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.

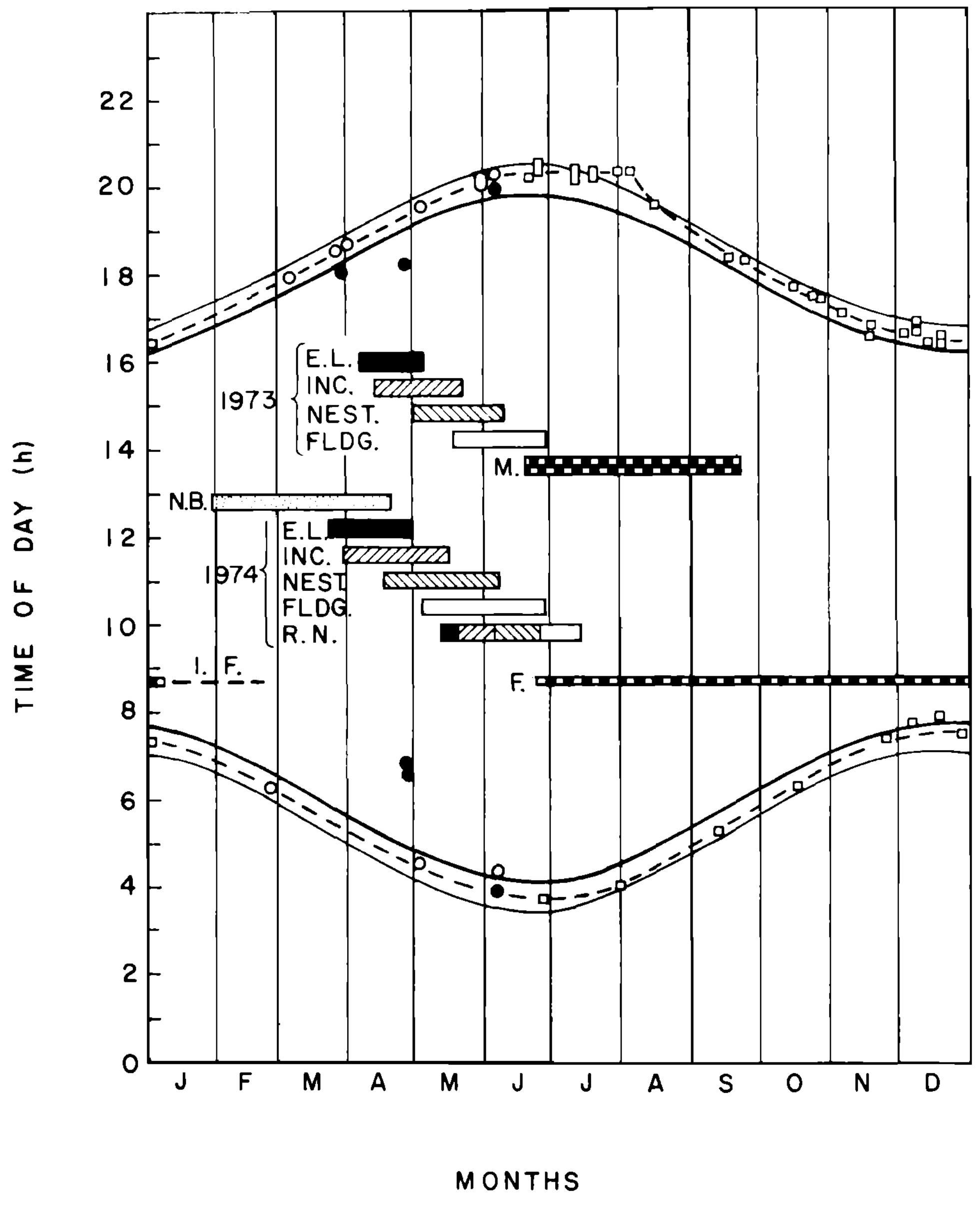

FIGURE 8. Annual cycle of Black-billed Magpies. Lengths of diurnal and nocturnal periods are plotted as a function of the time of year, with heavy solid lines representing daylength, and thin solid lines, civil twilight. Times of entering and leaving the roost are indicated by squares and rectangles during the nonreproductive period, and by open (for males) and closed (for females) circles and ovals during the reproductive period. Rectangles and ovals indicate times of extended activity within the roosting grove. The dashed line connecting these points at each end of the day describes the diurnal activity pattern over the annual cycle. Horizontal bars describe timing of various reproductive stages for both 1973 and 1974, duration of the molt, pattern of evening flocking, and intermittent flocking. N. B. = nest building; E. L. = egg-laying stage; INC. = incubation stage; NEST. = nestling stage; FLDG. = fledgling stage; R. N. = renesting (the pattern in this bar describes the chronology of the events from egg laying to fledging for the renesting effort); M. = molt; F. = evening flocking; I. F. = intermittent flocking.

The first eggs in the study area were found on 22 March, and the last new egg was discovered on 27 April. The length of the egg-laying period for a given bird depended on the size of the clutch. The hen usually laid an egg per day (in the morning) but sometimes (especially where large clutches were produced) skipped a day. The average clutch size (±SD) was 6.17 ± 1.29 ($n = 18$), with a range of 3–8. The female did not incubate the eggs during the day until the clutch was complete but she did roost within the nest dome, and so presumably incubated them at night during the laying period.

