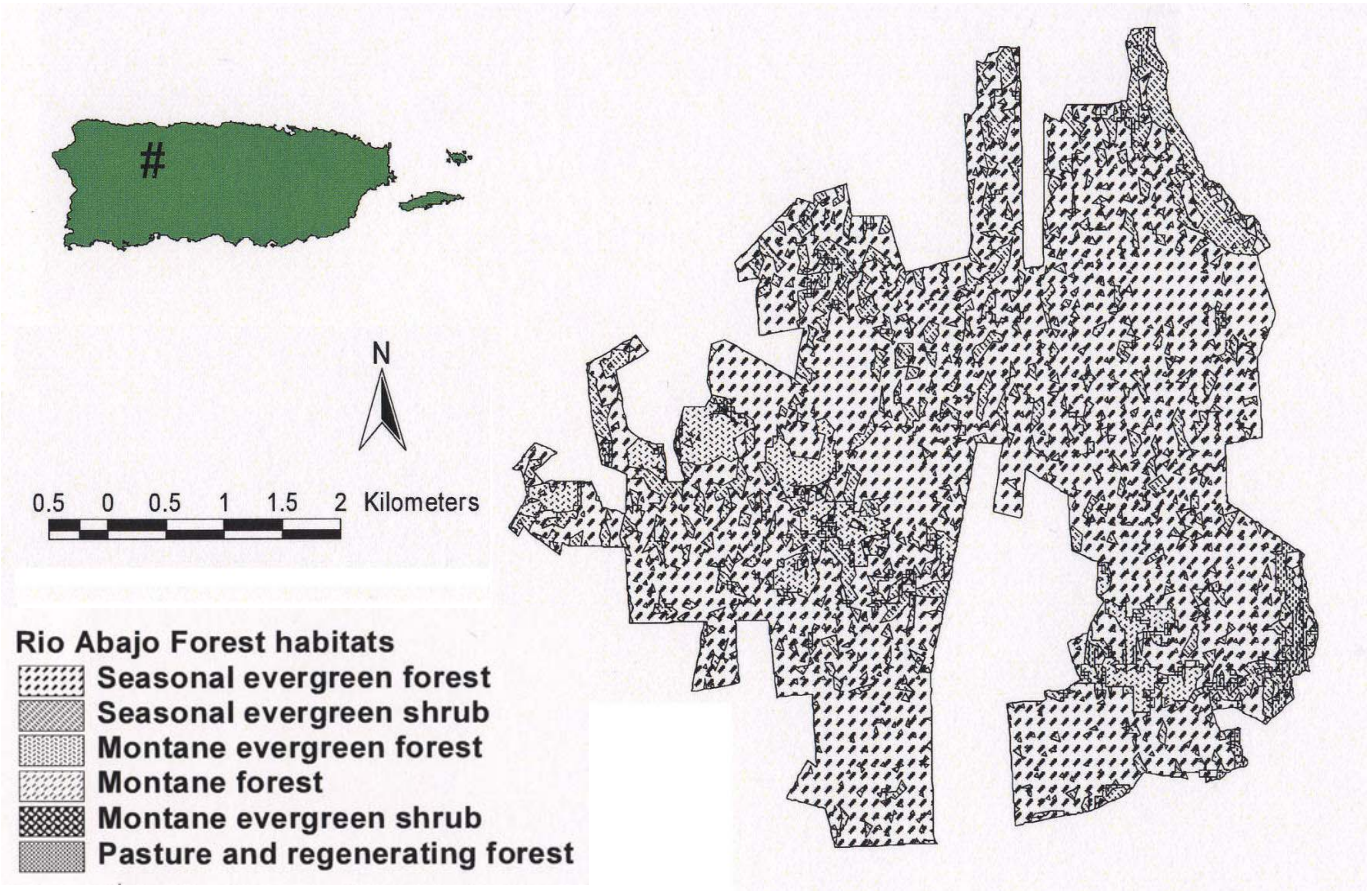

FIG. 1. Habitat associations of Rio Abajo Forest, Puerto Rico (landcover classes modified from Helmer *et al.* 2002).

Broad-winged Hawk annual and seasonal home ranges, movements, and juvenile dispersal. Additionally, we report broadwing macrohabitat use patterns and discuss the relevance of our findings to the conservation of this endemic subspecies and its forest habitats in a forest reserve and surrounding private lands.

METHODS

Study area. We studied the Broad-winged Hawk in north-central Puerto Rico. We conducted our research in the Rio Abajo Forest (18˚20'N, 66˚42'W) managed by the Department of Natural and Environmental Resources' Forestry Division and surrounding private lands within the moist limestone region of the island (Ewel & Whitmore 1973). The rugged limestone region or karst of Puerto Rico encompasses of 27.5% of the island's surface and contains the largest tree species richness on the island (Lugo *et al.* 2001). We selected Rio Abajo Forest because broadwings were known to be relatively abundant in this area compared to other known localities on the island (Delannoy 1997). The Rio Abajo Forest encompasses an area of 2300 ha with elevations ranging from 200 to 420 m, and is characterized by six habitat associations of mature secondary forest (Fig. 1). Tree species such as moca (*Andira inermis*), capá prieto (*Cordia alliodora*), and guaraguao (*Guarea guidonia*) dominate the overstory of deep valleys and narrow sinkholes. Timber plantations (30–50 years old) of Honduras mahogany (*Swietenia macrophylla*), maría (*Calophyllum brasiliensis*), teca (*Tectona grandis*) and mahoe (*Hibiscus elatus*) were found along wider valley bottoms and mid-slopes in areas of montane evergreen forest (Cardona *et al.* 1987).

