Chapter 25: Offshore migration of Peregrine Falcons (*Falco peregrinus*) along the Atlantic Flyway

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Chapter 25 Highlights

Characterizing fall migration patterns of Peregrine Falcons using the Atlantic flyway

Context[1]

Numerous studies have characterized risks that wind turbines pose to raptors in terrestrial settings, and Peregrine Falcon (*Falco peregrinus*; peregrine hereafter) fatalities have been documented at terrestrial wind facilities. As peregrines feed and migrate offshore, they may also encounter offshore wind energy developments. While many survey techniques used for raptors in terrestrial studies are not feasible in the offshore environment, animal tracking technologies are increasingly improving the ability of researchers to document long-distance movement and behavior patterns of migratory animals.

We used satellite telemetry to document space use for fall migrant peregrines to improve our understanding of peregrine ecology and to evaluate potential exposure to offshore development. We used a Dynamic Brownian Bridge Movement Model to develop Utilization Distributions (UDs) for individuals, and compared UD overlap with the mid-Atlantic Outer Continental Shelf study area. This modelling technique, while data-intensive, improves upon traditional (i.e., fixed kernel) approaches used in Chapters 20-22, because it accounts for the order in which locations were fixed, the time interval between them, and location error, and thus generates space use estimations that more accurately depict high and low use areas and movement corridors.

Study goal/objectives

Evaluate potential exposure of peregrines to offshore development by characterizing the migration of peregrines along the Atlantic U.S. coast, including peregrine use of the mid-Atlantic study area.

Highlights

- Peregrines commonly ventured into offshore habitats throughout the Atlantic Flyway.
- Peregrine migration routes were more concentrated in the northern portion of the U.S. Atlantic flyway (RI to NC) compared to the southern portion (NC southward), at which point migration routes were more diffuse.
- The majority of peregrines initiated transoceanic flights from in North Carolina.
- Proportions of peregrine UDs falling in the mid-Atlantic study area ranged from 0 – 59% (mean ± SD: 21 ± 21%). Peregrines varied widely in their probabilistic use of the mid-Atlantic study area.
- Peregrine locations recorded over water were at significantly higher altitudes than over land.

Implications

Peregrines from a broad geographic range use the Atlantic flyway during fall migration, and study findings suggest they use offshore habitats regularly. However, the proportion of the population that passes through with the mid-Atlantic study area, the frequency with which individuals might encounter turbines, and the behavioral responses of peregrines to offshore turbines remain unknown.

[1] For more detailed context for this chapter, please see the introduction to Part V of this report.

Abstract

Peregrine Falcons (*Falco peregrinus*; peregrines hereafter) are among a limited number of raptors capable of enduring extended journeys over open water. This characteristic may increase their exposure to offshore wind energy facilities being considered for development in both state and federal waters along the Atlantic Flyway. We fitted 16 migrant peregrines with satellite transmitters in Maine and Rhode Island to characterize their migration patterns, and to evaluate their space use relative to the mid-Atlantic Outer Continental Shelf study area (mid-Atlantic study area hereafter) containing Delaware, Maryland, and Virginia Wind Energy Areas (WEAs). Peregrine tracks were more concentrated in the northern portion of the U.S. Atlantic Flyway (Block Island, RI, to Cape Hatteras, NC) compared to the southern portion (Cape Hatteras, NC southward), at which point southbound peregrines migrated over a broader front. The 120-km stretch of shoreline spanning between Cape Lookout and Cape Hatteras, North Carolina was significant to the migratory ecology of peregrines along the Atlantic flyway: nearly all peregrines initiated transoceanic flights from this stretch of coastline. Proportions of peregrine utilization distributions (UDs) coinciding with the mid-Atlantic study area ranged from 0 – 59% (mean ± SD 21 ± 21%). Thirty-three percent of peregrines entering the mid-Atlantic study area had <10% of their UDs in the study area, while remaining individuals generally: (a) travelled down the Delmarva Peninsula and crossed over the southern portion of the mid-Atlantic study area, (b) ventured, often repeatedly, from the Atlantic coastline into the mid-Atlantic study area and returned, or (c) chose an offshore migration route either within or to the east of the study area. Peregrines spent between <1 d and 14 d in the latitudinal zone of the mid-Atlantic study area, and roughly half of this time (mean ± SD: 56 ± 34%) was spent over water vs. over land. Altitude estimates from two instrumented peregrines indicated peregrines flew significantly higher when over water compared to when they were over land. Peregrine flight altitudes suggested peregrines fly above, within, and below the rotor sweep area when offshore. Findings from this study emphasize the close association between peregrines and open water habitats during migration. Peregrines may have increased collision risks with offshore turbines if they are attracted to them for perching and foraging, as has been observed for other lighted structures (i.e., oil drilling platforms, offshore vessels) or if they encounter them during times of limited visibility.

Introduction

Peregrine Falcons (*Falco peregrinus;* peregrines hereafter) are one of the most widely distributed raptors worldwide (White et al. 2013). Due primarily to adverse effects of persistent synthetic chlorinated hydrocarbons (DDT and others) on reproduction, peregrine populations declined precipitously throughout large portions of their range in the mid-20th century (Ratcliffe 1980, Cade et al. 1988, White et al. 2002). Populations residing in the eastern U.S. (*F. p. anatum*) were fully extirpated, while notable declines were observed in migratory *F. p. anatum* and *F. p. tundrius* from arctic and subarctic regions (Kiff 1988, Henny et al. 2009). Federal protection under the Endangered Species Act (transferred from the Federal Endangered Species Conservation Act of 1969) the banning of DDT, and unprecedented population reintroduction and recovery efforts were largely successful in reestablishing breeding populations throughout much of their former range, prompting removal of *F. p. anatum* from the U.S. Federal Endangered Species List in 1999 (Cade and Burnham 2003, USFWS 2003). Resident Peregrine populations continue to recover but remain listed on threatened and endangered species lists in many eastern U.S. states. Data from long-term hawk count migration stations along the Atlantic

Flyway, a major migration corridor for peregrines, has shown increasing population trends in migrating peregrines (Farmer et al. 2008), and notable declines in DDT exposure have been observed (Henny et al. 1996, 2009). Fall migrant peregrines using the Atlantic Flyway likely represent a combination of reestablished local residents (formerly comprised by the *anatum* subspecies) and far greater numbers of peregrines originating from arctic regions across North America and Greenland (primarily comprised of the *tundrius* subspecies; White et al. 2013).

Interest in renewable energy development has increased in the United States and internationally over the last several decades. State and federal mandates for generating a portion of energy production from renewable resources have encouraged the development of offshore wind energy technologies in the U.S. Wind energy facilities are associated with positive environmental benefits, particularly lessening greenhouse gas emissions associated with fossil fuel combustion. In 2010, the U.S. Department of the Interior launched the "Smart from the Start" initiative to promote the siting and construction of wind energy projects on the Atlantic Outer Continental Shelf, an area under federal jurisdiction (>3 nautical miles from shore; USDOE and USDOI 2011). The Bureau of Ocean Energy Management designated Wind Energy Areas (WEAs) in specific locations along the Atlantic coast to minimize conflicts with other marine uses such as shipping and naval activities. Four mid-Atlantic WEAs off the coasts of New Jersey, Delaware, Maryland, and Virginia were the first proposed areas for potential development under this initiative. Other offshore lease and planning areas are in various stages of development in both state and federal waters along the Atlantic coast (BOEM 2015*a*). Completion of an offshore wind energy facility off the coast of Block Island, Rhode Island is anticipated in 2017, which would make it the first operational offshore wind project in the U.S.

Wind energy facilities can have adverse effects on birds, particularly if they are located in areas of high bird use; however, proper citing of facilities through preconstruction planning can reduce risks to individuals (Langston and Pullan 2003, Smallwood and Thelander 2008, Smallwood 2013, Miller et al. 2014). The extent to which offshore wind energy facilities might impact wildlife populations remains poorly understood for many species. Wind energy facilities are associated with numerous risks to bird populations including those related to collision, increased energy expenditure due to avoidance behaviors, and displacement from foraging areas (Langston and Pullan 2003, Chamberlain et al. 2006, Drewitt and Langston 2006, Fox et al. 2006). The potential for adverse effects of wind turbines on birds have prompted several efforts to develop species vulnerability assessments to be used in future wind energy planning efforts and risk evaluations (Garthe and Hüppop 2004, Watts 2010, Furness et al. 2013, Willmott et al. 2013). These studies have focused almost exclusively on waterbirds, with the exception of Willmott et al. (2013), whose authors largely discounted risk for migratory landbirds on the assumption that they spend minimal time over the Atlantic Outer Continental Shelf.

Negative impacts on survivorship, particularly adult survival, can have significant and long-term consequences on the stability of raptor populations, particularly for long-lived or endangered species (Newton 1979, Grier 1980, Carrete et al. 2009). Thus, further investigations of the potential risks offshore wind facilities may pose to raptors are warranted. The primary negative effects of wind turbines associated with raptors in terrestrial settings are related to displacement (primarily focusing on foraging raptors) and collision (Madders and Whitfield 2006, De Lucas et al. 2008, Smallwood and

Thelander 2008, Garvin et al. 2011). A study in Spain suggests collision fatalities are not related to raptor abundance (De Lucas et al. 2008). Topography, species-specific flight behaviors, turbine height and local weather patterns have been found to influence raptor collision risks with wind turbines (De Lucas et al. 2008, Garvin et al. 2011). Compared to other raptors such as Golden Eagles (*Aquila chrysaetos*) and Red-tailed Hawks (*Buteo jamaicensis;* Smallwood and Thelander 2008), reports of peregrine collisions with wind turbines in terrestrial settings are relatively uncommon. Peregrine fatalities have been documented at multiple terrestrial wind facilities in Europe and the United States (Meek et al. 1993, Hötker et al. 2006, Mizrahi et al. 2009, Dürr 2011). To date, peregrine fatality risks are difficult to assess in marine settings because most survey techniques used in terrestrial settings are not feasible in the offshore environment. Peregrines are known to travel over water during migration, and large numbers of individuals may commonly use some migratory corridors offshore.

