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Monitoring feeding behaviour of brent geese *Branta bernicla* using position-sensitive radio transmitters

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Though the occurrence of night time feeding has been demonstrated in numerous species of wildfowl, accurately quantifying this behaviour visually is inherently difficult and so alternative techniques are required. During the course of two distinct projects on the ecology of brent geese *Branta bernicla* in England (Studies A and B) and another in Germany (Study C) we used position-sensitive radio transmitters, attached to thin leather neck collars, to monitor feeding behaviour remotely. In this paper, we present a collective account of the method. Transmitter units emitted pulses at two different intervals depending on the orientation of a built-in tilt switch; generally shorter intervals (ca 1.1 seconds) when a bird lowered its neck to feed and longer intervals (ca 1.4 seconds) when in upright positions, though in some units this was reversed. Daytime observations of each radio-marked goose were required to produce predictive equations which described the proportion of time feeding in terms of mean pulse interval (Study B), number of long intervals between pulses (Study C) or the proportion of time in which pulses were received at short (or in some cases long) intervals (Study A). Coefficients of determination ranged within 0.13-0.95. These equations could be used to interpret data that was received and stored at regular intervals (30 or 60 seconds) during night time by a data logging system. Each study also assessed whether the collars affected the behaviour of the geese. No significant behavioural differences were observed for free-ranging birds wearing collars compared to nearby birds without. This technique is a realistic option for ecological studies of wildfowl requiring construction of feeding time budgets through the night as well as the day.

Key words: activity budgets, behaviour, brent geese, nocturnal feeding, telemetry, wildfowl

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Nocturnal feeding is a frequently overlooked, yet potentially important, aspect of the ecology of wildfowl and shorebirds (Madsen 1988, McNeil, Drapeau & Goss-Custard 1992). Our limited knowledge of night time behaviour has undoubtedly arisen through the difficulty of observing birds directly at night and is compounded by the lack of good remedial techniques. The value of image intensifiers, for example, is limited because their range is short and the resolution varies with the intensity of ambient light so biasing collection of data in favour of behaviour characteristic of good light conditions (S.J. Lane, pers. obs.).

Recently, feeding behaviour of oystercatchers *Haematopus ostralegus* (Exo, Eggers Laschefski-Sievers & Scheiffarth 1992), golden plovers *Pluvialis apricaria* (Whittingham 1996) and blue ducks *Hymenolaimus malacorhynchos* (Douglas & Pickard 1992) has been monitored remotely using position-sensitive radio transmitters mounted as backpacks. The transmitters emitted pulses at two distinct intervals depending on the changed orientation of the birds' backs when leaning forward to feed compared with upright postures typical of non-feeding behaviours. Thus pulses received at short intervals (e.g. 1.1 seconds) indicated feeding, whilst pulses at longer intervals (e.g. 1.5 seconds) were indicative of some other activity. The change in pulse interval was achieved through the incorporation of a tilt switch within the circuitry of the transmitter. When the receiving unit is linked to a data logging system then feeding behaviour can be monitored remotely. Hence, this system potentially provides a means of quantifying time allocated to feeding behaviour regardless of whether day or night conditions prevail, provided that the bird remains within the range of the receiver.

In this paper, we describe how we adapted this technique to investigate night time foraging behaviour of brent geese *Branta bernicla* in three separate projects: two in England (Study A performed by SJL and MH; Study B performed by SMP) and one in Germany (Study C performed by MS and BP). Transmitters were fitted against the necks of birds on leather collars and we present both the details of the technique and our investigations of whether the use of the transmitters affected the behaviour of the geese. Especially during the initial stages of the three projects each group worked rather independently of the others and so application of the technique differed in some details between the three studies, as did our methods of assessing whether the transmitters affected behaviour. Despite this, our objectives were, broadly speaking, the same. Firstly to determine whether the proportion of time feeding could be measured reliably, and secondly to ensure that the technique did not affect the behaviour of the birds adversely.