The topography of Rio Abajo Forest is dominated by karst formations characterized by subterranean drainages, caves, dome shaped hills or "mogotes", and deep sinkholes. Two dry seasons occurs at Rio Abajo, one from January to March and the other from July through September (Ewel & Whitmore 1973). The closest National Oceanic and Atmospheric Administration (NOAA) weather station to our study site recorded precipitation of 210.7 cm in 2001 and 195.9 cm in 2002, and mean temperature of 24.1˚C in 2001 and 24.3˚C in 2002.

Trapping and tadiotelemetry. We trapped, radiotagged, and tracked Broad-winged Hawks from May 2001 through December 2002. Past studies had banded chicks at the nest and no trapping was involved (Delannoy 1997). We used a combination of trapping techniques to maximize our opportunities for captures. We used octagonal and quonset style bal-chatri traps (Berger & Mueller 1959, Erickson & Hoppe 1979), a modified dho-gaza net (Hamerstrom 1963, Clark 1981, Hengstenberg 2003) with a live Red-tailed Hawk (*Buteo jamaicensis*), and a pigeon with a noose harness. Active nest trees were climbed when the nestlings were approximately 28–30 days old and nestlings gathered from the nest. Each adult and juvenile broadwing was weighed and aged. To minimize handling time, we did not determine gender of nestlings. To determine gender, we collected approximately ± 5 µl of blood from the brachyal vein of the left wing of every captured individual and used DNA typing. We recorded the following standard morphological measurements (Vekasy *et al.* 2002) for birds of prey: natural wing chord (cm), tail length (cm), wingspan (cm), weight (g), culmen length (mm), culmen depth (mm), lateral tarsus (mm), tarsometatarsus length (mm), tarsus width (mm), hallux claw length (mm), 1st toe (mm), 2nd toe (mm), and 3rd toe (mm). Each Broad-winged Hawk was banded with a color-coded leg band on the left leg and a USGS Bird Banding Laboratory band on the right leg.

Birds were fitted with a 14.7 g backpack mounted radiotransmitter (Holohil Systems, Model RI-2CP) with a unique frequency (164–165 MHz) attached via a break-away backpack harness constructed from 6.35 mm wide tubular Teflon ribbon and a leather keel plate (Vekasy *et al.* 1996). Transmitter weight never exceeded 5% of a Broad-winged Hawk's total weight. Transmitters were equipped with an activity switch that produced a slower pulse rate (0.52–0.85 pulses/sec) when positioned vertically (perched bird) and a faster pulse rate (0.74–1.2 pulses/sec) when in a horizontal position (flight, feeding, preening, and incubation). A minimum convex polygon (MCP) was created for the trap sites to determine the distributional area (ha) of broadwing captures. Observer error was evaluated by placing transmitters on limestone hills and sinkholes. Project personnel took compass bearings to known transmitter locations recorded with a Global Positioning System (GPS). Bearings collected by project personnel were compared to known transmitter bearings to determine observer error. Telemetry error was further minimized by relying more on homing techniques to locate radiomarked Broad-winged Hawks than triangulation.

Radio-tagged Broad-winged Hawks were located using a Telonics TR-5 MHz receiver, a RA-14K flexible antenna, a 3-element handheld Yaggi antenna, and a vehicle-mounted omni-directional antenna. After locating a radio-tagged hawk we did not relocate it again for ≥ 1 h (Andersen & Rongstad 1989) to minimize serial correlation between successive locations (White & Garrot 1990). We visually located all birds on a weekly basis and, whenever possible, we avoided using triangulations due to the extreme topography of the area. In one instance when a bird could not be located from the ground, a fixed-wing aircraft was used to obtain telemetry locations. For each sighting, we recorded UTM coordinates of the telemetry station or the location of the bird using a hand-held GPS unit. We used rangefinders, binoculars, and a compass to obtain a vertical distance and azimuth to the bird from a known location. When birds were observed perched, we recorded tree species and perch height. Angular bearings, distances, and GPS coordinates of telemetry stations were used to calculate UTM coordinates of every Broad-winged Hawk location (White & Garrott 1990). Generated UTM locations were compared to estimated locations plotted in the field to confirm these were correctly calculated.

Home range, core areas, and weekly movements. We developed 95% fixed kernel home range and core area (50% of all telemetry locations) estimates with the least squares cross validation smoothing parameter (Worton 1989) using the Animal Movement extension (Hooge *et al.* 1999) in ArcView 3.2. To delineate seasonal home ranges, we established January to July as the breeding season based on Broad-winged Hawk nesting phenology in the moist karst forest of Puerto Rico (Hengstenberg & Vilella 2005), and the remainder of the year as the nonbreeding season. Average weekly movements were generated by creating polylines from point file features using the movement extension in ArcView 3.2 (Hooge *et al.* 1999). Two adult nesting males (5052 and 5202) were monitored during the 2001 and 2002 breeding season using direct observation and radiotelemetry. We calculated mean and maximum distance traveled by the adult males from their respective nest sites for the 2001 and 2002 breeding seasons using the calculate distance feature of the movement extension (Hooge *et al.* 1999). We also calculated dispersal distances for two juvenile Broad-winged Hawks from their respective nests.