Rapid advances in the field of animal tracking technologies over the last two decades are increasingly improving researchers' abilities to document movement and behavior patterns of widely roaming species (Seegar et al. 1996, Walls and Kenward 2007, Kie et al. 2010, Lanzone et al. 2012). Several tracking technologies including satellite telemetry and high resolution GPS telemetry now enable animals to be tracked at a global scale for consecutive years (Mellone 2013, Sokolov et al. 2014, Watson et al. 2014). In parallel to the rapid advances in the field of animal tracking, our ability to model animal movements has notably improved in recent years (Kie et al. 2010, Fischer et al. 2013). Traditional home range estimation methods such as fixed kernel approaches have limitations because they consider each animal location independently and they do not generate utilization distributions based upon movement paths. In 2007, Horne et al. introduced the Brownian Bridge Movement Model (BBMM) to model animal movements, and the approach has since been widely used (Farmer et al. 2010, Fischer et al. 2013, Watts et al. 2015). The BBMM improves upon traditional approaches because it does not consider location estimates independently, it incorporates location accuracy information, and it employs a probabilistic estimation of an animal's path from data recorded at intervals (Fischer et al. 2013). Recently, Kranstauber et al. (2012) proposed the 'Dynamic Brownian Bridge' approach to modelling animal movements with Brownian Bridges, which allowed the Brownian movement variance to vary with time and space.

Unlike the majority of non-piscivorous North American raptors, peregrines have a close association with aquatic habitats, particularly marine ecosystems. Long, pointed wings and favorable wing loading characteristics enable peregrines to use of powered flight to cross large expanses of open water where thermal formation is generally poor (Kerlinger 1985, Newton 2008). As a result, peregrines are commonly observed foraging or perching far from shore at offshore islands, oil drilling platforms, and large offshore vessels (Voous 1961, Cochran 1975, 1985, Russell 2005, Johnson et al. 2011, DeSorbo et al. 2012). Limited efforts to track migrant peregrines along the Atlantic coastline have documented that peregrines may commonly use offshore habitats, and that they are capable of flying for several consecutive days across large expanses of open water (Cochran 1975, Fuller et al. 1998, Desorbo et al. 2012). Peregrines are possibly the most commonly observed raptor flying in inclement weather, and several accounts have also documented nocturnal soaring (Enderson 1965, Cochran 1975, Russell 1991) and nocturnal foraging on birds disoriented by lights on offshore structures (Johnson et al. 2011). These cumulative observations raise concerns that peregrines may have elevated collision risks with offshore wind turbines, particularly if they are attracted to them for perching or foraging.

In this study, we instrumented peregrines with satellite transmitters to: (1) characterize their migration patterns along the Atlantic flyway, and (2) evaluate potential for exposure to offshore wind development by characterizing use of the mid-Atlantic Outer Continental Shelf study area and the three WEAs (DE, MD, VA) within it.

Methods

Study area

We characterized the movements of peregrines at two spatial scales (Figure 25-1): (1) the Atlantic coast, spanning from Block Island, RI (our primary deployment site) to the southern tip of Florida, and (2) the mid-Atlantic Outer Continental Shelf study area (mid-Atlantic study area hereafter) and the three WEAs within it (Figure 25-1).

Peregrine capture, PTT instrumentation and programming

We captured migrant peregrines at two demonstrated fall migration stopover sites: (1) Monhegan Island, 16 km off the mid-coast of Maine (2010), and (2) Block Island, 21 km off the southern Rhode Island coast (2012-2014). Block Island was chosen as our primary capture site because it was presumed to be a peregrine migration stopover site, was logistically attractive, and it is approximately 350 km north of the northern periphery of the mid-Atlantic study area.

Migrant peregrines were captured using standard methodologies in which dho gaza nets, mist nets, and bow nets were arranged around lures (Hull and Bloom 2001). Upon capture, we removed peregrines from traps, banded them using U.S. Geological Survey (USGS) leg bands, and collected standard morphometric data (flat wing cord, tail, culmen, body mass) following standard protocols. We attached satellite transmitters (Platform Transmitter Terminals, or PTTs) to a subset of captured individuals, prioritizing peregrines that were visibly healthy and heavier, such that the PTT package remained ≤3.5% of bird body mass. Transmitters were instrumented to individuals with a backpack-style harness made of 0.63 mm (0.25 in) Teflon® ribbon (Bally Ribbon Mills, Bally, PA) sewn with Teflon® thread through a Teflon® kangaroo leather patch centered on the breast (Kenward 2001, Steenhof et al. 2006, Walls and Kenward 2007, Fair et al. 2010).

We used the Argos satellite system to track peregrine movements (CLS 2015). We used two types of satellite transmitters (manufactured by North Star Science and Technology, King George, VA). Nine female peregrines (7 captured on Block Island, 2 captured on Monhegan Island) were instrumented with 22 g solar GPS PTTs programmed to fix 4 (Monhegan) to 11 (Block Island) GPS locations distributed evenly throughout daylight hours, plus one location at midnight EDT (04:00 GMT). Additional locations were estimated by Doppler-shift (Argos locations hereafter) during 8-hour transmission cycles following a 30-hour off cycle. Two females and six males were instrumented with 12 g solar PTTs programmed to fix Argos locations during all daylight hours as unit charging permitted.

Argos locations were estimated by CLS America (CLS) using the least squares method. Argos locations are classified by CLS into seven location classes (LCs), generally associated with increasing levels of accuracy: Z, B, A, 0, 1, 2 and 3 (CLS 2015). Given that low-quality Argos locations (LCs Z, B, A, and 0) are often associated with high errors, a filtering strategy is commonly adopted to exclude outliers. We used the merged minimum-redundant-distance and distance-angle-rate tests within the Douglas-Argos Filter (DAF) to remove implausible locations from our dataset (Douglas et al. 2012). The user defined MAXREDUN parameter within the DAF has a strong influence on the extent to which locations are excluded or retained. A lower MAXREDUN setting (i.e., 5 km) produces outputs with higher overall accuracy, but more locations are excluded from analysis. Conversely, a higher MAXREDUN setting (i.e., 15 km) retains more locations, with less stringent requirements on overall location accuracy. We used moderately conservative filtering criteria (MAXREDUN = 10 km) to remove implausible low-quality Argos locations from our peregrine data. Given our filtering parameter settings, 68^{th} percentile location error estimates for each low-quality post-filtered Argos LC have been reported as (in km): Z (4.7), B (7.6), A (4.1), 0 (6.8; Douglas et al. 2012). Location errors reported by Douglas et al. for unfiltered LC 1, 2, and 3 locations were 2.5, 1.0, and 0.4 km, respectively (see also CLS 2015). Accuracy of GPS locations fixed by units used in this study generally range between 5 – 15 m (K. LeSage, Geotrak, Inc., pers. comm.). Rare instances of GPS locations with large errors were identified by implausibly high movement rates, and were excluded.

Characterizing movements of peregrines along the Atlantic coast

To characterize the general flight paths of fall migrant peregrines using the U.S. Atlantic flyway, we mapped fall and spring tracks of individuals between Block Island, Rhode Island to southern Florida and qualitatively described migration patterns. We characterized the distance fall migrant peregrines travelled from shore during migration by calculating the distance between each location estimate and the Atlantic shoreline along the U.S. Atlantic coast. The Euclidean distance (m) was calculated between overwater peregrine location estimates and the nearest segment of the NOAA Medium Resolution Digital Vector Shoreline (1:70,000; NOAA 2014) using the Near Tool in ArcMap 10.2.2 (ESRI 2013). We then calculated the mean daily distance that each individual travelled from shore. Based on observations that Cape Hatteras, NC was significant geographically to the distance migrants travelled from shore, we compared distance measures between individuals in two broad geographic regions: Block Island to Cape Hatteras, and Cape Hatteras to the southern tip of Florida.

Altitude

Two GPS transmitters deployed in 2013 were programmed to collect altitude data. The accuracy of altitude estimates generated by PTTs vary with each satellite fix according to numerous factors. Altitude error for units used in this study typically range from 10 – 30 m (K. LeSage, Geotrak, Inc., pers. com.). To provide perspectives on peregrine flight altitude relative to the height of offshore wind turbines, we categorized location estimates between Block Island and the southern tip of Florida as either over land or over water, and then characterized flight heights into the following generalized rotor height categories: (1) < 20 m; below the rotor swept zone; (2) 20 – 200 m; within the rotor swept zone, and (3) >200 m; above the rotor swept zone. The rotor swept zone of offshore wind turbines varies with manufacturer, turbine type and tides. Rotor sweep zone categories used in our analyses are based on those used in Willmott et al. (2013), considered to cover a variety of possible turbine types and tidal effects.

Peregrine use of the mid-Atlantic study area and WEAs

To characterize movements of fall migrant peregrines within the mid-Atlantic study area, we used a dynamic Brownian Bridge Movement Model (dBBMM; Horne et al. 2007, Kranstauber et al. 2012) to generate individual utilization distributions (UDs; Worton 1989) for the 15 instrumented peregrines that crossed the northern latitude of the mid-Atlantic study area. Traditional approaches to generating UDs (i.e., fixed Kernel methods) are limited because they do not account for the order in which location estimates were fixed, the time interval between them, or location error. The dBBMM accounts for these factors, and thus generates UDs that are more accurate in depicting high and low use areas and identifying migratory corridors (Kernohan et al. 2001, Kie et al. 2010, Kranstauber et al. 2012, Fischer et al. 2013). We quantified space use of fall migrant peregrines relative to potential wind energy development within the study area by calculating the proportion of each animal's UD that intersected the mid-Atlantic study area boundary and the Delaware, Maryland and Virginia WEA boundaries. Since we were only interested in relative use as peregrines pass through the study area in the fall, we limited our analysis of the UDs to the approximate northern (38.8940°) and southern (36.5461°) latitudinal boundaries of the mid-Atlantic study area (Figure 25-1).

