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Satellite Tracking Data Reveals High-Use Areas for Immature Bald Eagles from Kentucky

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Abstract.—Immature raptors often travel long distances and move nomadically from the time they leave their natal area to the time they are recruited into the breeding population. Emphasis on identifying the nesting and winter habitat of Bald Eagles (*Haliaeetus leucocephalus*) has overshadowed the need to understand the habitat and spatial use of young eagles prior to reaching maturity. We used satellite telemetry to track the movements of immature Bald Eagles hatched in western Kentucky during 2010–2016. We analyzed movement data to identify high-use areas for eagles in their first and second years during warm and cool periods. Five out of seven eagles migrated north to the Great Lakes region during their first year. Using Brownian Bridge Movement Modelling, we identified 47 noncontiguous high-use areas during the warm period and 67 during the cool period. Public lands comprised 17% of warm period high-use areas and 43% of cool period high-use areas. High-use areas were located in Illinois, Indiana, Kentucky, Arkansas and Tennessee, and were often near federally-owned dams, rivers with sandbars, or areas with abundant waterfowl. Our small sample of tracked eagles correctly identified known Bald Eagle concentration areas within the study area; thus, we infer that previously unrecognized high-use areas identified by this study are likely to be concentration areas important to the larger population. We further suggest remote sensing data, even in limited datasets, as an efficient way to identify Bald Eagle concentration areas.

Introduction

Immature raptors often travel long distances from the time of natal dispersal to the time they become part of the nesting population (Clark *et al.*, 2004). The emphasis of research on the nesting and winter habitats of Bald Eagles (*Haliaeetus leucocephalus*) has overshadowed the need to understand habitat used by young eagles prior to reaching maturity. Bald Eagles are a highly mobile bird and identifying important areas used by the species before they start breeding is imperative for understanding pre-breeding habitat use and the factors that influence the survival of immature birds (Clark *et al.*, 2004; Morrison and Wood, 2009).

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The Bald Eagle is a well-studied species that continues to receive special protections under the Bald and Golden Eagle Protection Act, despite its removal from the Federal List of Threatened and Endangered Species in 2007 (U.S. Fish and Wildlife Service, 2007). Accordingly, conservation attention has continued for this species, and the Kentucky Department of Fish and Wildlife Resources (KDFWR) has monitored the nesting population in Kentucky as part of national post-delisting nest monitoring efforts (Slankard, 2019). The national Midwinter Bald Eagle Survey (MES) further identifies areas important to wintering eagles, including some communal roosts, where several individuals roost together within a relatively confined space (Eakle *et al.*, 2015; Watts *et al.*, 2007).

Recruitment of immatures into the adult breeding population is a key population metric overlooked in these ongoing monitoring efforts. Identifying and monitoring foraging and roosting sites used by immature Bald Eagles in summer and winter can provide informative data for population management. At the Chesapeake Bay (Virginia and Maryland), conservation groups and wildlife agencies monitored eagle "concentration areas," defined as areas regularly used seasonally or annually by eagles from the early 1980s until 2007 (Watts *et al.*, 2007). Concentration areas have traditionally been identified by boat, road, or aerial surveys which require extensive searching and repeated visits to document usage. However, movement data from modern satellite transmitters can allow for remote identification of concentration areas outside of long-term survey routes, removing search bias and reducing searcher effort. In the Midwestern U.S.A., satellite telemetry-based research has not yet explored concentration areas and instead has focused on other aspects of eagle ecology. For example, eagle migration routes and home range size were documented for Wisconsin Bald Eagles, which migrated south to winter in Missouri along the Mississippi and Illinois Rivers (Mandernack *et al.*, 2012), Bald Eagles wintering in Louisiana were tracked to estimate home range and document movements to summering sites in the central U.S. and Canada (Smith *et al.*, 2017), and a nesting Bald Eagle's home range was described in Kentucky (Slankard *et al.*, 2021). In the eastern U.S.A., eagle concentration areas have been identified with tracking data (Mojica, 2006; Watts and Mojica, 2012; Watts *et al.*, 2015), but no prior studies have used satellite GPS technology to identify concentration areas in the central U.S.A.

