THE USE OF STOMACH TEMPERATURE RECORDS FOR THE CALCULATION OF DAILY FOOD INTAKE IN CORMORANTS

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Summary

We present a new method of measuring the food intake in cormorants based on stomach temperature recordings. Stomach temperature loggers were deployed both in captive and in free-living birds. We examine the accuracy of this method and compare it with the standard methods of evaluating food intake by pellet or stomach content analysis.

Introduction

Cormorants eat fish and are often seen as direct competitors of man (Im and Hafner, 1984; Deufel, 1987; Linn and Campbell, 1992). The impact of cormorants on fish populations is consequently an important feature in cormorant research. The daily amount of food eaten by these seabirds is normally determined by analysing regurgitated pellets or stomach contents (Duffy and Jackson, 1986). Pellets consist of mucus and hard prey remains and are regularly egested by the birds. These pellets can be easily collected at breeding sites or roosting areas, and prey remains, such as otoliths, may be analysed and the species and masses of prey determined. Diet can be also assessed by collecting stomach contents, mainly of shot birds (Madsen and Spärck, 1950; Rand, 1960), although in some circumstances birds may be tame enough to be caught by hand and induced to regurgitate (Wilson, 1984; Duffy and Jackson, 1986). Both methods have different drawbacks and, consequently, neither is ideal for the determination of prey quantities (Van Dobben, 1952; Duffy and Laurenson, 1983; Johnstone et al. 1990).

Wilson et al. (1992) recently proposed using variations in stomach temperature caused by the intake of cold food in homeotherms to determine the amount of food eaten by seabirds and the time of feeding. We attempted to test this new method by recording the stomach temperature of captive cormorants (Phalacrocorax carbo sinensis) and of free-
living bank cormorants (P. neglectus) by using ingestible temperature loggers. Here we present the results of this study and compare them with the classic methods of pellet and stomach content analysis.

**Materials and methods**

Stomach temperature curves were recorded using the EATL (Einkanaliger Automatischer TemperaturLogger; Elkutec Electronic GmbH, D-84174 Eching, Germany) and the SICUP (single-channel unit processor; Driesen and Kern GmbH, Am Hasselt 25, D-24576 Bad Bramstedt, Germany).

The EATL consists essentially of a memory chip, a quartz clock, a temperature sensor (range 20–45 °C; with relative and absolute accuracies of at least 0.1 °C and 1.0 °C, respectively, no drift) and a lithium battery. The electronics fit in a watertight titanium housing and record the temperature at the surface of the housing every 16 s. The unit weighs approximately 80 g, is 100 mm long and has a diameter of 23 mm. The temperature sensor sits flush with the titanium housing so that temperature changes in the housing occurring not immediately adjacent to the sensor may still be conducted to the sensor (full details are given by Wilson et al. 1992).

The SICUP is very similar to the EATL but only weighs 17 g and is smaller (72 mm×12 mm diameter). The SICUP temperature sensor has relative and absolute accuracies of at least 0.4 °C and 1.0 °C, respectively, within a range of 0–50 °C (no drift). Both units were calibrated in a waterbath at 37 °C.

The first part of the study was conducted during February 1992 on four captive great cormorants (Phalacrocorax carbo sinensis) at the zoo in Neumünster, Germany. The birds were housed in a 300 m² pen equipped with three pools. At dawn daily, birds voluntarily took a herring (Clupea harengus) within which an EATL was housed. The birds were subsequently fed at intervals during the day *ad libitum* with herring and roach (Rutilus rutilus) of known mass and temperature. The units were egested as pellets the next morning. We recorded the activity patterns of the unrestrained birds on a manual data recorder.