Time spent over water vs. over land

To estimate the amount of time peregrines spent between the northern and southern latitudinal boundaries of the mid-Atlantic study area, we input peregrine location data between Block Island, RI and Cape Hatteras, NC, into a Continuous-time Correlated Random Walk Model (CTRCW) developed for animal telemetry data (Johnson et al. 2008). A primary function of the CTRCW model is to convert telemetry data, typically collected at irregular intervals, into a time-series of location estimates that are uniformly spaced in time. We parameterized the CTRCW model using the 68% error percentiles presented in Douglas et al. (2012) for location accuracy of Argos locations, and 28 m for GPS location accuracy. We provisioned the CTRCW to predict locations for each peregrine migration at 1-hr intervals. We then categorized the predicted locations as either 'over water' or 'over land' by noting location relative to the NOAA Medium Resolution Digital Vector Shoreline (1:70,000; NOAA 2014). Times were calculated for each peregrine track using predicted locations closest to the respective point of entry and exit for each track. We considered this approach to be an improvement over using raw PTT data, which occasionally harbors large time intervals between 'raw' locations for some individuals. We considered two consecutive annual fall migration tracks for one peregrine (HYF02) independent in analyses.

Data analysis

We used the package 'move' (7 July, 2015) in R (R Core Team 2014)to calculate dBBMM probabilities and contours. We used the package 'crawl' (19 February, 2015) in R to run the Continuous-time Correlated Random Walk model used to estimate the amount of time individuals spent within the latitudinal boundaries of the mid-Atlantic study area to estimate time individuals spent over land vs. over water. Animal movements were mapped using ArcMap 10.2.2 (ESRI 2013). Animal UDs were summarized using the 'summarize by zones' tool in ArcMap 10.2.2. Data summaries were performed in JMP 9.0 (SAS 2010).

Results

Peregrine captures and PTT deployments

We captured 157 peregrines on Block Island and 35 on Monhegan Island. Of these, the vast majority (99%) were young of the year (hatching year; HY hereafter). We instrumented 14 peregrines with satellite transmitters on Block Island and two peregrines on Monhegan Island. Thus, data from 16 instrumented peregrines were available for analysis. Of these individuals, two were adult females, six were HY males, and eight were HY females.

Characterizing movements of peregrines along the Atlantic coast

After filtering, a total of 3,044 location estimates fixed between Block Island, RI and southern Florida remained in our dataset. Sixty percent of these locations (n = 1,814) were Argos locations, while the remaining 40% (n = 1,230) were GPS locations. The higher proportion of Argos locations was due to the use of non-GPS 12g solar transmitters on six males and two females. Argos location estimates in location classes 1 – 3 comprised 22% of all locations received, while 'lower-quality' location classes (0, A, B, Z; Douglas et al. 2012, CLS 2014) comprised the remaining 38% of all locations.

The majority of individuals instrumented with satellite transmitters (87%; 14 of 16) migrated southward following departure from capture sites (Figure 25-2). One exception to this pattern, HYM02, travelled approximately 1,500 km eastwards before travelling another 1,300 km south and then returned to the general vicinity of the capture site prior to travelling another 900 km south to a location >200 km offshore east of Pamlico Sound, NC where it ceased transmitting (Figure 25-3). This individual is considered an outlier, and was presumed to be perching on offshore vessels intermittently during this period based on observed daily travel rates consistent with the speed of offshore vessels. The second individual that did not travel southwards following PTT instrumentation was an adult female, ADF02, that overwintered on Block Island after capture and then migrated to Greenland the subsequent spring. One individual (HYM05), migrated as far south as the VA / NC state border, before reversing direction and heading 170 km north to Assateague Island (a barrier island in coastal MD and VA; a well-known stopover for migrant peregrines; Seegar et al. 2012), where it was recovered near the base of a Bald Eagle (*Haliaeetus leucocephalus*) nest. In general, however, peregrines exhibited more typical north-south migratory movements. We obtained a single fall migration dataset for most birds. We did record two fall migration tracks from one HY female (HYF02) that migrated from the Hudson Strait during its second fall, destined for a second winter in the Bahamas.

Our sample of instrumented peregrines suggested that the 530 km stretch of coastline between Cape Charles, VA and Cape Fear, NC is of strategic importance to peregrines using the Atlantic flyway. Instrumented peregrines reaching this shoreline zone in the fall either: (a) initiated a significant transoceanic flight, or (b) continued along the Atlantic coastline to Florida. Of thirteen peregrines continuing migration beyond the Mid-Atlantic coast, 92% (12 of 13; all HYs) initiated transoceanic flights from locations between Cape Charles, VA and Cape Fear, NC (Figure 25-2). Of these 12 peregrines, 69% (6 HY females, 3 HY males) departed from points along the 120 km stretch of coastline between Cape Hatteras and Cape Lookout (5 from Cape Lookout, 3 from Cape Hatteras; Figure 25-4 to Figure 25-8). One individual, HYF02, was tracked during two consecutive fall migration seasons, departed from the

Cape Fear area of NC during her first migration, and Ocracoke Island, NC during her second journey (Figure 25-4). The only individual that did not venture on a transoceanic flight was an adult female, ADF01, who continued down the Florida coastline (Figure 25-6). Excluding ADF02 that did not migrate, 46% (7 of 15) instrumented individuals stopped at Assateague Island along the coast of Maryland and Virginia.

Distance to shore

Excluding outliers HYM02 and ADF02, individual pooled overwater locations between Block Island and Cape Hatteras ranged from <1 to 1,495 km from shore (mean ± SD; 67 ± 196, n = 1,153). Individual pooled locations between Cape Hatteras and southern Florida ranged from <1 to 2,081 km from shore (271 ± 376 km, n = 376). Individuals had mean daily distances from shore of <1 to 299 km (30 ± 78 km, n = 14) in the northern region and 16 – 976 km (228 ± 262 km, n = 13) in the southern region.

Within the latitudes of the mid-Atlantic study area, individual pooled overwater location estimates ranged from <1 to 222 km from shore (n = 311). The mean daily distance peregrines in this subgroup travelled from shore ranged from <1 km – 57 km (16 ± 19 km, n = 14). The inclusion of the offshore-dwelling HYM02 had a strong influence on these measures (range: <1 km – 790 km, mean ± SD: 68 ± 200, n = 15).

Altitude

Two instrumented Peregrine Falcons acquired 1,884 total altitude estimates between October 2013 and June 2014. In total, 1,642 points were over land and ranged from 0.3 – 4469.2 m (mean ± SD: 105.5 ± 265.6) and 242 points were over water, which were significantly greater than land points which ranged from 0.3 – 4811.8 m (mean ± SD: 390.5 ± 747.9; $\chi^2 = 76.5$, $p < 0.0001$). The error of altitude estimates ranged from 4.9 – 85.8 m (mean ± SD: 20.4 ± 13.8 m). All altitude estimates between Block Island, RI and southern Florida (n = 349) occurred in October 2013. Fifty percent (n = 175) of altitude estimates within this area were fixed over water off the Atlantic coast, while the remaining 50% (n = 174) were fixed over land. Peregrine HYF06 ranged in altitude from 0.03 – 465.9 m (mean ± SD: 55.9 ± 100.3, n = 60) while over land along the coast between Block Island and southern Florida and ranged between 0.33 – 3313.9 m (mean ± SD: 338.7 ± 705.9, n = 106) while over water. Peregrine HYF07 ranged in altitude from 0.24 – 783.6 m (mean ± SD: 77.6 ± 152.1 m, n = 114) over land and between 4.1 – 1890.9 m (mean ± SD: 361.9 ± 337.8, n = 69) while over water. No significant differences in altitude were observed between the two birds for points occurring over land between Block Island and southern Florida; however, altitude estimates for HYF07 were significantly greater than HYF06 for points over water in this area ($\chi^2 = 22.5$, $p < 0.0001$). Forty percent of points that occurred over water between Block Island and Florida (n = 242) were located above 200 m (Figure 25-9, Figure 25-10). Thirty-one and 29% of estimates occurred within the 0 - 20 m and 20 – 200 m zone, respectively.

Spring migrants

Of the 16 peregrines instrumented in this study, three provided information on spring migration routes. One of these three migrants (HYF02) used the Atlantic coast during spring migration and provided information about spring migration patterns relative to the mid-Atlantic study area (Figure 25-4). The other two spring migrants used overland migration routes from Florida to breeding sites in Manitoba and Saskatchewan, Canada.

Peregrine use of the mid-Atlantic study area and WEAs

In total, 586 location estimates fell between the northern and southern latitudinal boundaries of the mid-Atlantic study area. GPS locations comprised 53% of location estimates in this area. Estimates in location classes 1 – 3 comprised 22% of all locations, while low quality location classes (0, A, B, Z) comprised the remaining 27% of locations. Of the 16 peregrines instrumented in this study, all but one (ADF02) reached the northern latitude of the mid-Atlantic study area (Figure 25-4 to Figure 25-8). One peregrine, HYF02, completed two fall migrations through the Mid-Atlantic study area.

Migrant peregrines displayed widely varying use patterns within the mid-Atlantic study area. Of the 15 peregrines, the proportions of their UDs falling in the mid-Atlantic study area ranged from 0 – 59% (mean ± SD 21 ± 21%; Table 25-1). Only one peregrine, HYM02, had a UD entirely outside (to the east) of the study area. However, 33% (5 out of 15 individuals) of instrumented peregrines entering the mid-Atlantic study area had <10% of their UDs in the study area. In general, peregrines with <10% of their UDs in the study area (i.e., HYF03 – HYF05, ADF01; Figure 25-5 to Figure 25-6) appeared to be following the Atlantic shoreline during migration. The remainder of individuals can be loosely characterized as: (a) travelling down the Delmarva Peninsula and crossing over the southern portion of the mid-Atlantic study area (i.e., HYF06, HYF07, HYM06), (b) venturing, often repeatedly, from the Atlantic coastline into the mid-Atlantic Outer Continental Shelf and returning (HYM05, HYF02), or (c) choosing an offshore migration route either within or to the east of the study area (i.e., HYM01, HYF01). The mean percentage of UDs falling within the mid-Atlantic study area showed a tendency to be higher in males compared to females (Table 25-1).