Study areas

Studies A, B and C were conducted at sites in north Norfolk (UK), Lindisfarne (UK) and Westerhever (Germany), respectively. At the Norfolk site up to 4,500 brent geese roosted at Scolt Head Island and fed on surrounding saltmarsh vegetation (729 ha) and nearby agricultural land (343 ha) along a 13 km stretch of the coastline (Vickery, Sutherland, Watkinson, Lane & Rowcliffe 1995). The Lindisfarne study site comprises 1,000 ha of intertidal mudflat and 100 ha of adjacent saltmarsh. Approximately 1,700 brent geese feed mostly on eelgrass *Zostera* spp. stands on the mudflats, but spend some time on the saltmarshes, particularly around high tide (Percival, Sutherland & Evans 1996). Brent geese at Westerhever feed on saltmarsh (265 ha) and up to 4,000 individuals are present each spring between March and May (Stock 1992).

Methods

Bird capture and marking

During the three studies, 38 brent geese were fitted with radio transmitters (Table 1). The brent geese were caught between November 1991 and February 1993 either by cannon nets or dazzling at night. Captured birds were weighed, aged (juvenile/adult) and fitted with a numbered metal ring. In Studies A and B all birds but one also had a standard colour ring, a yellow engraved darvic ring, or both for individual identification in the field. Birds in Study C were not given individual marks.

Table 1. Data on the birds caught in the three studies during November 1991 - February 1993.

Study	No of geese fitted with transmitters	Date	Capture method	Identification	Dye
A	7	Nov 1991 - Feb 1992	Night lighting	None or engraved darvic	Rhodamine B
	6	Oct 1992 - Jan 1993	Night lighting	Engraved darvic or colour ring	Picrid acid
	5	Feb 1993	Cannon net	Engraved darvic and colour ring	Picrid acid
B	7	Dec 1991	Cannon net	Colour ring combination	Picrid acid
C	13	Mar-Apr 1992	Cannon net	None	Picrid acid

The white tail coverts and lower abdominal feathers of all birds were dyed with rhodamine B (red) or picric acid (yellow) to help locating them in the large flocks typically formed by brent geese (see Table 1).

During Study A an additional seven captive brent geese (held under licence) were available for preliminary trials of collar attachment as well as detailed behavioural observations later in the project.

Temporary transmitter attachment

In the three studies transmitters were fitted to the birds similarly via attachment to a neck collar designed to fall off the birds within a few months. The collars were made from strips of brown or black leather and were 20 mm wide at the centre, where the transmitter was glued with 'Rapid Set Araldite' epoxy resin, tapering to 10 mm at either end to minimise both weight and disruption to the feathers (Fig. 1). The collars were fastened with a second small strip of soft black leather 40 x 10 x 2 mm which had been cut into two 20 mm halves and then rejoined using three stitches of a single thread of 'Dexon Plus' polyglycolic acid suture (Smith, Davis & Geck Ltd., Southampton, UK) which would eventually dissolve. Using a single thread meant that when one stitch broke the other two would also be released and the collar would fall off. Decomposition of the sutures was promoted by roughening their surfaces with fine sand paper. The small strips of leather were glued to the thicker strips using cyanoacrylate adhesive ('Superglue'). When fastened the collar had to be sufficiently tight to prevent it from slipping up the neck and over the bird's head when this was lowered, but sufficiently loose for it to rotate freely round the base of the neck so that the transmitter could slip round below the neck when the bird was feeding (Fig. 2). Thus, the circumference of each collar was adjusted to fit the neck of individual birds and, in Study A, varied within 118-146 mm.