Much emphasis has been placed on full life cycle conservation of birds in recent decades (Partners in Flight, 2021). Identifying areas where immature Bald Eagles concentrate spatially and temporally can provide opportunity for more effective conservation, as well as insight into nomadic movements, habitat requirements, and limiting factors (Morrison and Wood, 2009; Watts *et al.*, 2007). Our objective in this study, was to use satellite transmitter data to track the movements of immature Bald Eagles hatched in western Kentucky and to identify high-use (*i.e.,* potential concentration areas) in the broader region. We also set out to compare these areas to those identified with other methods to assess the utility of smaller satellite tracking datasets for the identification of eagle concentration areas. We further assess survival and describe the dispersal movements of the individuals we tracked.

METHODS

FIELD METHODS

Bald Eagle nests were identified for this project at Ballard Wildlife Management Area (WMA) (–89 01 43, 37 09 22), Doug Travis WMA (–89 05 44, 36 47 25) and on private land in Carlisle County (–88 52 42, 36 53 50), Kentucky. All coordinates are within 2 miles of the nests. We tagged eagles as nestlings, 50–55 d of age, during May and June 2010–2015. We determined the sex of nestlings with morphological measurements (Pyle, 2008) and banded each with a U.S. Geological Survey aluminum tarsal band (Permit #23400). We selected one nestling from each nest to which we attached a 70 g (less than 2% body weight), solar powered, Argos/GPS satellite transmitter (PTT-100) (Microwave Telemetry, Inc., Columbia, Maryland, U.S.A.) via a backpack harness with Teflon straps (Buehler *et al.*, 1995). The PTTs collected hourly locations during daylight hours and one location at midnight with ±18 m accuracy.

As part of annual, long-term monitoring, we monitored all Bald Eagle nests in western Kentucky via helicopter surveys in early March (incubation/early nestling) and late April (mid nestling), 2010–2016. We determined the age of nestlings during this survey in order to plan the timing of transmitter deployment and followed up with ground observations, when needed. We display locations for all known Bald Eagle nests in selected figures to show areas with high Bald Eagle nest density.

SPATIAL ANALYSES

We performed spatial analyses using ArcMap 10.5.1 (ESRI, 380 New York Street, Redlands, California, 92373). Data were truncated for each individual in Figure 1 by removing points that were less than 20 km apart or occurred on the same date. In order to identify high-use areas used by the tracked birds, we defined the study area (277,111 km^2) as any six-digit Hydrologic Unit Code (HUC) watershed that contained GPS fixes from at least three Bald Eagles. The resulting study area included portions of the Ohio River, Mississippi River, Illinois River, and Wabash River. Data were excluded that occurred prior to dispersal of individuals from their natal area (excluded fixes = 3453). We defined the beginning of dispersal as the point at which the individual moved at least 5 km from the nest and remained beyond this distance for more than one week. GPS fixes were divided into cool (Oct.–Mar., starting in the hatching year) and warm (Apr.–Sep., starting in the second year) periods. We excluded the hatch-year, warm period from analysis due to the limited time between dispersal and the beginning of the first cool season.

We used Dynamic Brownian Bridge Movement Modeling (dBBMM; Kranstauber *et al.*, 2012) to construct utilization distributions (UD) for each immature Bald Eagle within the study area. All UDs were created in R (R Core Team, 2020; Vienna, Austria) using the MOVE package (Kranstauber *et al.*, 2013). The UDs were weighted with the number of GPS fixes for each bird. We then combined the weighted UD of each individual by creating a 1 km^2 grid of the entire study area and exporting a table with the track weights and grid locations for each bird. The track weights between overlapping grid locations were combined, resulting in high-use areas for the warm and cool months. The high-use areas were then displayed in ArcMap over a 1 km^2 grid of the study area and this resulted in a minimum size of 1 km^2 for the resulting high-use areas. Jenk's Natural Breaks were used to create a color ramp for display and the first natural break was omitted from each seasonal model (warm: 0.4%; cool: 0.8%) in order to illustrate and measure the areas of highest use. For Figure 2, one central point is included for each noncontiguous high-use area in order for the results to display more legibly on a region wide map. We also measured the proximity of high-use areas to state and federal conservation lands, federal dams, and solid waste landfills (Kentucky only).