Time spent over land vs. over water

The amount of time peregrines spent within the northern and southern bounding latitudes of the mid-Atlantic study area varied substantially among individuals. Peregrines spent between 18 – 357 hrs within this latitudinal zone (0.8 – 14.9 d; mean ± SD: 67 ± 82 hrs, n = 16 tracks, 15 individuals). Of the 10 tracks intersecting the mid-Atlantic study area, time spent within this zone ranged from 18 – 357 hrs (0.8 – 14.9 d; mean ± SD: 87 ± 100 hrs, n = 10 tracks, 10 individuals). These figures were notably influenced by HYF02a, a peregrine that conducted multiple foraging forays into the mid-Atlantic study area from the Atlantic shoreline (HYF02a; 357 hrs). Exclusion of this individual resulted in an average time spent ranging between 18 – 119 hrs (0.8 – 5.0 d; mean ± SD: 56 ± 31 hrs, n = 9 tracks/individuals).

Peregrines were estimated to spend between 8 – 100% (mean ± SD: 55.8 ± 34.3%, n = 16 tracks, 15 individuals) of their time within the bounding latitudes of the mid-Atlantic study area over areas of open water. Of the 10 tracks/individuals intersecting the mid-Atlantic study area at least once, peregrines spent 27.5 – 100% (mean ± SD: 70.5 ± 24.6%, n = 10 tracks/individuals) of their time over water. Seventy percent (7 of 10) individuals spent >50% of their time within the bounding latitudes of the mid-Atlantic study area over water, while 50% spent >75% of their time over water.

Discussion

This study improves upon limited previous characterizations of peregrine migration along the Atlantic flyway. Efforts to gather baseline information on raptor migration patterns and space use in this flyway are particularly needed, as this area concentrates substantial portions of fall migrant raptors originating from a very broad geographic range. The Atlantic flyway also holds a substantial number of offshore wind energy planning and lease areas in state and federal waters (BOEM 2015*b*), and researchers are striving to understand wildlife patterns and evaluate risks prior to construction of facilities. To date, raptors have been poorly represented in efforts to evaluate the risks that offshore wind energy facilities may pose to bird populations. For peregrines, this is in part because: (a) compared to many waterbirds, peregrines are generally considered to migrate quickly through WEAs, (b) they travel individually and are rarely observed in high densities, and (c) exposure and collision risks are often assumed to be low or moderate in the offshore environment.

Peregrines and other raptors are commonly considered in risk assessments for terrestrial wind power projects (Madders and Whitfield 2006, Smallwood and Thelander 2008, Garvin et al. 2011, Miller et al. 2014). Raptors are generally considered to have higher collision risks when foraging, or when visibility is limited, but numerous factors such as topography, lighting, season, and habitat of the surrounding area are also important (Drewitt and Langston 2006, Madders and Whitfield 2006). While many species associated with collision risks at terrestrial-based wind energy facilities (i.e., Golden Eagles, *Aquila chrysaetos*) are rarely encountered offshore, peregrines, Merlins (*Falco columbarius*), and several other species are capable of enduring open water journeys, and they are commonly encountered offshore. Most survey techniques used to evaluate risks that terrestrial-based wind facilities pose to birds in are not appropriate or practical for understanding the ecology of peregrines in marine settings. At present, fitting individuals with tracking devices and modelling their movements may be the best approach available to learn about raptor space use offshore and to evaluate exposure to or interactions with offshore wind energy facilities. Animal tracking data has a wide range of additional conservation applications, such as establishing migratory connectivity among populations, identifying important habitats for conservation, and improving our understanding of migration ecology.

Characterizing movements of peregrines along the Atlantic coast

In general, movement patterns of our sample of transmitter-instrumented peregrines were consistent with previous knowledge of peregrine migration within the Atlantic flyway (White et al. 2002, Cade and Burnham 2003). The majority of individuals migrated relatively quickly down the Atlantic seaboard, generally following the coastline. A portion of individuals used well-known peregrine migration stopovers such as Assateague Island (Yates et al. 1988) during migration. Migration tracks and distance to shore measurements demonstrated that the peregrine migration corridor was generally more concentrated in the northern portion of the U.S. portion Atlantic flyway (i.e., from the primary deployment site, Block Island, RI, to Cape Hatteras, NC) compared to the southern portion (i.e., southward from Cape Hatteras, NC), at which point migrants spread out over a broader front. Our findings also demonstrated that peregrines regularly ventured substantial distances offshore. This finding is consistent with seemingly regular observations of peregrines foraging or perching far from shore at offshore islands, oil drilling platforms, and large offshore vessels (Voous 1961, Cochran 1975, 1985, Russell 2005, McGrady et al. 2006, Johnson et al. 2011, DeSorbo et al. 2012), but these behaviors remain poorly quantified. Individuals in our study also revealed details of some noteworthy behaviors, as some peregrines: (a) travelled approximately 1500 km eastwards into the Atlantic while presumably resting on offshore vessels, (b) reversed direction in North Carolina to migrate 170 km northwards back to Assateague Island in the fall, and (c) remained in the mid-Atlantic coastal zone areas for 26 d while making regular presumed foraging trips offshore.

Our findings highlighted the significance of the mid-Atlantic region of the U.S. to the migratory ecology of peregrines. Of the 14 fall peregrine migration tracks (13 individuals) reaching the Mid-Atlantic study area, 69% departed the mainland on transoceanic flights from a 120 km stretch of shoreline between Cape Hatteras, NC and Cape Lookout, NC. This area is known for its use by birds as a staging area and a 'launching area' (UNC 2009). This finding may be important in efforts to conserve staging areas for avian migrants, as well as investigations of the potential impacts offshore wind energy facilities in this region may pose to migrant raptors.

Peregrine use of the mid-Atlantic study area and WEAs

This study provided valuable perspectives on peregrine space use in the mid-Atlantic study area, which will be needed to assess potential exposure to offshore WEAs. Peregrines moving between the northern and southern latitudes of the mid-Atlantic study area exhibited an overlap of between 0 – 59% (mean ± SD: 21 ± 21%) of their UDs with the study area. Of the peregrine tracks reaching the northern latitude of the study area, only one had a UD entirely outside of the study area, and it was located farther offshore (Figure 25-7). One third of individuals had <10% of their UDs fall within the study area, and these individuals tended to be those following the Atlantic shoreline. In general, individuals with >10% of their UDs within the study area were those who: (a) travelled down the Delmarva Peninsula and crossed over the southern portion of the study area, (b) ventured on presumed 'foraging flights' into the study area and returned to the shoreline, or (c) chose offshore migration routes either within or to the east of the mid-Atlantic study area. The latter group tended to be those with highest proportions of their UDs in the study area; however, among individuals, higher UDs within the study area did not necessarily always correspond to an increased amount of time spent within the study area. Peregrines whose flight paths intersected the greatest proportion of the study area but moved through the area quickly could have a higher proportion of their UD in the study area than individuals that used a broader area, but displayed a longer residence time. For example, 43% of the UD for HYM01 overlapped with the mid-Atlantic study area, but this individual travelled through most of the study area in approximately 20 hours (approximately 11.3 km/hr).

Peregrines varied widely in the amount of time spent within the latitudinal boundaries of the mid-Atlantic study area. One individual spent 0.8 d (18 hrs) in this zone, while another resided there for over two weeks (357 hrs; mean ± SD: 67 ± 82 hrs). Peregrines in this zone spent over half (56 ± 34%) of their time over water. Some inaccuracies in time spent or over water estimates may have arisen due to interpolation errors generated by the CTRCW model. One-hour interval data, as selected for our analysis, may have resulted in some misclassification errors of over land vs. over water habitat types, particularly for individuals that spent large amounts of time in the intertidal zone. Nonetheless, the majority of locations were easily classified, and the model use probably improved upon estimates generated with raw, irregular spaced PTT data.

The proportion of peregrines' UDs falling within the Delaware, Maryland, and Virginia WEAs ranged from 0 – 7% and mean proportions of UDs in each of the WEAs were <1%. Low proportions of UDs within the WEAs are to be expected, given the size of WEAs relative to peregrine travel rates. For example, Fuller et al. (1998) found migrant peregrines travelled at an average rate of 172 km/d during fall migration (Fuller et al. 1998), while DE, MD and VA WEAs range in size from approximately 323 – 456 km^2.

Peregrines and offshore wind energy

The vulnerability of raptors to collisions varies depending on flight behavior, weather, season, location and other factors (Richardson 2000, Madders and Whitfield 2006). The extent to which peregrines may be vulnerable to collisions with offshore wind turbines remains largely unknown. While peregrine collisions with wires (e.g., transmission lines) have been well-documented (Olsen and Olsen 1980, White et al. 2002), there are few accounts of direct mortalities from terrestrial wind turbine collisions. Our literature search revealed two cases of peregrine mortalities associated with terrestrial-based wind turbines in Belgium (Hötker et al. 2006), four in Germany (Dürr 2011), one in Scotland (Meek et al. 1993), and one in New Jersey, U.S.A. (Mizrahi et al. 2009). Each case is associated with site-specific circumstances that often complicate comparisons among projects, particularly with those based offshore. To date, no peregrine fatalities have been documented at European offshore wind projects, although offshore mortality monitoring methodologies are inadequate to properly detect or assess collision risks of peregrines. We identified only two sources that speculate about peregrine vulnerability at offshore wind projects. Using data from visual surveys and general impact assessment methods, including the project's magnitude of pressure (intensity, duration, and spatial range) and sensitivity of environmental factors, Jensen et al. (2014) considered peregrines to have a low collision risk at the Horns Rev 3 wind farm planned for construction off the coast of Denmark. Willmott et al. (2013) assessed and ranked collision vulnerability of various species found in the Atlantic Outer Continental Shelf using metrics such as population size, annual occurrence, flight behaviors, and displacement sensitivity. Peregrine Falcons were qualitatively ranked as "medium" in collision sensitivity in that study.

