Population estimation, harvest management, and landscape-scale spatial ecology of wild turkeys in Maine

Year 1 Progress Report

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Disclaimer: The findings contained in this report represent preliminary results of ongoing research, and they should be cited as unpublished data until they have undergone peer review and publication. We expect that estimated values and interpretation of results could change as additional years of data are collected. These changes will be incorporated into future reports and final published products.

Abstract

Wild turkeys were extirpated from Maine in the early 1880s due to overharvesting and habitat loss. The population's recovery since can be attributed to a successful reintroduction campaign, which has led to viable populations that extend beyond their historic range and into areas that likely lacked turkeys prior to European settlement. Here we report on data collected and preliminary results from the first year of a multi-year research project seeking to aid in the Maine Department of Inland Fisheries and Wildlife (MDIFW) goal to "maintain a healthy turkey population below biological carrying capacity while providing hunting and viewing opportunity." To that end, we used a combination of banding, VHF radio-telemetry, and GPS transmitters to collect data on wild turkey survival, reproduction, harvest, and seasonal space use. Incorporating science-based approaches to estimate population size and gaining a better understanding of overall wild turkey ecology in Maine will guide the management and wise use of this resource. Disease is also an often overlooked aspect of population ecology that may affect MDIFW's ability to meet management goals. Therefore, we also examined the effect of a recently detected or emerging viral pathogen, Lymphoproliferative Disease Virus (LPDV), on wild turkey individual and population health. In 2018, we established four study areas in Penobscot, Hancock, and Cumberland counties. During January through March of 2018, we captured 123 unique wild turkeys among these four study areas. We collected blood from 56 female, 33 male, 65 adult, and 24 juvenile wild turkeys. Sixty-nine (78%) of the 89 individuals sampled were infected with LPDV. We monitored survival of 54 hens using a combination of VHF and GPS backpack transmitters. Weekly survival rates indicated that LPDV-infected hens experienced lower survival compared to uninfected hens; the cumulative hen survival rate from capture to early November was 0.775 (0.364–0.939 95% CI) for uninfected hens and 0.299

(0.151–0.464 95% CI) for LPDV infected hens. We located and monitored 31 nests from 25 individual females. Daily survival rates for nests did not change according to individual hen characteristics (including LPDV status), but did decrease with age of the nest. The probability of a nest surviving to 38 days (the expected total length of laying and incubation) was 0.268 (0.076–0.504, 95% CI). We also quantified seasonal home ranges for 10 GPS-marked hens using dynamic Brownian Bridge Movement Models. Seasonal 95% Utilization Distributions were produced for each individual, with winter seasonal home ranges averaging 1.28 km^2 (0.81-2.38 km^2) compared to 1.95 km^2 (0.79-3.26 km^2) for nesting seasonal home ranges. Seasonal movements between winter and nesting home ranges averaged 4.26 km, and ranged from a low of 1.65 km to a high of 9.08 km. We will continue collecting data through 2020, and will expand these analyses in future years.

Introduction

The restoration of wild turkeys to Maine has been very successful, as evidenced by a robust population throughout their historical range within the state, and viable populations that now extend into areas that likely lacked turkeys prior to European settlement. Wild turkeys are now established and successfully reproducing in all Maine counties. Over the last 30 years the wild turkey program has grown from one focused on re-establishment and very limited harvest, to one that is now focused on relatively liberal spring and fall hunting seasons. Initially the wild turkey hunt was conservative; the first spring season in 1986 was limited to 500 hunters resulting in a harvest of 9 birds. Presently both spring and fall seasons are open to all interested participants, and the program supports around 19,000 wild turkey hunters, including an estimated 2,500 youth. In recent years Maine hunters have averaged a spring harvest of 6,000 bearded turkeys, and a fall harvest of 2,000 turkeys of either sex (MDIFW 2017). A recent assessment of

wild turkey populations across the country suggests that Maine's eastern wild turkey populations is increasing at one of the higher rates (Erikson et al 2016).

With the success of this reestablished population, MDIFW is now faced with the challenges of managing for a viable turkey population and a successful hunting program, while simultaneously addressing social and ecological issues associated with an abundant wildlife species that often lives at the human/wildlife interface. Maine's wild turkey population continues to increase and expand into nearly all corners of the state. This is an obvious benefit to wild turkey hunters by providing opportunities for quality hunting, and recent surveys suggest that 92% of Maine turkey hunters are satisfied with their wild turkey hunting experience in the state (Responsive Management 2016). However, increases in wild turkey abundance also inherently increase the potential for human-turkey conflicts (Miller et al. 2000), and the same survey revealed that approximately 30% of Maine residents believe the abundance of wild turkeys should be reduced in the state (Responsive Management 2016). Thus, MDIFW is likely to face societal pressures in coming years to manage Maine turkey populations based on competing objectives.

Our project began in 2018 as a component of MDIFW's implementation of the Big Game Management Plan. In this new management plan, goals and objectives were established through a thorough public input process to guide the Department's wild turkey management over the next 10 to 15 years. Our project will provide data to address the population and habitat goal to "Maintain a healthy turkey population below biological carrying capacity while providing hunting and viewing opportunity." This research will also examine risk factors associated with a recently detected or emerging viral pathogen, Lymphoproliferative Disease Virus (LPDV), in wild turkeys in Maine; data which is important for better understanding and predicting the local

impacts of pathogen infection on turkey populations. Monitoring and understanding the role of pathogens has been identified as a key priority in the MDIFW's Big Game Management Plan.

Greater densities of wildlife are often associated with heightened risk of disease transmission, as well as increased potential for interaction with domestic poultry resulting in a higher risk of pathogen spillover. Information on pathogen prevalence and distribution in Maine wild turkeys is scarce, and little is known about the effects of disease on individual and population health, the potential for disease transmission across the state, or transmission to humans, other wildlife, or domestic animals. In other wild turkey populations, greater than 25% of morbidity or mortality cases have been attributed to infectious diseases (Van Riper III and Forrester 2007). Avian pox, characterized by skin lesions that often result in emaciation or predation (Macdonald et al. 2016), is considered a major contributor to this mortality (Van Riper III and Forrester 2007). LPDV is an avian retrovirus that was recently identified in wild turkeys in the United States (Allison et al. 2014) and manifests similarly to avian pox. Previously, LPDV had only been documented to naturally occur in domestic turkeys in Israel and Europe (Biggs et al. 1978), and was found to also cause disease in experimentally-infected chickens (Ianconescu et al. 1983). Following initial detection in 2009 in the United States, a survey of hunter-harvested wild turkeys from 17 states revealed an overall LPDV prevalence of 47%, with variation by state (Thomas et al. 2015). In Maine, prevalence was found to be considerably higher (>80%). While the majority of infected birds appear asymptomatic (Thomas et al. 2015), infection can cause skin lesions and lymphoid tumors in organs, including the spleen, thymus, liver, and pancreas (Biggs et al. 1978). Other studies have linked LPDV infection with mortality of wild turkeys (Allison et al. 2014), and domestic turkeys (Biggs 1997) suggesting the disease could have negative effects on population viability.

In modern wildlife management, a number of toolkits exist for addressing complex management challenges in the face of uncertainty. Adaptive harvest management and structured decision making are two examples, and these tools clearly have high potential for addressing management questions that are unique to wild turkeys (e.g. Robinson et al. 2017). However, nearly all comprehensive approaches to management require adequate data to inform decisions, and much of the information necessary for informed decisions about wild turkey management is currently lacking in Maine. The overall goal of our project is to produce rigorous information on a host of biological processes for turkeys in Maine, including population dynamics, survival and harvest rates, habitat use and reproductive success, seasonal movements, and disease prevalence and transmission. This information can then be used to develop tools for wild turkey management. Our specific objectives are to 1) improve MDIFW's ability to monitor wild turkey population trends by exploring population models that incorporate variables such as weather, productivity, harvest, sex, age, natural mortality, pathogen infection and other factors; 2) improve the quality and availability of wild turkey harvest data; 3) inform management that can be used to stabilize wild turkey populations in portions of southern and central Maine and increase the size and distribution of turkey populations in portions of northern, eastern, and western Maine; and 4) identify individual risk factors of LPDV infection and explore the relationship between LPDV infection and both nest success and survival to elucidate population-level impacts in wild turkeys in Maine. In this report we detail results from our first year of data collection, which provide preliminary insights to some of these objectives.

Methods

Study Areas

Wild turkey captures took place in 4 study areas located in Wildlife Management Districts (WMD) 17, 18, 21, and 26 (Figure 1). Our north-western study area (NW) is located in Penobscot County, Maine, USA (44.98912°N, 69.07784°W). NW is within WMD 17 and encompasses the towns of Exeter, Corinth, Charleston, and Bradford. Property within NW is primarily privately owned and its land use is characterized by rural agricultural and pasture fields intermixed with forested areas. Human population density within NW ranges from fewer than 50 up to 100 individuals per sq. mile (USDC 2012) and the landscape has moderate road coverage with both paved, gravel, and dirt roads common in rural areas. NW is in central Maine and experiences moderate winters compared to more Northern regions of the state, but more severe winter weather than more southern regions.

Our north-central study area (NC) is also located in Penobscot County (44.91855°N, 68.66162°W). NC is primarily in the northern part of WMD 26, with some overlap of WMD 17 and 18. Research takes place within the towns of Orono, Old Town, Veazie, and Bangor. This area is primarily characterized by suburban and urban human residential areas with population density ranging from 100 to greater than 500 individuals per sq. mile (USDC 2012). Road density and residential development is higher in NC compared to our other study areas; however, forested area and agricultural lands are still present in the study area, albeit far more sparse and isolated compared to the other study areas. NC is in the same climatic zone as NW and experiences comparable weather.

Our north-eastern study area (NE) is located in both Penobscot and Hancock County, Maine, USA (45.01749°N, 68.39635°W). NE is located in WMD 18 between the towns of

Greenfield and Amherst. Human population density in NE is very low with fewer than 50 individuals per sq mile (USDC 2012), and includes large expanses that are completely uninhabited and undeveloped. Despite this, substantial human activity occurs in the form of forestry operations within the privately-owned commercial forests that dominate the area. Moderate road cover of maintained gravel and dirt roads are also present, although many of these roads become inaccessible in the winter after considerable snowfall. NE is in the same climatic zone as NW and NC, and experiences similar weather patterns.

