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Plumage temperatures of Dippers *Cinclus cinclus* on the roost and in the hand: implications for handling small passerines

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The outer breast plumage temperature of Dippers *Cinclus cinclus* roosting beneath river bridges was measured using an infra red thermometer over the environmental temperature range –0.8 to +10.9°C. Plumage temperature was close to, and directly related to, the temperature of the birds' surroundings, but significantly higher (ΔT = 2.87°C), suggesting slight heat loss across the plumage to the environment. Plumage temperatures were also measured in Dippers held in the hand; they were much elevated over environmental temperatures (ΔT = 17-18°C at 0°C), indicating substantial heat loss during handling.

Dippers (genus *Cinclus*) are the only passerines that dive and swim; they are also the smallest adult diving birds (*ca* 50-70 g). They forage, predominantly on insects, in streams and rivers and their distribution extends into cold temperate and mountainous areas where water temperatures may fall to 0°C and air temperatures reach -40°C (Bakus 1959). Cold water poses more of a thermal challenge than cold air because the thermal conductivity of water is about 23 times that of air (review of Denny 1993). Dippers dive repeatedly for periods of up to 30 s, normally to no more than about 1 m depth (O'Halloran *et al* 1990, Tyler & Ormerod 1994). Between dives they bob to the surface, shedding water efficiently. Anatomical study has revealed that dippers have an unusually dense plumage, with the American Dipper *Cinclus mexicanus* having an individual mean contour feather count of 4,200 (Goodge 1959) compared with counts below 3,000 in a range of similar-sized passerines (Wetmore 1936). More importantly, dippers have a very dense down between the feather tracts, instead of naked skin as in most other birds (Murrish 1970a). Dippers also have a relatively large uropygial gland (about ten times the size of that of other passerines of similar size), making the plumage extremely water-repellent (Tyler & Ormerod 1994). American Dippers have a thermoneutral zone (ie the range over which no changes in metabolic rate in relation to temperature change occur) ranging from 11.5°C to 34°C. American Dipper body temperatures were close to 40°C at air temperatures ranging from -30°C to +33°C, but rose at higher temperatures. At air temperatures above 36°C, body temperatures rose uncontrollably. Overheating appears to be a greater problem for dippers than does cooling during exposure to cold water or air. Field and laboratory investigations show that American Dippers combat overheating by immersing their uninsulated legs in available cool water (Murrish 1970a, b).

Here we report a study on the Dipper *Cinclus cinclus*, which may be approached during nocturnal roosts without disturbance. Breast plumage temperatures were measured with a non-invasive infra red (IR) thermometer. The hypothesis being tested was that plumage surface temperatures should be nearly identical with environmental temperature, to minimize energy expenditure during roosting. We also report on plumage temperatures of Dippers held in the hand while morphometric and mass measurements were made; these have relevance to autumn/winter handling protocols of small birds in general.

METHODS

Study area

Dippers were studied at night in river systems in Counties Cork and Waterford, Ireland, between September and February in 2000-2001 and 2001-2002 (see Smiddy *et al* 1995 for more details). All birds roosted individually under river bridges, sometimes in gaps between stones, sometimes on open ledges of steel support girders. The temperature recording protocol was added to a long-term population study of Dippers that necessitated their regular capture (O'Halloran *et al* 1992, 1999, 2000, Smiddy *et al* 1995).

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Temperature recording

All field temperature recording was carried out using a Stix 610LC infra red (IR) thermometer (Metrix Electronics PLC) set to a thermal emissivity of 0.95 (similar to the emissivity of water, rock, metal and skin) held 1-3 cm from the plumage of the bird being studied (thus ensuring that the measurement area was only 1-2 cm across), or from the stones/girders on which the bird roosted. Pilot experiments using an electronic thermometer as well as the IR thermometer had established that air temperature and stone/girder temperature were invariably very close, probably because the observations were conducted at night, when solar warming is absent. IR measurements took about 5 s. The IR thermometer had a resolution of 1°C and was calibrated against an alcohol-in-glass thermometer (resolution 0.1°C) over the temperature range 0-35°C, using water as the calibration medium. A regression equation between real temperature and IR temperature was used to calibrate the IR readings. The IR thermometer was held at environmental temperature between readings to avoid condensation on the IR sensor, but readings were impossible on occasions when relative humidity was very high due to heavy rainfall. Correct IR thermometer function was checked regularly during each field session by repeatedly measuring throat temperature (37°C) of the thermometer operative. To take measurements in the hand, the bird was held by the tarsal joints by one operative, while another used the IR thermometer to measure temperature of the crown, breast and belly (from a distance of 1 cm), the whole procedure taking about 15-20 s.

