

STOMACH TEMPERATURE VARIATIONS IN A CAPE GANNET *MORUS CAPENSIS* AS AN INDEX OF FORAGING ACTIVITY AND FEEDING RATES

VERANDERINGEN VAN DE TEMPERATUUR IN DE MAAG BIJ KAAPSE JAN VAN GENTEN ALS INDEX VAN VOEDSELOPNAMEN EN FOERAGEERSUCCES

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Animal-mounted electronic devices are powerful tools for studying seabirds at sea. The potential handicap of additional load should be minimised, while nevertheless measuring relevant field data. In this paper, we show how records from a 16g stomach temperature logger may be used to calculate the key values of foraging effort and feeding rate in an avian marine predator.

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INTRODUCTION

For flying seabirds such as gannets, basic information on at-sea distribution and feeding behaviour, in terms of the number, frequency and duration of dives as well as on foraging rhythms, can be collected by direct observation conducted from research vessels (Goethe 1970, Tasker *et al.* 1984). Further, detailed information on the at-sea behaviour of the birds may be also gathered using animal-mounted electronic devices such as VHF transmitters (Trivelpiece *et al.* 1986), satellite transmitters (Jouventin & Weimerskirch 1990), activity loggers (Cairns *et al.* 1987), or dead-reckoners (Wilson & Wilson 1988). However, the total additional load caused to the birds obviously has to be minimised (Wilson *et al.* 1986), while collection of relevant data should be maximised. In this paper we present an example of this optimisation process, where a single 16g stomach temperature logger is used to determine the key value of catch per unit effort in a foraging seabird.

METHODS

Between 24 and 28 October 1992 two Cape Gannets *Morus capensis* breeding at Bird Island, Lambert's Bay (32°05'S, 18°07'E; South Africa) were equipped with stomach temperature loggers (SICUP, Single Channel Unit Processor, Driesen & Kern GmbH, Am Hasselt 25, D-24576 Bad Bramstedt Germany). The main elements of the device were a quartz clock, a PT100 temperature sensor and a volatile RAM of 128 Kbytes powered by a 6v-lithium battery. The logger registered temperature between 0° and 50°C with a relative accuracy of 0.2°C (absolute accuracy 1°C, no drift). The electronics were encapsulated in a titanium housing, 69 mm long and 12 mm in diameter. The temperature sensor was set flush with one end of the housing, which was directed to the top of the stomach. The complete unit weighed 16g and was of the 'sinker' type (c. 1.5% of the stomach volume; see Wilson *et al.* (1995) for further technical details).

Both incubating Cape Gannets were caught under licence at the nest site just after their partner had returned from a feeding trip. The device was introduced into the bird's stomach by concealing it in a fish, which was swallowed by the bird. The first individual was then observed for 35 min until it was seen to fly out to sea. Its nest site was checked every two hours between dawn (07:30 h) and dusk (20:30 h, local time) until the bird had returned, when it was caught and induced to regurgitate its stomach contents (including logger) by turning it upside down. The second equipped bird remained at the nest site where the logging unit was found regurgitated after 16 hrs.

The recorded stomach temperature data (Fig. 1), were analysed as follows. Short-term drops in stomach temperature, which only occurred when the first equipped bird was at sea (Fig. 2), were identified as PDER-events (Precipitous Drop and Exponential Rise, *sensu* Wilson *et al.* 1992). These reflect the intake of cold food (seabirds are considered to drink only small quantities of water at any one time, which do not influence these measurements; see Wilson *et al.* (1995)). These events were analysed following Wilson *et al.* (1992, 1995) and the TRIM method described in Grémillet & Plös (1994) so as to determine the time of feeding as well as the individual estimated mass of prey-items, *M*. Thus:

$$M = \frac{I}{mSH(T - T_{\min})}$$

where *I* is the surface of the PDER-event calculated using the TRIM method, *m* is a constant taken to be 0.496 (which corresponds to the *m*-value given by Grémillet & Plös (1994) for TRIM calculations, corrected for highly active birds (Wilson *et al.* 1995)), *SH* is the specific heat capacity of water taken to be 4.17

$J^{\circ}C^{-1} g^{-1}$, T_{asym} is the temperature ($^{\circ}C$) recorded after prey warming has been is the minimum temperature ($^{\circ}C$) of the PDER-event (see for more details). Individual prey masses calculated in this way are accurate to $\pm 15\%$ (Grémillet & Plös 1994).

