

sensor was painted with flat black Krylon. All measurements were made with the radiation sensor in a horizontal position, facing upward for global and scattered radiation, and downward for reflected radiation. The value for the direct beam was calculated from Eq. 5,

$$S_p = (S_{Tt} - S_s) / (\cos \beta \cos \delta \cos h + \sin \beta \sin \delta) \quad (5)$$

where  $S_{Tt}$  is global radiation,  $S_s$  is scattered radiation,  $\beta$  is the latitude of the study area ( $46^\circ 37.5'$ ),  $\delta$  is the solar declination taken from the ephemeris for the day in question, and  $h$  is the hour angle of the sun (List 1971).

Longwave sky radiation was estimated in three ways. On clear days or days with scattered clouds, longwave sky radiation was estimated from the Idso-Jackson (1969) equation for atmospheric radiation and corrected for cloud cover (Monteith 1973). On some days, sky temperatures were measured with a Wahl Heat Spy radiation thermometer (Model HSA-120, William Wahl Corporation, Los Angeles, California, U.S.A.) and converted to irradiance using  $\epsilon = 1.0$  for sky emmissivity. On completely overcast days, or within a shady canopy, or within the roosting grove at night, longwave ground and sky radiation were estimated from measurements of total incoming radiation ( $Q$ ) made with a modified Moll-Gorczyński solarimeter fitted with a polyethylene dome and a thermocouple thermometer on the cold junction of the sensor's thermopile (Mugaas 1976, Campbell et al. 1978). The longwave component was then estimated by subtracting the total shortwave reading ( $S_{Tt}$ ) from  $Q$ .

*Air and ground temperatures.*—Air temperature was measured with a 26 ga copper-constantan thermocouple shaded from sky radiation with an aluminum foil shield. Measurements were made at 9 cm (mid-height on a bird standing on the ground) and 160 cm (fence-post height) above the ground. Ground temperatures were measured with this same thermocouple by pulling the aluminum shield back from the junction and laying the junction on the ground. In all cases of air and ground temperature, the maximum and minimum temperatures observed for a one-minute period were recorded and the average of these used in data presentation. Ground temperature was also used to calculate longwave terrestrial radiation.

*Windspeed.*—A Hastings model RB-1 anemometer with an omnidirectional probe was used to measure windspeed. Measurements were made at 9 cm and 160 cm above the ground for a period of one minute at each height and the maximum and minimum values recorded for that interval. The average of these was used as the mean windspeed.

## RATIONALE AND METHODS OF TIME-ACTIVITY AND ENERGY BUDGET ANALYSIS

### BEHAVIORAL CATEGORIES

Behavior was described in units called Bouts. Bouts (Table 1) defined an individual's position within the habitat, and the length of a Bout was determined by the amount of time spent in that position. For example, a Ground Bout started when a bird landed on the ground and ended when it left it. Fence, Telephone Pole, and Roof Bouts were combined into a single Bout abbreviated FTTPR. Within each Bout, the basic energy-requiring movements, called activities, were quan-

TABLE 1  
 BEHAVIORAL CATEGORIES USED IN QUANTIFYING DAILY ACTIVITY PATTERN AND ENERGY  
 EXPENDITURE OF BLACK-BILLED MAGPIES

Bout	Activity
Air	Flight >3 sec. Flight ≤3 sec.
Ground	Stand Walk Hop Run
FTPR <sup>a</sup>	Alert perch Rest perch Hop
Bush	Alert perch Rest perch Hop Laying or incubating Nest attendance Roosting

<sup>a</sup> Fence, Telephone Pole, and Roof Bouts were combined into this one category.

tified (Table 1). Perching was subdivided into alert and rest perching, and flying into flights lasting three seconds or less, and those lasting more than three seconds.

Movements such as preening, calling, and pecking were considered accessory to those already categorized as activities, and although their occurrence was recorded they were not included in budgets of either time or energy. Calling, for example, was performed while the birds walked, flew, hopped, ran, or perched, and at this time it is difficult if not impossible to determine the energy added to these other activities by vocalizations, preening, or pecking. Furthermore, the frequency of these movements within various activities was not continuous or predictable, which obscured their energy requirement even more.

