

## A MODEL OF ENERGY CONSUMPTION IN BALD EAGLES: AN EVALUATION OF NIGHT COMMUNAL ROOSTING

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Bald Eagles (*Haliaeetus leucocephalus*) are found only in North America and are associated primarily with coastal estuaries, inland lakes, and rivers throughout their range. In fall and winter they migrate from northern areas of harsh climate to coastal or southern areas with milder climates and more readily available food. They often concentrate in areas where food resources are plentiful, particularly in conjunction with anadromous fish runs or large concentrations of waterfowl. In these areas (e.g., Glacier National Park, McClelland 1973; Klamath Basin, Keister 1981), Bald Eagles frequently use night communal roosts with as many as 400 individuals on a given night. Similar behavioral patterns have been described for American Robins (*Turdus migratorius*) (Walsberg and King 1980), Red-winged Blackbirds (*Agelaius phoeniceus*) (Meanley 1971), nuthatches (*Sitta* spp.) (Kilham 1971), finches (*Lecosticte* spp.) (French 1959), Eastern Bluebirds (*Sialia sialis*) (Frazier and Nolan 1959), Common Grackles (*Quiscalus quiscula*) (Meanley 1971), and European Starlings (*Sturnus vulgaris*) (Francis 1976).

The adaptive significance of communal roosting in birds is not well understood, although a number of hypotheses have been proposed. One hypothesis assumes that selection of communal roosts with more favorable microclimates than surrounding areas aids in thermoregulation and energy conservation. Kelty and Lustick (1977) reported that European Starlings selected favorable microclimates provided by pine woods and thereby reduced daily existence metabolism by 12 to 38%. Likewise, Stalmaster (1981, 1983) found that Bald Eagles near the Nooksack River in Washington conserved energy by roosting in coniferous forests as compared with deciduous riparian areas. In contrast, Walsberg and King (1980) found that such behavior by the American Robin produced only a slight thermoregulatory benefit. They suggested that the thermal significance attributed to selection of nocturnal roosts in other studies (see Calder 1973, Calder and King 1974, Kelty and Lustick 1977) may not be applicable to most species and settings.

In this study, we developed a mathematical model of energy metabolism for Bald Eagles on the basis of microclimatic conditions in 4 communal roosts. This model was used to answer the following questions: (1) Do

communal roosts have more favorable microclimatic conditions than general local conditions? (2) Do communal roosts in the same general locality have different microclimatic conditions? (3) What is the energetic advantage, if any, of communal roosting? In addition, we asked which factors were most important in determining use of roosts by Bald Eagles.

#### STUDY AREA

The Klamath Basin is located in southcentral Oregon and northern California and is bordered by the Cascade Mountains to the west, the Fremont Mountains to the east, and the Medicine Lake Highlands to the south. Climate of the Klamath Basin is determined by elevation (~1250 m) and prevailing winds from the Pacific Ocean. The area has a mean annual precipitation of 36.3 cm with 70% falling between October and March, of which a large portion is snow. Mean monthly maximum temperatures range from 29.0°C in summer to 3.6°C in winter. Mean monthly minimum temperatures range from 10.9°C in summer to -6.0°C in winter (U.S. Dept. Commerce 1969). Natural vegetation changes with increasing elevation from grass-to-shrub to tree-dominated communities.

Three major Bald Eagle feeding areas and five communal roosts were located in the southern portion of the Klamath Basin. Feeding areas were associated with flooded areas on the basin floor and roosts were located 6–20 km from feeding areas on forested land at 1400–1950 m in elevation. The vegetation of four roosts was dominated by ponderosa pine (*Pinus ponderosa*); the other roost was in a mixed-conifer forest. A more detailed description of forest stand characteristics and roost trees is presented by Keister and Anthony (1983).

#### MATERIALS AND METHODS

*Microclimate instrumentation and data collection.*—Instruments were placed at each of four roost sites to measure air temperature, windspeed, solar radiation, and net radiation. Data were collected throughout most of the winter of 1979–80. In addition, regional weather data were obtained from Kingsley Field in Klamath Falls located on the floor of the Klamath Basin (U.S. Air Force and National Weather Service data).

A Thermilinear Thermistor (P/N 44203, Yellow Springs Instrument Corp.) protected from radiant heat exchange by a shield (Model No. 43103A, R. M. Young Co.) was used to measure air temperature. Wind speed was measured with a cup anemometer (Model No. 6101, R. M. Young Co.). Wind speed was corrected by 0.715 m/sec, which is the velocity necessary to begin cup rotation. An Eppley Black & White pyranometer (Model 8-48, Climatronics Corp.) was used to measure incoming solar radiation. Net radiation was measured with a Fritschen net radiometer (Model 3030, Weathertronics). All sensors were mounted on a specially designed assembly and secured approximately  $\frac{3}{4}$  up the trunk (15.8–22.6 m) on the south side of the selected roost tree. The sensors were leveled after attachment to insure proper response.