Long-term variations in stomach temperature (Fig. 1 and 2) were also recorded. These variations, which are not related to feeding, have been shown to reflect activity, higher temperatures generally being associated with greater energy expenditure (Wilson *et al.* 1992, 1995; Wilson & Grémillet 1996). In power fliers such as Gannets, there is thus a particularly clear-cut difference between high, variable temperature patterns related to time periods spent flying and plunge-diving, and lower, stable temperature patterns related to time periods spent resting at the water surface or on the nest. Knowing that the second equipped bird remained at the nest site throughout the measurement, we used its mean ($\pm$ SD) abdominal temperature ($39.7 \pm 0.65^{\circ}C$, 16 hours measurement) to define the body temperature of a resting bird. The sum of this mean and of its standard deviation ($40.4^{\circ}C$) was then used to discriminate between periods of time spent foraging (flying and plunge-diving, $T > 40.4^{\circ}C$) and periods of time spent resting ($T \leq 40.4^{\circ}C$) in the first equipped bird foraging at sea. The validity of this technique has been recently confirmed by Garthe *et al.* (in press) who equipped Northern Gannets with both stomach temperature loggers and activity sensors.

RESULTS

A total of 104 hours of stomach temperature data was successfully recorded when the first equipped bird was at sea. This period of time spent at sea corresponds to the mean length of foraging trips conducted by undisturbed conspecifics observed during our study (90 hrs, $n = 4$). Eleven feeding events were recorded, all occurring during daylight (0730 h to 1900 h), with 73% of them being recorded before 1200 h. The first feeding event occurred only 25 min after the bird left the colony, indicating that travelling time to the first prey patch was extremely short. The mean ($\pm$ SD) interval between the ingestion of prey items was 2.5 ± 2.5 hrs during daylight hours (range 0.35-6.8 hrs, $n = 5$, see below), so that mass determination following Wilson *et al.* (1992) is predicted to be accurate to at least 15% (see Methods and Wilson *et al.* 1995). The calculated median prey mass was $136 \pm 20g$ ($n = 11$, range $58 \pm 9g - 973 \pm 146g$) and the median daily food intake was $254 \pm 38g$ ($n = 5$, range $120 \pm 18g - 1425 \pm 214g$). Analysis of the long-term variations in stomach temperature indicated that the bird spent 57% of its time at sea resting and 43% of its time flying and plunge-diving. Mean ($\pm$ SD) abdominal temperature was $39.8 \pm 0.31^{\circ}C$ when the bird was resting and $41.2 \pm 0.74^{\circ}C$ when the bird was flying/plunge-diving. These temperature sets are significantly different ($t = 3.51$,

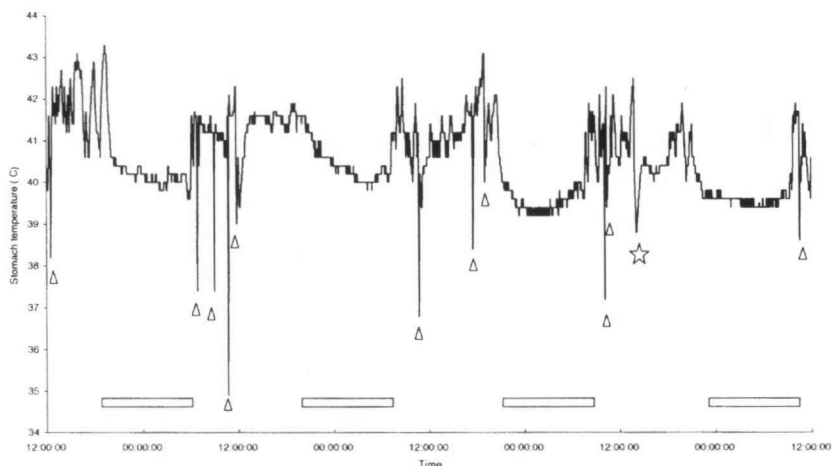


Figure 1. Long term variation in the stomach temperature of a Cape Gannet at sea. The black bars indicate night. The triangles indicate prey ingestion. The temperature drop indicated by an asterisk was ignored, as both decrease and increase in the stomach temperature were slow and thus did not fit the definition of a PDER-event after Wilson et al. (1992).

