TABLE 3

SEASONAL AND DAILY VARIATION OBSERVED IN SIX METEOROLOGICAL VARIABLES

Variable	July (clear)		January (clear)		November[a] (cloudy)	
	max.	min.	max.	min.	max.	min.
Air temperature[b] (°C)	30.0	8.0	−11.5	−22.0	6.5	0.5
Windspeed[b] (m s^{-1})	5.0	0.5	10.0	0.3	15.6	0.9
LW ground radiation[c] (W m^{-2})	600	325	265	210	305	280
LW sky radiation[c] (W m^{-2})	410	305	250	220	325	310
Total SW radiation[c] (W m^{-2})	900	0	415	0	115	0
Direct SW radiation[c] (W m^{-2})	940	0	940	0	0	0

[a] Values for daytime only.

[b] Values for maximum and minimum measured 160 cm above the ground.

[c] LW = longwave, SW = shortwave; measured under open sky on a horizontal surface.

of an hour. These standardized expressions could then be averaged over the period of a composite day, providing a mean and standard deviation for each day (Table A-1). Sample sizes for the composite days differed by the number of periods of visual contact.

THE THERMAL ENVIRONMENT AND ITS INFLUENCE ON THE BIOLOGY OF THE MAGPIE

METEOROLOGICAL MEASUREMENTS AND THE MICROCLIMATIC SET

On the study area noteworthy thermal differences developed among various hillside exposures and valley bottoms and different heights above the ground. These differences were greater on clear than cloudy days and also showed seasonal variation. Within this collage of thermal extremes several distinct thermal steps were identified, and taken together, these constituted the magpie's microclimatic set. Each thermal step in turn was a composite of several meteorological variables. Table 3 summarizes the daily and seasonal variation found in six of these meteorological variables measured for clear-sky conditions in July and January, and cloudy conditions in November. These data reflect the trends shown in the bulk of the measurements.

Two general discriminators of thermal steps were air temperature and windspeed, both of which varied as a function of height above the ground. Figure 1 presents air temperature and windspeed profiles for July, January, and March to demonstrate the variation that occurred due to seasonality and cloud cover. In both cases the rate of change was greatest between the surface and about 9 cm above the ground. This corresponded to the midpoint of the body of a magpie standing on the ground. Air temperature profiles showed the greatest variation in the summer, and slight variation in winter and on partly cloudy days. Wind profiles, however, showed their greatest variation with respect to windspeed and not sky conditions.

The following thermal steps in the microclimatic set of a magpie were distinguished as a result of these vertical variations. For a sunny day these were (1) open ground, (2) fence top high or higher in the open, (3) in the shade within or under dense foliage shielded from the sky, and (4) in the shade but exposed to the sky. These basic thermal steps were further modified by the extent to which

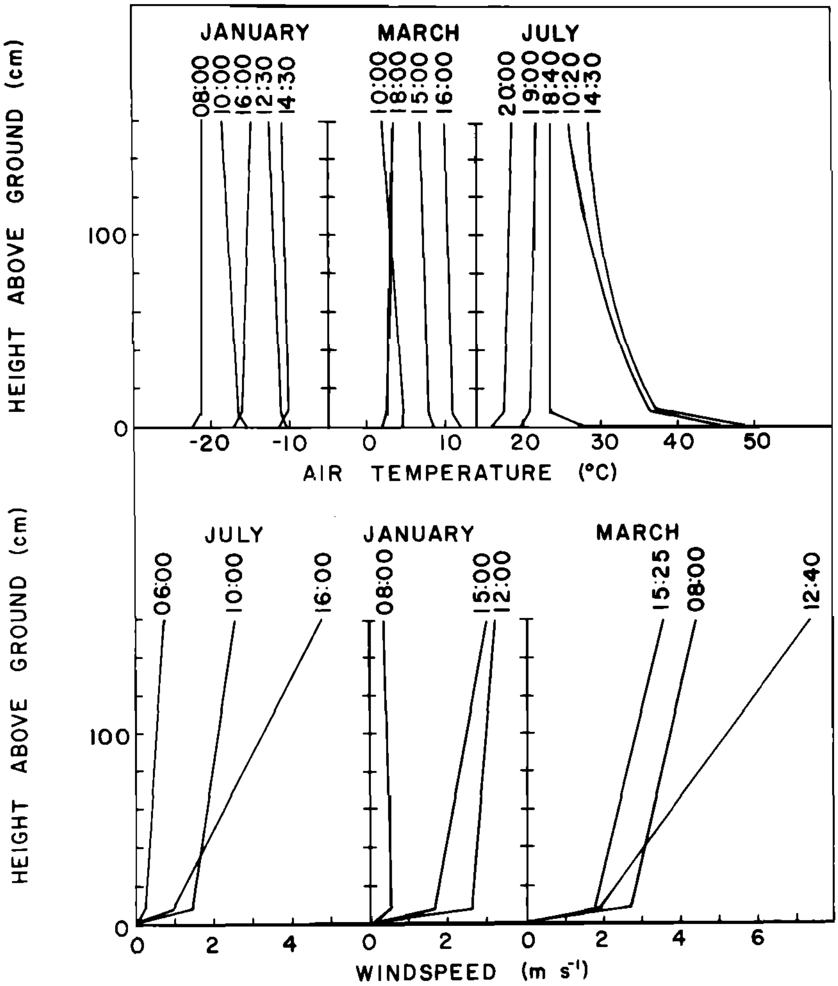

FIGURE 1. Air temperature (°C), and windspeed (m s^{-1}) profiles for selected months. Upper panel describes temperature profiles for a clear January day, a partly cloudy March day, and a clear July day. Lower panel describes windspeed profiles for the same months. Numbers associated with each profile line represent time of the day measurements were made.

they were sheltered from wind. On cloudy days, or at night, the shaded/unshaded aspect disappeared and the slope of the vertical temperature profile diminished. But because the wind profile was still present, differences in the potential for thermal exchange still occurred stepwise between ground, and fence-post high or higher above ground, and between sheltered and unsheltered places.