With the exception of the pair involved in renesting, the last adult-fledgling interactions, for any of the other pairs, were seen during the last week in June, and this signaled the end of five months of reproductive activity. The pair that renested after their first clutch was destroyed started their second clutch on 13 May, and the last interaction between fledglings and adults at this nest was observed on 14 July.

Reproduction 1973.—During May and June of 1973, nestlings from 16 of the 17 nests on the study area were weighed and banded. The ages of these nestlings at the time of banding were estimated, using nestling growth curves from the 1974 season. From this information and the average length of the various stages during the 1974 season, the history of each of these nests was reconstructed and the chronology of the 1973 reproductive period plotted on Figure 8. Using this technique it was determined that egg laying in 1973 started 6 April and ended 4 May.

According to this reconstruction, egg laying started 15 days earlier in 1974, but the end of the fledgling period was about the same for each year. This may indicate that, rather than 1974 being an earlier season, there was more synchrony in the reproductive effort of the population in 1973 than in 1974.

Because the ground has such potential as a source of thermal stress, it is not surprising that this primarily ground-foraging species has an early reproductive season. Linsdale (1937) reports for both the Yellow-billed Magpie, *Pica nuttalli,* and the Black-billed Magpie that the nesting season is completed by the time the daily average air temperature reaches 28°C. On this study area, egg laying began as early as 22 March, and in most nests feeding of the incubating female by the male, and nestlings by both sexes occurred during that part of the year when a large percentage of the days were cloudy to partly cloudy (Fig. 2). This minimized the period of the breeding season during which ground level T_e's would be high enough, at least during part of the day, to interfere with foraging and feeding of nestlings.

Molt.—Records of molt were kept on all free-living birds captured during 1973 and 1974, as well as on five captive birds during the summer and fall of 1974. Molt was first detected in the middle of June and was completed by the middle of September (Fig. 8). In the field the onset of molt closely followed the termination of the fledgling period, and since it involved the loss of the middle rectricies, it was first recognizable in unrestrained birds as a gap which gave them a V-shaped tail. Later, as middle rectrices were replaced and the outer retricies lost, adults had a short-tailed appearance. Since young of the year do not molt their rectricies, and have long tail feathers, they were easily distinguishable from adults at this time. Body molt was heaviest during the end of July, and the first part of August, and even in free-living birds it was common to see individuals with patches of bare skin on the head and neck. Flight feather and tail feather

TABLE 8

PHENOLOGICAL EVENTS, MONTHS, AND DATES OF BEHAVIORAL OBSERVATION OF BLACK-BILLED MAGPIES TOGETHER WITH AVERAGE LENGTH OF ACTIVE PERIODS, HOURS OF VISUAL CONTACT, AND PERCENT OF THE ACTIVE PERIOD IN VISUAL CONTACT FOR EACH COMPOSITE DAY

	Data collection				
Phenological events	Month	Days	Avg. length (h) active period	h visual contact	% active period in visual contact
Nonreproductive period					
Molt	July	14, 24, 25, 31	16.6	13.9	84.0
	Aug.	1, 3, 4, 15, 16	15.2	13.5	89.1
	Sept.	11, 12, 19	13.2	8.9	67.2
Nonmolt	Oct.	17, 18	11.5	8.6	75.2
	Nov.	9, 10, 13, 14	9.8	3.1	31.3
	Dec.	20, 19	8.9	5.7	64.5
Reproductive period					
Egg laying	Mar. (♀)	26, 28, 30	12.8	5.7	44.2
	Mar. (♂)	26, 27, 28, 29	13.2	17.2	130.0[a]
Incubation	Apr. (♀)	24, 25, 26	11.5	10.2	88.9
	May (♂)	1, 2, 4	15.1	11.5	76.0
Nestling	June (♀)	3, 6, 7	16.0	15.7	98.1
	June (♂)	6, 8	16.0	10.2	63.8

[a] Because of the great amount of overlap between sequential daily observation periods, and the ability to keep the bird in view virtually all the time, there are more hours of visual contact recorded for this bird than there are hours in the active period, yielding more than 100% visual contact.

replacement was essentially complete on about 1 September, while completion of the body molt (especially the legs) extended to the second half of September.

Flocking.—The nest territory was not defended from other magpies after the young birds fledged, and near the end of the fledgling period, birds of the year and adults flocked together in the late afternoon and went to roost together in a pine grove on the study area (Fig. 8). By late August, many of the young of the year had disappeared from the study area, but the remaining birds still formed an evening flock and roosted together with flocks from two other populations in a large sheltered hawthorn thicket at the southern end of the study area. This thicket was used as a communal roost through September.

From October to the middle of January the study population operated as a loose flock throughout the day and confined their activities to the southern third of the study area. In the evening, they joined the other two flocks, and roosted with them in the large well-sheltered fir grove.

After mid-January, and until the middle of nest building, the formation of the evening flock was less predictable (period of intermittent flocking, I. F., in Fig. 8) and during this time the population dispersed over the study area as pairs. If the weather during this interval was good, evening flocking often did not occur; and even if it did, the flock would disperse as paired birds went to roost near their potential nest sites. On very stormy days, however, the paired birds formed a flock near the sheltered fir grove (often in the company of the other two populations) and roosted there as they had done earlier. From about the last half of nest building to the end of the fledgling period, flocking did not occur.