In addition to trapping and radiotelemetry, we delineated territories of other unmarked Broad-winged Hawk pairs using spot map-

ping by direct observation from limestone hilltops. We made weekly observations from various lookout points and aggregated all locations per broadwing pair. From these locations, we created 95% and 50% fixed kernel home range estimates for eight mapped pairs.

Analysis. We tested distribution of home range and movement data for normality using a Kolmogorov-Smirnov Goodness-of-Fit Test (Sheskin 2000). Because variables were normally distributed, we used two sample t-tests to evaluate if annual home range, core area, and weekly movements differed between adults and juveniles (Snedecor & Cochran 1980).

The degree of home range overlap of radio-tagged Broad-winged Hawks was compared using the static interaction analysis in the Animal Movements ArcView 3.2 extension (Hooge *et al.*1999). Static interaction measures the degree of spatial overlap throughout a time interval of interest without considering whether two animals use the same space simultaneously or at different times (Kernohan *et al.* 2001). For the static interaction, telemetry locations must be collected at regular independent intervals during each animal's activity period (Doncaster 1990). Static interaction analysis examines the similarity in location of high-use areas, and is not affected by sample size or differences in the spatial frame of reference (Kernohan *et al.* 2001). The static interaction analysis generates 400 Monte Carlo simulations and compares the kernel probability surfaces to randomly generated surfaces in each home range and area of overlap (Doncaster 1990). A Spearman rank correlation is used to test the null hypothesis that utilization distributions are not associated. Results indicating a positive correlation implied similar utilizations (attraction) and negative correlation separate utilizations (avoidance).

All home ranges of radio-tagged birds were clipped to an available digital landcover of Puerto Rico (Helmer *et al.* 2002). We modified vegetation classifications in Helmer *et al.* (2002) for our study area into more concise habitat associations. From the landcover we were able to calculate the area used (ha) of each habitat association within each Broad-winged Hawk home range. The digital landcover was compared to color aerial photos to verify whether habitat associations were correctly classified. We used a Chi-square Goodness-of-Fit test to examine BHWA habitat use patterns (Neu *et al.* 1974). To meet analysis assumptions, we grouped geographically contiguous habitat associations where broadwings seldom occurred yet represented a small portion of available habitat, to reduce the number of habitat associations with five or fewer expected observations (Neu *et al.* 1974). Due to our small sample size of radio-tagged hawks and the number of habitat associations we used a Chi-square as the most appropriate test for our habitat use analysis (Alldredge & Ratti 1986). If Broad-winged Hawks exhibited disproportionate use of habitat, we created Bonferroni confidence intervals from the z-statistic (Sheskin 2000) to test whether a particular habitat association was used more than expected (selection), used less than expected (avoidance), or used in equal proportion (Neu *et al.* 1974, Byers *et al.* 1984). We used a Type I error probability of 5% ($\alpha = 0.05$) for hypothesis testing.

RESULTS

We trapped eight Broad-winged Hawks during January 2001 and July 2002 within the Rio Abajo Forest. A total of 1400 person-h were required to obtain this relatively small sample of broadwings. In 2001, we captured three paired adult males within 75 m of their nest sites using a pigeon noose harness, a bal-chatri baited with domestic chickens and a

TABLE 1. Morphological measurements and associated mean ± SE (range) of adult (n = 4) and juvenile (n = 4) Broad-winged Hawks captured during 2001 and 2002 in Rio Abajo Forest, Puerto Rico.

Morphological characteristics	Adult	Juvenile
Weight (g)	363.4 ± 28.5 (291–425)	369.9 ± 30.9 (299–448.5)
Wing chord (cm)	28.6 ± 1.0 (27–32.5)	20.9 ± 2.2 (18–27.5)
Tail length (cm)	14.8 ± 0.3 (14.1–15.9)	10.7 ± 1.9 (6.6–15.6)
Wingspan (cm)	81.6 ± 3.5 (68.6–87.9)	69.1 ± 3.8 (61–79.4)
Culmen length (mm)	19.3 ± 0.1 (19–19.8)	18.3 ± 0.7 (16.8–20.2)
Culmen depth (mm)	15.1 ± 0.0 (15–15.1)	n/a
Tarsus width (mm)	9.0 ± 0.4 (8–10)	8.0 ± 0.2 (7.4–8.4)
Tarsometatarsus length (mm)	68.2 ± 2.7 (60.5–74.2)	64.4 ± 1.3 (62.2–68.2)
Lateral tarsus (mm)	6.5 ± 0.3 (6.2–6.7)	n/a
Hallux claw length (mm)	20.0 ± 0.5 (18.4–21.2)	18.0 ± 0.7 (16.9–20.1)
1st toe (mm)	19.5 ± 0.1 (19.4–19.6)	n/a
2nd toe (mm)	16.5 ± 0.3 (16.2–16.8)	n/a
3rd toe (mm)	13.2 ± 0.1 (13.1–13.2)	n/a

TABLE 2. Age, sex, date released, number of locations, home range sizes, weekly movements, and number of days monitored of Broad-winged Hawks radio-marked in Rio Abajo Forest, Puerto Rico during 2001–2002.

