



## EFFICACY OF MIGRATION COUNTS FOR MONITORING CONTINENTAL POPULATIONS OF RAPTORS: AN EXAMPLE USING THE OSPREY (*PANDION HALIAETUS*)

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**ABSTRACT.**—Recent research has confirmed the efficacy of migration monitoring to estimate trends in the populations of raptors sampled at traditional watch-sites. We used autumn satellite tracks of 57 adult Ospreys (*Pandion haliaetus*) captured on the breeding range in North America between 1995 and 2000 to assess the extent to which migration monitoring sampled their populations. We used (1) 3-km-wide and 6-km-wide linear trajectories (migration paths) that connected locations with straight lines and (2) utilization distributions derived from Brownian bridge movement models to estimate the proportions of Ospreys likely to have been detected by watch-sites and watch-sites likely to have detected tagged birds, and to describe the geography of southward migration between North America and South America. The migration path method estimated continental detection rates of 12–23%, with regional maxima of 21–36% in eastern North America. This analysis indicated that 8–20% of all watch-sites could have detected  $\geq 1$  of the satellite-tracked Ospreys. The Brownian bridge method estimated that 95% of the utilization distributions of migrating Ospreys in North America intersected  $\geq 1$  watch-site and that 89% of all watch-sites intersected  $\geq 1$  utilization distribution. Using this method, regional probabilities of detection (mean  $\pm$  SD) for individuals were estimated to be  $33.8 \pm 28.8\%$  in eastern,  $5.8 \pm 6.6\%$  in midwestern, and  $4.7 \pm 4.9\%$  in northwestern (Pacific coast) North America. Migrating Ospreys appear to concentrate along well-defined, narrow fronts and to use land bridges where available, rather than travel along broad fronts and engage in large water crossings during autumn migration. Received 25 August 2009, accepted 19 April 2010.

Key words: Brownian-bridge analysis, migration, migration behavior, Osprey, *Pandion haliaetus*, populations, raptors, sampling techniques, satellite telemetry.

### Eficacia de los Conteos Migratorios para el Monitoreo de Poblaciones Continentales de Aves Rapaces: un Ejemplo Basado en *Pandion haliaetus*

**RESUMEN.**—Algunos estudios recientes han confirmado la eficacia de los monitoreos migratorios para estimar las tendencias poblacionales de aves rapaces muestreadas en sitios tradicionales de observación. Usamos registros satelitales de 57 individuos adultos de *Pandion haliaetus* capturados en su área de distribución reproductiva en América del Norte entre 1995 y 2000 para determinar el grado al que el monitoreo migratorio muestreó sus poblaciones. Usamos (1) trayectorias lineales de 3 km y 6 km de ancho (rutas de migración) que conectaban localidades en líneas rectas y (2) distribuciones de utilización derivadas de modelos de movimiento Browniano para estimar la proporción de individuos que fue probablemente detectada en los sitios de observación y la proporción de sitios que detectaron individuos marcados, y para describir la geografía de la migración hacia el sur entre América del Norte y América del Sur. El método de ruta migratoria estimó tasas de detección continentales de 12–23%, con un máximo regional de 21–36% en el este de América del Norte. Este análisis indicó que el 8–20% de todos los sitios de observación podría haber detectado uno o más de los individuos seguidos por satélite. El método basado el modelo Browniano estimó que el 95% de las distribuciones de utilización de los individuos migratorios en América del Norte interceptaron uno o más sitios de observación y que el 89% de todos los sitios de observación interceptaron una o más distribuciones de utilización. Utilizando este método, las probabilidades de detección regionales (media  $\pm$  DE) para individuos fueron estimadas en  $33.8 \pm 28.8\%$  en el este, en  $5.8 \pm 6.6\%$  en el centro-oeste, y en  $4.7 \pm 4.9\%$  en el noroeste (costa Pacífica) de América del Norte. Los individuos migratorios de esta especie parecen concentrarse a lo largo de frentes angostos y bien definidos usando puentes terrestres cuando están disponibles, antes de viajar a lo largo de frentes anchos e involucrarse en cruces de larga distancia sobre agua durante la migración de otoño.