On clear days, extremes within and between these thermal steps were dominated and maintained by shortwave solar radiation, but modified by windspeed. On cloudy days extremes between these steps were less, and wind became the major contributor to differences between them.

Figure 2 indicates the percentages of clear, partly cloudy, and cloudy days that occurred monthly from June 1973 to June 1974 at the airport in Lewiston, Idaho,

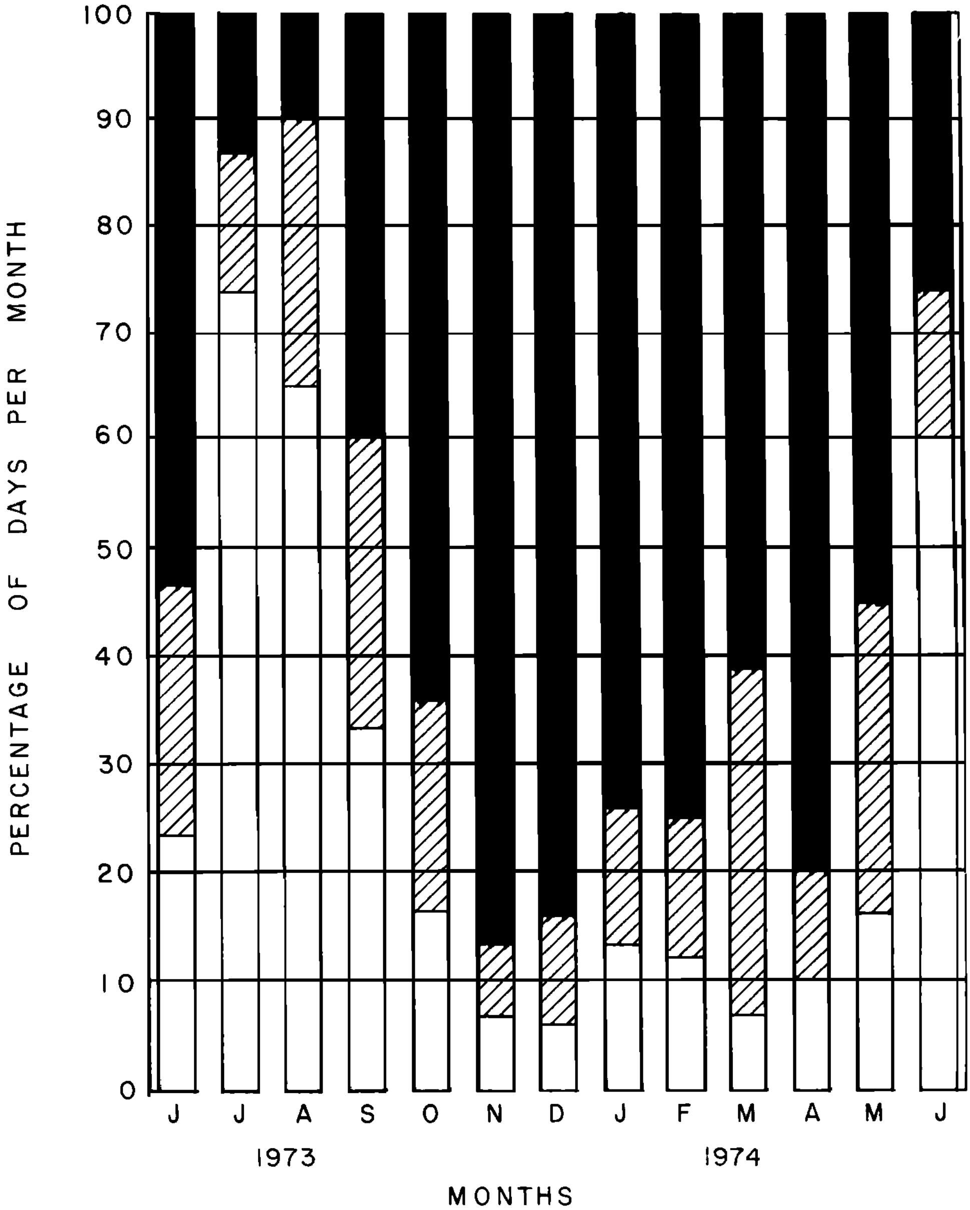

FIGURE 2. Percentage of days each month (June 1973–June 1974) having cloudy (solid), partly cloudy (hatched), and clear (open) skies.

18 air miles southeast of the study area (U.S. Department of Commerce Publication). Although the percentages may have differed a little between the two places, the data for Lewiston probably described accurately enough the general sky conditions for the study area. Summer months had mostly clear days (more than 50% clear to partly cloudy); therefore, shortwave radiation was the dominant meteorological variable that generated differences between thermal steps, and

TABLE 4
BODY WEIGHT, BODY DIMENSIONS, TOTAL SURFACE AREA, AND RATIO OF BODY DIAMETER TO BODY LENGTH OF FEMALE AND MALE BLACK-BILLED MAGPIES