Bird ID	Age	Sex	Date released	Home range size (ha)	Core area (ha)	Weekly movement (m)	Number of locations	Days monitored
5202	Adult	Male	4-11-01	110.2	7.7	4097.9	180	463
5052	Adult	Male	5-2-01	62.6	10.6	2078.0	274	254
5167	Juvenile	Unknown	5-9-01	90.1	8.5	2374.5	62	74
5123	Juvenile	Unknown	5-14-01	224.3	25.5	3373.9	149	195
5166	Juvenile	Unknown	10-24-01	45.8	7.6	2610.0	158	464
5520	Adult	Female	5-2-02	417.4	69.7	4425.0	61	159

dho-gaza net with a live Red-tailed Hawk. Three juvenile Broad-winged Hawks were caught by hand from their nests during May 2001. One six-month-old juvenile female was trapped using a bal-chatri baited with domestic chickens. In 2002, we recaptured an adult male and replaced the radiotransmitter. On 2 May 2002, we captured the only paired adult female of the study using an octagonal bal-chatri baited with a gerbil. Although we included the Rio Abajo Forest and surrounding areas in our sampling, our overall trapping efficiency was low (175 person-hours per broadwing) and captures were distributed within a relatively small area (140 ha).

Morphological measurements of captured Broad-winged Hawks (Table 1) indicate that at time of capture, juveniles were slightly heavier than adults, though wing chord and other measurements were greater for adults. The overall processing time of all birds, from capture to release, was ≤ 60 minutes. All birds resumed normal activities shortly after release, and no problems associated with the backpack transmitter were detected. The estimated life span of the transmitters was 24 months. However, the mean lifespan of transmitters

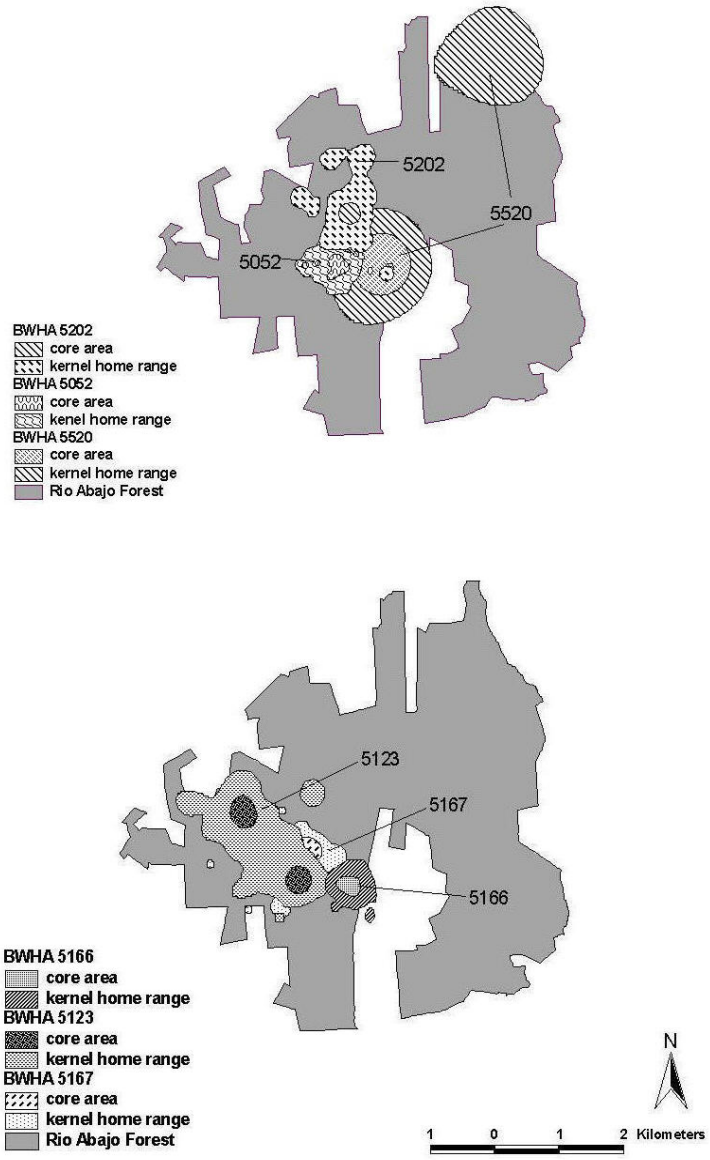

FIG. 2. Fixed kernel home range and core area of 3 adult (above) and 3 juvenile (below) Broad-winged hawks at Rio Abajo Forest, Puerto Rico 2001–2002.

deployed was 218 days (range 31–464 days). The standard deviation of our radiotelemetry angular error was ± 2°. Unfortunately, the radiotransmitter of two Broad-winged Hawks (adult male and juvenile) failed shortly after release. We confirmed radiotransmitter failure by resighting marked birds and verifying color bands.

