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Effectiveness of GPS-based Telemetry to Determine Temporal Changes in Habitat Use and Home-range Sizes of Red Wolves

John Chadwick[1,*], Bud Fazio[2], and Melissa Karlin[1]

Abstract - Four adult male *Canis lupus rufus* (Red Wolf) were monitored with GPS collars in 2006–2008 on the Albemarle peninsula of North Carolina in the first high temporal resolution (4 locations/day) study of this endangered species in the wild. The Wolves occupied home ranges during 11–18 month observation periods, and the GPS data were divided into 30-day subsets to evaluate changes in the spatial characteristics of the home ranges over time. The subset location data were then combined with land-cover maps derived from Landsat satellite imagery. Proportions of different land-cover types occupied by the Wolves were seasonally cyclic, with increased use of agricultural areas when tall row crops were available from summer to autumn and increased use of adjacent grass, brush, and forest areas from winter to late spring when tall crops were absent. The spatial extents of home ranges (95% fixed-kernel probability areas) were also seasonally variable, reaching maximum sizes (73–121 km^2) in early autumn to winter and contracting by 40% to 63% during whelping and pup-rearing in the spring. Our study shows the potential for GPS collars to provide useful information about space and habitat use by Red Wolves, and that at least a full year of observation may be required to fully determine the variability of home-range characteristics.

Introduction

Canis lupus rufus Audubon and Bachman (Red Wolf) historically ranged over an extensive portion of the southeastern US, and possibly throughout the eastern woodlands to Maine (Nowak 1979, 2002; Paradiso and Nowak 1971; Riley and McBride 1972). Extermination and habitat loss dramatically reduced the population during the 19th and 20th centuries, and by the 1960s they only survived in isolated, marginal habitats in Texas and Louisiana (Carley 1975, Shaw 1975). On the verge of extinction, they were federally listed as endangered in 1967, and the remaining wild Wolves were brought into captivity between 1973 and 1980 to begin a captive-breeding program (McCarley and Carley 1979, USFWS 1990, van Manen et al. 2000). The Red Wolf was thought to be extinct in the wild by 1980 (McCarley and Carley 1979).

Based on morphological criteria, 14 founders were selected for the Red Wolf captive-breeding program. That program was successful, and 4 pairs of Wolves were reintroduced in the wild in 1987 on the Albemarle Peninsula in eastern North Carolina (Parker 1987, Phillips 1994). The reintroduction and ongoing management program have been successful, with annual counts

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between 114 and 131 individuals during 1999–2007, 10 to 22 wild breeding social groups, and 33 to 55 pups born per year. The reintroduced population is intensively managed by the USFWS. Although the Wolves are federally listed as an endangered species (USFWS 2007), this population is considered a non-essential experimental population (Parker and Phillips 1991).

The US Fish and Wildlife Service (USFWS) Red Wolf recovery and management area encompassed about 6900 km^2 in portions of 5 counties on the Albemarle Peninsula (Fig. 1). That area included Alligator River and Pocosin Lakes National Wildlife Refuges and private lands largely consisting of agriculture (corn, soybeans, and cotton in summer and fall, winter wheat in winter and spring) and managed pine plantations. Approximately half of the recovery area consisted of managed and native forests, but these were fragmented by farms, open areas due to recent timber management, and stands in various stages of regeneration. Cypress trees and pocosin wetlands dominated the coastal areas of the peninsula.

An animal's home range is the spatial expression of its survival and reproductive behaviors (Burt 1943), and can be influenced by seasonal environmental variation (Wingfield 2005). Previous studies of Red Wolf home-range characteristics were limited to durations of a few months using conventional radiotelemetry collars and abdominal transmitters (Beck 2005, Hinton 2006, Mauney 2005). These studies revealed that Red Wolves

