Documenting home range, migration routes and wintering home range of breeding Peregrine Falcons in New Hampshire

Monitoring Report: 2016 Stantec Research and Development Grant

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

Executive Summary

We used satellite telemetry to learn about the ecology of Peregrine Falcons breeding in north-central New Hampshire throughout their year-round breeding cycle. During summers of 2014-2016, we instrumented three adult female Peregrine Falcons (peregrines hereafter), associated with two different nest sites, with satellite transmitters. We documented the size and shape of peregrine home ranges in breeding areas. Annual breeding area home range estimates (95% isopleth) for the Bear Mountain female were 9,582 km^2 (2014), 12,670 km^2 (2015) and 5,402 km^2 (2016) over three separate breeding seasons. The two female peregrines instrumented at the Rattlesnake Mountain nest site in 2014 and 2016 dispersed from their territories earlier than would be expected during the chick rearing period, and early fledgling mortality is suspected at this site in both seasons. Annual home range size estimates for these two early dispersing females were 12,403 km^2 (2014) and 6,626 km^2, (2016) (Table 5-3).

We documented migration routes and wintering areas for two of the three adult female peregrines instrumented in this study. The other female peregrine dispersed early in the chick rearing cycle and made two consecutive trips between the breeding area and Victoriaville, Quebec before eventually ceasing transmissions near the breeding area in November 2014. Two peregrines provided four southbound fall migration route tracks in 2014 through 2016 seasons, and at the time of our data cutoff date for analyses in this report, one peregrine provided two consecutive annual northbound spring migration route tracks (spring tracks from both females in 2017 are pending).

Peregrines generally followed a relatively direct southwesterly route during fall migration, travelling from breeding areas in southwestern New Hampshire, through western Massachusetts and Connecticut, to two areas roughly 150 km apart in southeastern Pennsylvania. Qualitatively, the habitat types within wintering area home ranges differed between individuals; with one area being dominated by forested ridgelines proximate to urban areas, and the other being primarily comprised of farmland and fragmented forest. The area of peregrines' wintering area home ranges (95% isopleth) ranged from 4,465 –33,925 km^2 overall. To date, all peregrines instrumented with satellite transmitters displayed notable annual fidelity to both breeding and wintering areas. We documented the seasonal timing of departures and arrivals on breeding and wintering areas. The median departure date from breeding areas was 14 October and the median arrival date in wintering areas was 22 October. The median departure date from wintering areas was 1 March, and the median date of arrival on breeding territories was 14 March. Our literature review revealed that a limited number of studies have collected similar information on this species, and very few comparison studies exist for populations nesting in inland temperate forests.

1.0 Introduction

North American populations of the American Peregrine Falcon (*Falco peregrinus anatum*) were at their lowest in the 1960s and 1970s, when the species was eliminated from all breeding sites in the eastern and midwestern U.S., and severely reduced in the western U.S. The Peregrine Falcon (peregrine hereafter) was federally listed as Endangered in 1970 under the Endangered Species Conservation Act, a precursor to the Endangered Species Act. Following a ban on use of the pesticide DDT, an extensive nationwide restoration program coordinated by The Peregrine Fund and the U.S. Fish and Wildlife Service (USFWS hereafter) began in the mid-1970s. After about 20 years, this eventually resulted in reestablishment of a self-sustaining breeding population by the mid-1990s. As a result, the peregrine was removed from the federal List of Threatened and Endangered Species in 1999, and the breeding population has continued to grow over the nearly 20 years since formal delisting.

Peregrines ceased to breed successfully in New Hampshire by the late-1950s. They were categorized as Endangered on New Hampshire's first List of Threatened and Endangered Wildlife in 1979. Recovery efforts were jump-started locally by the release of 98 captive-bred nestlings at two New Hampshire hack sites in the White Mountains between 1976 and 1987. In the post-DDT era, the first confirmed breeding at a traditional cliff site *anywhere* in the eastern U.S. took place in New Hampshire's Franconia Notch in 1981. In 2000 there were 10 breeding pairs in New Hampshire that produced a total of 25 fledglings. As a result of progress towards full population recovery, the state conservation status of peregrines in New Hampshire was revised from Endangered to Threatened in 2008. In 2016 (Figure 1-1) there were 21 New Hampshire breeding pairs that produced 32 fledged young. Wildlife biologists affiliated with New Hampshire Audubon (NHA hereafter) and the New Hampshire Fish and Game Department (NHFGD hereafter) and trained volunteer observers continue to the present day to document annual territory occupancy, nesting success, and productivity at all known breeding sites in the state.

A historically-used (until 1955) breeding site located near Rattlesnake Mountain in Rumney, NH was first confirmed reoccupied in 1994. It has hosted a territorial pair for 23 consecutive years through 2016 and has produced a total of 46 fledged young during that period. Another breeding site near Bear Mountain in Hebron, NH with no documented historic use (but located less than 2 km northwest of Sugarloaf, a historically-used site in Alexandria, NH) was first confirmed occupied in 2006. This site has hosted a territorial pair for 11 consecutive years through 2016 and has producing a total of 19 fledged young during that period.

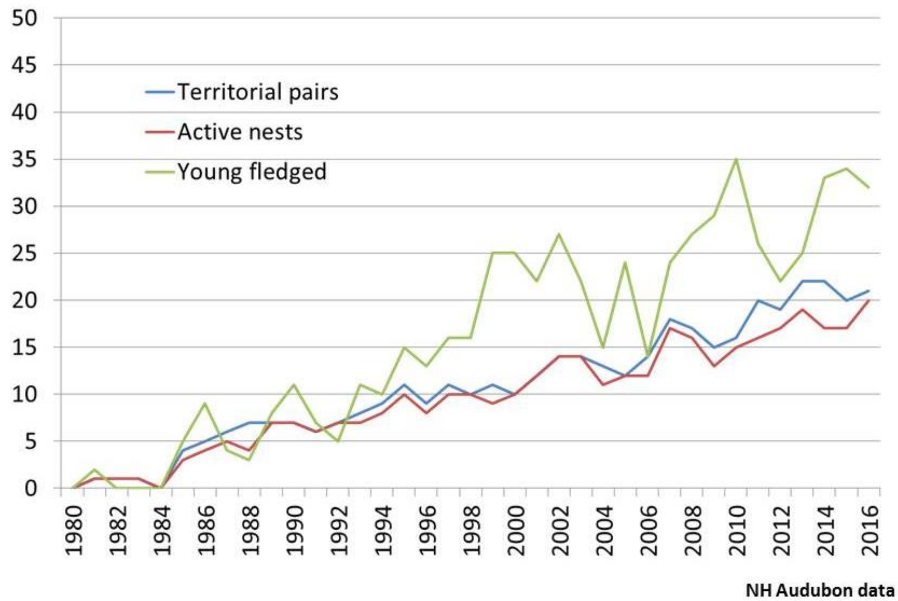

Figure 1-1. Reproductive statistics for breeding Peregrine Falcons in New Hampshire, 1980–2016.

1.1 Tracking Peregrine Falcon Movements

As a result of breeding site monitoring associated with recovery efforts, baseline data concerning breeding site productivity, behavior, and phenology for New Hampshire peregrines are well documented (NHA data). Additionally, analysis of nearly 1000 peregrine fledglings banded in New England between 1990 and 2006 has provided solid information about fledgling survivorship and parameters of natal dispersal (Faccio et al. 2013). However, almost no information is available about annual movements of adult peregrines, particularly how they use space within their breeding season home range, characteristics of their migration routes and timing of movements, and how they utilize wintering areas. Some New Hampshire peregrines are known to remain on their breeding territories throughout the non-breeding seasons, while others disperse once breeding season is completed.

While standard observational methods are quite useful for monitoring activity at breeding sites, these methods are ineffective for tracking the movements of dispersing individuals, or even following resident peregrines in their daily flights away from their nesting/roosting sites. Also, on-site field monitoring generally takes place only during the April-July breeding season, which represents only 33% of an individual's annual activity, and is focused on a very limited area where the nest is located. To address these shortcomings in our ability to follow peregrines throughout the year, Stantec Consulting Services (Stantec hereafter), Biodiversity Research Institute (BRI hereafter), and NHA collaborated to capture and fit satellite transmitters on adult peregrines in order to track them throughout their diurnal and annual cycles.