A substantial portion of peregrines, particularly *tundrius* peregrines originating from Greenland and Arctic Canada, and restored peregrine populations in many Atlantic U.S. states, migrate along the Atlantic flyway enroute to southern wintering areas. Thus, efforts to understand migration ecology and risks for individuals are warranted. Findings from this study indicating peregrines commonly use offshore habitats along the Atlantic coast are consistent with their general evolutionary-based association with water for nesting, foraging, and during migration (Ratcliffe 1980, White et al. 2002, 2013). Our limited sample suggests use of offshore habitats may be relatively common during migration. The extent to which our sample reflects movements of the broader population of fall migrant peregrines using the Atlantic flyway remains unknown. Our sample, comprised primarily of migrant *tundius* peregrines, may not reflect movement patterns of resident peregrine populations in various Atlantic U.S. states. Movement patterns of resident populations remain poorly documented for resident populations in most states along the Atlantic U.S.

Our selection of offshore islands for trapping locations may have biased our sample toward individuals with greater tendencies to travel offshore; however, wind conditions, patterns of food supply, body condition, and other factors may play an equal or larger role (Newton 2008, 2010). Age class and gender may also influence peregrine movement patterns observed in this study. Our sample was comprised by only two adults, and both behaved notably differently compared to HY individuals. Overall, migration tracks of the two adults appeared relatively deliberate and time efficient compared to many HYs, whose movements generally appeared more exploratory. First-year peregrines, still refining their hunting skills, may be more inclined to venture out over water where avian prey is more vulnerable to capture. In a radio tracking study of nine HY peregrines captured on Assateague Island and followed by aircraft, Cochran (1985) considered HY peregrines of both sexes to be 'somewhat independent of land' and he speculated that use of offshore habitats was preferred by peregrines and may increase with age and experience. Cochran (1985) also suspected adult male peregrines to be somewhat 'pelagic' (Cochran 1985). While our limited sample size for adult birds did not support this latter idea, our data do suggest that peregrine migration patterns in the Atlantic flyway are not particularly limited by proximity to land. While larger sample sizes are needed, males in our study showed a tendency to spend more time in the mid-Atlantic study area compared to females (Table 25-1), and males showed a tendency to migrate further than females to reach wintering areas.

It remains unknown how peregrines might respond to turbines encountered offshore. The two peregrines providing flight altitude data in this study demonstrated that peregrines fly above, within, and below the rotor swept zones for turbines currently proposed for use in the offshore environment. While our sample size for evaluating flight altitude is limited, local weather conditions likely have a predominant influence on flight altitude choices during migration (Newton 2007, Shamoun-Baranes et al. 2010, Mandel et al. 2011, Mellone et al. 2011, Bohrer et al. 2012, Lanzone et al. 2012). Peregrines likely fly at lower altitudes during migration when looking for prey along the water surface. A wide variety of other factors including behavior state (i.e., foraging or migrating) and patterns of prey populations also influence on the flight altitude selected by peregrines and their risks of colliding with offshore turbines. Lighted structures such as oil drilling platforms and barges may attract peregrines for foraging or resting. Johnson et al. (2011) observed peregrines feeding nocturnally on birds disoriented by lights on offshore structures. Peregrines may have an elevated collision risk with offshore wind turbines if they are attracted to them for perching and especially foraging, or if they encounter them during inclement weather during the day or at night.

Findings in this study would be strengthened by increased sample sizes, particularly within age and gender classes. It remains unknown what proportion of migrant peregrines using the Atlantic flyway travel offshore, or the extent to which our selection of offshore capture sites may have influenced our findings. Continuing advancements in animal tracking technologies, such as high resolution GPS, or 'GSM' transmitters (i.e., cellular network based; Global System for Mobile Communications; Lanzone et al. 2012) can produce location data with higher sampling rates and greater horizontal and vertical accuracy, which could improve insights gained in future investigations. Further weight reductions for all transmitter types will enable biologists to better understand the movements of peregrines, particularly males, and smaller raptors such as Merlins, American Kestrels (*Falco sparverius*) and Northern Harriers

(*Circus cyaneus*) that also use the Atlantic coast during migration. Efforts to characterize raptor movement patterns and evaluate collision risks with turbines are particularly important along the Atlantic Flyway given the substantial quantity of individuals using this region during fall migration, and the number of proposed wind energy planning and lease areas in state and federal waters in various stages of development.

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Figures and tables

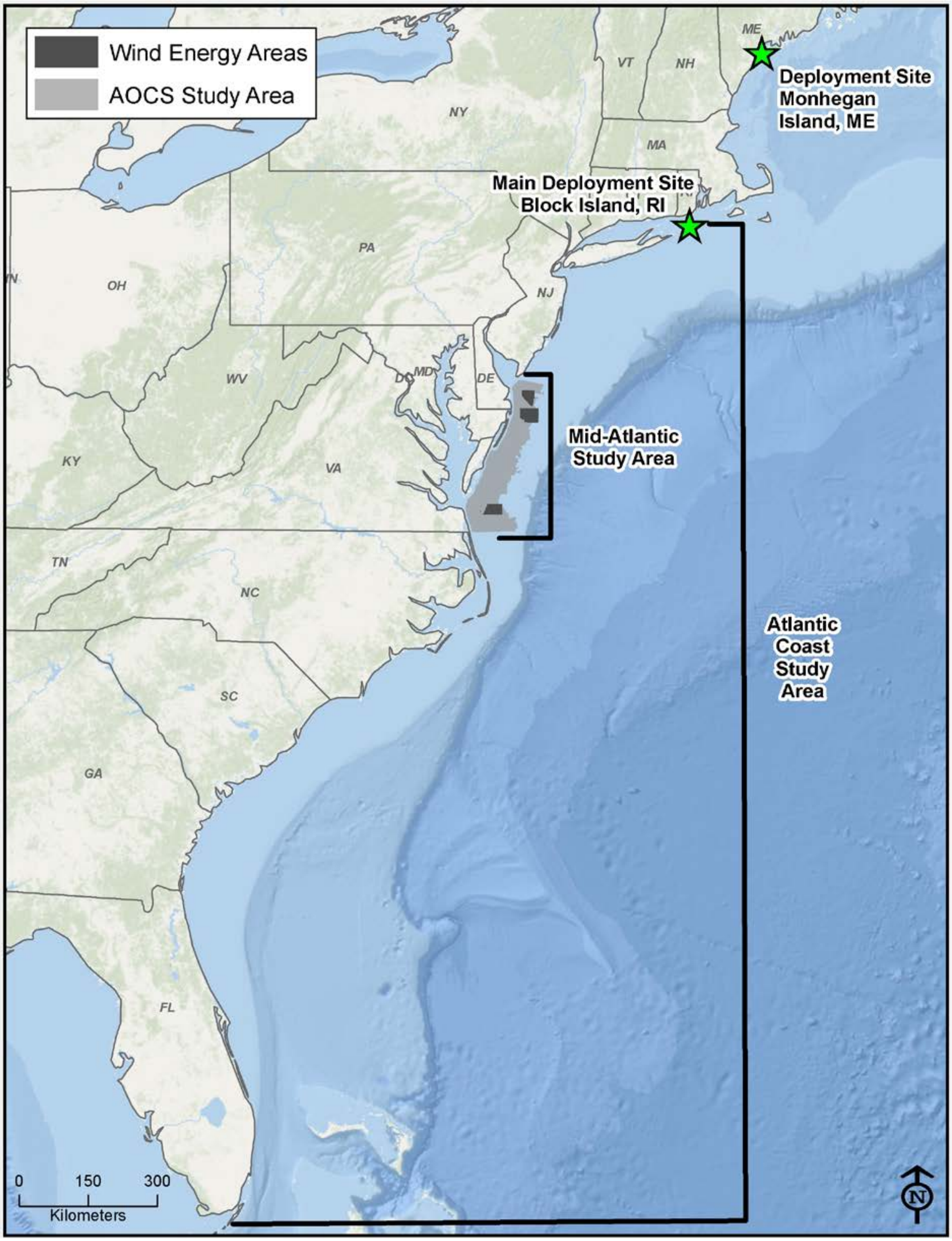

Figure 25-1. Atlantic coast study area, Mid-Atlantic Study area and Wind Energy Areas, and two satellite transmitter deployment locations.