TABLE 9

DAILY TIME BUDGET OF BLACK-BILLED MAGPIES DURING NONREPRODUCTIVE MONTHS[a]

		Number of hours					
Bout	Activity	July	Aug.	Sept.	Oct.	Nov.	Dec.
Nocturnal							
Bush	Roosting	7.49	8.80	10.80	12.50	14.20	15.10
Diurnal							
Ground	Walk	2.62	2.61	1.66	1.64	1.74	1.58
	Stand	4.33	3.82	4.36	2.85	3.30	2.78
	Run	0.03	0.12	—	0.02	—	—
	Bout total	6.98	6.55	6.02	4.51	5.04	4.36
FTPR	Hop	0.003	0.12	0.001	0.01	0.10	—
	Perch (alert)	2.57	0.71	1.00	1.28	0.94	0.37
	Bout total	2.573	0.83	1.001	1.29	1.04	0.37
Bush	Hop	0.027	0.03	0.003	0.01	0.15	0.13
	Perch (alert)	1.23	1.58	1.48	2.51	2.09	2.33
	Perch (rest)	5.31	5.90	4.08	1.96	—	—
	Bout total	6.57	7.51	5.56	4.48	2.24	2.46
Air	Flights ≤3 sec.	0.01	0.05	0.08	0.13	0.01	0.24
	Flights >3 sec.	0.38	0.26	0.54	1.09	1.47	1.47
	Bout total	0.39	0.31	0.62	1.22	1.48	1.71
Total time		24.00	24.00	24.00	24.00	24.00	24.00

[a] Male and female time budgets are considered to be the same during these months.

DAILY TIME-ACTIVITY BUDGET

Table 8 summarizes, by month, the dates of behavioral observation. The resulting time-activity budgets for the months of March through December are given in Tables 9 and 10 for nonreproductive and reproductive periods, respectively. The time spent performing each type of activity within each Bout, as well as the total time spent in performance of each Bout, are summarized for each composite day. The tables are divided into nocturnal and diurnal periods representing the inactive and active portions of each day, respectively.

Activity at night was confined to roosting in Bush Bouts, while during the day all other Bouts and activities were performed. Examination of the time spent in performance of each type of activity within Bush, FTPR, and Ground Bouts reveals that most time was spent performing activities requiring the lowest level of energy expenditure (perching, standing, and roosting). However, in Air Bouts, which represent the highest level of energy expenditure, more time was spent in level flapping flight than in the less expensive gliding flight. Comparison of males and females during the reproductive period shows that females spent more time than males performing activities associated with low levels of energy expenditure, and females had shorter activity periods than males during egg laying and incubation. Time devoted to various Bouts during the daytime for each composite day is shown in Figure 9.

Ground Bouts.—Except for the incubating female, who spent only about 0.3 hours per day on the ground, the least amount of time spent in Ground Bouts

TABLE 10
DAILY TIME BUDGET OF BLACK-BILLED MAGPIES DURING VARIOUS REPRODUCTIVE STAGES

		Number of hours					
		Egg laying		Incubation		Nestling	
Bout	Activity	Female	Male	Female	Male	Female	Male
Nocturnal							
Bush	Roosting	11.24[a]	10.82	12.55[b]	8.90	8.00	8.00
Diurnal							
Ground	Walk	0.47	0.90	0.05	3.90	1.02	2.62
	Stand	1.95	2.90	0.31	4.74	2.82	5.04
	Run	0.08	—	—	0.01	0.02	0.02
	Bout total	2.50	3.80	0.36	8.65	3.86	7.68
FTPR	Hop	—	0.001	—	0.02	0.05	0.02
	Perch	0.19	0.18	0.68	1.45	2.14	2.80
	Bout total	0.19	0.181	0.68	1.47	2.19	2.82
Bush	Hop	0.17	0.08	0.03	0.15	0.18	0.16
	Perch (alert)	8.50	8.84	0.32	2.98	3.58	2.88
	Perch (rest)	—	—	—	0.71	3.15	—
	Laying or incubating	1.22	—	9.96	—	—	—
	Attending nest	—	—	—	0.21	2.11	0.88
	Bout total	9.89	8.92	10.31	4.05	9.02	3.92
Air	Flights ≤3 sec.	0.03	0.06	0.02	0.08	0.24	0.19
	Flights >3 sec.	0.15	0.22	0.08	0.85	0.69	1.39
	Bout total	0.18	0.28	0.10	0.93	0.93	1.58
Total time		24.00	24.00	24.00	24.00	24.00	24.00

[a] The female went to roost earlier and left the roost later than the male, giving her a longer roosting period.

[b] The female left the nest for the first time after sunrise, and made her last short exit from the nest long before sunset.

occurred during the egg-laying phase in both the male and female members of a pair. Males tending incubating females and nestlings spent the most time in Ground Bouts. From July to October the time spent in Ground Bouts decreased, and then remained fairly constant from October through December.

Air Bouts.—The amount of time spent in Air Bouts varied from a low of 0.1 hour per day for an incubating female to a high of 1.70 for birds in December. Other low values occurred in both males and females during egg laying, and in molting birds in July and August. Males tending incubating females and nestlings and females tending nestlings spent relatively large amounts of time in flight. October, November, and December were the only months during the nonreproductive period when more than an hour per day was spent on Air Bouts.

FTPR Bouts.—The amount of time spent per day in FTPR Bouts varied during the year from 0.18 to 2.82 hours per day. The shortest times occurred during the egg laying phase for both females and males, and the longest times (longer than two hours per day) during July, and the nestling stage. In September, October, and November, and for the male attending the female during incubation, FTPR Bouts accounted for intermediate amounts of time, while during August and December and for the incubating female they accounted for relatively shorter periods of time.

