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TIME AND ENERGY BUDGETS OF BALD EAGLES WINTERING ALONG THE CONNECTICUT RIVER

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Abstract.—We studied populations, activity patterns, and energetics of Bald Eagles (*Haliaeetus leucocephalus*) wintering along the lower Connecticut River. Because this population is relatively undisturbed by human activity, data on energy requirements provide a baseline for assessing the potential impact of disturbance. We censused and studied movements by counting birds at roosts and by having 32 observers make simultaneous counts throughout the study area. We quantified time spent roosting, perching, flying, feeding, and waiting to feed by continuously observing birds, and used these and climatic data to predict energy and food requirements.

Maximum counts of Bald Eagles increased from 24 in 1981 to 40 in 1986. Eagles congregated at sites where food was most readily available and moved 1 to 6 km/d (to 10 km from roosts). Time budgets showed that birds spent most of the day perching. Adults spent significantly more time perched and significantly less time in flight than juveniles and fed more efficiently than juveniles. The more energetically conservative behavior of adults reduced their energy and food requirements compared to juveniles. However, Connecticut River eagles used more energy than eagles in Washington, because in Connecticut birds were more active, the climate was colder, and day length longer. Moreover, in Connecticut the energetic requirements of adults were just offset by consumption, whereas birds ate more prey than they required in Washington. This suggests that Connecticut River adults have limited prey available. The higher energetic demands and feeding inefficiency of juveniles may mean that juveniles have difficulty meeting energy requirements.

These findings indicate that increased human disturbance with its consequent higher energy demands could have a negative impact on winter survivorship in this population, particularly if the eagle population continues to grow. We recommend that efforts be made to minimize disturbance of eagles along the Connecticut River.

PRESUPUESTO ENERGÉTICO DURANTE EL INVIERNO DE *HALIAEETUS LEUCOCEPHALUS* EN EL ÁREA DEL RÍO CONNECTICUT

Resumen.—Estudiamos las poblaciones, patrones de actividades y energética de águilas calvas (*Haliaeetus leucocephalus*) invernando a lo largo del Río de Connecticut. Debido a que esta población ha sido relativamente, poco perturbada por el ser humano, datos recopilados sobre los requisitos energéticos proveen la información base para evaluar los impactos potenciales de futuras perturbaciones. Se estudiaron los movimientos mediante el contaje de águilas en dormideros y mediante el contaje simultáneo llevado a cabo por 32 observadores a través del área de estudio. Se cuantificó el tiempo que permanecieron en dormideros, posadas, volando, alimentándose y esperando para alimentarse estas aves, observando las águilas continuamente. Se utilizó esta información y datos climatológicos para predecir los requerimientos energéticos y de alimentación de estos pájaros. Contajes máximos de águilas calvas aumentaron de 24 en el 1981 a 40 en el 1986. Las águilas calvas se congregaron en los lugares donde los alimentos eran más disponibles y se movieron de 1 a 6 km/día (a 10 km desde los dormideros). Presupuestos de tiempos demostraron que las águilas invierten la mayoría de las horas del día posadas. Los adultos se alimentan más eficientemente que los juveniles e invierten significativamente más tiempo posados y menos tiempo volando que los juveniles. Los patrones de conducta energéticos, más conservadores en los adultos que en los juveniles, reduce sus requerimientos alimenticios. Sin embargo, las águilas del Río Connecticut utilizaron más energía que águilas en Washington dado el caso de que en Connecticut eran más activas, el clima más frío y los días más largos. Además, en Connecticut los requisitos energéticos de los adultos eran compensados por el consumo, mientras que las águilas de Washington ingerian más de lo requerido. Esto sugiere que las águilas adultas en Connecticut están limitadas por la disponibilidad de presas. Las demandas energéticas más altas y la ineficiencia de los juveniles en la captura de presas tiende a señalar, que estos, tienen dificultad en llenar sus requisitos energéticos. Estos hallazgos indican que la perturbación por parte del humano y su consecuente incremento en demanda energética, puede tener un impacto negativo en la supervivencia durante el invierno de esta población de águilas, particularmente si ésta continua creciendo. Se recomiendan los esfuerzos necesarios para minimizar la perturbación de la población de águilas del Río Connecticut.