The second part of the study was conducted during October 1992 on 20 free-living bank cormorants (Phalacrocorax neglectus) raising small chicks at Dassen Island (33°25′S, 18°05′E), South Africa. The cormorants were caught by hand on their nests and induced to swallow a SICUP together with a fish of known mass and temperature. The birds were never restrained for longer than 1 min. Devices were fed so that the non-sensor end was put in first. These devices were also egested after a maximum period of 22 h. When the SICUPs were egested with a pellet, the associated hard remains such as fish otoliths or crustacean carapaces were measured and the lengths and masses of the corresponding prey items back-calculated using formulae given in Batchelor and Ross (1984). As with captive cormorants, activity patterns were recorded using a Husky field computer.

The intake of cold prey by homeotherms leads to precipitous drops in the stomach temperature followed by an exponential rise (termed PDER events by Wilson *et al.* 1992; Fig. 1). Wilson *et al.* (1992) found a linear relationship between the integral under the
asymptote, \( \text{Int} \ (\degree \text{C} \times \text{s}; \text{see Fig. 1}) \), and the energy invested to warm the food, \( \text{En} \ (\text{J}) \), whereby:

\[
\text{Int} = m \times \text{En}
\]

(Wilson et al. 1992), where \( m \) is a constant.

\( \text{En} \) itself is related to the mass of food eaten, \( M \ (\text{g}) \), its specific heat capacity, \( SH \ (\text{J} \degree \text{C}^{-1} \text{g}^{-1}) \), its temperature \( T \ (\degree \text{C}) \) and to the stomach temperature after warming has been completed, \( T_s \ (\degree \text{C}) \) (i.e. when the slope is zero; see Fig. 1) by:

\[
\text{En} = M \times \text{SH} \times (T_s - T)
\]

(Wilson et al. 1992), where \( SH \) is taken to be that of water, \( 4.17 \degree \text{C}^{-1} \text{g}^{-1} \).

Thus, the amount of food ingested at each PDER event can be calculated using:

\[
M = \text{Int} / [m \times \text{SH} \times (T_s - T)]
\]

(Wilson et al. 1992).

In addition to the analytical method of Wilson et al (1992), we used a modified method proposed by Grémillet (1993), the temperature rise integral method (TRIM), because the PDER events we recorded did not always show the precipitous drops described by Wilson et al. (1992). We thus chose to use only the second part of the PDER events (the exponential rise, ER events) for the determination of \( \text{Int} \) (Fig. 2). This facilitated the analysis of stomach temperature curves that occurred when the temperature probe was swallowed together with a fish, because in these cases only the exponential rise of the temperature is registered. Here, the additional energy invested to warm the logger must be considered for the calculation of \( \text{En} \). This energy is related to the temperature of the logger before warming, \( T_{\text{logger}} \ (\degree \text{C}) \), which is related to \( T \), to its mass, \( M_{\text{logger}} \ (\text{g}) \) and to its specific heat capacity, \( SH_{\text{logger}} \ (\text{J} \degree \text{C}^{-1} \text{g}^{-1}) \), \( (SH_{\text{cat}}=0.612 \degree \text{C}^{-1} \text{g}^{-1}, \ SH_{\text{sicup}}=1.25 \degree \text{C}^{-1} \text{g}^{-1}; \text{K. Pütz, unpublished data}) \). The amount of food eaten can be then determined as follows:
\[ M = \left\{ \frac{\text{Int}}{m \times \text{SH} \times (T_s - T)} \right\} - \left( M_{\text{logger}} \times \frac{\text{SH}_{\text{logger}}}{\text{SH}} \right), \]  

(4)

where the term \( \text{SH}_\text{logger}/\text{SH} \) gives the ‘water equivalent’ mass of the logger.

Since captive cormorants were fed with fish of known mass, it was possible to express the variation \( (D) \) between calculated mass, \( M \) (g), and true mass, \( M_t \) (g), of food eaten as a percentage of its real mass:

\[ D = \left( \frac{(M_t - M)^2}{M_t^2} \right) \times 100. \]  

(5)

This allowed us to compare the accuracy of the two methods of analysis used.