Our southern study area (S) is in Cumberland County, Maine, USA (43.71543°N, 70.39268°W), and was chosen to represent a distinctly different region of the state than the previous three study areas. S is within WMD 21 and located between the towns of Gorham and Gray. The landscape within S spans a gradient between rural areas and the suburban edge of the greater Portland metropolitan area. This gradient of land use leads to mixed landcover and human activity levels. The landscape is a mix of residential areas, agricultural fields, and fragmented forests. Human population density in this area is greater than 200 individuals per sq. mile (USDC 2012). Being farther south and closer to the coast, S is in a separate climactic zone compared to the other 3 study areas and experiences generally milder weather compared to NW, NC, and NE.

Wild Turkey Capture

Capture of wild turkeys took place from January through March 2018. During this time of year, wild turkeys form large flocks and are more likely to frequent bait sites due to snow obscuring normal food sources. We trapped both male and female wild turkeys using either drop nets (Glazener et al. 1964) or rocket nets (Grubb 1988). Turkeys were weighed (+/- 0.5 lbs) using a spring scale. The sex and age of each bird was assessed based on its plumage and

presence of a beard and spurs (Dickson 1992). Each turkey received either a size 22 (female) or 28 (male) butt-end aluminum leg band (National Band and Tag Co., Newport, Kentucky, USA) with an identification number for the bird as well as contact information for reporting the bird if harvested or otherwise discovered dead. Each turkey also received an additional mark in the form of an aluminum rivet band, patagial wing tag, or color leg band. During subsequent years we will be using only a combination of aluminum and rivet bands. Disease processing for each captured individual included collecting blood from the brachial vein into two separate tubes for (1) pathogen coinfection analysis and (2) LPDV diagnostics and genetic characterization. Three cloacal swabs were also collected for gut microbiome analysis, salmonella analysis, and virus detection. Tarsus length was measured for all birds as well as spur and beard length, if present.

Wild turkey hens were fitted with a VHF or GPS transmitter, or banded only, based on trap site location, sex and age, and status of deployed transmitters. We deployed transmitters to disperse them within and among the four primary study areas, with a goal of maintaining a 50:50 ratio between adult and juveniles females when possible. VHF packages consisted of an 80g transmitter from Advance Telemetry Systems (Isanti, Minnesota, USA) attached using a backpack-style harness. GPS packages were 90g Litetrack GPS transmitters with a built in VHF component (Lotek Wireless Fish and Wildlife Monitoring, Newmarket, Ontario, CA), also attached with a similar backpack-style harness. We only deployed GPS transmitters in the three northern study areas (NW, NC, NE) as these study areas were located within the same climatic zone and represented the major landcover types (agricultural, suburban-urban, forested) relevant to our objectives on movement and space use of wild turkey hens. Transmitters were secured to each bird using paracord tied around the base of both wings. Any transmitters that were recovered and still functioning were reserved so they could be redeployed at a later capture.

Transmitters did not exceed 4% body mass, and all capture and handling of wild turkeys was approved by the University of Maine Institutional Animal Care and Use Committee (IACUC Protocol # A2017_11_03).

GPS Transmitter Programming and Monitoring

GPS transmitters were programmed to take locations every hour during daylight from November through July, along with a single overnight location to document roosting sites. To extend the battery life of the transmitters to collect data over two nesting seasons per bird, the number of daytime points collected were reduced from August through October to only a morning (9am), afternoon (3pm), and roost location. This model of GPS transmitter requires downloading of data remotely from the transmitter using a Pin Point Commander unit. We located birds approximately once weekly to download waypoint files from the transmitters as needed to preserve battery life. We uploaded waypoint files to Movebank.org (Wikelski and Kays 2018) to ensure a backup and to easily convert them for viewing and analysis.

Adult Survival Monitoring

At least once a week, we recorded a signal from each bird with a VHF or GPS transmitter using a hand-held three element directional antenna and receiver. When a VHF-marked bird was located, the Live-Dead status was recorded based on the speed of the transmitter signal. Status of GPS-marked birds was determined from downloaded locations where sequential points at the same location indicated a potential death. For two weeks following a trapping event, birds were monitored with increased frequency to more accurately detect any trapping-related mortality. Birds that died during this time period were censored from the survival analysis. Following the two-week post-capture period, any deaths were attributed to normal causes and assumed to not

be capture-related. If a bird was suspected dead, the transmitter was approached to determine fate and record a plausible cause of death.

Band Reporting

During the spring and fall wild turkey hunting seasons, an online website and phone line were made available for hunters to report marked birds that were harvested. All wild turkeys harvested by hunters must be reported to a registration station within 18 hours, where band information is also recorded if a hunter declines to contact us directly. For each bird harvested, we obtained identification codes from all tags that remained on the bird, the date and time of harvest, the town in which the bird was harvested, and whether the bird was seen with any other turkeys.

Nest Monitoring

We monitored tagged hens for suspected nesting behavior from April 15 to July 30. Locations of VHF-marked individuals were collected at least twice a week via short-distance triangulation. If a hen was found alive in the same location during two successive visits, she was assumed to be on a nest. After 2 weeks, we approached the hen's location and flushed her to confirm nesting and locate the nest. We then floated 3-4 eggs to determine incubation stage, estimate the initiation date of the nest (Westerskov 1950), and to predict a hatch date. We continued to monitor the nest at least once a week, with a goal of 3 visits per week when possible. We increased visits around suspected hatch date to better determine actual hatch date. Once a hen was suspected to have left the nest, we approached the nest to assess its fate, hatched or failed. If a nest failed, we assessed whether it was abandoned, depredated, or if the hen was predated.

Location data from GPS-marked hens was downloaded weekly and point locations were reviewed in Google Earth. If we observed that a hen was making repeated visits to a single location around the same time of day, or had settled in a location she had previously visited regularly, we assumed she was nesting. Once the hen began regular movements or discontinued regular daily visits in the case of failure during the laying phase, we visited the suspected nest site to verify the nest and its fate. We did not disturb GPS hens while on nests so that we could assess the effect of nest monitoring, which was based on comparison between nests of VHF-marked hens (flushed, regularly visited) and GPS-marked hens (never disturbed while nesting).

LPDV Analysis

Within 24-hr post-capture, blood was processed (see below) and additional aliquots were archived in the -80°F freezer. Blood tubes with no anticoagulant (red-top) were centrifuged to separate the serum layer, which was collected and stored for pathogen coinfection analysis; this serum will be sent to the UMaine Cooperative Extension Veterinary Diagnostic Laboratory to test for individual exposure to other pathogens, such as *Salmonella* and avian pox virus. Anticoagulant-treated (purple-top) tubes were also centrifuged to enable the collection of the buffy coat layer (concentrated white blood cells), which has been shown to have a high sensitivity and specificity for LPDV testing in live birds (Alger et al. 2015). If the buffy coat layer could not be obtained, we used whole blood, which has also been found to be reliable for LPDV diagnostics (Alger et al. 2015). We stored cloacal swabs at -80°F until processing. The swabs were allowed to thaw prior to vortexing with lysis buffer to dislodge material for DNA extraction.

DNA was extracted with the Qiagen DNeasy Blood and Tissue Kit (Qiagen, Valencia, CA). An approximately 413 base pair region of the retroviral *gag* gene in LPDV was amplified

through polymerase chain reaction (PCR), using the following primer sequences: LPDV-F 5'-ATGAGGACTTGTTAGATTGGTTAC-3', and LPDV-R 5-TGATGGCGTCAG GGCTATTTG-3 (Allison et al. 2014). PCR reactions took place in a total volume of 25uL, using the following reagent concentrations: 150 ng to 250 ng DNA extract, 0.2 μM primers (Integrated DNA Technologies, Coralville, IA), 1.5 mM $MgCl_2$ (Promega, Madison, WI), 0.2mM dNTPS (Amresco, Solon, OH), 0.625 units of GoTaq Flexi DNA Polymerase and buffer (Promega). The PCR cycling conditions involved an initial denaturation at 94^0C for 2 minutes, followed by 44 cycles of 94^0C for 45 seconds, 50^0C for 1 minute, and 72^0C for 1 minute, and ended with a final elongation step for 2 minutes at 72^0C. Amplification of the target region was confirmed by electrophoresis, using a 1% agarose gel, and visualized with an Azure c150 Imaging System (Azure Biosystems, Dublin, CA). Both extraction and PCR negative controls were used. In addition, a positive PCR control was included from a previously identified LPDV-positive wild turkey in Maine, courtesy of Dr. Pete Milligan (University of Maine-Augusta). All positive PCR products were sent to the UMaine Sequencing Facility for genetic sequencing in both forward and reverse directions using the same primers listed above. Sequence data will be used for genetic characterization of the virus and to examine LPDV transmission dynamics.

Analytical Methods

Hen Weekly Survival Rate

We compiled weekly live/dead status for each VHF- and GPS-marked wild turkey hen to create an encounter history which indicated the week the hen was captured (First Found), the last week it was found alive (Last Alive), the last week it was checked (Last Checked), and its final status at the end of the monitoring period for this report (Fate). We modeled the female weekly survival probability using the nest survival model in the RMark package (Laake 2013) in

program R (R Core Team 2013). We chose this approach because it allowed for irregular monitoring of individuals, which best fit our study design where sometimes we were unable to locate hens following extended or irregular movements. We compared models of weekly survival probability using Akaike Information Criterion (Burnham and Anderson 2003). Models considered were based on month of the year, season of the year (determined by movement behavior, see below), age of the turkey, study area, and LPDV infection status. We identified supported variables by comparing univariate models against a null, where covariates of models with $\Delta AIC \leq 2.0$ compared with the null were combined into a best fit model. We evaluated the importance of variables by examining the 85% Confidence Limit (CL) of each parameter coefficient (Arnold et al 2010), where variables were supported if the CL did not include zero.