	Female $\bar{x}$ ± SD (n)	Male $\bar{x}$ ± SD (n)	t	P[a]
Body weight (g)	162.4 ± 8.4 (4)	182.9 ± 9.0 (6)	3.62	$P < 0.1$
Total length[b] (cm)	15.8 ± 1.2 (4)	16.7 ± 1.1 (6)	1.23	$0.3 > P > 0.2$
Body length[c] (cm)	9.8 ± 0.65(4)	10.8 ± 0.88(6)	1.93	$0.1 > P > 0.05$
Body diameter[d] (cm)	7.3 ± 0.2 (4)	7.5 ± 0.2 (6)	1.55	$0.2 > P > 0.1$
Head radius (cm)	1.8 ± 0.11(4)	1.9 ± 0.13(6)	1.26	$0.3 > P > 0.2$
Total surface area (cm^2)	224.6 ± 16.1(4)	263.2 ± 22.3(6)	2.97	$P < 0.02$
Ratio of body diameter to body length	0.75 ± 0.045(4)	0.70 ± 0.049(6)	1.63	$0.2 > P > 0.1$

[a] Probability for t-test between sexes.
[b] Measured from base of beak to base of pygostyle. Characteristic dimension (d) for a bird facing into the wind.
[c] Measured from base of pygostyle to middle to neck on a bird in perched position with neck retracted.
[d] Measured at widest part of the body. Characteristic dimension (d) for a bird broadside to the wind.

windspeed played a modifying role. Fall, winter, and spring months on the other hand, had mostly cloudy days (fewer than 40% clear to partly cloudy), so during those months windspeed was the dominant variable creating differences between thermal steps. In all seasons, differences between thermal steps at night were a function of the degree of exposure to longwave sky radiation and wind. These general features illustrate that differences between thermal steps were dominated and modified by different meteorological variables during different seasons or times of the day. The formal heat budget and T_e analysis used in this investigation explicitly identified the environmental and organismal variables that coupled the magpies to their thermal surroundings, and serve to sort out those variables that have been most important in exerting selective pressure on their thermoregulatory attributes.

CALCULATION OF T_e AND ITS VARIABILITY

In the field magpies changed the magnitude of T_e at any one spot by changing their orientation to the direct solar beam and wind direction. These maneuvers altered R_{abs} and r_a terms, respectively, of Eq. 1 and directly affected the magnitude of T_e. The magnitudes of R_{abs} and r_a at any one locality and for any one posture were also related to body size. Since male magpies are larger than females, gender had to be considered in calculating T_e. This section examines the variability of T_e due to both postural changes and size differences between sexes.

Size differences between sexes.—Females were smaller than males (Table 4) and differed significantly ($P \leq .05$) from them in mean body weight, mean body length, and mean total surface area. There was no difference between females and males ($P > .05$) in mean total length, which is the characteristic dimension for a bird facing into the wind; mean body diameter, the characteristic dimension for a bird standing broadside to the wind; mean head radius; or the ratio of body diameter to body length.

Determination of R_{abs}.—Mean absorptivities for solar radiation by white belly feathers, black back feathers, and black chest feathers were 0.35, 0.79, and 0.83, respectively (Table 5). Birkebak (1966) gives values of 0.81 and 0.54 for black wing and white breast feathers, respectively. His values for black plumage agreed

TABLE 5
ABSORPTIVITY OF BLACK-BILLED MAGPIE PLUMAGE TO SHORTWAVE RADIATION

Museum[a] number	Shortwave absorbance White belly feathers	 Black back feathers	 Black chest feathers
60–489	0.305	0.800	0.787
51–105	0.390	0.797	0.831
521	0.550[b]	0.776	0.865
Mean ± SD	0.35 ± 0.06	0.79 ± 0.01	0.83 ± 0.04

[a] Specimens provided through the courtesy of the Conner Museum, Washington State University.
[b] Not included in the mean; see text for explanation.

with the measurements presented here, but his white plumage value agreed only with number 521 (Table 5), whose plumage was very stained and worn. Because of this, the white plumage value of bird 521 was not used in estimating the mean absorptivity for white feathers.

To estimate the mean absorptivity of the magpie to various sources of shortwave radiation the bird was apportioned into four surfaces: an upper surface (dorsal view), which received direct and scattered shortwave; a lower surface (ventral view), which received reflected shortwave; a lateral surface (side view), which received the direct beam when the bird was broadside to the sun; and a frontal surface (front view), which received the direct beam when the bird faced the sun. The upper surface and frontal surface were considered as all black and were given absorptivities of 0.79 and 0.81, respectively, where 0.79 is the average absorptivity of the black back feathers and 0.81 is the average of the black back and black chest feathers. The lateral surface and lower surface have extensive areas of white as well as black. Therefore, an average absorptivity was estimated for these surfaces on the basis of the percentage of white and black surface areas. The profiles of these surfaces and their black and white boundaries (minus the head for the lateral surface) were traced on paper. The profiles were then cut apart and the white and black portions weighed to find the percentage of each plumage type for each surface. Average values for the lower surface were 47% white and 53% black, and for the lateral surface 33 % white and 67 % black. Average absorptivity of the lower surface was estimated as 0.60 [(0.83) (0.53) + (0.35) (0.47)], and for the lateral surface 0.66 [(0.81) (0.67) + (0.35) (0.33)]. The lateral surface of the head was given an absorptivity of 0.81.