RESULTS

We tagged 10 nestling Bald Eagles between 21 May 2010 and 26 May 2015. One female died shortly after fledging in 2010 and another male died before fledging in 2015, when its

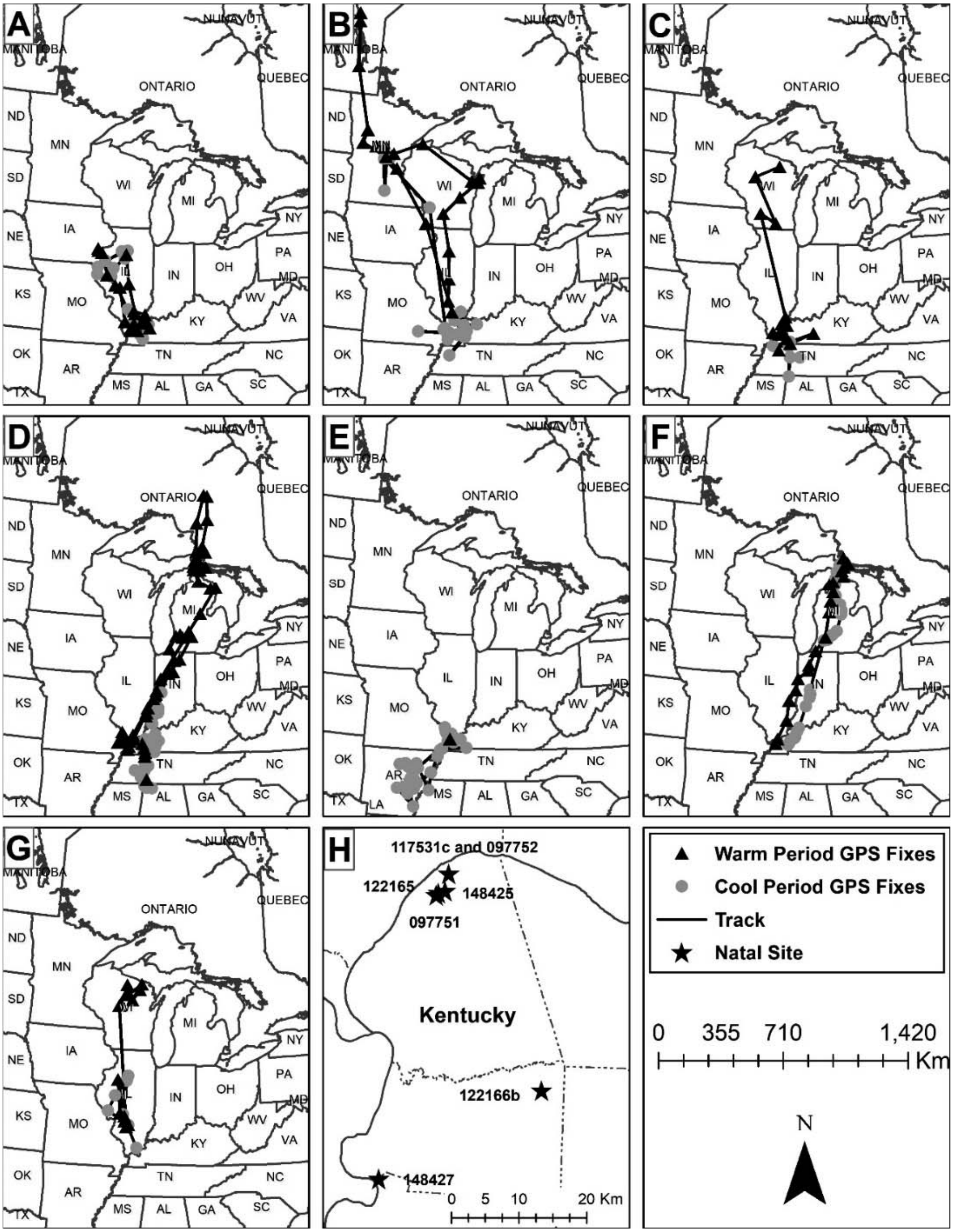

FIG. 1.—The track and fixes for each immature Bald Eagle for 1 y after leaving their natal area; (**A**) 097751 (Male; dispersed: 8/2/2010), (**B**) 148425 (Male; dispersed: 7/6/2015), (**C**) 148427 (Female; dispersed: 7/24/2015), (**D**) 122165 (Male; dispersed: 7/28/2013), (**E**) 117531c (Male; dispersed: 8/27/2014), (**F**) 122166b (Female; dispersed: 7/20/2014), (**G**) 097752 (Female; dispersed: 9/15/2010), (**H**) The natal sites of each immature eagle in Ballard, Carlisle, and Hickman County, Kentucky. Figures 1A–1G are scaled as shown in the legend; whereas Figure 1H is scaled differently

