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SEASONAL VARIATION IN SPACE USE BY NONBREEDING BALD EAGLES WITHIN THE UPPER CHESAPEAKE BAY

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Abstract.—Access to food resources is essential to self-maintenance and reproduction and, for species of conservation concern, foraging areas are considered critical habitat. Human disturbance is an important factor restricting access to prey resources for Bald Eagles (*Haliaeetus leucocephalus*) and guidelines in the Chesapeake Bay have been developed to mitigate its impact. However, our ability to implement such guidelines has been limited by a lack of information on important foraging areas. We used Brownian bridge movement modeling to develop a population-wide utilization probability surface for Bald Eagles along shorelines within the upper Chesapeake Bay. We used locations ($n = 320\,304$) for individuals ($n = 63$) tracked with GPS satellite transmitters between 2007 and 2011 in the analysis. We examined seasonal variation by developing utilization surfaces for summer and winter. Although shoreline use was widespread, segments receiving high levels of activity were relatively rare. Shoreline classified as having the highest category of use and accounting for 10% of the total utilization made up 0.41% and 0.55% of the total shoreline for winter and summer, respectively. From a management perspective, there is a clear pattern of diminishing returns in conservation value for including sequentially lower-use shorelines in land-use management plans. Shoreline use shifted dramatically in both location and extent between seasons. During the summer months, use was highly concentrated on shorelines along the main stem of the Chesapeake Bay or along major (>1 km wide) tributaries. During the winter months, use shifted away from the main stem of the bay and was more focused on minor (<100 m wide) tributaries and inland ponds. Seasonal shifts in shoreline use suggest the need for season-based management objectives.

Key Words: *Bald Eagle*; Haliaeetus leucocephalus; *Brownian bridge movement modeling*; *Chesapeake Bay*; *foraging*; *land planning*; *shoreline use.*

VARIACIÓN ESTACIONAL EN EL USO DEL ESPACIO DE INDIVIDUOS NO REPRODUCTIVOS DE *HALIAEETUS LEUCOCEPHALUS* EN LA PARTE SUPERIOR DE BAHÍA CHESAPEAKE

Resumen.—El acceso a las fuentes de alimento es esencial para la pervivencia y la reproducción. Además, para las especies con interés en conservación, las áreas de alimentación son consideradas hábitats críticos. Las molestias de origen antrópico son un factor importante que restringe el acceso a las presas a *Haliaeetus leucocephalus*, por lo que se han desarrollado pautas de gestión en la Bahía Chesapeake para mitigar estos impactos. Sin embargo, nuestra capacidad para implementar dichas pautas se ha visto limitada por la falta de información sobre las áreas importantes de alimentación. Utilizamos el modelo de movimiento de puentes Brownianos para desarrollar una probabilidad de uso del espacio en poblaciones de *H. leucocephalus* a lo largo de la costa de la parte superior de la Bahía Chesapeake. Para el análisis utilizamos localizaciones ($n = 320\,304$) de individuos ($n = 63$) seguidos mediante transmisores satelitales entre 2007 y 2011. Examinamos la variación estacional del uso del espacio durante el verano y el invierno. Aunque la línea de costa se usó ampliamente, los segmentos que evidencian niveles de actividad elevados fueron relativamente raros. Las costas que presentan la categoría de uso más alta y que representan el 10% del uso total constituyen el 0.41% y el 0.55% del total de costa para el invierno y el verano, respectivamente. Desde una perspectiva de gestión, se evidencia un claro patrón de rendimiento secuencial decreciente del valor de conservación de costas de bajo uso en los planes de manejo del uso de la tierra. El uso de la costa cambió dramáticamente en cuanto a ubicación y extensión entre estaciones. Durante los meses de verano, el uso se concentró mayoritariamente en las costas a lo largo del río principal de la Bahía Chesapeake o a lo largo de sus tributarios mayores (>1 km de ancho). Durante los meses de invierno, el uso se alejó del río principal de la bahía y se ubicó con mayor intensidad en los tributarios menores (<100 m de ancho) y en los estanques tierra adentro. Los cambios estacionales en el uso de la costa sugieren la necesidad de objetivos de gestión basados en las estaciones del año.