Signals from the sensors were conducted through moisture-proof connectors and plastic-jacketed, electrically-shielded, multipair cables. The recorder (Model CR5, Campbell Scientific, Inc.) was placed in a metal box at the base of the roost tree. A small circuit board was added to the recorder to modify the signals so that they were within the proper voltage range for the recorder. The recorder contained a four-channel integrator which took 0.3-sec samples of the signals every 2.4 sec and computed time averages. The millivolt average of each channel was printed on paper tape at 2-h intervals. In addition, the printer identified each set of measurements by date and time (end of 2-h average) of collection. The entire system was powered by a sealed, lead-acid battery to assure reliable operation during periods of low temperature.

Pretesting of the four microclimate recording systems at the same conditions showed excellent agreement among each of the measured variables. Temperature and solar radiation measurements were within  $\pm 1\%$ . Windspeed measurements were within  $\pm 3\%$  of each other, and net radiation compared to within  $\pm 8\%$ . These tests were conducted over a uniform grass surface at a height of 1 m.

We defined night as those hours between 18:30 and 04:30 PST to assure that no daylight (shortwave radiation) would be included in the energy metabolism analysis for any days between Oct. and March. Because the CR5 recorder printed 2-hr means for all variables, night was divided further into five recording periods. To eliminate bias between roosts due to comparing values printed at different times (e.g., 22:45 vs 21:00), data were interpolated to represent the same time periods for each roost.

Collection of microclimate data in the Three Sisters roost was restricted to 27–30 Oct. 1979 and 13 Feb. to 13 March 1980 because of animal damage to the cable. Data from all other roosts were grouped into two periods: "late-winter," corresponding to data collected at Three Sisters, and "midwinter," corresponding to data collected during periods when equipment at Three Sisters was not in operation.

*Statistical methodology.*—Minimum (2-h) daily temperature and maximum (2-h) daily windspeed of roosts and Kingsley Field were compared to determine whether any of these areas offered protection against weather. To determine whether differences in microclimate between roosts were biologically significant to Bald Eagles, total energy (TE) and peak metabolic production rate (PMP) for each night at each roost were estimated using an energy metabolism model.

Variation in microclimate variables within each roost was much greater than that between roosts due to large scale changes in conditions as a result of time of day and major weather systems moving through the area. In order to remove this large variation in microclimate in each roost so that difference in microclimate between areas could be examined, each area's maximum wind speed, minimum temperature, TE, and PMP were referenced to the average of all roosts for any particular day by subtracting the mean values for all roosts from the values in each roost each day. Multivariate analysis of variance was used to determine significant differences between areas on the basis of climatic variables and energy requirements. The union-intersection method was used to test for differences (Morrison 1976:170–224), because it leads directly to simultaneous confidence intervals for group or response differences.

To determine which factors were important to roost preference by Bald Eagles, multiple regression was performed for each roost with relative (% of total) Bald Eagle population at a particular roost as the dependent variable. Average TE for three nights prior to an eagle census at a particular roost and relative use of each of three feeding areas by Bald Eagles were the independent variables.

#### DEVELOPMENT OF THE ENERGETICS MODEL

Models of energy metabolism have been developed for mammals (Monteith 1973) and birds (Robinson et al. 1976, Walsberg and King 1980, Hayes and Gessaman 1980). The model used in our study has similar assumptions and definitions, and a more detailed description is presented in Keister (1981). (See Table 1 for definitions of symbols.) Assumptions used to develop the equations were:

- (1) The shape of a Bald Eagle may be approximated by that of a cylinder with length 0.508 m and a diameter of 0.190 m with a feather thickness of 0.0254 m (based on measurements of three Bald Eagles).
- (2) The Bald Eagle is dry, i.e., heat loss by evaporation due to being wet is negligible.

TABLE 1.