We performed a specific calibration for the bank cormorants using the PDER events resulting from the intake of a SICUP and a fish. Since these events only consisted of the warming of the SICUP together with a fish, we chose to back-calculate the mass of the prey item using equation 4. The best fit between \( E_n \) and \( \text{Int} \) was not linear, but exponential. The equation used to determine \( M \) was:

\[ M = \left\{ \frac{\ln(\text{Int}) - a}{b \times \text{SH} \times (T_s - T)} \right\} - \left( M_{\text{sicup}} \times \frac{\text{SH}_{\text{sicup}}}{\text{SH}} \right), \]  

(6)

where \( a \) and \( b \) are the slope and coefficient of the regression between \( E_n \) and \( \text{Int} \) (with \( E_n \) as the independent variable), \( M_{\text{sicup}} \) and \( \text{SH}_{\text{sicup}} \) are the mass (g) and the specific heat capacity (J °C\(^{-1}\) g\(^{-1}\)) of the SICUP, respectively.

Consequently, another form of equation 3 was used to calculate the mass of each prey taken by the birds during their foraging bouts:

\[ M = \frac{(\ln(\text{Int}) - a)}{(b \times \text{SH} \times (T_s - T))}. \]  

(7)

Results

In captive birds, drops in the stomach temperature of more than 0.4 °C per measurement interval were attributed to the intake of food. However, 40% of these events, unlike the PDER events described by Wilson et al. (1992), showed a stepwise
The decrease of the stomach temperature after the bird had been fed a prey item (Fig. 3). The captive cormorants were observed to drink while bathing but this never caused the stomach temperature to drop, probably because the small amounts of water taken in were warmed before entering the stomach.

The masses of 10 prey items (real mean mass 137 g; S.D. 42 g) taken by the cormorants containing an EATL at the zoo were calculated using equation 3 \( m = 1.04, r^2 = 0.52 \) to have a mean error, \( D \), of 27\% (Fig. 4).

The masses of the same 10 prey items were also calculated using the TRIM and equation 3 \( m = 0.93, r^2 = 0.65 \) with a mean error, \( D \) of 15\% (Fig. 5).

The masses of 27 items swallowed together with an EATL (mean real mass 180 g; S.D. 109 g) were...
72 g) were calculated according to equation 4 \( (m=1.08, r^2=0.78) \). The slope of the regressions between \( En \) and \( Int \) (see equation 1) for the two last groups of prey items are not statistically different \( (t\text{-test}, P>0.05, \text{Fig. 6}) \).

The mean daily food intake of captive cormorants in real mass was 309 g (s.d. 120 g, \( N=16 \)) in birds equipped with EATLs and 336 g (s.d. 98 g, \( N=16 \)) for controls. These values are not significantly different \( (t\text{-test} \, P>0.05) \). The pellets collected with the EATLs were also normal in their form and contents.

In free-living birds, only 12 of the 19 SICUPs used were recovered after being egested by the birds. Seven of the 12 recovered units were regurgitated after less than 9 h, in six
cases before any food had been taken by the bird, and five units were regurgitated after at least 17 h. The SICUPs were found in and around the nests.

The masses of the 11 fish taken with the units (mean real mass 56 g) were back-calculated using equation 6 with a mean error, $D$, of 5% (Fig. 7). Sixty feeding events were registered for six different birds over 17 foraging trips (an example is shown in Fig. 8). All PDER events occurred while the birds were away from the nest. We used equation 7 to calculate the mass of the 60 prey items (mean 28 g; s.d. 28 g; range...
5–100 g). We found a mean food intake of 87 g (s.d. 74 g; N=13; range 0–295 g) per foraging bout and 282 g (s.d. 150 g; N=5; range 193–547 g) per day.