[Traducción del equipo editorial]

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An animal's ability to acquire food is essential for self-maintenance and reproduction. Because Bald Eagles (*Haliaeetus leucocephalus*) are sensitive to human disturbance (Fraser 1985), continual human activity within potential foraging habitat will effectively render those areas unsuitable and prevent eagles from accessing prey populations (McGarigal et al. 1991). Over time, this loss in access to resources may reduce the capacity of the area to support eagles and the population may be expected to decline to a new equilibrium with the remaining landscape. This relationship is the basis for protection of important foraging areas under the ''disturb and sheltering provisions'' of the federal Bald and Golden Eagle Protection Act (Eagle Act) of 1940 (16 U.S.C. 668-668c) and why their management is considered within the National Bald Eagle Management Guidelines (U.S. Fish and Wildlife Service [U.S.F.W.S.] 2007).

Considerable research has been conducted over the past 30 yr to determine what conditions disturb eagles within foraging areas (e.g., Stalmaster and Newman 1978, Knight and Knight 1984, McGarigal et al. 1991, Brown and Stevens 1997). Frequent human activity associated with shoreline development has led to the avoidance of shorelines by foraging birds or presumptive habitat loss (Buehler et al. 1991a, Chandler et al. 1995, Clark 1992). Management recommendations designed to protect important foraging areas include setbacks of residential and industrial development from the shoreline (Buehler et al. 1991a). Episodic human activities from the water (Knight and Knight 1984, McGarigal et al. 1991, Brown and Stevens 1997), air (Stalmaster and Kaiser 1997), or land (Stalmaster and Kaiser 1988, Grubb and King 1991) flush eagles from the shoreline and disrupt hunting behavior. Because the effects of these activities decline with distance (Smith 1988, McGarigal et al. 1991, Watts and Whalen 1997), management recommendations include the establishment of protective buffers around important foraging areas (Howard and Postovit 1987, Knight and Skagen 1988, Rodgers and Schwikert 2003, U.S.F.W.S. 2007).

The Chesapeake Bay is an area of convergence for post-nesting and subadult Bald Eagles (Buehler et al. 1991a, Watts et al. 2007) from three distinct breeding populations (Chesapeake Bay, northeastern states/provinces, southeastern states). In late spring and early summer, eagles migrate north from Florida and other southeastern states to spend the summer months in the bay (Broley 1947, Millsap et al. 2004, Mojica et al. 2008). In the late fall, eagles from breeding populations within the Canadian Maritimes and New England migrate south to spend the winter months in the Chesapeake Bay (McCollough 1989). Human activity throughout the Chesapeake Bay has a dramatic influence on the distribution of nonbreeding eagles (Buehler et al. 1991b, Watts and Whalen 1997). Human activity within 200 m of the shoreline (whether in the uplands or in the near shore) has been related to shoreline avoidance by eagles. Although we understand how human activities influence eagle distribution, and have developed approaches to mitigate such effects, a major obstacle preventing the implementation of recommendations is the identification and delineation of the activity areas themselves. Our objectives here were to use satellite tracking data to delineate areas of high eagle use within the upper Chesapeake Bay and to examine seasonal (summer vs. winter) variation in the distribution of these areas.

Study Area

Our study area (5415 km^2) included the northern portion of the Chesapeake Bay from the Bay Bridge at Annapolis, Maryland, to just above the Conowingo Dam on the Susquehanna River (Watts and Mojica 2012). The eastern portion of the study area is primarily rural with forest lands interspersed with agriculture. The western portion contains the urban areas of Baltimore and Annapolis, but also includes Aberdeen Proving Ground (APG), a 350 km^2 military installation that is primarily forested with extensive shorelines. APG is the major U.S. Army testing facility. Since establishment in 1917, the installation has been the site of intense research and development, and large-scale testing of munitions, weapons, and material. The site also serves as a training area for the Navy, Air Force, and Marines supporting firing ranges, impact areas, vehicle test tracks, and other facilities. In a previous investigation within the study area, Buehler et al. (1991b) identified pedestrian use of the shoreline and near-shore boats as two human activities that had a significant effect on the likelihood of eagle occurrence. They recorded pedestrians and boats along 56.3% and 69.0% of shoreline segments, respectively. They recorded significantly more pedestrians and boats along the shoreline in summer compared to winter.