Written explicitly, the expression for absorbed radiation is

$$R_{abs} = (A_p/A_t)\alpha_s S_p + (A_s/A_t)\alpha_s S_s + (A_{sr}/A_t)\alpha_s S_r + (A_{Ld}/A_t)\alpha_L L_d + (A_{Lu}/A_t)\alpha_L L_u \qquad (11)$$

where A_p is the projected surface area perpendicular to the solar beam (m^2), A_s is the surface area receiving scattered shortwave radiation (m^2), A_{sr} is the surface receiving reflected shortwave radiation (m^2), A_{Ld} is the surface area receiving longwave sky radiation (m^2), A_{Lu} is the surface area receiving longwave terrestrial radiation (m^2), A_t is the total surface area (m^2), α_s is the absorptivity of the surfaces receiving direct, scattered, and reflected shortwave radiation, α_L is the absorptivity of the surfaces receiving longwave radiation (0.98; Hammel 1956), S_p is direct shortwave irradiance perpendicular to the solar beam (W m^{-2}), S_s is

TABLE 6

A_p/A_t RATIOS FOR BODIES AND HEADS OF FEMALE AND MALE BLACK-BILLED MAGPIES

	Orientation to Sun		
Sex	0°[a]	90°[a]	90°[b]
Female	0.20	0.28	0.02
Male	0.19	0.26	0.02

[a] Calculated for body, exclusive of the head.

[b] Calculated for head, exclusive of the body.

scattered shortwave irradiance (W m^{-2}), S_r is reflected direct and scattered shortwave irradiance (W m^{-2}), L_d is sky longwave irradiance (W m^{-2}), and L_u is terrestrial longwave irradiance (W m^{-2}).

Maximum and minimum values for the A_p/A_t ratio for each sex were obtained by calculating values (Eq. 4) both for standing broadside and for facing the sun (Table 6). For a bird facing the sun, the head blocks out an area from the body equal to that area on the head receiving direct radiation. Therefore, the head was ignored when considering the A_p/A_t ratio for a bird facing the sun. This was not the case for a bird broadside to the sun, and the A_p/A_t ratio for the head (0.02 for both males and females; Table 6) was included for this orientation.

The areas receiving longwave radiation from the sky and ground, scattered shortwave, and reflected shortwave were considered separately as the upper and lower surfaces of the body. Therefore ratios of the upper and lower surfaces become 0.5, and were substituted for A_s/A_t, A_{sr}/A_t, A_{Ld}/A_t, and A_{Lu}/A_t of Eq. 11. Using this and the other constants described above, Eq. 11 reduced to

$$R_{abs} = 0.20(0.81)S_p + 0.5[0.79S_s + 0.60S_r + 0.98(L_d + L_u)]$$

and

$$R_{abs} = 0.28(0.66)S_p + 0.02(0.81)S_p + 0.5[0.79S_s + 0.60S_r + 0.98(L_d + L_u)]$$

for a female facing and broadside to the sun, respectively. Equations for males were similar except that the A_p/A_t ratios were different.

Effect of posture and body size on T_e.—Figure 3 summarizes the effects of body size and different orientations to sun and wind on T_e for Black-billed Magpies on a sunny March day. Radiation absorbed was influenced by the A_p/A_t ratio (larger for females than males; Table 6), and r_a by the characteristic dimension d (smaller for females than males, though not significantly so; Table 4). Since facing into the wind maximized r_a, and standing broadside to the sun maximized R_{abs}, that postural combination (combination 1, Fig. 3) provided the highest possible T_e. Minimizing R_{abs} by facing into the sun and reducing r_a as much as possible by standing broadside to the wind provided the lowest possible T_e (combination 4, Fig. 3). Other possible orientations gave intermediate values of T_e. Included for each postural variant in Figure 3 are the T_e values calculated for both female and male magpies. In each case T_e was larger for females than for males.

The difference in T_e between sexes on a sunny day was never greater than 2°C, and usually less than 1°C (females always higher). The difference of 2°C was calculated for the warmest parts of clear, cold days in January, and differences of about 1°C for the warmest parts of sunny summer days. On cloudy days and at night, differences in T_e between the sexes were about 0.1°C. Although the

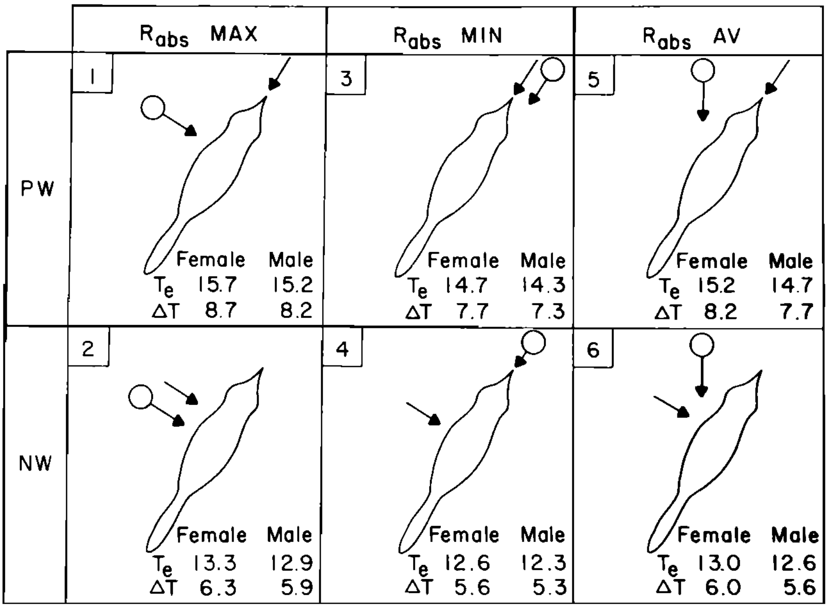

FIGURE 3. Range of effect of different orientations to sun and wind on T_e of the Black-billed Magpie. In each box direct beam of sun is indicated by a circle with a small protruding arrow, and direction of the wind by a single plain arrow. Values given are for a sunny March day with the magpie perched on top of a fence post. Various combinations of orientation to sun (broadside, facing, and quartering) and to wind (parallel and normal) are numbered 1–6 for correlation with the text. ΔT = difference in °C for T_e and T_a.

calculated differences between sexes on sunny days were not large, they were consistent through the entire daylight period for each orientation within a particular thermal step. When these sunny-day values for the sexes for any one posture and thermal step were compared over the entire daylight period by use of the Wilcoxon paired sample test (Sokal and Rohlf 1969), the slightly higher T_e's of females differed significantly from those of males ($P < 0.01$).