2.0 Study Area

Our study focused on two active peregrine breeding sites located in north-central New Hampshire. One site is known as Rattlesnake Mountain in the White Mountain National Forest in the township of Rumney, NH. The Rattlesnake Mountain nesting cliff is generally south-facing and overlooks the Baker River, which runs along the western and southern sides of Rattlesnake Mountain. This area is predominantly open agricultural lands along the river floodplain with scattered forest patches, wetlands, and a moderate amount of residential and commercial development. The Rattlesnake Mountain peregrine breeding territory has been occupied annually since 1994. In both 2014 and 2015, the peregrines laid eggs in a former Common Raven (*Corvus corax*) nest located near the base of an outcrop known locally as the Summit Cliff. In 2016, their nest site was located in another old raven nest less than 100 meters to the southeast, but on an adjacent outcrop known as Yellowknife Buttress.

The other breeding site, Bear Mountain, is located on privately-held land in the township of Hebron, NH. The nesting cliff forms the southeastern flank of Bear Mountain and overlooks expansive Newfound Lake to the east. The surrounding area consists of extensive forests, a few agricultural fields, much open water, scattered wetlands, and a moderate amount of residential and youth camp development. The Bear Mountain peregrine breeding territory has been occupied annually since 2006. In both 2014 and 2015, the peregrines laid eggs in a former raven nest located in the lower portion of a vertical chimney feature near the center of the cliff. In 2016, their nest was located on an open ledge in the upper center section of the cliff.

3.0 Objectives

The goals of this study were to:

1. Characterize the home range of breeding peregrines in north-central New Hampshire.
2. Document fall and spring migration routes and timing for peregrines in north-central New Hampshire.
3. Determine wintering areas of New Hampshire peregrines and characterize wintering area space use.

4.0 Methods

4.1 Approvals and Permits

This study was a collaboration among Stantec, BRI, and NHA. All activities conducted during this study were reviewed and approved by the New Hampshire Fish and Game Department (NHFGD) and the U.S. Fish and wildlife Service (USFWS) prior to fieldwork. Activities were endorsed by NHA, who has been the lead organization responsible for New Hampshire's peregrine monitoring, management and conservation work for several decades. Stantec obtained landowner approvals for the Bear Mountain site (private holding) and the Rattlesnake Mountain site (White Mountain National Forest) prior to the onset of fieldwork and provided the funding for this study under Stantec's Corporate Research and Development Program. BRI holds permit authority to capture, band, sample, and instrument peregrines with satellite transmitters under the auspices of appropriate state (NHFGD) and federal (USGS Bird Banding Laboratory) permits.

4.2 Breeding Peregrine Falcon Monitoring

NHA's peregrine breeding site monitoring conforms to or exceeds monitoring protocols developed for the federal post-delisting monitoring program implemented by the USFWS in 2003 (USFWS 2003). Monitoring visits were conducted from suitable observation points during favorable weather by experienced observers. During all visits, observers used binoculars and spotting scopes and recorded the number and plumage (adult vs. sub-adult) of peregrines seen, as well as any behavioral or physical evidence of breeding activity. An initial site visit generally occurred at each nest site in March to confirm territory occupancy and determine current breeding stage. During typical statewide monitoring efforts, occupied sites are revisited every 2–3 weeks in order to detect onset of incubation, determine location of the nest, and estimate expected hatch date. Site visit frequency was increased to 1-2 weeks in order to improve nesting chronology estimates to better inform the appropriate timing of capture attempts for this study. A subsequent visit is timed to take place shortly after hatch during the early nestling stage, and a final visit usually occurs roughly a month after hatch to determine number of young reaching the late nestling stage. Occasionally another visit is made during the post-fledging stage, but number of young fledged is based upon last pre-fledging count.

4.3 Capture, Banding and Transmitter Fitting

Adult breeding peregrines were captured on their nests as close to estimated hatch date as possible just prior to hatch (pre-fledge/incubation nesting stage). A climber accessed the nest from rappel. Incubating females were flushed from the nest by the rappelling climber. To avoid risk of breakage, eggs were removed from nests and placed in a padded plastic case and kept warm. Wooden imitation eggs were placed in the center of a noose gin trap (Henny et al. 2000) and the trap was anchored with weights and tent stakes and covered with nesting debris. If the female did not get captured upon returning to the nest and settling on the eggs, a climber rappelled downward to flush the female, at which point females' talons often become entangled in monofilament nooses. Once entangled, females were immediately hand captured by a climber on rappel, and the female was lowered to the ground for processing. Eggs were returned safely to the nest prior to releasing captured individuals. At both nests, incubating females returned to nests after processing and transmitter fitting to resume incubation, presumably shortly after climbers' departure.

Each peregrine captured was fitted with a standard lock-on USGS bird band (size 7A) on one leg and a size 7 alpha-numeric marked bi-colored band (type 12, Black over Green; Acraft, Edmonton, Canada) on the other leg. Color banding has been conducted in coordination with regional partners throughout the population recovery (Faccio et al. 2013). Two to 3 rump feathers and 2 to 3 flank feathers were collected from individuals to be used for contaminant analyses and sample archives.

Transmitters were instrumented to individuals using a backpack harness made from 0.25-inch tubular Teflon ribbon (Steenhof et al. 2006). Deployed package weights, including a neoprene pad and harnessing material, was 15.2 g (1.4% body mass) for ADF01, the 2014 Rattlesnake female; 15.9 g (1.4% body mass) for ADF02, the Bear Mountain female; and 15.9 g (1.65% body mass) for ADF03, the 2016 Rattlesnake Mountain female.

4.4 Transmitter Programming, Location Error and Filtering

We instrumented female peregrines with 11 g solar capacitor powered satellite transmitters manufactured by GeoTrak, Inc. (Apex, North Carolina, USA). Transmitters fixed locations during daylight hours as unit charging permitted. Transmitters were programmed to fix 'Argos' (Advanced Research and Global Observation Satellite) or Doppler locations via the Argos satellite system, managed by CLS America (CLS 2016). Argos satellites receive messages from transmitters and use changes in Doppler-shift frequency to calculate the approximate location of instrumented animals. The accuracy of location estimates improves with the number of messages received and other factors (CLS 2016). Location estimates are then relayed to servers for user download and analysis.

Argos locations were estimated using the least squares method. A hybrid of minimum redundant distance and distance-angle-rate tests within the Douglas-Argos Filter (DAF) was used to remove implausible locations from the dataset (user-defined MAXREDUN input = 10 km) (Douglas et al. 2012). The DAF enables a standardized approach for excluding implausible locations and retaining location estimates in lower location accuracy classes that might otherwise be excluded from analysis. Argos locations are assigned to location classes (LC), associated with an estimated error radius as follows by CLS America: LC3 (≤250 m), LC2 (250 to < 500 m), LC1 (500 to < 1500 m) and LC0 (>1500 m) (see Douglas et al. 2012). Location accuracy for location classes LCA, LCB, and LCZ (< 3 Argos messages) are not estimated by CLS America but the accuracy of these locations have been estimated elsewhere (Nicholls et al. 2007, Douglas et al. 2012). After filtering with the DAF (with a MAXREDUN = 10 km), Douglas et al. (2012) determined that 95% error percentiles for 'low-quality' locations LC0, LCA, LCB, and LCZ were 15.1, 11.3, 18.0, and 14.8 km of the true location, respectively. Location classes LC1, LC2, and LC3 were found to be 7.6, 3.3, and 1.5 km and do not require filtering (Douglas et al. 2012). Satellite transmitters were programmed to collect sensor data for transmitter temperature, activity count, and battery voltage.

4.5 Breeding Area Home Range

We used satellite transmitter data to characterize home range of peregrines at eyries during the breeding season. In order to standardize the number of days of data used in home range estimations, we restricted data inclusion in analyses to those falling between the estimated median hatch date (day 0; estimated by visual observations during monitoring efforts) and the day upon which the first hatched young would be 70 days old. This period of time encompasses the entire pre-fledge nesting stage (approx. 0–42 days) and likely a portion of the period between fledging and adult dispersal from the territory. In cases where instrumented peregrines dispersed from the territory prior to 70 days, we used only data leading up to the date upon which dispersal or migration occurred. Overall, localized movements were relatively distinct from migratory movements. We identified the beginning of migration as occurring when location estimates indicated a continuous, directional movement away from the nesting area for >1 day. Dates of data included in home range estimates are listed in Table 4-1.

Table 4-1. Dates used to generate home range estimates for the 0–70-day period (based on chick age) for three different female Peregrine Falcons at two different eyries in north-central New Hampshire, 2014–2016. Data spanning between (and including) estimated hatch dates and 70 days were used in home range analyses unless indicated otherwise.

