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INFLUENCE OF ROOST SITE SELECTION ON THE ENERGETIC EFFICIENCY AND DISTRIBUTION OF STARLINGS AND BLACKBIRDS: A WAY OF CONTROLLING BLACKBIRD POPULATIONS NEAR AIRPORTS

Sheldon Lustick
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In an effort to ascertain the energetic savings realized by blackbirds utilizing various roost sites and to compare the thermoregulatory benefits afforded by different types of roosts, this study utilized data on the metabolic rates of blackbirds and starlings with forced convection. Measurements of the percent cover and the wind velocity in several roost types were used to compare and contrast the energetic requirements of blackbirds and starlings utilizing these types of roost sites at night during the winter. (continued)

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Energy budgets were calculated for all groups of birds in various roost types from values for net radiation exchange and metabolic rates with forced convection. The calculated metabolic rates of all species tested except the starling exceed their peak metabolic capabilities at -10°C in the open and in a deciduous roost with 18% cover. In the pine roost (75 to 96% cover) calculated metabolic rates were below peak metabolic capabilities for all birds except the female redwing blackbird.

Habitat manipulation by thinning was suggested as a possible control method for blackbirds and starlings. This would increase net radiative and convective heat loss such that it would no longer be thermally advantageous to use that roost to alleviate energetic stress.

INFLUENCE OF ROOST SITE SELECTION ON THE ENERGETIC EFFICIENCY AND DISTRIBUTION OF STARLINGS AND BLACKBIRDS: A WAY OF CONTROLLING BLACKBRID POPULATIONS NEAR AIRPORTS

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INTRODUCTION

To augment their physiological and physical thermoregulatory capacity, many birds display long-term behavioral adjustments; the significance of this has been considered, yet detailed information is lacking (Dawson and Hudson 1970; Calder and King 1974). One such behavioral adjustment appears to be communal roosting in sheltered areas during winter nights. This behavior has been demonstrated in nuthatches (Sitta spp.) (Knorr 1957), finches (Leucosticte spp.) (French 1959; King and Wales 1964), eastern bluebirds (Siala sialis) (Frazier and Nolan 1959), red-winged blackbirds (Agelaius phoeniceus), brown headed cowbirds (Molothrus ater), bronzed grackles (Quiscalus quiscula) (Francis 1976), and starlings (Sturnus vulgaris) (Francis 1976; Yom-Tov et al. 1977). Congregating in sheltered roost sites must alter some of those environmental factors which comprise the thermal climate space (Porter and Gates 1969) of the organism and in doing so, confer an energetic advantage upon the inhabitants.

To further quantify the energetic advantage of the starling's nocturnal roose site selection in a dense coniferous pine woods, this study was undertaken to determine: (1) what microclimate factors distinguish areas of the pine woods selected as nocturnal roost sites from those that are not and (2) what is the energetic advantage of roost site selection and is this advantage dependent upon large roosting concentrations of birds.

MATERIALS AND METHODS

Study Area

To answer these questions field data were collected during the winter 15 December - 21 March in a 1.5 km^2 pine woods (Pinus strobus) located 0.6 km north of Rathbone, Delaware County, Ohio. Trees within the pine woods averaged 9.3 m in height, 3.1 m apart in rows 4.6 m apart. During the winter, this pine woods housed a large communal roosting flock, the size of which was estimated to be between 0.5 and 1.0 million birds. A detailed census of birds roosting in the pine plantation was not undertaken. From direct observations of the evening entry of birds into the woods and by mist netting operations, the species composition of the roosting flock was estimated to be 85% starlings, 5% red-winged blackbirds, and 10% other species, such as robins (Turdus migratorius), cowbirds, and grackles.

Roost Site Observations

Microhabitats within the pine woods selected by starlings as nocturnal roost sites were determined by observing where individuals settled upon their evening entry and by noting amounts of excreta on trees and forest floor. To determine vertical positioning of birds, we constructed an observation shelter within the roost. Birds were viewed after dark with the air of a flashlight and infrared spotting scope (Varo Inc., model 9902 E'A) and a starlight scope.

Micrometerology

Four micrometeorological parameters were measured and comparisons between the roost site and areas immediately outside the pine woods were made. Air temperatures were recorded with thermocouples connected to a Bailey Instruments, model Bat Four. Relative humidities were measured with an electric hygrometer (Hygordynamics Inc., model 15-3030E). Wind velocities were recorded with a hand-held, three cup anemometer (starting speed 0.15 mps; Central Scientific Co., model 13B-1064) and a hotwire anemometer (Datametrics, model 800Vtp). Bird and environmental surface temperatures were measured with an infrared thermometer (minimum target diameter 3.8 cm; Mikron Instruments Co., model 44), the accuracy of which was verified by comparing surface temperature readings with the Bat Four thermometer.

Vertical temperature gradients within the roost were obtained by placing thermocouples at 0.0, 2.2, 3.7, 4.4, and 6.1 m above the forest floor in a centrally located tree. Temperature differences between the roost site and outside of the pine woods were obtained by additional temperature recordings at 2.2 m in a field located upwind of the pine woods. Horizontal and vertical wind velocity profiles were obtained at the same sampling sites, except that vertical measurements within the roost sites were taken at 0.0, 15., 2.2, 4.7, 6.1 and 7.5 m above the forest floor. Measurements of relative humidities, which were subsequently converted to ambient water vapor pressures, were made at 2.2 m at the previously described sampling sites. These data were collected hourly on nights varying in both air temperature and wind velocity.

To establish the radiant environment, surface temperatures of sky, trees, and ground were measured. In addition, surface temperatures of five starlings (tethered to a hardware cloth platform on tree branches and allowed to settle for at least 30 min) were measured. Birds were placed in precisely the location in which individuals had roosted during clear cold nights. Tethering prohibited flight but allowed for postural changes. Simultaneous to measuring surface temperatures, cloacal temperatures of one of the birds was telemetrically monitored with a temperature sensitive radio transmitter (Mini-Mitter Co., Inc., model L-PM) in conjunction with a portable receiver (Lafayetter Radio Electronics Corps., model HA-420). In a similar manner, microclimatic data and surface and cloacal temperatures of tethered starlings were recorded in an adjacent open field.

To calculate radiation exchange, estimates of that percentage of a bird's surface exposed to the night sky and that percentage exposed to the coniferous microhabitat were necessary. To this end, measurements of the vegetation cover by use of a hemispherical fish-eye lens were made. Hemispherical photographs were taken by pointing the camera in an upward direction at different heights above the ground. Percent cover is then obtained by super imposing a standard grid on the photographs as described by Anderson (1964).

Through hemispherical photography it was estimated that the coniferous, trees shielded 75% of the birds dorsal surface from the night sky. Incident nocturnal long wave radiation was measured with a net radiometer with a unidirectional attachment (Swissteco Pyt. Ltd., type S-1).

Experimental Animals

Thirty starlings were mist netted during January and February at the roost site. Animals were housed in individual cages in a walk-in environmental chamber (Scheer-Gillet, model 810). Birds were kept at ambient temperatures ranging from 5.0 to -10.0 C on natural photoperiods and were provided turkey pellets (Ralston Purina Co.) and water *ad libitum*. Birds were in the laboratory for at least 1 week prior to any metabolic rate determinations.

Oxygen Consumption

Metabolic rates (oxygen consumption) of 30 starlings were measured at three temperatures (-10.0, 0.0, 5.0 C) and at four wind velocities (0.0, 2.9, 7.3, 15 km h^{-1}). Oxygen consumption was measured in an open circuit system connected to an oxygen analyzer (Beckman Instruments Inc., model EUW-20A). A plexiglass tunnel equipped with a fan connected to a variable speed transformer, described by Neal (1976), was the respiration chamber. Desired chamber temperatures (± 1.0 C) were maintained by placing the apparatus in the walk-in environmental chamber. Water vapor pressure within the respiration chamber was not controlled during metabolic rate determinations.

Oxygen consumption was measured in darkness during 1800-2400 h on birds that have been fasted at least 2 h. Values were taken only after birds had maintained a steady state for 20-30 min. Having recorded the steady state value, I dimly lit the environmental chamber to observe behavioral reactions of birds to wind. After each oxygen consumption determination, except at the 5.0 C test temperature, the cloacal temperature of the bird was measured with a telethermometer (Yellow Springs Instruments, model 428C).

Statistics

Paired t-tests were used to compare temporally comparable microclimate data. Non-paired data were tested with the Student's t-test. The Jonckheere test was used with ordered alternatives when data fitted the one-way layout construct (Hollander and Wolfe 1973). A test devised by Skillings and Wolfe (1976) was used to test for ordered alternatives in block design experiments. Kendall's test was used to calculate correlations of microclimate data. Regression and correlation analyses of metabolism data were also used. All statistical analyses were performed at the 0.05 significance level.

RESULTS

Roost Site Observations

Differential use of certain areas in the pine woods for nocturnal roosting sites was displayed by starlings throughout winter. Initially (Dec. 1-9), roosting was vertically and horizontally homogeneous throughout the pine woods. By mid-December, however, roost site selection, which would last the duration of the winter, shifted from the periphery to the center of the woods. Roost site selection was refined as birds generally roosted between 1 and 4 m above the ground on windy and/or clear nights and between 1 and 9 m on cloudy, windless nights. At all times birds roosted beyond bodily contact distance from each other.

Micrometeorological

Micrometeorological data recorded during winter months (Table 1), and analyzed with paired t-tests revealed that nocturnal air temperatures recorded at 2.2 m adjacent to the pine woods were not different from those taken at 0.0, 2.2, and 3.7 m within the roost. Temperatures high in the trees (4.9 and 6.1 m) were lower than those taken adjacent to the roost. Within the roost an inverse correlation existed between measurement height and temperature (Kendall's test). Ambient water vapor pressures did not vary between roost and periphery recordings.

Micrometeorological data recorded during winter (radiation exchange study), (Table 2) and analyzed with student's t-test revealed that air temperature, wind, velocity, and ambient water vapor pressure recorded at 1.8 m within the roost did not differ from recordings at 0.9 m at the periphery. Similarly, sky temperature and ground surface temperature did not differ between the same recording sites. Within the roost site, ground surface temperature, tree surface temperature, and air temperature were not different. Cloacal temperatures of birds inside the roost and at the periphery of the woods were similar (Table 2). Bird surface temperatures exceeded ambient temperatures to a greater degree within the roost site than at the periphery (Fig. 1).

As pointed out earlier the pine roost supplied at least 75 percent cover with some measurements as high as 96 percent cover.

Oxygen Consumption

Metabolic response to wind velocity (Fig. 2) which was analyzed with the Skillings-Wolfe test revealed that increasing wind velocity (0.0 to 15.1 km h^{-1}) caused a concomitant increase in metabolic rates at -10.0, 0.0, and 5.0 C. Metabolic rates at 0.0 and 5.0 C were not different and were combined. At these temperatures, metabolism increased linearly with the square root of wind velocity, and the empirically weighted regression equation describing the data is:

$$MR = 13.68 + 2.68X; \qquad r = 0.98$$

where: MR = metabolic rate (mW g^{-1})

X - wind velocity (km $h^{-1^{1/2}}$)

Metabolic rates at -10.0 C increased linearly from 0.0 to 7.3 km h^{-1}, and regression equation describing these date is:

$$MR = 16.80 + 3.01X; \qquad r - 0.70$$

At -10.0 C, subjecting birds to 15/1 km h^{-1} wind velocity caused metabolic rates to increase nonlinearally.

To estimate total heat flow, heat transfer coefficients were calculated according to Calder and King (1974). Heat flow is related to metabolism and temperature by the following equation:

$$h = H/T_b - T_a$$

where: h = heat transfer coefficient (mW $g^{-1}C^{-1}$)

H = heat loss (mW g^{-1}), which equals metabolic rate since cloacal temperature remained constant (Table 3; Skillings-Wolfe test)

T_b = cloacal temperature (C)

T_a = ambient temperature (C)

Increasing wind velocity generally caused corresponding increased heat transfer coefficients (Table 3; Skillings-Wolfe test) at -10.0 and 0.0 C.

Birds faced the convective current at all temperatures. At lower temperatures (-10.0 and 0.0 C). We observed marked piloerection and beak tucking. These behavioral patterns subsided when the wind velocity was returned to zero.

DISCUSSION

Evidence presented suggest that starlings select as nocturnal roost sites microclimates within the pine woods where air temperature, wind velocity, and radiant environment are altered to form thermally tolerable environments.

Air Temperature and Wind Velocity

Nocturnal air temperature varied spatially and temporally, and roosting behavior varied accordingly. Cold air temperatures in conjunction with wind caused roost site selection to be central rather than peripheral and low in the canopy rather than high. Although air temperatures and cooling rates did not differ between roosting areas and adjacent fields, Francis (1976) and Yom-Tov et al.(1977) suggest that metabolic heat production of large numbers of birds elevates roost temperature. This discrepancy may reflect size differences in roosting flocks studied. Estimates of our roosting flock were one third and one eighth the flock sizes reported by Francis (1976) and Yom-Tov et al. (1977), respectively. Metabolic heat production of large and possibly more densely roosting flocks may cause elevated air temperatures. Because ambient water vapor pressure did not differ, it apparently did not influence roosting behavior. Nocturnal roosting sites were chosen such that exposure to wind was virtually eliminated and heat loss by forced convection was thereby minimized.

To estimate the energetic advantage gained by roost site selection, we measured starlings' metabolic response to wind and temperature simultaneously. Increased wind velocity elevated metabolism at all temperatures tested. Increased metabolic heat production is required to counterbalance total heat loss that is accelerated upon subjection to wind, and not sufficiently reduced by the behavioral heat conserving mechanisms of piloerection, orientation, and beak tucking. Of total heat loss, that due to forced convection priamrily causes enhanced metabolic rates. Heat loss via conduction is minimal, as only feet contacted the repiration chamber. Evaporative heat loss is a small percentage of total heat loss in birds below thermal neutrality, and radiative heat loss is constant regardless of wind velocity. At all combinations of temperature and wind velocity, except the -10.0 C and 15.1 kmh^{-1} combination, metabolic rates increased linearly with the square root of wind velocity. Hence, Gessaman's (1973) equation relating metabolic rate to wind velocity is applicable and expressed as:

$$MR = f(X)^{\frac{1}{2}}$$

where: MR = metabolic rate ($\mathrm{mW\ g}^{-1}$)
X = wind velocity ($\mathrm{km\ h}^{-1}$)

Synergistic effects of a 15.1 kmh^{-1} wind velocity plus a -10.0 C test temperature caused metabolic rates to increase in a non-linear way. An explanation for these markedly increased metabolic rates is that forcibly penetrates the feather layer. Interruption of feather's physical integrity would increase heat loss from the bird's skin down the steep thermal gradient existing between skin surface and air temperature.

Temperature and Radiation

Calder (1974) and Southwick and Gates (1975) suggest that nest site selection by hummingbirds reduces heat loss via thermal radiation from birds to the cold night sky. An analogous situation appears to exist concerning nocturnal roosting of starlings in dense coniferous pine plantations. By combining radiation exchange formulae with metabolic rates of starlings, the energetic advantage accruing to sheltered roost inhabitants can be estimated.

Net radiation exchange is the difference between incident radiation from the environment and outgoing radiation from bird surfaces. This has been calculated according to the following equations:

$$Hr = (SA)\varepsilon_b\sigma T_b^4 - ((\varepsilon\sigma T^4)0.5\ S.A. + (\varepsilon_t\sigma T_t^4)(0.5\ S.A.)Z + (\varepsilon_S\sigma T_S^4)(0.5\ S.A.)1 - Z)$$

$$Hr = {}_bT_b - ((\varepsilon_g\sigma T_g^4)(0.5\ S.A.) + (\varepsilon_S\sigma T_S^4)(0.5\ S.A.))$$

where: Hr = net radiation exchange (W bird^{-1})

= infrared emissivities of radiating surfaces,

where $\varepsilon_b = \varepsilon_{bird}$ = 1.00 (Calder and King 1974)

$\varepsilon_t = \varepsilon_{trees}$ = .090 (Sellers 1974)

$\varepsilon_g = \varepsilon_{ground}$ = 0.97 (Sellers 1974)

$\varepsilon_s - \varepsilon_{sky}$ = 0.060 (calculation based upon measured sky temperature and incident long wave radiation according to Monteith 1975)

T = temperature of radiating surfaces (K)

where $T_b = T_{bird}$ (it is assumed that radiation from bird surface is uniform)

$T_t = T_{trees}$

$T_g = T_{ground}$

$T_s = T_{sky}$

σ = Stefan-Boltzman constant (8.14 X $10^{-11}$by $\text{min}^{-1}\text{K}^{-4}$ Seller, 1974)

$Z.$ = percentage of bird dorsal surface exposed to trees, estimated 75%. Outside the pine woods, it is assumed that one-half of the surface is exposed to ground and one-half is exposed to sky.

$T_g = T_{ground}$

$T_s = T_{sky}$

S.A. = bird's surface area (cm^2), estimated by a cloth-covering technique (Veghte, 1975)

Z = percentage of bird's dorsal surface area exposed to the trees, where Z is estimated at 75%. Outside of the roost it is assumed that one-half of the bird's surface is exposed to the ground and one-half is exposed to the sky.

Calculated radiative heat losses from birds located outside the pine woods were greater (Kruskal-Wallace Test; $P<0.001$) than those calculated for birds inside the roost and ranged from 2.68 W $bird^{-1}$ at 1.0°C to 1.96 W $bird^{-1}$ at -10.0°C. For birds within the roost receiving 25% of night sky radiation upon their dorsal surfaces and the remainder from coniferous microhabitat, heat losses ranged from 1.95 W $bird^{-1}$ ± at 2.0° C to 1.24 W $bird^{-1}$ at -10°C. Other heat loss values were calculated for roost inhabitants receiving 18 and 4 percent night sky radiation.

These estimates of differences between radiative losses within and outside the roost are conservative in that counter radiation to birds is based solely upon tree temperature. This is legitimate because large numbers of birds in this study did not alter air temperatures in the roost, even though bird surface temperatures slightly exceed air temperatures.

Nocturnal heat production of starlings from -10°C to 5.0°C is described by the following equation:

$$HP = 1.13 - 0.02X; \quad r = 0.45$$

where: HP = heat production (W $bird^{-1}$)

X = air temperatures (C)

From this equation, heat produced below thermal neutrality can be calculated and subsequently compared with calculated heat losses from radiation exchange formulae.

Heat loss to heat production ratios (HL/HP) analyzed by Jonckheere test revealed that those ratios of birds outside the pine woods exceed those of birds within the roost (Fig.3). For birds outside the woods the ratio always exceeds unity, whereas those of birds within the roost and with the most cover from sky radiation are less than one (except at the highest temperature). Birds with an estimated 82% cover from sky display HL/HP ratios intermediate between birds of the previously described locations (75% and 96% cover).

