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USE OF SATELLITE TRANSMITTERS TO DELINEATE BALD EAGLE COMMUNAL ROOSTS WITHIN THE UPPER CHESAPEAKE BAY

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ABSTRACT.—Although Bald Eagle (*Haliaeetus leucocephalus*) roosts are protected under the federal Bald and Golden Eagle Protection Act, we have little systematic information on the distribution and abundance of roosts, and a policy framework that governs day-to-day management decisions has not been developed. We used satellite transmitters ($n = 63$) deployed on Bald Eagles that represented a cross section of age classes and populations present within the study area. The units were programmed to record nocturnal roost locations ($n = 10\,321$) to assess roosting behavior and to delineate the boundaries of communal roosts within the upper Chesapeake Bay. More than 27% ($n = 2800$) of roost locations were not associated with communal roosts and were assumed to reflect solitary roosting. The remaining 72% ($n = 7475$) of roost locations were clustered within 170 communal roosts that varied in area (0.04–20.13 ha), relative use (5–755 roost-nights), and number of transmittered birds present (2–35). The number of communal roosts within the study area has grown 10-fold over the past 20 yr, presumably reflecting the growth of source populations and eagle use of the area.

KEY WORDS: *Bald Eagle*; *Haliaeetus leucocephalus*; *Chesapeake Bay*; *communal roost*; *satellite transmitter*.

USO DE TRANSMISORES SATELITALES PARA DELINEAR DORMIDEROS COMUNALES DE *HALIAEETUS LEUCOCEPHALUS* EN LA BAHÍA ALTA DE CHESAPEAKE

RESUMEN.—Aunque los dormitorios de *Haliaeetus leucocephalus* están protegidos por la Ley Federal de Protección del Águila Calva y Dorada, poseemos poca información sistemática sobre la distribución y abundancia de los dormitorios y no se ha desarrollado un marco político de decisiones diarias de manejo. Usamos transmisores satelitales ($n = 63$) colocados en individuos de *H. leucocephalus* que representaron una muestra cruzada de clases de edad y poblaciones presentes en el área de estudio. Las unidades fueron programadas para registrar las localizaciones de los dormitorios nocturnos ($n = 10\,321$) y así evaluar el comportamiento vinculado a los dormitorios y delinear los límites de los dormitorios comunales en la parte superior de la Bahía de Chesapeake. Más del 27% ($n = 2800$) de las localizaciones de los dormitorios no estuvo asociado con dormitorios comunales y fueron considerados como dormitorios solitarios. El 72% ($n = 7475$) restante de las localizaciones de los dormitorios fue agrupado en 170 dormitorios comunales que variaron en superficie (0.04–20.13 ha), uso relativo (5–755 noches dormitorio) y número de aves presentes con transmisores (2–35). El número de dormitorios comunales dentro del área de estudio ha aumentado 10 veces a lo largo de los últimos 20 años, reflejando presumiblemente el crecimiento de poblaciones fuente y el uso del área por parte de las águilas.

[Traducción del equipo editorial]

Congregations of nonbreeding Bald Eagles (*Haliaeetus leucocephalus*) form around rich food resources (McClelland et al. 1982, Isaacs and Anthony 1987, Hunt et al. 1992), and associated communal roosts typically are clustered around profitable feeding patches (Keister et al. 1987, Wilson and Gessaman 2003). Feeding and roosting are exclusive activities, require different habitats, and are often separated by considerable distances (Swisher 1964,

Edwards 1969, Keister and Anthony 1983). The distribution of communal roosts is believed to reflect a dynamic balance between the cost of travel to and from feeding areas, the relative profitability of feeding areas, and the energy savings achieved from roosting within protected microclimates (Stalmaster and Gessaman 1984, Keister et al. 1985). For this reason, loss of communal roosts may negatively impact energy budgets or cause the abandonment of important feeding sites. Because communal roosts play an important role in the life cycle of Bald

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Eagles, they are protected 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 their management is incorporated into the National Bald Eagle Management Guidelines (U.S. Fish and Wildlife Service 2007a). These guidelines define communal roost sites as areas where Bald Eagles congregate to perch overnight in forested areas protected from inclement weather and close to foraging areas (U.S. Fish and Wildlife Service 2007a).