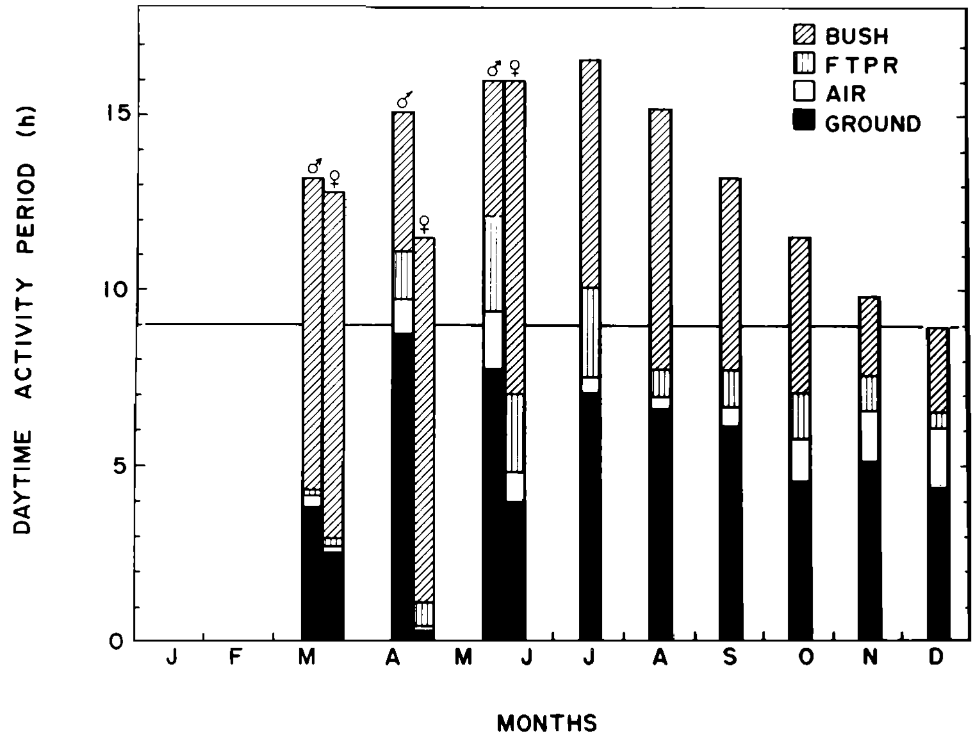

FIGURE 9. Diurnal activity pattern of Black-billed Magpies for composite days of each reproductive stage and nonreproductive month. Length of each vertical bar represents length of the active period, while pattern of shading within each bar shows time spent on each type of Bout. Vertical bars for reproductive stages (from left to right: egg laying, incubation, and late nestling stages) are paired with each pair of bars representing activities of a different nesting pair. Single vertical bars represent the nonreproductive period, with each bar showing the activity of both males and females. The solid horizontal line represents the number of hours in the shortest composite day (December) and provides a reference point for visualizing the effect on activity of increasing daylength.

Bush Bouts.—The amount of time spent in Bush Bouts varied from 2.24 to 10.31 hours per daytime period. Incubating females and egg-laying females spent the most time in Bush Bouts, followed by females with nestlings and the male of a pair during egg laying. The male tending an incubating female and the male tending nestlings spent about the same amounts of time in Bush Bouts. Time spent in Bush Bouts increased from July to August and then declined through September and October to the lowest values during November and December.

METABOLIC COST OF ACTIVITY

The activities performed during each period of visual contact were converted into energy expenditure, using the appropriate energy equivalents (Table 2) for each activity. These were then standardized as the per-hour metabolic cost of activity (kJ h^{-1}), divided by $\dot{H}_b$, and plotted in Figure 10 as a multiple of $\dot{H}_b$. During the course of the year these multiples varied from 1.2 to 4.6 × $\dot{H}_b$. The means for the various composite days varied from 1.35 to 3.07 × $\dot{H}_b$. Means less