Winter is a harsh period for many animals of temperate regions (see Kendeigh 1961). Hence, survivorship in wintering populations of the endangered (U.S. Fish and Wildlife Service 1982) Bald Eagle (*Haliaeetus leucocephalus*) may be reduced by human disturbance. This is particularly true in the urbanized northeastern United States, where the potential for human disturbance is great.

Winter food for eagles may be limiting (Sherrod et al. 1976), and Stalmaster and Gessaman (1984) predicted that excessive disturbance could elevate energy and thus food requirements above available supplies, thereby increasing winter mortality. Fraser et al. (1985) showed that eagles are indeed sensitive to disturbance when they found eagles preferred nest sites away from developed shoreline and could be flushed from up to 503 m away. Moreover, Stalmaster and Newman (1978) reported reduced use of feeding areas when human activity in them was high. Similarly, in Connecticut we have observed birds being flushed at prime feeding sites where disturbance has kept them from feeding. In 1985 when the lower Housatonic River, Connecticut was opened to the public, the number of wintering eagles declined approximately 80% from the previous 3 yrs (L. Fischer, pers. comm.). Despite these observations, Knight and Knight (1984) suggested that eagles habituate to disturbance, although their data cannot eliminate the alternate explanation that birds become too energy stressed to respond.

We studied numbers, activities, and energy use of eagles wintering along the lower Connecticut River to establish a baseline for assessing the potential effects of disturbance on northeastern birds. The Connecticut River is unusual among major northeastern rivers in having a largely undeveloped, inaccessible shoreline and no major city at its mouth. The rural character of the area provides a system that for locally wintering eagles is probably similar to pristine conditions.

STUDY AREAS AND METHODS

We made most observations on the portion of the Connecticut River from the Saybrook Bridge to Salmon Cove (Fig. 1), where the greatest

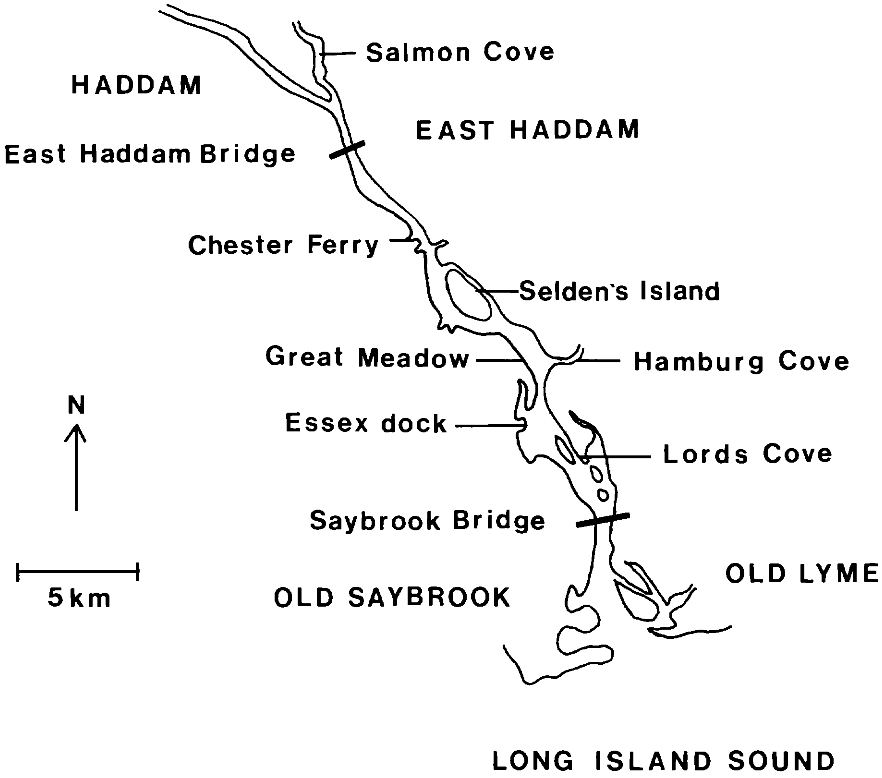

FIGURE 1. The lower Connecticut River, Connecticut.

number of wintering birds are found. The river in this region is tidal, with salt water intruding upriver to the East Haddam Bridge during low river flows (Meade 1966). The shoreline is largely forested and has steep slopes, cliffs, marshes, and floodplain swamps that make much of it inaccessible. During the coldest weather the river freezes nearly to the Saybrook Bridge, although more typically it is largely ice free to at least Hamburg Cove (Fig. 1). Ice breakers also maintain an open channel through the study area.