Site	Year	Animal ID	Incubation Initiated[a]	Estimated Hatch[b]	70 days
Rattlesnake Mountain	2014	ADF01	21-Apr	25-May	3-Aug[c]
Bear Mountain	2014	ADF02	15-Apr	19-May	28-Jul
Bear Mountain	2015	ADF02	14-Apr	18-May	27-Jul
Bear Mountain	2016	ADF02	11-Apr	15-May	24-Jul
Rattlesnake Mountain	2016	ADF03	28-Mar	1-May	10-Jul[d]

a. Median date incubation initiated based upon field monitoring visits
b. Median hatch date based upon field monitoring visits
c. Early dispersal. Last local location: 7/26/2014 21:53:01 GMT
d. Early dispersal. Last local location: 6/28/2016 21:10:07 GMT

The utilization distribution (UD) is an estimate of the relative probability of an animal occurring in an area in a given time period. We consider home range the density of animal use across the landscape calculated from animal location estimates (see Powell and Mitchell 2012 and citations therein). Fifty-percent (commonly referred to as 'core-use areas') and 95% isopleths, the most commonly reported in literature (Worton 1989, Fischer et al. 2013, Loring et al. 2014), are displayed. UDs and isopleths were generated using the ‘move’ package in R, version 3.3.2 (R Core Team 2016).

We generated utilization distributions (UDs) for individuals during each breeding season using a Dynamic Brownian Bridge Movement Model. ‘Traditional’ home range estimation methods such as fixed kernel approaches have limitations because they consider each animal location independently and they do not generate UDs 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 increasingly used (Farmer et al. 2010, Fischer et al. 2013, Watts et al. 2015, Mojica et al. 2016). 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 between data points recorded at intervals considering elapsed time and distance between points (Fischer et al. 2013). Recently, Kranstauber et al. (2012) proposed the ‘Dynamic Brownian Bridge Movement Model’ (dBBMM) approach to modelling animal movements with Brownian Bridges, which allowed the Brownian movement variance to vary with time and space.

4.6 Migration Routes and Timing

4.6.1 Migration Routes

We documented spring and fall migration routes by mapping post-filtered satellite transmitter location estimates fixed during both fall and spring migration events. Location estimates fixed during migration were distinguished from those considered to be in wintering and breeding periods using the using uni-directional movement cues as described above.

4.6.2 Dispersal Timing

We documented dispersal timing for peregrines from breeding and wintering areas by mapping and qualitatively analyzing post-filtered satellite telemetry data. In both breeding and wintering areas, we considered dispersal to have occurred on the day upon which the first distinct, continuous directional movement away from the breeding area for >1 day occurred each season.

4.7 Wintering Area Home Range

We used satellite transmitter data to characterize peregrine space use in wintering areas. Following breeding area home range definitions, we define wintering area home range as the density of animal use across the landscape in the wintering area calculated from animal location estimates (see Powell and Mitchell 2012 and citations therein). Locations fixed in wintering areas were distinguished from those during migration using clear evidence of uni-directional movements as described above for other analyses. Similar to home range analyses in the breeding range, we used a Dynamic Brownian Bridge Movement Model (Kranstauber et al. 2012) to generate utilization distributions (UDs) and we present 50% and 95% isopleth home range estimates for wintering areas.

5.0 Results

5.1 Satellite Transmitter Deployments

As of Jan 2017, project collaborators have captured three different female peregrines and fitted them with satellite transmitters (Table 5-1). Two females, one from Bear Mountain, and one from Rattlesnake Mountain, were captured in 2014. No peregrines were instrumented in 2015. The Bear Mountain female instrumented in 2014 was recaptured in 2015 during attempts to capture the resident male at that site. She and her transmitter were in good condition and were therefore released. In 2016, we captured the resident female at Rattlesnake Mountain and fitted her with a transmitter.

Table 5-1. Capture date, animal ID and PTT IDs for three adult Peregrine Falcons instrumented with satellite transmitters in north-central New Hampshire, 2014-2016.

Site	Year	Animal ID	PTT ID	Capture Date	Status
Rattlesnake Mountain	2014	ADF01	129175	13-May	Last transmition on 15-Nov near nest site
Bear Mountain	2014	ADF02	129176	12-May	Still transmitting as of 30-Jan 2017
Rattlesnake Mountain	2016	ADF03	149264	28-Apr	Still transmitting as of 30-Jan 2017

5.2 Data Summary

In total, the three transmitters instrumented to female peregrines in this study fixed a total of 3,998 location estimates between transmitter deployment and 28 November 2016 (Table 5-2). Filtering with the DAF resulted in the removal of 1,731 location estimates; 43% of the original dataset. As is to be expected for small-sized non-GPS satellite transmitters, the majority of location estimates fixed were of location classes considered ‘low quality’ (LC0, LCA, LCB, LCZ) in terms of accuracy (Douglas et al. 2012) [1]. After filtering, the majority of location estimates were LC0, followed by LC1, LCA, LCB, LC2, LCZ, and LC3.

[1] See section 4.4 for location errors associated with Argos location classes.

Table 5-2. Number and proportion of satellite transmitter location estimates falling into seven different location accuracy classes (location classes) fixed by units instrumented to three resident Peregrine Falcons in central New Hampshire in 2014–2016.

	LCZ	LB	LA	L0	L1	L2	L3	Total
All Pre Filter	81 (2%)	614 (15%)	417 (10%)	2465 (62%)	335 (8%)	79 (2%)	7 (<1%)	3998
All Post Filter	17 (1%)	173 (8%)	191 (8%)	1465 (65%)	335 (15%)	79 (3%)	7 (<1%)	2267
Home Range (Filtered)	8 (1%)	64 (8%)	80 (10%)	521 (62%)	130 (15%)	34 (4%)	4 (<1%)	841
Winter Range (Filtered)	3 (1%)	36 (6%)	43 (7%)	378 (65%)	95 (16%)	21 (4%)	2 (<1%)	578

** Location classes in columns are arranged from the least accurate (leftmost columns) to the most accurate (right). Percentages indicated in parentheses calculated within rows. Refer to section 4.4 for details on location errors associated with location classes.

5.3 Breeding Area Home Range

Satellite transmitter location estimates enabled the development of space use estimates for resident peregrines during multiple breeding seasons from both the Rattlesnake Mountain site and the Bear Mountain site (Table 5-3, Figure 5-1). The Bear Mountain female (ADF02) displayed similar space use characteristics at 50% and 95% isopleth levels among years. While the 50% 'core use area' for the Bear Mountain female (ADF02) was relatively similar among 2014, 2015 and 2016, the 95% isopleth area was notably smaller during the 2016 season. Home range shapes and sizes at the Rattlesnake Mountain site varied more noticeably between ADF01's use area in 2014 compared to ADF03's use area in 2016 (Table 5-3, Figure 5-1).

Fifty percent isopleth breeding season home range areas for all sites and years ranged from 597 km^2 to 1,036 km^2, while 95% isopleth home ranges ranged from 5,402 to 12,670 km^2 (Table 5-3). The mean 50% isopleth home range area (608 km^2; n = 2) for peregrines at the Rattlesnake Mountain site was smaller compared to the 50% isopleth home range area for the Bear Mountain site (848 km^2; n = 3); however, the mean 95% isopleth home range area for peregrines using the Rattlesnake Mountain site (10,515 km^2; n = 2) appeared larger than the corresponding mean at the Bear Mountain site (9,218 km^2; n = 3). Given the females at the Rattlesnake Mountain site appeared to have dispersed from their territories early relative to the chick rearing period during both 2014 and 2016, these home ranges are not likely directly comparable to those from Bear Mountain. Calculations of home range areas for the Bear Mountain female provided valuable measures of inter-annual variability in home range size: 50% isopleth home range areas ranged from 664 km^2 to 1,036 km^2, while 95% isopleth home range sizes for this female ranged from 5,402 km^2 to 12,670 km^2.

Table 5-3. Breeding area home range size (km^2) estimates (50% and 95% isopleths) for three breeding female Peregrine Falcons instrumented with satellite transmitters at two sites in north-central New Hampshire, 2014–2016.

				km^2	
Site	Year	Animal ID	Season	50%	95%
Rattlesnake Mountain	2014	ADF01	Summer	619	12,403
Bear Mountain	2014	ADF02	Summer	846	9,582
Bear Mountain	2015	ADF02	Summer	1,036	12,670
Bear Mountain	2016	ADF02	Summer	664	5,402
Rattlesnake Mountain	2016	ADF03	Summer	597	8,626

5.4 Migration Routes and Timing

Peregrines instrumented with satellite transmitters in this study revealed previously undocumented information about fall and spring migration routes and migration timing. ADF01, the 2014 Rattlesnake female, dispersed from her territory early in the breeding season and made two separate trips to Victoriaville, Canada before returning to the general vicinity of the breeding site in the fall (Figure 5-2). The transmitter instrumented to ADF01 stopped transmitting in the general region containing its nest in Nov 2014 and therefore did not provide clear information on migration routes, wintering areas or dispersal timing.