Five of the six devices that were ejected after at least 17 h were recovered surrounded by a thick layer of mucus and food remains. Three of the five pellets contained remains of a rock lobster (*Jasus lalandii*) with estimated masses of 80–100 g, 110–140 g and 100–120 g. One pellet contained only mucus and the last pellet contained otoliths from four pilchards (*Sardinops ocellatus*), with estimated masses of 7, 8, 17 and 25 g, and from one horse mackerel (*Trachurus trachurus capensis*) with an estimated mass of 16 g. Mean daily food intake estimated by pellet analysis was thus 80 g (s.d. 49 g; N=5; range 0–140 g).

**Discussion**

The relationship between the amount of food eaten and the integral of the corresponding PDER event can be influenced by six main factors: the volume of the temperature probe; the position of the device in the stomach; the fullness of the stomach; the degree of stomach churning; the body mass of the bird; and the activity level of the bird.

Further miniaturisation of the devices used, which should help to minimise any disturbance caused to the birds, will also lead to a reduction of the surface area of the highly conductive titanium housing and will reduce the likelihood that prey items will come into contact with the temperature logger. This ultimately means that smaller units will be overall less sensitive to the ingestion of prey. We believe that this problem may be resolved by making loggers which tend to stay in the upper part of the stomach, and which will be less affected by stomach fullness and therefore be better placed to react to ingested prey.

A recent study on cormorants (*P. carbo sinensis*) (D. J. H. Grémillet and D. Schmid, unpublished data) showed that the logger usually stays upright in the stomach, which is not wide enough to allow the device to be inverted. In addition, bank cormorant pellets composed of SICUPs invariably had prey remains stuck to the non-sensor end of the device, indicating that this end stayed on the bottom of the stomach until egestion. We thus recommend that the device be given to the birds so that the sensor is directed towards the top of the stomach. This should prevent the sensor end from being isolated through semi-solid food and therefore being affected by the fullness of the stomach. This method allowed us to detect single prey items calculated to weigh as little as 6 g.

Wilson *et al.* (1992) make the assumption that the stomach contents, i.e. food, gastric fluid and temperature logger, are well mixed at all times. Thus, any variation in temperature at any point in the stomach should be detected by the logger, and the intake of cold food should generate a precipitous drop of the stomach temperature followed by an exponential rise. However, most of the feeding events we registered did not begin with a precipitous drop but with a slower decrease in the stomach temperature (Fig. 3). This is presumably due to poor contact between the cold food and the temperature sensor, which could be attributed to the insulation of the logger through semi-solid food. Conversely, no irregularities were found during the second part of the PDER events (exponential rise, see
Fig. 3), probably because stomach churning had then been initiated, following the stimulus of prey ingestion. We therefore consider that the first part of a PDER event gives a less accurate indication of the mass of the fish eaten and recommend that the energy invested to warm the food be correlated with the integral of the ER event (exponential rise of the stomach temperature) under the asymptote. This results in an improvement of the mean accuracy of 12% \( D=27\% \) for an analysis following Wilson et al. (1992) against \( D=15\% \) for the method proposed for the experiments with captive cormorants.

An increase in body mass generally results in an increase of the mass of thermogenetic tissues. Thus, heavier birds should be able to warm their prey more quickly than lighter birds. Calibration should consequently be species-specific and dependent on the individual body mass.

Heat generated by metabolic processes is 75% of overall energy expenditure in homeotherms (Schmidt-Nielsen, 1991). It is thus likely that the integrals of the ER events are highly correlated with the activity level of the bird during and after feeding (Wilson and Culik, 1991). Since the captive cormorants were kept in a very large pen, they could display variable activities after food intake, e.g. bathing, walking, resting or sleeping. Conversely, the free-living bank cormorants studied at Dassen Island returned to their nests within a few minutes of being released and subsequently rested for extended periods (mean 135 min, s.d. 41 min; the mean warming time of the prey item taken with the SICUP was 15 min). These behavioural differences are likely to account for the relatively low accuracy of our method at the zoo compared with the results obtained in the field. In captive birds, the amount of heat generated was very variable, giving variable rates of ingesta warming. The free-living birds all generated similar amounts of heat and thus generated standard warming conditions with a consequent high accuracy in prey size estimates. In addition, swimming and diving in cormorants is likely to result in an important increase in heat production and/or heat loss to the water, which presumably brings additional variability to the ER integral per unit prey mass. We plan to recalibrate this method under natural conditions by training tame cormorants to catch fish of known mass in a pool.