Daily Nest Survival Rate

We modeled nest daily survival rate (DSR) using the RMark package (Laake 2013) in program R (R Core Team 2013). To produce a probability of nest success, we exponentiated the DSR by the average nest exposure period (average length of laying and incubation periods observed during this study). We compared models of nest survival to identify important predictors of nest success. Models were based on day of the year, age of the nest in days, nest initiation date, age of the turkey (first nesting season vs second or later nesting season), study area, transmitter type (VHF vs GPS), and LPDV infection status. We compared model sets individually for DSR using Akaike Information Criterion (Burnham and Anderson 2003) and parameter coefficients using the same criteria described for our survival analysis above.

Seasonal Home Range and Movements

We fit a dynamic Brownian Bridge Movement Model (dBBMM) to the movement track of each GPS-marked hen using the move package (Kranstauber and Smolla 2013) in program R (R Core Team 2013). We *a priori* described expected categories of seasonal movement behavior, which included winter, winter to pre-nesting movement, pre-nesting, and summer. Brownian motion variance (σ_m^2) is a measure of how irregular the path of an animal is between successive locations (Byrne et al 2014) by accounting for changes in movement distance and direction. We delineated seasonal changes in movement behavior by quantifying changes in daily σ_m^2 over time (Kranstauber et al 2012), averaged across all marked hens. Based on patterns of individual changes in σ_m^2, we subset movement tracks into seasonal categories of movement and created individual utilization distributions (UDs) for each category of movement for each hen. If a hen did not survive from capture to August 1, it was censored from estimation of average total range size. Seasonal movements between winter and nesting home ranges were quantified as the distance between the centroids of the winter range and the nesting range.

LPDV Analysis

All pathogen data was analyzed using Program R (R Core Team 2013). We used a Generalized Linear Model assuming a binomial distribution with a logit link function to test for a significant difference in LPDV prevalence by the categorical variables of age, sex, site, and study area. Since age was found to be significant (results below), we subsequently used the same model to assess the relationship between spur length (as a proxy for continuous age) and LPDV infection in male turkeys.

Evaluation of Closed Capture Removal Models

We conducted a pilot simulation analysis to assess the potential use of closed capture removal models to estimate turkey population size from harvest reporting data. Results and background of that analysis were presented in a previous report (Mangelinckx and Blomberg 2018).

Results

From January through March of 2018, we captured 124 unique wild turkeys between our four study areas. Of these, 72 turkeys were captured at NW, 4 were captured at NC, 20 were captured at NE, and 28 were captured at S. 26 of these were identified as adult males, 13 as juvenile males, 63 as adult females, and 22 as juvenile females. We fitted 42 females with VHF transmitters, 34 on adults and 8 on juveniles, and 12 with GPS transmitters, 9 on adults and 3 on juveniles (Table 1). Five of 39 males banded were harvested and reported during the 2018 spring turkey hunting season, while 2 of the 85 females we banded were reported during the 2018 fall either sex hunting season. In this later case, one radio-marked hen was shot, recovered, and reported, while a banded-only female was shot and not initially recovered but was found later and reported.

We collected blood from 89 turkeys (56 female and 33 male; 65 adult and 24 juvenile). Sixty-nine (78%) of the 89 trapped wild turkeys were infected with LPDV. The 89 birds sampled spanned 10 sites within the four study areas. Twenty birds were sampled from NE, 4 from NC, 37 from EC, and 28 from S.

Weekly Adult Survival Rate

Of 54 hens fitted with a transmitter in 2018, 12 were censored due to death within the first two weeks after release from capture. The majority of censored turkeys appeared to be killed by predators around capture areas, however we cannot rule out death due to other causes (e.g. capture myopathy) followed by scavenging. Of the remaining 42 hens, 21 survived until November 11, 2018.

Our top model of weekly hen survival probability was based on contraction of LPDV (ΔAIC = 0.0; Table 2). Hens infected with LPDV had a lower weekly survival probability (β = -1.56; -0.49 – -2.64, 85% CI) compared to uninfected hens. The weekly survival probability was 0.994 (0.976–0.998, 95% CI) for uninfected hens and 0.971 (0.955–0.981, 95% CI) for LPDV infected hens (Figure 2). When exponentiated across the length of the study thus far (41 weeks), this difference in weekly survival rate translates to a cumulative probability of survival of 0.775 (0.364–0.939 95% CI) for uninfected hens compared to 0.299 (0.151–0.464 95% CI) for infected hens.

There was some support for our Month model (ΔAIC = 4.49; Table 2). Although it did not perform well enough to be considered the best model, it did perform better than the null model (ΔAIC = 4.71; Table 2) and showed that weekly survival rate was variable throughout the length of the project (Figure 3). The lowest weekly survival probability occurred during the month of May (0.934; 0.881 – 0.964, 95% CI) and the highest was in July (1.000; 0.999-1.000, 95% CI). We did not find strong support for differences in weekly survival rates between seasons, age classes, or study areas (Table 2).

Daily Nest Survival Rate

During Spring 2018, we located 31 wild turkey nests, 27 belonging to GPS or VHF-marked hens and 3 belonging to unmarked hens. Of the 27 nests of marked hens, 22 were first attempts, 4 were second attempts, and 1 was a third attempt. The average clutch size of VHF-marked hens was 10.9 ($\pm$3.4 SE). Six of 22 first attempted nests hatched, 2 of 4 second nests hatched, and the single third attempt nest hatched. The average dates of initiation for first, second, and third nests were May 2, May 27, and June 23 (single nest), and average predicted hatching dates were June 7, July 3, and July 29 (single nest).

The top model for predicting nest DSR was based on a linear relationship with age of the nest (ΔAIC = 0.0; Table 3). As nest age increased in days, the probability of daily survival decreased (β = -0.054; -0.017 – -0.091, 85% CI). Nest DSR was 0.996 (0.969-0.999, 95% CI) on Day 1 compared with 0.974 (0.956-0.985, 95% CI) on Day 38, the approximate hatch date for a bird with the average clutch size of 10.9 (Figure 4). The probability a nest survived a 38-day exposure period was 0.268 (0.076–0.504, 95% CI; Figure 5). We did not find strong support for differences in nest DSR when comparing nest initiation date, LPDV infection, age of the hen, transmitter type, study area, or time during the year (Table 3).

Seasonal Home Range and Movements

Of the 12 hens fitted with GPS transmitters, 2 died within the first two weeks post-capture and were censored from analysis. An additional bird died while moving from her winter home-range, and one bird died while incubating a nest. One additional female has been missing since April 19, 2018 despite frequent searches with hand held, truck mounted, and aerial telemetry. Data for these females were included in the analysis until their death or disappearance.

The average area of use (95% UD) for GPS-marked females that survived from capture until August 1 was 7.13 km^2 (3.00 km^2 – 21.53 km^2; Table 4, Figure 6, 7). The average area of seasonal use (95% UD within each discrete season) was 1.28 km^2 (0.81 km^2 – 2.38 km^2) for wintering home ranges, 1.95 km^2 (0.79 km^2 – 3.26 km^2) for nesting home ranges, and 7.33 km^2 (0.18 km^2 – 27.33 km^2) for summer home ranges (Table 4; Figure 8, 9). The average seasonal movement distance between wintering home range and nesting home range was 4.26 km, and individual female movements ranged from 1.65 km to 9.08km (Figure 8, 9). Qualitative observations of hen movement indicated that individual females employed a variety of movement strategies, including among females from within the same study area or winter flock (Figure 10).

Brownian motion variance (σ_m^2) appeared to correspond with changes in seasonal movement behavior throughout the year (Figure 11). Using the average daily σ_m^2 calculated from full dBBMM assessment of home ranges for January through July, we identified 4 periods of distinct movement (Figure 12). The winter period was characterized by steady, low values for σ_m^2 as females made regular movements throughout relatively consistent winter home ranges. Females initiated movements from winter to nesting ranges shortly after the beginning of April, when σ_m^2 values gradually increased for a relatively short period (~3 weeks). Females entered nesting home ranges during the last week of April, which was characterized by the greatest daily average σ_m^2 values as females established nest sites and began laying eggs. Average motion variance gradually decreased as birds began incubation, but then increased again (the second peak in Figure 12) when nests hatched and females moved into their summer brood ranges, or as nests failed and females attempted a second nest. During July, the beginning of the summer

brood rearing season, σ_m^2 values began to level off at values slightly higher than winter but lower than peak movement times during pre-nesting.

LPDV Analysis

We did not find a significant difference in LPDV prevalence by site, study area, or sex. Prevalence varied 50–100% by site (sample size range: 2–17), and 50–81% by study area (sample size range: 4–37), but small sample size likely precluded the ability to find a significant difference. Males sampled had a slightly lower prevalence (73%) than females (80%), however the effect of sex was not significantly different than zero (β = -0.43; 95% CI = -1.44 to 0.60, p = 0.41). We did find a significant effect of age on LPDV prevalence (β = -2.28; 95% CI = -3.45 to -1.19; $p < 0.0001$), with adults having a significantly higher prevalence (89%) than juveniles (46%). Spur length as a surrogate to male age was also a significant predictor of LPDV prevalence (β = 1.38; 95% CI = 0.31 to 2.74; p = 0.02), where males with longer spurs were more likely to be infected with LPDV. It is important to note that spur length is generally correlated with, but is not a consistent predictor of individual age, and spur length can only be measured in males, reducing our sample size for this comparison.

Four dry cloacal swabs from LPDV infected birds (confirmed through blood analysis) were tested for LPDV to determine the sensitivity of using cloacal swabs as a less invasive ante-mortem detection method. Two of these samples were PCR-positive, indicating a sensitivity level of 50%. These preliminary results regarding turkey disease, nesting, movement, home range, and survival will be built upon in multiple subsequent field sampling seasons to increase sample size overall, increase data collection per individual, and to address these data on a temporal scale.