5.4.1 Fall Migration Routes

ADF02 (the Bear Mountain female) and ADF03 (the 2016 Rattlesnake female) provided four fall migration routes by the time of this report preparation (Figure 5-3). Overall, fall migration routes for AD02 (three trips) and ADF03 (one trip) generally followed similar flightpaths from breeding areas through southwestern New Hampshire, Northwestern Massachusetts, southeastern New York, to northeastern Pennsylvania (Figure 5-3). ADF03 was the primary exception, as it followed a more northerly fall migration route leading to the Catskill Mountain region in New York and ended further south in Lancaster, just west of Philadelphia, Pennsylvania. ADF02 used notably similar fall migration routes in 2015 and 2016, but followed a more southerly route in 2014.

5.4.2 Spring Migration Routes

At the time of this report preparation, one of the three peregrines instrumented with satellite transmitters in this study provided data on spring migration routes from two separate spring migration events (Figure 5-4). ADF03, the second female instrumented from Rattlesnake Mountain, is still in the wintering area at the time of this report preparation, and ADF01 is discussed at the introduction of section 5.4. ADF02 generally followed similar spring migration routes in 2015 and 2016 (Figure 5-4). Overall, spring migration routes were similar to those used in the fall; however, qualitatively, spring migration routes appeared more to be more direct and faster (Figure 5-2).

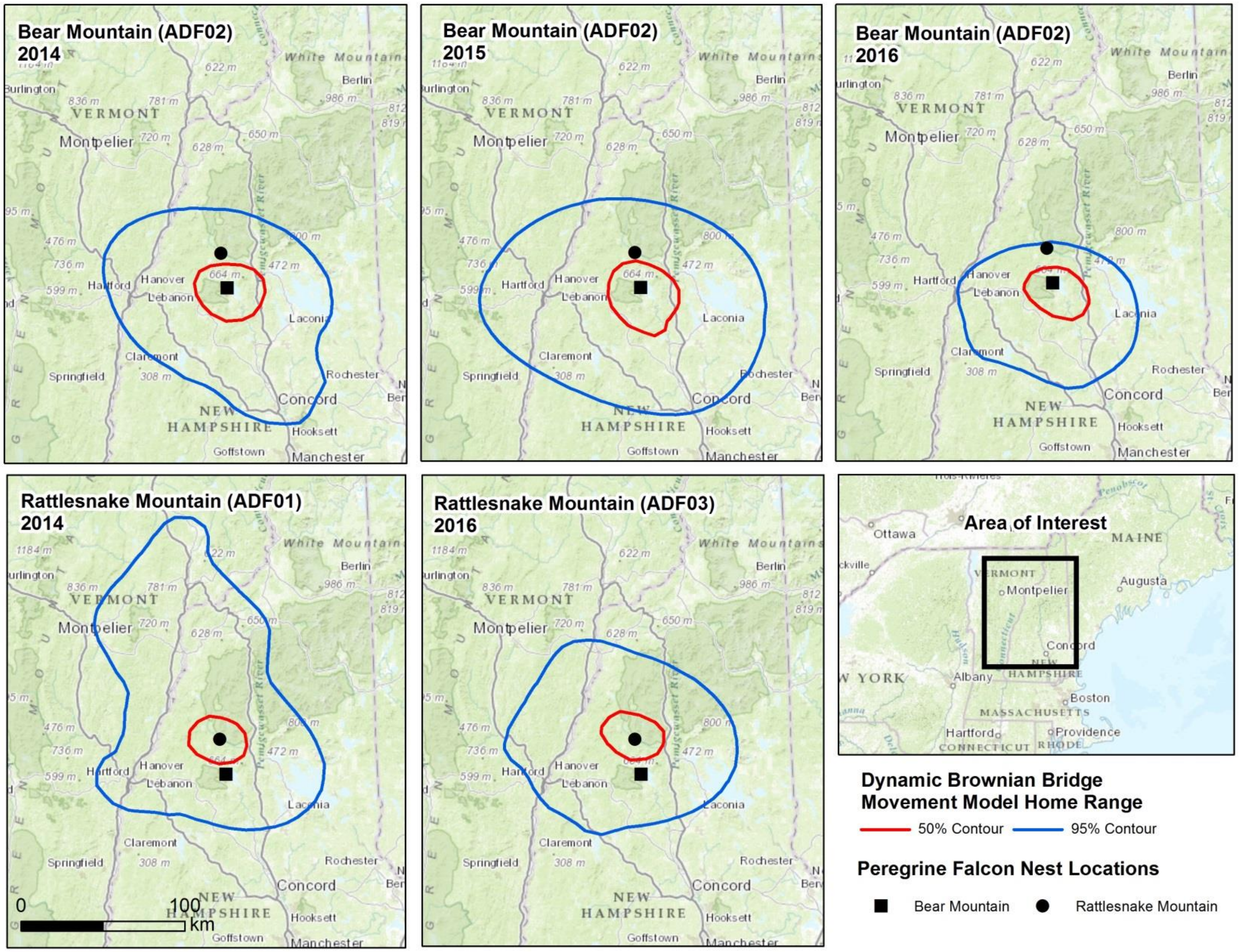

Figure 5-1. Breeding area home range (50% and 95% contour) estimates for three Peregrine Falcons fitted with satellite transmitters in north-central New Hampshire, 2014-2016.

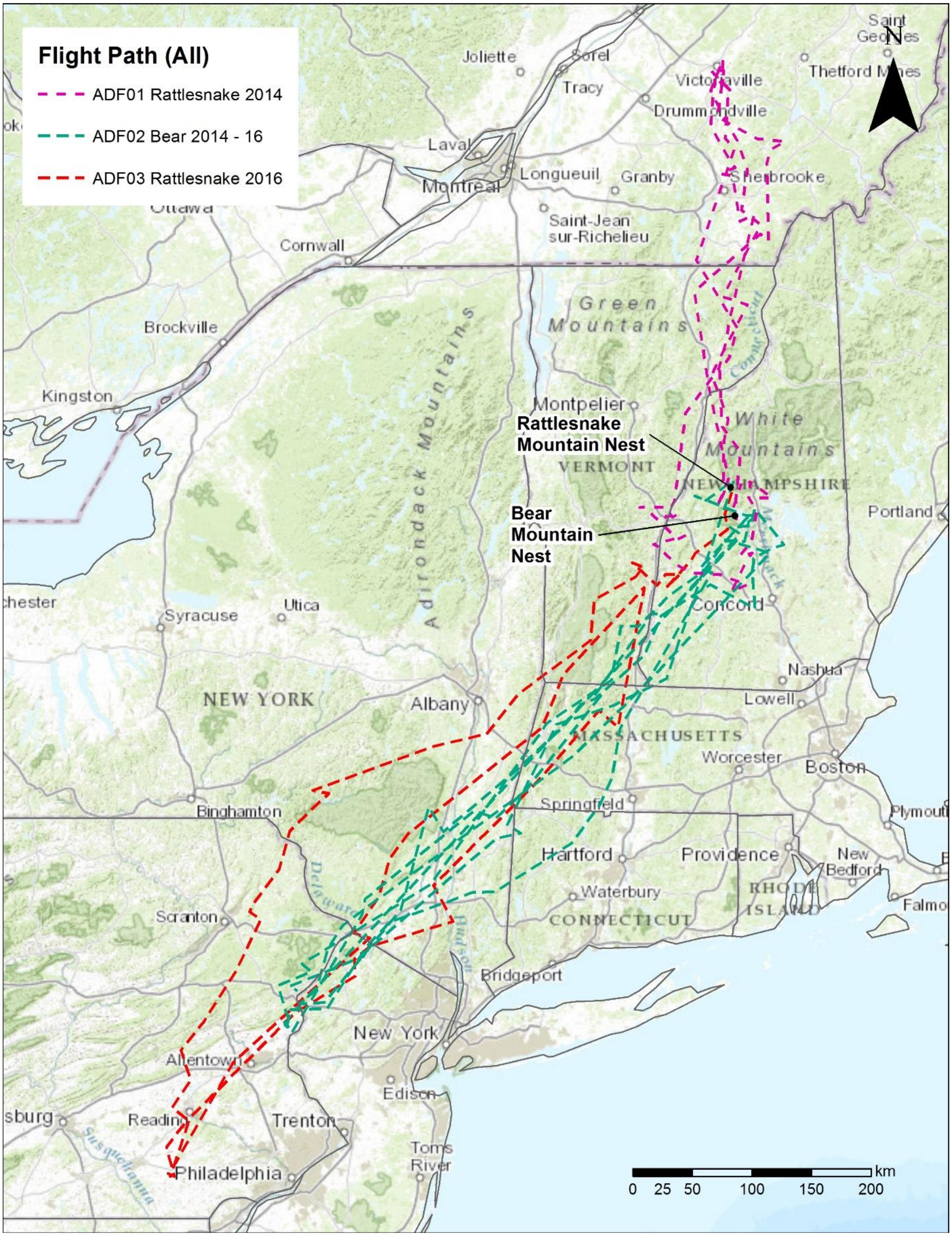

Figure 5-2. All compiled movements of three Peregrine Falcons instrumented with satellite transmitters, 2014-2016. Shown are fall and spring migration events (ADF02 and ADF03) as well as post-breeding movements (ADF01) and pre-breeding (ADF03) movements (see Figure 5-5).