Figuur 1. Variaties in de maagtemperatuur bij een Kaapse Jan van Gent op zee. De zwarte balken geven de nacht aan, de driehoekjes geven het effect van ingeslikte prooi aan. De temperatuurafname aangegeven met een sterretje werd genegeerd, omdat zowel de afname als toename traag verliepen en daarom niet voldeden aan criteria voor een 'precipitous drop and exponential rise' volgens Wilson et al. (1992).

$P < 0.001$), confirming that the frequency distribution of abdominal temperature was bimodal. Combining activity data and feeding rates, we finally determined mean catch per unit effort values of 0.96 ± 0.14 grams of prey taken per minute for foraging periods (high activity and abdominal temperature level) and of 0.41 ± 0.06 g of prey taken per minute for the entire foraging trip.

DISCUSSION

Foraging effort and feeding rates as determined above are key values necessary for a comparative assessment of seabird foraging strategies (Perry & Pianka 1997). In this respect, it is interesting to notice that all previous investigations

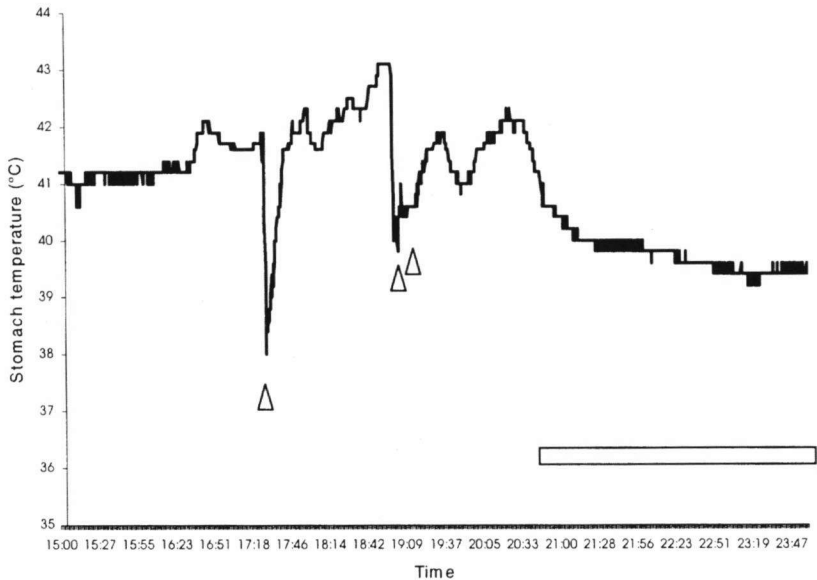


Figure 2. Short term variations in the stomach temperature of a Cape Gannet at sea. The black bar indicates night. The arrows indicate prey ingestion - the first arrow shows a typical feeding event involving a single prey item, whereas the second and third arrows show a feeding event that may have resulted from the ingestion of more than one prey item. The final temperature decrease is related to the activity level of the bird and does not mark prey ingestion (see also Fig. 1).

Figuur 2. Korte termijn veranderingen in maagtemperatuur bij een Kaapse Jan van Gent op zee. De zwarte balken geven de nacht aan, de pijlen wijzen op het effect van ingeslikte prooien. De eerste pijl staat bij een typisch geval (een enkele prooi), terwijl de tweede en derde pijl momenten aangeven waarop verscheidene prooien werden ingeslikt. Het uiteindelijke daling in temperatuur hangt samen met de activiteit van de vogel en wordt niet veroorzaakt door nieuwe ingeslikte prooien (zie ook Fig. 1).

attempting to determine such features in seabirds at sea necessitated deployment of combined, elaborate telemetric techniques (Chappell *et al.* 1993; Wilson & Grémillet 1996; Grémillet 1997; Wanless *et al.* 1998). Our method delivers comparable data via an internal, but non-implanted data logger, thus incurring no problems with aero/hydrodynamic drag, nor potential surgery shock. No detrimental effect has been shown for birds equipped with stomach temperature loggers; the digestive tract is not damaged in any way, and the device is usually ejected by the bird in normal pellet regurgitations (Wilson *et al.* 1998).