Bald Eagles throughout the conterminous United States have increased from an estimated low in 1963 of 417 pairs (Sprunt 1963) to 5748 pairs by 1998 (Millar 1999) and 9789 pairs by 2007 (U.S. Fish and Wildlife Service 2007b). Presumably, the subadult population has increased at a comparable rate, and by 2007 likely exceeded 40 000 (based on expected age distribution for a population at equilibrium). Increases in breeding populations are reflected during the nonbreeding period when migrant adults and subadults congregate together within overwintering (Steenhof et al. 2002) and over-summering locations (Chester et al. 1990, Watts and Byrd 1999) and during the breeding season when local subadults congregate within breeding areas (Curnutt 1992). For this reason, population increases likely have resulted in a proliferation of communal roosts throughout the species' range, particularly within regions supporting large numbers of nonbreeders.

The Chesapeake Bay is a convergence area for Bald Eagle populations along the Atlantic coast. In addition to a resident breeding population that has recovered to historic levels (Watts et al. 2008), the Chesapeake Bay supports populations of northern and southern migrants (Watts et al. 2007). 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, Wood 1992, Millsap et al. 2004, Mojica et al. 2008). In the late autumn, eagles migrate south from New England and the maritime provinces of Canada to spend the winter on the bay (McCollough 1986, Buehler et al. 1991a). Nonbreeders from all three populations congregate in several concentration areas distributed within low-salinity reaches (Watts et al. 2007). Within these areas, communal roosts have been identified that support several to well over 100 birds during different periods of the year (e.g., Wallin and Byrd 1984, Haines 1988, Buehler et al. 1991b).

Despite similar protections afforded under the Eagle Act for roosts and nests, most management activities have focused on nest sites. Furthermore, throughout most of the species' range, we have comparatively little systematic information on the abundance and distribution of Bald Eagle roosts (Isaacs et al. 1996). We here report on our use of satellite transmitters to delineate a network of communal Bald Eagle roosts within the upper Chesapeake Bay.

METHODS

Our study area included the northern part of the Chesapeake Bay from the Bay Bridge at Annapolis, MD to just above the Conowingo Dam on the Susquehanna River (Fig. 1). This area (2729 km²) includes the Upper Chesapeake Bay Bald Eagle Concentration Area (Watts et al. 2007) and is very similar in distribution and extent to that described by Buehler et al. (1991a). 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-km² military installation that is primarily forested with extensive shorelines. The northern part of the study area contains the Susquehanna Flats, a historically important site for wintering waterfowl (Lynch 2001). This area, along with the nearby Conowingo Dam, supports a significant number of eagles during the fall and winter months (Steenhof et al. 2008). Eagles within the area feed primarily on fish during the summer months, but switch to waterfowl and mammals during the autumn and winter when fish move to deeper waters and many waterbirds migrate into the bay (DeLong et al. 1989, Mersmann 1989).

We captured resident and migrant Bald Eagles ($n = 63$) on APG, banded, and fitted them with satellite transmitters between August 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 ($n = 17$). We conducted floating fish and leg-hold trapping during the summer months to target resident and southern migrants. We conducted rocket-net trapping in the winter months to target