As seen (Fig.3), HL/HP ratios gradually decrease from highest to lowest air temperatures. This seemingly paradoxical result can be reconciled. First, at lower temperatures heat production is greater. Second, because the difference between birds' su face temperatures and air temperature is greater at higher temperatures, a greater temperature gradient exists between birds and other environmental surfaces. This would result in a greater net radiative efflux from birds at warmer temperatures.

The discussion to this point has bealt with radiation exchange between birds and clear night skies. Cloud cover alters heat flow interactions. For example, at -3.0°C, calculated heat losses from birds located outside the pine woods and exposed to clear skies (mean temperature = -28.0°C) averaged 1.83 W bird^{-1}, whereas that for birds exposed to cloudy skies (mean temperature = 3.0°C) was 0.165 W bird^{-1}. Cloud induced changed in heat flow interactions correlate with alterations in roost site selection, as birds roosted nearer the canopy on cloudy, windless nights and away from the canopy on cold, clear, and/or windy nights.

From the preceeding discussion, the primary microclimatological determinants of starlings' roost site selection at a particular temperature appear to be a reduction in radiative and forced convective heat losses.

With the results from our wind and radiation studies, it is possible to estimate the energy savings derived from reduced radiative and convective heat losses afforded to starlings roosting in the sheltered pine plantation. At the -10.0°C test temperature, subjecting the birds to wind velocities from 0.0 to 15.1 Km hr^{-1} caused the metabolic heat production required to counterbalance the radiative heat loss at -10.0°C is 1.24 and 1.96 W bird^{-1}, within and outside of the roost respectively. Together the resting metabolic rate at -10.0°C must be increased 4.27 times in order to maintain thermal homeostasis if the birds are exposed to the described convective and radiative heat losses outside of the roost. This value approaches the limit of the ability of winter acclimatized starlings to increase their metabolic rate, which has been reported by Lustick and Adams (1977) to be 5.14 W bird^{-1}. If, as in the previous example, the resting metabolic rate at -10.0°C has to be increased by 4.27 times, the metabolic heat production would be 5.76 W bird^{-1}. It is apparent, then, that the total physiologic thermogenic potential of birds of this species would be inadequate to maintain thermal homeostasis when confronted with the high rate of convective and radiative heat losses present outside of the roost. It appears, therefore, that precise roost site selection in this species is a requisite component of its thermoregulatory ability and is equally as important as the physiological and insulative mechanisms governing thermal homeostasis. We should point out that the maximum wind speed tested was 15.1 Km hr^{-1} and this is a low wind speed compared to the wind speeds measured outside the roost.

Table 1. A comparison of micrometeorological characteristics inside and outside of an active nocturnal communal roosting site of starlings during winter, wind velocity tests ($\bar{X}$ ± S.E.).

Microclimatic Factor	Height of Recording (m)	n	Inside Roost	n	Outside Roost
Air temperature (C)	0.0	25	-3.3±0.8		—
	2.2	25	-3.8±0.9	25	-3.5±1.0
	3.7	25	-3.5±0.9		—
	4.9	25	-3.5±0.9		—
	6.1	25	-4.1±0.4		—
Wind Velocity (Km h^{-1})	0.0	8	0.5±0.3		—[a]
	1.5	8	0.0±0.0		—[a]
	2.2	28	0.0±0.0	28	8.8±1.1
	3.1	8	0.0±0.0		—[a]
	4.7	8	5.0±1.4		—[a]
	6.1	8	9.87±1.6		—[a]
	7.5	8	15.10±2.5		—[a]
Ambient Water Vapor Pressure (Hg)	2.2	22	3.0±0.2	22	2.9±0.2

[a] wind velocity recorded at 2.2 m ranged from 10.0 to 22.0 km h^{-1}

Table 2. A comparison of microclimatological characteristics and starling cloacal temperatures recorded inside and outside a starling communal roosting site during winter radiation exchange tests. ($\bar{X}$±S.E.).

Microclimatic Factor	Inside Roost (recording height 1.8m)	n	Outside Roost (recording height 0.0m)	n
Air Temperature (C)	-2.4±1.0	10	-3.4±0.9	9
Wind Velocity (Km h^{-1})	0.0±0.0	8	0.2±0.1	8
Ambient Water Vapor Pressure (mm Mg)	1.9±0.3	8	2.0±0.3	8
Ground Surface Temperature (C)	-1.7±0.8	10	-2.8±1.2	9
Sky Temperature (C)	-24.4±2.5	10	-24.3±2.7	9
Tree Surface Temperature (C)	-2.4±1.0	10	—	
Cloacal Temperature (C)	38.3±0.5	10	38.1±0.3	8

Table 3. Laboratory metabolic rate (MR in mW g^{-1}), body temperature (T_b in C), and heat transfer coefficients (h in mW $g^{-1}C^{-1}$) of 30 starlings at various ambient temperatures (T_a in C) and four different wind speeds (X±S.E.).

	0.0 km h^{-1}			2.93 km h^{-1}			7.30 km h^{-1}			15.10 km h^{-1}		
T_a	MR	T_b	h	MR	T_b	h	MR	T_b	h	MR	T_b	h
5.0	13.11± 0.95			18.30± 1.67			21.43± 2.44			23.05± 4.46		
0.0	13.28± 0.75	37.4± 0.5	0.34± 0.02	20.00± 1.73	36.5± 0.3	0.58± 0.03	20.07± 1.73	35.0± 0.4	0.57± 0.05	20.48± 2.73	38.0± 0.4	0.59± 0.09
-10.0	16.85± 1.23	35.0± 0.4	0.35± 0.02	21.20± 1.73	35.6± 0.2	0.48± 0.03	25.28± 1.06	34.8± 0.3	0.50± 0.03	45.37± 0.73	35.5± 0.3	1.01± 0.01

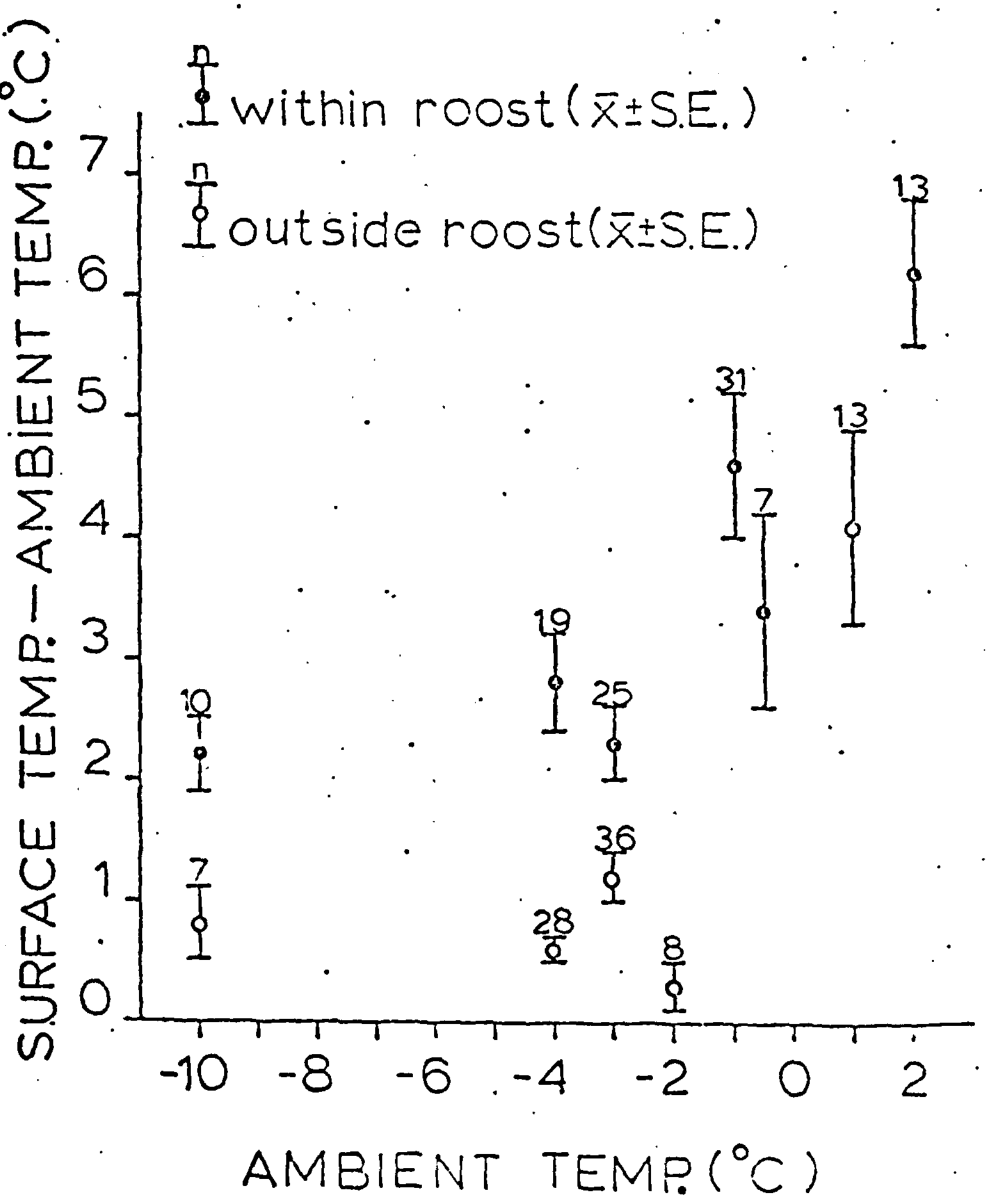

Figure 1. Surface temperatures of starlings within the roost and outside the roost minus ambient temperature.

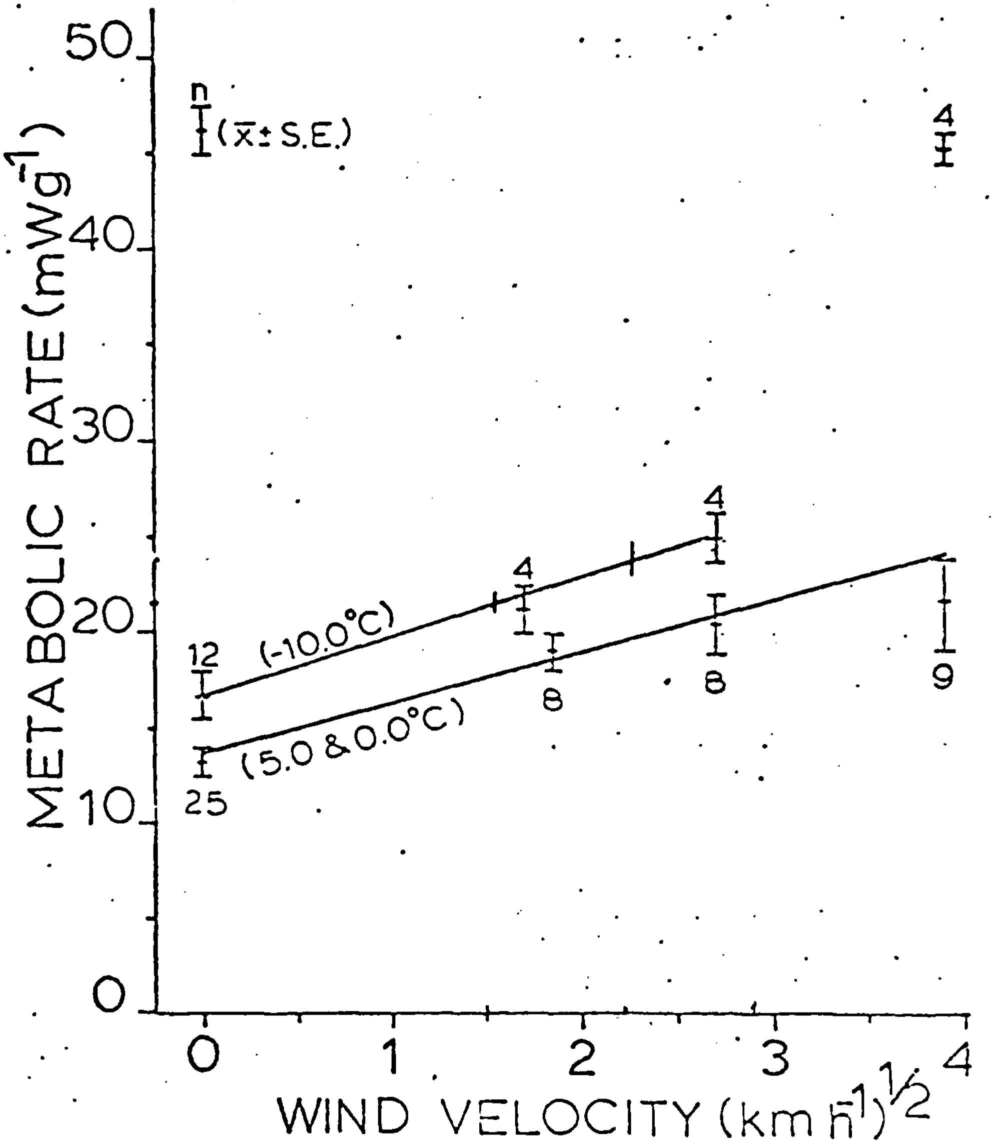

Figure 2. Metabolic rates of 30 starlings at three temperatures and four wind velocities. At -10.0 C, the data for 1.71 km h^{-1} is shifted to left to avoid confusion.

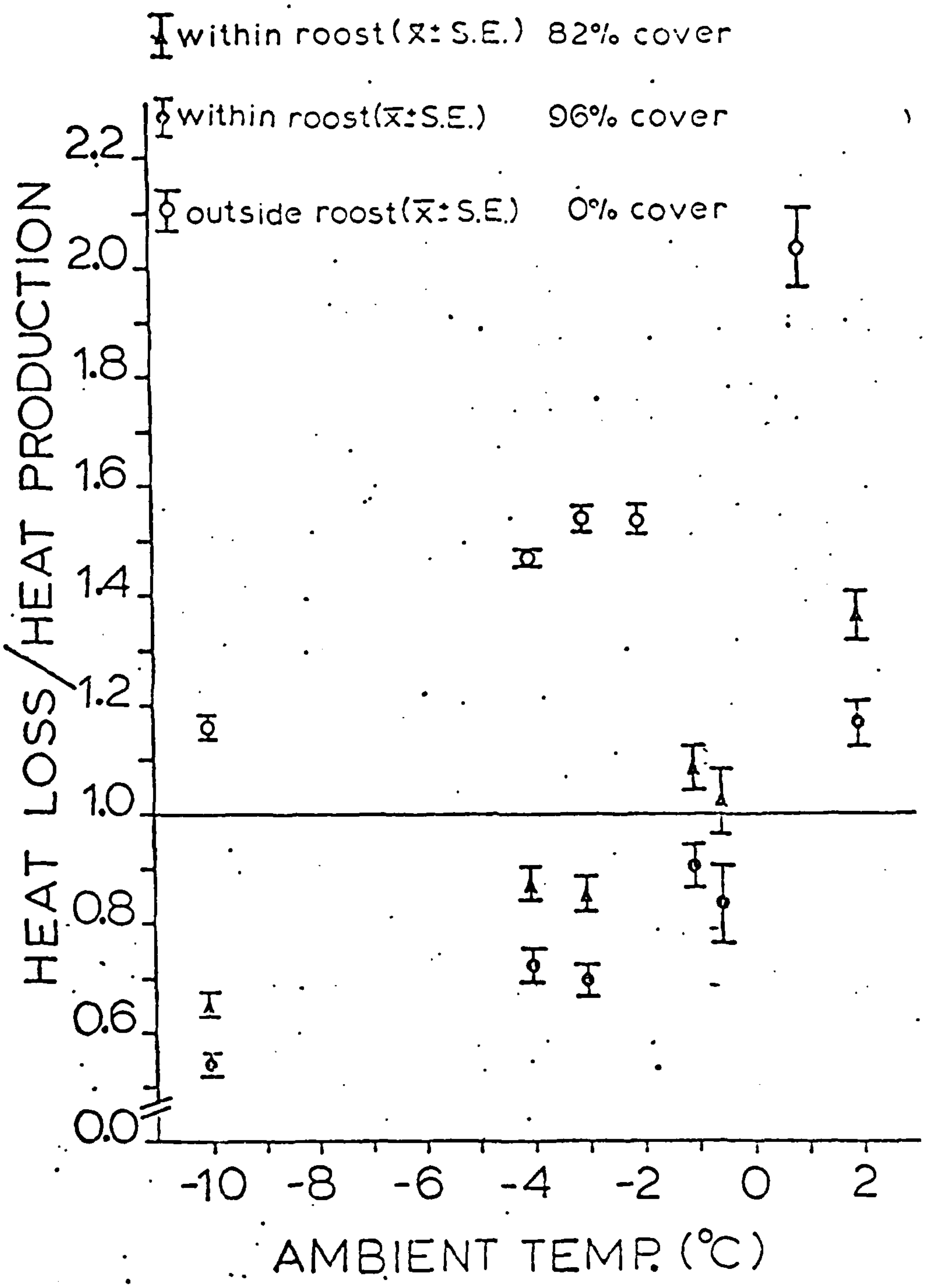

Figure 3. Ratios of heat loss to heat production of starlings located outside the roost and inside the roost with different estimates of cover from the night sky. Sample sizes given in Figure 1.

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SECTION II

Data on standard and Peak (maximum) metabolic rate for Starlings, Redwings, Grackles, and Cowbirds, was taken from a previous work by this investigator on the seasonal variation in the effects of wetting on the energetics and survival of Blackbirds and Starlings.