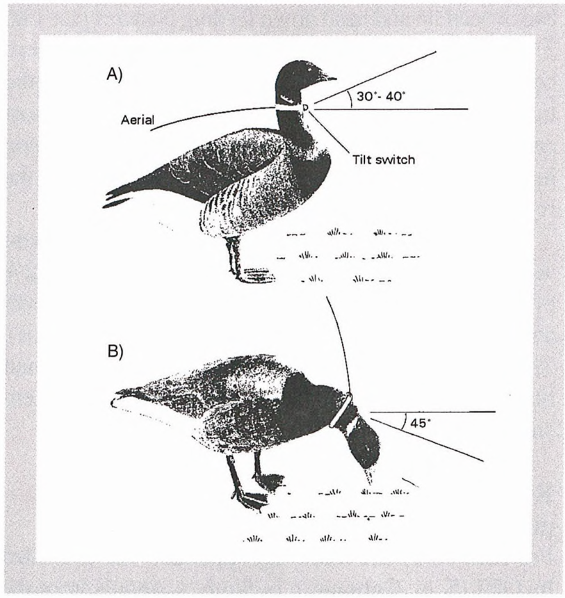

Figure 2. Position of collar when head and neck were in the resting (A) and feeding (B) positions, respectively. When resting the switch was at 30-45° above the horizontal and the transmitter emitted signals at longer intervals, whereas during feeding the angle was ≥45° below the horizontal and signals were emitted at shorter intervals. Note that for illustrative purposes the collars are shown in white, though they were painted black when attached to the geese during the study.

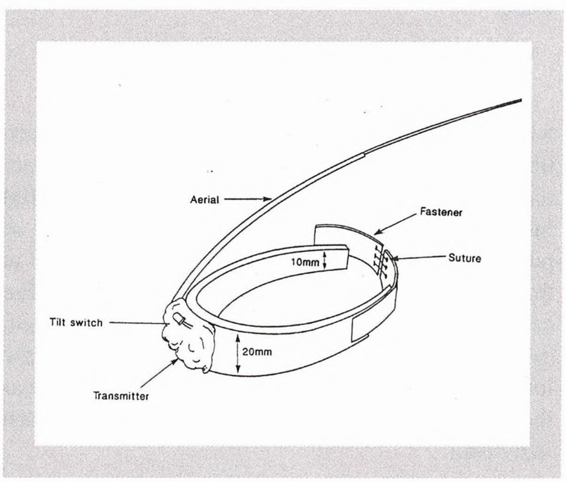

Figure 1. Design of the leather neck collar to which the position-sensitive radio transmitter was attached with the tilt switch embedded in epoxy resin.

Transmitters

Three types of transmitter were used. One model was provided by GFT (Gesellschaft Für Telemetriesystems, Kiel, Germany) and two models, designated TW2 and TW3, were provided by Biotrack (Wareham, UK). In Study A, seven GFT and 10 TW3 transmitters were used, in Study B all seven units were TW3 transmitters, and in Study C 14 transmitters of the TW2 type were used. Each transmitter incorporated a mercury tilt switch (see Fig. 1) and sent pulses at long or short intervals depending on orientation. In Studies A and B these intervals were approximately 1.0 and 1.4 seconds, but in Study C the intervals were 0.75 and 1.15 seconds. The tilt switches were mounted on the transmitters externally and their precise position relative to the main body of the unit could be adjusted. Preliminary trials using the seven captive birds showed that angles of 30-45° above the horizontal with the birds' necks in upright positions gave maximum differentiation of signal pulse rate between head up and head down feeding postures (see Fig. 2). Once we were satisfied that the tilt switches were correctly orientated they were immobilised against the transmitters in 'Rapid Set Araldite' epoxy resin. In most cases short pulse intervals indicated feeding and long intervals non-feeding, head-up, behaviours, however, the reverse was true in some instances in Study A.

The mean mass (± S.E.) of collars, transmitters and aerials used in Studies A and B was 23.4 ± 0.61 g (< 2% of the mass of the birds to which they were attached), and 17.2 ± 0.6 g in Study C (ca 1.3% of body mass). Transmitters, epoxy resin and collars were painted matt black to minimise disruption to social interactions (Lensink 1968).