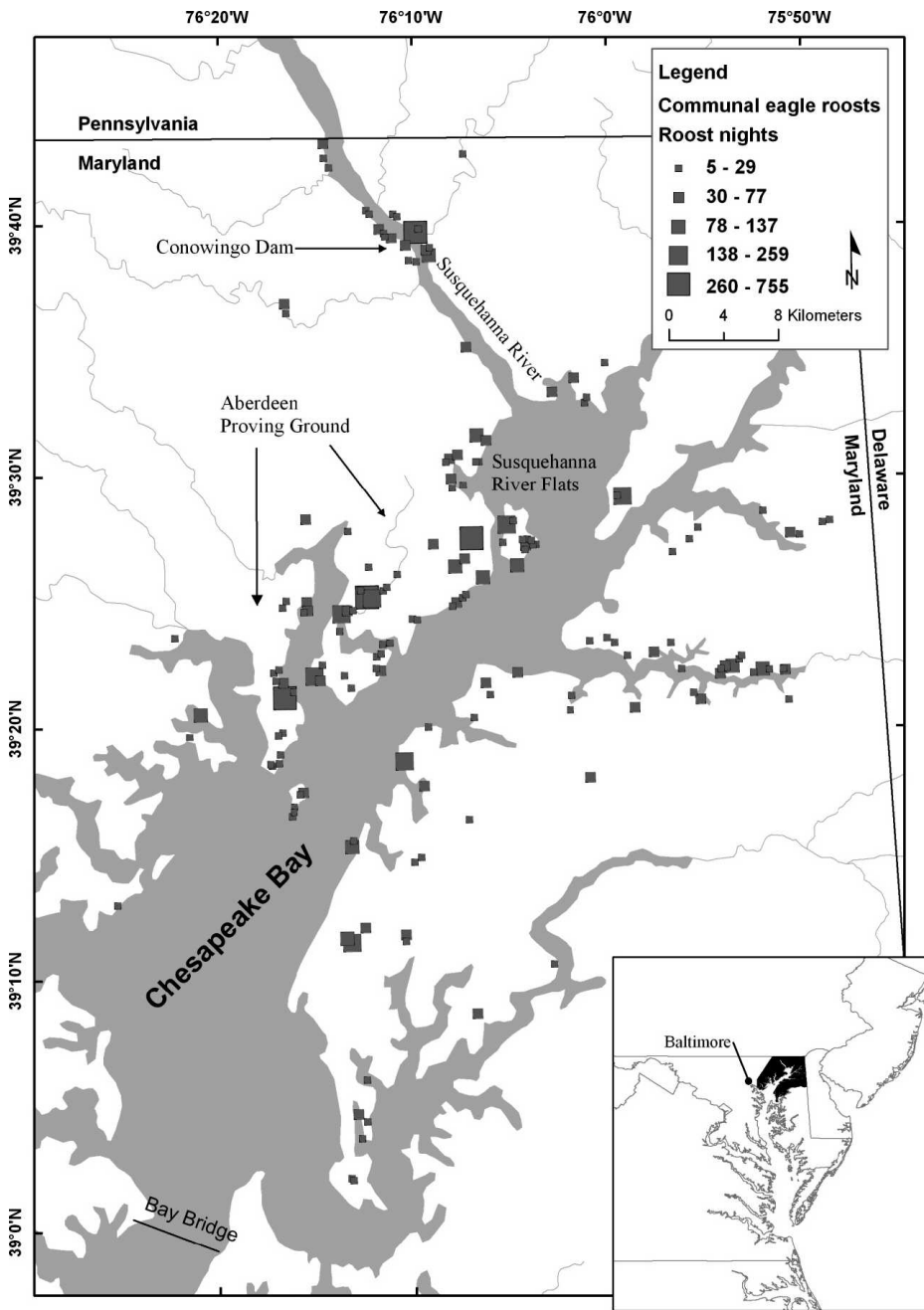


Figure 1. Upper Chesapeake Bay including communal roosts within the study area. This portion of the tidal reach of the bay includes the Upper Chesapeake Bay Bald Eagle Concentration Area.

resident and northern migrants. Eagle capture and handling methods were in compliance with IACUC protocols at the College of William and Mary (IACUC-20051121-3).

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 satellites (CLS America, Largo, Maryland, U.S.A.) and stored online by Satellite Tracking and Analysis Tool (Coyne and Godley 2005).