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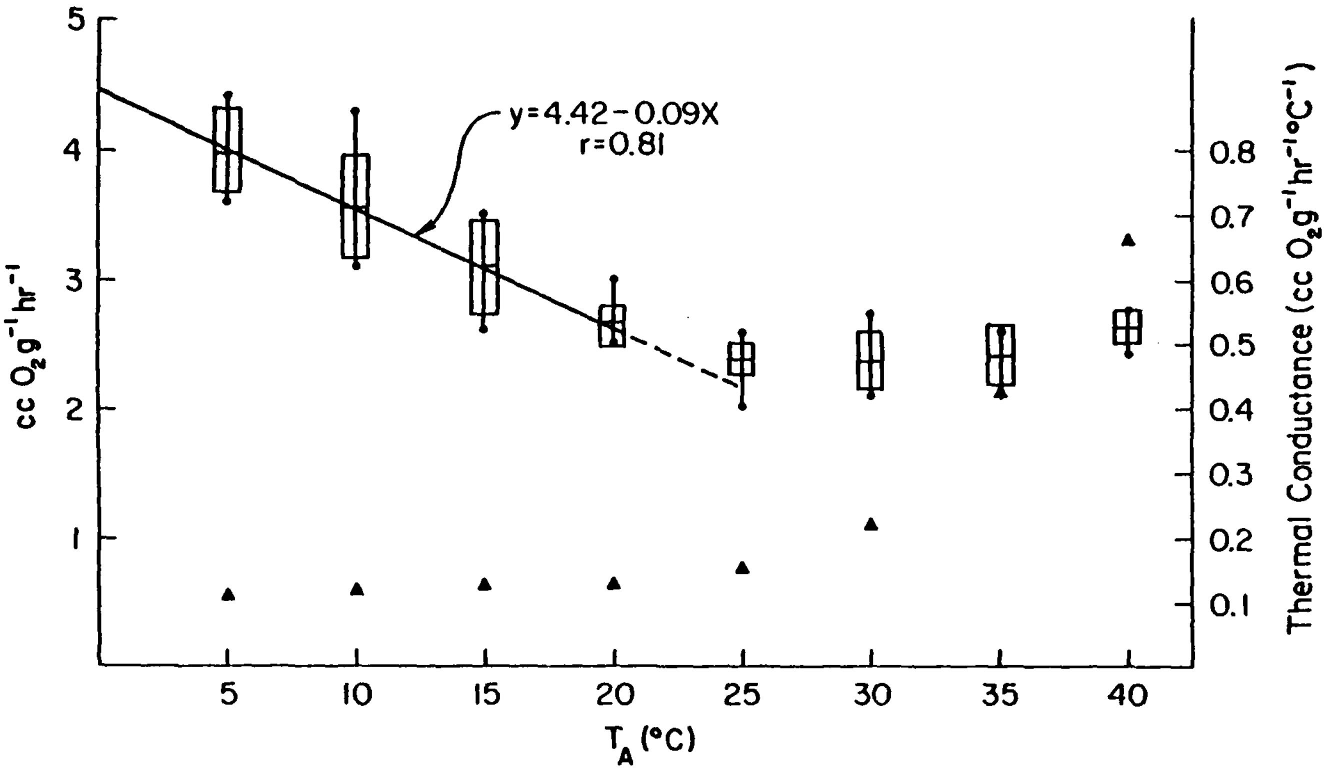


Figure 1. Oxygen consumption (boxes) and thermal conductance (▲) for 39 dry summer-acclimated starlings. Symbols as previously described.

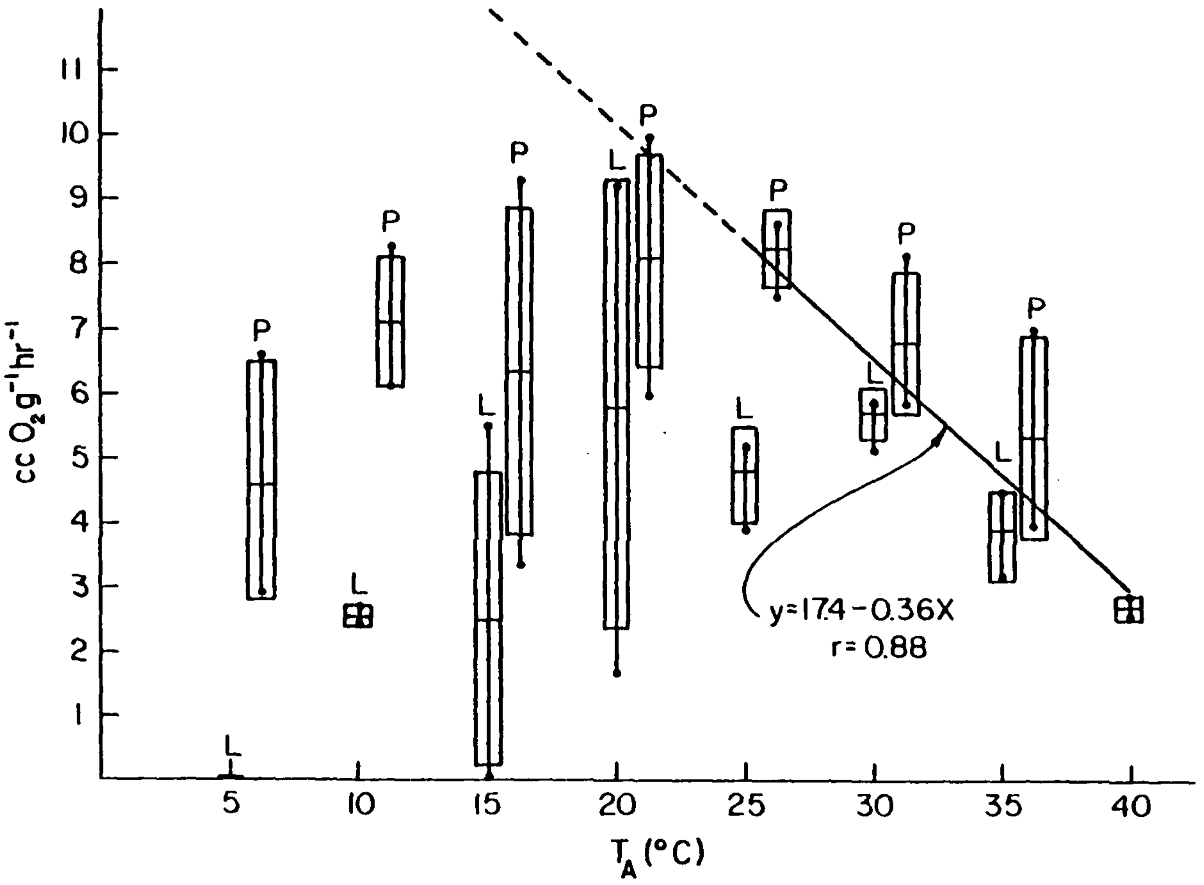
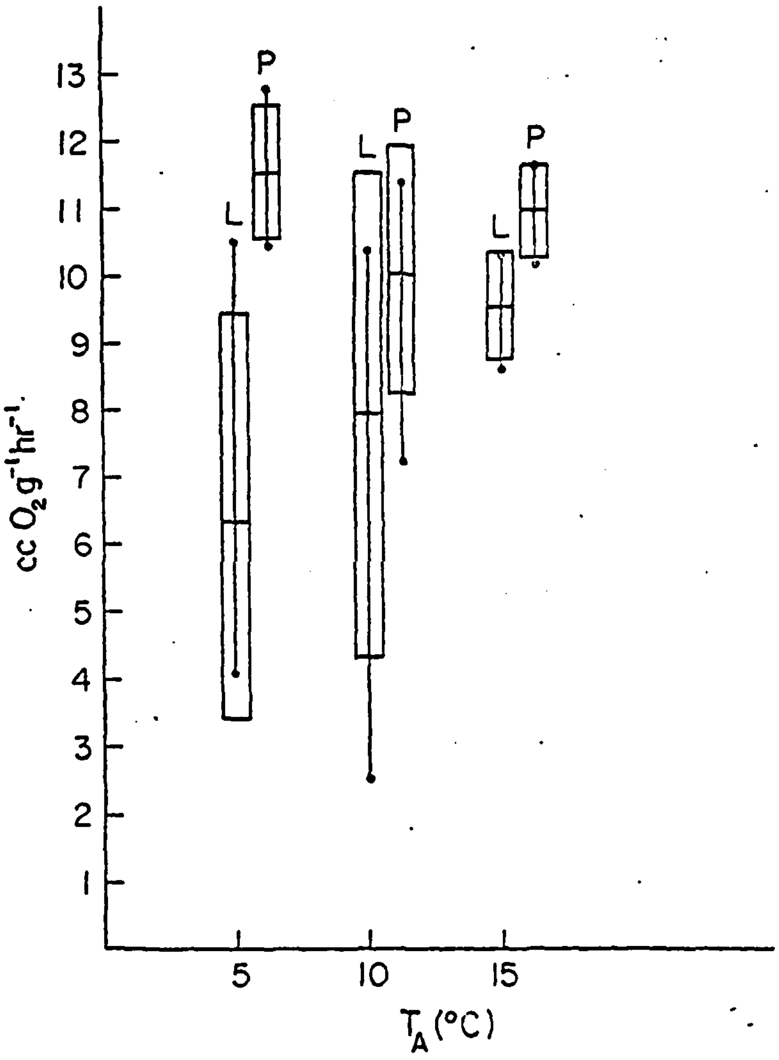


Figure 2. Peak (P) and low (L) oxygen consumption of 29 totally-wet summer-acclimated starlings over a T_A range of 5-40C. Symbols as previously described.



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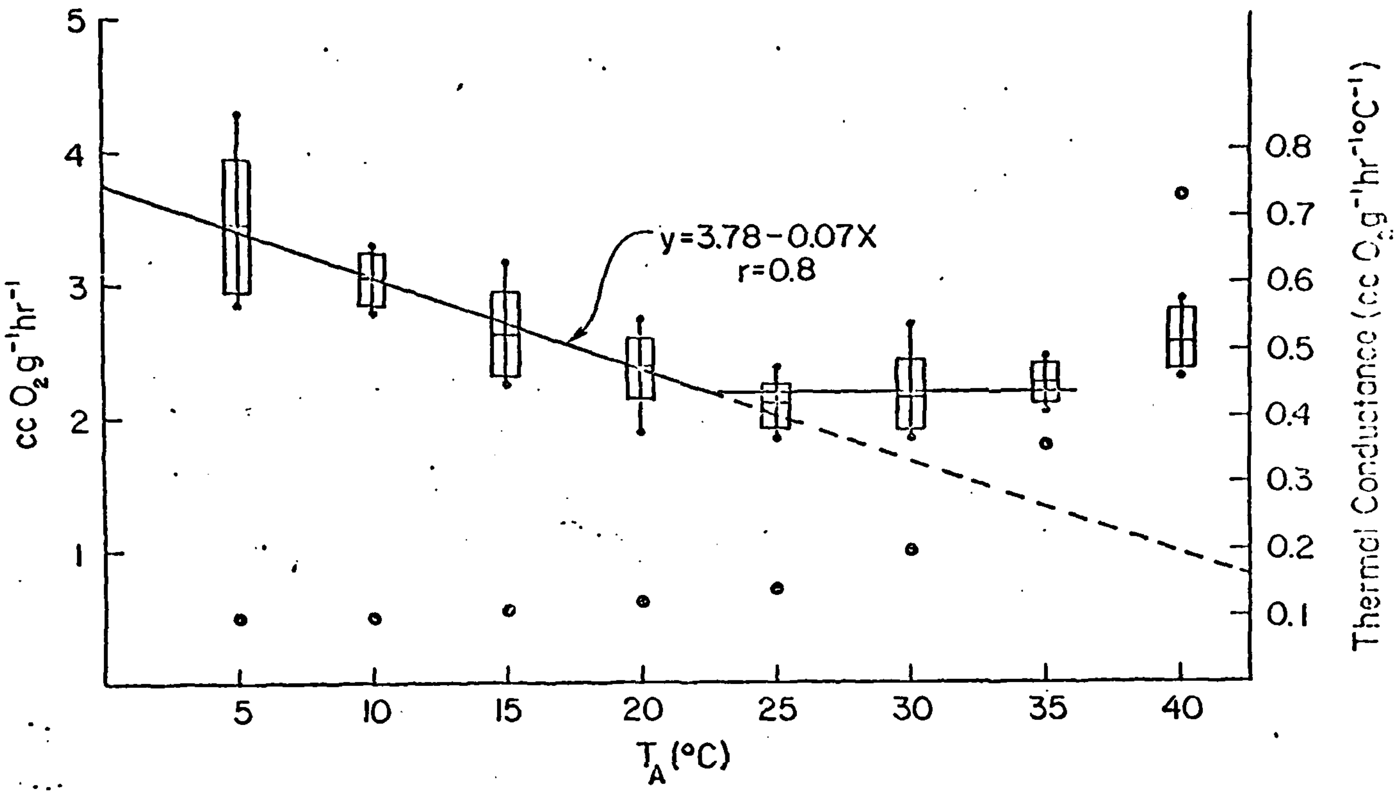

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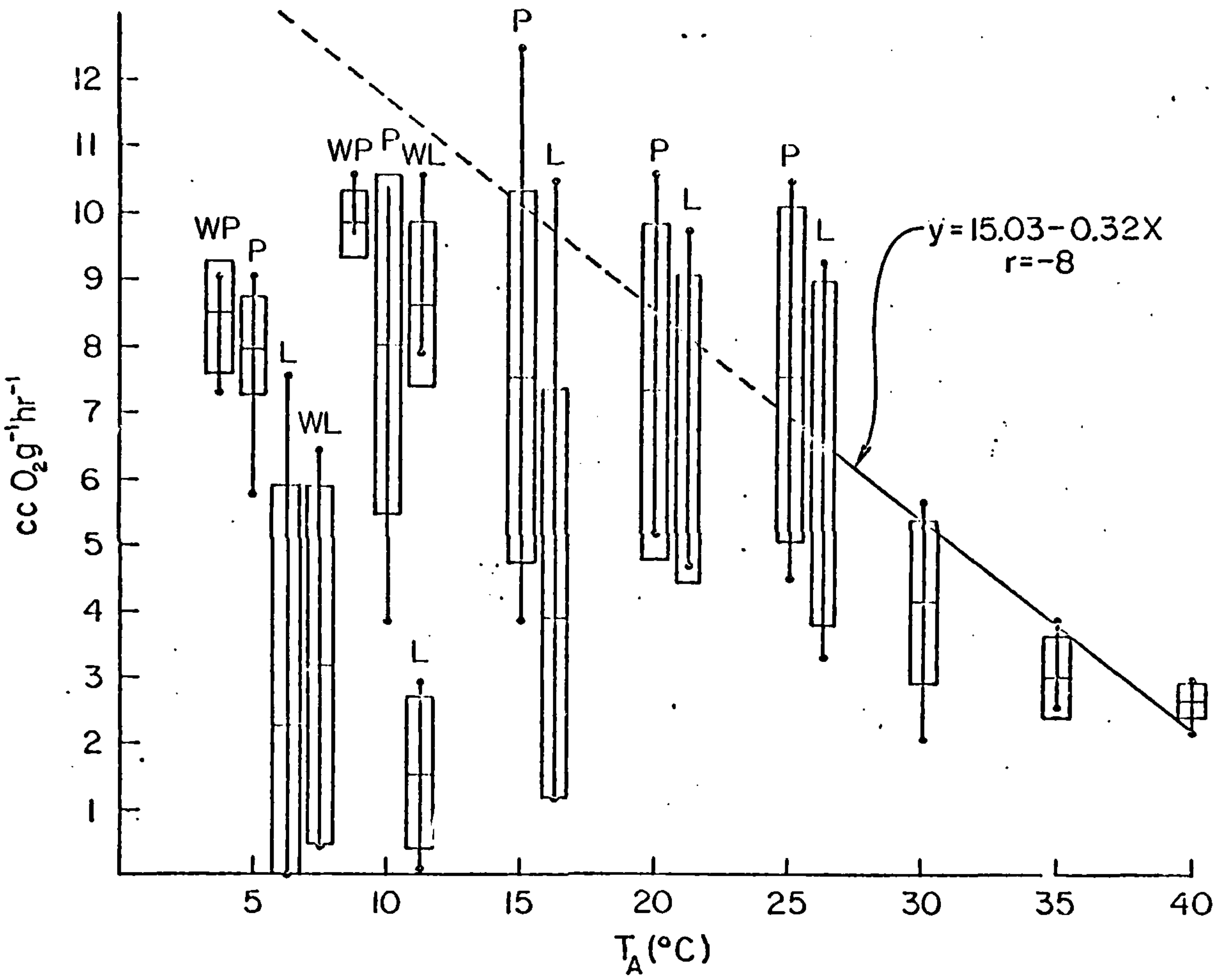

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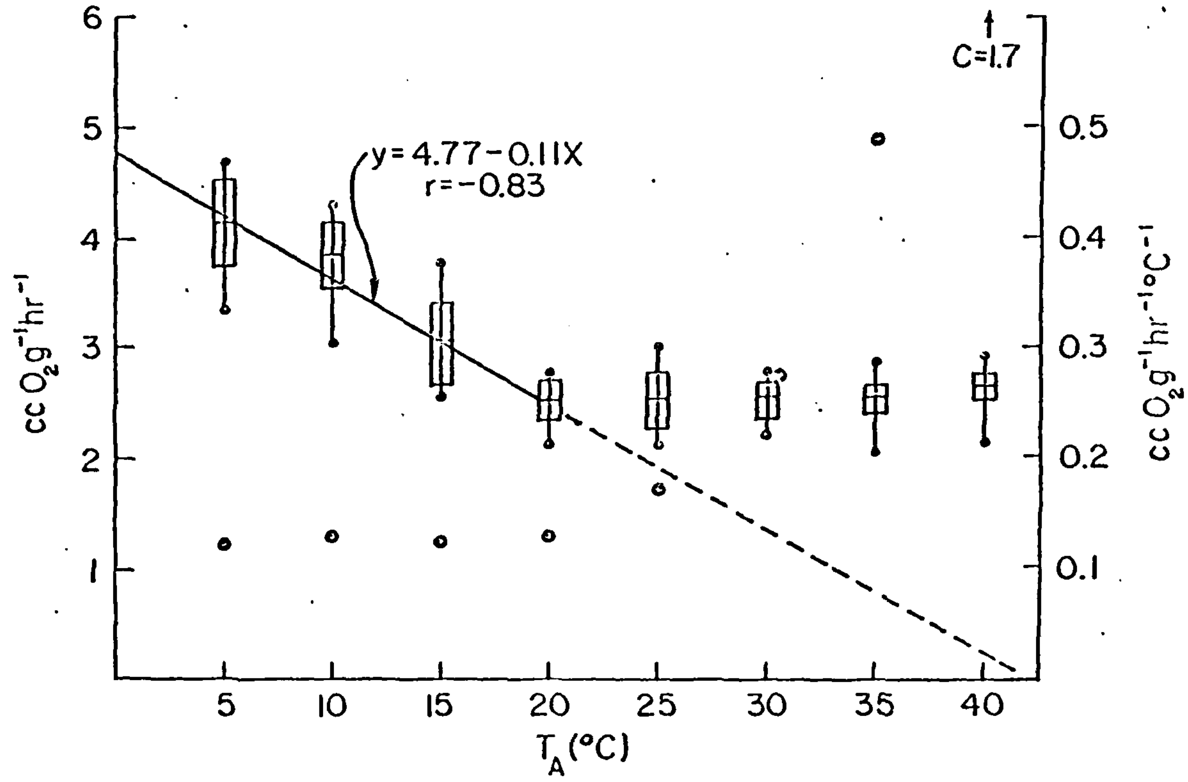


Figure 6. Oxygen consumption and thermal conductance of 48 red-winged blackbirds over an ambient temperature range of 4-50C. Vertical = range, horizontal line = mean and the boxes = 95% confidence limits. Solid circles are thermal conductance.