Most wintering eagles begin appearing along the Connecticut River by mid-December and depart by late March. We report on observations made during this period in 1986 and on pertinent observations from other years, but energetic data were collected from dawn to dusk on 20 d from 3 Jan. to 28 Feb. 1986. These two months are usually the most climatically severe, when the birds are presumably under the greatest physiological stress.

To simultaneously count birds throughout the study area and to plot movements of individuals continuously followed, we stationed 32 observers along the lower river on 11 Jan. At least once each week we and collaborators also counted birds using different portions of the river and birds at roosts. In observations we recognized two age classes: juveniles, predominantly brown birds, and adults, birds with nearly or entirely white heads and tails.

Craig quantified activity patterns by following individuals until they were lost from view, a method that provides the most reliable time budget estimates for birds observable for long periods (Bradley 1985). Observation sites, mostly Essex, Great Meadow, and Lords Cove (Fig. 1), provided a view of about 6 km of river so that activities over a wide area could be surveyed. All behavior seen from the observation sites was noted and assumed to represent a random sample of activities occurring along the river. Following Stalmaster and Gessaman (1984) we recorded: (1) perching, daytime sitting in trees or on the ground, (2) active (flapping) flight, (3) passive (soaring and gliding) flight, (4) feeding, and (5) waiting to feed, standing near other feeding birds. Based on observations at roosts (night perches), 15 min after sunset to 15 min before sunrise was used as the average time spent roosting by adults and juveniles.

To determine the energetic cost associated with observed activities we used three models which compute (1) daily energy budget, the total energy metabolized, (2) daily energy consumption, the total food energy required, and (3) daily food requirements, the total mass of prey required. Details of these computations are in Stalmaster and Gessaman (1984), but briefly they involve assessing the effects of longwave radiation, convection, conduction, evaporation, and rate of heat storage on metabolic heat production, the effect of air temperature (T_a in °C), standard metabolic rate, and the effect of T_a on existence metabolism, gross energy intake, and wet matter (prey) intake. Daytime levels of these factors are multiplied by the proportion of a 24 h day spent perching, feeding, and waiting to feed, and nighttime levels are multiplied by the proportion of the day spent roosting. The increase over basal metabolic rate associated with flight is also computed.

The models require data on air temperature, wind speed, precipitation, and downward longwave radiation. For the first three variables we used data reported by the Bradley Airport meteorological station located near the Connecticut River 45 km N of the study area (NOAA 1986a,b). We calculated day and night averages for each day with data taken at 3 h intervals and calculated downward longwave radiation (R) as follows:

$$R = \delta T_k^4 0.67(1670.0Q_s)^{0.08} \tag{1}$$

where δ is the Stefan-Boltzmann constant (5.67×10^8 watts m^{-2} T_k^{-4}), T_k is air temperature in °K, and Q_s is specific humidity:

$$Q_s = 0.622E_v(P - 0.378E_v) \tag{2}$$

where E_v is ambient vapor pressure:

$$E_v = E_s(Rh) \tag{3}$$

P is air pressure ($\cong$1000 millibars), E_s is saturated vapor pressure:

$$E_s = 6.1078e^{(17.269T_a)(237.3+T_a)} \tag{4}$$

Rh is relative humidity expressed as a decimal fraction, and e is the base of natural logarithms, 2.718 (Jones 1983, Sun 1985). Day-night averages of relative humidity were also derived from Bradley Airport data. At the study site we recorded daytime temperatures at 3 h intervals beginning at 0700 to compare with readings recorded simultaneously at Bradley Airport.