DEFINITIONS OF SYMBOLS USED IN AN ENERGY METABOLISM MODEL FOR A BALD EAGLE

A	Surface area of a bald eagle (m <sup>2</sup> )
C <sub>p</sub>	Specific heat of air (1010 J/kg°K)
D	Diameter of a bald eagle (m)
d	Density of air (kg/m <sup>3</sup> )
e	Thermal emissivity
G <sub>2</sub>	Conductive heat loss to the perch (W/m <sup>2</sup> )
HE	Evaporative heat loss (W/m <sup>2</sup> )
k	Thermal conductivity of air (W/m°K)
M	Metabolic heat production rate (kcal/h)
Nu	Nusselt number
PMP	Peak metabolic production rate for a particular night (kcal/h)
r <sub>b</sub>	Resistance to heat loss through skin and feathers (sec/m)
r <sub>c</sub>	Resistance to convective heat loss (sec/m)
r <sub>r</sub>	Resistance to radiative heat loss (sec/m)
r <sub>rr</sub>	Resistance to convective and radiative losses, operating together (sec/m)
Re	Reynolds number
Rm	Radiation measured by a net radiometer (W/m <sup>2</sup> )
S	Stefan-Boltzmann constant (5.67 × 10 <sup>-8</sup> W/m <sup>2</sup> K <sup>4</sup> )
T <sub>a</sub>	Ambient temperature (°K)
T <sub>b</sub>	Body temperature (°K)
T <sub>e</sub>	Effective environmental temperature (°K)
TE	Total metabolic energy required for a Bald Eagle to stay overnight in a particular roost and maintain a constant body temperature (kcal)
v	Kinematic viscosity of air (m <sup>2</sup> /sec)
W	Wind speed (m/sec)

- (3) The body temperature remains constant at 40°C. (Hayes and Gessaman [1980] and Stalmaster [1981] found body temperatures of large raptors varied only slightly near 40°C.)
- (4) The ratio of evaporative heat loss from respiration to total metabolic production (HE/m) is 0.10 (Robinson et al. 1976, Calder and King 1974).
- (5) The ratio of conductive heat loss to a perch to total metabolic production (G<sub>2</sub>/m) is 0.02. (This term has rarely been measured for animals [Monteith 1973:152]. The term is small but must be >0.0 so 0.02 was assumed for completeness. Its inclusion has negligible effects on the model.)
- (6) The resistance of the Bald Eagle feather layer to heat loss (r<sub>b</sub>) is the same per unit thickness (70% of still air) as that of a red fox (*Vulpes vulpes*) and resistance of Bald Eagle skin is comparable to other animals (Monteith 1973:122).
- (7) Resistance to heat loss (r<sub>b</sub>) through feathers per unit feather thickness decreases with increasing windspeed at the same rate as that of a White-crowned Sparrow (*Zonotrichia leucophrys*) (Robinson et al. 1976).
- (8) Thermal emissivity of feathers (e) is 0.98 (Hammel 1956).

These assumptions were used to develop the following equations:

- (1) Effective environmental temperature ( $T_e$ ) =  $T_a + Rm(r_{hr})/dC_p$ .
- (2) Metabolic heat production rate ( $M$ ) =  $0.977AdC_p(T_b - T_c)/(r_{hr} + r_b)$  in kcal/hr (the constant 0.977 contains the appropriate conversion factor to change from watts to kcal/hr).
- (3) Total energy requirement (TE) =  $2 \sum_{i=1}^5 M_i$ ,  $i$  = each 2-hr period during night.

Where,  $Rm$  = radiation measured by the net radiometer and can be shown mathematically to be equivalent to the radiation received by an eagle if the plumage surface were at air temperature (isothermal net radiation).

Resistance, ( $r_{hr}$ ), is computed by  $1/r_{hr} = 1/r_r + 1/r_h$  and its components by:

resistance to radiant heat loss ( $r_r$ ) =  $dC_p/4eST_a^3$  and  
resistance to convective heat loss ( $r_h$ ) =  $dC_pD/kNu$ .

Convective heat transfer, which determines the magnitude of  $r_h$ , depends only on forced convection when the Grashof number is  $< 0.1Re^2$  (Monteith 1973:103), where  $Re$  is the Reynolds number computed as  $WD/v$ . Therefore, for a cylinder with a diameter of 0.19 m, forced convection applies when wind speed ( $W$ )  $\geq 0.73$  m/s. In these calculations,  $W$  is almost always greater than 0.73 m/sec because of the inability of the anemometer to measure wind speeds below 0.715 m/sec (see *Microclimate instrumentation*). The appropriate equations are:

Nusselt number ( $Nu$ ) =  $0.024Re^{0.81}$  if  $W > 2.8$  m/sec or,  
( $Nu$ ) =  $0.17Re^{0.62}$  if  $W \leq 2.8$  m/sec.