Receiving apparatus and automated data logging

For each study the receiving apparatus was provided by GFT (Kiel, Germany). In Study A signals from the transmitters were received by a telepolaris omnidirectional antenna and a 9-element directional antenna mounted in combination on a chimney 10 m above the field laboratory. Signals were relayed through a pre-amplifier to an MWTR receiver. In Study C an omnidirectional telepolaris aerial was mounted at 47 m on a lighthouse and the signals passed through an EGV/2 amplifier to the receiver, while in Study B signals were obtained by a three-element yagi antenna mounted on top of a 3 m high telescopic mast. In all cases received signals were automatically logged on a computer by the ACTIV500 (ver 4.0) software interfacing with the receiver (Exo et al. 1992). For time periods of 30 or 60 seconds the following information was stored: date, times at start and end of recording period, total time in contact with the transmitter, number of pulses received at short and long intervals, mean duration between pulses (± standard deviation), total number of pulses, and the number of erroneous or interference signals. At the end of each 30 or 60 second time period the process was repeated. The ACTIV500 could monitor only one transmitter at a time, so when more than one transmitter was operating the system obtained data from each sequentially by switching from the frequency of one transmitter to the next (to a maximum of 10 transmitters) before returning to the first unit and so on.

Predictive equations relating radio signals with behaviour

To relate the radio-telemetry data to the proportion of time birds spent feeding, sample observations of focal birds feeding during the day were correlated with automatically logged telemetry data collected simultaneously. During spring 1992 in Study A simultaneous visual and radio-telemetry observations of focal birds feeding in flocks were made over periods of 3-10 minutes. As brent geese feed with their heads down for over 70% of the time in winter, this resulted in a cluster of points around this value, so during the winter of 1992/93 simultaneous observation periods were reduced to 60 seconds. This meant that the full range of 0-100% feeding was generally obtained. Data were collected similarly in Studies B and C in periods of 30 seconds and five minutes, respectively.

Predictive equations were built with these data in different ways between the three studies. In Study C four of the 13 birds marked with transmitters were used to make visual observations, but sufficient data were obtained from only one of these to produce a reliable equation using the number of signals received at long intervals as the independent variable. This relationship was subsequently used for all data received from all birds. In Study B predictive equations were produced for two birds using mean pulse interval as the independent variable. These equations were then combined to produce a single relationship which was then used to quantify feeding behaviour of all individuals.

In Study A, a different approach was taken. Predictive equations were constructed for individual birds since in some cases transmitters were emitting pulses at short intervals during feeding and in others at long intervals and further to this the long and short pulse intervals differed between the GFT and Biotrack transmitters. Moreover, the independent variables used in Studies B and C resulted in low coefficient of determination (r^2) values in Study A, but improved results were achieved using:

$$\arcsin\sqrt{p/t}$$

where t is the duration of the 60 second period in which the bird was in radio contact and p the number of seconds in which signals were received at short (or long) intervals. The latter is obtained from the product of pulse length interval and number of signals logged at that rate. Periods when $t < 50$ seconds were rejected. For each bird, two predictive equations were constructed, one using the short pulse interval and the other the long interval. The equation with the highest r^2 was then selected to quantify the feeding behaviour for that individual.

Table 2. Number of brent geese losing radio collars prior to spring departure and numbers returning to the study areas with and without the collars the following winter. Birds in study C were not marked individually so some may have returned the following winter without the collars and thus without being noticed, hence the '?'.

Study		Total fitted with collars	No losing collar prior to spring departure	No returning without collar in subsequent winter[a]	No returning with collar in subsequent winter
A	1991-1992	7	0	1	0
	1992-1993	11	1	2	0
B	1991-1992	7	0	5	1
C	1991-1992	13	7	?	0
Total		38	8	8	1

[a] Does not include birds losing collars prior to spring departure

Effects of collars on behaviour and body condition of captive birds

Each study aimed to assess whether or not the collars affected the behaviour of the birds. During Study A, work was initially conducted with the captive flock. These birds were weighed on 5 February 1992, and four were fitted with dummy radio collars while the other three acted as controls. Behavioural observations were then made two, 16, 31 and 48 days later. At five-minute intervals throughout the day activities of the birds were recorded and allocated to the following categories: feeding (defined as time spent with the head below horizontal while pecking at the sward), preening, walking or running, standing alert, roosting, and 'other' (including swimming, drinking and social interactions). The behavioural data, expressed as percentages, were arcsin$\sqrt{}$ transformed and analysed by ANOVA in which dates and treatments were fixed factors and birds were random factors nested within treatments (Zar 1984). Body condition of the captive birds was monitored by weighing them again at 58 and 158 days after fitting the collars and the data were subjected to ANOVA. More frequent weighing was avoided as the process stressed the birds.