Summary and Future Directions

Of the 39 male turkeys we banded and released, 12.8% were reported shot during the spring bearded turkey hunting. This reflects a direct recovery rate that reflects a spring harvest rate under an assumption of no mortality between handing and the hunting season. While some researchers have found this assumption to be generally valid (Diefenbach et al. 2012), in future years we plan to radio-mark a subset of males to evaluate late winter mortality directly. Furthermore these results only include birds reported directly to our phone line, and does not account unreported harvest or birds that were shot but not recovered. Thus, 12.8% is likely an underestimate of male harvest during the spring hunting season, and we plan to address the assumptions mentioned above in future work. We will also expand our banding efforts into additional WMDs across the state to increase our sample size and spatial replication for band reporting. This expanded trapping will allow us to incorporate geospatial information to increase the accuracy of harvest rate estimates. We will use this information in a band recovery model (Brownie et al 1985) to produce an estimate of harvest rate that accounts for variation in harvest across the state. The harvest rate estimate combined with total harvest information provided by MDIFW will be used in a Lincoln estimator to produce estimates of population size (Diefenbach et al 2012). Harvest reporting includes information by year, WMD, age, and sex, which means we should be able to produce estimates of abundance for each of these strata.

Our best model for weekly hen survival was based on LPDV infection status. The observed difference in survival of infected individuals and the large proportion of individuals infected could indicate that LPDV infection is a major driver of population size. LPDV prevalence was found to increase with turkey age, which may impact population demographic structure. The increase in LPDV infection with age may indicate turkeys are able to survive

infection and continue to harbor the pathogen, increasing the potential of exposure to others. In future years we plan to include flock size and local population density as covariates in the LPDV model to determine what role, if any, these factors may play in disease dynamics. We will also assess whether LPDV infection affects turkey daily movement or home range size. The preliminary cloacal swab analysis did not result in a particularly high sensitivity, however we will increase sample size for this comparison by processing the rest of our 2018 samples, and by collecting more samples in subsequent seasons. We will also refine the cloacal swab DNA extraction protocol to provide insight into the validity of this method compared with detection of LPDV in blood. Genetic sequence data will enable us to distinguish between strains of LPDV and identify transmission pathways, which will also address the level of turkey connectivity and movement across the landscape.

We also found evidence for variable survival throughout the year, with the greatest apparent decrease in survival occurring in May, which corresponded with peak nesting activity for hens based on our Brownian Motion Variance analysis. This decline in survival during the spring nesting season has been observed in other studies of wild turkeys (Kurzejeski et al 1987, Hubbard et al 1999) and likely is caused by increased vulnerability to predation of hens while nesting (Speake 1980). A recent study of ruffed grouse in Maine also found that female survival was substantially reduced during nesting (Mangelinckx 2017), and it is likely that ground nesting birds are particularly vulnerable to predation, in general, during this period.

We found that daily nest survival varied depending on the age of the nest, but there was no evidence that survival differed based on individual hen characteristics. As our sample size for nests increases through future seasons, these results may change. While we continue to collect data on nest location and nest survival, we will expand our analysis to assess nesting habitat

quality across our study areas. To do this, we will incorporate landcover characteristics with nest site selection and nest success to estimate the probability of selection at multiple scales and the probability of success given a site is selected. We will then develop a multi-scale predictive model for wild turkey nesting habitat quality that can be used to asses nesting habitat across a landscape.

Using GPS transmitters, we collected data on wild turkey hen locations which showed apparent variability in movement patterns among seasons and individuals. Moving forward, we plan to use this information in two capacities. First, we will incorporate landcover characteristics to identify potential sources of variation in movement throughout the year. We will identify sources of variation in probability of use within each season as well as seasonal movements across the landscape. Second, we will use individual variation in movement behavior to account for individual heterogeneity in nest survival. We will quantify movement variables including seasonal movement distance, pre-nesting home range size, laying movements, movement phenology, and nesting home range fidelity to identify variation in individual hen nest success.

This pilot year has afforded us insight into turkey population ecology through the integration of demographic, spatial ecology, harvest, landscape ecology, and disease ecology data to inform Maine Department of Inland Fisheries and Wildlife's goal to "maintain a healthy turkey population below biological carrying capacity while providing hunting and viewing opportunity." Future field sampling over the next 2 years will enable us to better address this goal.

Acknowledgements

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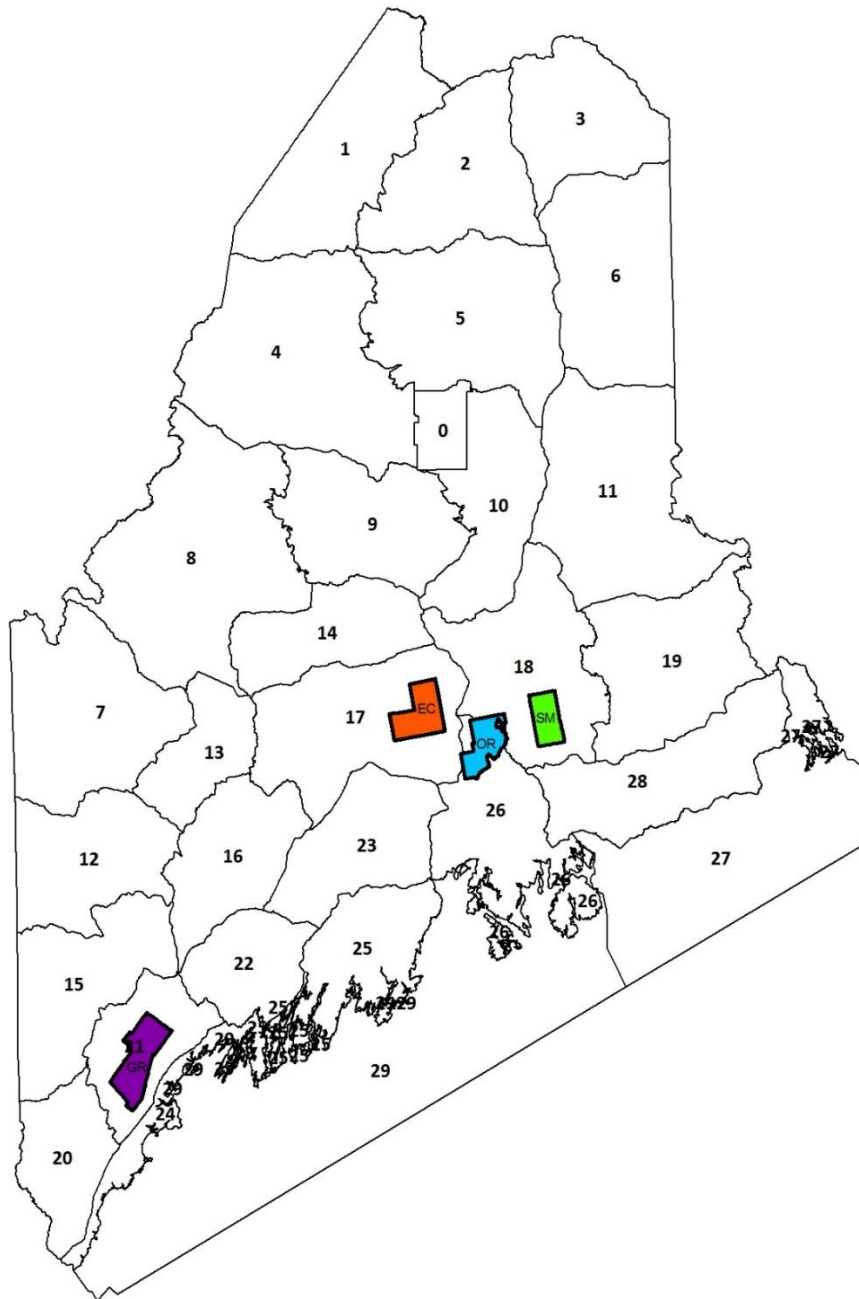
Figure 1. Map of the state of Maine depicting Wildlife Management District boundaries (numbered) and approximate study area boundaries for Exeter/Corinth (NW, Orange), Orono/Old Town (NC, Blue), Greenfield/Stud Mill Road (NE, Green), Gray/Gorham (S, Purple)).

Table 1. Unique wild turkey captures, by age and sex, at our four study areas in Maine, USA during January through March of 2018. Birds were captured in the areas of Exeter/Corinth (NW), Orono/Bangor (NC), Stud Mill Rd./Greenfield (NE), and Gorham/Gray (S).

	Adult Male	Adult Female	Juvenile Male	Juvenile Females	Total
Banded					
NW	18	34	0	20	72
NC	0	0	4	0	4
NE	7	12	1	0	20
S	1	17	8	2	28
Total	26	63	13	22	124
VHF					
NW	0	13	0	6	19
NC	0	0	0	0	0
NE	0	7	0	0	7
S	0	14	0	2	16
Total	0	34	0	8	42
GPS					
NW	0	4	0	3	7
NC	0	0	0	0	0
NE	0	5	0	0	5
S	0	0	0	0	0
Total	0	9	0	3	12

Table 2. Model selection results based on Akaike's Information Criterion (AIC) to determine which group covariates affect weekly survival probability (S) of wild turkey hens in the Exeter/Corinth, Stud Mill Rd./Greenfield, and Gorham/Gray study areas in Maine, USA. We modeled S as a function of age, sex, study area, LPDV infection status, Month of the year, and Season of the year using a daily survival rate approach (Laake 2013). All models compared are shown.