And, from regression of tabular values at various temperatures,

density of air ( $d$ ) =  $1.294 - 0.00466(T_a - 273.16)$ ,  
thermal conductivity of air ( $k$ ) =  $2.431 \times 10^{-2} + 6.6 \times 10^{-5}(T_a - 273.16)$ , and  
kinematic viscosity of air ( $v$ ) =  $1.331 \times 10^{-5} + 8.6 \times 10^{-8}(T_a - 273.16)$ .

The resistance to heat loss through skin and feathers ( $r_b$ ) decreases with increasing wind speed ( $W$ ) because wind penetrates the feathers,  $r_b = 916 - 12.8W^{0.5}$ .

The following example, constructed from measured values, illustrates the use of these equations:

$$\begin{aligned} \text{If, } Rm \text{ (net radiation)} &= -4.44 \text{ W/m}^2, \\ T_a \text{ (ambient temperature)} &= 277.32^\circ\text{K, and} \\ W \text{ (wind speed)} &= 0.73 \text{ m/sec;} \end{aligned}$$

$$\begin{aligned} \text{then, } r_b &= 916 - 12.8(W)^{0.5} = 916 - 12.8(0.73)^{0.5} = 905.0 \text{ sec/m} \\ d &= 1.2924 - 0.00466(T_a - 273.16) = 1.273 \text{ kg/m}^3 \\ k &= 2.431 \times 10^{-2} + 6.6 \times 10^{-5}(T_a - 273.16) = 2.458 \times 10^{-2} \text{ W/m}^2\text{K} \\ v &= 1.331 \times 10^{-5} + 8.6 \times 10^{-8}(T_a - 273.16) = 1.367 \times 10^{-5} \text{ m}^2/\text{sec} \end{aligned}$$

$$\begin{aligned} \text{and, } Re &= WD/v = (0.73)(0.19)/(1.367 \times 10^{-5}) = 1.015 \times 10^4 \\ Nu &= 0.17Re^{0.62} = 51.82 \end{aligned}$$

$$\begin{aligned} r_r &= dC_p/4eST_a^3 = 271.2 \text{ sec/m} \\ r_h &= dC_pD/kNu = 191.8 \text{ sec/m} \\ r_{hr} &= 1/(1/r_h + 1/r_r) = 112.3 \text{ sec/m} \end{aligned}$$

$$\begin{aligned} \text{Therefore, } T_e &= T_a + Rm(r_{hr})/dC_p = 277.32 + (-4.44)(112.3)/(1.273)(1010) \\ &= 276.93^\circ\text{K and,} \end{aligned}$$

$$\begin{aligned} M &= 0.977AdC_p(T_b - T_e)/(r_{hr} + r_b) \\ &= (0.977)(0.303)(1.273)(1010)(313.16 - 276.93)/(112.3 + 905) \\ &= 13.56 \text{ kcal/h} \end{aligned}$$

Then, total energy expended (TE) for a 2-h period is,

$$TE = 2 \times 13.56 = 27.11 \text{ kcal}$$

#### RESULTS AND DISCUSSION

*Microclimate of roosts.*—The minimum (2-h) daily temperature varied greatly within each roost. The mean for all roosts ranged from 8.0 to  $-14.9^\circ\text{C}$  during the winter and fluctuated as much as  $15.0^\circ\text{C}$  in a 5-d period (Fig. 1). High variability in temperature for all roosts was predominate over any seasonal changes. Maximum (2-h) daily wind speed was relatively low for the Mt. Dome and Bear Valley roosts with a high of 2.5 m/sec for the two sites (Fig. 2). Maximum daily wind speed was greater and more variable for the Three Sisters and Caldwell roosts than for the other roosts, with a high of 6.9 m/sec. Maximum daily wind speed was greater and more variable for the Kingsley weather station than for any of the roosts, with a high of 17.4 m/sec (Fig. 2).

When weather conditions for midwinter were compared, several differences were found between areas. The minimum temperature at the Kingsley weather station was significantly less ( $P \leq 0.05$ ) than for any roost except Mt. Dome (Table 2). Maximum windspeed also was significantly greater ( $P \leq 0.01$ ) for Kingsley weather station than for any roost. In addition, maximum windspeed at the Caldwell roost was significantly greater ( $P \leq 0.01$ ) than that for Mt. Dome and Bear Valley. During late winter, maximum windspeeds were similar for Caldwell and Three Sisters but significantly greater ( $P \leq 0.01$ ) than those for Mt. Dome and Bear Valley. Maximum windspeed at Kingsley weather station was greater ( $P \leq 0.05$ ) than that of any roost; the minimum temperature of the Kingsley weather station, however, was not less ( $P > 0.05$ ) than the average minimum temperature for all roosts during late winter. Minimum temperature for Mt. Dome was less ( $P \leq 0.01$ ) than the minimum temperature of Kingsley and the other roosts during late winter.