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POPULATIONS OF MOST bird species can be monitored at large geographic scales only by the use of mass-engagement, multi-site counting schemes, such as the Breeding Bird Survey (Sauer et al. 2008) and Christmas Bird Count (National Audubon Society 2002). However, many large, sparse, or inconspicuous species are difficult to count reliably in this way because individuals are encountered so rarely and at so few locations (Fuller and Mosher 1981, 1987; Kirk and Hyslop 1998; Dunn et al. 2005; Farmer et al. 2007). This has led to the quest for alternative large-scale population assessment methods, including monitoring at migration sites (Hussell and Ruelas Inzunza 2008). The notion is that counts at a small number of key sites, involving fewer observers, can capture large-scale trends in populations.

Because of their size, low-level daytime flight, and use of traditional corridor routes, raptors and other soaring birds perhaps lend themselves to migration-based monitoring in a way that other birds do not. Many species are readily counted visually at traditional migration watch-sites situated on major flightlines (Bernis 1975, Titus and Fuller 1990, Dunn and Hussell 1995, Bildstein 1998, Shirihai et al. 2000, Smith and Hoffman 2000, Zalles and Bildstein 2000). This is particularly true in North America, where 33 of 36 raptor species are either partial or complete migrants (Goodrich and Smith 2008).

Recently, several publications have demonstrated the efficacy of migration monitoring using traditional watch-sites to estimate trends in the source populations sampled by these sites (Hoffman and Smith 2003; Farmer et al. 2007, 2008; Bildstein et al. 2008; Smith et al. 2008a, b). Research on other bird population surveys has shown that it is important to document and account for sources of bias in trend estimation (e.g., Sauer et al. 1994, Link and Sauer 1997, Nichols et al. 2000), including variation in the probability of detection. To make the best use of trend estimates from migration monitoring, we need to better understand migration patterns and the relationship between birds detected at watch-sites and their source populations (Farmer and Hussell 2008). To develop this understanding will require that we (1) know which monitored populations (*sensu* Dunn and Hussell 1995) are sampled at each watch-site or combination of watch-sites, (2) estimate detection probabilities at watch-sites, (3) determine what proportion of a monitored population is sampled at each watch-site, and (4) identify migration corridors and changes in these corridors over time (Bildstein et al. 2008).

A requirement shared by these four objectives is an accurate record of the movements of individual raptors from their breeding areas through the period of migration. The recent development of satellite tracking provides the means to generate such records (Meyburg and Fuller 2007). Indeed, many aspects of raptor migration have already been investigated using this technique, including migration routes (e.g., Meyburg et al. 1995, Brodeur et al. 1996, Fuller et al. 1998), responses to topographic and geographic features (Fuller et al. 1998; Meyburg et al. 2002, 2003), migration timing (Schmutz et al. 1996, Kjellén et al. 2001, Meyburg et al. 2004), migration speed and altitude (Hedenström 1997, Kjellén et al. 2001), and the effects of weather on migration (Meyburg et al. 1998; Thorup et al. 2003, 2006). Information on all these aspects was reviewed recently by Newton (2008). Detection probability and its components that are attributable to the effects of species identity, observer ability, and distribution of watch-sites (coverage)

have been investigated in only a few cases (Sattler and Bart 1984, Berthiaume et al. 2009, M. W. Miller et al. unpubl. data).

We used satellite tracking data for Ospreys (*Pandion haliaetus*) migrating in North America to investigate the geography of migration and its relationship to the distribution of migration watch-sites. Our objectives were to (1) estimate coverage probability (i.e., probability of passing within detection range of at least one watch-site) for migrating Ospreys, (2) determine whether Ospreys migrated along a broad front or were concentrated in a way that makes migration monitoring an effective means of estimating population trends, and (3) identify important migration watch-sites for sampling Ospreys from three sectors of their northern breeding range (eastern, midwestern, and northwestern [Pacific coast] North America).

## METHODS

We used autumn migration tracks from 57 adult Ospreys captured on their breeding areas in New England, Florida, Minnesota, and Oregon between 1995 and 2000. Each Osprey was fitted with a 30- to 35-g battery or solar-powered satellite transmitter (PTT; Microwave Telemetry, Columbia, Maryland). Capture and attachment methods, movement patterns, and the timing of movements of these birds were previously described by Martell et al. (2001, 2004). We defined the onset of migration as the date on which each bird began to make daily southward movements without returning to the area of capture. An average ( $\pm$  SE) of  $1.5 \pm 0.20$  relocations per day (range: 0.1–6.0) were collected from the tagged Ospreys. Error (SD) in position estimates was reported by Service Argos as one of six “location classes” (LC): LC3 = <150 m, LC2 = 150–350 m, LC1 = 350–1,000 m, LC0 = >1,000 m, and LCA and LCB = no location accuracy (CLS 2008). Although LCA and LCB have no error estimates, their accuracies are often comparable to LC1 or LC0 (Hays et al. 2001). We used all relocations of LC1–LC3 and filtered relocations of LC0, LCA, and LCB that appeared to be erroneous because they deviated from the general migration route or necessitated an unrealistically high speed of travel from adjacent relocations. Osprey positions based on relocation data were plotted using ARCMAP, version 9 (ESRI, Redlands, California). We analyzed migration trajectories using two complementary methods.