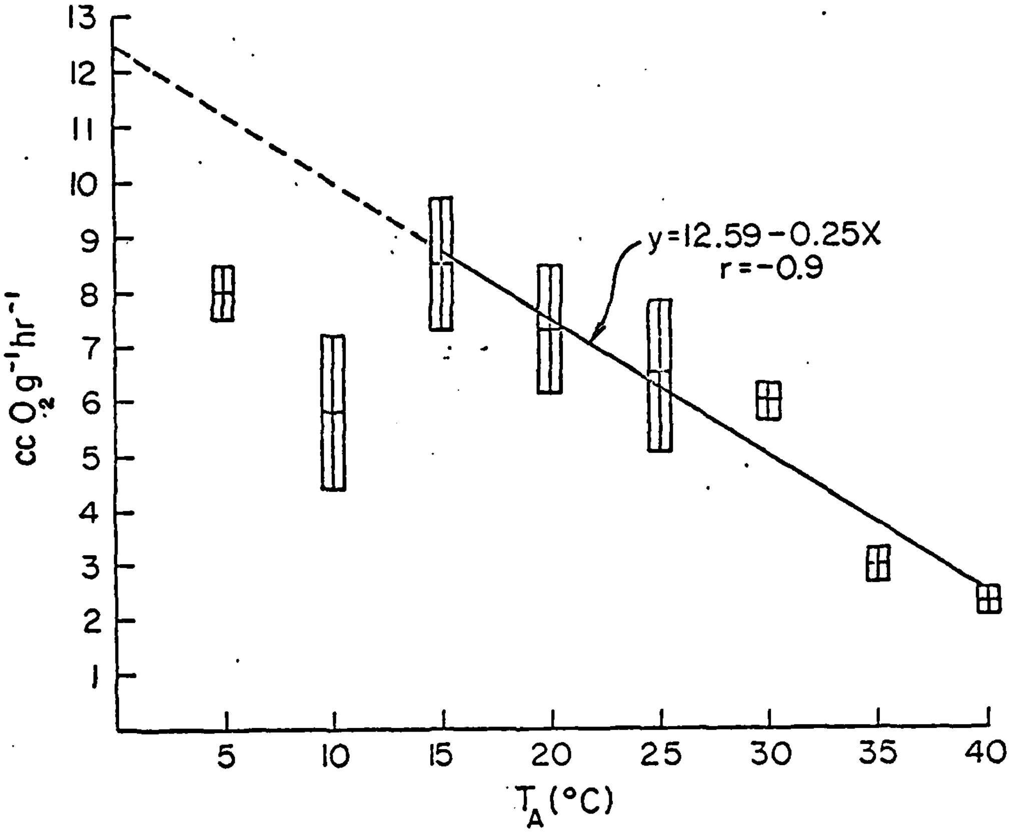
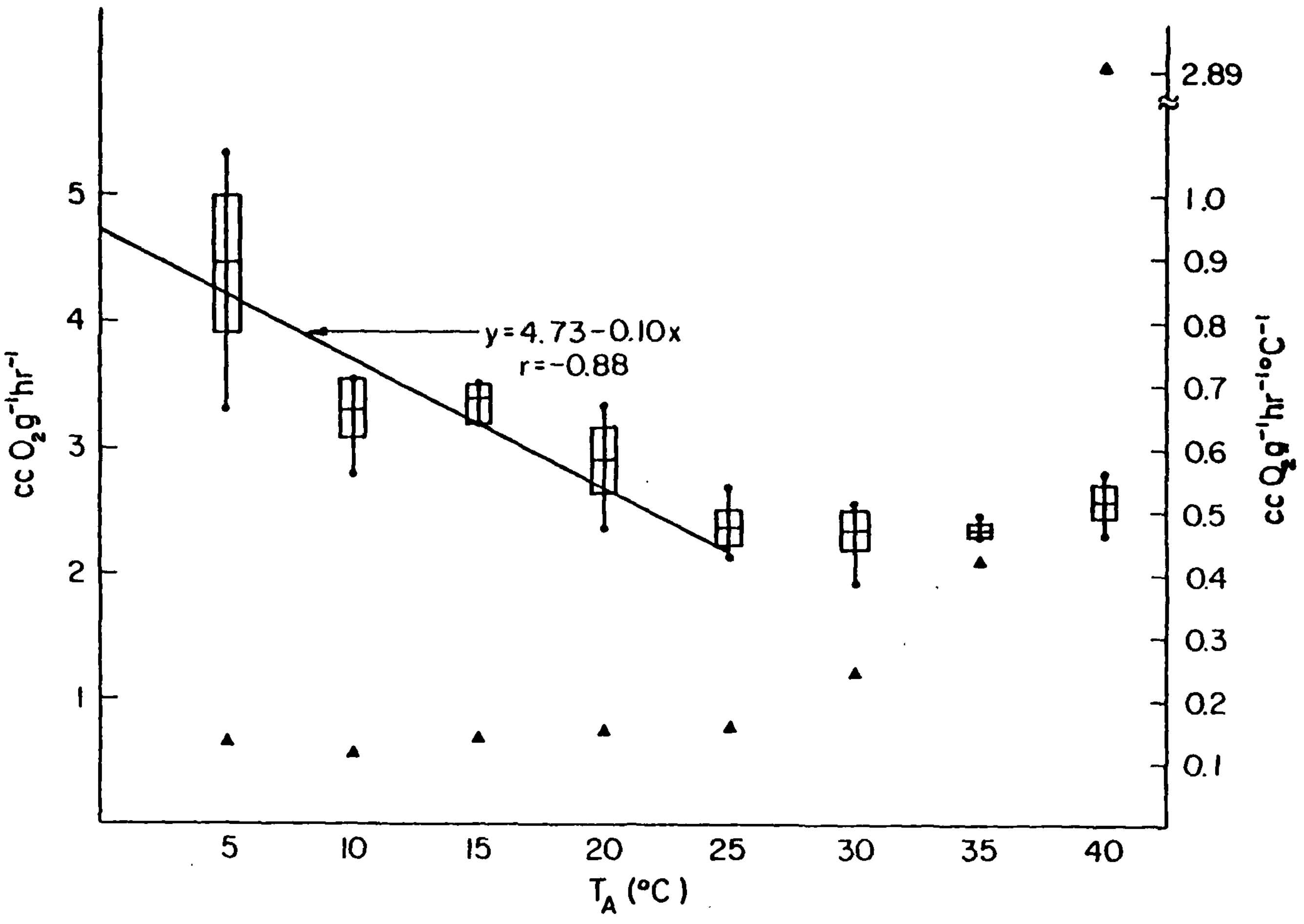


Figure 7. Peak oxygen consumption of wet summer-acclimated redwings over an ambient temperature range of 5-40C. Symbols as in Fig. 1. N = 40.



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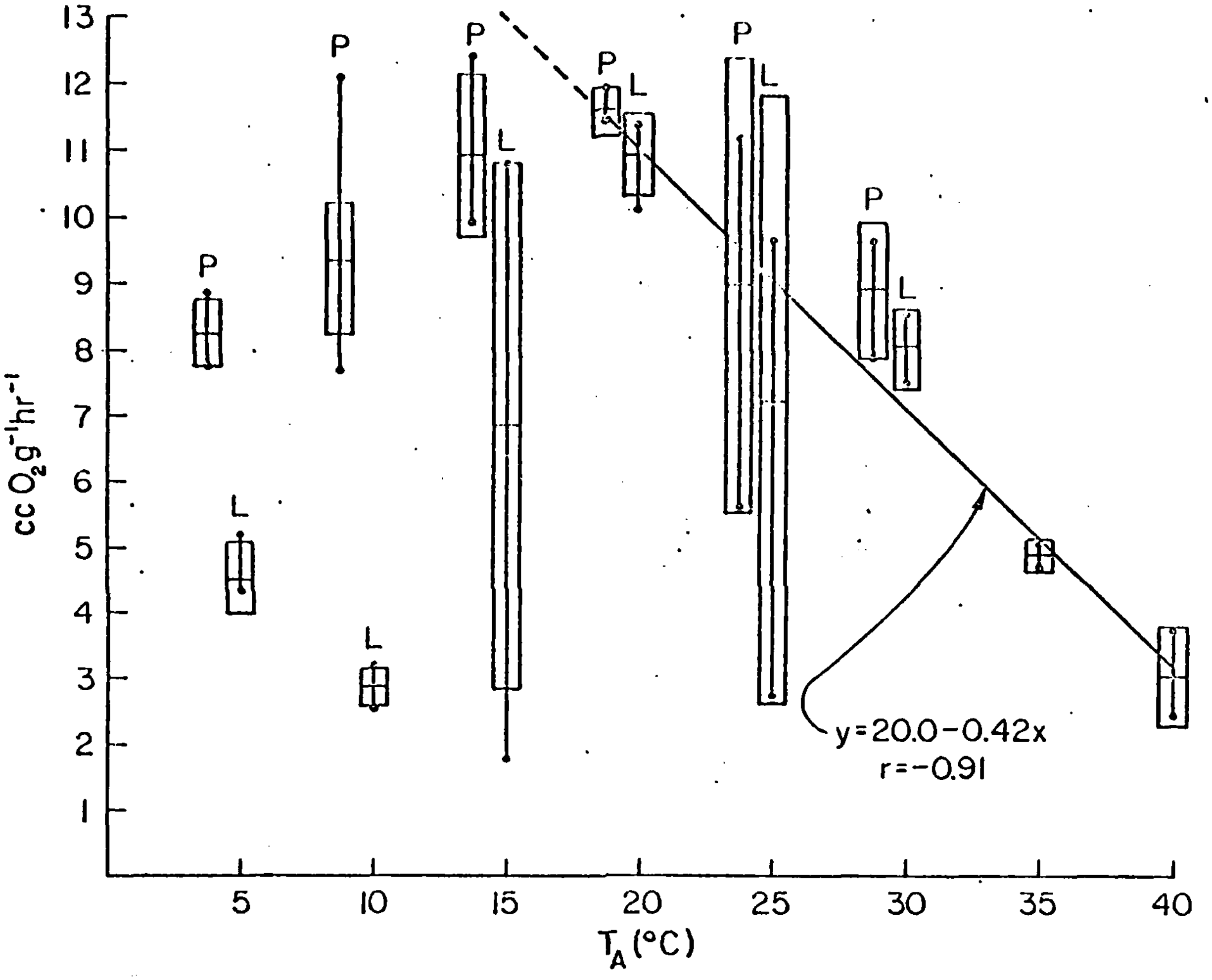

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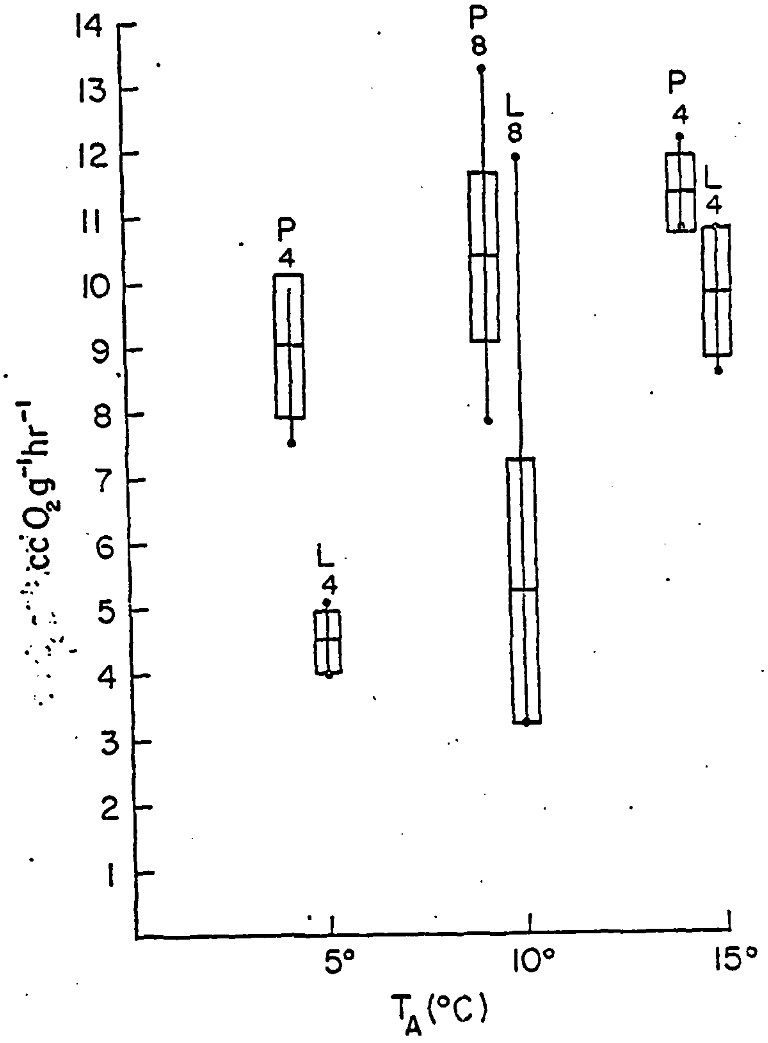

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SECTION III

COMPARISON OF BLACKBIRD AND STARLING ENERGETICS AMONG SEVERAL TYPES OF ROOSTS IN WINTER

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INTRODUCTION

Birds must be capable of adjusting to the thermal environment which surrounds them. To do so requires adjustment to the four primary factors which comprise the "climate space" of Porter and Gates (1969). These factors include radiation, humidity, wind velocity, and ambient temperature.

Failure of birds to successfully adjust to one or more factors of the climate space may result in death. Accounts of large-scale mortality in birds are prevalent in the literature. Several reports suggest that periods of severe weather are directly responsible for mortality. A study of bird mortality by Odum and Pitelka (1939) cites high winds up to 48 mph (77.8 kmh^{-1}) coupled with driving rain and a sharp drop in temperature as the cause for 4% mortality in a roost of 25,000 birds. Similar conditions resulting in soaked birds caused the death of 8,046 Cowbirds (Molothrus ater) in Columbus, Ohio (Kessler et al. 1961).

Lack of sufficient food or the ability to forage coupled with severe weather may also result in mortality. This may occur directly through depletion of fat stores and subsequent starvation or by causing weakened birds which are then more susceptible to the effects of severe weather. Jogi (1959) found 4,500 dead House and Sand Martins (Hirundinidae), many of which were juveniles. A large number of these birds appeared to have died of starvation due to lack of food or an inability to forage during a period of severe weather. Many were found huddled together in an apparent effort to conserve body heat. Graber and Graber (1979) noted that heavy snowfall and extreme cold in Illinois resulted in a mortality rate higher among ground foragers and smaller species. This presumably indicated that ground foragers were unable to find sufficient food.

When severe weather does not result in mortality, it can serve to limit foraging rates and alter foraging substrate. Grubb (1975; 1978) found that wintering woodland birds in central Ohio decreased foraging rates with increasing wind velocities and decreasing temperatures in an apparent effort to reduce convective heat loss. In addition, several species changed the foraging substrate by moving to substrates which appeared to offer greater protection from the wind. Nuthatches and woodpeckers switched to larger branches and the trunks of trees while chickadees and titmice switched from the twigs of trees to the twigs of shrubs.

Birds adjust to severe weather by seeking favorable micro-climates. The advantage of a favorable micro-climate is well illustrated in a study by Stewart (1978). The mortality rate among Starlings (Sturnus vulgaris) roosting in trees was 15% during two nights of very cold (-24.4° and -17.2°C) temperatures, while the mortality figures for the same period was 0.4% for a group of 2,500 Starlings roosting in a nearby barn which offered greater protection. Use of favorable microclimates has been demonstrated for the Pygmy Nuthatch (*Sitta canadensis*) (Knorr 1957); Eastern Bluebirds (*Sialia sialis*) (Frazier and Nolan 1959); House Sparrows (*Passer domesticus*) (Kendeigh 1961); Redwing Blackbirds (*Agelaius phoeniceus*), Common Grackles (*Quiscula quisculus*), and Brown-headed Cowbirds (Francis 1976); Starlings (Yom-Tov et al. 1977; Kelty and Lustick 1977); Monk Parakeets (*Myiopsitta monachus*) (Caccamise and Weathers 1977); juvenile Herring Gulls (*Larus argentatus*) (Lustick et al. 1979); and Black-billed Magpies (*Pica pica hudsonia*) (Reese et al. 1980).

Favorable microclimates serve to reduce the energetic requirements of birds through alteration of one or more of the four factors comprising the climate space. Energetic requirements may be decreased through a reduction of wind velocity in the roost (Francis 1976; Kelty and Lustick 1977), a reduction in the radiation of thermal energy to the environment by increasing percent cover (Calder 1973; 1974; Kelty 1977), a decrease in in-coming short wave solar radiation to birds at moderate temperatures (Lustick et al. 1979), and by allowing an increase in local temperature above ambient temperature due to local effects of roost location in protected areas (Yom-Tov et al. 1977), to temperature inversions in mountainous areas (Reese et al. 1980), or to enclosed roosting or nesting cavities (Kendeigh 1961; Caccamise and Weathers 1977).

While three of the elements of the climate space: radiation, humidity, and ambient temperature have been extensively studied with regard to their effects on avian energetics, the effects of wind velocity, or forced convection, have been examined primarily through utilization of heat transfer theory (Porter and Gates 1969; Calder and King 1974; Bakken 1979; Walsberg and King 1980). Use of heat transfer theory to determine the effect of the roost on avian energetics might lead to an underestimate of the energetic signifance of the roost to the bird. This may in part be due to a lack of experimental inforamtion on the effect of wind on the bird's metabolic rate. For example, Walsberg and King (1980) concluded that the roosting behavior of the American Robin (*Turdus migratorius*) in dense vegetation during winter nights in eastern Washington produced only a slight thermoregulatory benefit (3-5%) over birds roosting in the open. The metabolic rates of Starlings with forced convection in wind tunnel experiments by Kelty and Lustick (1977) suggested a savings of 12-38% for birds roosting in well protected versus open sites.

Metabolic rates were found to increase linearly with the square root of the wind velocity in experimental studies of the effects of wind velocity on birds by Gessaman (1972) on the Snowy Owl (*Nyctia scandiaca*), Robinson et al. (1976) on the White-crowned Sparrow (*Zonotrichia leucophrys gambelii*), and Kelty and Lustick (1977) on Starlings. At a wind velocity of 15.2 kmh^{-1} Kelty and Lustick found that the metabolic rate of the Starlings increased abrubtly in a non-linear fashion. Robinson did not use wind velocities of this magnitude.

In addition to the above studies with live birds, Chappell (1980a) reported that heat trasfer in heated, skin-covered metal casts of arctic shorebirds in a wind tunnel also increased with the square root of the wind velocity. The identical technique used with arctic mammal skins resulted in a more accurate prediction when regressions of heat loss were made on the wind velocity rather than the square root of wind velocity (Chappell 1980b).

In an effort to ascertain the energetic savings reaslized by blackbirds utilizing various roost sites more accurately and to compare the thermoregulatory benefits afforded by different types of roosts, this study utilized data on the metabolic rates of blackbirds and starlings with forced convection. Measurements of the percent cover and the wind velocity in several roost types were used to compare and contrast the energetic requirements of blackbirds and starlings utilizing these types of roost sites at night during the winter. Energy budgets for blackbirds and starling were derived based on measured metabolic rates, and assumptions concerning radiative heat loss derived from measurements on redwings, and starlings Kelty and Lustick (1977), Moen (1973), and Calder (1973). These energy budgets were used to illustrate the relative value of each roost type in promoting thermoregulation. Finally, some conclusions were made concerning the possible use of these information in the control of blackbirds.