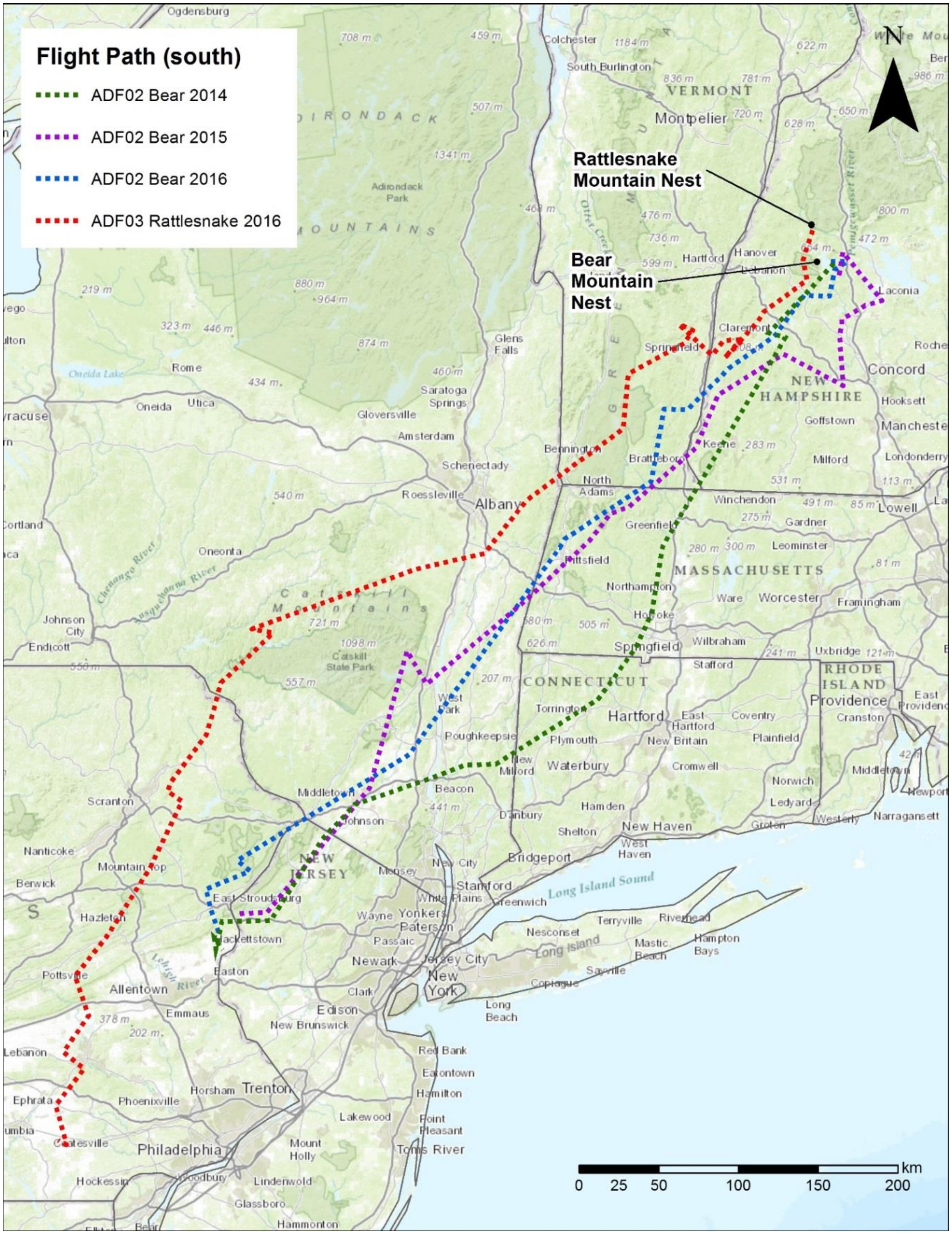

Figure 5-3. Fall migration routes of two Peregrine Falcons instrumented with satellite transmitters in north-central New Hampshire, 2014-2016.

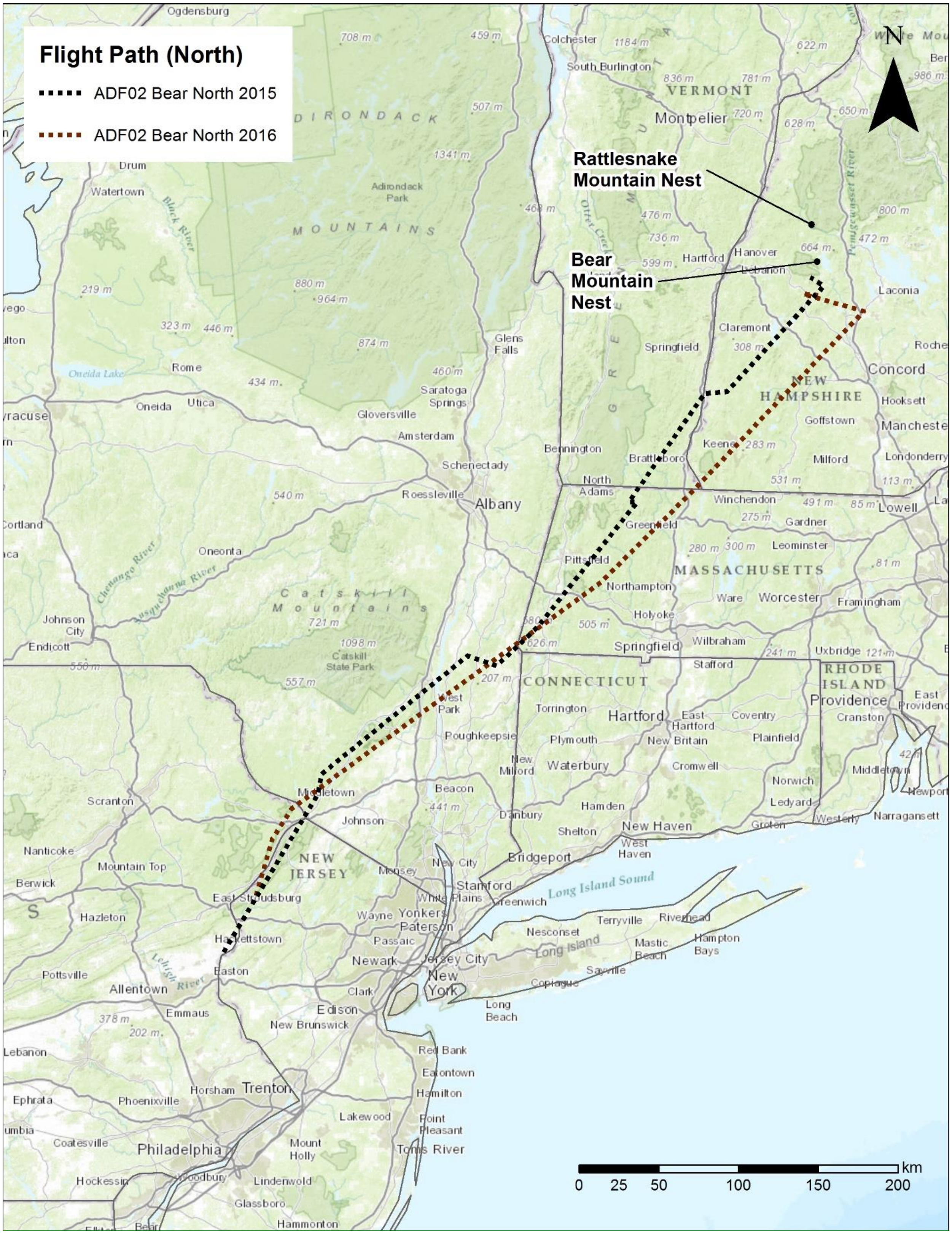

Figure 5-4. Spring migration routes used by Peregrine Falcons instrumented with satellite transmitters in north-central New Hampshire, 2014-2016.