Therefore, we consider that this method minimises potential measurement artefacts while maximising relevant data collection. However, we wish to stress some limitations of the above analysis: (1) the time budget analysis suggested in this paper can be easily applied to power fliers such as gannets or cormorants, or in other seabirds for which locomotion is clearly related to higher metabolic rates. However, this may be more difficult in gliding fliers such as albatrosses, for which abdominal temperature levels are much more stable (Weimerskirch & Wilson 1992); (2) abdominal temperature levels cannot help detect plunging activity in foraging Gannets, preventing further calculations based on different metabolic rates for flying and plunging birds (Garthe *et al.*, in press); (3) further measurements of the stomach temperature in Sulidae fed with fish of known mass are still required to validate our calculations of individual prey mass; and (4) previous dietary studies conducted on Cape Gannets (Batchelor & Ross 1984) determined a mean mass of 34g for prey items taken by the birds, which is *c.* one quarter of the value given above. The value reported by Batchelor & Ross (1984) is likely to be an underestimate. This is due to the fact that their data are based on regurgitated stomach contents, in which the mass of single prey items may be already reduced via digestion. However, we have to consider that PDER-events (Fig. 2) recorded during the present study may be related to the ingestion of more than one prey item. This is more likely to explain the important discrepancy between mean and maximum prey masses calculated above compared with those given by Batchelor & Ross (1984), as well as the small number of feeding events (2.2 per day on average) recorded during this study.

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SAMENVATTING

Van veel vliegende zeevogels zoals jan van genten Sulidae kan basale informatie over het foerageergedrag, over bijvoorbeeld het aantal en de frequentie van stootduiken worden vergaard door waarnemingen te doen op volle zee. Aanvullende informatie kan worden verzameld door de vogels met allerhande elektronische apparaten de zee op te laten vliegen. Zo zijn we met de huidige technische kennis in staat om satellietzenders of VHF radiozenders te ontwerpen die gemakkelijk door een vliegende vogel vervoerd kunnen worden, maar ook zijn er tal van apparaatjes ontwikkeld waarmee allerhande activiteiten van de vogels worden geregistreerd. Er zit uiteraard een grens aan wat met vogels kan worden meegegeven; het mag allemaal niet te zwaar worden. In dit artikel wordt het functioneren en worden de resultaten besproken van een apparaatje met een gewicht van 16g, waarmee temperatuurveranderingen in de maag van bijvoorbeeld de Kaapse Jan van Gent *Morus capensis* konden worden vastgelegd. In oktober 1992 werden twee Kaapse Jan van genten van Bird

Island (Zuid Afrika) met dergelijke *loggers* uitgerust. De belangrijkste componenten waren een quartz-uurwerk, een PT100 thermometer, een geheugenchip (RAM) van 128 Kbytes, van stroom voorzien door een 6V lithium batterij. Het apparaatje werd aan de vogel 'toegediend' door het in een aangeboden vis te verstoppert. Bij terugkeer op het nest werd de vogel vervolgens gedwongen om de maaginhoud op te braken, waardoor de verzamelde gegevens eenvoudig konden worden uitgelezen.

Acute afnamen in temperatuur, gevolgd door een exponentiële toename werden geïnterpreteerd als voedselopname (het inslikken en opwarmen van koude prooidieren). Daarnaast werden ook geleidelijke en dikwijls langdurige veranderingen van temperatuur geregistreerd, die bijvoorbeeld het gevolg waren van opwarming door langdurige activiteit (bijvoorbeeld vliegen).

Bij de eerste vogel werden gegevens verzameld over een periode van in totaal 104 uren. Een dergelijke periode komt overeen met één enkele foerageertrip, die bij 'ongestoorde' soortgenoten vogels gemiddeld ongeveer 90 uren besloeg. In totaal werden in dit tijdsbestek 11 ingeslikte prooien geregistreerd, alle opgedoken tijdens daglicht (07:30-19:00u), waarvan 73% voor het middaguur (12:00u) werd bemachtigd. De eerste prooi werd al na 25 minuten opgedoken, waaruit bleek dat de afstand tot de eerste voedsel-*patch* buitengewoon gering was. De gemiddelde tijd ($\pm$ SD) tussen verschillende prooien bedroeg 2.5 ± 2.5 uren (range 0.35-6.8 uren). Op basis van de 'klap' in de maagtemperatuur kon de grootte van de prooi worden ingeschat en deze bedroeg gemiddeld 136 ± 20 g (range 58 ± 9 g - 973 ± 146 g). De mediane dagelijkse voedselopname bedroeg 254 ± 38 g ($n = 5$, range 120 ± 18 g- 1425 ± 214 g). Het bleek dat de vogel 57% van de tijd rustend op zee had doorgebracht en 43% van de tijd vliegend en stootduikend. De gemiddelde temperatuur van de ingewanden beliep $39.8 \pm 0.31^\circ\text{C}$ in perioden van rust en $41.2 \pm 0.74^\circ\text{C}$ in tijden van activiteit (vliegen of stootduiken).