#### METHODS OF OBSERVATION

During the nonreproductive period, males and females traveled together as pairs or as flocks of mixed sexes, and since the behavior of any one bird was representative of his fellows, the activities of males and females were considered to be the same at this time. During the reproductive period, three pairs were observed. One pair during egg laying, one pair during incubation, and one pair during the late nestling stage. Each member of a reproductive pair was marked as an individual by dyeing its white scapulars with food dye, and a separate record was made for each member of a pair.

It was generally not possible to make a complete diurnal record in one day. Instead, a composite day was constructed as it was for the micrometeorological data. Birds were followed for at least four hours on any one day, and as much of that period as possible was spent in continuous visual contact with one or more individuals. An effort was made to overlap these four-hour periods from day to day so that by the end of the two to four days required to complete the series,

TABLE 2  
 CATEGORIES AND CONVERSIONS USED IN ESTIMATING DAILY ENERGY EXPENDITURE ( $H_{TD}$ ) OF  
 BLACK-BILLED MAGPIES

Categories	Multiple of $\dot{H}_b$ <sup>b</sup>	kJ h <sup>-1</sup> <sup>a</sup>	
		Female	Male
<b>Activity Metabolism</b>			
Stand	1.70	9.5	10.7
Alert perch	1.70	9.5	10.7
Rest perch	1.27	7.1	8.0
Nest attendance	1.85	10.36	11.66
Walk	2.00	11.2	12.6
Hop	2.00	11.2	12.6
Run	2.15	12.1	13.6
Flight >3 sec.	11.00	61.6	69.3
Flight ≤3 sec.	6.00	33.6	37.8
Incubation, diurnal	1.27	7.1	
Incubation, nocturnal	$\dot{H}_b$ + thermoregulatory requirement		
Roosting	$\dot{H}_b$ + thermoregulatory requirement		
<b>Production</b>			
Egg laying	0.45	2.5	
Molt	0.13	0.7	0.8
<b>Thermoregulatory requirement<sup>c</sup></b>			

<sup>a</sup> kJ/4.184 = kcal.

<sup>b</sup> Basal Metabolic Rate ( $\dot{H}_b$ ) is 5.6 kJ h<sup>-1</sup> for females and 6.3 kJ h<sup>-1</sup> for males.

<sup>c</sup> See Eq. 9.

the record for the composite day would represent the bird's complete dawn-to-dark activities.

Observations of individual birds were made using either 8 × 35 field glasses or a variable power spotting scope. An individual's behavior was recorded as long as it was visible. If it disappeared the record was stopped, and unless it was relocated a new record was started on a different bird. Periods of individual visual contact, therefore, varied from three minutes to as long as six hours. When the bird was out of sight, but known to be performing a certain type of Bout, the activities performed during that interval were estimated from the averages obtained for Bouts when the bird was in view. Other out-of-sight periods were strictly unknowns with respect to what the birds were doing, and these went into an unrecorded time category. The percentages for the Bouts performed during visual contact were then prorated over the entire diurnal period. No attempt was made during this study to restrict observations to periods of clear weather. Observations were conducted under prevailing conditions, whatever they were.

The birds' activities were reported on voice tape along with a metronomic signal (Wiens et al. 1970) which provided a continuous time base for the behavioral commentary. This information was then transcribed and analyzed by computer.

#### ENERGY EQUIVALENTS

The energy equivalents assigned to the various activities and physiological processes are given in Table 2. The following narrative explains their derivation.

*Size dimorphism between sexes.*—Male magpies weighed 182.9 g ( $n = 6$ ,  $SD = 9.0$ ) and females weighed 162.4 g ( $n = 4$ ,  $SD = 8.4$ ). Because of this size dimorphism, separate energy requirements were estimated for each sex. From Stevenson's (1971) measurements of basal metabolic rate for a mixed population, the basal metabolic rates were estimated to be 6.3 and 5.6  $\text{kJ h}^{-1}$  for adult males and females, respectively.