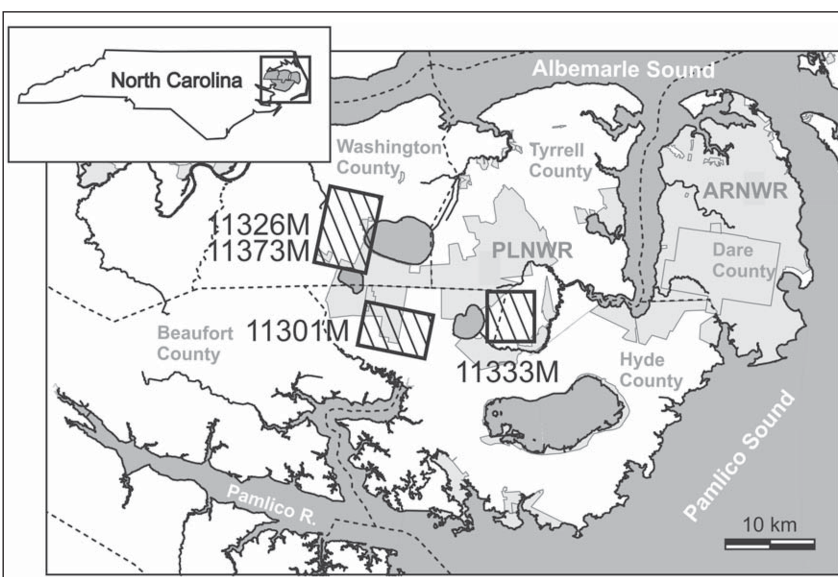

Figure 1. The Red Wolf recovery area located on the Albemarle Peninsula in northeastern North Carolina, encompassing approximately 6900 km^2 in 5 rural counties. Hachured boxes show the 3 general locations of home ranges of the 4 Wolves in the study (Wolves 11326M and 11373M shared a similar area). Federal lands, including Pocosin Lakes and Alligator River National Wildlife Refuges (PLNWR and ARNWR) are shown in gray.

are habitat generalists, with highly variable home ranges (7.8–272.8 km^2). In-depth knowledge of Red Wolf home-range characteristics and how they vary over time can improve current management practices, aid with determining the carrying capacity of the Albemarle management area for this species, and enhance the success of future reintroduction projects (USFWS 1990) elsewhere within the historic range of the Red Wolf.

Animal-tracking collars with global positioning system (GPS) capability can acquire frequent, accurate positions over long periods of time and have become an important tool for monitoring and managing free-ranging canids and other species over a broad range of temporal and spatial conditions (e.g., Demma et al. 2007). Our primary goal was to test the utility of GPS data to determine the temporal variability in patterns of land-cover use and the sizes of home ranges of Red Wolves on the Albemarle Peninsula.

Methods

GPS data acquisition and processing

We collected GPS locations from 4 adult male Wolves and mapped land-cover types in their home ranges using multispectral Landsat Thematic Mapper satellite imagery. All 4 Wolves were wild-born in the recovery area in 2004, and all but Wolf 11333 had been previously captured by USFWS personnel prior to our study (C. Lucash, USFWS, Columbia, NC, pers. comm.). Two of the Wolves were collared and released in 2006 and 2 in 2007 (Table 1). The Wolves were captured as part of routine management activities in which a portion of the population is captured to radiocollar new individuals, replace aging or failed collars, manage breeding- and health-related issues, and to respond to complaints by local residents. Following capture, the animals were transported in kennels to a central processing facility where biologists conducted a physical examination, administered vaccines, and collected a blood sample. After the GPS collars were fitted on the Wolves, the animals were released by USFWS personnel near their capture location.

We used Lotek model 4400S GPS collars (Newmarket, ON, Canada). With no differential correction, the manufacturer reported a horizontal error of <35 m for 95% of acquired locations. After deployment, the collars collected locations 4 times per day, during evening through morning hours, at 4-hour intervals (2000, 0000, 0400, and 0800 hours; local Standard Time;

Table 1. Observation periods and GPS data summary for 4 Red Wolves, Albemarle Peninsula, NC, 2006–2008.

Animal no.	Release date	Observation period	Duration (months)	No. locations	GPS success rate[A]
11301M	18-Jan-06	Apr 06–Sep 07	18	1823	83%
11333M	18-Jan-06	Mar 06–Jan 07	11	1271	95%
11326M	31-Mar-07	May 07–Aug 08	16	1774	91%
11373M	31-Mar-07	May 07–Apr 08	12	1340	92%

[A]Proportion of all scheduled GPS locations that were successfully acquired by each collar.

1 hour later during Daylight Savings Time) when the Wolves were thought to be most active.