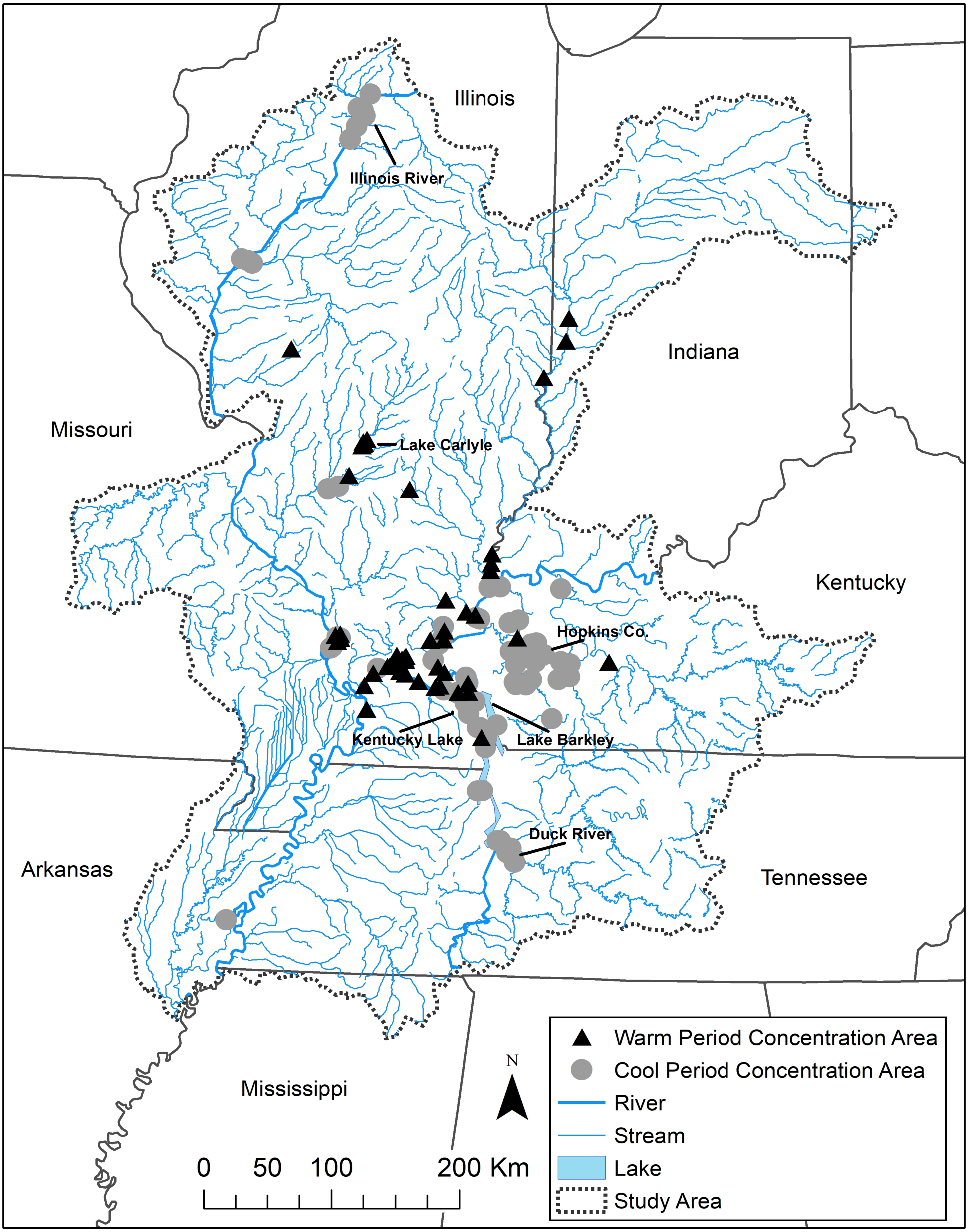

FIG. 2.—High-use areas (central points) for the immature Bald Eagles within the study area

nest was blown out by a windstorm. The PTT for a female, tagged in 2011 stopped transmitting on 11 Oct. 2011. This bird was photographed in good condition shortly after the transmitter stopped sending locations, thus we assumed this PTT failed.