*Thermoregulatory requirements.*—The metabolic requirements for  $T_c$ 's below the  $T_{lc}$  were estimated as follows. Evaporative water loss may be expressed as a function of  $\dot{H}_m$ ,

$$\lambda E = \dot{H}_m X \quad (6)$$

where  $X = \lambda E / \dot{H}_m$ , and other symbols are as described above. Substituting Eq. 6 for  $\lambda E$  in Eq. 2 gives

$$\dot{H}_m - \dot{H}_m X = [\rho_a c_p / (r_b + r_c)] (T_b - T_c) \quad (7)$$

and solving for  $\dot{H}_m$ ,

$$\dot{H}_m = [\rho_a c_p / (r_b + r_c)] (1 - X) (T_b - T_c) \quad (8)$$

Metabolism predicted by this equation includes both basal and thermoregulatory requirements. The predicted thermoregulatory requirement (total metabolic requirement minus basal metabolic requirement) below the  $T_{lc}$  forms a straight line described by

$$\dot{H}_t = (0.736 - 0.145 T_c) \quad (9)$$

where  $\dot{H}_t$  is the thermoregulatory requirement ( $\text{kJ h}^{-1}$ ), and  $T_c$  is as described above.

*Standing and perching.*—Standing ( $\dot{H}_s$ ) and alert perching ( $\dot{H}_{AP}$ ) were assigned an energy requirement of  $1.7 \times \dot{H}_b$ , and rest perching ( $\dot{H}_{RP}$ ) an energy requirement of  $1.27 \times \dot{H}_b$  (King 1974).

*Incubation.*—The energy requirement of incubation ( $\dot{H}_i$ ) seems to be predictable (West 1960, Kendeigh 1963, Drent 1970, Ricklefs 1974) but there is disagreement as to how this requirement is satisfied. King (1973) maintains that until shown otherwise, it is reasonable to assume that the residual heat from the resting metabolism of a bird can "supply a large fraction, if not all, of the heat required for incubation." In opposition to this view (West 1960; Kendeigh 1963; El-Wailly 1966; Drent 1970, 1972; Ricklefs 1974) is the opinion that the major fraction of this requirement is additive to the bird's metabolic requirement at rest and as such is derived from its "productive energy" resources.

White and Kinney (1974) have demonstrated that egg temperature during incubation is regulated by either adjusting the tightness of sit on the eggs or the degree of attentiveness and not by increasing thermogenesis except when needed at  $T_a < T_{lc}$ . Walsberg and King (1978a, 1978b) used formal heat budget modeling to assess the total energy requirement of incubating Mountain White-crowned Sparrows (*Zonotrichia leucophrys oriantha*), Red-winged Blackbirds (*Agelaius phoeniceus*), and Willow Flycatchers (*Empidonax traillii*), and demonstrated it to be 15–18% lower than that of a bird perched outside the nest but exposed to the same microclimate. This supports the contention that, at least for these species and perhaps for any species that builds a well-insulated nest, incubation

will substantially reduce rather than increase total parental energy expenditure. King's (1973) viewpoint was therefore chosen for this investigation.

Several features of incubation in the Black-billed Magpie prompted this decision: (1) the nest of the magpie is large and appears to be well insulated (from outside in it is composed of an outer woven tangle of sticks that completely surrounds and usually forms a dome over a thick-walled nest cup that is composed of mud and small sticks and lined with such materials as fine roots, horse hair, grass, soft twigs, and shreaded bark), (2) the female alone incubates, is more than 90% attentive (Table 10), and is fed periodically on the nest by the male, and (3) when she does leave the nest it is for short periods during the warmer part of the day when  $T_e$  is usually well above her  $T_{lc}$ . With this pattern of incubation, the cumulative heat needed to rewarm the eggs is minimized and egg temperature during the remainder of the day could be maintained primarily by adjusting tightness of sit on the eggs. It was assumed, therefore, that during the day this activity, plus the occasional changing of position in the nest, and the task of periodically turning the eggs would make incubating equivalent in cost to rest perching ( $1.27 \times \dot{H}_b$ ). At night the metabolic output was assumed to be the same as for a roosting bird ( $\dot{H}_b$  plus any thermoregulatory requirement), which is probably an overestimate since no effort was made to assess the insulative value of the nest and its possible role in reducing the thermoregulatory requirement.

*Nest attendance.*—Whenever a male was attending an incubating female, or the male and female were attending nestlings, they performed a combination of activities which included occasional hopping, alert standing, and manipulating objects with the beak. It was not possible to observe all of these activities in the enclosed nest, and so it was assumed that nest attendance ( $\dot{H}_{na}$ ) was energetically less costly than walking but more costly than perching, and it was assigned an intermediate value of  $1.85 \times \dot{H}_b$ .