We used midnight locations ($n = 10\,321$) to delineate communal roosts occupied from August 2007 to August 2009. Locations from breeding adults roosting near nests were excluded. Locations from nestlings were not included until after they began roosting away from the natal site. Minimum convex polygons (MCP) of roost boundaries were delineated using a nearest neighbor clustering script in Crimestat III (Levine 2004). Cluster parameters were set to search a fixed distance of 100 m for a minimum of five midnight locations (i.e., roost-nights). At least two individual eagles had to visit a roost during the study period for it to qualify as a communal roost. Roosts used by single eagles were manually removed from the dataset. Landscape features of each roost were evaluated using digital raster graphics in ArcMap 9.3 (Environmental Systems Research Institute, Inc. © 1999–2009, Redlands, California, U.S.A.). Roosts within the same forest patch and within 200 m of one another were merged into a single MCP. Once established, roost boundaries were overlaid on roost locations to evaluate seasonality and relative magnitude (i.e., number of roost-nights, number of individuals) of use.

RESULTS

All of the eagles tracked in this study had non-breeding home ranges within the study area at the time of capture. We deployed transmitters on 17 local nestlings. Based on the review of positions in the months following transmitter deployment on free-flying birds, we deployed transmitters on an additional 29 residents, 13 northern migrants, and 4 southern migrants.

We delineated 170 communal roosts within the study area (Fig. 1). Eagles roosted widely throughout the upper bay and 7475 (72%) midnight locations fell within the definition of a communal roost used in our analysis. Remaining locations (2846) were not associated with other transmitted eagles and were assumed to be locations resulting from solitary roosting. Communal roosts were skewed to more rural parts of the study area and included the Eastern Shore, the lower Susquehanna River and APG. APG alone accounted for 40% of delineated

roosts. In contrast, the metropolitan areas within the southwestern portion of the study area supported very little roosting.

Relative use of communal roosts varied dramatically such that a small number of roosts accounted for a large portion of overall roosting activity. Overall, the number of roost-nights per roost varied from 755 to the established minimum of 5 (44 ± 6.1 , mean \pm SE), the number of calendar nights from 455 to 5 d (37 ± 4.3 d) and the number of different transmitted birds supported from 35 to 2 (7 ± 0.47). These three parameters were intercorrelated (correlation coefficients Pearson's $r > 0.72$, $P < 0.05$), suggesting that the roosts receiving the highest use were also the most consistently used roosts and accommodated the largest number of individuals. The result of variation in relative use is a "decelerating utility function" such that 10%, 30%, and 50% of roosts support 52%, 78%, and 89% of roost nights respectively (Fig. 2).

The total area encompassed by all roost sites was 322.1 ha, or 0.1% of the study area. Area of communal roosts varied from 0.04 to 20.13 ha (mean = 1.9 ± 0.21 ha) and the density of use ranged from 5.3 to 427.5 roost-nights/ha for the study period. A significant portion (48%) of this area was owned by the government or conservation organizations, including roosts on lands controlled by the military (33%), nongovernmental organizations (7.8%), state and local governments (5.8%), other federal agencies (1.6%). The remaining roosts were on privately owned land (52%). A plot of the minimum area trajectory indicated that 10% and 20% of the roost area supported more than 30% and 50% of the roosting activity, respectively (Fig. 3).

DISCUSSION

The number of communal roosts within the upper Chesapeake Bay appears to have increased dramatically over the past 20 years. Buehler et al. (1991b) used conventional VHF transmitters ($n = 73$) to locate communal roosts within the same study area (1988–89). They followed individuals to nocturnal roost sites twice weekly for 12 mo to reveal the roost network and monitored delineated roosts from the ground. They classified roosts as communal based on visual observations of additional eagles using the roosts. Of the 17 communal roosts described, 13 were still active during our study. In the intervening years, the number of active roosts has proliferated, with an average doubling time of just over 6 yr, representing a 10-fold increase