Methods

Transmitters. We captured resident and migrant Bald Eagles (n = 63) on APG, banded them, and fitted them with satellite transmitters between July 2007 and May 2009. Free-flying eagles were trapped on three sandy beaches (n = 10) using padded leg-hold traps (King et al. 1998), in three open fields (n = 26) using rocket nets baited with deer carcasses (Grubb 1988) and on open waters (n = 10) using floating fish traps (Frenzel and Anthony 1982, Cain and Hodges 1989, Jackman et al. 1993). We climbed nest trees throughout APG to access broods (8–10 wk of age) and deployed a transmitter on one nestling per brood (n = 17). Eagle capture and handling methods were in compliance with IACUC protocols at the College of William and Mary (IACUC-20051121-3), Maryland scientific permit 42687, and U.S.G.S. Bird Banding Laboratory permit 21567.

We used solar-powered, 70-g, GPS-PTT satellite transmitters (Microwave Telemetry, Inc. Columbia, Maryland, U.S.A.) to track eagle movements. Transmitters were attached using a backpack-style harness constructed of 0.64-cm Teflon® ribbon (Bally Ribbon Mills, Bally, Pennsylvania, U.S.A.). Transmitters were programmed to collect GPS locations (±18 m) every daylight hour and one additional location at midnight. GPS locations were processed by Argos equipped weather satellites (CLS America, Largo, Maryland, U.S.A.) and stored online by Satellite Tracking and Analysis Tool (Coyne and Godley 2005).

Movement Modeling. We used Brownian bridge movement models (BBMM; Horne et al. 2007) to develop utilization distributions (UD; Worton 1989) for Bald Eagles within the study area using locations (n = 320 304) collected between August 2007 and June 2011. We produced BBMM-derived UD surfaces across a grid system of 1-ha cells (n = 541 476) overlaid on the study area. In order to reduce ''edge effects'' for movement probabilities we created an 80-km buffer around the study area and included positions within the buffer in modeling. Independent surfaces were produced for all nonbreeding eagles with transmitters including Chesapeake Bay residents (42), northern migrants (13) and southern migrants (4; n = 59; three birds were determined to hold breeding territories and one nestling died at fledging and were excluded). Two maps including summer (May through August) and winter (November through March) were produced to reflect the migration seasons and possible variation in shoreline use. Data from birds marked as nestlings were excluded until the birds dispersed from the natal area (typically in the early to mid-fall period). We combined UD surface maps produced for individual birds to create a population-wide UD for both winter and summer seasons. We assume that nonbreeding birds from different breeding populations behave the same within the study area. This assumption is supported by Buehler et al. (1991a), who found no difference in space use within the study area related to population of origin. Because sample sizes varied between individuals, surfaces were weighted according to the number of locations per individual, combined, and standardized.

Statistical Analysis. We used an arbitrary schema to stratify the UD surface for analytical and presentation purposes. The population-wide UD was estimated over a large study area with a relatively high level (1 ha) of spatial resolution resulting in a large number of probability values. To facilitate presentation, we ordinated cell values from highest to lowest and grouped cells within categories that represented 10% of the total eagle utilization such that the first category was comprised of the cells with the highest utilization. This approach allows for an examination of the relationship between the level of utilization and area (i.e., the first category reflects the minimum area to achieve 10% of the total utilization, the second category reflects the minimum area to achieve the next 10% of the total utilization, etc.). Because this treatment is focused on shoreline use, we overlaid the shoreline on the utilization surface and assigned use classes to the shorelines according to the underlying surface. This allowed for mapping utilization intensity and distribution.