MATERIALS AND METHODS

Metabolic Rates

The standard metabolic rates (MR) of 10 male Brown-headed Cowbirds, seven male and six female Redwing Blackbirds and nine male and six female Commor Grackles were determined at five temperatures (10°, 5°, 0°, -5°, and -10°C) with four wind velocities (0.0, 3.5, 12.4, and 15.2 kmh^{-1}). The metabolic chamber consisted of a plexiglass wind tunnel described by Neal (1976). The chamber utilized a flow-through system. Maximum wind velocity measured in the tunnel was 15.2 kmh^{-1}. The chamber was connected to a Beckman F-3 paramagnetic oxygen analyzer in conjuction with an Easterline Angus Model MS401BB strip chart recorder. Dried Air was introduced to the chamber at a rate of 1000 cc. min^{-1}. The chamber was placed in a walk-in environmental chamber at the desired temperature.

All birds were tested in the dark between 0800 and 1800 hours. Values for oxygen consumption were taken only after a steady state had been maintained for approximately twenty minutes. At each temperature birds were tested at wind velocities of 0.0 and 12.4 kmh^{-1} in one trial and 3.5 and 15.2 kmh^{-1} in a second trial. Only one trial was conducted per day for each bird. Each bird was used in ten separate trials spanning twenty days or more.

Following each trial body temperature (T_b) was measured with a thermocouple inserted 1-2 cm. into the cloaca. This temperature was then used to determine the heat transfer coefficient (h) at wind velocities of 12.4 and 1.52 kmh^{-1}.

Percent Cover

The percentage of vegetative cover in several deciduous roosts, one cattail (Typha latifolia) roost and an eastern red-ceder tree (Juniperus virginiana) was determined using 180° hemispherical fisheye lens photographs taken from the approximate level of roosting birds. Photographs were analyzed with the use of a circular grid as described by Anderson (1964). Photographs of three deciduous roosts taken during the winter with no foliage were compared to ones taken during the summer with maximum foliage.

Roost Micrometeorology

Wind velocity was measured simultaneously inside and outside on the windward side of several deciduous roosts, one cattail roost and a single Eastern Redceder tree. Wind velocity within the roost was then recorded as a percentage of the velocity recorded outside the roost. This percentage remained essentially constant down to very low wind velocities. Measurements were made between two and three meters above the ground with a hand-held anemometer (starting speed 0.15 ms^{-1}; Central Scientific Co., Model 13B-1064) and two Field Recording Wind Monitors (R.M. Young Co., Model 6101 anemometer and chart recorder).

Measurements of sky, ground, tree, and bird surface temperatures were made inside the R&F deciduous roost on two nights in January and February 1980. Temperatures of the ground, air, and trees were determined with a thermocouple connected to a Bailey Instruments (Model Bat Four) thermometer, while bird and sky temperatures were determined with a Mikron 44 infrared thermometer. To measure bird surface temperatures male and female Redwing Blackbirds were tethered to a tree and allowed to settle for 20 minutes before measurements were made. Tethered birds could assume normal postural positions. These measurements were then compared with similar measurements made in a pine roost on starlings.

Energy Budgets

Energy budgets for the five groupings of birds were calculated by adding the net radiative heat loss to the metabolic rate determined as previously noted. Net radiative heat loss was calculated as previously described and represents the net radiation exchange between the bird and the ground, trees, and sky.

In order to calculate the energy budgets it was necessary to make several assumptions. Birds were assumed to have a surface temperature constant over the entire body surface (T_r). In reality the surface temperature varies somewhat over the body surface. HOwever, with passerines of the sizes used in this study the variation is small. The surface temperature of a Gray Jay (Perisoreus canadensis pacificus Gmelin) determined by radiometric analysis by Veghte and Herreid (1965) at a T_a of -8°C varied from 3.5° to 6.8°C. Smaller species show less variation.

The T_r at each T_a was assumed to be the same for all five groups of birds. At a T_a of -10°C the T_r in the open was -3°C and in all roosts 0°C. At a T_a of 0°C the T_r in the open was 6°C and in all roosts was 8°C. These T_r's fall between values calculated from Calder (1973) for a hummingbird (T_r of 3°C and 10.4°C at a T_a of -10°C and 0°C respectively) and Moen (1973) for a Sharp-tailed Grouse (Pedioecetis phasionellus) (T_r of -2.6°C and 6.0°C at -10°C and 0°C respectively). The Gray Jay used by Veghte and Herreid had a T_r of 4.59°C at -8°C and -4.88°C at -18°C averaged for the entire body surface area but making no adjustment for the area of each separate part. The male and female Redwings used in this study had a T_r of 2.5°C and -2.0°C respectively at a T_a of -7°C.

Sky temperatures (T_s) of -30°C at a T_a of -10°C and -25°C at 0°C were used for the calculations. Under overcast conditions $T_s = T_a$ as suggested by Monteith (1975).

Statistics

Regression lines were fitted to the data on metabolic rates using the least squares method. Metabolic data was analyzed using the General Linear Models Procedure of the Statistical Analysis System to test for main effects. The means of the metabolic rates at each test temperature and each wind velocity were compared using Duncan's Multiple Range Test. Maximum R-square improvement and stepwise regression procedures were used to determine the best model for each group of birds for prediction of the metabolic rate given the ambient temperature and wind velocity. To test for differences in the body temperature and heat transfer coefficients at each temperature between the wind velocities of 12.4 and 15.2 kmh^{-1} t-tests were conducted. Duncan's Multiple Range Test was used to test for differences in body temperature and heat transfer coefficients at either wind velocity between the five test temperatures.

RESULTS

Roost Micrometeorology

The percentage of vegetative cover measured during the winter in several deciduous roosts may be seen in Table 1. Cover varied from a low of 9% in the Brand Rd. roost to a high of 22.3% in the McGowen Rd. roost. Three roosts measured again during July varied from 51% cover in the R&F roost to 94% in the Airport roost. A cattail roost measured during the winter contained 61% cover. A single Eastern redceder tree has 81.3% cover while a pine woods showed 75-96% cover.

The wind velocity measured in the deciduous roosts varied from a low of 25% of the velocity measured outside the roost in the Airport and McGowen Rd. roosts to a high of 73% in the R&F roost. Wind velocity 0.5 meters above the water surface in the cattail roost was 10-16% of the velocity 2.5 meters above the water surface. In the Redceder tree the velocity was 15% of that outside the tree's cover, while 100 meters inside the pine woods was 0% of the velocity recorded outside. The wind velocity outside the pine roost reached a maximum of 48.6 kmh^{-1} during recording.

Wind velocity in the roosts was affected not only by the density of growth within the roost, but also by the surrounding topography. Roosts located in open areas were less effective in reducing the effects of the wind than roosts located in low spots or near buildings. In addition, the size of the roost was an important factor in cutting the wind velocity. In the Airport roost the wind velocity recorded 100 meters inside the roost was 43% of the velocity recorded outside while the velocity 200 meters inside the roost was only 25% of that outside. If the outside velocity was 15.1 kmh^{-1} this represents a difference of 2.7 kmh^{-1} between the two recording locations.

Sky, Ground, Tree, and Bird Surface Temperatures

Measurements of the surface temperatures of the sky, ground, trees, and a male and female Redwing were made in the R&F roost on two clear nights in January and February, 1980. The results may be seen in Table 2. T_g and T_t approximated T_a. T_s was much lower than T_a since the sky was clear.

Bird surface temperatures were measured with a thermocouple held on the bird's wing on night 1 resulting in disturbance of the birds. On night 2 bird surface temperatures were measured from 10 meters with a Mikron 44 infrared thermometer which caused less disturbance in the birds. Because of this the energy budgets were calculated based on the results of night 2.

Heat Transfer Coefficients

Values for the heat transfer coefficients were calculated according to Calder and King (1974), where:

$$h = \frac{H}{(T_b - T_a)}$$

and h is the heat transfer coefficient or thermal conductance in $mWg^{-1}hr^{-1}{}^{\circ}C^{-1}$, H is the heat loss, which equals the metabolic rate (in $mWg^{-1}hr^{-1}$) when the body temperature remains constant, T_b is the body or cloacal temperature, and T_a is the ambient temperature.

The mean heat transfer coefficients are presented in Table 6 and Figures 1-5. In all groups the mean heat transfer coefficients decreased slightly or remained constant over the range of temperatures tested.

A small difference between values for h at 12.4 and 15.2 kmh^{-1} at each T_a existed for all groups. This difference, although present in all cases, was significantly different ($p<.25$) only for male Redwings at 0°, -5°, and -10°C and Cowbirds at 0°C. The difference resulted from a greater heat loss at the higher wind velocity due to a greater heat flux across the insulating feather layer as a result of flattening or disruption of the feather layer. This necessitated increasing the metabolic rate in order to maintain T_b.

An obvious discrepancy appears in values of h for female Redwings at 5° and 10°C. The values of h at 12.4 kmh^{-1} are larger than those at 15.2 kmh^{-1}. This discrepancy resulted from problems encountered in measuring T_b with the first three females used. If results from only the second group of three birds are used at these ambient temperatures this discrepancy disappears.

A comparison of h at each temperature for the two wind velocities separately reveals that for Cowbirds and both groups of Redwings h decreases slightly and then levels off. At 12.4 kmh^{-1} in all three groups the means for h at 10° and 5°C are significantly greater than means at 0°, -5°, and -10°C, which are not significantly different. At 15.2 kmh^{-1} only Cowbirds show a significant difference at 0°C. All other values of h are not significantly different. Mean values of h for both wind velocities in male and female Grackles show no significant differences.

Body Temperatures

Mean body temperatures (T_b) may be seen in Table 6 and Figures 1-5. The mean combined T_b at each T_a decreased 1.6° and 2.1°C for Cowbirds and female Redwings respectively over the range of test temperatures. There are, however, no significant differences among T_b between any test T_a at either wind velocity. The mean combined T_b for male Redwings and male and female Grackles remain essentially constant across the range of T_a's.

While small differences in T_b at any one T_a between the two wind velocities exist, especially noticeable with Cowbirds, none are significantly different ($p<.025$), except for female Redwings at 10°C. This difference again reflects poor data from three of the birds.

Metabolic Rates

The mean metabolic rates (MR) may be seen in Table 6 and Figures 6-10. The MR of all birds increased linearly with the square root of the wind velocity ($v^{1/2}$) at each T_a. The MR decreased linearly with increasing T_a at each wind velocity.

Regression equations of MR on $V^{\frac{1}{2}}$ are presented in Table 3. Table 4 contains regression equations of MR on T_a. Regression lines of MR on wind velocity for each group are presented in Figures 6-10.

An analysis of variance (ANOVE) for a 2-way classification was performed on data for each of the five groups of birds. In all cases significant differences were found between levels of T_a and between levels of wi wind velocity. No significant interaction between T_a and wind velocity was noted in any group.

To test for differences in mean MR at all levels of T_a and wind, Duncan's Multiple Range Test was performed. The results from these tests are included in Tables 3 and 4. Means which were found to be significantly different are denoted by different letters before each equation. All means for each level of T_a and each level of wind were significantly different for Cowbirds (Figure 6). Female Redwings (Figure 8) showed significant differnces between all levels of T_a except 0° and 5°C, and 5° and 10°C. For levels of wind differences were found between 0 kmh $^{-1}$ and 12.4 and 15.2 kmh^{-1}. No differences between the two higher or between the two lower wind velocities were present.

Male Redwings (Figure 7) showed differences between -10°, -5°, and 0°C, but not between 0°, 5°, or 10°C. Differences between all levels of wind were significant.

All levels of T_a were significantly different for female Grackles (Figure 10). For levels of wind differences were present between 3.5 and 12.4 kmh^{-1}, and 0, 3.5, and 15.2 kmh^{-1}, but between 12.4 and 15.2 kmh^{-1}.

Male Grackles (Figure 9) only showed differences between -10°C and 5° and 10°C, between -5°C and 5° and 10°C, and finally between 0°C and 5° and 10°C. Differences between levels of wind are the same as for female Grackles.

A stepwise regression analysis was performed for each group of birds to determine the best equations for prediction of MR for any T_a or wind velocity. These equations appear in Table 5.

Energy Budgets

Calculated net radiative heat losses for all groups of birds at -10° and 0°C in four roost types under clear and fully overcast skys appear in Table 7. A comparison of combined radiative and convective heat losses at -10 C in the four roost types when the wind velocity in the open is 15.2 kmh^{-1} may be seen in Table 9. Also present are maximum heat production values (± 1 S.E.) for each species calculated from maximum metabolic rates presented previously.

from maximum metabolic rates presented previously. The conditions presented are typical for central Ohio during January and February.

The values presented for net radiative heat loss (Hr) show two important features. Values of Hr when birds are under cover are lower than those for birds in the open. The Hr in a pine roost with 96% cover is only 32% of the value in the open at -10°C. In addition under overcast skys Hr is lower than under clear skys, varying from 14% of the clear sky Hr in the open to 91% in a pine roost with 95% cover. This is due to the fact that under heavily overcast conditions the clouds are often in thermal equilibrium with surface temperatures and the emissivity increases to approximately 1.00 (Monteith). These conditions result in the sky and the bird being in approximate thermal equilibrium.

From Tables 8 and 9 one may see the pronounced energetic savings which result from the use of pine roosts. NOt only is the radiative heat loss lower in a roost, but the wind velocity is reduced as well. These additive effects of a roost may result in a 38-43% cenergy savings in a pine roost with 96% cover over birds remaining in the open at -10°C. Under overcast conditions where clouds are assumed to have an emmissivity of 1.00, radiative heat losses in the pine roost may slightly exceed losses in the open. However, savings reamin considerable (17-26%) when there is a moderate wind.

The total heat loss under overcast conditions is considerably lower and in the open at a T_a of -10°C with a wind of 15.2 kmh^{-1} this amounts 21-26% less than under clear skys. Inside the pine woods with 96% cover the total heat loss in reduced 1-2%.

For all blackbirds tested the peak MR is exceeded at 0°C under clear skys for birds in the open and in the 18% cover deciduous roost. In addition female Redwings exceed peak MR in the 75% pine roost under clear skys and in the open and deciduous roost under overcast conditions. At -10°C all blackbirds again exceed the peak MR in the open and deciduous roosts, though the starling could survive in a deciduous roost. Under fully overcast skys the peak MR is exceeded in the open by male and female Grackles and in the deciduous roost by female Grackles. The female Redwings exceed peak MR under all conditions at -10°C.

DISCUSSION

Roosts

In the South, Redwings generally choose weland areas in which to roost, but also make use of deciduous thickets, pines, canebrakes, and sugarcane fields (Meanley 1965). Blackbird roosts in Tennessee and Kentucky were often composed of loblolly pine (Pinus taeds) (Francis 1976; Robertson et al. 1978; Dolbeer et al. 1978), in Ohio Pinus Strobus (Kelty and Lustick 1977), and (in Washington) Robins utilize Douglas-fir

(Pseudotsuga menziesii) (Walsberg and King 1980). Dense cover is important in a roosting site (Meanley 1965), as all of these habitats suggest, as well as protection from the wind.

Blackbirds often roost throughout late summer and early fall in deciduous roosts. At this time deciduous roosts provide a great deal of cover (51-94% for the three roosts measured) and protection from the wind. However, abandonment of deciduous roosts for pine roosts occurs in October or November. In a roost in Olean, New York (Cattaraugus County) this abandonment coincided with the dropping of leaves and temperatures falling to 0.5°C on mostly clear nights. It is reasonable to assume that birds abandoned this roost because it no longer offered the degree of protection it had before the leaves fell.

The wind velocity in winter deciduous roosts varied not only due to the amount of cover in a roost but also due to the surrounding topography, distance of the anemometer from the windward edge of the roost, size of the roost, and the direction of the wind where obstructions might reduce the wind velocity in one direction but not another. For these reasons roosts such as the Brand Road roost, with only 9% cover but with second growth fields, woodlots, and houses surrounding it, showed a lower wind velocity than others with more cover but located in open areas, such as the Kitzmiller Road roost.

Body Temperature

Although body temperatures (T_b) within all five groups of birds showed no significant difference over the T_a range from 10°C to -10°C, in cowbirds and female redwings a small but noticable decrease is present. As noted by Hart (1962) for Starlings, Lustick (1970; 1972) for Cowbirds, Redwing Blackbirds, Grackles, and Starlings, Misch (1960) for Blue Jays (Cyanocitta christata), and Veghte (1964) for Gray Jays, T_b ordinarily decreases a small amount over a wide T_a range.

The decrease in T_b for Cowbirds and female Redwings may be more evident than for the other three groups over the relatively narrow range of test temperatures due to the size of these birds. Cowbirds (46.74g) and female Redwings (43.81g) had lower average weights than male Redwings (63107g), female Grackles (80.74g) and male Grackles (110.1g). Since birds with a smaller body size present a greater surface area relative to their volume over which heat loss may occur a greater portion of the heat they produce may be lost. This heat loss may not be fully compensated by an increase in MR, resulting in a decrease in T_b.

Additionally, these maller birds are not capable of carrying as much plumage per unit surface area as larger birds. The amount of plumage per unit surface area varies as a linear function of body weight (Calder and King 1974). As a result smaller birds have less insulation per unit surface area and thus greater heat loss.

In order for Cowbirds and female Redwings to maintain their T_b at the level of the larger Grackles they must increase their MR to a greater extent. Female Redwings, with a T_b in the same range as that of the Grackles, have a MR 30-35% greater than male Grackles. This represents a much greater cost for the maintenance of homeothermy. Cowbirds have a MR 20-30% greater than male Grackles, but also a lower T_b. These results are consistent with those of Kendeigh (1969) who states that "small species are compelled to increase thier heat production for body temperature regulation to a greater relative extent than are large species".

It is well known that some species, most notably hummingbirds (Lasiewski 1963; Wolf and Hainsworth 1972; Hainsworth et al. 1977) and poorwills (Withers 1977), may allow their T_b to drop, thereby entering a state of torpor. This situation results in reduced energetic demands at low ambient temperatures and is therefore of significant value for small species unable to store large quantities of fat or during periods of low food abundance. The birds used in this study may be utilizing this response to a limited degree (but not entering a state of torpor) as a means of reducing heat loss and thus energy expenditures, but lower T_b may only be a passive response to low T_a.

Heat Transfer Coefficients

The heat transfer coefficient (h) is of importance because it is the sum of several features affecting heat loss in animals (Gordon 1977). Among these features are blood circulation, piloerection, rate of evaporative water loss, and posture. Birds may control each of these to control heat loss in sub-thermoneutral conditions. At some point below the lower critical temperature thermal conductance is reduced to a minimal level and increased heat production becomes the only means of compensating for heat loss.

For all groups of birds tested the values of h remain essentially constant except at a wind velocity of 12.4 kmh^{-1} between 10° and 5°C for Cowbirds and Redwings. An increase in MR is therefore the only avenue by which all birds are compensating for the increasing heat loss below 5°C.