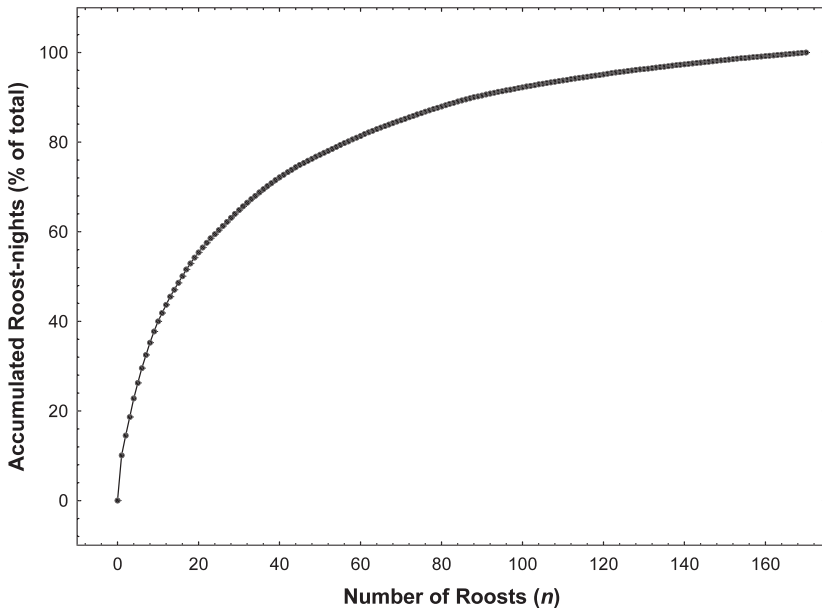


Figure 2. Relationship between the number of roosts and the cumulative proportion of roost-nights supported. The graph reflects the minimum number of roosts to support the highest portion of roost-nights. Roosts were ordinated from high to low according to the number of roost-nights supported. An accumulation curve was then generated by sequentially adding each roost to the total and expressing the result as a portion of the total roost-nights against the number of roosts included.

in 20 yr. Over this same period, the breeding population has exhibited a comparable increase within the portion of the study area that has been surveyed annually (J. Pottie and J. Paul unpubl. data). The distribution of roosts described here was similar to that described by Buehler et al. (1991b), with most roosts occurring along the Eastern Shore, on the lower Susquehanna River, or on APG lands and very little roosting activity in the urbanized landscape including the cities of Baltimore and Annapolis.

Throughout the network of communal roosts, the use of individual sites varied dramatically, such that 10% of the roosts accounted for more than 50% of the total roost activity. Variation in the relative significance of roosts has been noted in other study areas. Keister and Anthony (1983) collected pellets under six communal roosts in the Klamath Basin and found that nearly 49% of the total pellets were from a single roost and that more than 80% were from the two largest roosts. Although the range of use was narrower, Isaacs et al. (1996) found that eagles wintering along the Upper John Day River in Oregon typically used small roosts that were an order of magnitude smaller than the largest roosts. Within the current study site, monthly surveys of

four communal roosts (1996–2003) indicated that use varied more than an order of magnitude between sites (General Physics 2004). Here, the use of roosts varied by more than two orders of magnitude. Together, these studies illustrated that roost sites vary considerably in terms of their relative use and presumed value to eagle populations.

More than 2800 (27%) roost-nights were not associated with areas delineated as communal roosts and were assumed to represent solitary roosting events. Solitary roosting has been reported elsewhere (e.g., Southern 1964, Stalmaster 1976, Grubb et al. 1989) and results presented here were comparable to those in other studies that have systematically evaluated roosting behavior. An intensive investigation of roosts and roosting behavior in Oregon classified more than 30% of roosting events as solitary roosts (Isaacs et al. 1996). Within the upper Chesapeake, solitary roosters accounted for 41% of documented ($n = 81$) roost-nights in the 1980s (Buehler et al. 1991b). Because of the large portion of roost-nights attributed to solitary roosters and their wide distribution, they greatly expand the overall portion of the study area used by roosting eagles.