Dates for dispersal from the natal territory ranged from 6 Jul. to 15 Sep. All but one individual (117531c) moved in a northerly direction during the first month after dispersal (Fig. 1). Seven individuals survived their first cool period (winter) and were included in the cool season high-use area analysis. We analyzed a total of 6966 locations for the cool period between the dates of 1 Oct. and 30 Mar. 2010–2016. Six individuals then survived into their second spring and were included in the warm period analysis, with one female (122166b) being excluded due to death on 16 Mar. 2015 (suspected shooting). We analyzed a total of 4320 locations for the warm period between the dates of 1 Apr. and 30 Sep. 2011–2016.

We identified 47 noncontiguous high-use areas during the warm season and 67 during the cool period (Fig. 2). The sum of all warm high-use areas was 200 km^2 (0.07% of the study area) and the sum of all cool high-use areas was 921 km^2 (0.3% of the study area). High-use areas ranged in size from 1 km^2 to 249 km^2 (mean = 12.5 km^2) during the cool period and 1 km^2 to 29 km^2 (mean = 4.7 km^2) during the warm period. Public lands (state and federal) comprised 16.7% of the sum of all warm high-use areas and 42.6% of the sum of all cool high-use areas (Figs. 3, 4). Nineteen percent (9/47) of high-use areas were located within 5 km of federally owned dams during the warm period and 16% (11/67) were located within 5 km of dams during the cool period. Bald Eagles did not use municipal solid waste landfills in Kentucky in the warm period and only one hourly fix from one eagle was located at a landfill during the cool period.

Discussion

Past telemetry studies have focused on the migration or home range of Bald Eagles and ours is the first to report satellite GPS-based high-use areas and dispersal patterns for immature Bald Eagles in the Midwestern U.S.A. (Mandernack *et al.*, 2012; Smith *et al.*, 2017; Slankard *et al.*, 2021). Smith *et al.* (2017) described nonbreeding home ranges for Bald Eagles from Louisiana tracked via satellite GPS transmitters and using dBBMM. A nonbreeding adult from that study spent two summers in our study area (IL) with some overlap in use during 2014 of high-use areas we identified near the Illinois River. However, the majority of the birds tracked by Smith *et al.* (2017) from Louisiana migrated north to summer in Canada.

Most of the birds we tracked covered considerable distance during their first year after dispersal venturing as far north as Ontario and Manitoba, Canada (Fig. 1). The migration northward of Bald Eagles from southern natal areas has been documented in other studies in Arizona, California, and Florida (Hunt *et al.*, 1992; Hunt *et al.*, 2009; Mojica *et al.*, 2008). Our study confirmed a similar movement pattern in midwestern Bald Eagles. The immature Bald Eagles we tracked demonstrate linkage to the Great Lakes region, with five out of seven birds migrating there during their first year. Whereas sparse band recoveries from Kentucky and satellite tracking studies from similar latitudes (K. Slankard, unpubl.; Mandernack *et al.*, 2012) have demonstrated the migration of eagles from the Great Lakes south to this region, our data further suggests a south-to-north migratory link between eagle populations of the Great Lakes and Kentucky/Tennessee. Despite many of the eagles we tracked visiting the Great Lakes region, our study area for the high-use area analysis did not include this area. Fixes from the Great Lakes were quite widespread and did not meet the definition for inclusion (watersheds for which at least three individuals had visited). High-use areas were thus located in the Midwest/Midsouth, with more areas north of the natal sites than south.