Each collar was programmed to emit a VHF locator beacon each day for 4 hours, enabling USFWS field personnel to locate the Wolves every 4–6 weeks and download the stored data. To acquire the data, Wolves typically were first tracked from an airplane to identify the general location, allowing ground teams to download the data from a location approximately 100–300 m away, the distance depending on vegetation density or the presence of other physical barriers.

At the end of the monitoring period, we divided the final data sets for each Wolf into 30-day increments (i.e., 120 GPS location attempts). Two locations (of the 4/day) between each 30-day subset were not used, resulting in a total of 12 subsets of equal duration spanning a calendar year (equaling 365.5 days; the first 2 locations from 1 January were used in both the first and last subsets of a calendar year). These 30-day periods closely approximate calendar months for ease of interpretation (e.g., the first 30-day period approximates the month of January [January 1–30], the second 30-day period approximates February [January 31–March 2], and so on) and have durations that are short enough to reveal short-term and seasonal variations in patterns of land use and home-range sizes.

Satellite image data processing

Preliminary field observations suggested that the Wolves occupied large (>75 km^2), contiguous blocks of agricultural fields at least part of the time. To investigate variability in the proportions of different land-cover types occupied by the Wolves over time, we mapped land cover in the study area using Landsat 5 Thematic Mapper (TM) satellite images (US Geological Survey, Sioux Falls, SD; 30-m spatial resolution; Path 14, Row 35). The cloud-free images were acquired on 1 August 2006, 20 August 2007, and 6 August 2008, when crops were near their peak and prior to any agricultural harvesting or leaf senescence of trees.

To produce land-use maps for each year, we used ENVI image-processing software (ITT Visual Information Solutions, White Plains, NY) and a conventional maximum likelihood supervised classifier (e.g., Foody et al. 1992, Swain and Davis 1978), which categorizes each image pixel into a spectral class based on its brightness values in the 6 visible, near-, and mid-infrared spectral bands. Ground-truthing was conducted to identify the 8 dominant summer land-cover types in the study area (corn, soybeans, cotton, managed conifer forest, native mixed deciduous-conifer forest, bare soil [recent timber harvest areas], tall wild grasses or brush in previously harvested forest stands or fallow agriculture fields, and water), to locate training and validation areas for each class, and to evaluate the accuracy of the land-cover mapping. We obtained GPS coordinates for 10 locations within each land-cover type. We used 5 locations for each land-cover type as training observations for image classification and the remaining 5 to assess the accuracy of the land-cover classification. We used minimum-mapping-unit (Saura 2002) and pixel-clumping techniques to consolidate and remove small regions of minor classes. Overall classification accuracy was 90–93% for the 3 images, and classification accuracy exceeded 75% for all classes. Commission errors were highest for the 2 forest classes (9–19% commission of conifer pixels in the mixed trees class) and 2 agriculture classes (23–26% commission of soybean pixels in the cotton class). Other than annual rotation of crops, little land-cover change took place (<10 km^2 total area) for the time period corresponding to the 3 images, and most changes were a result of forest management. In winter months, the areas mapped as corn, soybeans, and cotton had bare soils or were used to grow winter wheat.

We grouped the classified land-cover types into 3 land-use categories (excluding water) based on vegetation height and seasonal permanence: row-crop agriculture, mixed grasses-brush, and forest (managed and native). We delineated the 3 land-use categories based on the 2006, 2007, and 2008 classified images with vector polygons via heads-up digitizing in ENVI, and combined the vector maps in a geographic information system (ArcGIS 9.2, ESRI, Inc., Redlands, CA) with the 30-day subsets of GPS data from the corresponding years to calculate the proportions of the 3 land-use types associated with Wolf locations during each 30-day interval.

Home-range area

We calculated home-range areas using all GPS data for each Wolf (11–18 months) and for each of the 30-day subsets. We calculated home-range sizes with a fixed-kernel method, which uses location data to estimate the probability that an animal will be in a particular location, and delineated home-range boundaries based on the area encompassing the 95% utilization distribution (Seaman and Powell 1996, Seaman et al. 1999, Worton 1989). Kernel methods provide the most accurate measures of space use (Kernohan et al. 2001, Worton 1995) and exclude large areas not used by an animal (White and Garrott 1990). We calculated the smoothing parameter (h statistic) with Animal Space Use 1.2 (Horne and Garton 2007) using likelihood cross-validation (CVh), which conforms better to the distribution of location data than least squares cross-validation (Horne and Garton 2006). The value of the smoothing parameter influences the calculated area of a home range, so we generated a smoothing parameter for each 30-day subset for each Wolf and used the average values in the 30-day home-range calculations, which allowed us to make direct comparisons of the areas over time. This average smoothing parameter was also used to calculate the long-term home-range areas using the full GPS datasets.