TABLE 3. Mean annual home range (ha), core area size (ha), weekly movements (m), range and SE for adult, juvenile, breeding season, nonbreeding season, and pooled estimate for Broad-winged Hawks radio-marked in Rio Abajo Forest, Puerto Rico, 2001–2002.

Group	N	Mean home range (ha)	SE	Mean core area size (range)	SE	Mean weekly movements	SE
Adult	2	86.4 (62.6–110.2)	23.80	9.15 (7.7–10.6)	1.45	3087.5	1009.50
Juvenile	3	120.1 (45.8–224.3)	52.66	13.9 (7.6–25.6)	5.86	2786.1	301.64
Breeding	2	82.5 (53.6–133.1)	17.42	7.5 (4.0–12.7)	1.87	3107.8	595.78
Nonbreeding	2	126.3 (73.8–178.9)	52.57	16.2 (11.8–20.6)	4.40	3098.5	892.6
Pooled	5	106.6 (45.8–224.3)	31.44	12.0 (7.6–25.6	3.44	2906.8	367.09

Home range size, core area size, mean weekly movements, number of telemetry locations, and total days monitored were estimated for six Broad-winged Hawks captured during 2001 and 2002 (Table 2). The adult female exhibited the largest home range (417.4 ha), core area (69.7 ha), and mean weekly movement (4425 m) of all radio-tagged Broad-winged Hawks. The female home range was divided into a nesting territory and a disjunct nonbreeding area where she was last located (Fig. 2). Home range size of Broad-winged Hawks in Rio Abajo Forest (Table 3) averaged 106.6 ha (SE = 31.4, range 45.8–224.3 ha), core area 12.0 ha (SE = 3.4, range 7.6–25.6 ha), and weekly movement averaged 2906.8 m (SE = 367.1, range 2078.0–4097.9 m). Home range and core areas of juveniles were greater than adults. However, adults exhibited greater weekly movements than juveniles. Also, while the home range of adult male Broad-winged Hawks was smaller during the breeding season, they exhibited greater weekly movements, likely related to prey provisioning activities (Table 3). Home range size ($t = -0.471$, $df = 3$, $P = 0.670$), core area size ($t = -0.622$, $df = 3$, $P = 0.578$), and mean weekly movements ($t = 0.356$, $df = 3$, $P = 0.746$) did not differ between adult and juvenile Broad-winged Hawks.

Nest sites of adult Broad-winged Hawks were located within their core area (Fig. 2). The mean 2001 breeding season home range was 71.6 ha (range 69.7–73.5 ha, SE = 1.9), core area averaged 6.6 ha (range 5.9–7.2 ha, SE = 0.7), and weekly movements averaged 2612.5 m (range 2078.1–3146.8 m, SE = 534.3). The mean distance traveled for both adult male Broad-winged Hawks from their nest sites in 2001 was 217.7 m (208.4–227.1 m) and maximum distances traveled averaged 798.6 m (643.7–953.5 m). Nonbreeding season home range averaged 126.3 ha (range 73.8–178.9 ha, SE = 52.6), mean core area was 16.2 ha (range 11.8–20.6 ha, SE = 4.4), and weekly movement averaged 3098.5 m (range 2205.9–3991.1 m, SE = 892.6). The 2002 breeding season home range averaged 93.5 ha (range 53.6–79.5 ha, SE = 39.8), core area 8.4 ha (range 4.0–12.7 ha, SE = 4.4), and weekly movement averaged 3603.1 m (range 2439.7–4766.5 m, SE = 1163.4). The mean distance moved by both adult male Broad-winged Hawks from their nest sites in 2002 was 187.4 m (118.3–256.5 m), and maximum movements averaged 743.2 m (range 436.4–1050 m). Adult male Broad-winged Hawk 5052 had a nonbreeding home range of 14.1 ha, core area of 2.0 ha, and mean weekly movement of 1305.6 m.

The territories of eight unmarked broad-wing pairs were mapped during 2001 and 2002 from limestone hilltops and fixed kernel home range estimates developed for each pair. The home range of unmarked pairs averaged

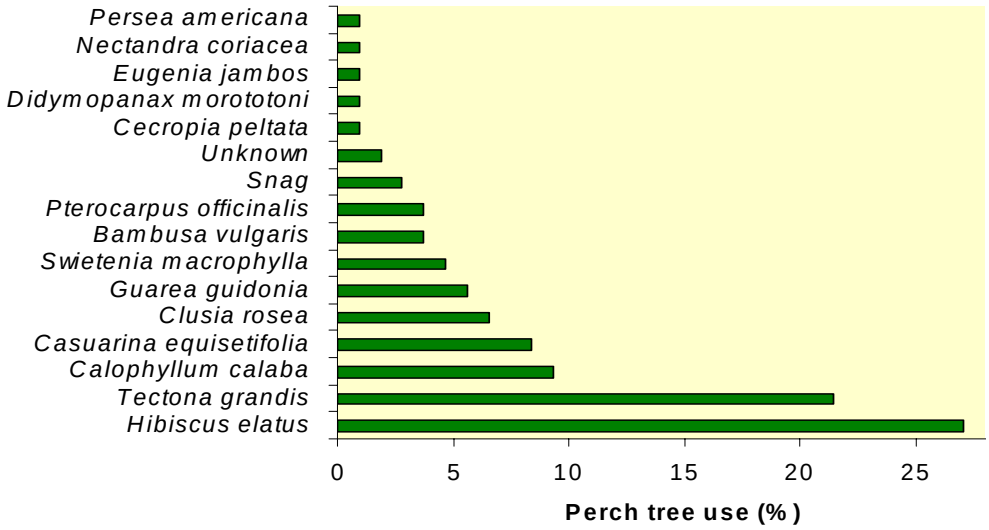

FIG. 3. Perch tree species and percent use by radio-marked Broad-winged Hawks in and around Rio Abajo Forest, Puerto Rico 2001–2002.