*Migration path buffers.*—This analysis generated migration paths by buffering straight lines between consecutive satellite relocations with widths (“path widths”) of 3.0 and 6.0 km. These widths represented liberal (3.0 km) and conservative (1.5 km) estimates of the distance on either side of an observation point at which migrating Ospreys were likely to be visually detected using 7–10 $\times$  binoculars. For many watch-sites, the 6-km-wide migration path model is probably realistic. For example, under clear skies at Hawk Mountain Sanctuary in Pennsylvania, Ospreys are observable with the naked eye passing behind a landmark 2.9 km from the observation point. With the 7–10 $\times$  magnification binoculars commonly used to detect migrants, Ospreys within a 3-km radius of most watch-sites are therefore likely to have a high probability of detection. Most Ospreys appear to fly within 1 km of ground level (see Kerlinger 1989: table 8.5), and we assumed that no birds were likely to have been excluded by altitude. Ninety-five percent of 274 Ospreys passing Hawk Mountain Sanctuary in 2006 and 2007 were estimated to be  $\leq 200$  m above the lookout, or  $\sim 0.5$  km

above sea level (Hawk Mountain Sanctuary unpubl. data), which further supports this assumption. We also assumed that Osprey migration over land occurs primarily during daylight hours (but see DeCandido et al. 2006).

To assess the effect of violations of our assumption that migratory flights did not occur at night, we compared daily travel distances with those reported by Martell et al. (2001) for our three analysis regions (eastern =  $214 \pm 81$  km day<sup>-1</sup>, midwestern =  $230 \pm 61$  km day<sup>-1</sup>, northwestern =  $296 \pm 55$  km day<sup>-1</sup>). We considered any flight segment characterized by a mean daily travel rate  $>1$  SD above these regional averages to potentially contain nocturnal flights. We then calculated the proportion of all flight segments intersecting watch-site observation areas that met these criteria.

We compared the migration paths with the coordinates of 133 active autumn-migration watch-sites on the Hawkcount web-site (see Acknowledgments) operated by the Hawk Migration Association of North America. We used Hawth's tools (Beyer 2004) to determine the number of instances that a buffer around one of the migration paths intersected a point representing a watch-site. For the purposes of this paper, we defined the following three regions: eastern North America (east of 75°W), midwestern North America (75–104°W), and northwestern (Pacific coast) North America ( $>104^\circ$ W).

We also analyzed the proportion of migration paths within a 25-km radius of the Mississippi River in midwestern North America. We chose the Mississippi River for analysis because it is the most likely leading line for migrants traveling through this portion of the continent. Beginning with the interval 45–50°N, we calculated the number of migration paths falling within the 25-km radius at 5° intervals of latitude as far south as the northern coast of the Gulf of Mexico. We excluded from the analysis any locations that occurred before the onset of migration.

*Migration utilization distributions.*—Our second method was a probabilistic analysis using Brownian bridge movement models (BBMMs) that estimated habitat utilization by explicitly modeling movement between positional fixes (Horne et al. 2007). This method assumes *a priori* a conditional random walk to model animal movement between two consecutive relocations simultaneously, taking into account the error in determining the true position of the tracked animal. Migration is often a highly directed movement, not likely to be matched well by a conditional random walk per se; however, BBMMs take into account the fact that individuals have to be at more-or-less known locations at fixed times.

Brownian bridge movement models allow the estimation of a variance component (Brownian movement variance, BMV) of the conditional Brownian motion from the trajectory using cross-validation techniques and maximum likelihood. Thus, it is possible to estimate the deviation from a straight line using the observed movement and to model different kinds of movements between relocations (Horne et al. 2007). Low BMV values produce movement models in which the probability of deviating from the straight line is low, and thus they closely match the trajectory of directed movements during migration (Horne et al. 2007). Using BBMMs allowed us to derive areas of probability of passage that took the error (Argos tracking precision) in estimated positions of the Ospreys into account and estimated deviation of the tracks from the straight line between the fixes (using observed individual movement patterns).