Results

The overall success rate for scheduled GPS acquisitions by the collars varied from 83% to 95% (Table 1). For most of the 30-day subsets, the proportion of successful location acquisitions was relatively high and consistent (88–100%), except for those from periods 7 and 8 (corresponding with the months of July and August), which were lower for all 4 Wolves (73–84%).

After release, the Wolves either temporarily occupied a confined area close to the release site or moved out of the area they would ultimately occupy as a home range, perhaps because of temporary disorientation, acute caution, or stress resulting from capture, confinement, and release. For 3 of the Wolves (11333M, 11326M, and 11373M), we excluded data from our analyses prior to the second full month after each release to remove the possible effects of the capture process on their movements, a method similar to that used in previous GPS studies of canids (e.g., Demma et al. 2007). Animal 11301M ranged over a wide area beyond its ultimate home-range boundaries for several weeks, so we did not use data from that Wolf prior to the third full month.

Wolves 11326M and 11373M were collared and released in late March of 2007, and began to share the same home range soon after their release. After May of 2007, 47% of the GPS locations of the 2 males were within 100 m of each other and 64% were within 1000 m. Field records suggest that 11373M was the sibling of the mate of 11326M, and both animals were part of an extended family group that included the breeding female and 3 pups born in April, 2008. Thus, our study involved 4 Wolves in 3 separate areas (Fig. 1).

The 30-day location subsets for each Wolf showed areas with high concentrations of locations corresponding with the spring denning areas of the 4 Wolves (2007: 11301M and 11333M; 2008: 11326M and 11373M; Fig. 2; C. Lucash, pers. comm.).

Land-cover use

A substantial percentage of all locations for each Wolf were in areas classified as agriculture (40.0% for 11301M, 66.7% for 11333M, 68.3% for 11326M, and 63.5% for 11373M). The remaining locations primarily were in the mixed wild grass-brush areas adjacent (<1 km) to these agricultural tracts (56.4% for 11301M, 30.6% for 11333M, 29.9% for 11326M, and 33.6% for 11373M). The fewest locations were in the forest land-use category (3.6% for 11301M, 2.7% for 11333M, 1.8% for 11326M, and 2.9% for 11373M).

The 30-day subsets combined with the land-cover maps showed variability in the proportions of different land-cover types used by the Wolves over time. This variability had a seasonal pattern, and the timing was similar among the 4 Wolves (Table 2, Fig. 3A). In summer and early autumn (periods 7–10; July–October), all Wolves increased their use of agricultural fields, with the greatest use occurring in July, August, and September. In winter to spring (periods 11–12 and 1–5; November–May), the proportion of locations in agricultural areas were substantially lower, and the use of grass-brush and forest areas adjacent to agricultural fields increased. Use of agricultural areas generally was lowest in winter and spring (Table 2, Fig. 3A).

Home-range size

Home-range areas for all collected GPS data (11–18 months) for each Wolf were 118.3 km^2 for 11301M, 81.6 km^2 for 11333M, 149.5 km^2 for 11326M, and 148.1 km^2 for 11373M. The 30-day home ranges were highly variable, but showed similar temporal patterns among the 4 Wolves (Table 2, Fig. 3B). The 5 largest areas calculated for each Wolf occurred almost exclusively in late summer to winter (periods 9–12 and 1–3; September–March; Table 2). The single exception was the large area we observed for 11301M (80.4 km^2) in June 2006. Home ranges for period 1 (January of 2007 and 2008) were at or near their maximum annual size (94–100%; Fig. 3B). Home-range areas were smallest during spring and summer (periods 4–8; April to August; Table 2). These home-range areas were 40 to 63% smaller than the largest seasonal home ranges.