The movement of cold air from high to low elevation may have been prevalent during midwinter but not during late winter, resulting in lower temperatures at Mt. Dome ( $\sim 610$  m higher) than at Kingsley during late winter. The Caldwell and Three Sisters roosts had higher winds than the Mt. Dome and Bear Valley roosts because of the topographical differences between the areas. Mt. Dome and Bear Valley roosts are both on northeast facing slopes that provide protection from major weather systems from

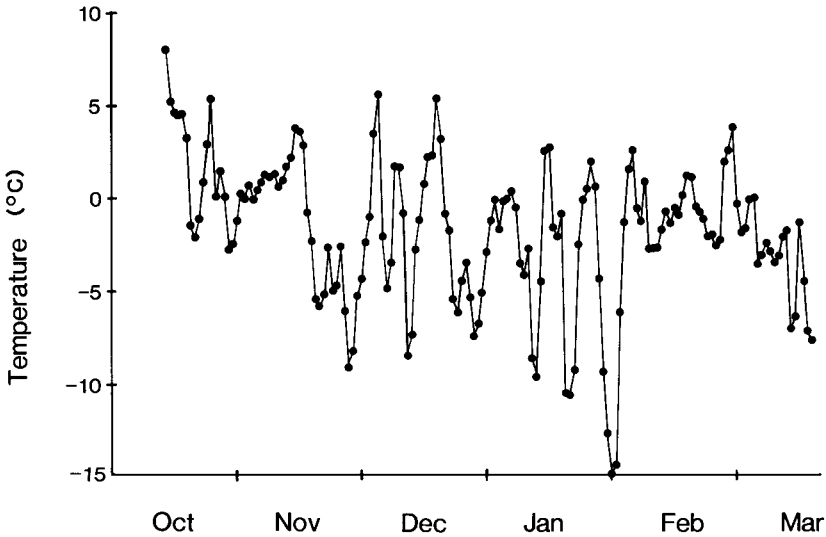


FIG. 1. Mean minimum daily roost temperatures of four Bald Eagle communal roosts in the Klamath Basin, 1979-80.

the south and west. The Three Sisters and Caldwell roosts are not on slopes and therefore were more exposed to prevailing winds. However, both of these roosts lie in slight depressions, and nearby buttes and trees provided some protection from wind. The wind speeds experienced in all roosts were significantly lower than those at the Kingsley weather station, which is located on the floor of the Basin with no protective topography. These data indicate that Bald Eagles in the Klamath Basin selected areas for communal roosting that have more favorable microclimates than the basin floor where feeding areas are located, and that differences in microclimate also exist between communal roosts.

*Roosting energy requirements.*—The nightly energy demand on Bald Eagles within each roost varied greatly (Fig. 3): from less than 120 kcal in Bear Valley in mid-October to 209 kcal in Mt. Dome in late January. Higher temperatures, lower radiation losses, and lower winds in Bear Valley (Table 2) contributed to a significantly lower ( $P \leq 0.01$ ) metabolic demand than any other roost during both mid- and late winter (Fig. 4). Bear Valley had a 5.6 kcal/night (4% of the mean nightly energy demand) energy savings over the Caldwell roost during midwinter and a 10.5 kcal/night (7%) savings over the Mt. Dome roost in late winter (Table 3). The energy demand in Mt. Dome was significantly greater ( $P \leq 0.01$ ) than in any other roost during late winter (Fig. 4, Table 3) due to a lower tem-