In all groups of birds the values of h at 15.2 kmh^{-1} are greater than at 12.4 kmh^{-1}. This indicates a greater loss of heat at the higher wind velocity and may result from an increasing disruption of the feather layer decreasing its effectiveness as insulation. This is consistent with measurements of h for Cowbirds, Redwings, and Grackles between 10° and 5°C with no wind by Lustick et al. (1972) where h was 0.70 $mWg^{-1}hr^{-1}{}^{\circ}C^{-1}$ for Cowbirds, 0.72 $mWg^{-1}hr^{-1}{}^{\circ}C^{-1}$ for Redwings and 0.56 $mWg^{-1}hr^{-1}{}^{\circ}C^{-1}$ for Grackles. At 12.4 and 15.2 kmh^{-1} in the present study h was 1.09 and 1.11 $mWg^{-1}hr^{-1}{}^{\circ}C^{-1}$ for Redwings (male and female combined), and 0.80 and 0.79 $mWg^{-1}hr^{-1}{}^{\circ}C^{-1}$ for Grackles (male and female combined).

Differences in h between 12.4 and 15.2 kmh^{-1} were not significant except at -10°, -5°, and 0 C for male Redwings and 0°C for Cowbirds.

Nonetheless the consistently higher values of h at -10°, -5°, and 0°C at a wind velocity of 15.2 kmh^{-1} in all groups demonstrates the effect of wind velocity on reducing the effectiveness of a bird's insulation.

The magnitude of h is also related to the size of the bird. Calder and King (1974) present an equation relating h to the weight of the bird whereby the heavier the bird the greater the reduction in heat loss. Using this equation Cowbirds should have a value of h approximately 37% greater than male Grackles with no wind. This relationship remains consistent at higher wind velocities as well. At 12.4 and 1.52 kmh^{-1} the values of h for Cowbirds are 22-36% greater than for male Grackles.

Metabolic Rates

The metabolic rates in this study were determined by testing birds in the dark but during daylight hours. The results obtained compared favorably with other studies using this method. Using the allometric equation derived by Kendeigh (1969) for MR at 0°C and comparing with values determined in this study no difference in MR for Cowbirds, male Redwings, and female Grackles exist. Female Redwings, which were at all times highly excitable, had an 18% greater MR, while male Grackles at 15-21% greater MR than predicted. Lustick (1976) also measured MR under conditions similar to those of this study for Cowbirds, Redwing Blackbirds, and Grackles at T_a's of 5-40°C (data included in Section II). Small differences in MR were present between the two studies for Redwings and Grackles. Lustick did not separate male from female data in his study while they were separated for this study. This alone would account for the minor differences present since males and females are sexually dimorphic with regard to body weight and MR is affected by the size of t the bird. Hart (1962) measured the MR of Evening Grosbeaks (Hesperiphona vespertina vespertina) and Starlings. Results of his study reveal MR's which are much higher than for the comparably sized male Redwings and female Grackles. This may in part be due to the brevity of the tests (one hour) and the lack of previous fasting.

Calder and King (1974) draw attention to the fact that the MR for resting birds in the dark during the day may be 20-25% greater than for resting birds at night. In the zone of thermal neutrality Pohl and West (1973) found a difference of 10%. With decreasing ambient temperatures this increased to 16.5%.

Lewies and Dyer (1969) measured the MR separately in male and female Redwings both during the day and night. A comparison of their results with those of this study reveals no difference between MR of males in this study with males at night of Lewies and Dyer, while females had MR's 34-41% higher than their females at night. For both males and females much higher MR's were recorded during the day than in this study. It is unknown whether Lewies and Dyer ran their daytime tests in the dark or the light. In Lewies and Dyer's study the birds were not given time to adjust to T_a (T_a was changed continually).

The Grosbeaks studied by Dawson and Tordoff (1959) had higher MR's than the Redwings used here even though the Grosbeaks were measured during the night. These birds are in roughly the same weight range.

Misch (1960) measured the MR of Northern Blue Jays (Cyancitta christata bromia) at night. The Blue Jays had MR's 26-34% and 18-30% lower than male Redwings and female Grackles respectively.

It is evident that values for MR determined here fall within the range of determinations from previous studies on the same or similar sized species. Only the MR for female Redwings is consistently greater.

Energy Budgets

The calculated net radiative heat losses and energy budgets reveal the importance of the roost to the birds using it in reducing total energy expenditures. For all birds the net radiative heat loss in a pine roost with 75-96% cover under clear skys was reduced 36-48% over the net radiative heat loss in the open. This is due solely to the increase in cover which the roost provides. This figure corresponds closely to the savings calculated by Calder (1974) for a hummingbird moving under branches to nest. When the additional effect of the roost in reducing the wind velocity is taken into consideration the total energy losses at -10°C in the roost are reduced 37-47% from those in the open. This percentage increases at higher wind velocities. For example, when the maximum recorded wind velocity outside the pine roost was 48.6 kmh^{-1} the velocity inside the roost remained at 0 kmh^{-1}. In this situation, at -10°C the total heat loss from a Cowbird in the open would amount to 3.91 W $bird^{-1}$ while for a Cowbird in the roost with 96% cover would total 2.16 W $bird^{-1}$. In this case the bird in the roost would be expending approximately 45% of the energy expended by the bird in the open as compared to 37% with the lower wind velocity of 15.2 kmh^{-1}.

The energy saving provided by use of the roost is also important on overcast nights due to the reduction in wind velocity caused by the roost even though the net radiative heat loss in the roost may be slightly higher. On calm nights where wind would not be a factor it may be advantageous for the birds to expose themselves to the clouds rather than to the trees, as the difference in net radiative heat loss for Cowbirds at -10°C would be 22%. We found some evidence to support this since birds reportedly roosted at the tops of the trees rather than under cover on some fully overcast windless nights.

The MR's for the energy budgets in Tables 8 and 9 were calculated using the entire body surface as derived according to Walsberg and King (1978). This may result in an error in that most birds tuck their beaks at night which effectively reduces the bird's surface area. This decreases the amount of surface area for the radiating of heat as well as cover a poorly insulated part of the body. In fact, many birds were found to have tucked their beaks during metabolic determinations. The average surface area of the beak is 7% of the skin surface area. When subtracted from the total body surface area the net radiative heat loss is reduced approximately 10% for a Cowbird at -10°C under a clear sky and the total energy budget is reduced approximately 4%. In fact this reduction may be underestimated since the beak may be one of the warmest regions of the bird (Vegthe and Herreid 1965).

Energy budgets will also be overestimated if the MR measured in this study is greater than the standard MR measured at night. The daytime MR's measured here are not consistently greater than the nightime MR of other studies, with the exception of the female Redwings. The female Redwings also exceed their peak MR in all oost conditions as seen in Table 8. However, if these energy budgets are re-calculated taking into account the difference between the data of Lewies and Dyer and this study, the MR of the female Redwings is less than the peak MR in both pine roosts. At -10 C, under clear skys the MR of females in the open drops from 3.86 W $bird^{-1}$ to 2.87 W $bird^{-1}$. In the pine roost with 96% cover the decrease is from 2.41 W $bird^{-1}$ to 1.74 W $bird^{-1}$. It should be pointed out that no Redwing blackbirds overwintered in the Columbus, Ohio area, though Starling, Cowbirds and Grackles do.

SUMMARY

Gates (1962) notes that birds "are magnificently constructed to conserve heat" and that a significant proportion of the heat which is lost is lost through radiation. Coupled with radiative heat loss is that of forced convection. Although heat is also lost through evaporation during breathing, this amounts to less than 5% of the total at the low temperatures discussed here (Calder and King 1974). To maximize their energetic efficiency it is therefore advantageous for wintering birds to make use of microclimates which reduce radiative and convective heat loss. This will be of increasing importance the smaller the bird since smaller birds are more tightly coupled to their environment (King as cited in Calder 1974). It is evident that pine roosts serve this function. In southern areas cattails also serve this purpose for Redwings since they too provide extensive cover and protection from the wind.

Blackbirds switch from deciduous to pine roosts coincident with the loss of foliage in the fall. Deciduous roosts clearly do not offer the energetic advantages of pine roosts due to the loss of cover and greater wind velocities within them.

In addition to the direct protection offered by them, winter roosts also promote more efficient use of limited food supplies and fat stores due to the reduced energy expenditures required of the birds. This will be of great importance where food supplies are limited. It is reasonable to expect blackbirds to maximize their energetic efficiency by roosting in protected areas even when weather conditions are not as severe as central Ohio. Birds doing this may require less foraging time to satisfy their caloric needs.

Under the conditions used in this study the value of a protective roost to a bird is clearly demonstrated even though these conditions are not extreme for central Ohio during the winter. More extreme weather conditions would only increase the importance of the roost to the bird.

All species tested except the Starling exceed their peak MR at -10°C in the open and deciduous roost with 18% cover. When the peak MR is exceeded birds lose heat more quickly than it can be produced which eventually leads to hypothermia and death if the conditions persist. Where food availability is low and birds cannot replenish their fat stores adequately, they may not be capable of even maintaining peak MR throughout an entire night, even where heat loss and heat production are balanced. This too may lead to death. Therefore the roost acts as a very important conservation mechanism for birds. The ability to make use of such roosts may allow extension of the winter range of blackbirds farther north than might otherwise be the case if heat loss acts as a limiting factor. This has been suggested by Lefebvre and Raveling for Canada Geese (Branta canadensis maxima and B.C. parvipes) (1967).

A major implication of these findings is that it may be practical to control or disperse large roosting congregations of blackbirds through alteration of the roost itself. In the past attempts to control large roosts viewed as health, agricultural, and safety hazards have been largely unsuccessful. Two principal methods have been used: scaring or noise devices which birds become accustomed to, and killing birds, especially by wetting with Turgitol, which depends upon specific weather conditions (Weatherhead and Bider 1979). In addition there has been much public criticism of killing of birds (Graham 1976) as well as questions raised as to the environmental impact of killing large numbers of birds and whether such action is actually justified by agricultural damage or public health hazards (Robertson et al. 1978).

Control of blackbird congregations through alteration of roosting sites may be accomplished by simply removing a percentage of trees and/or branches. This would reduce the percent cover causing an increase in the net radiative heat loss from the birds as well as to increase the velocity of the wind inside the roost causing greater heat loss by forced convection. Protection from the wind in a roost thinned 66% by Francis (1976) was greatly reduced. The wind velocity inside the roost increased from 0-7.6% of that outside the roost. For a Cowbird roosting in a pine roost with 75% cover this would amount to an increase in MR from 2.32 W bird $^{-1}$ on a clear night at -10°C to 3.123 W bird $^{-1}$ with two-thirds of the roost thinned (assuming the two-thirds of the cover is thinned). This amounts to approximately a 25% increase in MR. Furthermore this higher MR exceeds the peak MR of cowbirds. If these figures are reasonable approximations then it may be assumed that birds will disperse from a thinned roost, or not congregate at that roost during the establishment of that roost because it will no longer be energetically advantageous to do so. The result of such habitat manipulation would be dispersal of birds from a particular site without killing them.

The extent of thinning necessary to result in bird dispersal will most likely vary with each roost site. Factors of importance will be the surrounding topography, proximity and amount of food available to the roosting birds, and the amount of vegetation which can be thinned without destruction of the woodlot.

Habitat manipulation is likely to be of greatest benefit in northern areas where weather conditions are more extreme and birds consequently are stressed to a greater extent.

Table 1. Percent cover and wind velocity expressed as the percentage of the wind velocity outside the roost for several roost types.

Roost	Percent Cover	Wind Velocity %
Henderson Rd.	13%	63-73%
Roost #2	11-16%	50-60%
Kitzmiller Rd.	21.7%	55-58%
Worthington	16.6%	50-58%
R and F Roost	winter 18% summer 51-80%	50%
Brand Road	winter 9% summer 88%	42%
Airfield	winter 13-16% summer 87-94%	43% @ 100m 25% @ 200m
Morse Rd.	10.8%	35-38%
McGowen Rd.	22.3%	25-28%
Cattail Marsh	61.6%	10-16%
Cedar tree	81.3%	15%
Pine Roost	75-96%	0%

Table 2. Measured ambient temperature (T_a), ground temperature (T_g), tree temperature (T_t), sky temperature (T_s), and body temperature (T_b) of a male and female Redwing in the R and F Roost on two nights in January 1980. (Temperature = °C).

Night	T_a	T_g	T_t	T_s	T_b	T_b-T_a
1	-8°	-8°	-8°	-37°	-5° to -4°	3°-4°
2	-7°	-6°	-7°	-26°	♂ 2.5°	9.5°
					♀ -2°	5°

Table 3. Regression equations for metabolic rate (mW$g^{-1}hr^{-1}$) on the square root ($v^{\frac{1}{2}}$) of wind velocity at five temperatures.

Species	Temp. (°C)	Equation	r	N
Cowbirds	10°	*a $17.53 + 3.628v^{\frac{1}{2}}$	0.834	40
	5°	b $20.08 + 3.457v^{\frac{1}{2}}$	0.822	40
	0°	c $23.67 + 3.765v^{\frac{1}{2}}$	0.760	40
	-5°	d $28.61 + 3.085v^{\frac{1}{2}}$	0.730	40
	-10°	e $30.38 + 3.294v^{\frac{1}{2}}$	0.714	40
Male Redwings	10°	a $19.35 + 2.316v^{\frac{1}{2}}$	0.558	28
	5°	a $21.36 + 1.916v^{\frac{1}{2}}$	0.511	28
	0°	a $20.05 + 2.622v^{\frac{1}{2}}$	0.619	28
	-5°	b $23.10 + 2.681v^{\frac{1}{2}}$	0.606	28
	-10°	c $24.54 + 3.458v^{\frac{1}{2}}$	0.786	28
	10°, 5°, 0°	$20.25 + 2.285v^{\frac{1}{2}}$	0.562	84
Female Redwings	10°	a $25.82 + 2.939v^{\frac{1}{2}}$	0.533	24
	5°	ab $28.41 + 3.158v^{\frac{1}{2}}$	0.687	24
	0°	b $30.76 + 3.347v^{\frac{1}{2}}$	0.684	24
	-5°	c $36.96 + 2.725v^{\frac{1}{2}}$	0.517	24
	-10°	d $38.06 + 4.785v^{\frac{1}{2}}$	0.660	24
Male Grackles	10°	a $14.23 + 1.983v^{\frac{1}{2}}$	0.697	22
	5°	a $15.56 + 2.250v^{\frac{1}{2}}$	0.719	24
	0°	b $18.74 + 2.709v^{\frac{1}{2}}$	0.785	21
	-5°	b $17.87 + 3.226v^{\frac{1}{2}}$	0.885	16
	-10°	b $18.66 + 3.445v^{\frac{1}{2}}$	0.733	21
	5°, 10°	$14.92 + 2.125v^{\frac{1}{2}}$	0.694	46
	-10°, -5°, 0°	$18.52 + 3.091v^{\frac{1}{2}}$	0.773	58
Female Grackles	10°	a $14.66 + 2.196v^{\frac{1}{2}}$	0.698	24
	5°	b $15.52 + 2.789v^{\frac{1}{2}}$	0.875	24
	0°	c $17.37 + 3.919v^{\frac{1}{2}}$	0.845	22
	-5°	d $22.17 + 2.826v^{\frac{1}{2}}$	0.718	18
	-10°	e $23.03 + 3.817v^{\frac{1}{2}}$	0.883	16

*Equations denoted by the same letter are not significantly different ($P > .05$).

Table 4. Regression equations for metabolic rate ($mWg^{-1}hr^{-1}$) on ambient temperature (x) at four wind velocities.

Species	Wind Vel. (kmh^{-1})	Equation	r	N
Cowbirds	0.0	*a 24.79 - 0.771x	-0.803	50
	3.5	b 29.08 - 0.496x	-0.680	50
	12.4	c 36.23 - 0.519x	-0.704	50
	15.2	d 38.07 - 0.759x	-0.709	50
Male Redwings	0.0	a 22.55 - 0.318x	-0.562	35
	3.5	b 25.23 - 0.223x	-0.361	35
	12.4	c 28.64 - 0.408x	-0.506	35
	15.2	d 34.56 - 0.603x	-0.551	35
Female Redwings	0.0	a 33.05 - 0.789x	-0.769	30
	3.5	b 36.23 - 0.568x	-0.513	30
	12.4	c 44.66 - 0.712x	-0.575	30
	15.2	d 45.61 - 1.178x	-0.743	30
Male Grackles	0.0	a 17.46 - 0.321x	-0.690	28
	3.5	a 21.06 - 0.176x	-0.319	24
	12.4	b 26.57 - 0.396x	-0.591	26
	15.2	c 28.28 - 0.740x	-0.784	26
Female Grackles	0.0	a 19.67 - 0.528x	-0.705	27
	3.5	b 22.09 - 0.471x	-0.739	26
	12.4	c 29.40 - 0.778x	-0.920	26
	15.2	d 32.03 - 0.752x	-0.794	25

* Equations denoted by the same letter are not significantly different ($P > .05$).

Table 5. Regression equations for prediction of metabolic rate ($mWg^{-1}hr^{-1}$) from ambient temperature and wind velocity.

Species	Equation	R^2
Cowbirds	$MR = 24.864 - 0.636T_a + 1.253v - 0.026v^2$	0.721
Male Redwings	$MR = 23.422 - 0.263T_a + 0.003v^3 - 0.00009T_av^3 - 0.002T_a^2v$	0.554
Female Redwings	$MR = 33.204 - 0.638T_a - 0.858v - 0.0001T_av^3$	0.586
Male Grackles	$MR = 17.926 - 0.335T_a - 0.693v - 0.077T_av - 0.007T_av^2$	0.683
Female Grackles	$MR = 19.465 - 0.504T_a - 0.815v - 0.001T_av^2$	0.797

Table 6. Mean metabolic rates (MR, in $mWg^{-1}hr^{-1}$), body temperature (T_b, in °C), and heat transfer coefficients (h, in $mWg^{-1}hr^{-1}°C^{-1}$) of Cowbirds, Redwing Blackbirds, and Common Grackles. ($\bar{X}$ ± S.E.)