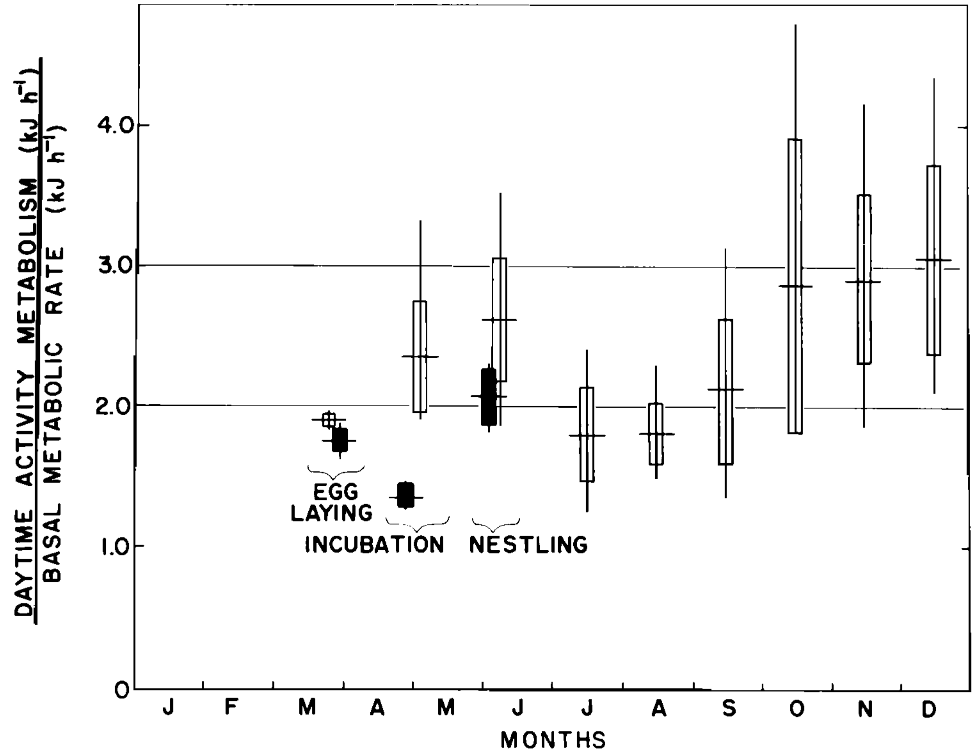

FIGURE 10. Change by months in the ratio of hourly metabolic cost of activity (kJ h^{-1}) to hourly cost of basal metabolism (kJ h^{-1}) of Black-billed Magpies. Vertical lines represent the range of values calculated for the various periods of visual contact, and horizontal lines, means for the composite days. Rectangle around means represent one standard deviation of the mean. For reproductive stages, open rectangles represent males, shaded rectangles, females.

than 2.0 × $\dot{H}_b$ are evident for both males and females during the egg-laying phase, females during incubation, and both sexes during July and August. These low means correspond to periods of productivity (egg laying for the females, and heaviest molt period for both sexes). Means greater than 2.0 × $\dot{H}_b$ occurred at times of the year when locomotor activity was high (the male tending the incubating female, males tending nestlings, and both sexes from October through December). Paired *t*-tests between composite days were performed to determine if there were statistically significant differences in the mean cost of activity (0.05 level). The data and results of these calculations are in Appendix Tables A-1 and A-2, and all references of significance or lack of it in the following comparisons can be checked there.

Reproductive period.—During the reproductive period males showed an increase in the per-hour cost of activity as they progressed through the various stages. The males during egg laying (1.89 × $\dot{H}_b$) had a significantly lower per-hour cost of activity than males during either incubating (2.35 × $\dot{H}_b$) or nestling (2.62 × $\dot{H}_b$) stages, but there was no significant difference between incubating and nestling stage males.

The female during incubation (1.35 × $\dot{H}_b$) had a significantly lower per-hour cost of activity than during either egg-laying (1.75 × $\dot{H}_b$) or nestling (2.06 ×

$\dot{H}_b$) stages, and the egg-laying stage was significantly lower than the nestling stage.

At all stages of reproduction, males expended significantly more energy per hour on activity than females.

Nonreproductive period.—Males and females were assumed to have performed the same bouts and activities from July through December, but because males are significantly heavier than females (Table 4), they will expend more total energy than females. Paired t-tests of the weight-specific metabolic cost of activity for both males and females during each month of this period showed that with the exception of August ($.02 > P$), the values for males were not significantly greater than those for females. In addition, the ratio of activity metabolism to $\dot{H}_b$ was the same for both sexes during these months, and comparisons between ratios should therefore hold for either sex. The means of the ratios for these months formed two distinct groups: July, August, and September (JAS); and October, November, and December (OND).

The metabolic cost of activity during July ($1.79 \times \dot{H}_b$), August ($1.79 \times \dot{H}_b$), and September ($2.11 \times \dot{H}_b$) was low. The per-hour cost of activity for September was significantly higher than for July and August, but there was no difference between the means for July and August. There was no significant difference between the high means for October ($2.86 \times \dot{H}_b$), November ($2.90 \times \dot{H}_b$), or December ($3.07 \times \dot{H}_b$) birds. The OND birds all expended significantly more energy per hour on activity than JAS birds.

Reproductive stage males compared with JAS and OND males.—The nestling stage male had a significantly higher per-hour cost of activity than males in July, August, and September. The incubating stage male had a significantly higher per-hour cost of activity than July and August but not September males. There was no significant difference between the male during egg laying and the JAS males. There is for males, therefore, a significant increase in the per-hour expenditure of energy on activity after the eggs are laid, followed by a significant drop after the nestling stage. It remained low through July and August, and then increased during September to levels comparable to the nestling and incubating stages.

The nestling stage male had a significantly lower cost of activity than did the December male but not October or November males. The incubating stage male had a significantly lower cost of activity than November and December but not October males, and the egg-laying-stage male was significantly lower than OND males. The greatest expenditure of energy by males for activity occurred during the incubating and nestling stages of the reproductive period and during October, November, and December of the nonreproductive period.

Reproductive stage females compared with JAS and OND females.—The nestling stage female had a significantly higher per-hour cost of activity than August females, but not July or September females. The incubating female had a significantly lower per hour cost of activity than any JAS female, but no difference was seen between egg-laying females and JAS females. With the exception of incubation, therefore, there was little change in the expenditure of energy by females for activity from the time egg laying started through September. This contrasted sharply with the pattern seen in the male during that same period.

With the exception of the nestling stage and October females, OND females expended significantly more energy on activity than females at any other time.