Discussion

The Wolves in our study showed considerable temporal variation with regard to land-cover use and home-range size but the temporal patterns were similar for the 4 animals over the study period (Fig. 3). Although Wolves

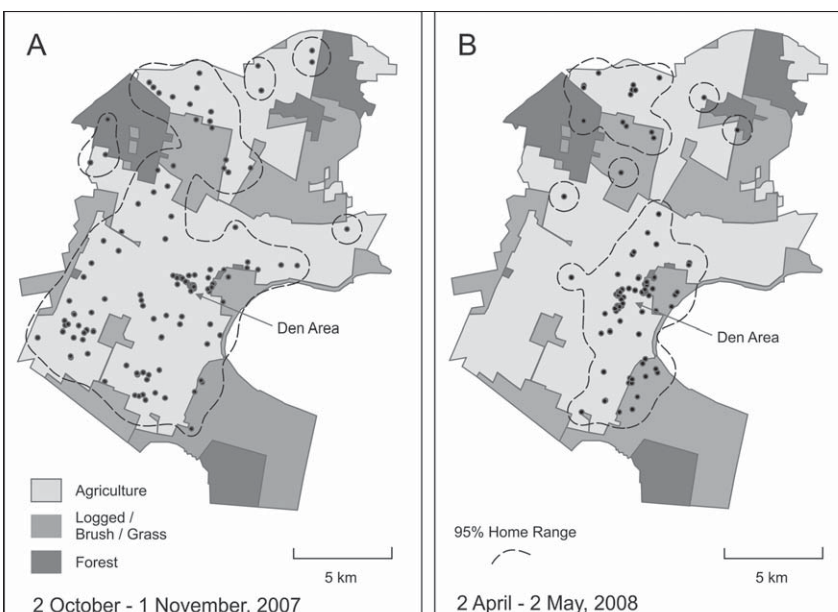

Figure 2. Fixed-kernel home-range boundaries (95%) for Wolf 11326M, Albemarle Peninsula, NC. The 30-day home range reached maximum size (A) in October 2007 (120.5 km^2) when agriculture land use was near a maximum (89.3% of locations). By April 2008 (B), the home range had decreased to 64.1 km^2, and agriculture land use was near a minimum (65.5% of locations). Pups were born to the mate of this Wolf in late April, and a large proportion of locations during the study period were in the den area.

Table 2. Proportions of home ranges classified as agricultural land use and home-range areas (km^2) of 4 Red Wolves, Albemarle Peninsula, NC, 2006–2008.

30-day Period:	1 (Jan)	2 (Feb)	3 (Mar)	4 (Apr)	5 (May)	6 (June)	7 (July)	8 (Aug)	9 (Sep)	10 (Oct)	11 (Nov)	12 (Dec)
Wolf 11301M												
2006 % agriculture	-	-	-	6.1	21.2	37.1	78.3	65.9	70.0	63.8	31.3	29.1
2007 % agriculture	35.1	28.4	33.3	4.2	7.9	46.9	64.1	70.9	81.3	-	-	-
2006 home-range area	-	-	-	51.7	61.8	80.4	58.0	58.1	74.1	81.6	73.0	78.0
2007 home-range area	96.4	83.4	84.4	48.0	35.3	68.1	58.6	54.0	59.4	-	-	-
Wolf 11333M												
2006 % agriculture	-	-	61.9	70.8	58.3	79.6	86.2	83.8	85.8	73.6	59.5	50.0
2007 % agriculture	61.2	-	-	-	-	-	-	-	-	-	-	-
2006 home-range area	-	-	63.5	52.4	44.0	50.6	44.5	51.1	70.2	68.0	70.7	73.0
2007 home-range area	69.3	-	-	-	-	-	-	-	-	-	-	-
Wolf 11326M												
2007 % agriculture	-	-	-	-	56.4	79.6	85.3	94.1	88.8	89.3	69.5	62.5
2008 % agriculture	58.1	55.0	56.9	65.5	63.6	83.5	91.5	94.3	-	-	-	-
2007 home-range area	-	-	-	-	98.6	94.5	90.6	109.4	114.9	120.5	113.4	113.9
2008 home-range area	116.1	99.3	74.1	64.1	54.3	65.8	72.0	62.6	-	-	-	-
Wolf 11373M												
2007 % agriculture	-	-	-	-	37.6	75.2	85.6	94.8	85.2	88.3	67.5	66.4
2008 % agriculture	58.5	9.6	30.8	31.3	-	-	-	-	-	-	-	-
2007 home-range area	-	-	-	-	76.1	61.0	75.3	95.5	107.3	112.5	111.9	120.9
2008 home-range area	113.5	105.3	86.8	50.7	-	-	-	-	-	-	-	-