74.3 ha (SE = 12.2, range 30.9–129.6 ha) and core area 7.6 ha (SE = 0.8, range 3.6–12.0 ha).

We estimated hatch year (HY, year 1) and after hatch year (AHY, year 2) home ranges for juvenile Broad-winged Hawk 5166 (Fig. 2). Hatch year home range was 77.0 ha, core area size of 14.0 ha and average weekly movement 3251.8 m. During year 2 (AHY), this juvenile reduced its home range to 35.6 ha, core area to 5.1 ha, and average weekly movement of 1968.2 m. We quantified dispersal of juvenile hawks (5123 and 5167) trapped by hand at the nest. Juveniles were radio-tagged from separate nests at 34 and 30 days during May 2001. Postfledgling dispersal distances from their nests were as follows: > 100 m (broadwing 5123 at 56 days and broadwing 5167 at 43 days), > 500 m (broadwing 5123 at 65 days and broadwing 5167 at 74 days), and > 1000 m (broadwing 5123 at 92 days and broadwing 5167 at 82 days). The greatest distance moved by juvenile broadwing 5167 from the nest was 1558m at 95 days of age. Juvenile broadwing 5167 was found dead at 99 days, approximately 300 m from its nest site. The cause of death was attributed to depredation by an adult Red-tailed Hawk. The greatest distance traveled from its nest site by juvenile 5123 was 2976 m at 161 days of age. The last location obtained for juvenile 5123 was 1109 m from the nest at 216 days.

Static interaction analysis indicated the movements of juvenile Broad-winged Hawks 5123 and 5166 were positively associated (r_s = 49.5, df = 30, $P < 0.05$). The area of home range overlap between these individuals occurred on the central sections of Rio Abajo Forest (Fig. 2). Moreover, there was a strong positive movement association (r_s = 34.65, df = 30, $P < 0.0001$) between adult 5052 and juvenile 5167 (offspring of 5052). Conversely, the movements of breeding adult males 5202 and 5052 were negatively correlated (r_s = -3.96, df = 30, $P < 0.05$). We recorded 107 perch tree locations from radio-tagged hawks. Broadwings were perched in 16 different tree species at an average height of 10.4 m (SE = 0.5428, 3–32 m). Tree species most frequently

TABLE 4. Habitats analysis for six radiomarked Broad-winged Hawks in the Rio Abajo Forest, Puerto Rico.

Habitat association	Observed use	Expected use	*Use interval 95% Bonferroni intervals
Seasonal evergreen shrub	0.21	0.56	0.18–0.25 (–)
Seasonal evergreen forest	0.50	0.24	0.46–0.54 (+)
Montane evergreen forest	0.05	0.13	0.03–0.07 (–)
Montane forest	0.03	0.01	0.02–0.05 (+)
Montane evergreen shrub	0.09	0.03	0.07–0.11 (+)
Pasture and regenerating forest	0.12	0.04	0.09–0.14 (+)

*Probability of disproportional use $P = 0.05$. (+) = used more than expected, (0) = used as expected, and (–) = used less than expected (Byers *et al.* 1984).

used as perches were *Hibiscus elatus* and *Tectona grandis* (Fig. 3). Radio-tagged Broad-winged Hawks exhibited disproportional use of habitat at Rio Abajo Forest ($\chi^2 = 805.89$, df = 6, $P < 0.001$). Broad-winged Hawks selected 4 of 6 available habitat associations (Table 4). These included; 1) seasonal evergreen forest, 2) montane forest, 3) montane evergreen shrub, and, 4) pasture and regenerating forest. Conversely, broadwings avoided seasonal evergreen shrub and montane evergreen forest.

DISCUSSION

The Broad-winged Hawk was a difficult raptor to trap, requiring an average effort of 175 person-h per capture. However, all individuals were captured within a relatively small area (140 ha). Based upon our experience the balchatri was the most effective trap used. However, we believe the dho-gaza net baited with a live Red-tailed Hawk could be just as effective, provided the trap is placed ≤ 100 m from an active broadwing nest. A loud Red-tailed Hawk recording should be broadcasted directly behind the dho-gaza net. However, we recommend this trap should only be used after nestlings have hatched to avoid abandonment by the adults, because raptors have been reported to be sensitive to disturbance during the nesting period (Reynolds *et al.* 1992). We had low success with the dho-gaza net which we attribute to disturbance caused by vehicle traffic through the trapping area and prolonged set-up time. Nevertheless, Broad-winged Hawks responded to the dho-gaza net by vocalizing and frequently swooping down at the lure Red-tailed Hawk. In one instance, a Broad-winged Hawk flew into the net but freed itself before capture.