All calculations and mappings for this analysis were performed in R, version 2.8.1 (R Foundation for Statistical Computing, Vienna), using the packages MAPTOOLS, SP, PBSMAPPING, PROJ4, RGDAL, ADEHABITAT, and FIELDS. The migration routes of Ospreys in our study covered a large geographic area from 47°S to 49°N, so we used oblique equal-distance projections to minimize distortions in distances and to convert the map units into metric units. We first projected the locations of the individual tracks into an azimuthal equal-distance projection in which the null longitude and null latitude were equal to the centroid longitude and latitude of all the locations of the individual. We determined the maximum-likelihood estimate of the deviation from the straight line (BMV) for every individual, using the R package ADEHABITAT and the function Liker. We assumed that the error in determining the position of the animals averaged 1 km, which was approximately the average amount of error for the retained classes of data.

We determined the utilization distribution (UD) using BBMMs to calculate the utilization probabilities for a grid system that consisted of  $500 \times 500$  grid cells and (depending on the length of the birds' journeys) resulted in cell sizes between 5 and 10 km per side. From these probability distributions we extracted the 95% kernel UD area for every individual. In order to obtain a visual impression of the density distribution of all tracked individuals, we calculated for a 0.1°-gridded map the total number of tracks contained in every grid cell. This map depicted the number of individuals that potentially used a given grid cell during autumn migration.

We placed a 3-km-radius circular buffer (observation area) around each watch-site location and used the intersection with the 95% UD derived from the whole trajectory to select bird-watch-site combinations for the calculation of the probability of passage. If a bird's 95% UD and the observation area intersected, we calculated the probability of passage for that combination of bird and watch-site. We first identified the section of the trajectory that was most proximal to the watch-site (i.e., the spatially closest segment of the whole trajectory defined by two consecutive relocations of the bird). We then calculated a new BBMM using the BMV estimated from the whole trajectory of this individual and the assumed positional error of 1 km to estimate the UD probability for the bird moving from the first to the second point (of the two selected relocations only). We then derived the 95% UD range for that BBMM (Fig. 1).

The probability of space use is not uniform in a BBMM, and the location of the watch-site observation area in relation to the UD was important to our analysis. A watch-site area peripheral in the UD range had lower probability of passage than one located on the straight connection of the two points. Likewise, observation areas close to known positions of birds had much higher probabilities of detection than watch-sites far from known locations. Because we were interested in the probability of passage of the bird over the watch-site observation area, we calculated the integral of the probabilities in a 6-km-wide channel and compared that with a known probability of passage.

If we assume that the bird used, with 95% probability, the width of the 95% UD area to move from the first point to the second point, the sum of the probabilities contained in a 6-km-wide channel should represent a 95% probability of passage for that