The roosting site was approached after dark by two operatives. Once the lead operative had established the presence of a roosting Dipper, the thermometer-carrying operative approached the Dipper, keeping low to avoid disturbance. The other operative carried a net. If the Dipper remained quiescent with its eyes closed and was within reach, its breast plumage temperature was measured before it was netted. If it was alert or out of reach it was immediately netted for biometric measurement and transferred to a standard cloth bird bag. In most cases, bridges housed several roosting Dippers. Usually capture of the first bird alerted the others, so that no further roosting temperature measurements were possible, though more birds were netted and transferred to bags. Thirty-one field temperature measurements were made on roosting birds. For each roosting bird a temperature measurement of its immediate surroundings was also taken.

After capture, the bagged birds were carried to a nearby car for processing. In-hand crown, breast and belly plumage temperatures were measured as soon as possible, usually 5-15 min after capture, immediately after birds were removed from their bags. It was not possible to standardize the in-bag time because of variable distances between capture site and the car. In-hand measurements were made on 96 birds, yielding 288 temperature values. After temperature measurement, birds were weighed and biometrics recorded. The birds were rebagged and released beneath the bridge of capture. It was not possible to record the duration of the entire capture-to-release sequence accurately, but 30 min would be representative. In-hand temperatures were compared with surface temperatures recorded from bridge roosting sites (range: –0.8 to +10.9°C).

RESULTS

Field breast plumage temperatures

The temperatures of the surface of breast plumage in roosting Dippers (n = 31) are presented in Figure 1. There is a strong positive linear correlation between the outer plumage temperature of the Dippers and the temperature of their surroundings. The 95% confidence intervals of the slope of the calculated regression line (1.023) encompass 1, showing that the slope does not differ significantly from that of the isotherm. Breast plumage temperature is therefore directly proportional to environmental temperature. However, the regression analysis also shows that breast plumage temperatures are generally significantly higher than environmental temperatures (regression ΔT= 2.87°C by comparison with isothermal line, where ΔT is a temperature difference), indicating consistent loss of heat from the plumage over the environmental temperature range of the study (–0.8 to +10.9°C).

In-hand plumage temperatures

The data for plumage temperatures in the hand (Figure 2) were treated in three ways. First, crown, breast and belly temperatures (Table 1) were tested for normality of distribution (Anderson-Darling test; all normal, P values 0.25 - 0.42). Second, crown, breast and belly temperatures were regressed separately against environmental temperatures (Table 2). In each case

Table 1. Plumage temperatures of Dippers in the hand. Data are from 31 birds.

Variable (°C)	Mean	Median	SD
Crown temperature	18.9	18.7	4.8
Breast temperature	20.3	20.6	5.9
Belly temperature	20.0	19.6	5.1
Environmental (surface) temperature	3.3	3.1	2.8