Wind Vel. (kmh^{-1})	10°C MR	10°C T_b	10°C h	5°C MR	5°C T_b	5°C h	0°C MR	0°C T_b	0°C h	-5°C MR	-5°C T_b	-5°C h	-10°C MR	-10°C T_b	-10°C h
COWBIRDS (N = 10)															
0.0	17.18± 1.00	—	—	20.43± 1.10	—	—	24.85± 1.38	—	—	29.49± 1.70	—	—	31.90± 1.39	—	—
3.5	24.63± 1.20	—	—	25.82± 1.38	—	—	28.71± 1.34	—	—	32.67± 1.18	—	—	33.69± 1.11	—	—
12.4	32.19± 0.94	37.39± 0.45	1.14± 0.07	32.46± 1.15	36.19± 0.27	1.04± 0.04	35.42± 0.99	35.69± 0.31	1.00± 0.03	39.57± 1.36	34.95± 0.41	1.00± 0.03	41.61± 1.47	34.99± 0.50	0.92± 0.05
15.2	29.82± 1.41	36.45± 0.22	1.12± 0.05	33.71± 1.25	35.75± 0.66	1.10± 0.04	40.66± 2.19	34.89± 0.42	1.19± 0.06	41.37± 1.49	35.99± 0.41	1.02± 0.04	44.92± 2.07	35.79± 0.37	1.01± 0.05
MALE REDWING BLACKBIRDS (N = 7)															
0.0	20.05± 1.40	—	—	21.53± 1.51	—	—	20.45± 1.33	—	—	24.28± 1.02	—	—	26.59 0.98	—	—
3.5	22.63± 1.70	—	—	24.84± 1.71	—	—	24.72± 1.66	—	—	26.44 2.09	—	—	27.44 0.97	—	—
12.4	25.89± 2.08	38.35± 0.47	0.92± 0.06	26.84± 2.40	38.43± 0.23	0.80± 0.07	26.35± 1.77	38.67± 0.33	0.67± 0.05	29.35± 1.50	38.59± 0.55	0.68± 0.04	34.80± 1.53	38.59± 0.22	0.72± 0.03
15.2	30.33± 2.89	39.14± 0.28	1.05± 0.11	30.01± 2.23	38.85± 0.54	0.89± 0.08	33.02± 2.68	38.64± 0.30	0.86± 0.07	37.23± 2.71	38.59± 0.22	0.85± 0.06	41.47± 1.44	38.79± 0.15	0.85± 0.03
FEMALE REDWING BLACKBIRDS (N = 6)															
0.0	26.01± 2.61	—	—	27.65± 1.40	—	—	32.47± 1.46	—	—	38.85± 2.41	—	—	40.13± 1.84	—	—
3.5	30.20± 3.42	—	—	35.60± 2.89	—	—	33.83± 1.47	—	—	38.81± 2.62	—	—	42.81± 3.72	—	—
12.4	40.26± 3.09	38.59± 0.29	1.57± 0.15	40.44± 2.96	37.50± 0.58	1.27± 0.10	42.10± 2.98	38.09± 0.27	1.16± 0.14	44.40± 2.25	37.59± 0.20	1.08± 0.06	56.08± 3.10	36.67± 0.71	1.12± 0.08
15.2	34.13± 2.79	38.75± 0.48	1.15± 0.14	39.28± 1.07	37.93± 0.66	1.19± 0.02	45.75± 2.76	37.93± 0.66	1.21± 0.07	51.08± 3.85	37.33± 0.60	1.23± 0.13	57.67± 4.97	36.59± 0.76	1.25± 0.10

Table 6 (Continued).

Wind Vel. (kmh^{-1})	10°C			5°C			0°C			-5°C			-10°C		
	MR	T_b	h	MR	T_b	h	MR	T_b	h	MR	T_b	h	MR	T_b	h
MALE COMMON GRACKLES															
0.0	13.52± 0.83	—	—	15.72± 0.60	—	—	19.24± 1.35	—	—	18.65± 1.37	—	—	20.01± 1.00	—	—
3.5	19.48± 2.62	—	—	19.34± 1.76	—	—	22.30± 1.86	—	—	22.33± 1.63	—	—	22.33± 1.06	—	—
12.4	21.83± 1.12	37.30± 0.97	0.81± 0.07	24.13± 2.09	36.50± 0.77	0.78± 0.08	28.53± 1.88	37.00± 1.48	0.77± 0.08	29.60± 1.44	38.00± 0.91	0.70± 0.04	29.31± 1.88	38.00± 0.77	0.60± 0.04
15.2	20.88± 0.89	37.50± 0.50	0.73± 0.05	23.96± 1.01	37.67± 0.33	0.70± 0.03	29.60± 1.57	37.17± 0.48	0.80± 0.05	30.87± 1.20	37.38± 0.90	0.74± 0.02	35.77± 4.59	36.75± 0.25	0.79± 0.10
FEMALE COMMON GRACKLES															
0.0	15.48± 1.79	—	—	16.09± 0.96	—	—	18.33± 1.77	—	—	23.72± 2.06	—	—	24.99± 1.21	—	—
3.5	17.30± 1.31	—	—	19.60± 1.26	—	—	22.92± 1.83	—	—	23.43± 2.05	—	—	27.02± 1.03	—	—
12.4	21.81± 1.54	37.08± 0.82	0.81± 0.07	25.52± 0.54	37.25± 0.60	0.79± 0.02	28.84± 1.01	37.5± 0.42	0.76± 0.04	33.47± 0.93	37.30± 0.30	0.80± 0.02	37.35± 1.22	36.63± 0.75	0.82± 0.03
15.2	24.45± 1.20	38.00± 0.34	0.87± 0.04	26.77± 1.16	37.17± 1.05	0.86± 0.04	35.12± 1.56	37.42± 0.42	0.94± 0.03	33.61± 2.83	38.00± 0.00	0.80± 0.06	39.37± 1.61	36.50± 0.50	0.89± 0.04

Table 7. Calculated net radiative heat loss (W $bird^{-1}$) for birds at -10° and 0°C in four roosting sites under clear and overcast conditions.

Species	Roost Type		Percent Cover	Hr 0°	Hr -10°
Cowbirds	Open	*c	0%	1.39	1.42
		o		0.503	0.547
	Deciduous	c	18%	1.36	1.33
		o		0.536	0.575
	Pine	c	75%	0.892	0.895
		o		0.640	0.665
	Pine	c	96%	0.719	0.734
		o		0.679	0.698
Male Redwings	Open	c	0%	1.70	1.74
		o		0.615	0.678
	Deciduous	c	18%	1.66	1.64
		o		0.655	0.713
	Pine	c	75%	1.09	1.10
		o		0.783	0.823
	Pine	c	96%	0.879	0.908
		o		0.829	0.867
Female Redwings	Open	c	0%	1.35	1.38
		o		0.512	0.557
	Deciduous	c	18%	1.32	1.30
		o		0.542	0.583
	Pine	c	75%	0.880	0.887
		o		0.642	0.669
	Pine	c	96%	0.716	0.735
		o		0.678	0.699
Male Grackles	Open	c	0%	2.44	2.52
		o		0.892	0.983
	Deciduous	c	18%	2.41	2.37
		o		0.951	1.03
	Pine	c	75%	1.58	1.60
		o		1.14	1.19
	Pine	c	96%	1.27	1.32
		o		1.20	1.25
Female Grackles	Open	c	0%	1.98	2.03
		o		0.692	0.771
	Deciduous	c	18%	1.93	1.90
		o		0.739	0.812
	Pine	c	75%	1.25	1.27
		o		0.890	0.942
	Pine	c	96%	1.00	1.04
		o		0.946	0.989
Starlings	Open	c			2.05
	Deciduous		18%		2.0
	Deciduous	c	30%		1.82
	Pine	c	75%		1.24
	Pine	c	96%		0.93
	Cedar Tree	c	81%		1.15

* c = clear sky, o = overcast sky

Table 8. A comparison of heat loss (W bird^{-1}) from birds by radiation and convection at 0°C in four roost types at a wind velocity of 15.2 kmh^{-1} in the open under clear and fully overcast skys.

Species	Roost Type	Percent Cover	Wind Vel.	MR^1	MR^2	Peak MR
Cowbirds	Open	0%	15.2	3.18	2.30	2.94±
	Deciduous	18%	7.6	2.95	2.13	0.15
	Pine	75%	0.0	2.00	1.75	
	Pine	96%	0.0	1.83	1.79	
Male Redwings	Open	0%	15.2	3.61	2.52	2.99±
	Deciduous	18%	7.6	3.38	2.38	0.44
	Pine	75%	0.0	2.35	2.05	
	Pine	96%	0.0	2.14	2.09	
Female Redwings	Open	0%	15.2	3.27	2.43	2.12±
	Deciduous	18%	7.6	3.07	2.29	0.29
	Pine	75%	0.0	2.23	1.99	
	Pine	96%	0.0	2.06	2.03	
Male Grackles	Open	0%	15.2	5.67	4.12	4.61±
	Deciduous	18%	7.6	5.30	3.84	1.69
	Pine	75%	0.0	3.64	3.20	
	Pine	96%	0.0	3.33	3.26	
Female Grackles	Open	0%	15.2	4.62	3.33	3.38±
	Deciduous	18%	7.6	4.20	3.01	1.24
	Pine	75%	0.0	2.65	2.29	
	Pine	96%	0.0	2.40	2.35	

1 = clear sky; 2 = fully overcast sky

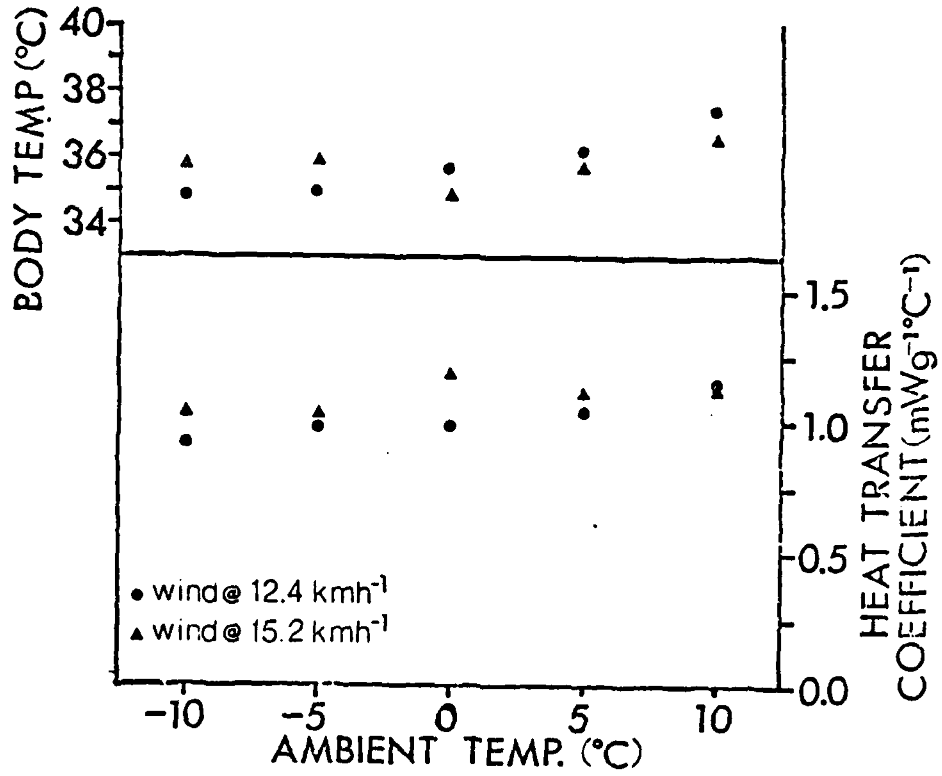

Figure 1. Body (cloacal) temperatures and heat transfer coefficients of male Cowbirds at five temperatures and two wind velocities.

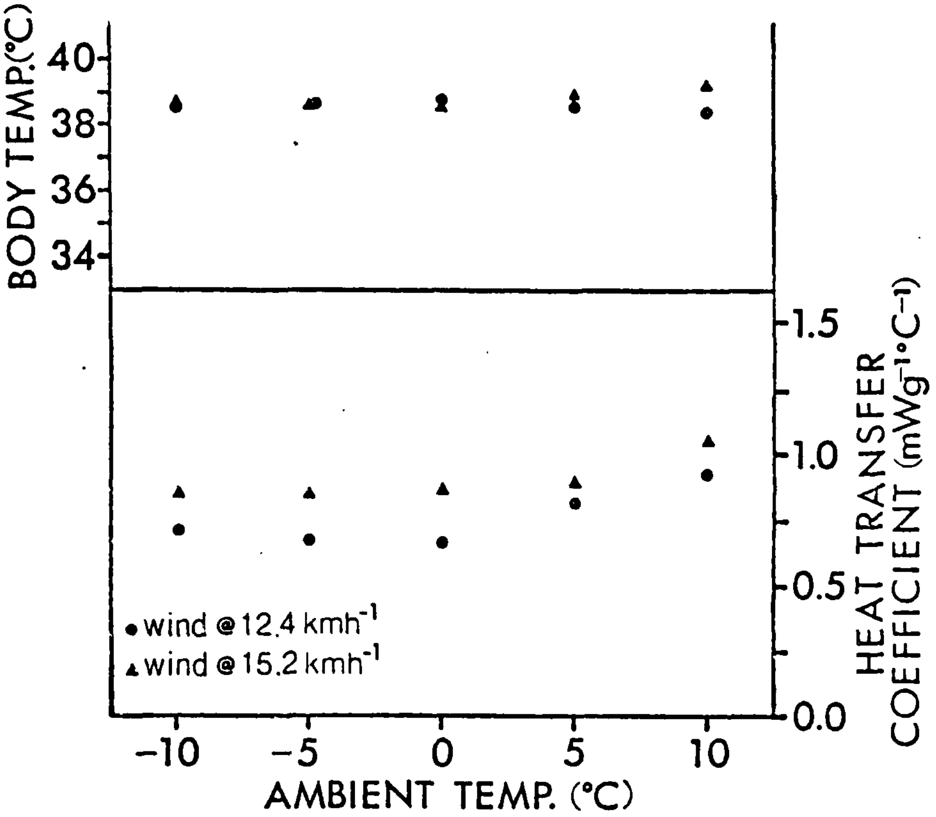

Figure 2. Body (cloacal) temperatures and heat transfer coefficients of male Redwing Blackbirds at five temperatures and two wind velocities.

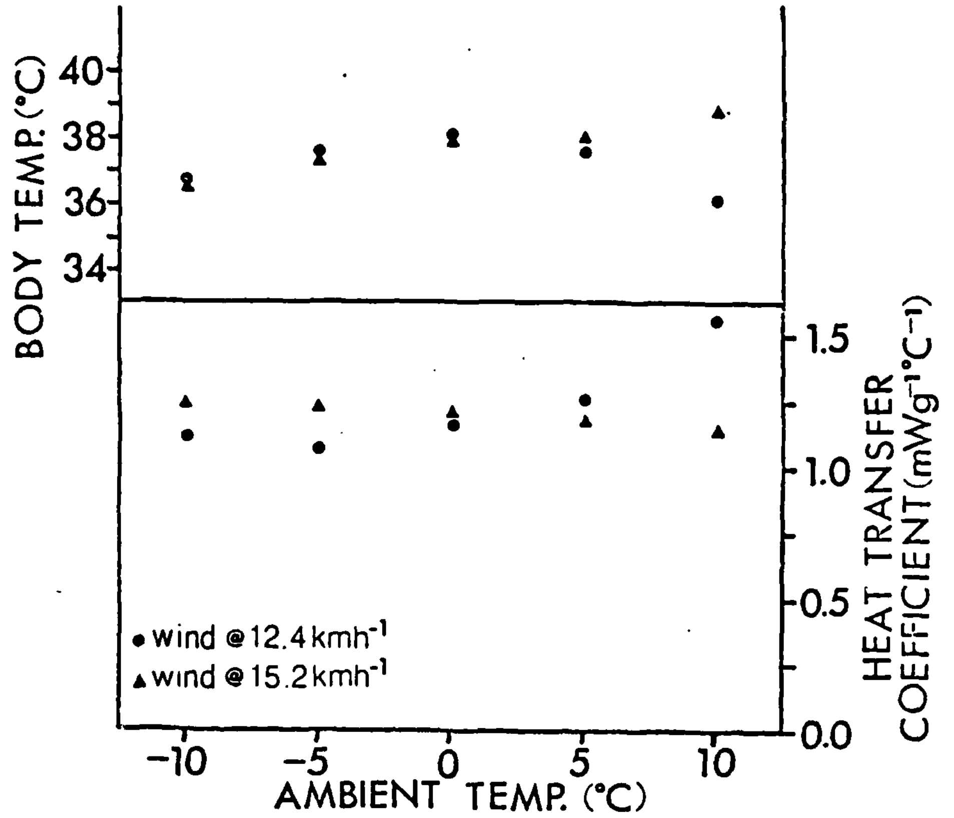

Figure 3. Body (cloacal) temperatures and heat transfer coefficients of female Redwing Blackbirds at five temperatures and two wind velocities.

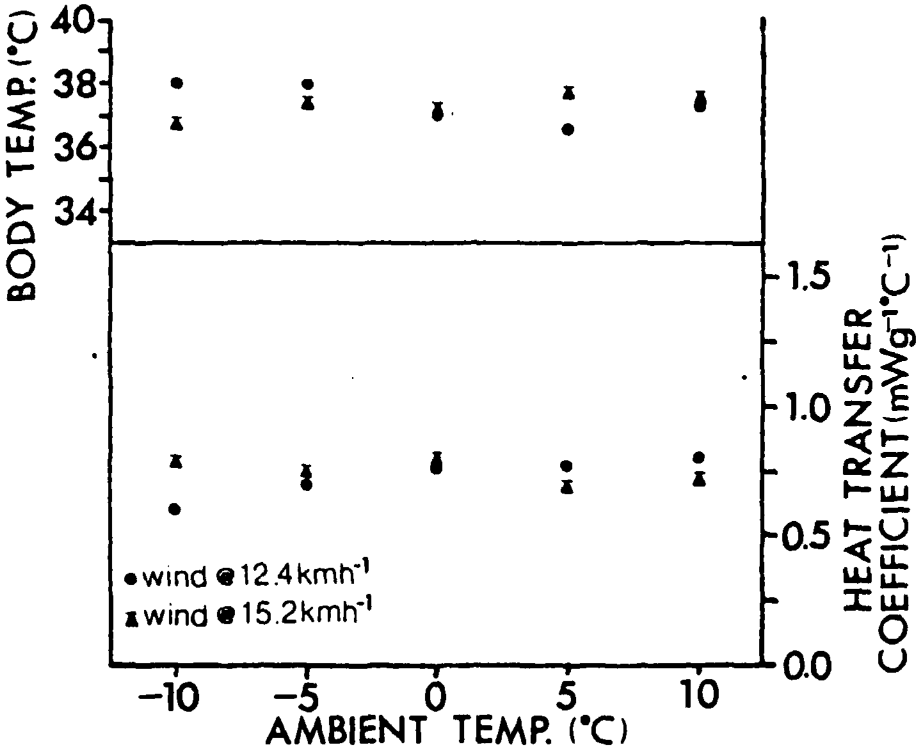

Figure 4. Body (cloacal) temperatures and heat transfer coefficients of male Common Grackles at five temperatures and two wind velocities.