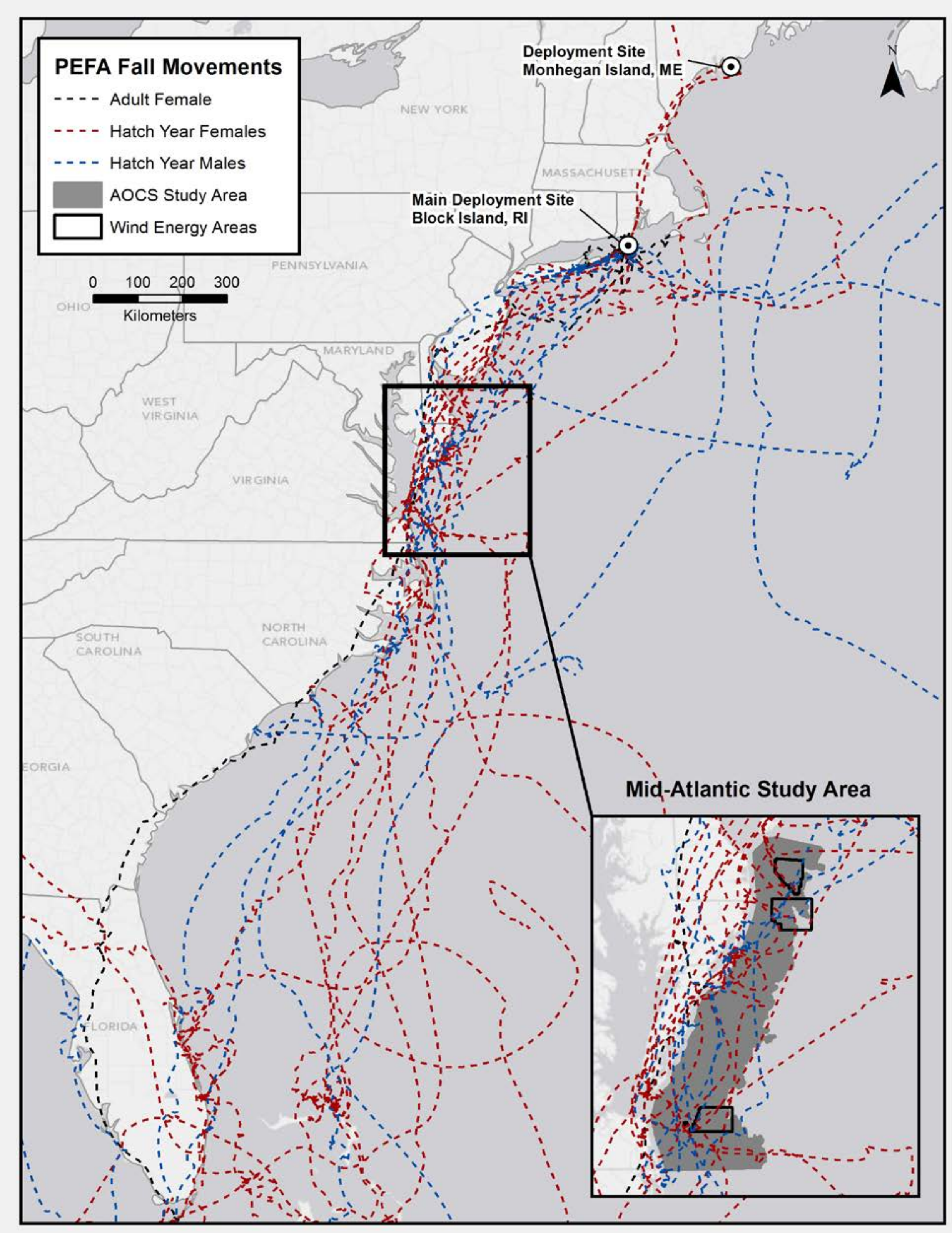

Figure 25-2. Movement patterns of 16 satellite transmitter instrumented Peregrine Falcons migrating along the Atlantic U.S. coast, fall, 2010 - 2014.

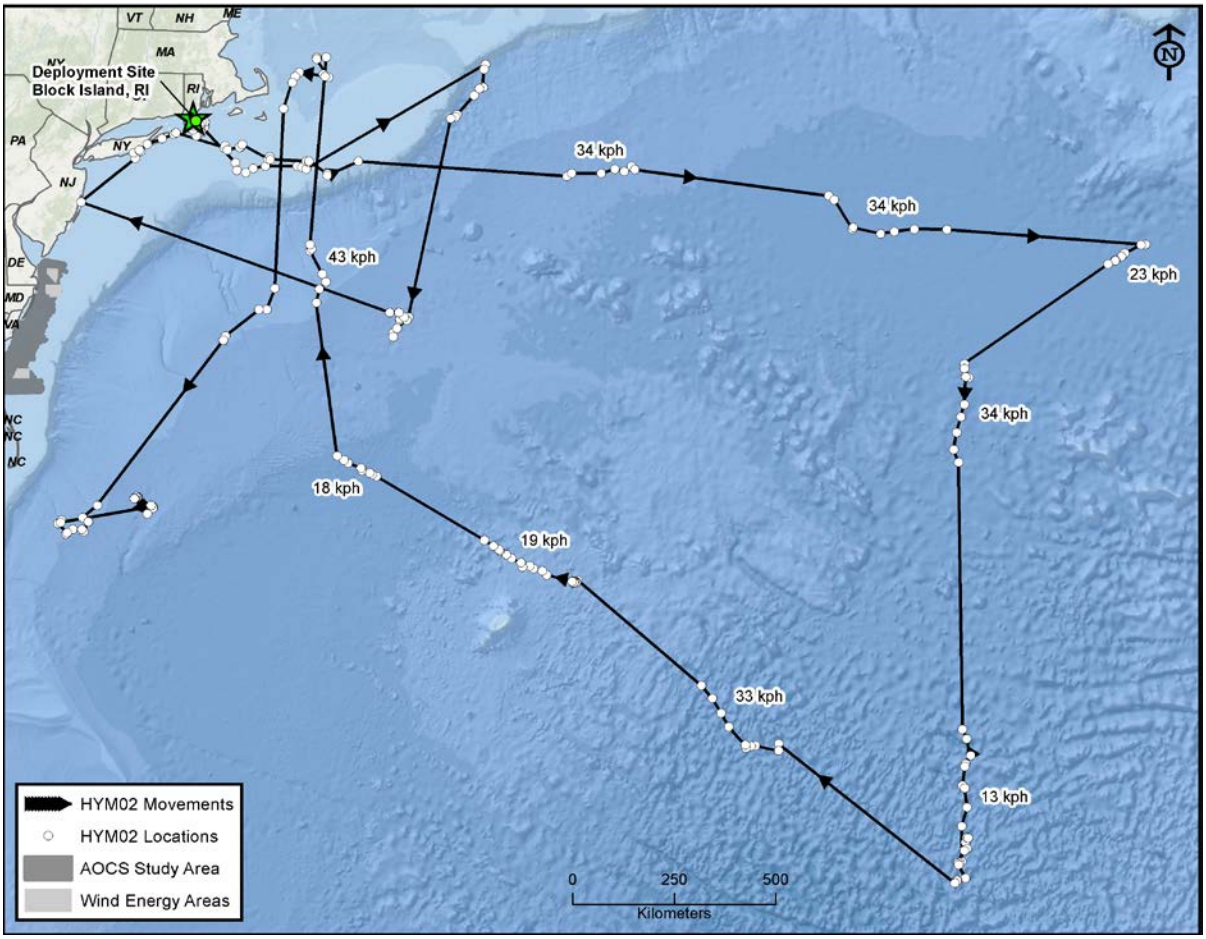

Figure 25-3. Movements of male hatching year Peregrine Falcon instrumented with a satellite transmitter during fall, 2012 at Block Island, RI. Rate of movement indicated for daily clusters of satellite location estimates.

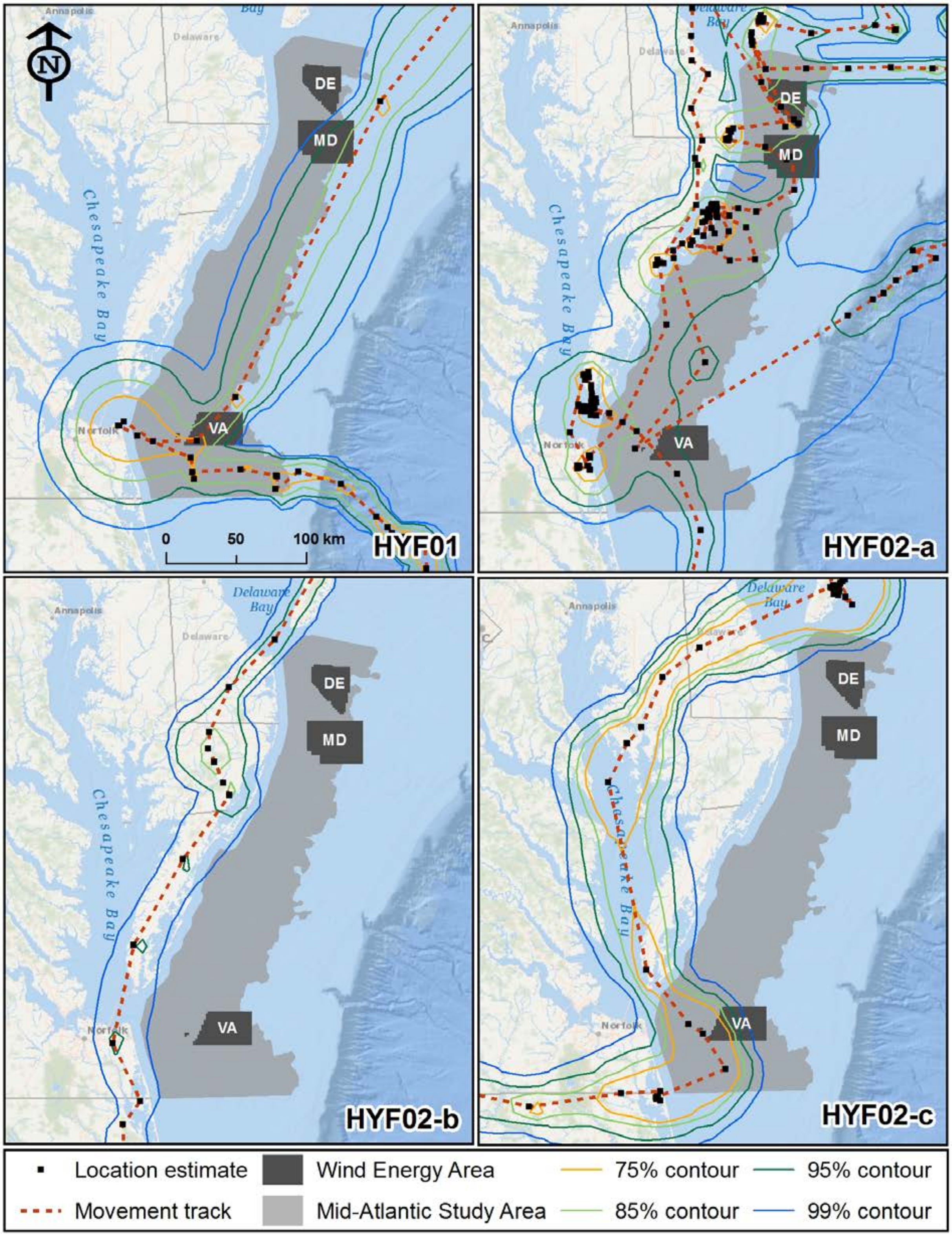

Figure 25-4. dBBMM utilization distribution contours for two migrating hatching year (HY) female Peregrine Falcons relative to the Mid-Atlantic Study Area and three Wind Energy Areas. Three migrations shown for HYF02 (a – 1st fall; b – 2nd fall; c – 1st spring). All maps shown at same scale; scale bar shown in first map pane.