Model[a]	AICc	ΔAICc[b]	w[c]	K[d]	Dev[e]
S(LPDV)	188.7557	0.0000	0.7414	2	184.7438
S(Month)	193.2429	4.4872	0.0787	10	173.0224
S(1)	193.4659	4.7102	0.0704	1	191.4620
S(Season)	193.5277	4.7720	0.0682	6	181.4439
S(Turk.Age)	195.1358	6.3801	0.0305	2	191.1239
S(Study.Area)	197.2099	8.4542	0.0108	3	191.1860

[a]LPDV: Infected, Uninfected, Unkown; Month: January-November; Season: Winter, Seasonal Movement, Early Nesting, Peak Nesting, Late Nesting, Summer; Turk.Age: Adult, Juvenile; Study.Area: NW, S, NE
[b]Difference in AIC compared with the lowest AIC model score
[c]AIC model weight
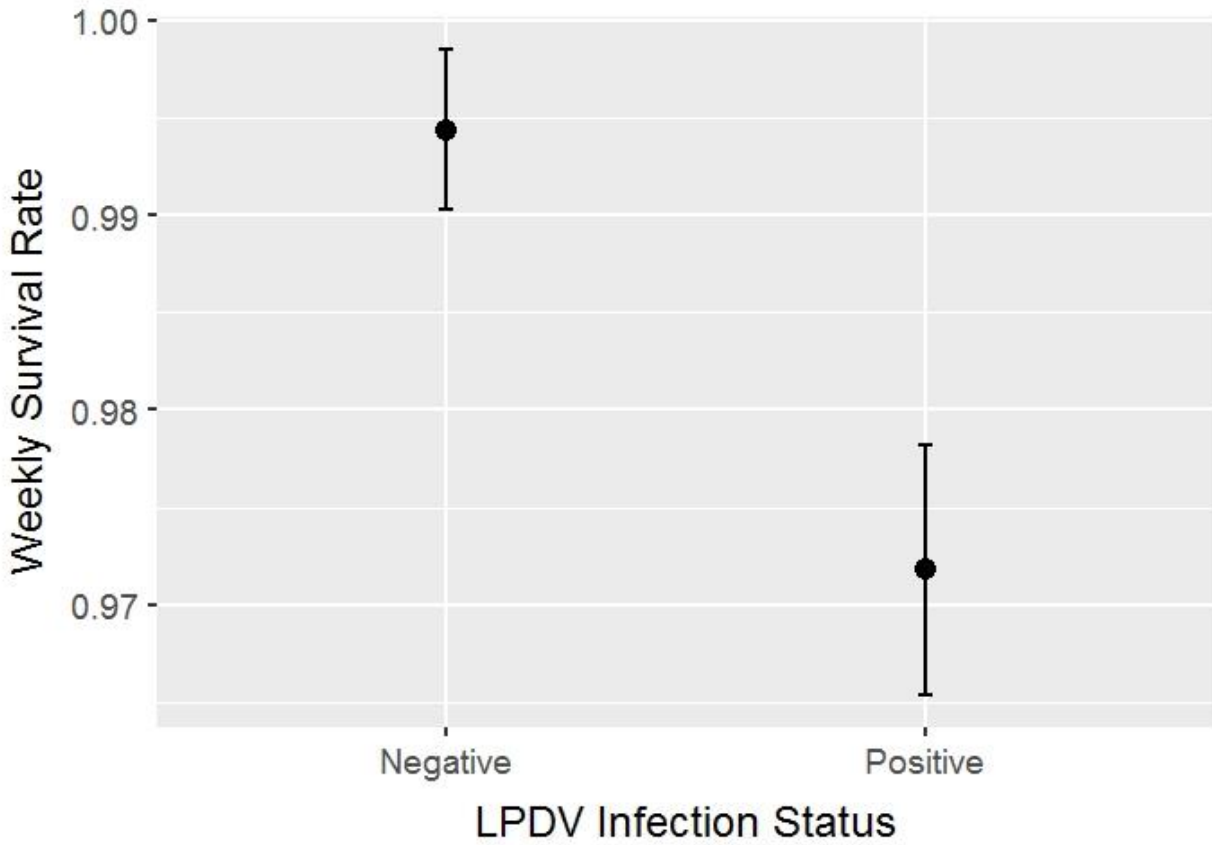[d]Number of model parameters
[e]Model Deviance

Figure 2. Weekly survival probability, by LPDV infection status, for wild turkey hens at 3 study areas in Maine, USA, from January 30, 2018 to November 11, 2018. Estimates were derived from the top performing weekly survival model according to AIC. Estimates are presented with error bars representing 95% confidence intervals.
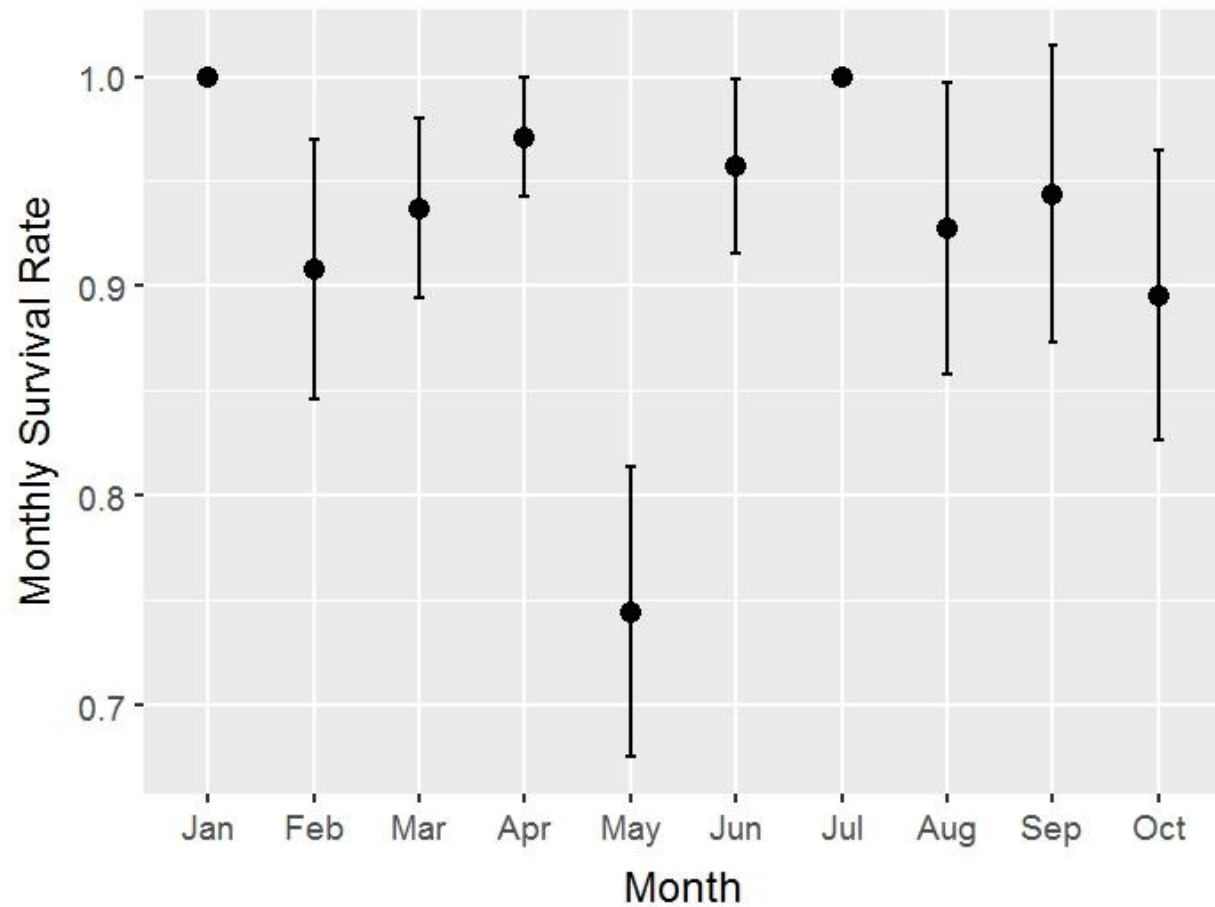
Figure 3. Weekly survival rates, by month, for wild turkey hens at 3 study areas in Maine, USA, from January 30, 2018 to November 11, 2018. Estimates were derived from the second best performing weekly survival model according to AIC. Estimates are presented with error bars representing 95% confidence intervals.

Table 3. Model selection results based on Akaike's Information Criterion (AIC) to determine which group covariates affect daily survival rate (S) of wild turkey nests in the Exeter/Corinth, Stud Mill Rd./Greenfield, and Gorham/Gray study areas in Maine, USA. We modeled S as a function of day of the year, age of the nest, initiation date, age of the turkey, study area, transmitter type, and LPDV infection status using a daily survival rate approach (Laake 2013). All models compared are shown.

Model[a]	AICc	ΔAICc[b]	ω[c]	K[d]	Dev[e]
S(NestAge)	136.3564	0.0000	0.5133	2	132.3354
S(1)	139.0366	2.6802	0.1344	1	137.0296
S(Nest.Init)	139.2025	2.8462	0.1237	2	135.1816
S(LPDV)	140.0871	3.7307	0.0795	3	134.0451
S(Turk.Age)	140.7702	4.4139	0.0565	2	136.7492
S(TagType)	140.8919	4.5355	0.0532	2	136.8709
S(Study.Area)	141.4876	5.1312	0.0395	3	135.4455
S(time)	341.2931	204.9367	0.0000	102	92.7762

[a]NestAge: number of days since nest established; Nest.Init: Date nest established; LPDV: Infected, Uninfected, Unkown; Turk.Age: Adult, Juvenile; TabType: VHF, GPS; Study.Area: NW, S, NE, time: days since first nest found