A magpie perched on a fence was able to change its orientation to sun and wind direction, and therefore the T_e at that spot, by making some rather small postural changes. The birds usually perched so they were facing into the wind. An upright posture presented the bird's body diameter as the characteristic dimension to the wind, and minimized r_a. By leaning into the wind, the characteristic dimension became the long axis of the bird, and r_a was maximized.

When the sun was high above the horizon, as during midday in summer, an upright posture would have produced an A_p/A_t ratio that approached 0.2 (that given in Table 6 for birds whose long axis is nearly parallel to the sun's rays) and minimized R_{abs}. This, coupled with the minimal r_a produced with the same posture, would have minimized T_e. On the other hand, a forward-leaning posture when the sun was high, would have produced an A_p/A_t ratio approaching 0.28 (long axis of the bird perpendicular to the sun's rays, Table 6) and maximized R_{abs}. This situation, coupled with the maximal r_a produced with the same posture, would have maximized T_e.

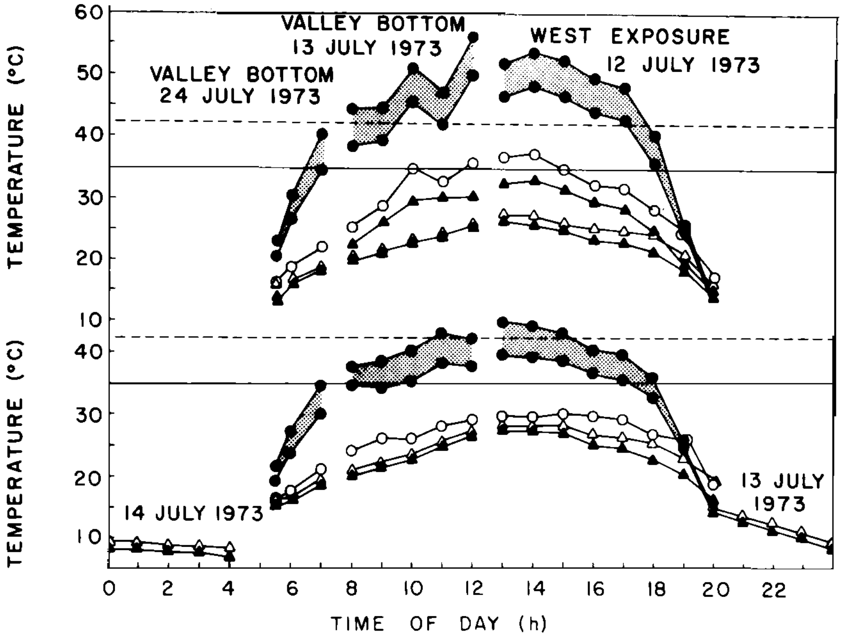

FIGURE 4. Equivalent blackbody and ambient air temperatures for Black-billed Magpies as a function of time (P. S. T.) during a composite day in July. T_e and T_a values for a bird on the ground (9 cm) are presented in the upper panel, and for a bird perched on a fence post (160 cm) in the lower panel. Symbols and conditions they represent are as follows: closed, T_e; open, T_a; circles, open unshaded areas; triangles, in shade or under the canopy of a grove or single bush; nighttime values, the roosting grove. Maximum and minimum values are plotted for daytime T_e's in the open, and the area between them is shaded to indicate the range of T_e's possible at that spot due to postural changes alone. Dates are those when meteorological variables were measured, and the topographical aspects those on which the measurements were made. Upper critical temperature (35°C) is indicated on each panel by the solid horizontal line, and the bird's body temperature (42.5°C) by the dashed horizontal line.

However, when the sun was lower in the sky (early morning or late afternoon in the summer, or midday in the winter) all postures except facing directly into the sun would have put the A_p/A_t ratio close to 0.28 and maximized R_{abs}. Under these conditions leaning into the wind while perched would have maximized T_e.

Therefore, magpies had the ability to change their T_e simply by altering their vertical posture. During the summer, except when winds were very strong, magpies minimized T_e by assuming the upright posture when perched. In the fall, winter, and spring they leaned forward into the wind, and maximized T_e. When they were on the ground, during any season, orientation to wind and sun was random and followed the path dictated by their foraging activities. Exceptions to this were seen on very windy days in both summer and winter when both the direction of foraging and posture when standing were into the wind.