RESULTS

Bald Eagles tracked with satellite transmitters moved widely throughout the study area and used most of the available shoreline (Fig. 1). A total of 2236 km of shoreline was delineated throughout the study area and 29% (648.9 km) of this length was classified as used to some level during either the summer or winter seasons or both. Areas with very little use include the southwestern corner of the study area around Baltimore where the landscape is dominated by urban development and the communities of Havre de Grace and Perryville at the mouth of the Susquehanna River. Although shoreline use was widespread, segments receiving high levels of activity were relatively rare. Shorelines classified as having the highest category of use and accounting for 10% of the total utilization made up 0.4% and 0.6% of the total shoreline for winter and summer, respectively. Even shorelines accounting

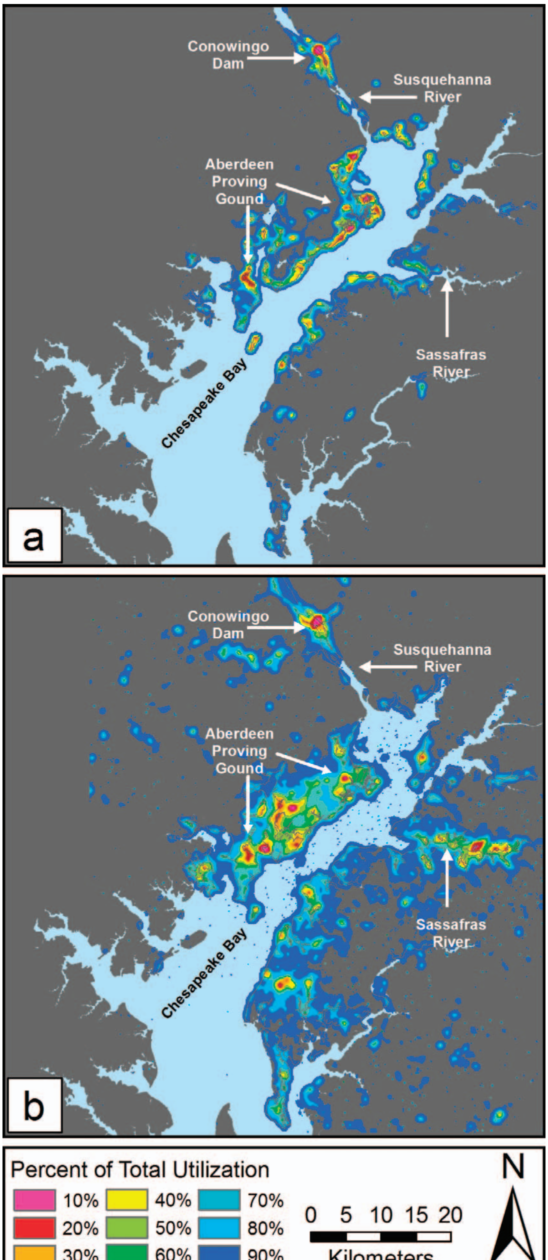

Figure 1. Bald Eagle utilization distribution or probability surface for the (a) summer and (b) winter from pooled locations analyzed with the Brownian Bridge Movement Model for 59 nonbreeding birds. Each successive category depicts the minimum area that encloses the proportion of utilization distribution.

for 40% of use collectively made up only 5.6% of the total shoreline for seasons, suggesting that shoreline use is highly aggregated in relatively few locations.

Eagles were more dispersed along the shoreline during winter when compared to summer. This is illustrated by examining the length of shoreline required to account for percentages of total utilization (Fig. 2). Interestingly, although there were shifts in location, high-use areas (<30% UD) occurred along similar lengths of shorelines between the two seasons. Low-use areas (>50% UD) were dramatically different, such that it requires more than twice as much shoreline to account for 80% of the eagle utilization in winter (270 km) compared to summer (115 km).