*Walking, hopping, and running.*—Energy equivalents for these activities were estimated from the relationship between running speed and oxygen consumption for the Bobwhite Quail, *Colinus virginianus* (Fedak et al. 1974). This quail is in the same bodyweight range as the magpie (165–208 g), and since the magpie is well adapted to terrestrial locomotion it was assumed that the costs of walking and running ( $\dot{H}_W$  and  $\dot{H}_R$ , respectively) would be comparable in these two species.

Data for the costs of walking and running in man (Margaria et al. 1963) demonstrate that at a certain speed, running becomes less costly (per km) than walking, and at that speed there is a shift from walking to running. It was assumed for the quail that the shift from walking to running represented its slowest running speed on the treadmill (1.0 km h<sup>-1</sup>; Fedak et al. 1974). Whereas  $\dot{H}_R$  at various speeds is a linear relationship, data for man demonstrate that  $\dot{H}_W$  at various speeds is curvilinear (Margaria et al. 1963). Immediately following the onset of walking,  $\dot{H}_W$  increases rapidly as walking speed increases. This is followed by a range of speeds over which the increase in  $\dot{H}_W$  with increasing walking speed is more moderate than the initial rate. Following this there is a range of walking speeds over which  $\dot{H}_W$  increases very sharply until it intersects the line describing the relationship between  $\dot{H}_R$  and speed of running. This second very sharp increase in  $\dot{H}_W$  occurs at a speed that is approximately three-fourths that of the

slowest running speed. A second assumption, therefore, was that a similar sharp rise in the cost of walking would occur for the quail at a speed about three-fourths that of its slowest running speed ( $0.75 \times 1.0 \text{ km h}^{-1} = 0.75 \text{ km h}^{-1}$ ). In the field, walking speed for the magpie was unpredictable. It depended on what the bird was doing, and whether it was moving uphill, downhill, or on the level. Consequently, it was arbitrarily decided that on the average magpies walked at a speed of  $0.75 \text{ km h}^{-1}$ . Fedak et al. (1974) present no data for  $\dot{H}_W$  in the quail, and it was impossible to fit this assumed curvilinear relationship onto their graph relating oxygen consumption and the speed of running. Therefore, the line relating oxygen consumption and running speed for the Bobwhite was extrapolated to  $0.0 \text{ km h}^{-1}$ , and the oxygen consumption at a speed of  $0.75 \text{ km h}^{-1}$  was read directly off the extrapolated line. This yielded an energy equivalent of  $2.0 \times \dot{H}_b$ , and while this is undoubtedly an overestimate, it is the value used in this report to estimate the cost of walking for the magpie. Magpies rarely hopped, and when they did it was only for a few hops at a time; therefore, for simplicity, the cost of hopping ( $\dot{H}_H$ ) was considered to be equivalent to  $\dot{H}_W$ .

Magpies ran infrequently, and when they did it was only for a few seconds as they dashed at a food item. It was assumed that under these conditions the birds would probably be moving at a speed very close to that at which  $\dot{H}_R$  becomes less than  $\dot{H}_W$ , and that this is equivalent to the slowest running speed for the quail on a treadmill. From these assumptions we estimated an energy equivalent of  $2.15 \times \dot{H}_b$  for the cost of running.

*Flight.*—Bernstein et al. (1973) measured oxygen consumption during flapping flight in the Fish Crow, *Corvus ossifragus*. Depending on air speed, power output for level flight varied from 23 to 24.5 Watts. Basal metabolic rate for the Fish Crow, estimated from the Aschoff-Pohl (1970) equation for passerine birds at night, is 2.17 Watts. This indicates that level flight costs between 10.6 and  $11.3 \times \dot{H}_b$  for the Fish Crow. An average value of  $11.0 \times \dot{H}_b$  was used in estimating the cost of magpie flights lasting longer than three seconds ( $\dot{H}_{F1}$ ). This is in agreement with a value of  $11.1 \times \dot{H}_b$  as calculated using Kokshaysky's (1970) equation for predicting the power output of flight ( $P = 84.5m^{1.015}$ , where  $P$  is power output in  $\text{cal h}^{-1}$ , and  $m$  is body weight in grams), but is greater than the value of  $8.3 \times \dot{H}_b$  as calculated using Berger and Hart's (1974) equation ( $P = 0.29m^{0.72}$ , where  $P$  is power output in  $\text{kcal h}^{-1}$ ).