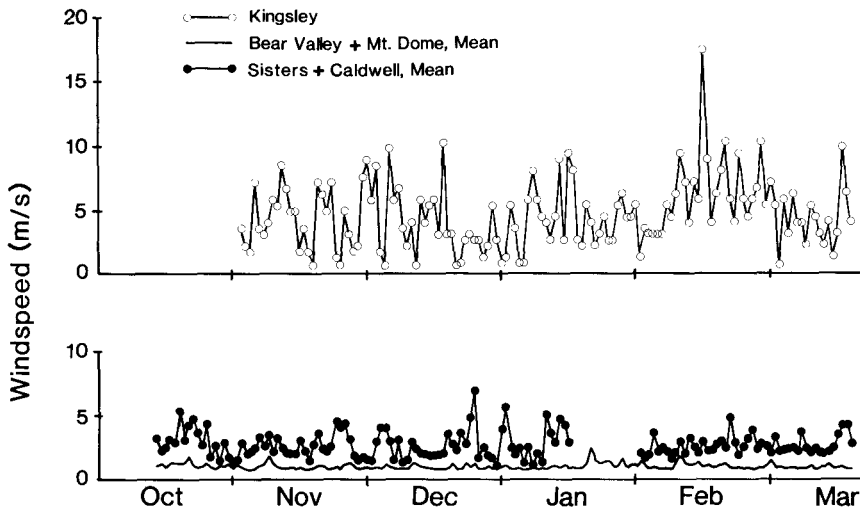


FIG. 2. Maximum daily windspeed recorded for Bald Eagle communal roosts and Kingsley weather station in the Klamath Basin, 1979–80.

perature during that period (Table 2). The energy demands in the Caldwell and Three Sisters roosts were similar to each other but between those of Bear Valley and Mt. Dome during late winter (Fig. 4, Table 3).

We wanted to compare energy demands between the roost with the mildest microclimate (Bear Valley) and feeding areas on the basin floor (represented by Kingsley weather station). Weather instrumentation and collection methods, however, were different between Bear Valley and Kingsley weather station and therefore data were not directly comparable. To compare these areas, we made the conservative assumption that net radiation loss at night was equal for the 2 locations ( $0.0 \text{ W/m}^2$ ) and further that  $T_a = 268.16^\circ\text{K}$  ( $-5^\circ\text{C}$ ),  $W = 2 \text{ m/sec}$  for Bear Valley. Weather differences found between the two areas (Table 2) were then used to estimate conditions at Kingsley (for midwinter  $T_a = 266.36^\circ\text{K}$ ,  $W = 4.85 \text{ m/sec}$  and for late winter  $T_a = 268.27^\circ\text{K}$ ,  $W = 6.23 \text{ m/sec}$ ). The metabolic production rate for eagles at Bear Valley under these conditions ( $18.13 \text{ kcal/h}$ ) was  $\sim 10\%$  lower than that for Kingsley weather station in midwinter ( $19.87 \text{ kcal/h}$ ) and  $\sim 6\%$  lower in late winter ( $19.16 \text{ kcal/h}$ ). Stalmaster (1981) calculated a savings of 7.8–9.8% (depending on radiation loss) in nightly energy production for Bald Eagles roosting in coniferous forests as compared with that in deciduous, riparian areas. Walsberg and King (1980) studied the microclimate of roost and nonroost areas of American



TABLE 2  
 MEAN DIFFERENCES IN MINIMUM TEMPERATURE AND PEAK WIND SPEED FOR FOUR COMMUNAL ROOSTS AND THE BASIN FLOOR (KINGSLEY) IN THE KLAMATH BASIN DURING THE WINTER OF 1979-80<sup>a</sup>

Area	Minimum temperature (°C)		Peak wind speed (m/sec)	
	Midwinter	Late-winter	Midwinter	Late-winter
Bear Valley	0.35	0.67	-0.52	-0.67 <sup>b</sup>
Caldwell	0.06	0.47	1.22 <sup>c</sup>	0.90
Three Sisters	—	0.42	—	0.74
Mt. Dome	-0.41	-1.55 <sup>c</sup>	-0.71	-0.97 <sup>b</sup>
Kingsley	-1.45 <sup>c</sup>	0.78	2.33 <sup>c</sup>	3.56 <sup>c</sup>

<sup>a</sup> Differences were calculated by subtracting the daily (24-h day) mean condition of all roosts from conditions in each area each day (see Statistical Methodology). A value of 0.0 would indicate no difference from the roost average.

<sup>b</sup> Peak windspeed in Bear Valley and Mt. Dome is significantly ( $P \leq 0.05$ ) less than in Caldwell and Three Sisters.

<sup>c</sup> Value is significantly different ( $P \leq 0.05$ ) from the roost average.

Robins in southeastern Washington and found a 4.4% reduction in energy demand within the roost.