To assess prey consumption in relation to food requirements we calculated the average number of minutes spent feeding per day by multiplying day length by the proportion of daytime spent feeding. We converted feeding time into grams of prey consumed using the relationship:

$$\text{Prey consumption (g min}^{-1}) = 78.44N^{0.49} \tag{5}$$

where N is the number of eagles feeding and waiting to feed on a prey item (Stalmaster and Gessaman 1984).

RESULTS

Populations and movements.—Our census on 11 Jan. estimated 12 adult and 20 juvenile Bald Eagles to be present. We further estimated that by late February a maximum of 43 birds were present, including three Golden Eagles (*Aquila chrysaetos*). Mid-January and peak populations during the previous 5 years were, respectively: 1985—27, 35 (adults and juveniles); 1984—25, 32; 1983—22, 27; 1982—20, 29; 1981—18, 24. In comparison, at the second principal wintering site in Connecticut, the lower Housatonic River, peak populations were: 1985—16, 1984—20, 1983—22, 1982—17, 1981—6 (L. Fischer, pers. comm.).

Observations throughout the study area indicated that groups of 5–10 eagles centered their activities near six areas: Lords Cove, Great Meadow, Salmon Cove, the East Haddam Bridge, the Chester Ferry, and Selden's Island (Fig. 1). Membership in groups was not rigid; some birds regularly spent part of the day near Great Meadow and the remainder near Lords Cove. However, individuals preferred certain portions of the river; a color marked juvenile and an adult with no tail always occurred between Salmon Cove and the Chester Ferry (Fig. 1). These activity centers were near the outflow of major tributaries, places where it is likely that dead fish, a principal food of wintering eagles (Griffin et al. 1982, Fischer 1985, this study), first appeared from under the ice. Riverbank trees near such outflows were favored as day (hunting) perches.

Eagles using particular activity centers were not necessarily in social groups, although Knight and Knight (1983) and Stalmaster and Gessaman (1984) found evidence that juveniles depend on groups for finding food. We also found evidence that family groups winter together. Along the Housatonic River from 1983 to 1986 we and collaborators found four juveniles banded in successive years in Maine. Three and probably all were from the same nest, and they associated with a banded Maine adult.

Moreover, in 1987 we observed one adult feed another adult on the Connecticut River (apparently a male feeding a female, based on relative size of the birds). Other observations of two adults and several juveniles associating for much of a day were inconclusive but also suggestive of family bonds. Faccio and Russock (1984) have provided additional data indicating that Connecticut eagles winter in family groups.

In four instances where individuals could be followed for most of the day (7.5–9.2 h), they ranged over 1–6 km ($\bar{x}$ = 4.0 km). In two other instances where a color marked juvenile and an adult with no tail were followed over several days, they ranged 6.5 and 10 km, respectively, from their roosts. In previous years we have estimated that Connecticut River eagles typically range over 3–7 km of river per day.

Activities.—Eagles were followed from 2 to 455 min ($\bar{x}$ = 125 min, n = 97), although 92% of observations were of birds followed >60 min ($\bar{x}$ = 182 min, n = 61). Normally six or fewer birds were present at an observation site, so individuals usually could be recognized by plumage differences (see also Faccio and Russock 1984).

Activities of Connecticut River eagles (n = 201.4 h) showed adult patterns similar to those of subadults (adults and subadults are thought to behave similarly) wintering in Washington (Stalmaster and Gessaman 1984). In both instances most of the day was spent perching, the least energetically expensive activity over a wide temperature range and the one that minimized conductive and convective heat loss (Calder and King 1974). However, Connecticut River adults averaged slightly more time in flight, slightly less time feeding, and less time waiting to feed than Washington birds (Table 1). Roost length averaged 810 min, compared to 972 min in Washington.

In comparison to adults, juveniles (Table 1) averaged 16.7% less time perching (Wilcoxon two sample T = 171, df = 15, $P < 0.01$), 11.1% more time in flight (T = 183, df = 15, $P < 0.01$; 2.0% more in active flight, 9.1% more in passive flight), and 5.6% more time feeding and waiting to feed (2.0% more feeding, 3.1% more waiting). This last trend is not statistically significant (T = 238, df = 15, $P > 0.01$; test criteria at $P = 0.01$ are used because these 3 data sets are related and the true α is thus approximated by 3α). However, 72% (129.5 min) of feeding by juveniles appeared inefficient, involving picking at bones or feeding intermittently. In contrast, only 6% (5 min) of adult feeding was intermittent. Nearly all identifiable prey (n = 18) were fish, although in one instance collaborators reported birds feeding on a deer carcass.