The metabolic cost for perching in the Fish Crow is 3.85 Watts (Bernstein et al. 1973). This is 1.65 times the Aschoff-Pohl estimate for  $\dot{H}_b$ , which agrees well with the estimate made above for the cost of active perching and standing ( $1.7 \times \dot{H}_b$ ).

The cost of predominantly gliding flight has been estimated for the Purple Martin, *Progne subis* ( $6.0 \times \dot{H}_b$ ; Utter and LeFebvre 1970), and the House Martin, *Delichon urbica* ( $4.8 \times \dot{H}_b$ ; Hails 1979). Since flights less than or equal to three seconds in duration by the magpie are primarily gliding flights, the value measured for the Purple Martin was used in estimating the cost of this type of flight ( $\dot{H}_{Fg}$ ). This agrees well with the  $6.34 \times \dot{H}_b$  cost measured for the Fish Crow flying at a  $6^\circ$  descent angle (Bernstein et al. 1973).

*Thermoregulatory requirements.*—Rubner (1910, from Ricklefs 1974) suggested that heat generated by specific dynamic action (SDA), production, and activity

could be used for temperature regulation. Available evidence would indicate that for muscular activity this is not always the case. Investigations of both birds (West and Hart 1966, Kontogiannis 1968, Pohl 1969, Pohl and West 1973) and small mammals (Hart 1952, 1957; Hart and Héroux 1955; Jansky 1959; Hart and Jansky 1963; Wunder 1970), indicate that work metabolism at low levels of activity is additive to resting metabolism over a very broad range of ambient temperatures. Partial substitution of heat from activity to cold-stimulated thermogenesis occurred in rats (Hart and Jansky 1963), white mice (Mount and Willmott 1967), and in *Clethrionomys glareolus* (Jansky 1959) acclimated to thermoneutral conditions. Hart (1960) and Jansky (1966) account for this by the assumption that the same muscle cannot be involved in two different activities; exercise replaces the shivering but not the nonshivering component of cold-stimulated thermogenesis. Mount and Willmott's (1967, from Hart 1971) data, however, suggest that their mice were using the same muscles for both locomotor activity and shivering; Pohl (1969) found partial substitution in Chaffinches, *Fringilla coelebs*, but its extent depended on the degree of cold stress and/or exercise level. Pohl and West (1973) found the heat of exercise almost totally substitutive for cold induced thermogenesis ( $-45^{\circ}\text{C}$ ) in the Common Redpoll, *Acanthis flammea*, during the fall, spring, and summer, but not winter. Wunder (1970) found partial substitution at low ambient temperatures during high but not low velocity treadmill running in the chipmunk *Eutamias merriami*. Pohl and West (1973) report on the basis of a personal communication with Berger and Hart that there is a total substitution of the heat of exercise for cold-induced thermogenesis in hovering hummingbirds. Nielsen (1938), and Nielsen and Nielsen (1962) report total substitution of exercise for thermoregulatory thermogenesis in man while Lefevre and Auguet (1933, 1934) report a partial substitution for man.

These various reports indicate that the relationship of activity to thermoregulatory thermogenesis depends on the species, its state of temperature acclimation, the season of the year, and the level of activity being performed. In this investigation, moderate activities such as standing, active perching, rest perching, walking, hopping, and running, were considered additive to thermoregulation, while flight was considered substitutive. Therefore, those hours during the day spent in flight when  $T_e$  was below the  $T_{lc}$ , were not included in calculations of diurnal thermoregulatory requirements.

Nocturnal energy requirements ( $\dot{H}_r$ ) at  $T_e$  below the  $T_{lc}$  were estimated from Eq. 8, which includes the thermoregulatory requirement. When  $T_e$  was above the  $T_{lc}$ ,  $\dot{H}_b$  alone was used in estimating the cost of roosting.