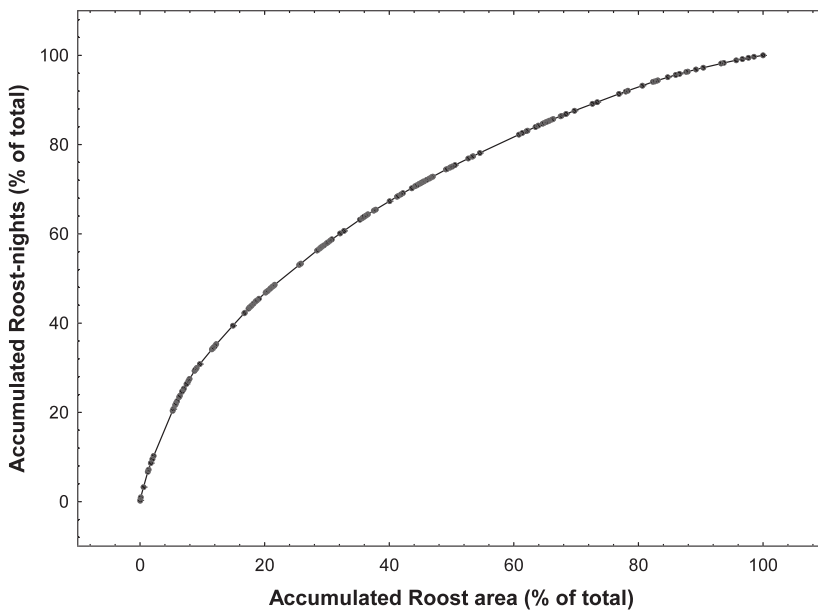


Figure 3. Relationship between the amount of land and the cumulative proportion of roost-nights supported. The graph reflects the minimum area to support the highest portion of roost-nights. Roosts were ordinated from high to low according to roost density (accumulated roost-nights/roost area). An accumulation curve was then generated by sequentially adding each roost to the total and expressing the result as a portion of the total roost-nights against the sum of roost area included.

Variation in the area of communal roost sites was comparable to that documented in other investigations where roost boundaries were mapped. Other studies have shown roosts that vary from a single tree (Isaacs et al. 1993) to a 254-ha forest patch (Keister and Anthony 1983), including roosts in North Carolina (1.3–5.0 ha; Chester et al. 1990), Maryland (0.39–1.0 ha; Buehler et al. 1991b), Florida (20 ha; Curnutt 1992), South Dakota (5 ha; Steenhof et al. 1980), Montana (42 ha; Crenshaw and McClelland 1989), and Oregon (2.4–28.3 ha; Isaacs and Anthony 1987).

Unlike nests that, from a regulatory perspective, are homogeneous in terms of their benefit to populations, the importance of roost sites may vary considerably. Bald eagles employ a wide range of roosting strategies. Here we have demonstrated roosting scenarios that vary from a large number of locations where individuals appear to roost alone to relatively few communal roosts that are used by many individuals throughout the year. Solitary roosts are numerous and cover nearly the entire study area. Small communal ephemeral roosts used on average less than 1 d/mo are widespread and common. Large roosts used throughout the year by individuals from

populations along the entire Atlantic coast, are much less common. The most significant roost detected was at the Conowingo Dam, and was used by 28 birds with transmitters, covered 9.8 ha, and accounted for >10% of all communal roosting activity. Ten percent of the roosts accounted for 50% of the roosting activity, but only 30% of the total area of all roosts.

The question of how or whether to manage the continuum of roost sites is central to the formulation of effective policy. Protections afforded to roost sites under the Eagle Act are nonspecific. The act does not define what constitutes a roost. Roosts have been defined as ≥ 1 eagle for ≥ 1 night (Grubb et al. 1989, Buehler et al. 1991b), and ≥ 3 eagles for ≥ 2 nights (Anderson et al. 1985). Although these definitions clearly describe biological events, they may not be viable from a regulatory perspective. Solitary roosts were numerous and widespread. Placing management buffers around these consumes all of the land within the study area. These sites also are the most likely to be ephemeral, such that managing them provides an uncertain benefit to the population. Although less pronounced, small communal roosts are also widespread and account for a relatively small portion of roosting activity, suggesting that the

benefit accrued to eagles for their protection relative to the burden to landowners is small. Within the current roost network, applying a management threshold of 0.5% (i.e., roosts accounting for >0.5% of roosting activity receive protection) would reduce the burden to managers and landowners by more than 75% with only minimal presumed impact to eagles.

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