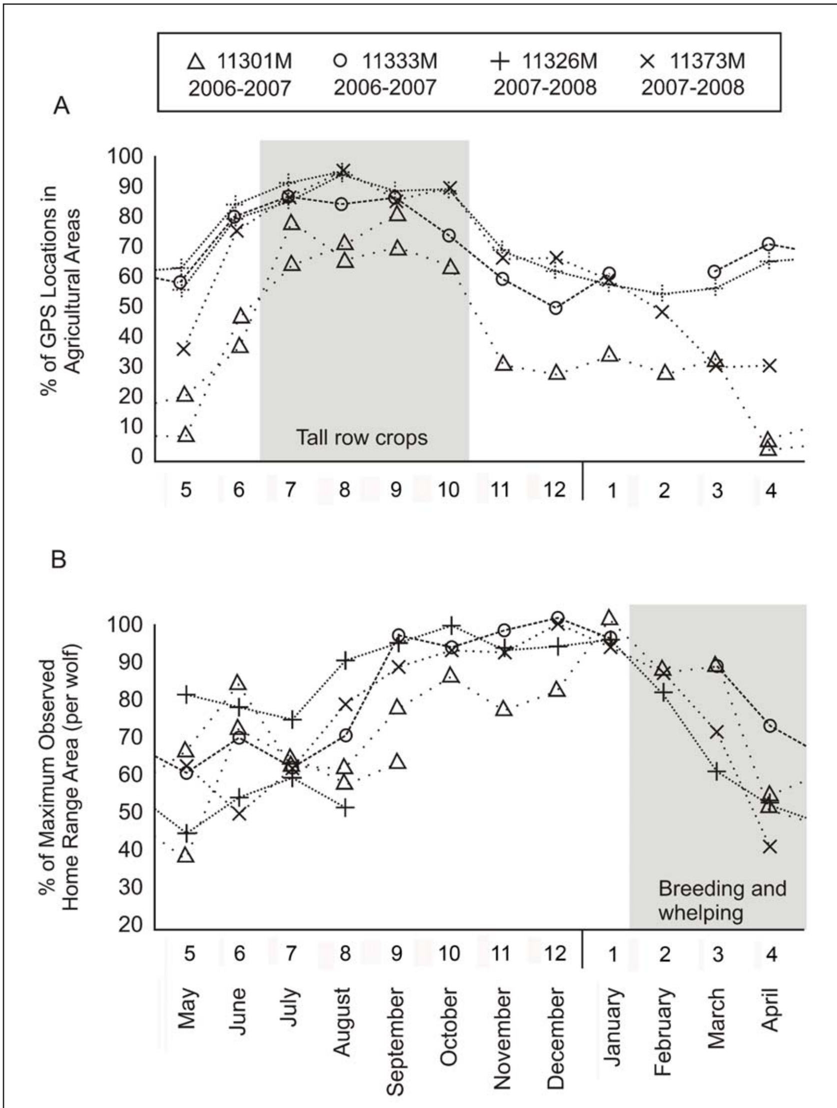

Figure 3. Time series of the proportions of GPS locations in agricultural land-use areas (A) and home-range areas (B) for the 4 Red Wolves in this study, Albemarle Peninsula, NC, 2006–2008. Graphs start in period 5 (May). (A) Monthly proportions of locations within mapped agricultural regions were seasonally cyclic and similar among the study Wolves, with maxima reached in summer months when row crops were tallest (gray area). (B) Monthly home-range areas, shown as the percentage of the maximum observed area for each Wolf. Home ranges generally were smaller in the spring, during whelping and pup-rearing periods (gray area), followed by a gradual increase in size during summer and autumn, and were largest in late autumn and winter. For all 4 Wolves, home ranges were 94–100% of their observed maxima in January.