Body measurements of captured Broad-winged Hawks confirmed the subspecies of Puerto Rico is smaller than North American conspecifics. The Broad-winged Hawk has been reported to exhibit moderate sexual size dimorphism. Given our small sample of sexed birds in our study we avoided comparison of body sizes between females and males. The wingspan of North American Broad-winged Hawks ranges from 81–100 cm compared to 61–88 cm for hawks of Rio Abajo Forest. Similarly, body mass of Broad-winged Hawks in North America ranges from 265–560 g compared to 291–449 g for birds captured at Rio Abajo Forest (Goodrich *et al.* 1996)

Our results suggest the Broad-winged Hawk in Puerto Rico has reduced space requirements compared with the continental form. Average annual home range of Broad-winged Hawks in our sample was 106.6 ha, with a breeding season home range of 82.5 ha.

In Minnesota and Wisconsin, Keran (1978) reported a Broad-winged Hawk nesting pair density of 1 pair per 320 ha. Previous work on the Broad-winged Hawk in Puerto Rico estimated an average nesting territory size of 39.5 ha, ranging from 22.1–76.9 ha (Tossas 1995, Delannoy & Tossas 2000). However, this information was limited to mapping Broad-winged Hawks during one breeding season and is likely a conservative estimate. Our estimates of breeding season home range for radio-tagged Broad-winged Hawks was more than double what Delannoy & Tossas (2000) reported, which we attribute to the benefits of radiotelemetry. However, average home range of unmarked Broad-winged Hawk pairs determined by spot mapping (74.3 ha) was similar to the highest estimate reported by Delannoy & Tossas (2000), yet considerably smaller than estimates obtained from radiotelemetry. Radiotelemetry generates more precise home range estimates compared to visual estimation techniques (i.e., spot mapping) because individual birds can be tracked and observed continuously below or above the canopy over extended periods of time (White & Garrott 1990). Furthermore, spot mapping in moist limestone forests may be particularly biased by extreme topography in addition to Broad-winged Hawk behavior, observer location, weather, and time of year.

The home ranges of the Broad-winged Hawk in Rio Abajo Forest during the breeding season were greater than the breeding season home range (57.8 ha) of the Ridgway's Hawk (*Buteo ridgwayi*) in the moist limestone forests of the Dominican Republic (Wiley & Wiley 1981). However, it should be noted that home range estimates for the Ridgway's Hawk were derived from spot maps constructed for three breeding pairs so these may underestimate actual home range size for the species. However, breeding season home range estimates for the Ridgway's Hawk were more similar to Broad-winged Hawk estimates obtained by spot-mapping.

Adult Broad-winged Hawks at Rio Abajo Forest maintained and defended small core areas year round (Fig. 2). However, while their breeding season home range sizes were smaller than annual home ranges, weekly movements were greater during the breeding season than year round. During the breeding season Broad-winged Hawks were very active and engaged in reproductive behaviors such as nest defense, prey deliveries, and nest maintenance (Hengstenberg & Vilella 2005). This may explain why breeding season home range and core area size were smaller while average weekly movements were larger. For the two adult males tracked during the breeding season, both core areas were situated around the nest site and most movements were recorded within an 8.4 ha area of their nest site. Across breeding seasons both adult males restricted their movements to within 250 m of their nest sites. This distance may reflect the space required to maintain communication by a Broad-winged Hawk pair while engaged in other activities away from the nest, such as hunting and territorial defense. Whereas we obtained a sufficient number of locations for the single female captured, we did not consider her representative of the larger sample of radio-tagged Broad-winged Hawks due to her larger and more disjointed home range (Fig. 2). However, it should be noted the observed home range and movements of this individual may actually be representative of female Broad-winged Hawks in Puerto Rico. Therefore, additional adult females need to be captured and radio-tagged to verify our observations.

Adult Broad-winged Hawks in the moist karst region maintained relatively exclusive territories and core areas did not overlap. The area of overlap was limited to the outside borders of their respective home range during the breeding and non-breeding season. Areas of

overlap were usually limestone hill ridges bounding the exterior of Broad-winged Hawk territories. Conversely, a significant amount of overlap occurred in two of three juvenile home ranges and all juvenile home ranges overlapped with adult home ranges. As expected, the home range of adult 5052 and his offspring 5167 exhibited a positive association. Both their respective home ranges and core areas overlapped. This reflects adult tolerance of offspring following fledging, during the postfledging dependency period, and into the nonbreeding season.

The observed reduced space requirements of the Broad-winged Hawk in Puerto Rico may be a function of adaptation to insular environments (Storz 2005). Additionally, environmental features (topography) and ecological components (prey abundance and population density) may influence use of space by Broad-winged Hawks in Puerto Rico. Karst topography adds much relief to the landscape, creating areas between limestone hills that may harbor high concentrations of prey. Several studies have suggested high number of available prey may result in territory compression and greater densities of individuals (Tubbs 1974, Bednarz & Dinsmore 1981, Titus & Mosher 1981, Village 1982, Janes 1985, Marzluff *et al.* 1997, Boal &Mannan 1998, Peery 2000). Newton (1986) reported Sparrowhawks (*Accipiter nisus*) in Scotland became sedentary when prey were abundant and ranged widely when prey became scarce.