[b]Difference in AIC compared with the lowest AIC model score

[c]AIC model weight

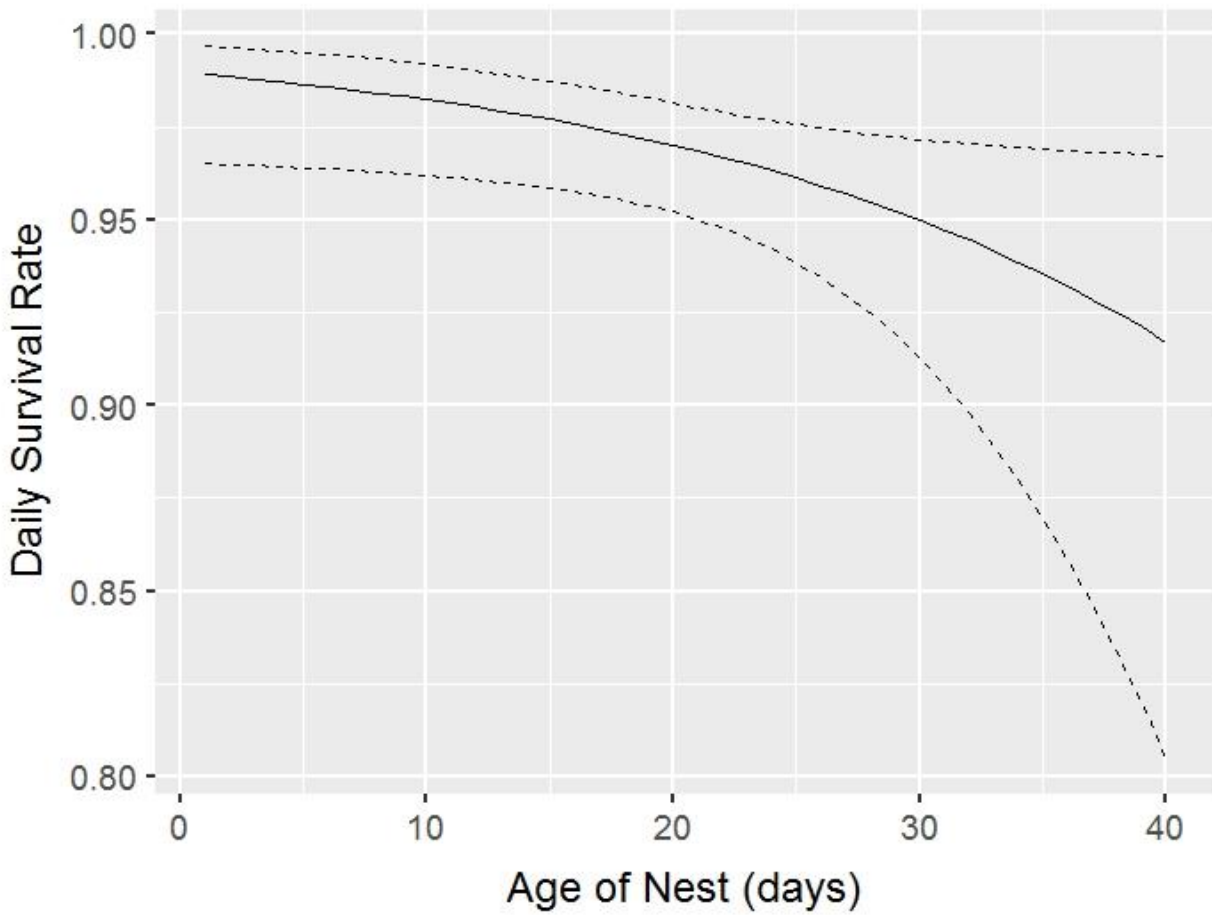[d]Number of model parameters

[e]Model Deviance

Figure 4. Daily survival rates, by age of nest, for wild turkey nests at 3 study areas in Maine, USA, from April to July 2018. Estimates were derived from the top perform daily survival rate model according to AIC. Estimates are presented with upper and lower 95% confidence intervals (dotted lines).
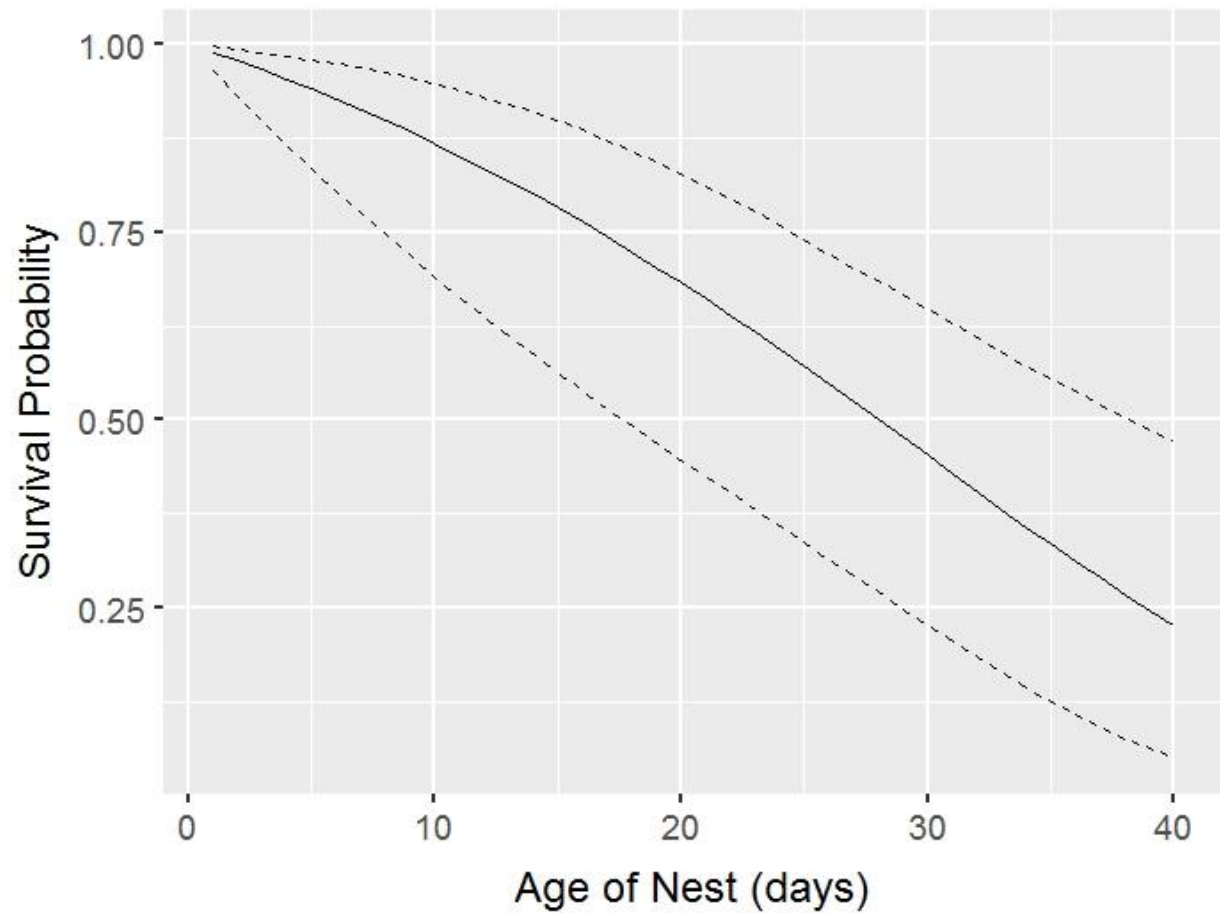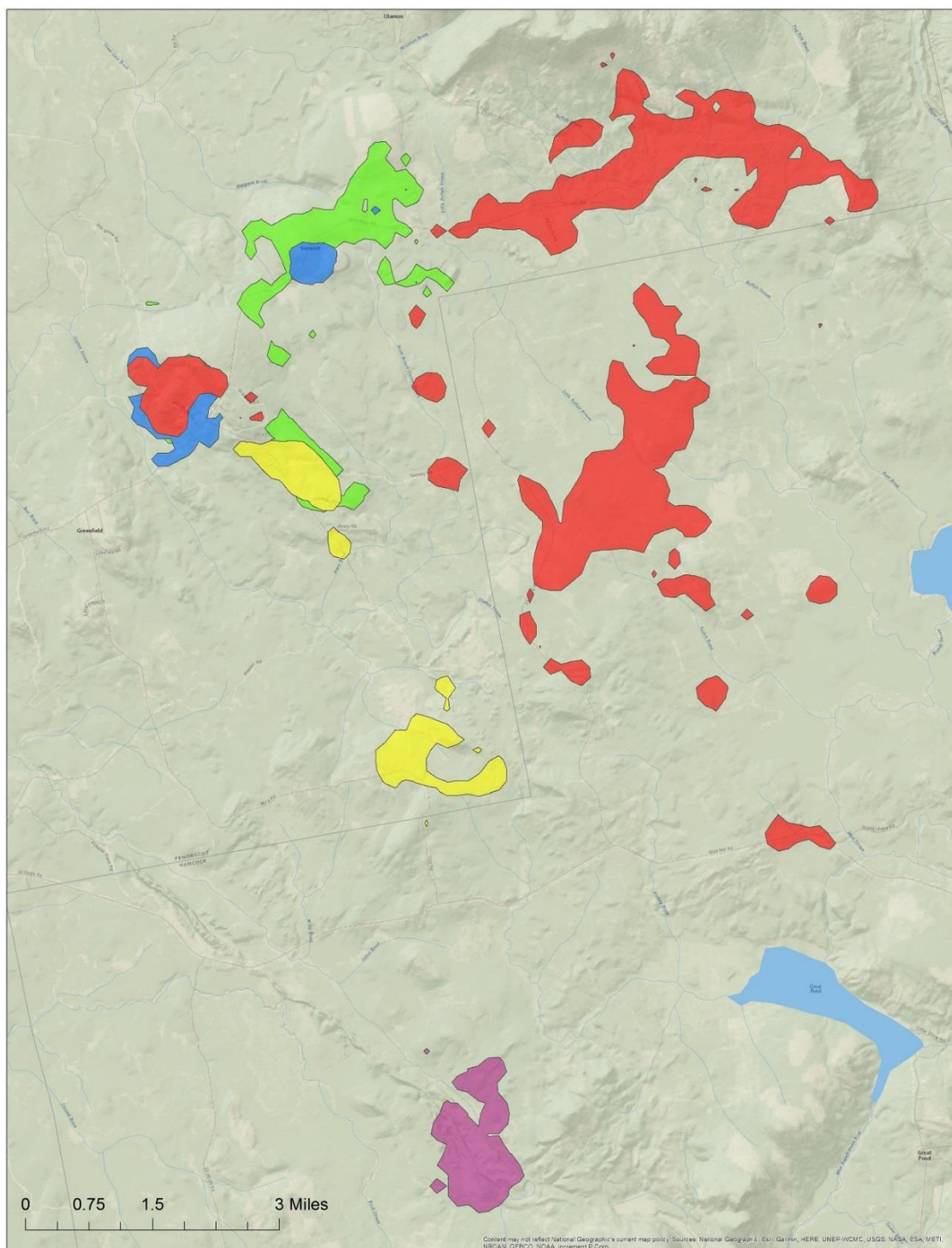
Figure 5. Cumulative probability of nest survival throughout a 40-day exposure period for wild turkey nests at 3 study areas in Maine, USA, from April to July 2018. Estimates were derived from the top perform daily survival rate model according to AIC. Estimates are presented with upper and lower 95% confidence intervals (dotted lines).