5.4.3 Migration Timing

Peregrines dispersed from breeding areas between 29 Jun and 25 Oct (Table 5-4, Figure 5-5). Based on the early seasonal dispersal dates for both of the females at the Rattlesnake Mountain site in 2014 and 2016 compared to the timing of their nesting chronology, we presume both females dispersed early in the season due to early fledgling mortality. Therefore, only the dispersal dates for the Bear Mountain female over three different seasons can be used to characterize dispersal timing of breeding peregrines in this region. Inter-annual variability in dispersal timing of the Bear Mountain female ranged by 15 days, while dates of arrival in the wintering area in the fall ranged a maximum of 12 days across three years. Timing of departure from the wintering area ranged from 9 Mar to 22 Feb; a 17-day difference. Annual variation in peregrine arrival dates back on territory in the spring varied little between the two years measured: 4 days (12 Mar to 16 Mar).

Table 5-4. Fall and spring arrival and departure dates at breeding and wintering areas for three Peregrine Falcons tracked using satellite telemetry.

Site	Animal ID	Year	Departure Breeding	Arrival Winter	Departure[a] Winter	Arrival[a] Breeding
Rattlesnake Mountain	ADF01	2014	21-Jul[b]	30-Jul[c]		
Bear Mountain	ADF02	2014	**25-Oct**	**31-Oct**	**9-Mar**	**12-Mar**
Bear Mountain	ADF02	2015	**14-Oct**	**22-Oct**	**22-Feb[d]**	**16-Mar**
Bear Mountain	ADF02	2016	**10-Oct**	**19-Oct**		
Rattlesnake Mountain	ADF03	2016	29-Jun[e]	3-Jul[f]		
	Median[g]		**14-Oct**	**22-Oct**	**1-Mar**	**14-Mar**

Comments:

a. Departure Winter and Arrival Breeding dates occur in the year following that listed in each row.
b. Early dispersal from territory to Victoriaville, QC.
c. On 22-Aug 2014 bird leaves wintering area, goes back to breeding area, and arrives on 25-Aug 2014. Departs breeding area a second time on 26-Aug 2014 and travels back to wintering area, arriving on 29-Aug 2014. Bird leaves wintering area a second time on 2-Sep 2014 and travels back to breeding area arriving on 6-Sep 2014 and remains until last transmission on 11-Nov 2014.
d. On 2-Mar 2016 bird leaves breeding area, goes back to wintering area arriving on 2- Mar 2016. Departs for a second time on 6-Mar 2016 and arrives on breeding area on 16-Mar 2016.
e. Early dispersal from territory to Lancaster, PA.
f. On 21-Sep 2016 bird departs wintering area, goes back to breeding area, and arrives on 25-Sep 2016. On 25-Sep 2016 bird leaves breeding area a second time and arrives on 2-Oct 2016.
g. Median dates for ADF02, Bear Mountain only **(calculated on bolded rows only)**.

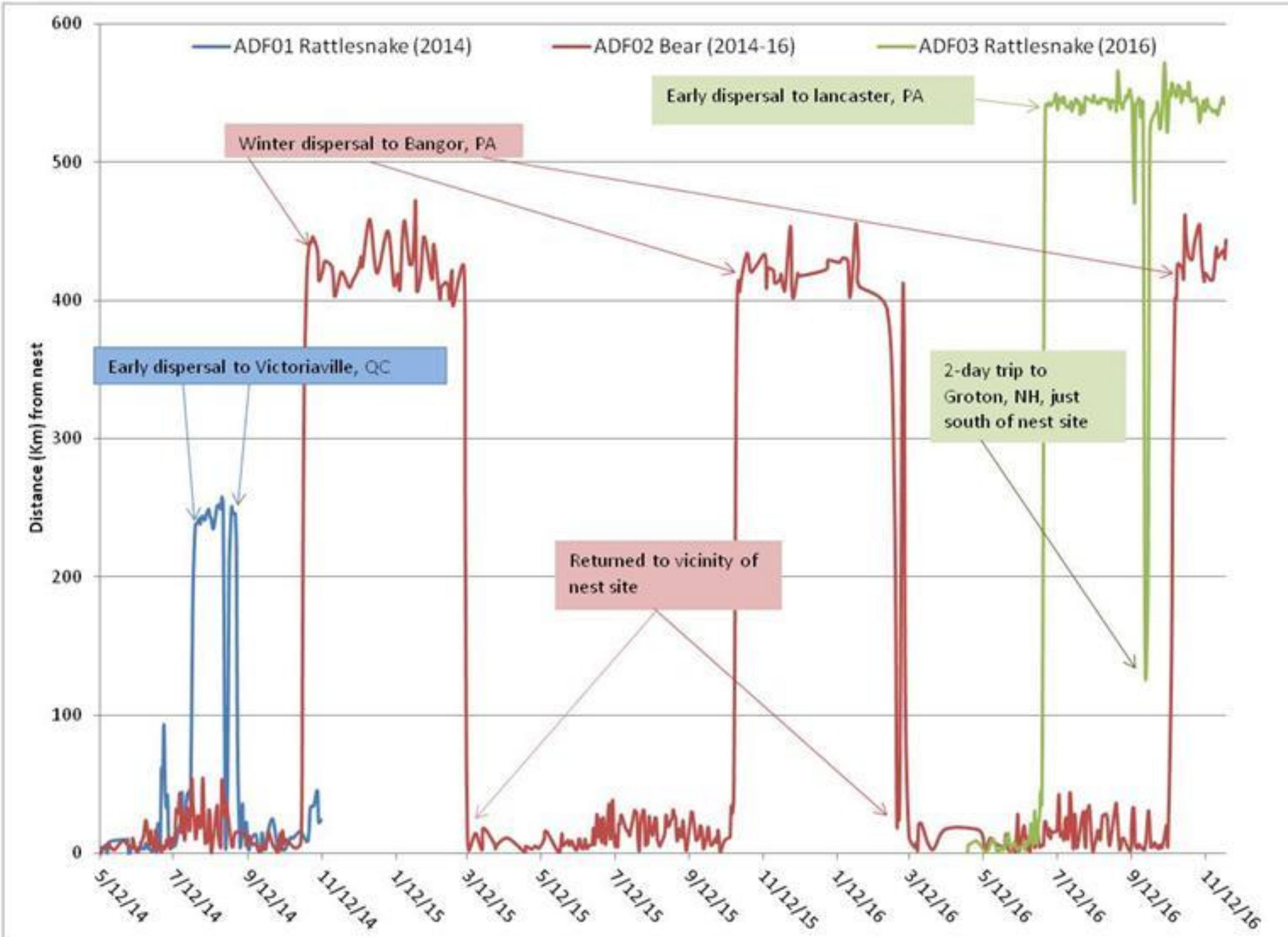

Figure 5-5. Major Migration events for three adult female Peregrine Falcons instrumented with satellite transmitters, as a function of distance travelled from nest sites

5.5 Wintering Area Home Range

Two individuals, Bear Mountain (ADF02) and Rattlesnake Mountain (ADF03) were tracked to wintering areas in two areas of Pennsylvania (Bangor and Lancaster) and enabled estimations of wintering area home range (Table 5-2, Figure 5-6). By the time of this report writing, ADF02, the Bear Mountain female, spent two full winters, and one partial winter in Pennsylvania. The main wintering area for ADF02 was centered around Blue Mountain Ridge, part of the Kittatinny Ridge that bisects much of Pennsylvania into New Jersey. The Kittatinny Ridge comprises a well-known portion of the broader Appalachian Mountain chain. The ridge is forested with open farmland and forest fragments on either side. ADF02 showed notable annual site fidelity to its wintering area during winters of 2014/15, 2015/16, and 2016/17. Overall, the shape of 50% and 95% isopleth wintering area home ranges for ADF02 did not vary notably among winters; all appeared to be more elongated in the latitudinal dimension, and somewhat compressed in the longitudinal dimension. Areas of 50% and 95% isopleth home ranges showed notable annual variation (Table 5-5, Figure 5-6). ADF03, the 2016 Rattlesnake Mountain female, appeared to have a smaller and more southerly home range in its wintering area as compared to ADF02 (Figure 5-6). The wintering area for ADF03 was approximately 76km south of the Hawk Mountain Raptor Count, 83km west of Philadelphia, PA and 15km east southeast of Lancaster, PA. The region within the wintering area home range of ADF03 is mostly comprised of open farmland and forest fragments. While the data included in the wintering area home range estimate for ADF03 was seasonally incomplete (necessitated by the timing of this report writing; 3 Jul – 28 Nov, 2016) comparisons with the 2016 wintering area home range for the Bear Mountain female (ADF02; also seasonally incomplete; 19 Oct – 28 Nov) lead us to believe that the smaller home range of ADF03 was not an artifact of the smaller date range of the data. Rather, ecological factors, such as higher densities and availability of food, probably negate the need for ADF03 to further expand its home range.