TABLE 11

DAILY ENERGY EXPENDITURE (kJ day^{-1}) OF BLACK-BILLED MAGPIES DURING NONREPRODUCTIVE MONTHS

		July		Aug.		Sept.		Oct.		Nov.		Dec.	
Bout	Activity	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
Nocturnal													
Bush	Roosting	41.9	47.2	49.3	55.4	60.5	68.0	70.0	78.8	79.5	89.5	84.6	95.1
Diurnal													
Ground	Walk	29.3	33.0	29.2	32.9	18.6	20.9	18.4	20.7	19.5	21.9	17.7	19.9
	Stand	41.1	46.3	36.3	40.9	41.4	46.7	27.1	30.5	31.4	35.3	26.4	29.8
	Run	0.4	0.4	1.5	1.6	—	—	0.2	0.2	—	—	—	—
	Bout total	78.8	79.7	67.0	75.4	60.0	67.6	45.7	51.4	50.9	57.2	44.1	49.7
FTPR	Hop	0.03	0.03	1.3	1.5	0.01	0.01	0.1	0.1	1.7	1.9	—	—
	Perch (alert)	24.4	27.5	6.8	7.6	9.5	10.7	12.2	13.7	8.9	10.1	3.5	4.0
	Bout total	24.43	27.53	8.1	9.1	9.51	10.71	12.3	13.8	10.6	12.0	3.5	4.0
Bush	Hop	0.3	0.3	0.3	0.3	0.03	0.04	0.1	0.1	1.7	1.9	1.5	1.6
	Perch (alert)	11.7	13.6	15.0	16.9	14.1	15.8	23.9	26.9	19.9	22.4	22.1	24.9
	Perch (rest)	37.2	42.5	41.3	47.2	29.0	32.6	13.9	15.7	—	—	—	—
	Bout total	49.2	56.4	56.6	64.4	43.13	48.44	37.9	42.7	21.6	24.3	23.6	26.5
Air	Flights ≤3 sec.	0.3	0.4	1.7	1.9	2.7	3.0	4.4	4.9	0.3	0.4	8.1	9.1
	Flights >3 sec.	23.4	26.3	16.0	18.0	33.3	37.4	67.1	75.5	90.6	101.9	90.6	101.9
	Bout total	23.7	26.7	17.7	19.9	36.0	40.4	71.5	80.4	90.9	102.3	98.7	111.0
Production													
Molt		18.0	20.0	18.0	20.0	18.00	20.00	—	—	—	—	—	—
Thermoregulation													
Nocturnal		—	—	—	—	—	—	3.8	4.2	9.6	10.7	9.8	10.1
Diurnal													
Clear day		—	—	—	—	—	—	—	—	1.3	1.4	1.1	1.2
Cloudy day		—	—	—	—	—	—	—	—	1.1	1.2	2.7	3.0
Total daily energy													
Clear day		228.0	257.5	216.7	244.2	226.7	255.1	241.2	271.3	263.8	296.7	265.4	297.6
× H_{db}		1.70	1.70	1.61	1.61	1.69	1.69	1.75	1.75	1.96	1.96	1.97	1.97
Cloudy day		—	—	—	—	—	—	—	—	263.6	296.5	267.0	299.4
× H_{db}		—	—	—	—	—	—	—	—	1.96	1.96	1.99	1.98

TABLE 12

Daily Energy Expenditure (jK day^{-1}) of Black-billed Magpies During Various Reproductive Stages

Bout	Activity	Egg laying[a]		Incubation[b]		Nestling[c]	
		♀	♂	♀	♂	♀	♂
Nocturnal							
Bush	Roosting	62.9	68.2	70.2	56.1	44.8	50.4
Diurnal							
Ground	Walk	5.3	11.3	0.6	49.1	11.4	33.0
	Stand	18.5	31.0	3.0	47.8	26.8	53.9
	Run	1.0	—	—	0.01	0.2	0.3
	Bout total	24.8	42.3	3.6	96.91	38.4	87.2
FTPR	Hop	—	0.01	—	0.3	0.6	0.3
	Perch (alert)	1.8	1.9	6.5	15.5	20.3	30.0
	Bout total	1.8	1.91	6.5	15.8	20.9	30.3
Bush	Hop	1.9	1.0	0.3	1.9	2.0	2.0
	Perch (alert)	80.8	94.6	3.0	30.9	34.0	30.8
	Perch (rest)	—	—	—	5.7	22.4	—
	Laying or incubating	8.5	—	69.7	—	—	—
	Attending nest	—	—	—	2.5	21.9	10.3
	Bout total	91.2	95.6	73.0	41.0	80.3	43.1
Air	Flights $\leq$3 sec.	1.0	2.3	0.7	3.0	8.1	7.2
	Flights >3 sec.	9.2	15.3	4.9	58.9	42.5	96.3
	Bout total	10.2	17.6	5.6	61.9	50.6	103.5
Production							
Egg laying		60.0	—	—	—	—	—
Thermoregulation							
Nocturnal		6.5	6.9	2.9	3.3	—	—
Diurnal							
Clear day		0.3	0.3	—	—	—	—
Cloudy day		3.4	3.7	—	—	—	—
Total daily energy							
Clear day		257.7	232.8	161.6	275.0	235.0	314.5
× H_{db}		1.91	1.54	1.20	1.82	1.75	2.08
Cloudy day		260.8	236.2	—	—	—	—
× H_{db}		1.94	1.56	—	—	—	—

[a] Late March.
[b] Late April, early May.
[c] Early June.