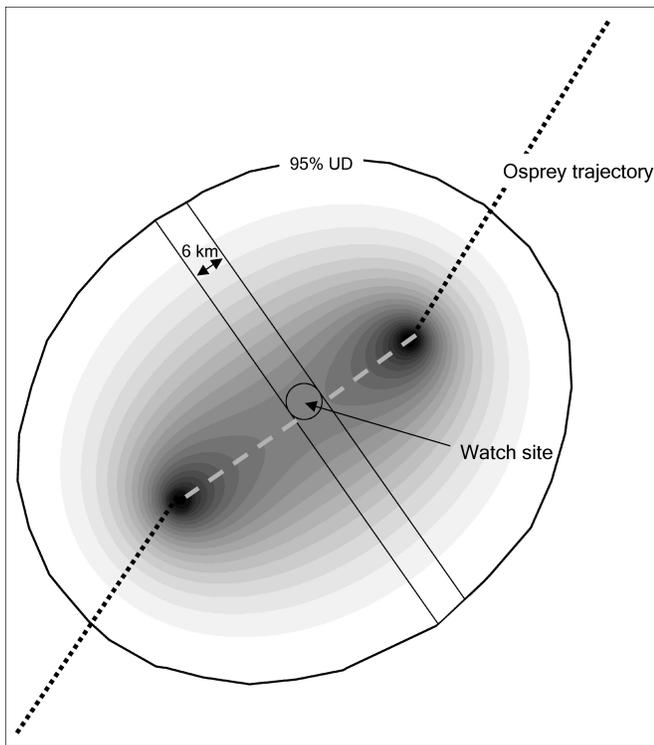


FIG. 1. Calculation of probability of passage. First, the segment of the whole trajectory (dashed lines) was found that was most proximate to the watch-site (gray part of the dashed line). Then, using the two points defining this segment, a Brownian bridge movement model (BBMM) was calculated using 1-km estimated positional error and a Brownian movement variance that was estimated from the whole trajectory of the individual. Within the 95% utilization probability distribution (95% UD; solid-line polygon), the sum of the probability contained in the watch-site observation area (circle) was compared with the sum of the probabilities contained in a 6-km-wide channel that ran across the 95% UD (two parallel solid lines) and went through the watch-site along the shortest connection between the watch-site center and the trajectory. The gray shades within the 95% UD represent the differences in the probability of space use according to the BBMM, with darker areas representing higher probabilities of utilization. The probability of passage was thus defined as the sum of the probabilities contained in the watch-site observation area divided by the sum of the contained probabilities in the 6-km channel multiplied by 95.

section of the route. Therefore, across the 95% UD range derived for the two selected points, we superimposed a 6-km-wide channel along the line of the shortest connection between the watch-site and the trajectory that maximized the utilization probabilities contained in the watch-site observation area. This was achieved by laying the 6-km-wide channel over the watch-site and in the direction of the shortest connection to the trajectory. Consequently, we quantified the probability that the bird passed over the watch-site as the proportion between the sum of the UD probabilities within the watch-site observation area and the sum of the probabilities in the 6-km channel.

For the sake of simplicity, we assumed that every individual that passed through the area derived from the above calculations was detectable. From the perspective of individual birds, the probability of being detectable at least once ( $p_{\text{tot}}$  [%]) along the migration route could be determined by taking into account the single probabilities of detection for each watch-site it crossed ( $p_i$ ) and was defined as

$$p_{\text{tot}} = 100 \cdot \left( 1 - \prod_{i=1}^n (1 - p_i) \right)$$

## RESULTS

*Migration path buffers: 6-km path width.*—Thirteen of 57 (or 23%) of 6-km-wide migration paths intersected at least one active migration watch-site (Figs. 2 and 3). Thirty-six percent of paths in eastern North America intersected active watch-sites, versus 11% in midwestern and 10% in northwestern North America. Fifteen percent of all paths intersected one watch-site, 5% intersected two, <2% intersected three, and <2% intersected seven. Overall, 15% of all watch-sites (20 of 134) were intersected by migration paths of tagged Ospreys. Watch-sites that intersected multiple migration paths included Chimney Rock, New Jersey (2); Duke Farms, New Jersey (2); Buckingham, Pennsylvania (2); Pipersville, Pennsylvania (2); and Bentsen Rio Grande State Park, Texas (2). Watch-sites that had a high density of migration paths within 10 km but did not intersect them included Florida Keys, Florida (4); Santiago, Cuba (3); and Kekoldi, Costa Rica (3). Our data were generally too sparse to estimate when Ospreys passed watch-site locations, but two migration paths definitely included nocturnal flights over the

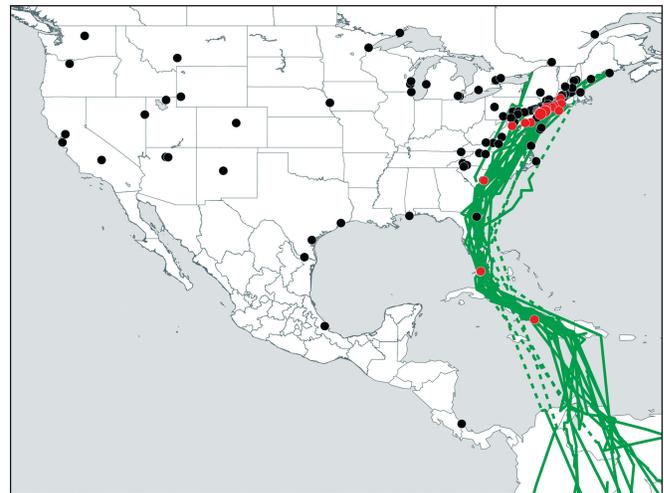


FIG. 2. Autumn migration paths of 28 satellite-tracked Ospreys originating in breeding areas in eastern North America. Black circles indicate migration watch-sites, red circles indicate watch-sites intersected by 1 migration path, and larger red circles indicate watch-sites intersected by >1 migration path. Dashed lines indicate path segments in which we have low confidence because of long intervals between samples.