Effects of collars on behaviour and body condition of released birds

To assess whether wearing a neck collar affected the behaviour of wild birds marked in Study A, we observed 10 of the radio-marked geese and their nearest neighbours on saltmarsh and pasture habitats irregularly, but at all times of the day between 1 November 1992 and 28 February 1993 (Giroux, Bell, Percival & Summers 1990). Behaviour was categorised as for captive geese and recorded instantaneously at 30-second intervals on 804 occasions, and the null hypothesis of no differences in behaviour between the two groups was assessed by χ^2-statistics. In Study B, focal marked and unmarked birds were observed for 10- to 15-minute periods during which their times spent in each behavioural activity were recorded. In Study C observations of marked and unmarked birds were made over a period of 30 days for totals of 1,875 and 3,682 minutes, respectively.

Results

Temporary transmitter attachment

Brent geese migrate from European coasts in late spring to breed in the arctic and return again to their wintering areas during September and October. The geese in Studies A and B were caught on their wintering grounds, while those in Study C were taken from a spring staging area just prior to migration. Consequently it was possible for birds either to lose their collars at their respective study sites, or to migrate northwards with the collars still attached. This made it difficult to assess how long a collar remained attached to a bird in many cases, so we judged success of the temporary attachment technique on the number of birds losing collars prior to migration and the number returning the subsequent winter without them (Table 2).

Overall eight birds (21%) lost their collars prior to departure and another eight were seen the following win-

Table 3. Type and performance of position-sensitive radio transmitters.

Study	Type of transmitter	Period tracked (days) Mean	N	Range	Reception range (km)	Reason for loss of reception: Bird departed	Battery depleted	Loss of collar	Technical failure[a]
A	TW3	39	11	0- 90	3	2	4	0	5
	GFT	18	7	0- 58	5	2	0	1	4
B	TW3	13	7	3- 46	3	6	0	0	1
C	TW2	22	13	1-161	1.5	1	0	7	5

[a] Technical failures were difficult to diagnose with certainty, but may have included failure of tilt switches and antenna breakages

Table 4. Predictive equations giving the relationship between the proportion of time spent feeding and the pulse frequency parameters for six birds in Study A, two in Study B and one in Study C. The dependent variable was the proportion of time spent feeding which in Studies A and B was arcsin√ transformed.

	Bird ID	N	Predictive equation and coefficient of determination	Independent variable
Study A	H7	76	$Y = 1.996 - 1.227X$ ($r^2 = 0.72$)	Arcsin√ proportion of 60 second unit in which signals received at long intervals
	H8	32	$Y = 1.424 - 0.878X$ ($r^2 = 0.847$)	Arcsin√ proportion of 60 second unit in which signals received at long intervals
	H9	26	$Y = 1.504 - 1.200X$ ($r^2 = 0.679$)	Arcsin√ proportion of 60 second unit in which signals received at short intervals
	HB	55	$Y = 1.428 - 0.704X$ ($r^2 = 0.343$)	Arcsin√ proportion of 60 second unit in which signals received at short intervals
	White	61	$Y = 0.152 + 0.983X$ ($r^2 = 0.502$)	Arcsin√ proportion of 60 second unit in which signals received at short intervals
	HO	34	$Y = 0.018 + 1.026X$ ($r^2 = 0.948$)	Arcsin√ proportion of 60 second unit in which signals received at short intervals
Study B	HF	14	$Y = 0.730 + 0.415X$ ($r^2 = 0.128$)	Standardised mean signal intervals during 30 seconds
	ZX	14	$Y = 0.189 - 0.988X$ ($r^2 = 0.326$)	Standardised mean signal intervals during 30 seconds
	HF, ZX	28	$Y = 0.561 + 0.580X$ ($r^2 = 0.197$)	Standardised mean signal intervals during 30 seconds
Study C	One bird (no ID)	56	$Y = 20.82 + 0.670X$ ($r^2 = 0.670$)	Number of signals received at long intervals during 300 seconds

ter without their collars. In Study B one bird was sighted the following winter with the collar still attached. Recall that in Study C birds were not given individual marks (colour or numbered leg rings) so it was not possible to know if any of the birds that departed in spring with the collars returned without them in the autumn.