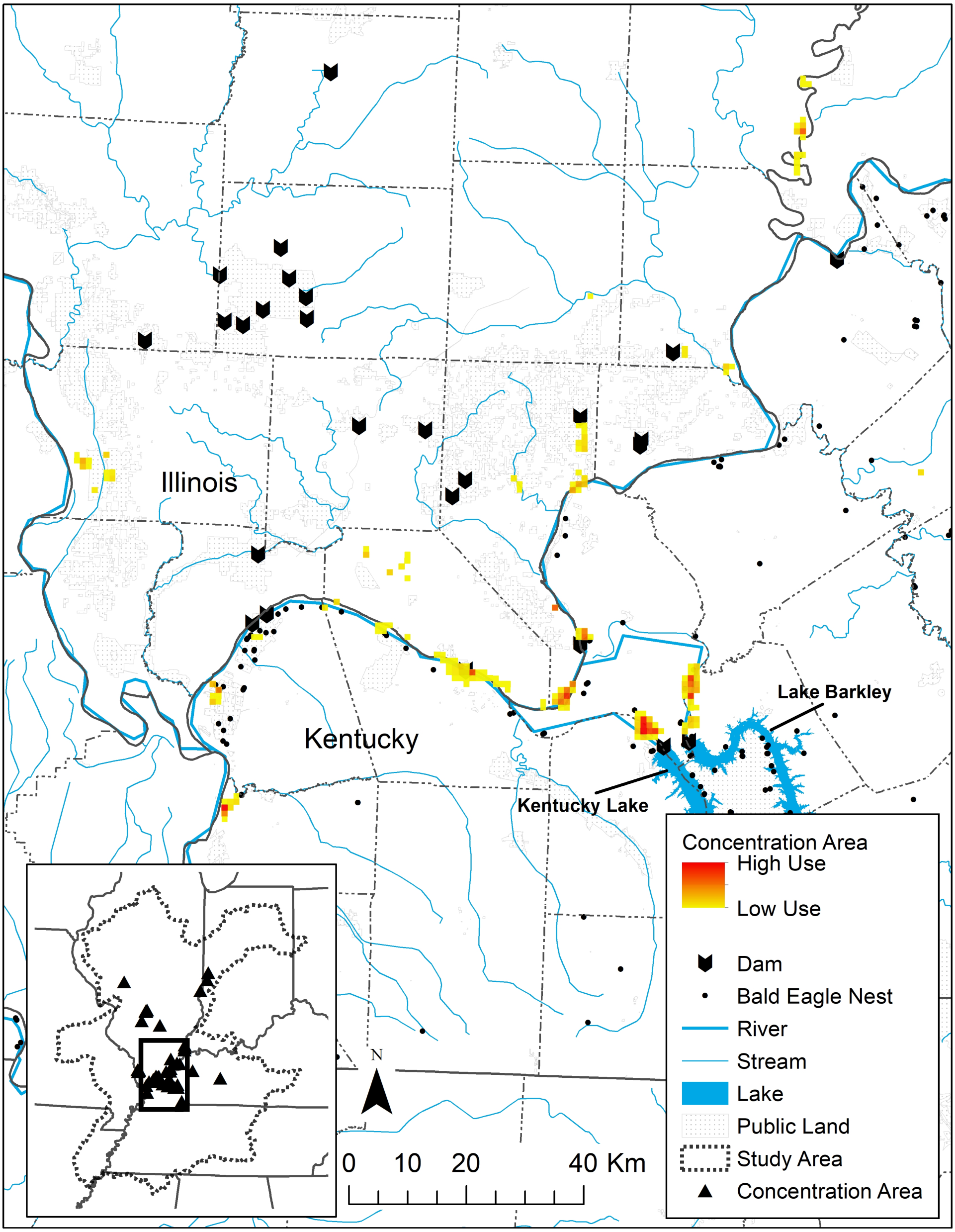

FIG. 3.—Warm period high-use areas for the immature Bald Eagles in western Kentucky and southern Illinois. Dams displayed are federally owned. Nest locations are shown for Kentucky only