Bald Eagles have been observed to shift roosting locations in response to stressful weather (Edwards 1969, Platt 1976, Steenhof et al. 1980). In this study, energy demands for the 3 d prior to counts for communal roosts were not significantly ( $P > 0.05$ ) correlated to the number of eagles

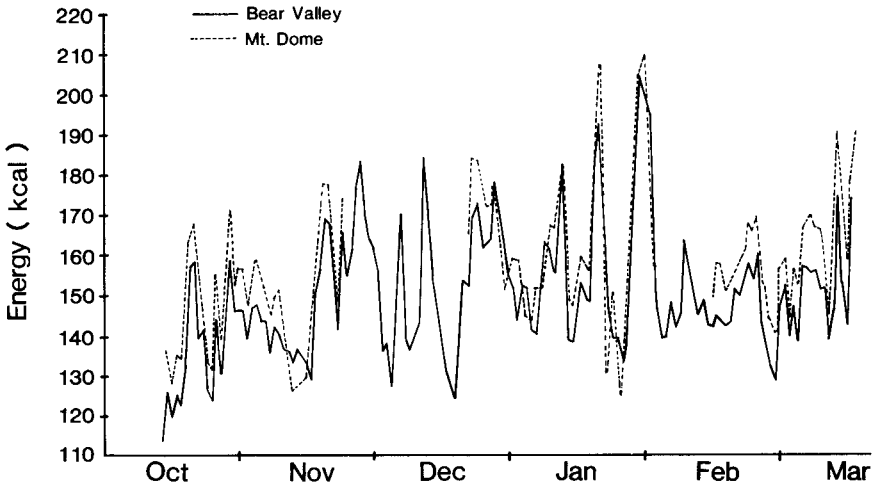


FIG. 3. Nightly energy expended by a Bald Eagle in the Bear Valley and Mt. Dome roosts during winter 1979-80.

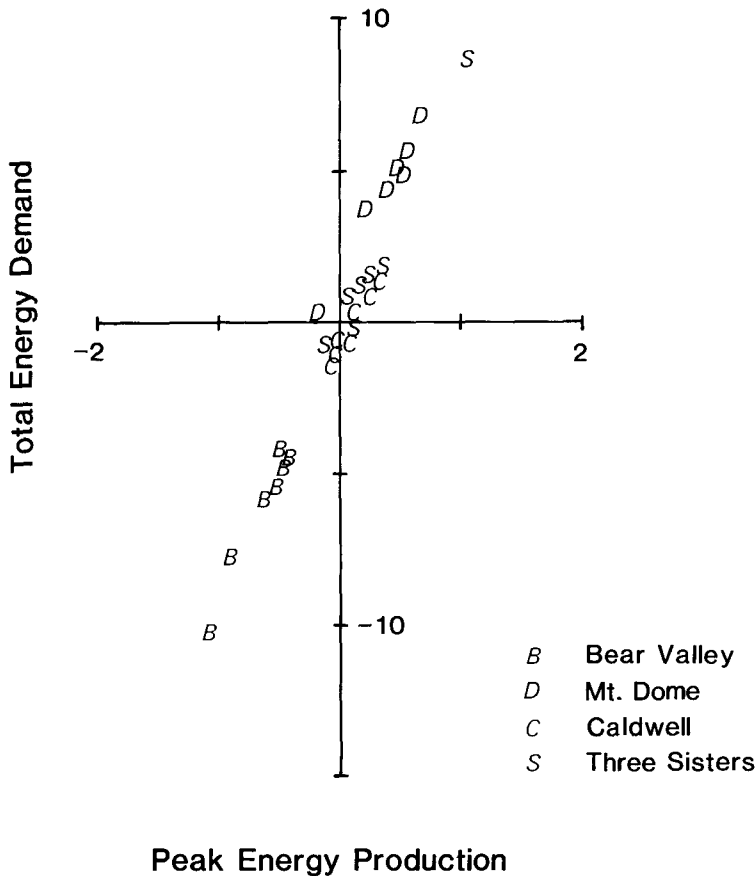


FIG. 4. Differences in total nightly energy demand (kcal) and peak energy production rates (kcal/h) of a Bald Eagle at four communal roosts in the Klamath Basin during late winter 1980. Values were calculated by subtracting the mean condition of all roosts from conditions in each roost each night. The axes represent roost averages.

using the roosts. Instead, numbers of Bald Eagles at a particular roost were positively correlated with eagle numbers at the nearest feeding ground (for four roosts:  $r = 0.47-0.84$ ,  $P \leq 0.05$ ), indicating that Bald Eagles selected roosts closest to where they were feeding. The lack of influence of energy demand on use of different roosts during 1979-80 was possibly due to: (1) high food availability and relatively mild weather conditions resulting in low energy stress, or (2) an increase in energy output required to fly a greater distance to a roost with only a 4-7% increase in nightly energy savings. The first explanation is supported by work done by Hayes

TABLE 3  
MEAN DIFFERENCES IN TOTAL NIGHTLY ENERGY DEMAND AND PEAK METABOLIC PRODUCTION OF A BALD EAGLE AT FOUR COMMUNAL ROOSTS IN THE KLAMATH BASIN DURING THE WINTER OF 1979-80<sup>a</sup>