Figure 6. 95% Utilization Distributions (UD) depicting space use of individual wild turkey hens from capture through July 31, 2018 in the NE study area, Maine, USA. UDs were derived using dynamic Brownian Bridge Movement Models. Individuals are represented by unique colors.
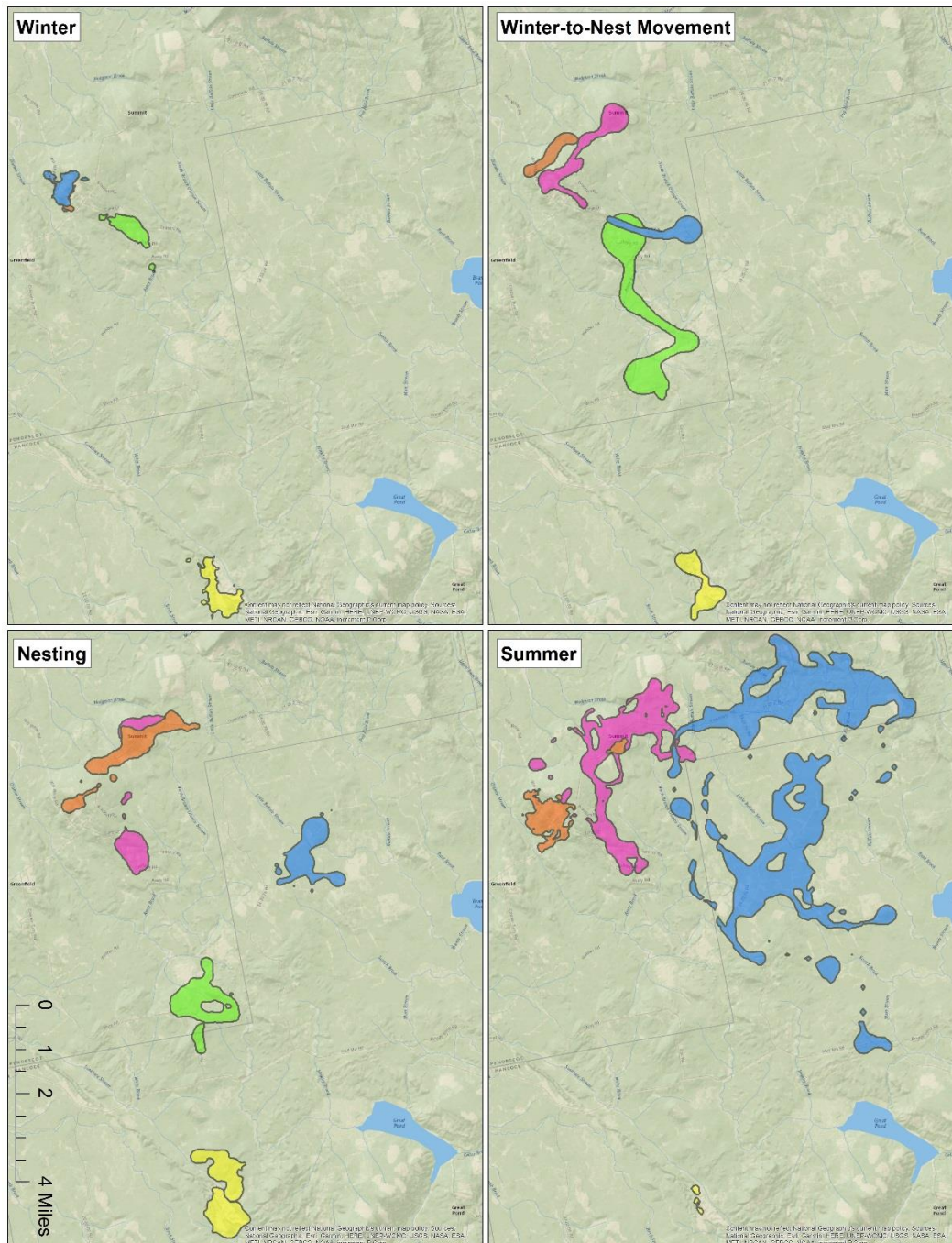
Figure 7. 95% Utilization Distributions (UD) depicting space use of individual wild turkey hens from capture through July 31, 2018, in the NE study area, Maine, USA. UD's were derived using dynamic Brownian Bridge Movement Models. Individuals are represented by unique colors.

Figure 8. 95% Utilization Distributions for seasonal home ranges of 5 individual wild turkey hens in the NE study area, Maine, USA. Seasonal ranges were derived using dynamic Brownian Bridge Movement Models. Individual hens are represented by unique colors. All maps displayed using the same scale and cover the same area.
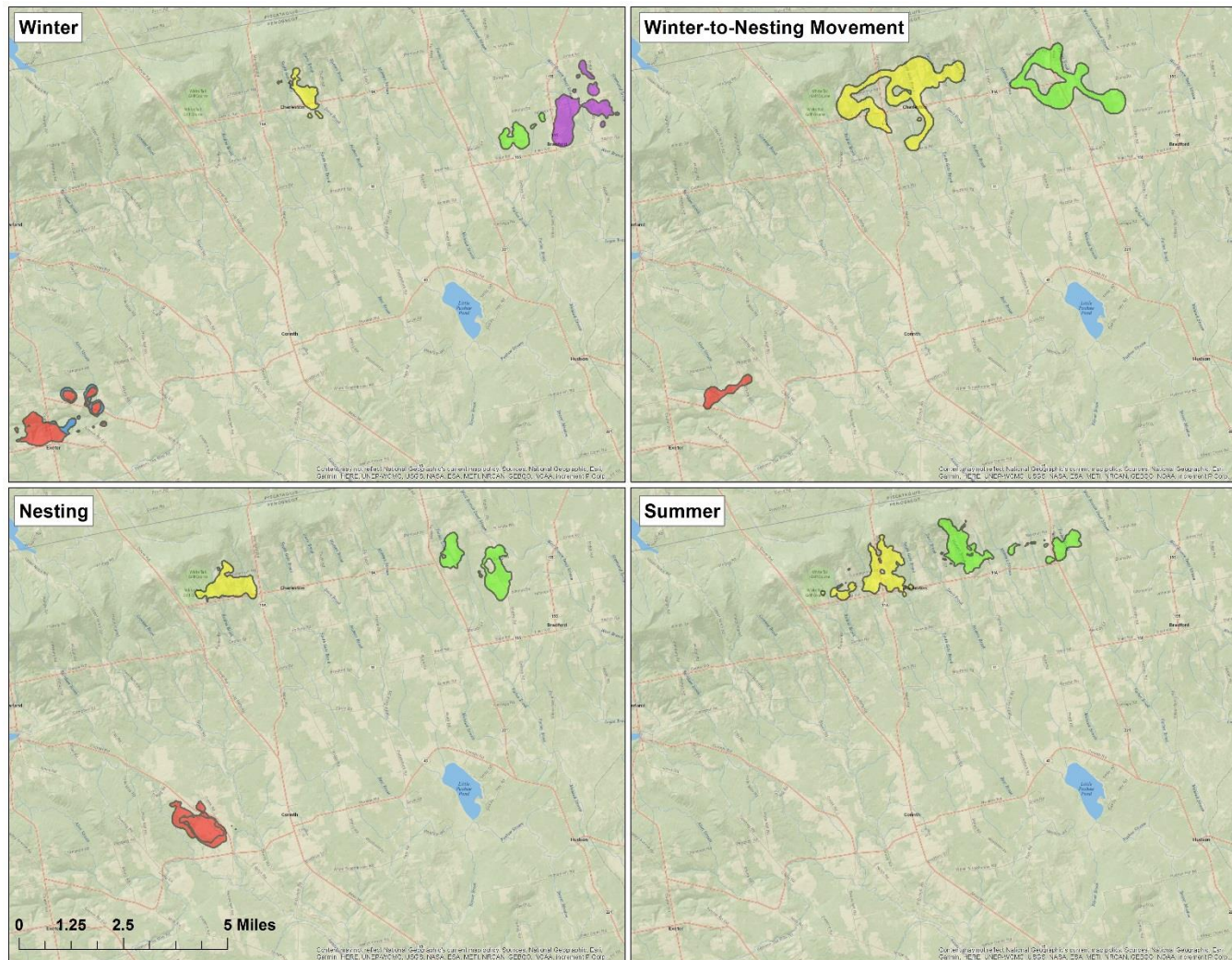
Figure 9. 95% Utilization Distributions for seasonal home ranges of 5 individual wild turkey hens in the NW study area, Maine, USA. Seasonal ranges were derived using dynamic Brownian Bridge Movement Models. Individual hens are represented by unique colors. All maps displayed using the same scale and cover the same area.

Table 4. Average area estimates for 50% and 95% Utilization Distributions (UD) by season for wild turkey hens at NW and NE study areas, Maine, USA, from January through July 2018. Estimates are presented in km^2 and were derived using dynamic Brownian Bridge Movement Models. Estimates are presented with the number of individuals sampled (n), the maximum value recorded during a given season (Max.), the minimum value recorded during a given season (Min.).