Shoreline use shifted dramatically in both location and extent between seasons (Fig. 1). During the summer months, utilization was highly concentrated on shorelines along the main stem of the bay or along major (>1 km wide) tributaries. An exception to both was the large concentration of birds below the Conowingo Dam where eagles congregated to feed on stunned fish around the outflow. During the winter months eagles shifted away from the main stem of the Chesapeake Bay and focused on minor (<100 m wide) tributaries and inland ponds. Dramatic examples of this pattern were the seasonal shifts apparent on Aberdeen Proving Ground and the Sassafras River. Use of Aberdeen Proving Ground in summer was concentrated on the outer shoreline, whereas in winter birds shifted inland and used smaller tributaries and ponds. Use of the Sassafras River in summer was focused on shorelines around the mouth, with little activity along the upper reaches. Utilization was reversed in the winter, with most of the activity recorded along the upper section.

The density of actual transmitter fixes along the shoreline for the study period varied from 1746 and 1540 locations/km for the highest-use category (10% utilization) during summer and winter respectively to 1.4 and 0.9 locations/km for the lowest-use category (90% utilization, Fig. 1). More than 60% of locations were concentrated along the highest-use shorelines (equating to 40% utilization from BBMM) that represent 5.6% or 126 km of the shoreline for both seasons. Although high-use (40% utilization) shorelines were similar in total length between summer and winter, 68% of the collective segments were exclusive to each season (Fig. 3, 4). The remaining 32%, or 39.6 km, of shoreline received high eagle use throughout the year.

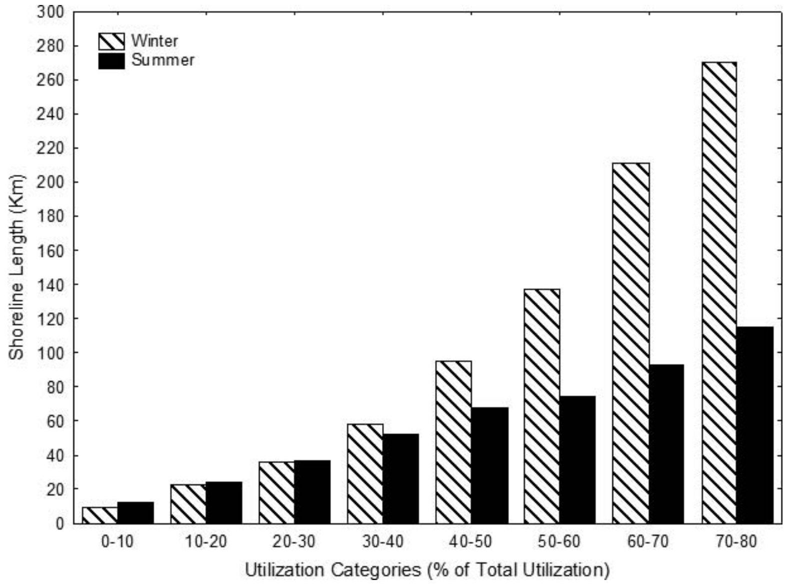

Figure 2. Shoreline lengths required to accommodate successive 10% intervals of Bald Eagle utilization within the upper Chesapeake Bay during winter and summer.

DISCUSSION

Although eagles were widely distributed throughout the study area, shoreline segments that were consistently highly used were relatively rare. This finding is consistent with studies within other locations (e.g., Keister et al. 1987, Garrett et al. 1993, Brown and Stevens 1997) that have documented the occurrence of eagle foraging areas where specific