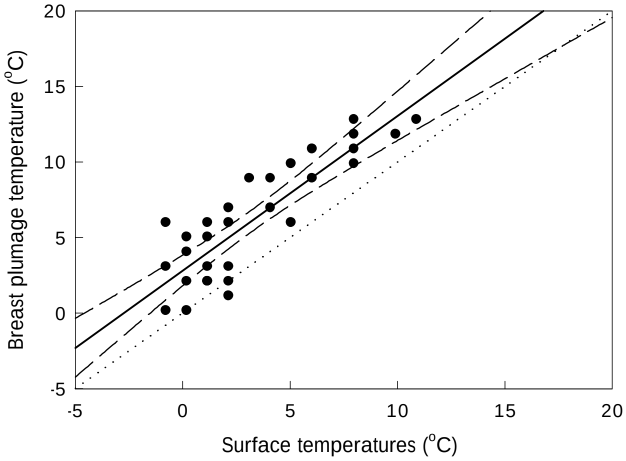

Figure 1. Thermal results collected from roosting Dippers. Filled circles show individual data; note that there are some overlapping points. Solid lines: regression fit. Dashed lines: 95% confidence intervals. Regression equation: $y = 2.87 + 1.023x$ ($n = 31$; $r^2 = 0.754$; $p<0.001$). Dotted line: indicates equal temperatures (isotherm). Slope of regression (1.023, SE 0.109) does not differ significantly from 1 (slope of isotherm: see text), indicating that plumage temperature is directly proportional to environmental temperature in roosting dippers.

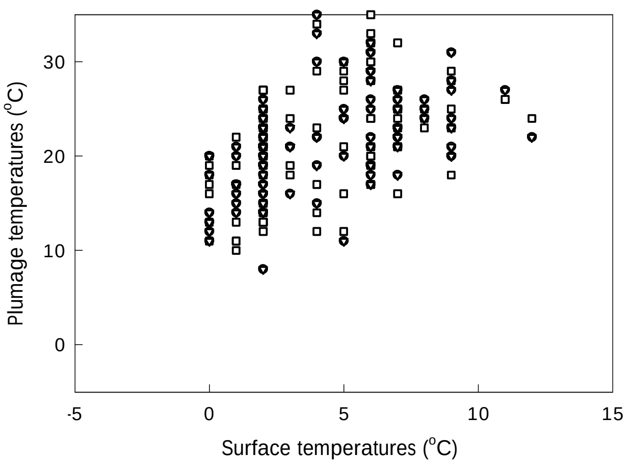

Figure 2. Plumage temperature data collected from Dippers in the hand. Open circles show belly temperatures, open squares show breast temperatures, and open triangles show crown temperatures.

Table 2. Results of linear regression analysis of Dipper plumage temperatures. Data are from 73 individuals. In each case, x = environmental temperature (°C)

y parameter (°C)	Regression Equation	r^2 (%)	P
Crown	y = 17.7 + 0.599 x	11.5	<0.005
Breast	y = 17.5 + 0.995 x	22.1	<0.005
Belly	y = 17.5 + 0.927 x	25.6	<0.005

there was a weak, but highly significant positive relationship between plumage temperature and environmental temperature: there was a slight tendency for plumage temperatures to rise with environmental temperature. Third, a linear mixed-effects model was used to explore the relationships between surface and body temperatures, and the differences between body regions. Mixed-effects models allow for repeated or multiple measures from individuals, and group the data so as to avoid pseudoreplication, or false inflation of the sample sizes, when generating the statistic results (Pinheiro & Bates 2000). The residuals from the model were normally distributed. The analysis was carried out using S-Plus version 6.2 for Windows. The resulting linear mixed-effects model is summarised in Table 3 and confirms that the body temperature of the birds was significantly positively related to the ambient temperature. Furthermore, the temperatures of the belly and breast did not differ significantly, but both were significantly warmer than the head by approximately 1°C.

DISCUSSION

The data presented here appear to be the first systematic, non-invasive records of outer plumage temperature derived from free-living roosting birds. While the relationship between plumage temperature and bird metabolism is likely to be complex, we believe that this technique may be of wider utility in ornithological studies.

Ireland has a mild maritime climate and the autumn/ winter temperatures encountered by Dippers in the

Table 3. Summary of a restricted maximum likelihood, linear mixed-effects model with temperature as the dependent variable and explanatory variables for body region (head, breast or belly) and ambient temperature. The data are grouped by individual bird. There are data from 73 birds. The parameter estimates for body region compare the head and breast against the belly.