Table 5-5. Wintering area home range size (km^2) estimates (50% and 95% isopleths) for two breeding female Peregrine Falcons instrumented with satellite transmitters at two sites in north-central New Hampshire, 2014–2016.

				km^2	
Site	Year	Animal ID	Season	50%	95%
Bear Mountain	2014	ADF02	Winter	2,226	33,925
Bear Mountain	2015	ADF02	Winter	908	13,930
Bear Mountain	2016	ADF02	Winter	1,343	15,149
Rattlesnake Mountain	2016	ADF03	Winter	203	4,465
Rattlesnake Mountain	2016	ADF03	Winter	734	4,995

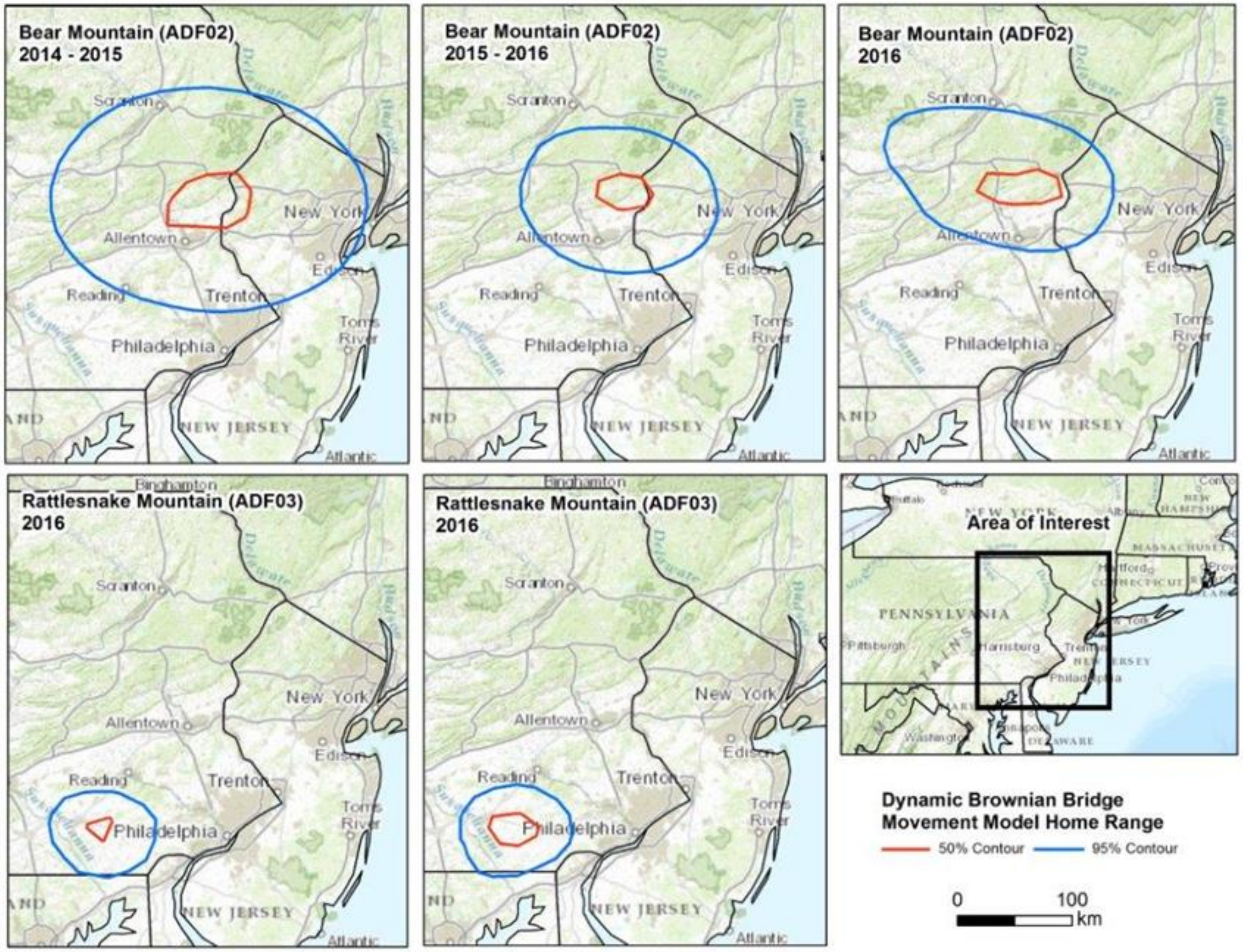

Figure 5-6. Winter home range (50% and 95% contour) estimates for two Peregrine Falcons instrumented with satellite transmitters in north-central New Hampshire, 2014-2016. Multiple maps displayed for ADF03 for two different time periods prior to and after a trip back to the nesting area from the wintering area (see Figure 5-5).

6.0 Discussion

This study provided first of its kind information characterizing various aspects of the ecology of breeding Peregrine Falcons in north-central New Hampshire, including breeding area home range, migration timing, migration routes, and wintering area home range. Similar information is generally lacking for other breeding peregrine populations throughout New England. Particularly unique to this study, we provide information at a level of spatial and temporal accuracy using individual tracking technologies that is generally lacking for breeding Peregrine Falcons as a whole.

6.1 Breeding Area Home Range

Satellite telemetry data in this study has enabled first-time estimates of breeding area home range for peregrines in New England. Previous home range analyses conducted on this dataset using data collected during 2014-2015 seasons were consistent with studies elsewhere showing that home range sizes increased substantially in the post-fledge period (i.e., chick age approx. ≥42 d) compared to the pre-fledge period. Home range areas for the two female peregrines instrumented in this study were notably larger than those reported in most other studies. Unfortunately, home range size estimates are not always directly comparable between studies because field techniques, analysis methods, habitat types, and food availability vary widely between studies and populations. Nonetheless, basic comparisons can still reveal interesting insights about our study population.

A radio-telemetry study of female peregrines in Scotland estimated home range size of 22 to 117 km^2 (analysis method not reported) during the late-nestling and early post-fledging periods (Mearns 1985), while a radio-telemetry study in South Africa estimated two female home ranges at 89.7 and 94.7 km^2 (100% minimum convex polygon) (Jenkins and Benn 1998). We suspect home ranges in these Scotland and South African study areas are notably smaller than those we found in New England due to distinct differences in habitat type and related prey availability. In particular, peregrines within a close proximity to large seabird colonies or large scale agricultural areas can be presumed to have a substantially greater access to food compared to those nesting in temperate forest settings. Radio telemetry-estimated home ranges of peregrines in Colorado are perhaps most similar to the figures in this study. Enderson and Craig (1997) estimated home ranges of 803–1,508 km^2 and 1,152–1,344 km^2 for two female peregrines (95% minimum convex polygon). Their estimates were notably higher than previous studies, which they contributed to vagaries in hunting success. Researchers in Russia tracked peregrines using satellite transmitters; they estimated the average home range size for female peregrines was 9.8 km^2 (95% minimum convex polygon), during the pre-laying, incubation, and early nestling stage combined (home range sizes did not differ between these periods) (Sokolov et al. 2014). In that study, female home ranges increased to 35.1 km^2 in the late nestling period and then tripled to 106.8 km^2 during the post-fledging period. We suspect that substantially larger home range size estimates for peregrines in our study compared to many others are likely due in part to site-specific factors such as geography, land cover, visibility and prey availability. Very few studies have evaluated home range characteristics for peregrines in temperate forest habitats, which presumably presents more challenges for foraging peregrines compared to open-space habitat types.