11326M and 11373M were in the same family group, their temporal patterns were similar to those of the other 2 Wolves, which occurred in different family groups and occupied separate home-range areas. Thus, our data may be suggestive of population-wide spatio-temporal patterns of Red Wolf movements and land use.

The observed shift from use of row-crop agriculture fields to other cover types in November coincided with intense agricultural harvesting of tall (>1 m) row crops. Corn harvesting began in September of each year, but agricultural cover was not completely removed until soybean and cotton harvesting was completed in November. Hunting seasons for various game animals also began in November, and the combination of the removal of tall agricultural cover and human disturbance may have forced the Wolves to increase their occupation of areas with year-round vegetation, which often occurred on the periphery of agricultural fields. The growth and harvest cycles of agricultural vegetation may also influence the primary prey species of Red Wolves, such as *Odocoileus virginianus* Boddaert (White-tailed Deer), which also may have contributed to the seasonal shifts in habitat use we observed. Additional studies will be required to fully characterize the temporal patterns of habitat use we observed, including those of Wolves that do not occupy agricultural fields.

Animal home ranges can be influenced by many factors (e.g., human activities, prey availability, conflicts with other animals, injuries; Wingfield 2005), but a seasonal pattern was apparent in our study. We observed a gradual increase in the extent of home ranges from May–June to January, when all home ranges were at or near their maximum annual size (Fig. 3B). The decline in home-range size after January coincided with mating, den preparation, and whelping during February–April, and the presence of relatively immobile pups and frequent visits to den sites by adults until early summer (C. Lucash, pers. comm.). Home ranges then gradually increased in size until autumn, when pups start fully participating in hunting activities with adults. This interpretation is consistent with studies of other canids. *Canis lupus* Richardson (Gray Wolf) exhibit lower mobility and more restricted activity near den sites during denning periods (Ballard et al. 1991, Harrington and Mech 1982, Walton et al. 2001). Home ranges of *Canis latrans* Say (Coyote) also vary seasonally (Laundré and Keller 1984).

The ≈10% reduction in successful GPS location acquisitions during July and August likely resulted in an underestimate of home-range size and use of agricultural areas. Previous studies have shown that thick summer vegetation can block GPS signals, resulting in fewer successful satellite fixes (Dussault et al. 2001, Rempel et al. 1995). The Wolves may have spent more time during these warmer months in a supine position in dense vegetation, which would have decreased the number of acquired locations.

The results of our pilot study indicated that home ranges of the 4 Wolves were not static over the course of a year and thus could not be fully characterized by short-term (days or weeks to a few months) observations. We suggest that future studies of the spatial behavior and habitat use of Red Wolves should be at least 1 year in duration. In-depth knowledge of Red Wolf spatial characteristics can be used to improve current management practices in the Albemarle reintroduction area and enhance the success of future reintroduction projects elsewhere within their historic range. For example, Coyote introgression and hybridization with Red Wolves has become one of the most urgent management problems in the recovery area, as the numbers of Coyotes continue to increase in eastern North America (Kelly et al. 1999, Phillips et al. 2003) and are increasingly observed and trapped within the Red Wolf management area (C. Lucash, pers. comm.). If the contraction of home ranges observed during the spring is common among Red Wolves with established home ranges, this could result in a temporary increase of the extent of unoccupied areas between home ranges. We speculate these temporarily unoccupied areas may be exploited by Coyotes during spring and summer months to enter the management area, possibly exacerbating this significant management problem. Future studies should acquire simultaneous location data from both Wolves and Coyotes in the Red Wolf management area to test this hypothesis and to better understand how the two species interact.

Conclusions

GPS locations (4 location attempts/day) from 4 Red Wolves acquired during 2006–2008 showed that land use and home-range sizes were highly variable over time. Long-term (>1 yr) location data would be necessary to fully characterize the variability and complexity of space use and movements of the species. Based on land-use data from satellite imagery, all 4 Wolves increased their use of agricultural areas when tall (>1 m) crops were present from summer to early autumn, and increased their use of natural, tall grass-brush areas when tall crops were not present (late autumn to spring). Home-range areas based on short-term data (30 days) also varied seasonally, and the temporal patterns were similar among the 4 Wolves. Home ranges were largest during late summer to winter, followed by a 40 to 63% reduction in size during the mating and whelping periods in spring, with a gradual increase in size over the summer.

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