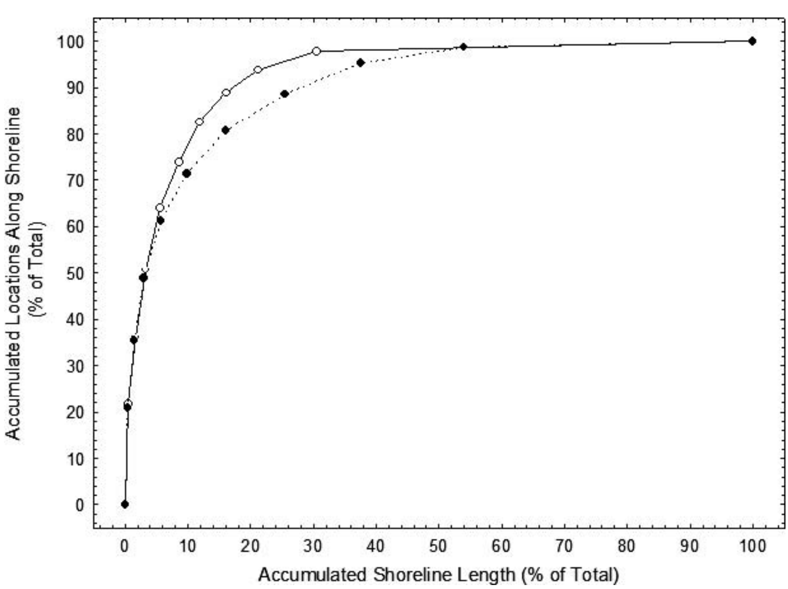

Figure 3. Relationship between the cumulative length of shoreline and the cumulative proportion of associated Bald Eagle locations for winter and summer periods. Locations were compiled from > 320,000 GPS fixes from 59 nonbreeding eagles between 2007–2011. White circles indicate summer and black circles indicate winter.

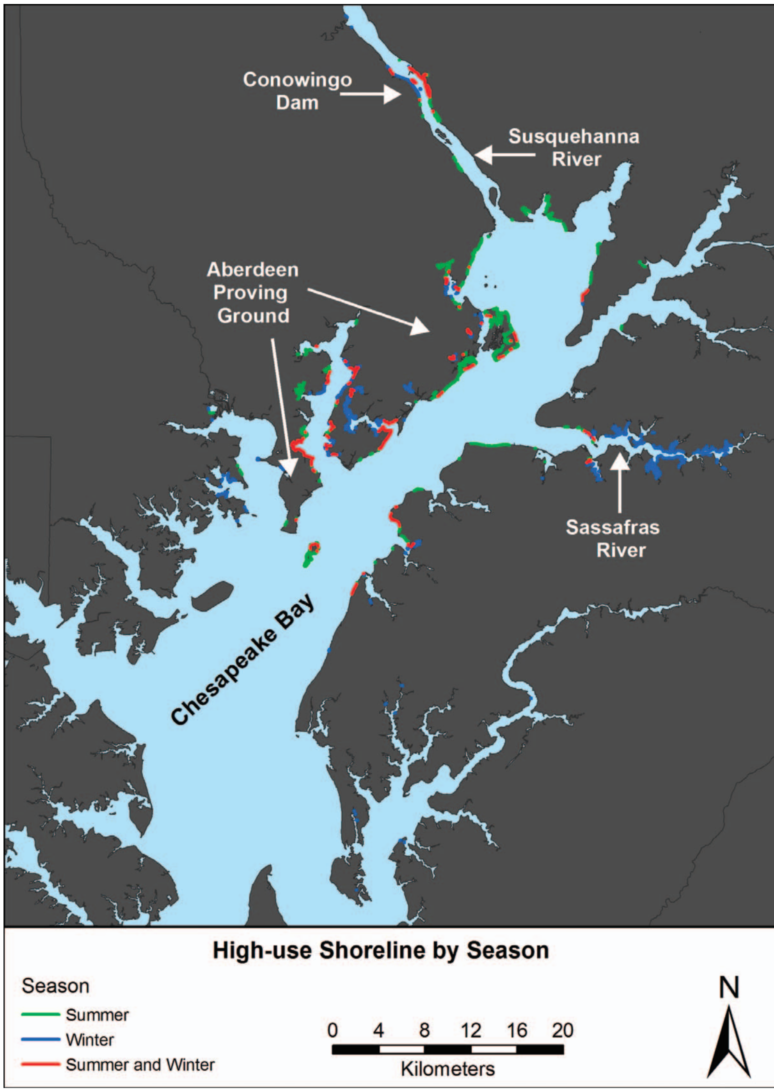

Figure 4. Location of high-use (40% utilization) shoreline segments used by Bald Eagles in the upper Chesapeake Bay during summer, winter, and both summer and winter seasons.