ANOVA

Term	F	df	P
Ambient temperature	83.07	1, 212	< 0.0001
Body region	4.187	2, 212	= 0.0165

Parameter estimates

Term	Value	SE	df	t	P
Intercept	16.38	0.69	212	23.71	< 0.0001
Ambient Temperature	1.088	0.12	212	9.11	< 0.0001
Breast	0.15	0.26	212	0.58	NS
Head	-0.43	0.15	212	2.83	< 0.01

current study (–0.8 to +10.9°C) were unexceptional for a species that reaches subarctic Scandinavia. However, these are below the thermoneutral zone reported for American Dippers by Murrish (1970a). In consequence, it must be presumed that these fairly mild temperatures involve an increased metabolic rate to maintain core temperature. Against expectation, roosting Dippers have outer plumage temperatures significantly above ambient, though far below the expected body temperature of about 40°C. Since experimental studies indicate that outer plumage temperatures of birds exposed to cold conditions should be close to ambient temperatures, thus minimizing heat loss (Scholander *et al* 1950), an explanation for this finding is required. Two opposing possibilities are obvious; first that Dipper insulation is not effective enough to contain a complete thermal gradient between skin and environment, or second that roosting Dippers manipulate their plumage to lose heat, perhaps to avoid hyperthermia, or over-heating. At present it is impossible to determine which of these possibilities is the correct one. Dippers are unusually well insulated; if their insulation leaks heat, then presumably passerines of similar, or smaller, size with poorer insulation would lose far more heat by this route. It is also worth noting that many passerines of similar, or smaller size than Dippers (eg House Sparrows *Passer domesticus*, Starlings *Sturnus vulgaris* and Wrens *Troglodytes troglodytes*) roost communally at night for the thermal benefit of huddling (Soper 1982, Davenport 1992), whereas Dippers roost in solitary fashion, even when several birds are roosting beneath a single bridge.

The thermal situation for Dippers in the hand is different from that at the roost. At an environmental temperature of 0°C, ΔT is 17-18°C (from the regression data shown in shown in Table 2). Clearly, Dippers in the hand are burning resources very rapidly. Interpretation of the high outer plumage temperatures in the hand is not straightforward. The stress of capture, which is presumably perceived by the birds as a predatory attempt (Silverin 1998) triggering an adrenocortical stress response (Smith *et al* 1994, Newman *et al* 1997, Hood *et al* 1998), will undoubtedly cause a rise in metabolic rate and increased muscular thermogenesis associated with attempts to escape. This will tend to cause a rise in body temperature, necessitating deployment of heat loss measures by the Dippers. Holding in a cloth bag probably exacerbates heat build up because it insulates against convective heat loss, even though it will quieten the bird. Murrish (1970a) noted that heat loss was a problem for American Dippers unless they could dip their legs in cold water, because they were unable to lose heat by gular fluttering. It is likely that one response is to reduce the efficiency of plumage insulation by manipulation of the piloerector muscles. However, handling may also cause minor disruption of the plumage, which might also degrade insulative efficiency.

Newton's Law of Cooling predicts that rate of heat loss is proportional to the temperature difference between the warm object and the cool surroundings. Conservatively, a Dipper handled at 0°C will lose heat across the plumage at least six times more quickly than it would have done if left undisturbed on the roost, and will continue to lose heat at this rate for a period of around 30 minutes in studies of the type reported here. This estimate assumes a constant rate of loss and an instant reversion to roosting loss rate at the end of handling. The wasted energy represents several hours (at least three, probably more) of that lost during normal metabolism and must be considered a significant cost to the handled bird. Although two of us (JO'H and PS) have caught and measured hundreds of Dippers over 13 years, and many birds have been caught up to 12 times, over several seasons, it would clearly be prudent to minimize capture frequency and handling time. For birds of this size and smaller, energy losses of this type should be considered when devising capture programmes. Capture, ringing and measurement of birds is justified as it provides information that aids their conservation (Baillie *et al* 1999). However, it would certainly increase the costs of ringing to capture passerines, with less effective insulation than Dippers, at night during cold winters when the heat loss associated with handling could compromise overnight survival.

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