The specific dynamic action (SDA) of food can substitute for thermoregulatory requirements and the compensatory heat increment is greater for proteins than for carbohydrates and fats. Its effect, however, is influenced by the nutritional status and history of the animal (King and Farner 1961, Kleiber 1961, Whittow 1965, Romijn and Vreugdenhil 1969, Calder and King 1974, King 1974) and even where it has been measured in domestic animals, the substitution may be present, partial, or absent (Hart 1963). Calder and King (1974) caution, therefore, that while SDA is of ecological interest as a potential substitute for regulatory calorogenesis in wild birds "general statements about the ecological significance of the heat increment of feeding in birds are not yet appropriate." Because nothing is

known of the SDA for the magpie, and because of the apparent nonuniformity of response between species, no attempt was made to include its possible contribution in estimates of thermoregulatory requirements.

*Production costs.*—Molt and egg laying were the two kinds of production considered in this investigation. During molt, production goes into the formation of new feathers, and during egg laying into the formation of the clutch of eggs. Various studies have shown that the total daily intake of food during the molt may be the same as in nonmolting birds (Davis 1955) or only slightly increased (West 1960, 1968; Blackmore 1969; Chilgren 1975), suggesting a compensatory shift in the partitioning of energy expenditure, perhaps between activity and production. Within the thermoneutral zone molting increases oxygen consumption over the entire molt period by an average of 13%  $\dot{H}_b$  (King 1974). Since  $T_r$ 's during the magpie's molt were well within their thermoneutral zone, the cost of molt ( $\dot{H}_{pM}$ ) was estimated at 13% of their daily  $\dot{H}_b$ . More recently, King (In press) compared the cost of molt as estimated by several investigators using three different techniques (of which oxygen consumption was one) and found them to be in close agreement. From the average of these data, he (King, In press) estimated molt to account for about 15% of a caged sparrow's daily energy expenditure; this is in close agreement with the 13%  $\dot{H}_b$  used in this investigation.

Reviews by King (1973) and Ricklefs (1974) provide information concerning the cost of production during the reproductive period for both males and females. In males, the cost of gonadal recrudescence and maintenance is negligible, being less than 1% of the daily  $\dot{H}_b$ , but in females it may require about 10% of the daily  $\dot{H}_b$  during the period of maximum enlargement (King 1973). Sperm production by males may require about 0.8% of the daily  $\dot{H}_b$  and is, therefore, negligible (Ricklefs 1974). King (1973) estimated the cost of ovogenesis for three species with altricial young at 45 to 58%  $\dot{H}_b$ , while Ricklefs (1974) estimated it at 45 to 50%  $\dot{H}_b$ . This indicates that the only significant production cost during the reproductive period is ovogenesis ( $\dot{H}_{pO}$ ) and it was assigned an energy requirement of 45% of  $\dot{H}_b$ .

#### CALCULATION OF DAILY ENERGY EXPENDITURE

Daily energy expenditure ( $H_{TD}$ ) was calculated from Eq. 10,

$$H_{TD} = t_{AP}\dot{H}_{AP} + t_{FI}\dot{H}_{FI} + t_{FS}\dot{H}_{FS} + t_H\dot{H}_H + t_R\dot{H}_R + t_{RP}\dot{H}_{RP} + t_S\dot{H}_S \\ + t_W\dot{H}_W + t_i\dot{H}_i + t_{na}\dot{H}_{na} + t_r\dot{H}_r + t_t\dot{H}_t + t_{pM}\dot{H}_{pM} + t_{pO}\dot{H}_{pO} \quad (10)$$

where  $t$ 's are time and  $\dot{H}$ 's are the energy equivalents as described above. The subscript for each  $t$  defines the time associated with the energy equivalents for various activities (Tables 9 and 10), periods of thermoregulation (Table 13), and production costs (taken to be 24 hours).

#### STATISTICAL TREATMENT

The methods used in this study provided a single  $H_{TD}$  value for one composite day for each month. Statistical comparisons of  $H_{TD}$  between the days of different months were, therefore, not possible. However, it was possible to compare the intensity of daytime activity between composite days of different months.

During each period of visual contact, time spent on each activity was recorded, and the energy expended due to the various activities standardized to the period



TABLE 3  
SEASONAL AND DAILY VARIATION OBSERVED IN SIX METEOROLOGICAL VARIABLES

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

<sup>a</sup> Values for daytime only.

<sup>b</sup> Values for maximum and minimum measured 160 cm above the ground.

<sup>c</sup> 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