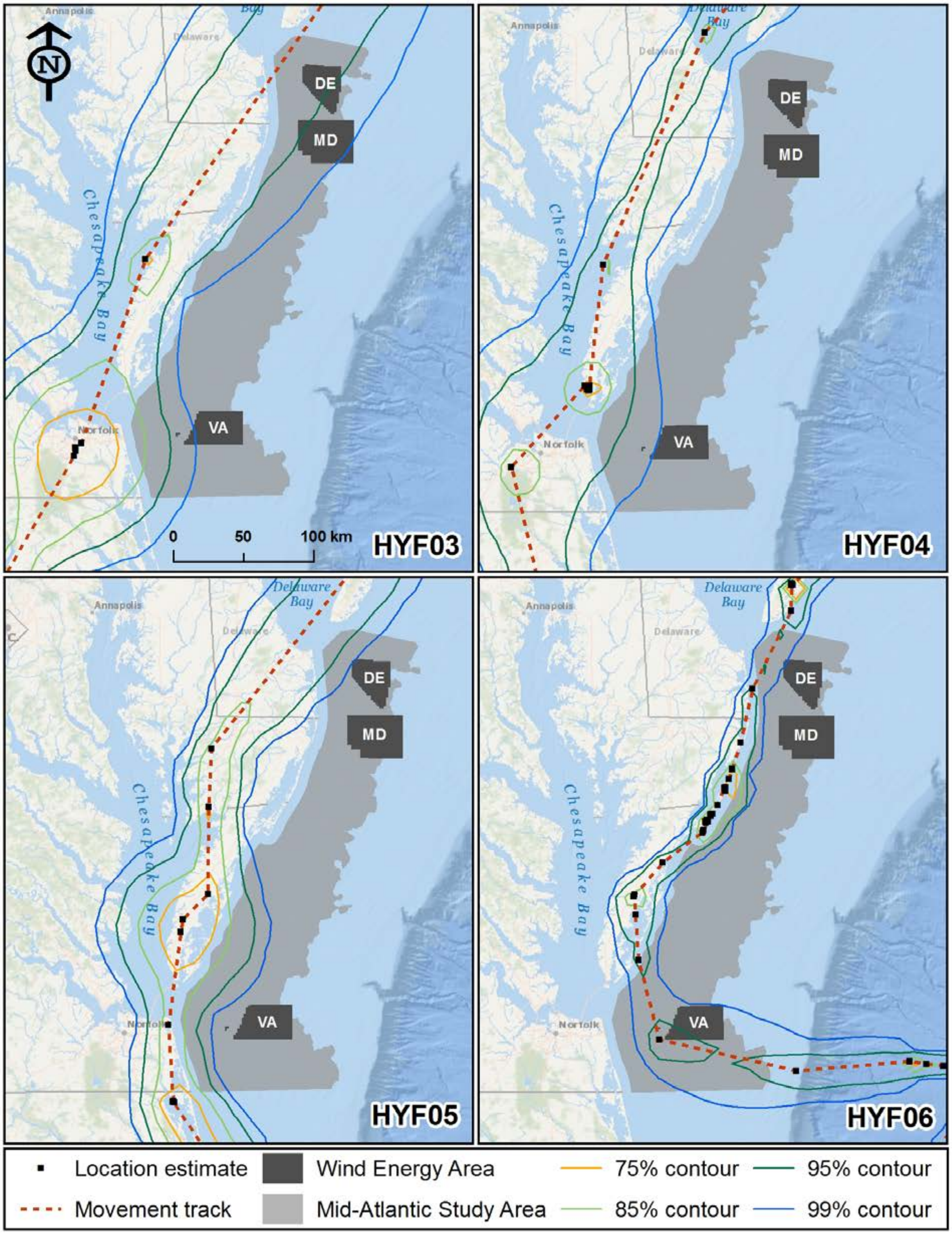

Figure 25-5. dBBMM utilization distribution contours for four migrating hatching year (HY) female Peregrine Falcons relative to the Mid-Atlantic Study Area and three Wind Energy Areas. All maps shown at same scale; scale bar shown in first map pane.

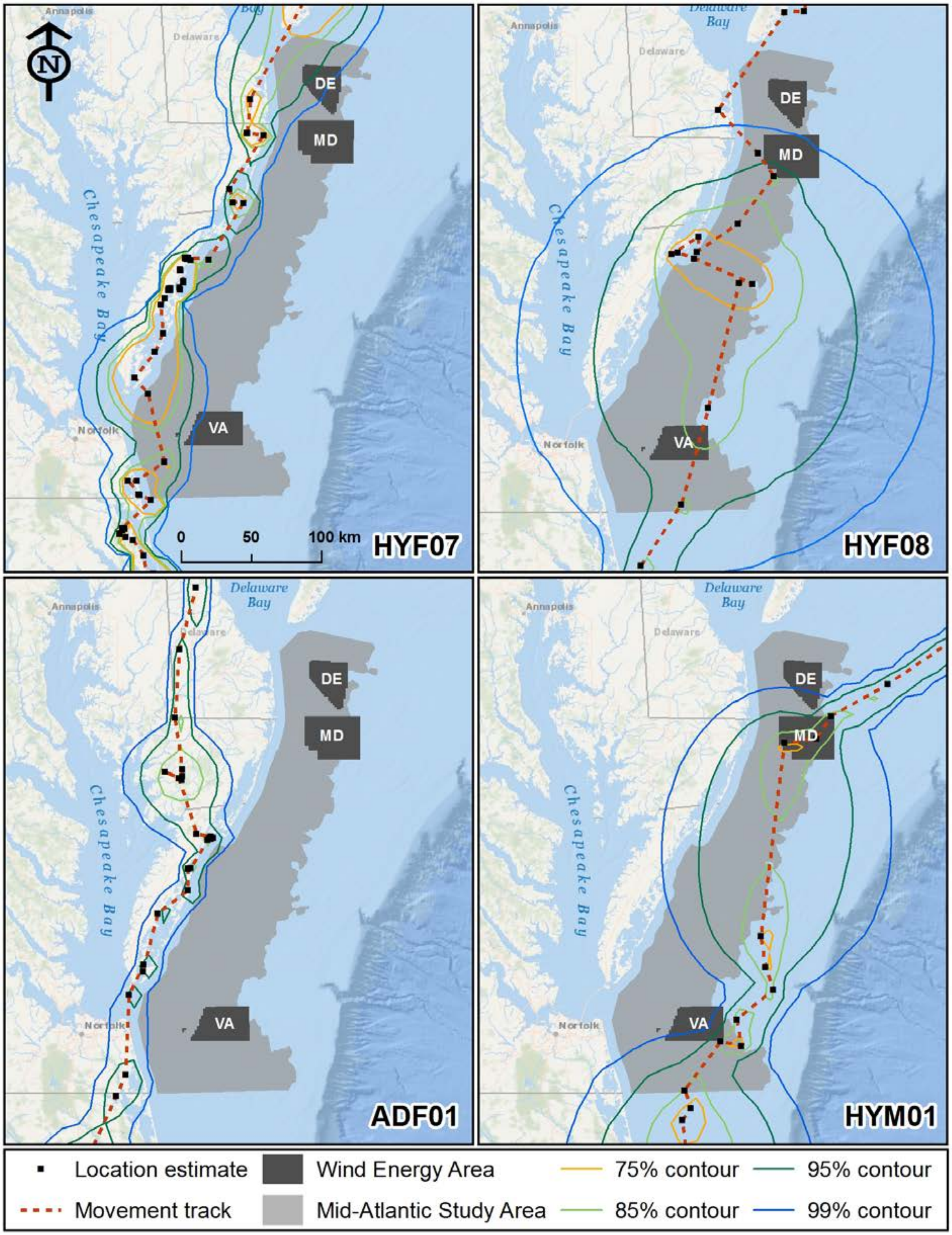

Figure 25-6. dBBMM utilization distribution contours for two migrating hatching year (HY) female, one adult (AD) female, and one hatching year male Peregrine Falcons relative to the Mid-Atlantic Study Area and three Wind Energy Areas. All maps shown at same scale; scale bar shown in first map pane.

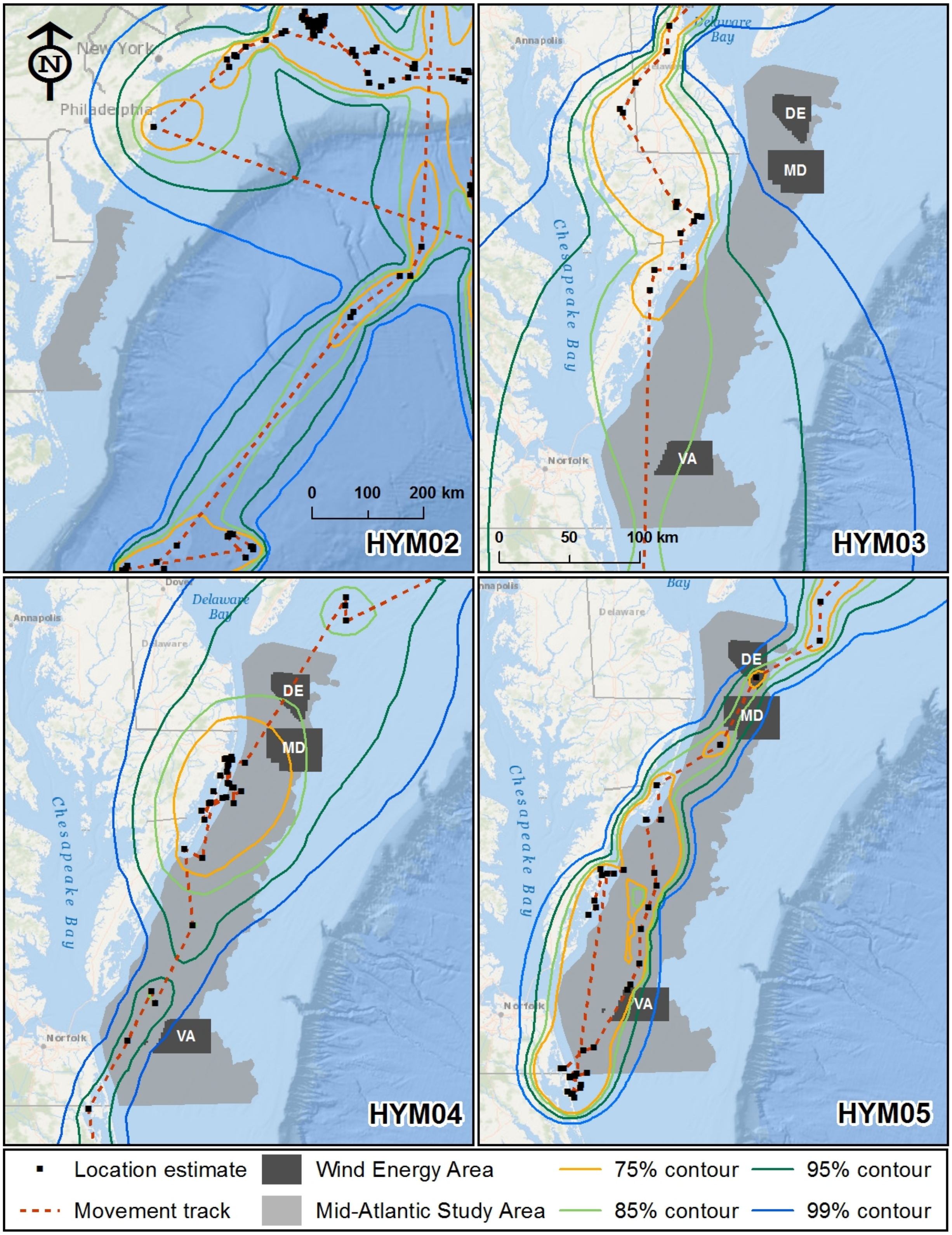

Figure 25-7. dBBMM utilization distribution contours for four migrating hatching year (HY) male Peregrine Falcons relative to the Mid-Atlantic Study Area and three Wind Energy Areas. First map pane shown at different scale; all others shown at same scale as second map pane.