Overall determination of special \( m \) coefficients for each mass class at a high activity level and using ER events for the analysis of the stomach temperature curves are expected to improve the present method.

**Comparison with other indicators of diet**

Pellet analyses can be used to determine the daily amount of food eaten by cormorants (Duffy and Laurenson, 1983; Im and Hafner, 1984; Worthmann and Spratte, 1987; Johnstone et al. 1990). The indigestible prey remains, such as otoliths, present in pellets sampled at breeding colonies give information about the lengths, and thus the masses, of fish eaten by birds. Derivation of the total mass of food ingested per cormorant per day and appropriate rescaling to derive population consumption estimates are, however, inadvisable for a number of reasons. (1) Cormorants might egest more or less than one pellet a day (Duffy and Laurenson, 1983; D. J. H. Grémillet, personal observations) and consequently the pellet content might not represent the remains of the food taken during 24h period. (2) Pellets containing large amounts of fish remains are preferentially
collected by the researcher because they are easier to find, which results in a bias. (3) Otoliths and other food remains can be wholly or partly eroded during digestion or get passed out as faeces (Duffy and Laurenson, 1983). The studies of Duffy and Laurenson (1983) and Worthmann and Spratte (1987) show that erosion is highly variable and difficult to correct for.

In this study, stomach temperature data from five bank cormorants gave information on 45 feeding events. For the same birds over the same period, the pellets sampled contained the remains of only eight prey items. Therefore over 80% of the prey were fully digested, or the birds produced more than one pellet.

Stomach content studies usually require that cormorants be shot or made to regurgitate (Wilson, 1984; Duffy and Jackson, 1986). The stomach contents from each bird are then considered to represent the amount of food eaten during one foraging bout. However, this also has a number of drawbacks. (1) Cormorants, when shot, may regurgitate at least part of their stomach contents (Van Dobben, 1952). (2) At the time of shooting, the stomach contents do not always represent the total amount of fish taken during one foraging trip, but rather a ‘snap-shot’ made at some point during the trip. The stomach often only contains part of the meal, either because the bird is not satiated or because some prey have already been evacuated from the stomach during digestion. (3) The number of foraging bouts per day can be highly variable (between zero and nine bouts per day in bank cormorants; Cooper, 1984). (4) The amount of food eaten during a foraging trip is also highly variable (between 0 and 294 g in bank cormorants, this study). Overall, we conclude that estimation of prey masses ingested per day can be determined reasonably accurately by stomach temperature sensors.

Dietary studies based on stomach temperature recording cause only relatively little disturbance to the birds. This occurs when fish and logger have to be put on the nest or when the bird has to be caught. Because captive cormorants or bank cormorants in the wild do not appear to have any difficulties in egesting the stomach temperature probes, we assume that these, when tolerated, cause only minor irritation to the birds. In addition, the captive cormorants did not appear to eat less when equipped with loggers, which indicates that the units do not impair appetite. The use of stomach temperature probes allows the accurate determination of the feeding rate of individual birds and can thus be used for estimating the fish consumption of a whole population without any projection of estimated food intake per foraging bout. Furthermore, stomach temperature curves deliver unique data concerning the time of feeding and the energetics of the birds studied (see R. P. Wilson and D. J. H. Grémillet, in preparation).

Despite a high rate of loss (37 %) of the devices, with associated high costs (each unit costs about 370 US dollars), and the fact that stomach temperature recordings do not provide information about diet composition, we consider the use of stomach temperature loggers to be promising for ecological investigations in free-living seabirds, particularly when used in conjunction with standard dietary methodologies.

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