Het aardige van de gevolgde methode is dat er bij de vogel uitwendig geen apparaatjes behoeften te worden aangebracht waardoor het dier in zijn bewegingen gehinderd werd. Bovendien werd een object ingebracht zonder het te implanteren, zodat er geen *surgery shock* kon zijn opgetreden. Al met al is deze methode een uiterst veelbelovende en bovendien diervriendelijke manier, waarmee belangrijke gegevens over de voedselstrategieën en voedselopnames van vrij in het wild levende zeevogels kunnen worden verzameld.

REFERENCES

- Batchelor A.L. & Ross G.J.B. 1984. The diet and implications of dietary change of Cape Gannets on Bird Island, Algoa Bay. *Ostrich* 55: 45-63.
- Cairns D.K., Bredin K.A., Birt V.L. & Montevicchi W.A. 1987. Electronic activity recorders for aquatic wildlife. *J. Wildl. Manage.* 51: 395-399.
- Chappell M.A., Shoemaker V.H. & Jones D.N. 1993. Energetics of foraging in breeding Adélie Penguins. *Ecology* 74: 2450-2461.
- Garthe S., Grémillet D., Furness R.W. in press. Foraging efficiency in breeding Northern Gannets: a case study from Shetland. *Mar. Ecol. Progr. Ser.*
- Goethe F. 1970. Märzaspekt des Vogel Lebens in der südlichen Nordsee. *Ber. Dt. Wiss. Komm. Meeresforsch.* 21: 430-443.
- Grémillet D. 1997. Catch per unit effort, foraging efficiency and parental investment in breeding Great Cormorants (*Phalacrocorax carbo carbo*). *ICES J. Mar. Sci.* 54: 635-644.
- Grémillet D. & Plös A. 1994. The use of stomach temperature records for the calculation of daily food intake in cormorants. *J. exp. Biol.* 189: 105-115.
- Jouventin P. & Weimerskirch H. 1990. Satellite tracking of Wandering Albatrosses. *Nature* 343: 746-748.
- Perry G. & Pianka E.R. 1997. Animal foraging: past, present and future. *Trends in Ecol. and Evol.* 12: 360-364.
- Tasker M.L., Jones P.H., Dixon T.J. & Blake B.F. 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. *Auk* 101: 567-577.

- Trivelpiece W.Z., Bengtson J.L., Trivelpiece S.G. & Volkman N.J. 1986. Foraging behavior of Gentoo and Chinstrap Penguins as determined by new radiotelemetry techniques. *Auk* 103: 777-781.
- Wanless S., Grémillet D. & Harris M.P. 1998. Foraging activity and performance of Shags *Phalacrocorax aristotelis* in relation to environmental characteristics. *J. Avian Biol.* 29: 49-55.
- Weimerskirch H. & Wilson R.P. 1992. When do Wandering Albatrosses *Diomedea exulans* forage? *Mar. Ecol. Progr. Ser.* 86: 297-300.
- Wilson R.P., Cooper J. & Plötz J. 1992. Can we determine when marine endotherms feed? A case study with seabirds. *J. exp. Biol.* 167: 267-275.
- Wilson R.P., Grant W.S. & Duffy D.C. 1986. Recording devices on free-ranging marine animals: Does measurement affect foraging performance? *Ecology* 67: 1091-1093.
- Wilson R.P. & Grémillet D. 1996. Body temperatures of free-living African Penguins (*Spheniscus demersus*) and Bank Cormorants (*Phalacrocorax neglectus*). *J. exp. Biol.* 199: 2215-2233.
- Wilson R.P., Peters G., Regel J., Grémillet D., Pütz K., Kierspel M., Weimerskirch H. & Cooper J. 1998. Short retention time of stomach temperature loggers in free-living seabirds. Is there hope in the spring? *Mar. Biol.* 130: 559-566.
- Wilson R.P., Pütz K., Grémillet D., Culik B., Kierspel M., Regel J., Bost C.A., Lage J. & Cooper J. 1995. Reliability of stomach temperature changes in determining feeding characteristics of seabirds. *J. exp. Biol.* 198: 1115-1135.
- Wilson R.P. & Wilson M-P. 1988. Dead reckoning: a new technique for determining penguin movements at sea. *Meeresforsch.* 32: 155-158.