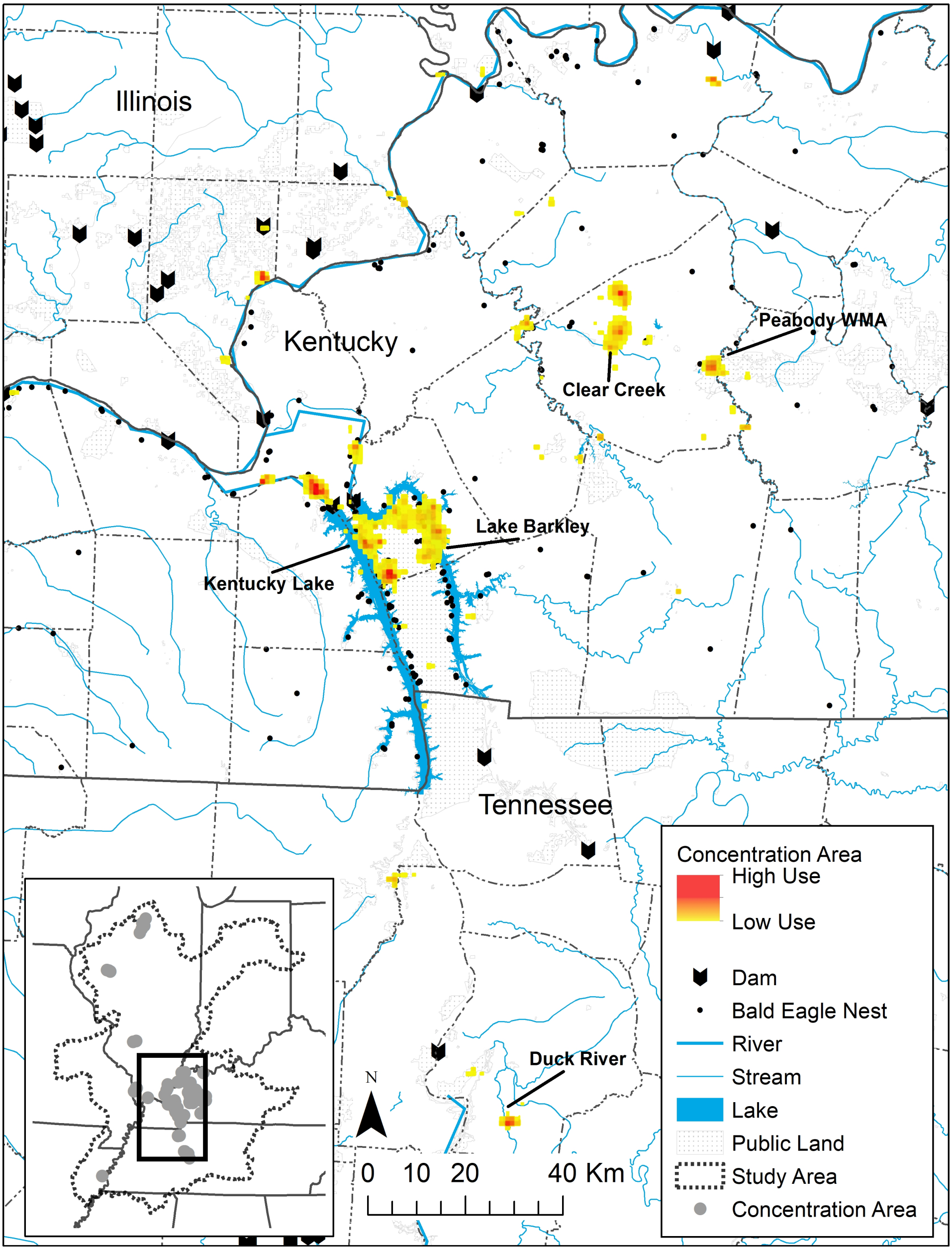

FIG. 4.—Cool period high-use areas for the immature Bald Eagles in western Kentucky, southern Illinois, and northwestern Tennessee. Dams displayed are federally owned. Nest locations are shown for Kentucky only

The Bald Eagles we tracked demonstrated some seasonality in their movements, generally moving north for the warmer months and south during the cooler months. Surprisingly still, we identified several cool period high-use areas on the Illinois River, well north of the natal area for these birds. The Central Illinois River region has been noted as important for Bald Eagles through winter eagle surveys for decades (Havera and Kruse, 1988). We also identified several high-use areas at and near Lake Carlyle, Illinois, during both warm and cool periods. The identification of these areas using transmitter data is an example of how traditional survey efforts can downplay areas important to young eagles. The MES conducted at Lake Carlyle from 1990–2005 recorded zero to six eagles annually, and these totals were relatively low in comparison to other surveys in the region (Steenhof *et al.*, 2008).

Several areas in Hopkins County, Kentucky, near Clear Creek and Peabody WMA were unexpectedly identified as cool period high-use areas, many of which were on reclaimed strip-mined land with numerous small lakes interspersed. These areas are not covered by MES and, although this county does support several Bald Eagle nests, the area was not generally regarded as a high priority for eagle conservation before this study. Despite two state owned Wildlife Management Areas, much of the land in the Hopkins County high-use areas is privately owned. Eagles are likely attracted to this area by abundant winter waterfowl populations and many small lakes and ponds stocked with fish for recreation (KDFWR 2021; T. Young, pers. comm.).