The per-hour expenditure of energy on activity by females was, therefore, greatest during the winter months.

Total Daily Energy Expenditure

The estimated energy budgets are given for each composite day in Tables 11 and 12 for nonreproductive and reproductive months, respectively. From July through December, activity was assumed to be the same for both sexes. The separation of males and females in Table 11, therefore, was on the basis of males

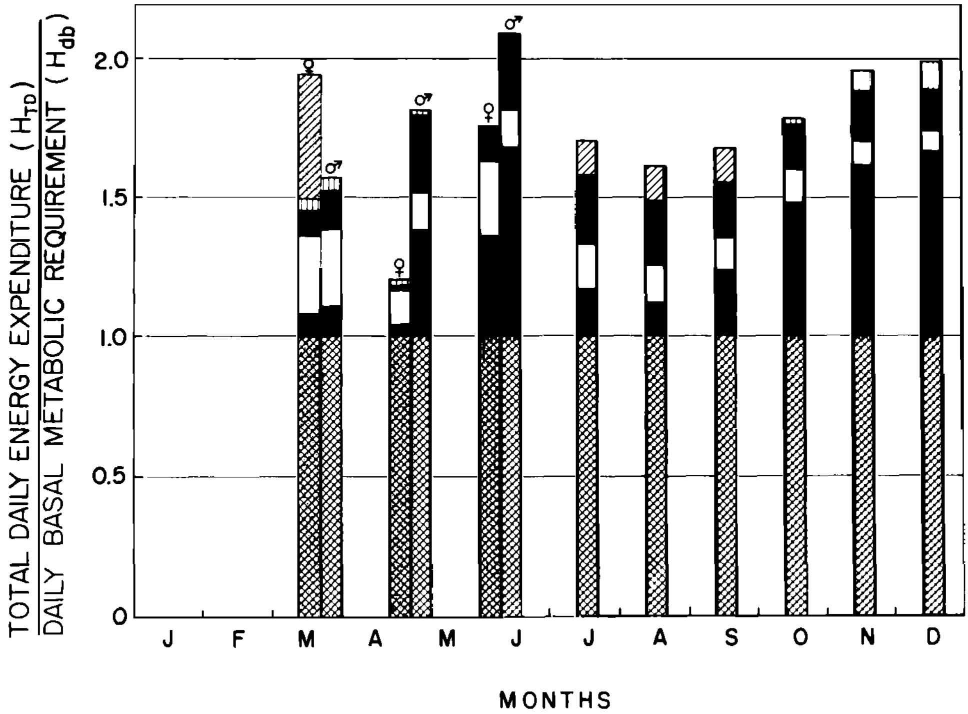

FIGURE 11. Ratio of total daily energy expenditure to daily basal metabolic requirement of Black-billed Magpies for composite days of each reproductive stage and nonreproductive month. The length of each bar represents total daily energy expenditure. Bars for reproductive stages (from left to right: egg laying, incubation, and nestling stages) are paired, with each pair of bars representing the activities of a different nesting pair. The pattern of shading within each bar delineates various major energy demands making up the total daily energy expenditure. Production (ovogenesis and molt) is represented by right-handed hatching, thermoregulation by vertical hatching, activity by the solid-open-solid segment (lower solid segment, Air Bouts; open segment, Bush + FTPR Bouts; upper solid segment, Ground Bouts), and daily basal metabolic requirement by crosshatching.

being heavier and having a higher total basal metabolic requirement than females. During the reproductive period (Table 12), however, the separation of males and females was based on the observed differences in activity between sexes. With the exception of the costs of individual activities the daily energy values were summarized, for ease of comparison, as a multiple of total daily basal metabolism ($\dot{H}_b \times 24$ hours $= H_{db}$) in Figure 11.

H_{TD} was not constant through the year but varied in response to behavioral and seasonal demands. Figure 11 emphasizes the point that, with the exception of the cost of egg production, most of the annual variation (1.20 to 2.08 × H_{db}) in H_{TD} was due to variation in energy expended in diurnal activity. The lowest H_{TD} occurred in the incubating female (1.2 × H_{db}). Levels of energy expenditure around 1.5 × H_{db} occurred in the male during egg laying, and birds during the period of molt. The highest levels of energy expenditure (1.75 to 2.08 × H_{db}) were estimated for the egg-laying female, the male tending the incubating female, the male and female tending nestlings, and birds during the OND period. Within that portion of the H_{TD} related to diurnal activity, the cost of Air Bouts fluctuated the most during the course of the year (Tables 11 and 12; Fig. 11), indicating that the total cost of activity, and consequently most of the observed variation in H_{TD}, was regulated to a large degree by the amount of time spent in flight.

The time budget data indicated that magpies spent the most time within a Bout (with the exception of Air Bouts) performing activities having low levels of energy expenditure (Tables 9 and 10). Examination of Tables 11 and 12 shows that these activities also accounted for the largest portion of the total energy cost of the Bout. In Air Bouts, the most time, and hence energy, were spent in the more expensive level flapping flight. Therefore, cost of all but Air Bouts was determined largely by the least expensive activity being performed for the longest period of time.