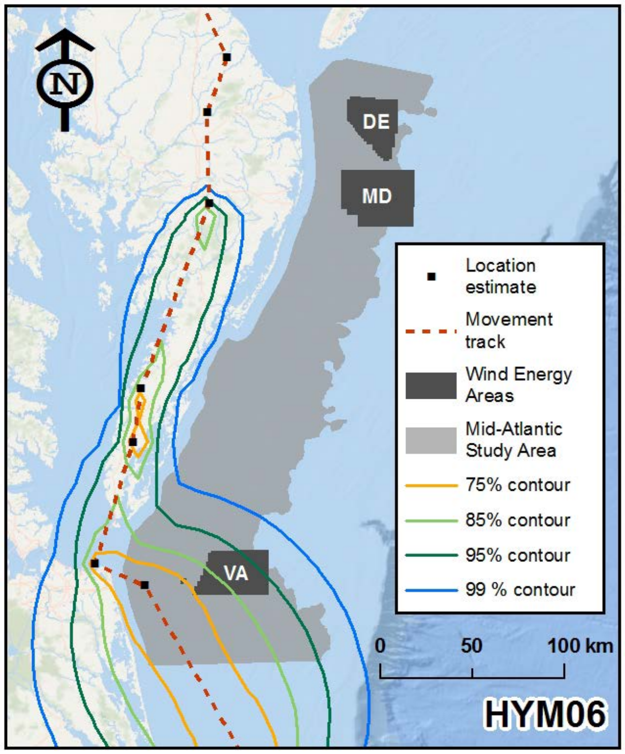

Figure 25-8. dBBMM utilization distribution contours for one hatching year (HY) male Peregrine Falcon relative to the Mid-Atlantic Study Area and three Wind Energy Areas.

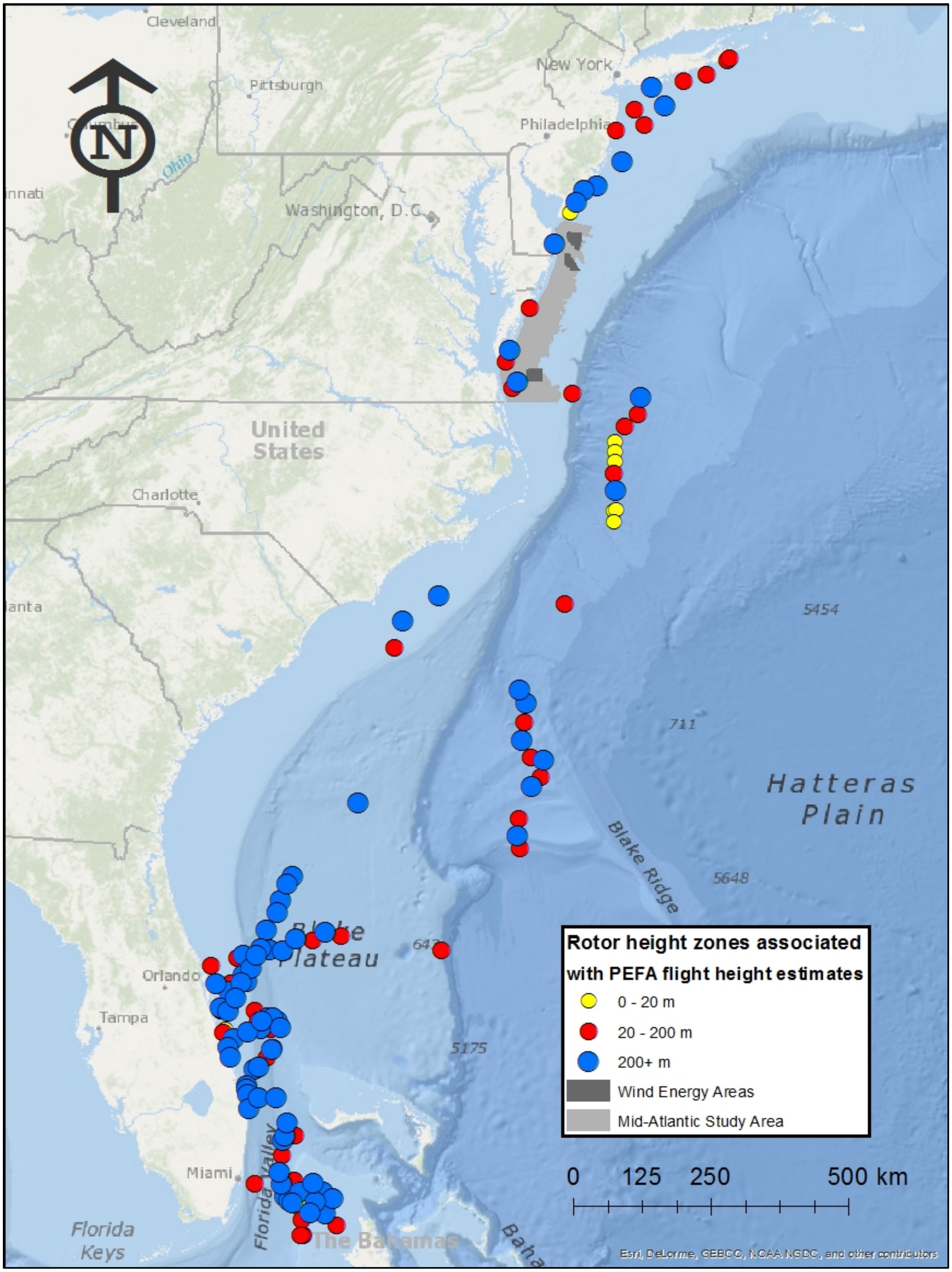

Figure 25-9. Flight altitude of two female Peregrine Falcons tracked using GPS satellite telemetry in four height categories related to proposed height of offshore turbines: (1) 0 – 20 m, (2) 20 - 200 m, and (3) >200 m.

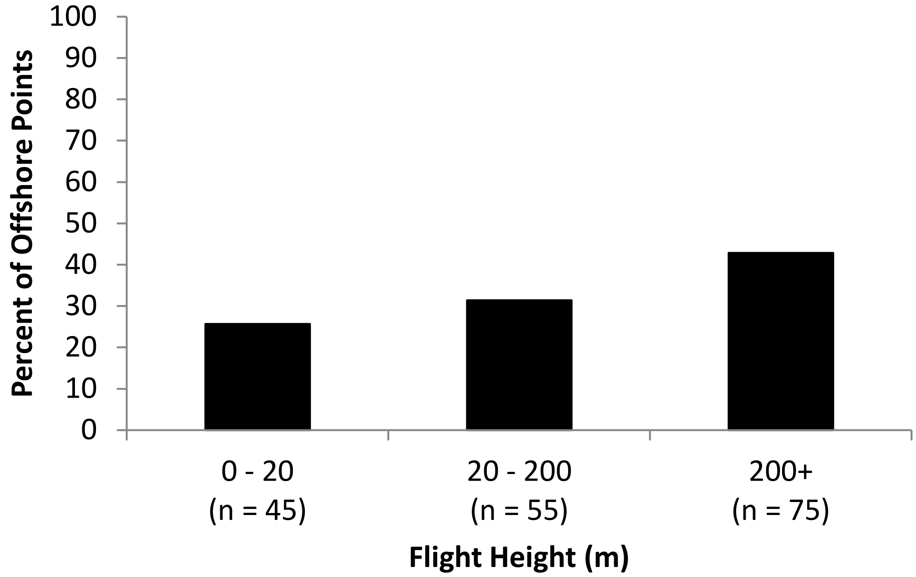

Figure 25-10. Proportion of altitude estimates of two migrant female Peregrine Falcons falling within three height categories related to offshore wind turbines. Categories: (1) below rotor-swept range (< 20 m), (2) within rotor-swept zone (20 – 200 m), (3) and above rotor height (>200 m).

Table 25-1. Proportion of female (n = 9), male (n = 6) and combined gender class (n = 15) Peregrine Falcon Utilization Distributions falling within the mid-Atlantic study area and Delaware, Maryland, and VA Wind Energy Areas (WEAs).

Area	Group	Mean	SD	Min	Max
Mid-Atlantic Study Area	All individuals	21%	21%	0%	59%
	Females	15%	19%	0%	56%
	Males	33%	22%	0%	59%
DE WEA	All individuals	0%	0%	0%	1%
	Females	0%	0%	0%	1%
	Males	0%	0%	0%	1%
MD WEA	All individuals	1%	2%	0%	7%
	Females	0%	0%	0%	1%
	Males	2%	3%	0%	7%
VA WEA	All individuals	1%	1%	0%	3%
	Females	1%	1%	0%	3%
	Males	1%	1%	0%	2%