Energetics.—Average January–February temperature at Bradley Airport was −3.0 C compared to 1.7 C for Washington. The Bradley temperature was 0.4 C above normal, and there was only one day below −18 C (NOAA 1986a,b; Table 2). A result of having no period of intense cold was that the river channel was ice free for much of the winter, although coves and backwaters remained frozen until late February. Precipitation for the period was 4.2 cm above normal (NOAA 1986a,b).

We found that daytime temperatures on the lower Connecticut River

TABLE 1. Daytime activity budgets of wintering eagles on the Connecticut River and in Washington.

	Activity				
	Perch	Active flight	Passive flight	Feed	Wait
Connecticut River					
Adult					
No. min	6757.7	233.1	156.6	84.0	20.3
% time	93.2	3.2	2.2	1.2	0.3
Juvenile					
No. min	3695.9	250.8	544.7	180.0	161.0
% time	76.5	5.2	11.3	3.7	3.3
Washington (Stalmaster and Gessaman 1984)					
Subadult %	92.9	1.8	1.3	1.5	2.5

(n = 52) averaged −1.4 C, 1.2 C higher than at Bradley Airport. Winter temperatures are known to average slightly lower in northern than in southern Connecticut (Brumbach 1965). However, a simultaneous comparison of temperatures at Essex and Great Meadow showed a difference of >1 C. We were unable to compare wind speed or precipitation at the study area and Bradley Airport, but differences between them in longwave radiation are negligible (Miller and Hammond 1979). Because eagles on the Connecticut River range over several km through varying microclimates, we believe energetic computations would be little improved by collecting meteorological data on site. Furthermore, sensitivity analysis has shown that, with the models used, even 25% variation in environmental variables has little effect on estimates of energy budgets (Stalmaster 1983).

Because roosts are predominantly on protected, conifer-forested slopes (pers. obs.), which Stalmaster and Gessaman (1984) found to reduce energy use by about 5%, values reported (Table 3) are reduced by 5% from initially computed values. Values thus determined for the daily energy budget, daily energy consumption, and daily food requirements (Table 3) are still higher than those reported by Stalmaster and Gessaman (1984). Moreover, juveniles had greater metabolic needs than adults for all three measures of energetics.

Estimates of food consumption based on Equation 5 show that adults averaged 519 g/d compared to requirements of 533 g/d (Table 3). Therefore the birds appeared to have a small food deficit of 14 g/d. Given the imprecision of our estimates and that temperatures on the lower Connecticut River average slightly higher than at the Bradley Airport meteorological station, food requirements and consumption likely are approximately balanced.

Juveniles, in contrast, had a calculated consumption of 1569 g/d com-

TABLE 2. Day and night monthly averages for environmental variables during the winter of 1986 (standard deviation in parentheses).

	Air temp. (°C)	Wind speed (m/s)	Precipitation (cm)	Relative humidity (%)	Longwave radiation (watts/m²)
January					
Day	−1.5 (5.9)	4.3 (1.6)	0.2 (0.5)	63.6 (16.6)	230.2 (30.4)
Night	−3.3 (5.4)	3.5 (1.1)	0.2 (0.6)	70.5 (11.6)	229.9 (28.8)
February					
Day	−2.5 (3.0)	4.0 (1.4)	0.1 (0.3)	63.2 (15.9)	224.3 (16.9)
Night	−3.7 (3.0)	3.7 (0.9)	0.1 (0.2)	69.7 (13.3)	224.7 (16.3)

pared to requirements of 608 g/d. However, observations of inefficient juvenile feeding indicates that Equation 5 poorly predicts juvenile feeding rate. Although their true consumption rate cannot be assessed adequately, it is clearly lower than the predicted value. Adults, which we observed to feed more efficiently, appeared to conform to the model more closely.