Roost	Total energy (kcal)		Peak metabolic production (kcal/hr)	
	Midwinter	Late-winter	Midwinter	Late-winter
Bear Valley	-3.62 <sup>b</sup>	-6.11 <sup>b</sup>	-0.386 <sup>b</sup>	-0.665 <sup>b</sup>
Caldwell	1.99	-0.19	0.305	0.064
Three Sisters	—	1.91	—	0.258
Mt. Dome	1.75	4.39 <sup>b</sup>	0.101	0.343

<sup>a</sup> Differences were calculated by subtracting the mean condition of all roosts from conditions in each roost each night. A value of 0.0 would indicate no difference from the roost average.

<sup>b</sup> Value is significantly different ( $P \leq 0.05$ ) than any other roost.

and Gessaman (1980), who found that cold stress began in American Kestrels (*Falco sparverius*) at  $-5.0^{\circ}\text{C}$  and 13.47 m/sec wind, but that the most severe conditions used ( $-17.0^{\circ}\text{C}$ , 13.47 m/sec,  $0.0 \text{ W/m}^2$  radiation) did not appreciably stress Red-tailed Hawks (*Buteo jamaicensis*) or Golden Eagles (*Aquila chrysaetos*). The latter conditions were more severe than weather conditions recorded in this study, and food was observed to be abundant, so Bald Eagles were probably not cold stressed during the 1979-80 winter. The second explanation is supported by Stalmaster and Gessaman (1984), who found that Bald Eagles roosting farther than 3.9 km from feeding areas would incur a net energy loss. If similar assumptions are made for Bald Eagles in the Klamath Basin (flightspeed = 45 km/h, energy for flapping [active] flight =  $12.5 \times \text{BMR}$ , energy for soaring [passive] flight =  $3.5 \times \text{BMR}$ ,  $\text{BMR} = 12.47 \text{ kcal/h}$ ; flight to and from roosts in the Klamath Basin is 50% active and 50% passive), the energy cost of flights to and from roosts is 2.22 kcal/km. If a Bald Eagle flew 7 km (14 km round trip) farther to use a more protected roost, the energy cost would be 31.0 kcal. If energy demand were 210 kcal/night (extreme conditions for 1979-80), a 7% energy savings (based on results from this study) would only be 14.7 kcal/night. Therefore, nightly energy savings from selecting a more favorable microclimate would not compensate for the increased energy expenditure required to fly to another roost.

In the Klamath Basin, Bald Eagles fly as far as 20 km (40 km round trip) to roost. This represents an energy expenditure of 88.7 kcal. Energy savings of 10% (the difference between Bear Valley and Kingsley) achieved during severe conditions by staying in a communal roost instead of roosting in the basin would represent 21 kcal/night and would not compensate

for the energy lost in flying to the roost. The shortest distance between any roost and a feeding area is 6 km, with an energy expenditure of 26.6 kcal required for travel. Therefore, communal roosting behavior by Bald Eagles in the Klamath Basin cannot be explained solely on the basis of energy savings. In fact, roosts that are more than about 5 km from the feeding area create an energetic disadvantage to communally roosting Bald Eagles. We conclude that although Bald Eagle roosts had favorable microclimates compared to local weather conditions on the basin floor, energy savings were negated by the cost of flying to these roosts, and the adaptive significance of such behavior must be explained by other phenomena.

#### SUMMARY

During the winter of 1979–80, microclimatic variables were measured in four Bald Eagle (*Haliaeetus leucocephalus*) communal roosts located in the forests around the Klamath Basin of northern California and southern Oregon. An energetics model for roosting Bald Eagles was developed from microclimatic variables to compare the different roosts. All roosts were relatively protected from high winds in comparison to feeding areas (represented by Kingsley weather station, which was located on the basin floor in nearby Klamath Falls, Oregon) and showed a temperature advantage during midwinter. Higher temperature, lower radiation loss, and lower winds in the Bear Valley roost contributed to a significantly lower ( $P \leq 0.01$ ) nightly energy demand on Bald Eagles than in any other roost. Bear Valley had a 4 and 7% savings in energy demand compared with the most stressful roost, and a 10 and 6% savings compared with Kingsley weather station during midwinter and late winter, respectively. Differential use of the four roosts by Bald Eagles for communal roosting was not related to differences in energy demand between the roosts. Savings in energy due to use of communal roosts during night were not great enough to explain flight of Bald Eagles to roosts in the Klamath Basin.

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