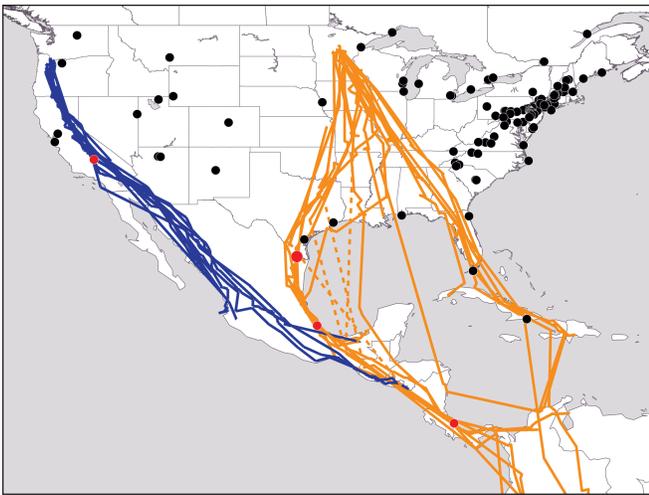


FIG. 3. Autumn migration paths of 29 satellite-tracked Ospreys originating in breeding areas in midwestern and northwestern North America. Black circles indicate migration watch-sites, red circles indicate watch-sites intersected by 1 migration path, and larger red circles indicate watch-sites intersected by >1 migration path. Blue migration paths originate in Oregon, and orange migration paths originate in Minnesota. Dashed lines indicate path segments in which we have low confidence because of long intervals between samples.

open water of the Gulf of Mexico. Additionally, 2 of 49 flight segments that intersected watch-site observation areas occurred during segments that may have included nocturnal flights.

**Migration path buffers: 3-km path width.**—Seven of 57 (or 12%) of all 3-km-wide migration paths intersected at least one watch-site (Figs. 2 and 3). Twenty-one percent of migration paths in eastern North America intersected watch-sites, versus 0% in midwestern and 10% in northwestern North America. Seven percent of all paths intersected one watch-site, 3% intersected two, and 2% intersected five. Overall, 8% of all watch-sites (11 of 134) were intersected by Osprey migration paths.

**Use of the Mississippi River corridor.**—Eighteen migration paths originated in northern midwestern North America (Fig. 3). At 45–50°N, 12 of these paths were within 25 km of the Mississippi River, versus 15 at 40–45°N, 5 at 35–40°N, 4 at 30–35°N, and zero at 25–30°N.

**Migration utilization distributions.**—The BBMMs suggested broad migration channels that differed little when we used different values of BMV. The width of the migration channels is caused by the long time interval between recorded positions, and as a consequence there was much uncertainty in the likelihood of presence between any two successive relocations. The map shows that most of the trajectories (maximum = 28 of 55) were via Florida and Cuba, and this was true for the majority of trajectories that originated from eastern or midwestern North America (Fig. 4). Very few individuals, all from midwestern North America, probably crossed the Gulf of Mexico.

Individuals in northwestern North America paralleled the Pacific coast through Central America en route to South America