Size estimates for the home range in breeding areas vary depending on numerous factors including gender, the stage of the breeding cycle, habitat type and prey availability (Enderson and Kirven 1983, Ratcliffe 1993, White et al. 2002, Lapointe et al. 2013). Stage of the nesting cycle has a pronounced influence on peregrine home range and foraging patterns (Palmer et al. 2001). During the early stages of the nesting cycle (incubation, first 2 weeks of nestling rearing), females generally spend more time on the nest than males. Home ranges are larger during later nesting stages as their need to tend the nest decreases and food demands increase (Mearns 1985, Sokolov et al. 2014). The number of young produced and their survival has a significant influence on food demands required from adults, and such demands can influence home range size (White et al. 2002, Lapointe et al. 2013). Other factors related to transmitter technology and spatial analyses can also play a factor in limiting comparability between studies and in influencing larger home range estimates in this study; these subjects are further discussed in section 6.3.

6.2 Migration Routes and Timing

Data charting migration timing and routes used by individual migrant birds is difficult to obtain in the absence of tracking technologies (Seegar et al. 1996, Fuller et al. 1998). Since no previous efforts have been undertaken to document the migration routes for New England peregrines, some of the findings from this study are the only that exist to date for peregrines in New Hampshire or New England. Prior to this study, it has remained unconfirmed whether breeding peregrines in New Hampshire migrated after the breeding season or remained in the vicinity of nest sites. We documented that both focal pairs in this study made long-distance movements to Pennsylvania following the nesting season. To date, the Bear Mountain female has made three separate trips to Pennsylvania using a migration route that cuts through southeast New York. Overall, that female has followed relatively similar flight routes annually during fall and spring movements. Since the 2014 Rattlesnake female returned to the nest vicinity after two long-distance flights to Quebec before transmissions ceased in early November, it is unclear whether this individual was going to remain in the nest site vicinity for the winter or if it was going to migrate. Overall, four tracks from two peregrines appeared to follow a relatively defined corridor during migration that spanned between north-central New Hampshire and eastern Pennsylvania and generally represented a shortest-distance path.

Our sample size is limited in this study, and ecological findings for the peregrines we studied are probably not indicative of patterns used by peregrines throughout the rest of the state or New England. Other studies have shown that peregrines from one breeding area can overwinter in very different regions during different years (McGrady et al. 2002). Peregrines nesting in urban areas, or those within a close proximity to abundant year-round food supplies may be less inclined to migrate than those associated with temperate forests where winter food supply is presumably notably more limited. A nest camera on a peregrine nest in southern Maine has documented nest visits on a roughly year-round basis, suggesting that this pair, near an urban center, does not migrate (P. Keenan, BRI, pers. comm.). Many of the resident peregrines in urban areas in New Hampshire and Massachusetts are thought to be year-round residents.

The peregrines tagged in this study have provided first-time characterizations of the timing of departures from both breeding and wintering areas, and the timing required to migrate between them. We suspect that early fledgling mortality influenced females from Rattlesnake to depart early in 2014 and 2016; those departures were relatively late in the summer and spanned a relatively large period (21 Jul and 29 Jun). By comparison, the Bear Mountain female departed her nesting area annually between 10 and 25 October over three years (median departure date: 14 October, 2014-2016). The Bear Mountain female took between 6 and 9 days to migrate to the wintering area, and her trips back to the breeding area in the spring took between 3 and 10 days. Interestingly, as can be observed in Figure 5-5, two peregrines tagged in this study made rapid, round-trip 'recon trips' from wintering areas to breeding areas and back again during the spring of 2016 (ADF02 Bear), the fall of 2016 (ADF03 Rattlesnake). Similarly, ADF01, the 2014 Rattlesnake female, made multiple quick-succession trips between Victoriaville, Canada and the vicinity of the breeding area in 2014. Such events have rarely been documented in such detail for this species. We suspect breeders use these trips to evaluate the status of snow and ice conditions on cliffs and related food supplies in breeding areas.

6.3 Wintering Area Home Range

The wintering ecology of peregrines is poorly studied (Palmer 1988, Ratcliffe 1993, McGrady et al. 2002). This study is the first to estimate wintering area home range for peregrines from the New England breeding population. Our limited findings are consistent with those elsewhere indicating peregrines can have high levels of fidelity to wintering areas (McGrady et al. 2002). The characteristics of wintering areas differed between individuals; the wintering area for ADF02 appears to be using areas centered upon a forested ridgeline, while ADF03 is likely using agricultural areas. Both females, however, are overwintering within commuting distance to the Kittatinny Ridge along the Appalachian Mountain chain.

ADF02, the Bear Mountain female, spent three consecutive winters in the same area in the vicinity of Bangor, PA. Overall, the shape of the wintering area home range for ADF02 varied little annually; however, annual changes in home range sizes were considerable. The wintering area home range for ADF03, the 2016 Rattlesnake female, was considerably smaller compared to that of ADF02. Few literature comparisons report wintering area home range. McGrady et al. (2002) estimated the home range of wintering peregrines on the Gulf of Mexico coast in Tamaulipas, Mexico. Estimates (90% convex polygon) ranged widely among individuals and years, with an overall two-year mean (± SD) of 169 ± 191 km^2; far lower than those estimated in this study. Ganusevich et al. (2004) estimated the home range (90% convex polygon) of a single peregrine that wintering inland in southern Spain as 213 km^2.

We suspect that both biological and analytical reasons might cause winter home range size estimates in this study to be larger than the few reported elsewhere. As noted for summer home range in section 6.1, significant differences among habitat types comprising different study sites among studies limits the comparability of wintering home range estimates between studies. For example, the area in which peregrines overwintered in the McGrady et al. (2002) study was an estuary in Mexico. This area, and also those identified as peregrine wintering areas in Ganusevich et al. (2004), is likely to harbor high prey concentrations compared to wintering areas identified in

Pennsylvania. In addition, several aspects of our analysis (i.e., 95% isopleth in our study vs. 90% minimum convex polygon, use of the dBBMM in our study) may have also inflated home range estimates in our study. Regular gaps in location estimates, likely caused by weather or feather coverage of solar panels, likely influenced the higher area of the 95% isopleth home range estimate in 2014 compared to subsequent years for ADF02. Past analyses of peregrine space use data from this study found that home range estimates generated using a dBBMM were often 25 to 50% larger than those generated using Kernel Density Estimates. Future analyses of space use data in this study will be reevaluated considering other analysis methods; however, the magnitude of the differences between home range areas in this study compared to most comparison studies is such that any changes in analyses are highly unlikely to change the overall conclusions of this study.

6.4 Conclusions

Findings from this study have improved our understanding of the ecology of peregrines in New England. Few other studies have attempted to collect information on the home range, migration routes and wintering areas of peregrines nesting in temperate forest habitats. While findings provided insights on three different pairs at two different nesting areas in north-central New Hampshire, information may be useful in informing management and conservation decisions elsewhere in New England. Our study suggests that peregrines nesting in temperate forest habitats require a relatively large home range area in order to meet their energetic needs and those of their developing young. In general, home range sizes for the individuals tracked in this study appeared to be notably larger compared to most comparisons; however, the majority of comparison studies emphasized peregrines nesting in notably different habitat types (i.e., coastal and arctic regions) and differences in tracking technologies and analysis methods limit direct comparisons. Regardless, it seems highly plausible that peregrines foraging in mountainous temperate forest regions would require larger home ranges compared to those nesting in coastal or arctic regions since (a) prey abundance is notably higher in coastal and arctic regions, and (b) foraging efficiency is likely higher in open habitats. Indications from satellite telemetry suggests that females departed the Rattlesnake Mountain territory earlier than would be consistent with chick rearing in both years, suggesting early fledgling mortality occurred in both years. Early fledgling mortality commonly goes undetected in raptor surveys and as a result, some intermittent raptor surveys may overestimate of population productivity (Ewins and Miller 1995, Steenhof and Newton 2007).

Satellite-instrumented peregrines in this study provided first-time indications of specific fall and migration routes used by peregrines. The spatial and temporal characterizations of peregrine travel routes during migration are often desired to help inform decisions related to the siting and operational timing of wind energy facilities throughout known or potential bird migration corridors (Miller et al. 2014, DeSorbo et al. 2015, Mojica et al. 2016).

This is one of a very limited number of studies characterizing the home range of peregrines in their wintering grounds. Peregrines spend a considerable portion of the year in the wintering areas, but research and conservation efforts have been disproportionately focused on breeding areas. The lacking emphasis on the wintering ecology of peregrines may limit or undermine conservation efforts (McGrady et al. 2002, Ganusevich et al. 2004). It remains unclear to what extent the findings from this study may be reflective of peregrines in other regions of New Hampshire and New England. Efforts to conduct similar studies on peregrines in other areas and other settings (i.e., peregrines nesting near agricultural areas, urban settings) would greatly improve our understanding of the ecology of peregrines throughout New England.

6.5 Acknowledgements

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