Annual Cycle of T_e in Specific Thermal Environments

Equivalent blackbody temperatures were calculated by hourly intervals in each locality utilized by magpies for a composite day of every month. For birds in the open, the minimum and maximum T_e's made possible through postural adjust-

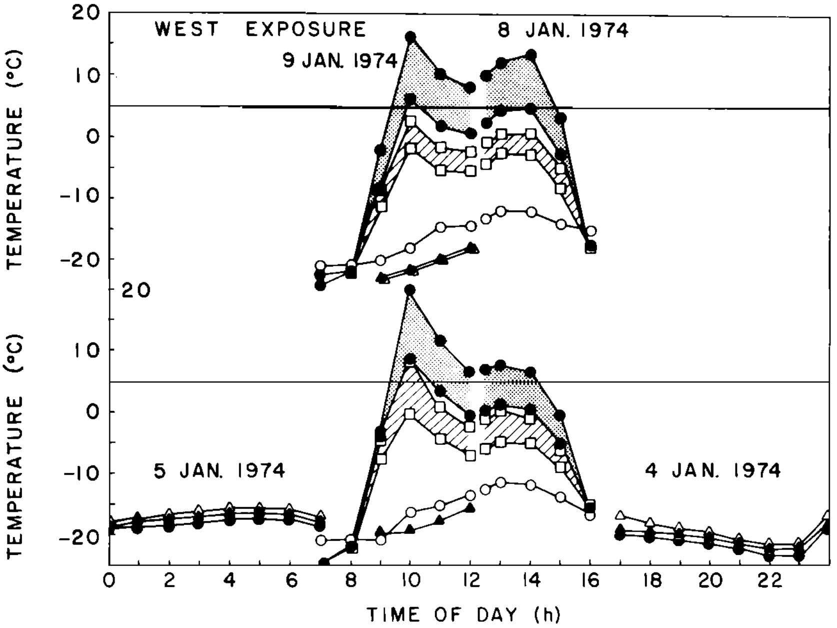

FIGURE 5. Equivalent blackbody and ambient air temperatures for Black-billed Magpies as a function of time (P. S. T.) during a composite day in July. Shaded areas with closed circles represent maximum and minimum T_e values calculated from measurements made on very cold days with clear skies and snow cover. To demonstrate the extent to which increased reflected shortwave radiation enhanced T_e's on those days (even pushing them above the lower critical temperature), values calculated for identical days without snow cover were also plotted and are represented by the hatched area and open boxes. Lower critical temperature (5°C) is represented on both panels by heavy solid horizontal lines. Other features and symbols of the figure are as described for Figure 4.

ments were also calculated. The data were then reduced to diagrams exemplified by Figures 4 and 5 (July and January, respectively). These permitted the diurnal variation of T_e and the thermal options available to the birds to be visualized. Similar diagrams for the remaining months of the year are shown by Mugaas (1976), and together these constitute an extremely detailed analysis of the daily, annual, and spatial variation in the magpie's thermal environment. Collectively, they represent the magpie's microclimatic set and spatial variants within it are called thermal steps to emphasize that the thermal options available to the birds are, because of their behavioral regime, typically discrete rather than continuous. These data provided the basis for the subsequent calculation of the thermostatic component of the energy budget.

The behavioral observations demonstrated that during the course of a day magpies used open ground, open perches (fence tops, tree tops, telephone poles, roofs, etc.), shaded perches within or under dense foliage shielded from the sky, and shaded perches exposed to the sky. Equivalent blackbody temperature analysis supported the premise stated earlier that these four localities represented four distinct thermal steps, each with well defined upper and lower limits of variation. These steps, and the variables needed in calculating T_e (Eq. 1) or $\dot{H}_m$ (Eq. 8) are summarized in Figure 6. During the daytime, a bird would occupy

TABLE 7
RELATIONSHIP OF T_e OF BLACK-BILLED MAGPIES TO T_a IN RESPONSE TO CLEAR OR CLOUDY SKIES

Thermal step	Diurnal Clear sky	 Cloudy sky	Nocturnal Clear sky	 Cloudy sky
1. Open ground	$T_e > T_a$	$T_e \simeq T_a$	$T_e < T_a$	$T_e \simeq T_a$
2. Fence top high or higher in the open	$T_e > T_a$	$T_e \simeq T_a$	$T_e < T_a$	$T_e \simeq T_a$
3. In the shade within or under dense foliage shielded from the sky	$T_e \simeq T_a$	$T_e \simeq T_a$	$T_e \simeq T_a$	$T_e \simeq T_a$
4. In the shade but exposed to the sky	$T_e < T_a$	$T_e \simeq T_a$	$T_e < T_a$	$T_e \simeq T_a$

any one of these steps, but at night a single step was utilized (3 in Fig. 6) that minimized exposure to wind and sky. By distinguishing between these steps on the basis of whether or not they were outside the magpie's blackbody T_n, it was possible to determine the times during which physiological thermoregulation was necessary. In each of these steps, T_e either approximated or deviated from T_a, as summarized in Table 7, depending on sky conditions and the resulting radiation environment. The analysis indicated that radiation was the preponderant variable in determining the magnitude of the difference between T_e and T_a, with wind playing a moderating role in diminishing this difference.

In low-radiation environments T_e approximated T_a, and changes in windspeed or orientation to the wind did not have much effect on the magnitude of T_e. Therefore, it was difficult to appreciate what these small changes in T_e (2°C or less) meant to the total energy budget of the bird. There was a sensible difference in heat loss under these conditions, however, that was related to changes in both windspeed and posture. These differences were determined with Eq. 8, where they emerged as different metabolic requirements. Below the T_{lc}, r_b was maximized and was so much larger than r_e ($r_b = 590$ s m^{-1}; $r_e = 27$ to 132 s m^{-1}) that it was the dominant element in heat transfer. The equivalent resistance, however, still operated as a variable barrier to heat transfer so that even after r_b was maximized, the total resistance of the bird ($r_b + r_e = r_t$ where r_b and r_e are in series) was still changeable within limits depending on windspeed, posture, and T_a. The extent of this variability was visualized by plotting the effect of windspeed on metabolic demand at T_e's below the T_{lc} when $R_{abs} \approx \epsilon\sigma T_a^4$ and $T_e \approx T_a$. Metabolic demand was estimated with Eq. 8 at T_e's of 3, −4, and −21°C at two orientations to the wind while all other factors except windspeed were held constant. The results of these calculations are presented in Figure 7A as paired curves at each T_e where the upper and lower lines in each case represent a female perched normal and parallel to wind, respectively. Changing orientation to the wind produced only a 2 to 3% difference in metabolic demand, but moving from an unsheltered spot with a relatively high windspeed (4 m s^{-1} or greater) to one that was sheltered (windspeed of 0.4 m s^{-1} or less) altered metabolic demands by as much as 12%. The response was closely coupled to r_a as evidenced by the fact that half the change possible in both $\dot{H}_m$ and r_a occurred between windspeeds of 1.9 and 2.3 m s^{-1} (Fig. 7A, B).