Breeding season home range size for Broad-winged Hawks in the moist karst region of Puerto Rico were similar to those reported for other *Buteo* species in temperate regions (Reynolds *et al.* 1992, Walls *et al.* 1999). Janes (1985) reported home range of Red-tailed Hawks ranged from 218 ha to 308 ha in North America. Dykstra *et al.* (2001) reported a home range of 165 ha for the Red-shouldered Hawk (*Buteo lineatus*). Paired Red-tailed Hawk breeding season home range estimates in North America ranged from 390 ha to 1890 ha (Andersen & Rongstad 1989, Petersen 1979, Smith *et al.* 2003). However, wintering areas of North American Broad-winged Hawks determined from satellite telemetry ranged from 1000 to 4300 ha (Haines *et al.* 2003).

Our results indicated the Broad-winged Hawk used four habitat associations more than expected in moist karst forests of Puerto Rico. Habitat associations used by the Broad-winged Hawk in the Rio Abajo Forest (seasonal evergreen forest, montane forest, montane evergreen shrub, pasture and regenerating forest) may offer greater abundance of prey, suitable nesting areas, and protection from predators, than other available habitats. The common feature of habitats selected by Broad-winged Hawks was the occurrence of closed canopy forest. In Puerto Rico, the presence of continuous closed canopy forests may represent the principal structural feature describing BWHA habitat suitability at a landscape scale. Nevertheless, while pasture and regenerating forest lack a closed canopy, these habitats may offer areas where Broad-winged Hawks can readily locate prey. At Rio Abajo Forest, areas of pasture and early successional forest were generally small in size and in close proximity to closed canopy forest. Radiotagged Broad-winged Hawks using these habitats were seen perched on the edge of closed canopy forest. Unlike adults, juvenile Broad-winged Hawks avoided the submontane evergreen forest. In this forest association, prey may be more difficult to capture for inexperienced juvenile hawks. Regardless of age or gender, Broad-winged Hawks used both mature secondary forest and timber plantations.

The vast majority (97%) of Broad-winged Hawk locations were confined to the boundaries of the Rio Abajo Forest. Radio-tagged adults used private lands ≤ 1% of the time,

whereas juvenile birds used private lands 6% of the time. This may suggest adults are able to secure the most suitable tracts of continuous, closed canopy forest but juvenile birds use areas on the periphery of the forest. However, openings may be preferred by juveniles to improve development of hunting abilities. Because the Broad-winged Hawk is primarily a perch hunter, use of fragmented areas may be limited by perch availability (Bloom *et al.* 1993). Nevertheless, available information on spot mapping and raptor surveys (Hengstenberg & Vilella 2004) indicated Broad-winged Hawks were frequently observed outside the forest boundaries. We identified three areas of particular importance to Broad-winged Hawks on the periphery of Rio Abajo Forest in the north-east, north-west, and south-central portions of the reserve (Fig. 1). Broad-winged Hawk pairs were observed engaged in courtship and territory display behaviors in privately owned lands during 2001 and 2002. These private lands comprised 693 ha of mostly closed-canopy forest and should be considered high priority areas for protection or acquisition. Protection of Broad-winged Hawk habitat in private lands surrounding Rio Abajo Forest will require cooperation between government agencies and landowners.

Radio-tagged juvenile Broad-winged Hawks at Rio Abajo Forest exhibited restricted dispersal from natal areas. Dispersal distance is believed to be related to territory size in birds (Bowman 2003). The greatest distance we detected a juvenile from its nest was 2976 m (BWHA 5123) at 161 days of age. This contrasts greatly with juvenile Broad-winged Hawks in North America. By the time continental Broad-winged Hawks are five months of age they have moved several thousand kilometers from their natal areas on their southward migration to wintering areas in the Neotropics (Goodrich *et al.* 1996, Haines *et al.* 2003).

Plant and animal forms (waif biotas) established via long-distance dispersal are found in many tropical islands (Carlquist 1974). Additionally, the dispersal ability of birds is subject to natural selection and appears to decrease with latitude (Diamond 1985). The concept of migration dosing has been presented as a model for island colonization by raptors whereby migrating individuals of continental forms may end up in areas geographically isolated from traditional wintering grounds (Bildstein 2004). Provided a sufficient number of displaced individuals arrive on an isolated site (i.e., Caribbean island), become settled, and reproduce, this can result in the development of locally adapted populations and may eventually culminate in the formation of new species (Storz 2005). Inexperienced juveniles may constitute the main source of arriving individuals, as they often migrate together and are known to be vulnerable to wind drift (Bildstein 2004).

In the case of the Caribbean Broad-winged Hawk endemic subspecies, it has been proposed island populations may either be dosed too frequently by continental forms to allow formation of separate species, or isolation has occurred too recently for speciation to occur (Bildstein 2004). Based on our limited observations, we suggest selective pressures on insular Broad-winged Hawk populations in Puerto Rico have resulted in behavioral patterns that preclude long-distance dispersal. Long-distance dispersal of insular forest raptors may result in juveniles lost at sea and unable to return to their native islands and natal areas. However, additional research is required on the endemic forest raptors of the insular Caribbean to verify the sedentary nature of these local forms, investigate juvenile dispersal mechanisms, and determine the role of migration dosing in the biogeography of Caribbean birds of prey.

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