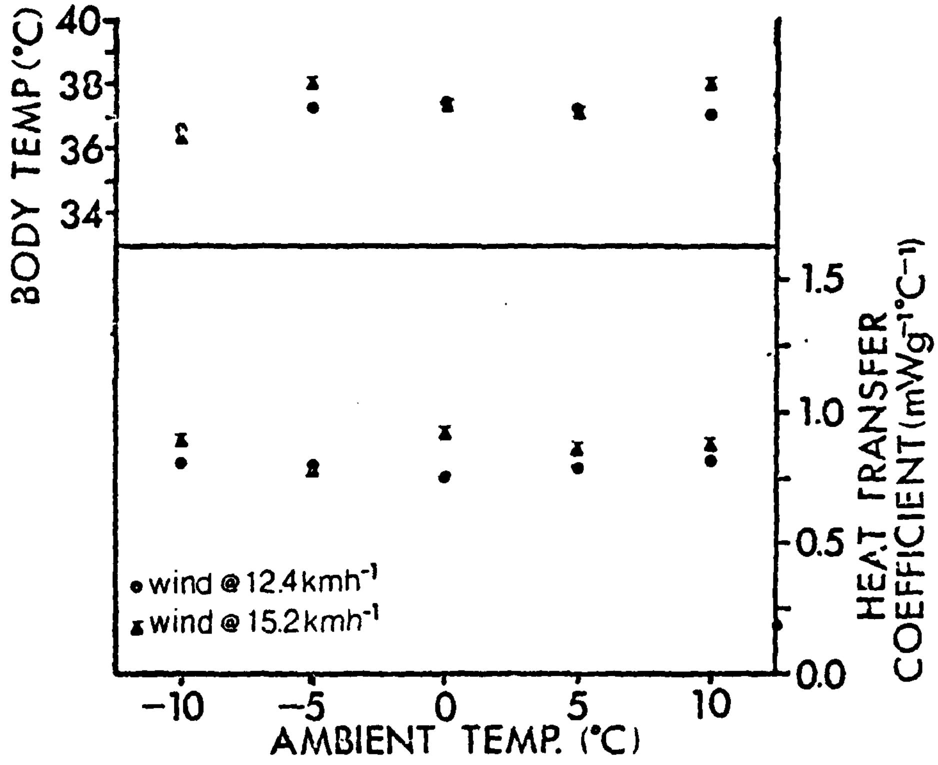

Figure 5. Body (cloacal) temperatures and heat transfer coefficients of female Common Grackles at five temperatures and two wind velocities.

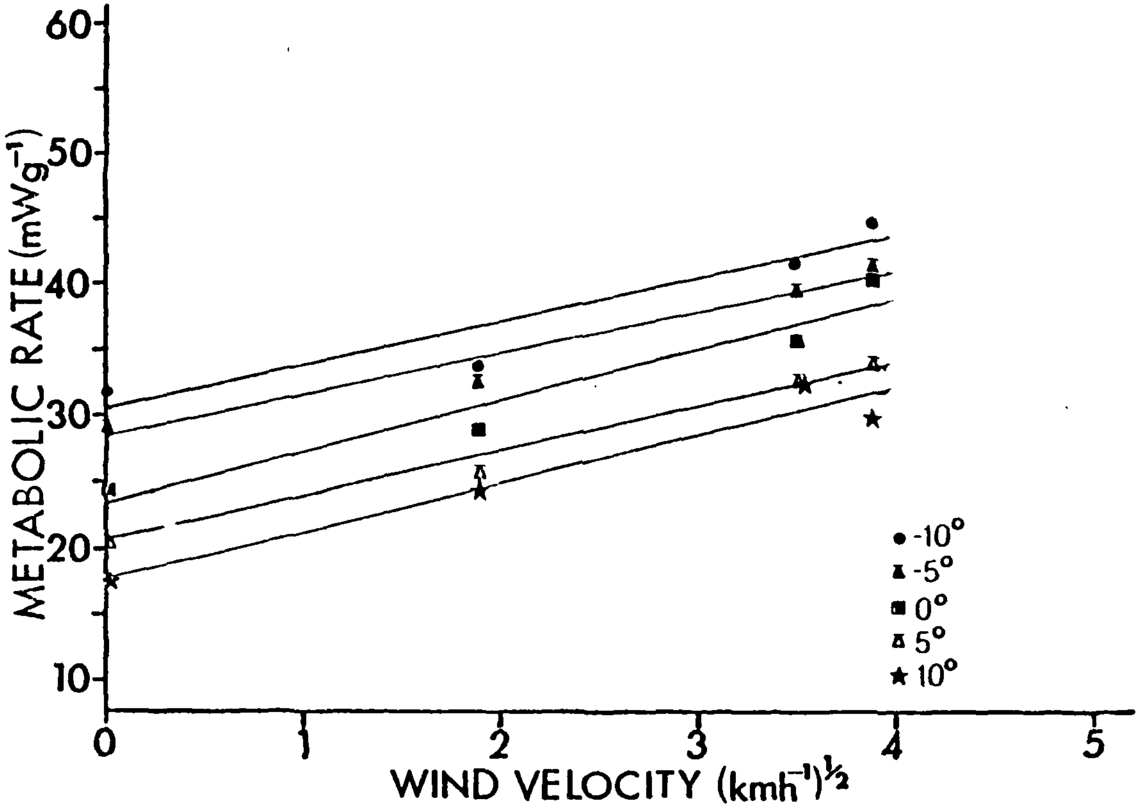

Figure 6. Metabolic rates of male Cowbirds at five temperatures and four wind velocities. Points represent means.

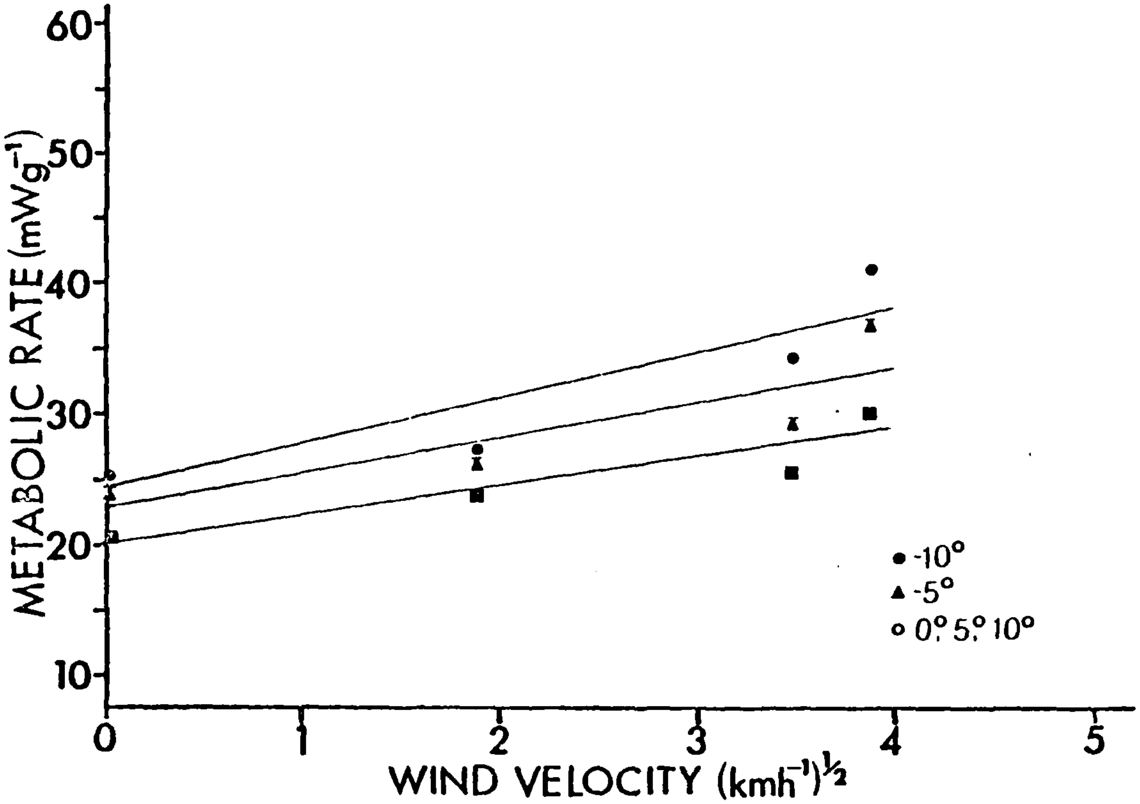

Figure 7. Metabolic rates of male Redwing Blackbirds at five temperatures and four wind velocities. Data at 0^{o}, 5^{o}, and $10^{o}C$ have been combined. Points represent means.

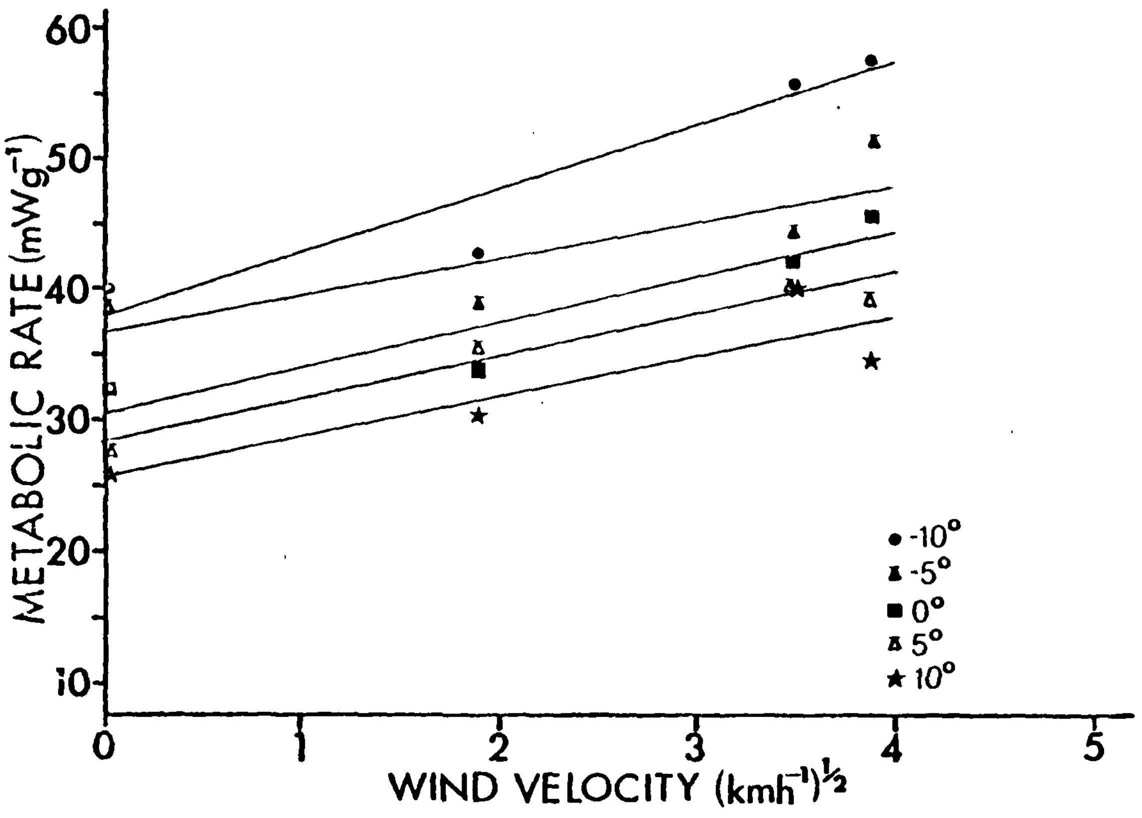

Figure 8. Metabolic rates of female Redwing Blackbirds at five temperatures and four wind velocities. Points represent means.

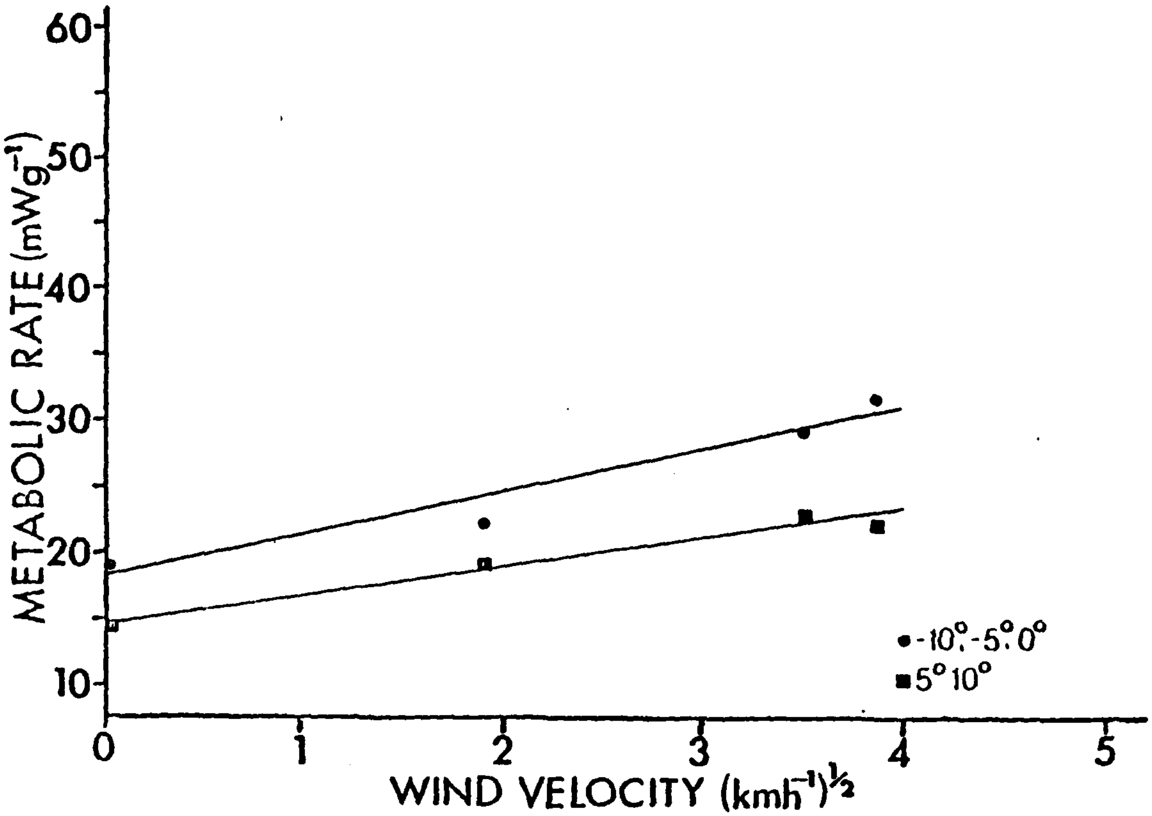

Figure 9. Metabolic rates of male Common Grackles at five temperatures and four wind velocities. Data at -10^{0}, -5^{0}, and 0^{0} and data at 5^{0}, and 10^{0}C have been combined. Points represent means.

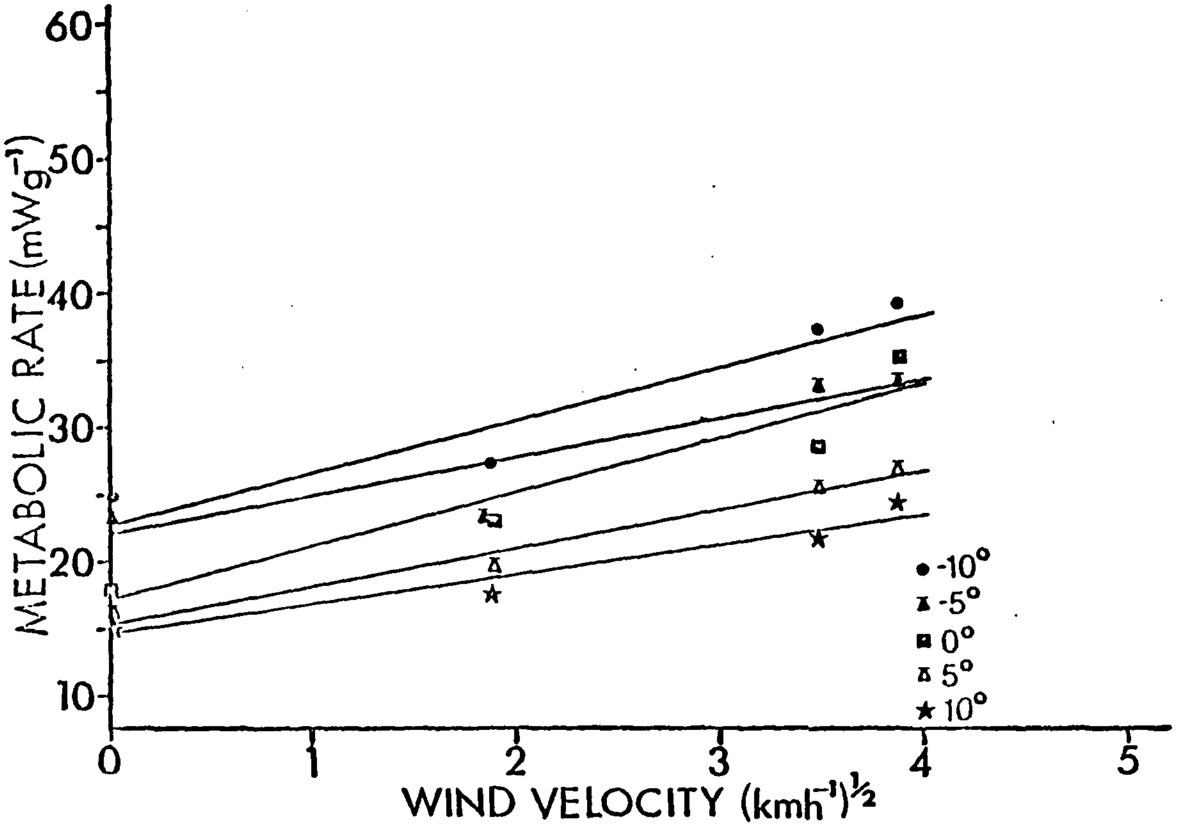

Figure 10. Metabolic rates of female Common Grackles at five temperatures and four wind velocities. Points represent means.

SUMMARY

1. The percent of vegetative cover and the wind velocity were measured in deciduous roosts, a cattail roost, a single Redceder tree, and a pine roost.

2. The metabolic rate (MR) was determined for Cowbirds, Redwing Blackbirds, and Grackles in a wind tunnel at temperatures of -10°, -5°, 0°, 5°, and 10°C at wind velocities of 0.0, 3.5, 12.4, 15.2 kmh^{-1}.

3. Body temperatures and heat transfer coefficients were determined for all test temperatures at wind velocities of 12.4 and 15.2 kmh^{-1}.

4. Energy budgets were calculated for all groups of birds from the values for net radiation exchange and metabolic rates with forced convection.

5. Metabolic rates increased linearly with the square root of the wind velocity and decreased linearly with rising ambient temperatures. Heat transfer coefficients were constant below 5°C and greater at a wind velocity of 15.2 than 12.4 kmh^{-1}. Body temperatures remained essentially constant below 5°C for all birds.

6. Calculated net radiative heat losses were greater under clear skys than under overcast skys, and decreased with an increase in the percent cover of the roost.

7. Calculated energy budgets for all birds exceeded peak metabolic rates at -10° and 0°C under clear skys in an open roost and a deciduous roost with 18% cover. In the pine roosts metabolic rates were below peak metabolic rates for all birds except female Redwings. Under overcast skys total heat loss was reduced.

8. Habitat manipulation by thinning was suggested as a possible control method for blackbirds. This would increase net radiative and convective heat loss such that it would no longer be thermally advantageous to use that roost.

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