One example of the ecological importance of avoiding strong winds at low temperatures was seen in the metabolic savings accrued by magpies as a result

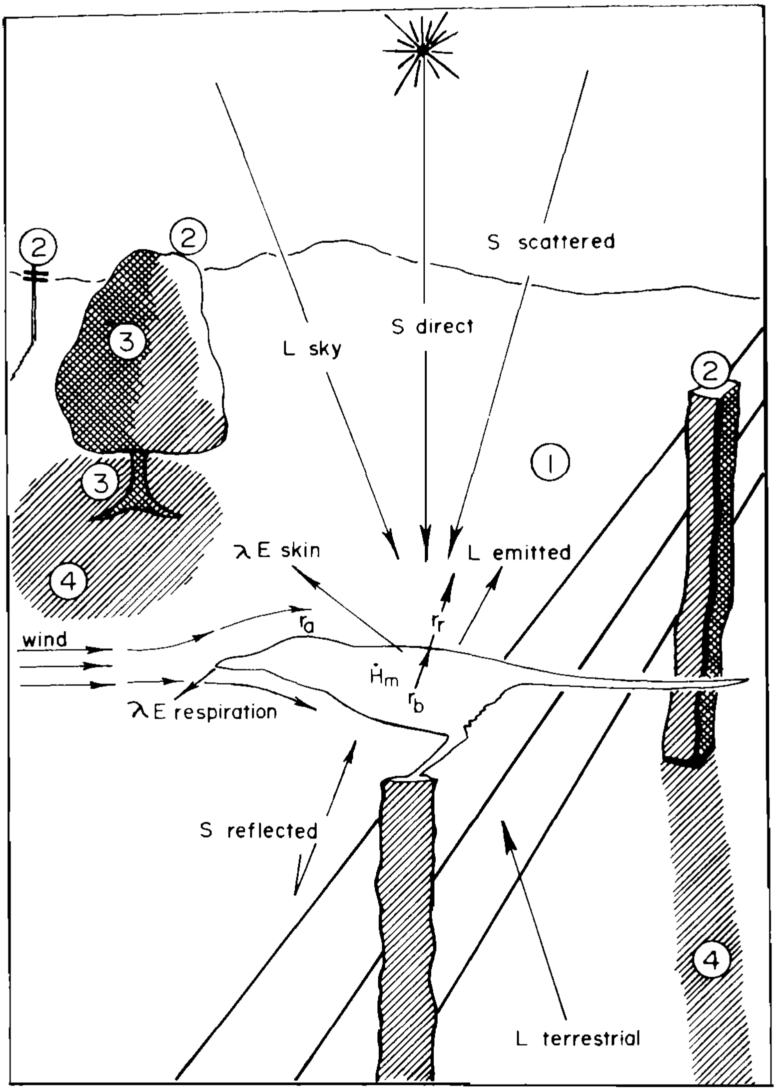

FIGURE 6. Summary of thermal steps (1, 2, 3, and 4) available to Black-billed Magpies, and variables used in calculating T_e and $\dot{H}_m$ for magpies. All symbols are as described in text.

of having selected a dense fir grove on the lee side of a hill for their winter roost. When a magpie roosted at low temperatures, its shape approximated a sphere (beak in scapular feathers and body feathers erected), so its charateristic dimension approached body diameter at its widest point. Assuming that a magpie was in the roosting posture on a cold (−20°C) cloudy night when windspeeds outside and inside the grove averaged 4.0 and 0.4 m s^{-1}, respectively (as measured in January), its potential metabolic demand was reduced by 8.3% when it elected to roost in the shelter of the grove (121.0 W m^{-2} as compared with 132 W m^{-2}). On a clear night, with other conditions remaining constant, the metabolic difference in and out of the grove would have been even greater since the foliage