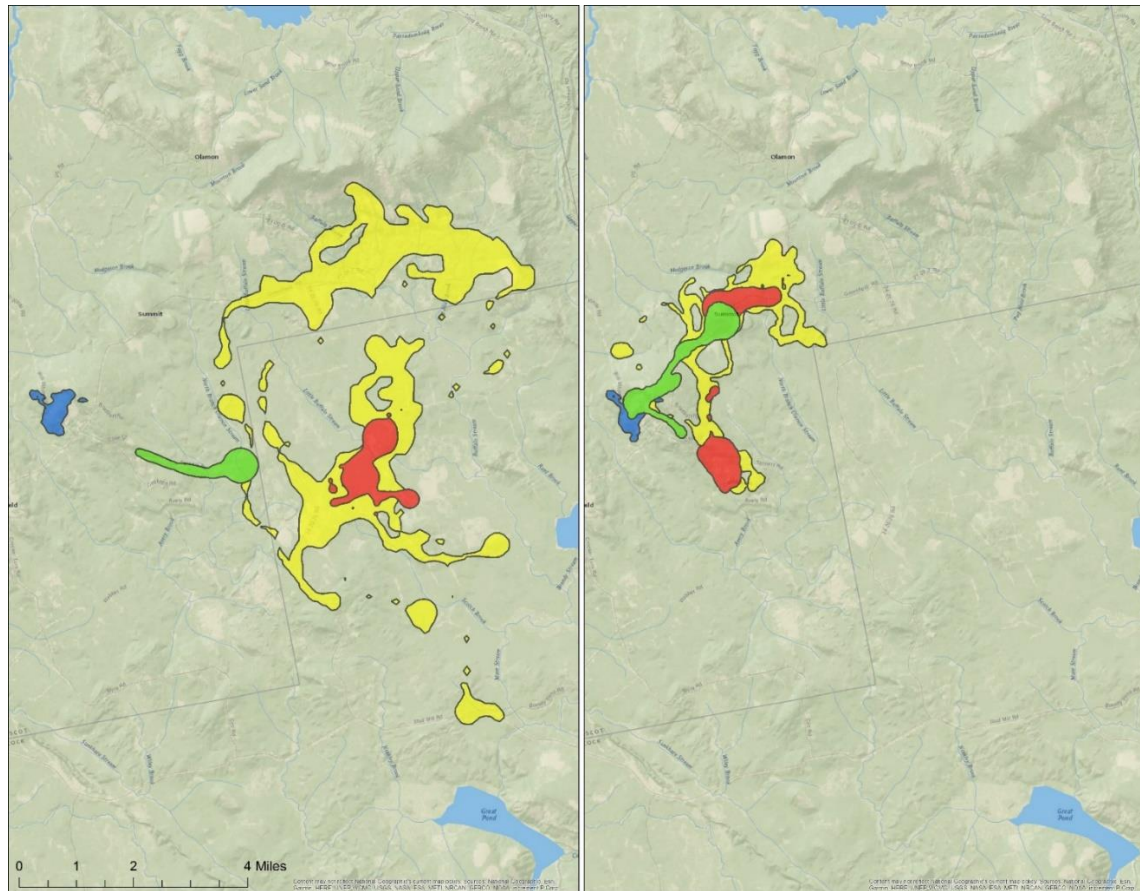|	n	Average	Max.	Min.
Capture-to-August 1				
50% UD	7	0.29	0.56	0.03
95% UD	7	7.13	21.53	3.00
Winter				
50% UD	10	0.13	0.22	0.04
95% UD	10	1.28	2.38	0.81
Winter-to-Nest				
50% UD	8	0.40	0.87	0.10
95% UD	8	2.94	6.39	0.71
Nesting				
50% UD	12	0.29	0.52	0.14
95% UD	12	1.95	3.26	0.79
Summer				
50% UD	6	0.62	1.91	0.03
95% UD	6	7.33	27.33	0.14

Figure 10. Example of 95% Utilization Distributions for seasonal home ranges of two wild turkey hens (ID 251, left panel, and 361, right panel) from the same flock in the NE study area, Maine, USA. This figure illustrates the potential variation in seasonal movements and home range sizes for female wild turkeys inhabiting the same area. Seasonal ranges were derived using dynamic Brownian Bridge Movement Models. Seasons are Winter (Blue), Winter to Nest Movement (Green), Nesting (Red), and Summer (Yellow). All maps displayed using the same scale and cover the same area.
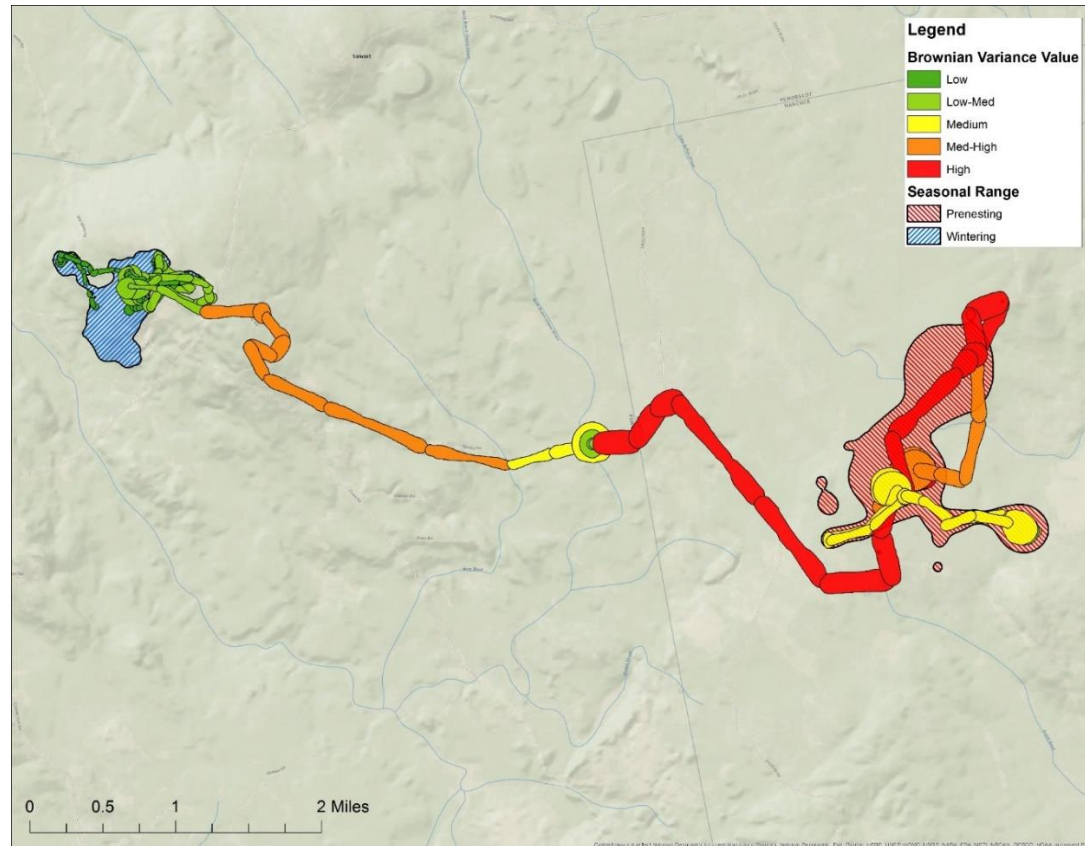
Figure 11. Example Utilization Distribution for time steps of an individual wild turkey hen (ID 355) in the NE study area, Maine, USA, as the female moved between winter range (Blue Stripes) and prenesting range (Red Stripes). Individual time steps and seasonal ranges were derived using dynamic Brownian Bridge Movement Models. Individual timesteps are depicted according to Brownian Motion Variance values, where hotter colors reflect more rapid movement with greater change in directionality.
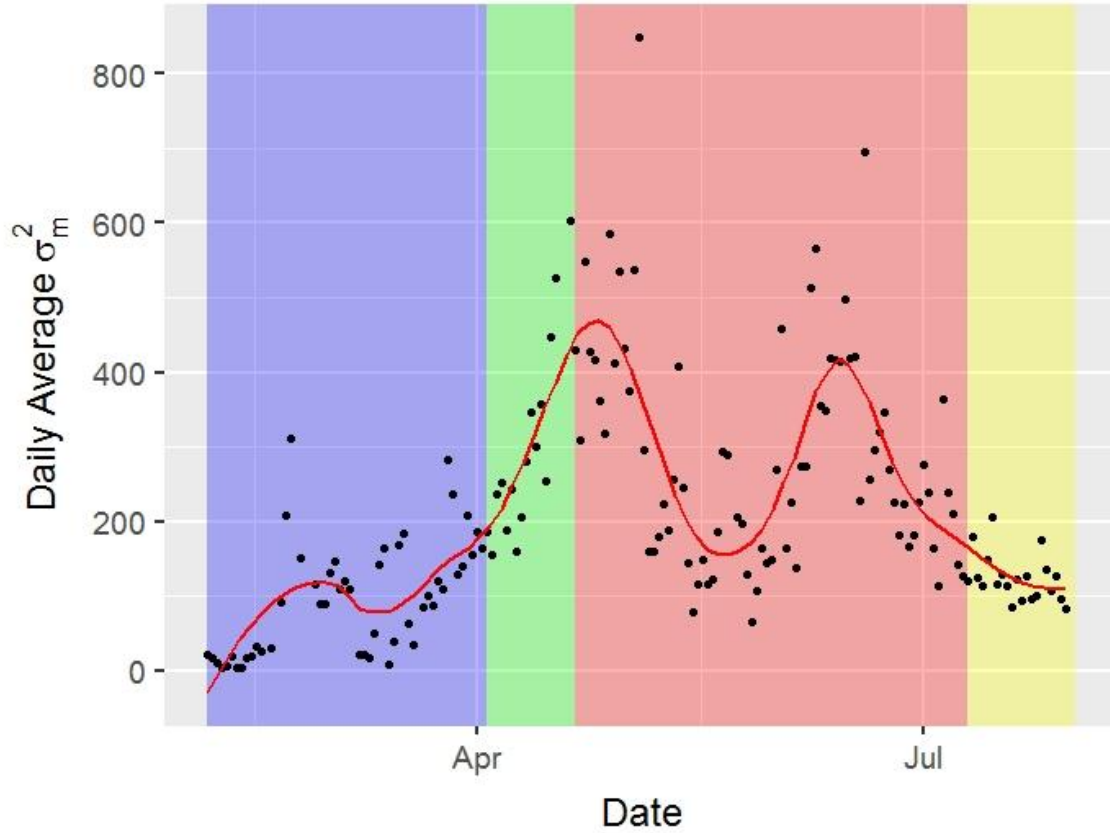
Figure 12. Daily average Brownian Motion Variance (σ_m^2), by date, for wild turkey hens in the NE and NW study areas, Maine, USA, from February 2 through July 31, 2018. σ_m^2 was derived using dynamic Brownian Bridge Movement Models. σ_m^2 are presented with a spline trend line, and colors depicting manually designated seasons, Winter (Blue), Winter to Nest Movement (Green), Nesting (Red), and Summer (Yellow).