The amount of energy expended on any type of Bout was related not only to the activities performed within the Bout, but also to the time spent performing the Bout. Therefore, as the behavioral requirements of an individual changed during the annual cycle, so did the emphasis as to the amount of time and energy spent in performance of the various Bouts. For example, during the reproductive period the female spent most of her time and energy in performance of Bush Bouts, while the male (with the exception of the egg-laying stage) spent most of his time and energy in the performance of Ground and Air Bouts, reflecting his behavioral role as primary food gatherer for the reproductive effort, and hers as the primary attendant of the eggs and young.

The daily production costs associated with molting were moderate, comprising about 8% of the H_{TD}. Those associated with ovogenesis were much higher and accounted for about 23% of the female's H_{TD}.

Thermoregulatory costs for $T_e > 35°C$ were not estimated because the birds either avoided those thermal steps, or shuttled between them and those with $T_e < 35°C$, to eliminate or minimize the need for evaporative cooling (Fig. 4). Consequently, the thermoregulatory requirement added into the H_{TD} was that associated with the cost of increased heat production at $T_e < 5°C$. National Weather Service data from the Palouse Conservation Field Station (4 miles northwest of the study area) and calculated T_e's (Mugaas 1976) were used in obtaining temperatures (T_e's) and times (t) needed to calculate thermoregulatory costs. The percentage of days for each month having no thermoregulatory requirement (daily minimum $T_a \geqslant 5°C$), a minimal thermoregulatory requirement (daily minimum $T_a < 5°C$, but daily average $T_a \geqslant 5°C$), and an absolute thermoregulatory requirement (daily average $T_a < 5°C$) are given in Figure 12. Thermostatic costs were calculated only for those days having an absolute thermoregulatory requirement. The thermal analysis showed that nighttime T_a's approximated roosting T_e's (Mugaas 1976); therefore, the nocturnal thermoregulatory requirement was calculated by substituting the mean nighttime T_a for T_e in Eq. 9 and multiplying this result by the length of the nocturnal inactive period. For diurnal periods the daily progression of T_e (Mugaas 1976) was used in estimating the approximate number of hours that T_e would be below T_{lc}, and the average T_e for those hours on both clear and cloudy days. Table 13 summarizes the number of hours per composite day having an absolute thermoregulatory requirement and the average T_e for that interval. To insure that the largest possible thermoregulatory cost would be calculated for each composite day, the information in Table 13 represents the coldest day recorded for the appropriate time interval.

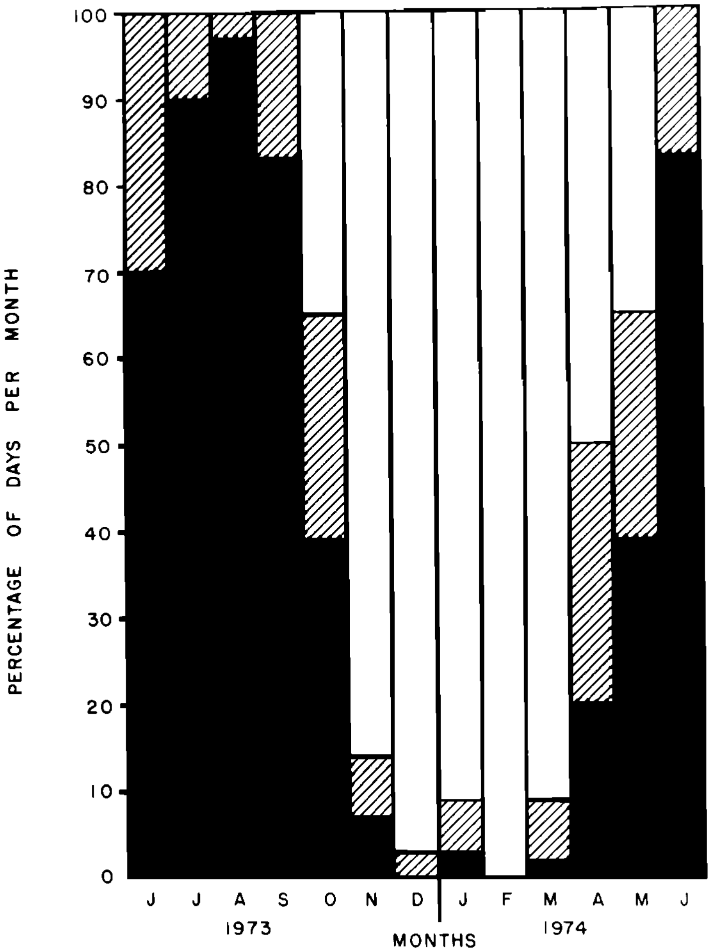

FIGURE 12. Variation by month in thermoregulatory requirement of Black-billed Magpies. Shaded area, no thermoregulatory requirement; hatched area, minimal thermoregulatory requirement; and clear area, absolute thermoregulatory requirement.

Even by selecting only the coldest days, the thermoregulatory contribution (Table 13) for any one composite day was small (1.7 to 4.4% of H_{TD}; Tables 11 and 12; Fig. 11). January had a two-week cold spell when on a typical night T_e averaged −19.4°C for 15 hours, and during a typical daytime period there was a 3.2-hour span when T_e averaged −7°C (see Fig. 5). No behavioral data were gathered during these cold days, but if the activity level remained the same as for the December birds, the thermoregulatory requirement would have comprised about 17% of H_{TD}. During the remainder of the winter, however, with its milder temperatures, thermoregulation was not a large component of the magpie's daily energy expenditure.

DISCUSSION

The microclimates of the study area imposed only small or negligible thermoregulatory requirements (Table 13), and food never appeared to be in short sup-