DISCUSSION

Growth of Bald Eagle populations wintering along the Connecticut River is likely related to increases occurring in northeastern breeding populations in the post-DDT era (McCollough et al. 1984). Why populations wintering along the lower Housatonic River have not shown as consistent a trend is uncertain, but may be related to the recent increase in human activity. Continued monitoring of the Connecticut River population will be essential for following future population trends and making inferences about the carrying capacity of the system.

Home ranges of Connecticut River eagles were similar to those of the riverine system studied by Stalmaster and Gessaman (1984), where birds averaged 6.1 km/d. As in our findings, other studies (e.g., Sherrod et al. 1976, Stalmaster and Gessaman 1984) have shown that eagles congregate near prime feeding sites. Moreover, Washington subadults have activity budgets comparable to those of Connecticut adults (Stalmaster and Gessaman 1984). Hence, the wintering strategies we observed seem characteristic of riverine populations. Additional data on movements and hunting success versus length of time spent using specific activity centers should provide further insights into optimal strategies in such systems.

Although small, differences in the activity budgets of Connecticut River adults and Washington subadults may reflect differences in prey base between the two localities. Washington eagles feed principally upon large chum salmon (*Oncorhynchus keta*) that accumulate on gravel bars (Stalmaster and Gessaman 1984). Connecticut River birds, in contrast, must search for prey that appear to be less concentrated and predictable, and therefore spend more time in flight (see also Griffin and Baskett 1985). Why Connecticut River adults appear to spend less time waiting to feed

TABLE 3. Daily averages for 3 measures of ecological metabolism for Bald Eagles on the Connecticut River, taking into account 5% energy savings from roosting in conifers (standard deviation in parentheses).

	Daily energy budget (kj/bird/d)	Daily energy consumption (kj/bird/d)	Daily food requirements (g/bird/d)
Connecticut River			
Adult	1873 (72)	2249 (77)	533 (17)
Juvenile	2088 (72)	2445 (76)	608 (21)
Washington (Stalmaster and Gessaman 1984)			
Subadult	1703	2068	489

is less clear, but may be related to their lower population density compared to Washington (Stalmaster and Gessaman 1984).

Higher energetic needs of Connecticut River birds compared with those in Washington are a function of lower winter temperatures, shorter roost intervals, and especially (Stalmaster 1983) activity budgets that require greater energy expenditure. Within the Connecticut River population, however, greater energy expenditure by juveniles is attributable to juveniles being more active than adults. During winter such energetically expensive behavior seems disadvantageous, and probably results from the inexperience and social subordination of juveniles (Knight and Knight 1983, Stalmaster and Gessaman 1984). Inexperience may be particularly significant in a system with dispersed prey, where the most efficient hunting techniques might have to be learned over several years. Such inexperience and inefficiency are likely principal factors contributing to the greater winter mortality suffered by juveniles (Sherrod et al. 1976).

The similarity of adult food consumption and food requirements contrasts with the finding of Stalmaster and Gessaman (1984), who reported subadult consumption 63 g/d greater than requirements. This suggests that Connecticut River adults are unable to compensate for greater energy needs by increasing prey consumption (i.e., prey are limiting), and are just able to find adequate food. The extent to which juveniles meet needs is less clear, but their greater energetic burden and feeding inefficiency indicate that juveniles may be energy stressed.

These findings point toward survival conditions for Connecticut River eagles already being suboptimal, although further data on prey availability and prey consumption rates are necessary for a complete assessment. If this population continues to grow, more birds will subdivide the available food; juveniles, being at a social (Stalmaster and Gessaman 1984) and energetic (this study) disadvantage, will likely be most negatively impacted by such a circumstance. Because juvenile survival is believed to regulate eagle populations (Sherrod et al. 1976), this could ultimately limit growth of breeding populations.

Stalmaster (1983) has shown that flight, a potentially manageable source of energy expenditure, is principally reponsible for influencing energy budgets. We therefore recommend that eagles be protected from disturbance that could lead to flushing, particularly at roosts and favored feeding locations. We emphasize, however, that birds may abandon areas where they are disturbed regardless of food availability (Stalmaster and Newman 1978).

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