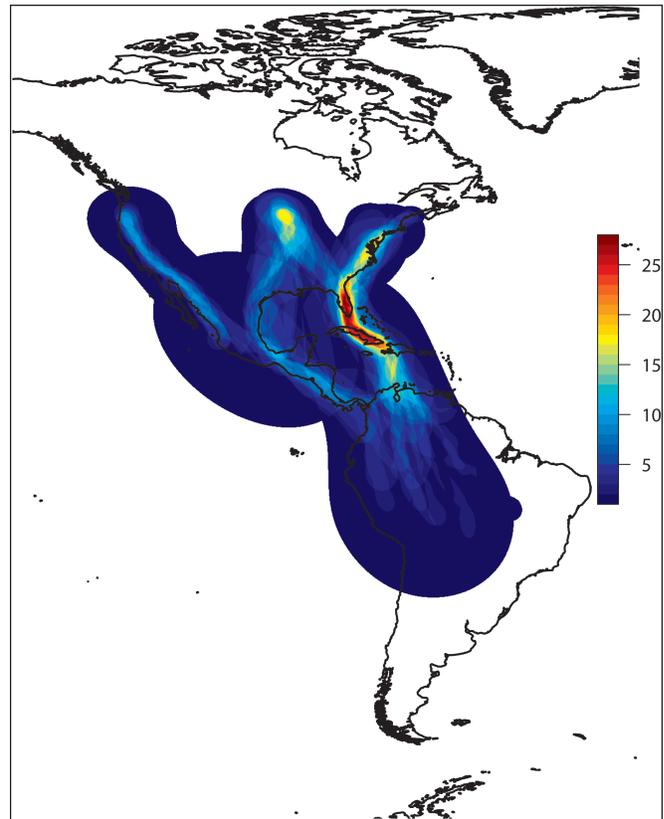


FIG. 4. Numbers of overlapping Brownian-bridge 95% utilization probability distributions of migrating Ospreys.

(Fig. 4). They generally stopped migration farther north than Ospreys from eastern and midwestern North America, as previously noted by Martell et al. (2001). In South America there was hardly any detectable concentration in the densities of the migration trajectories (Fig. 4).

Most of the watch-site observation areas (119 of 133, or 89%) intersected the 95% UD ranges of the migration tracks. Of 55 individuals included in this analysis, 52 (95%) crossed at least one watch-site observation area (median = 4 watch-sites per individual; range: 1–83). The median probability of any one of these 53 individuals being detectable at any of the 116 watch-sites was naturally low, at 1.2% (range: <0.006 to 49.6%; mean  $\pm$  SD = 2.0  $\pm$  2.7).

Detection probability per individual ( $p_{\text{tot}}$ ) along its entire migration route ranged from 0.0% to 91.2% (median = 8.6%). The probability of being detectable at least once along the migration route was significantly different depending on where the birds were tagged or initiated their migration (Kruskal-Wallis  $\chi^2 = 21.9$ ,  $df = 2$ ,  $P \leq 0.0001$ ; Fig. 5). Individuals of the eastern population had a mean ( $\pm$  SD) probability of being detectable at least once of 33.8  $\pm$  28.8%, whereas the probabilities for the other populations were one order of magnitude lower (midwestern = 5.8  $\pm$  6.6%, northwestern = 4.7  $\pm$  4.9%).

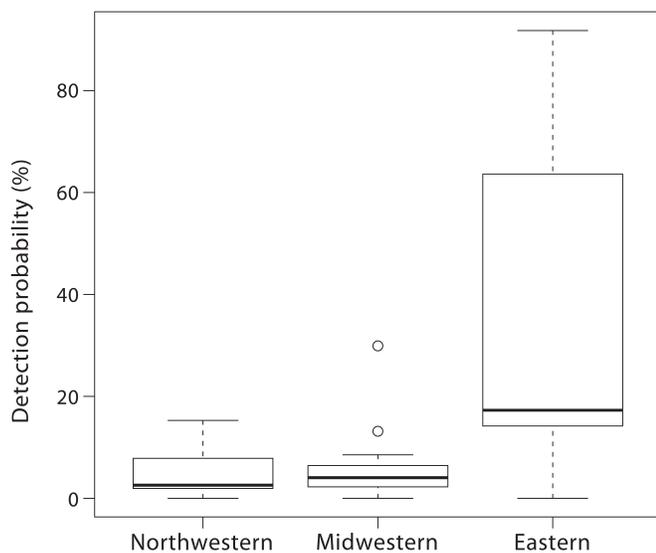


FIG. 5. Box plot of detection probability for satellite-tagged Ospreys originating in three regions of North America. The box shows first and third quartile with the median indicated by a thick line. Outer bars depict 1.5 $\times$  interquartile range and open circles indicate outliers beyond the range.

## DISCUSSION

The degree to which our satellite-tracked Ospreys were sampled by the current migration monitoring network was striking. Up to 36% of eastern migrants flew within a distance (3 km) that made them detectable at one or more watch-sites. On a broad continental scale, 23% of migrants were potentially detectable. Even more striking was the 95% coverage probability estimated by the BBMM analysis. Perhaps most important from the standpoint of population monitoring was that the highest rate of interception by watch-sites was achieved in eastern North America, which is believed to support the majority of the autumn passage of the North American population (Poole et al. 2002, Goodrich and Smith 2008). Estimates of coverage probability for a wider array of species, combined with species- and observer-specific estimates of detection probabilities at watch-sites (e.g., Sattler and Bart 1984, Berthiaume et al. 2009, M. W. Miller et al. unpubl. data), will facilitate the incorporation of detection probability into population indices derived from migration counts.