Kentucky Lake and Lake Barkley are well known concentration areas for Bald Eagles in Kentucky and Tennessee; thus, we were not surprised to find high-use areas near the dams for these lakes and on the lakes themselves. However, the seasonal shift of the high-use areas near these lakes is interesting. The high-use areas were much larger on the upstream side of the dams during the cool period with smaller high-use areas downstream of the dams; whereas, there were no high-use areas upstream of the dam during the warm period (Figs. 3, 4). This likely reflects a seasonal shift in habitat selection. Watts *et al.* (2015) used Bald Eagle satellite tracking data and dBBMM to identify seasonal use of foraging areas in the Chesapeake Bay. They found that summer use was concentrated on shorelines near the main bay and major tributaries; whereas winter use was focused on minor tributaries and inland ponds that could have provided superior shelter from inclement weather and winter winds. Water levels on Kentucky Lake and Lake Barkley are also higher in the summer than the winter and the shift in the eagles' spatial use may be in response to water level related changes in hunting opportunities.

The high-use areas probably exhibit characteristics that are rare and attractive for immature Bald Eagles, given they encompass less than a fraction of one percent of the study area. Our small sample of tracked eagles correctly identified known Bald Eagle concentration areas within the study area; therefore, we infer that previously unrecognized high-use areas identified by this study are likely to be concentration areas important to the larger population. These high-use areas likely provide resource rich areas that support many immature Bald Eagles and likely some non-breeding adults as well (Watts *et al.*, 2007, Smith *et al.*, 2017).

It is notable that 19% and 16% of the high-use areas were near large dams during the warm and cool period, respectively. It is known that Bald Eagles use dams as year round foraging areas due to scavenging opportunities provided by fish killed when passing through turbines (Ross and Follen, 1988; Kaltenecker *et al.*, 1998), but our data further confirms the use of these areas by first and second year Bald Eagles. Other high-use areas were located near rivers with abundant sandbars (*e.g.*, the lower Duck River region in Tennessee). We surmise slow moving, shallow waters likely bring fish near the surface in these areas, providing easier hunting opportunities for immature eagles. Kaltenecker *et al.* (1998) also found that Bald Eagles foraged from shallow river pools with a lower rate of flow.

The average size and sum of all high-use areas was smaller during the warm period than during the cool period. High-use areas may expand in size to support an increase in Bald Eagles during the cool period, as northern eagle populations migrate to winter in lower latitudes and local eagles congregate around limited food resources (Mandernack *et al.*, 2012; Watts *et al.*, 2007). Age and experience may also affect the movement data we used to delineate the high-use areas, given the eagles were older during the warm period. Individuals that have lived longer are likely to forage more efficiently and explore less (Mannan and Boal, 2000; Urios *et al.*, 2007). Our data also show high-use areas extended further from water sources during the cool period, suggesting alternative hunting areas and food sources may be important during that time (Grubb *et al.*, 2018; Schmuecker *et al.*, 2020).

High-use areas are likely important for immature Bald Eagles in this region; however, only 16.7% and 42.6% of areas we identified were on public land for the warm and cool period respectively. As many of these areas are not protected, data like ours may be used to prioritize land acquisition and protection and possibly for mitigation of habitat loss. Some of the high-use areas were near to, but not on public lands and these areas in particular could be prioritized for protection. For example, 77% of the Duck River, Tennessee, high-use areas were on private lands along the Duck River and not at the nearby National Wildlife Refuge.

Long term Bald Eagle monitoring efforts may be biased based on their focus on public lands, sites with easy access, and areas with high nesting density. Moreover, it is generally assumed that areas with high nest density, high MES counts and reliable communal roosts are the most important places for Bald Eagles. This study suggests traditional monitoring methods may overlook areas utilized by immature Bald Eagles. MES routes may not cover the exact areas where eagles concentrate or may miss important areas altogether. Warm season concentration areas are likely completely ignored by monitoring. However, even relatively small remote sensing datasets can be an efficient way to identify concentration areas important for immature Bald Eagles. Ignoring habitat needs for immature birds when planning eagle conservation may put populations at risk during a vulnerable part of the life cycle (Mojica *et al.,* 2008; Wheat *et al.,* 2007).

Monitoring the population health and spatial use of Bald Eagles over the long-term has utility beyond the conservation of this species. Bald Eagles are environmental indicators, given they feed at a high trophic level on water-dependent organisms (Bowerman *et al.,* 2002). Winter weather conditions (and resultant effects on prey availability and freezing of waterbodies) influence the movement and concentration of Bald Eagles (Lingle and Krapu, 1986; Watts *et al.,* 2007), and monitoring concentration areas on the long-term may be useful for assessing the ecological effects of climate change. In order to monitor and consider immature eagle high-use areas, periodic tracking of individuals may be utilized at regular intervals (*e.g.*, 10–20 years) depending on funding availability and management objectives.

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