elements, including rich food resources, quality perches, and low human activity, overlap on the landscape. Within the current treatment, protecting shorelines during winter with the highest 10% of utilization would require focused management along 9 km of shoreline, whereas protecting shorelines with the lowest 10% of utilization would require focused management on more than 1000 km of shoreline.

Use of the upper Chesapeake Bay landscape shifted dramatically with season with birds during summer concentrated along the widest (1–10 km) water within the study area and during the winter focused on narrower (<100 m) tributaries and inland areas. This pattern is consistent with previous studies that have documented seasonal shifts and suggested that birds are moving to avoid weather exposure (Yackel Adams et al. 2000). Steenhof et al. (1980), working along the Missouri River in South Dakota, showed that birds moved to protected perches and into communal roosts during periods of high wind and extreme wind chill. Stalmaster and Gessaman (1984), working along the Nooksack River in Washington, showed that eagles in winter conserve energy by selecting beneficial microclimates and shifting behavior depending on weather. However, Buehler et al. (1991c) modeled energy costs for travel and thermoregulation for shoreline and inland roosts within the upper Chesapeake Bay and found no energy savings for using inland roosts despite the fact that eagles shifted to inland roosts between seasons and inland roosts were more protected from prevailing winds (Buehler et al. 1991c). One possible explanation is that seasonal shifts in roost use may be driven by shifts in the distribution of available prey.

Bald Eagles within the Chesapeake Bay exhibit a seasonal shift in diet that reflects prey availability and may partly account for observed changes in the distribution of high-use areas. Breeding adults with dependent broods (Markham and Watts 2008) and summer migrants (Watts and Whalen 1997) feed almost exclusively on fish. A large portion of these fish appear to be captured live from or near the surface of the water but dead fish are frequently scavenged from the surface or along the shoreline. During winter, migrants and residents rely more heavily on waterfowl and mammals (Haines 1988, Mersmann 1989). Live fish move into deeper water during the winter months and are less accessible to surface or near-surface predators. DeLong et al. (1989) assessed prey availability with gillnet sampling and found that fish numbers in the upper bay declined seasonally November through March, while waterfowl abundances peaked in the winter months until departure in April. The study area is a historically significant waterfowl hunting area (Lynch 2001). However, we are unable to assess the correspondence between eagle and waterfowl distributions during winter due to the lack of data on waterfowl abundance and distribution.

Regardless of the underlying ecological factors, approximately two-thirds of high-use shorelines used by Bald Eagles in the upper Chesapeake Bay were exclusive to season and the remaining segments were used all year. Given equal habitat constraints for the populations between seasons, management priority should be given to shoreline segments that are used during both seasons because these sites meet eagle requirements throughout the year and have the greatest conservation value. Continual human activity within these areas effectively renders them unsuitable for eagle use and represents a presumptive loss of critical habitat (Buehler et al. 1991b). Flushing probabilities with distance to boats have been examined widely throughout the species range (e.g., Knight and Knight 1984, Buehler et al. 1991b, McGarigal et al. 1991, Watts and Whalen 1997, Rodgers and Schwikert 2003) with mean flushing distances ranging from 150 to 250 m. Flushing responses have led to recommendations of disturbance buffers for foraging birds in the range of 300-400 m. Consideration of these buffers around high-use shorelines in the summer months when planning discretionary activities would be beneficial to foraging birds. During the winter months, when eagles move into narrow tributaries, most birds would be flushed by any boat traffic because flushing distances are greater than channel width. Effective protection of foraging eagles during this time of year would require waterway closures.

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