The degree to which satellite tracking allowed us to refine our understanding of the geography of Osprey migration in North America was also striking. The Osprey has been characterized as a broad-front migrant for more than half a century (Österlöf 1951, Cramp and Simmons 1980, Palmer 1988, Forsman 1999, Poole et al. 2002). Our results show that Ospreys in North America migrate along several narrow fronts that become particularly concentrated along the coast of the Gulf of Mexico in the autumn. The latter observation suggests that Ospreys are dependent on land bridges where they occur, contrary to much of the current thought in the literature (see, for example, Ferguson-Lees and Christie 2001). Although our data showed that Ospreys cross large expanses of water, they also clearly showed that birds followed land bridges when they were available (e.g., the route from Florida through Cuba and

Hispaniola to Venezuela), and this pattern was also apparent in satellite-tracked movements between Europe and Africa (e.g., Hake et al. 2001, Alerstam et al. 2006). The migration of Ospreys from the northern United States appears to follow three well-defined corridors (Atlantic coast, central, and inland Pacific), previously described by Martell et al. (2001, 2004), that align with the four major routes south of the United States (Martell et al. 2001, Rodriguez et al. 2001, Goodrich and Smith 2008). The advantages of overland as compared with over-water routes presumably stem from the reduced risk and energy use afforded by land-based routes, where rising air currents reduce the costs of flight.

It is reasonable to expect that the Mississippi River may act as a leading line during southward migration for Ospreys that breed in the midwestern United States. However, we found that the proportion of Ospreys within 25 km of the river decreased from 67% at 40–45°N to 0% at 25–30°N, with most taking relatively direct routes to the east or west sides of the Gulf of Mexico. Relatively few flew directly southward across the middle of the Gulf (Fig. 3). This observation suggests that Ospreys will detour around large bodies of water, despite an ability to cross them. It also reinforces Alerstam et al.'s (2006) conclusion that migration tracks converge at intermediary locations to which migrating Ospreys regularly navigate although they diverge from straight paths between these locations. However, all our observations are of experienced adult Ospreys in fall, and it is possible that juveniles on their first migration may differ in behavior, perhaps making more over-water flights, as occurs in European Honey Buzzards (*Pernis apivorus*; Hake et al. 2003).

Our analysis relies on two key assumptions regarding Osprey movements, and violation of these assumptions may cause overestimation of coverage probability. Ospreys flying >1.5 km above a watch-site may not be detectable, and we have assumed that this either does not occur or is negligible, on the basis of published information (Kerlinger 1989). We have further assumed that Ospreys passing within detection range of watch-sites do so primarily during daylight hours, when observers are generally present. Our analysis suggested that  $\leq 4\%$  of our detectable Ospreys may have passed watch-sites at night, and our method may have overestimated coverage probability by this amount. However, the only flights that definitely occurred at night were over large bodies of open water, which is the same pattern reported by DeCandido et al. (2006).

In sum, the autumn migration patterns we describe, together with the high proportion of tagged Ospreys that were potentially detectable at watch-sites, suggest that migration counts are an effective means of monitoring North American Osprey populations and that migration counts are likely to be equally or more effective for many other species. Where migration routes lead to a land-bridge or other corridor, more tagged birds would be expected to appear at more southerly sites in North America (e.g., Florida Keys), and these watch-sites may therefore be the most important points for sampling migrant populations. The disparity between the high individual probability of detection for Ospreys that originated in eastern North America (33%) and the lower probabilities for those that originated in midwestern (5.8%) and northwestern (4.7%) North America results from the greater number of watch-sites in the east, highlighting the need for an expansion of monitoring efforts outside the eastern United States. Our maps offer the basis for a strategic plan to establish new monitoring sites geographically. Examinations of the satellite tracks of so-called

narrow-front migrants (e.g., Cooper's Hawks [*Accipiter cooperii*] and Sharp-shinned Hawks [*A. striatus*]) are particularly needed to determine the extent to which current arrays of migration watch-sites sample populations of migrating raptors.

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