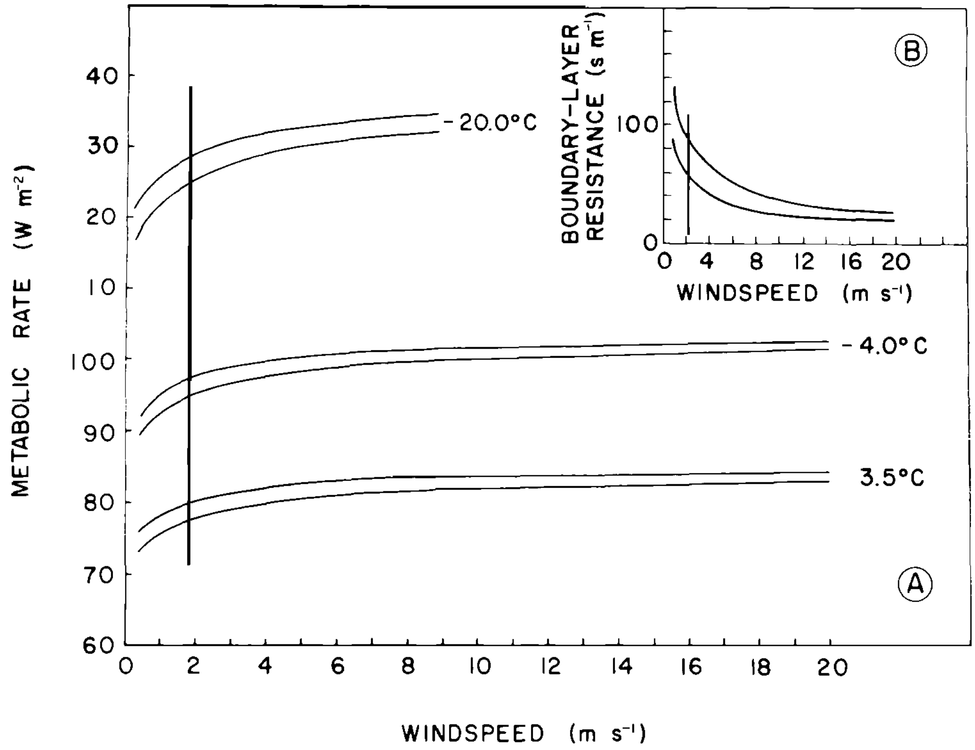

FIGURE 7. A. Effect of windspeed on metabolic requirements of Black-billed Magpies at various air temperatures, described by plotting metabolic rate (W m^{-2}) as a function of windspeed (m s^{-1}). Each pair of lines represents the effect at the air temperature (°C) indicated. Upper lines of each pair represent a female perched normal to the wind, and lower lines, parallel to the wind. B. Boundary-layer resistance (s m^{-1}) for Black-billed Magpies as a function of windspeed (m s^{-1}). Upper line is for a female parallel to the wind; lower line, normal to the wind. Solid vertical lines in both figures describe the windspeed at which one-half the change in both $\dot{H}_m$ and r_a occurs.

sheltered the birds from the sky as well as the wind. Kelty and Lustick (1977) calculated that Starlings, *Sturnus vulgaris*, reduced metabolic costs by 12% on cold winter nights when they avoided high windspeeds by roosting in the shelter of a pine woods, and Balda et al. (1977) reported similar wind avoidance habits in the winter roosting behavior of Piñon Jays, *Gymnorhinus cyanocephalus*. Wind avoidance and orientation to maximize r_a has also been shown to be a major behavioral pattern for deer, *Odocoileus virginianus* (Verme 1968), and pronghorn antelope, *Antilocapra americana* (Bruns 1977) when resting during cold winter months.

$T_e = T_b$ was arbitrarily picked as the point where physical activity and its associated higher metabolic heat production could be a detriment to the heat-loss capacities of evaporative cooling and could represent a point on the T_e diagrams above which thermal heat stress could occur. Owing to intense shortwave radiation and low windspeed, T_e exceeded T_b at 9 cm above the ground for substantial parts of clear days from May through September, even though T_a was rarely above 35°C. These high T_e's limited the time a bird could spend on open ground before experiencing heat stress, and could therefore have limited foraging time. During these months, fence tops represented a more moderate step, and T_e's exceeded T_b only when windspeed was very low. But, unlike the winter situation, in which the birds minimized but could not escape the cold, these places of potential heat stress were avoided and the birds simply moved into the shade.

Behavioral observations showed that magpies, when active during the hot part of a day, shuttled between the top of a fence and the ground, or between the open ground and the shade of a fence post. In fence-top shuttling, a typical sequence was as follows. A bird perched on the fence would fly to the ground and begin foraging. Soon its beak would open, indicating enhanced evaporative cooling. After some time on the ground, the bird would return to the top of the fence and perch in an upright posture, facing into the wind with wings drooped and beak open. Sometimes the breast and back feathers would be drooped open as well. Soon the beak would close, the wings would be retracted, the body feathers sleeked, and shortly thereafter the bird would return to the ground and the cycle would resume. Another typical pattern involved standing in the shade of a fence post and making occasional short forays out into the open sun after grasshoppers, then returning to the shade of another fence post. In addition, the magpies often retreated into dense shade for long periods of time and completely avoided foraging when it was very hot on the ground. Brown-headed Cowbirds, *Molothrus ater*, and European Starlings in the same pastures remained active during hot times of the day by foraging in the shade of grazing cows.

In October, T_e's still sporadically exceeded the T_{uc} at ground level, but from October through early April, they usually fluctuated around the T_{lc}. During this time of the year, on sunny days and even some cloudy days, T_e's exceeded the T_{lc} even when T_a did not. This indicated that, in general, the ground offered comfortable thermal conditions for the magpie during the daytime, even during very cold days in January (Fig. 5).

TIME-ACTIVITY AND ENERGY BUDGETING IN THE ANNUAL CYCLE

CHRONOLOGY OF EVENTS IN THE ANNUAL CYCLE

A summary of the annual cycle is presented in Figure 8. Daylength and length of civil twilight for the first day of each month at the latitude of Pullman (46°37.5′N) were taken from List (1971). Daylength was distributed equally around true solar noon for this longitude (117°08′W), with civil twilight added at dawn and dusk. Times of entering and leaving the roost were noted periodically throughout the year, corrected to true solar time, and plotted on Figure 8.

Reproduction 1974.—The chronology of reproductive events is superimposed on Figure 8. The horizontal bars represent the timing of the various reproductive stages for the 1974 season and were constructed from semi-weekly inventories of the nests within the study area. The construction of a simple stick platform signaled the onset of nest building and usually involved one or more false starts before the final nest site was selected. This activity was first noted during the last few days of January. By the end of February all pairs on the study area were engaged in nest building, which continued to just past mid-April, at which time there were 18 completed nests.