Transmitters

Range of reception varied between the three types of transmitter used (Table 3). TW2 transmitters had the advantage of being light, which was an important consideration in the study because of their position around the neck, but they had a range of only 1.5 km. In contrast the heavier TW3 model was effective at distances of up to 3 km. The best range was achieved with the GFT units and was conservatively estimated at 5 km. The number of days signals were received varied between 0 and 161 days (see Table 3). Reasons for loss of reception included collars falling from the birds prematurely, birds migrating with collars, and various technical failures or battery depletion. In two cases the tilt switches failed, either because of technical problems, or perhaps because they were orientated incorrectly. In these cases signals were received but no useful behavioural data were obtained.

Predictive equations relating radio signals to behaviour

In Study A, the predictive equations for the dependent variable proportion time spent feeding (arcsin√ transformed) were produced for six out of 11 marked birds in 1992/93 (Table 4). For four of these, higher coefficients of determination were obtained using the proportion of time signals were received at the slow rate and for two birds better relationships were obtained using the faster signal rate.

In Study B, mean pulse intervals gave predictive

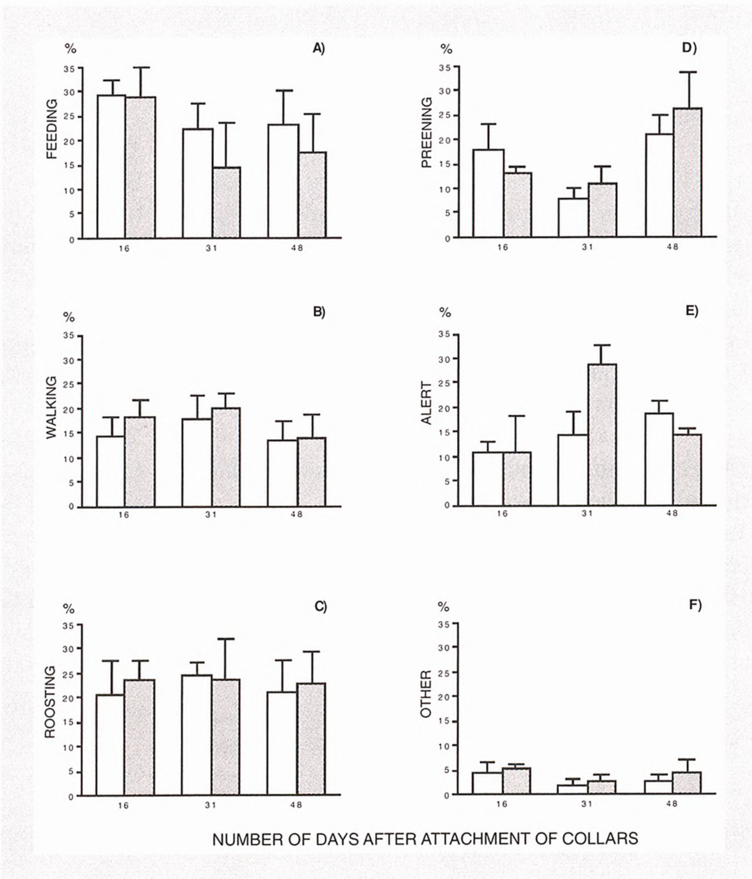

Figure 3. Mean time (in % ± S.E.) spent in the activities feeding (A), walking (B), roosting (C), preening (D), standing alert (E) and 'other' (F), by captive birds with (▒, N = 4) and without (□, N = 3) collars 16, 31 and 48 days after the collars were attached.

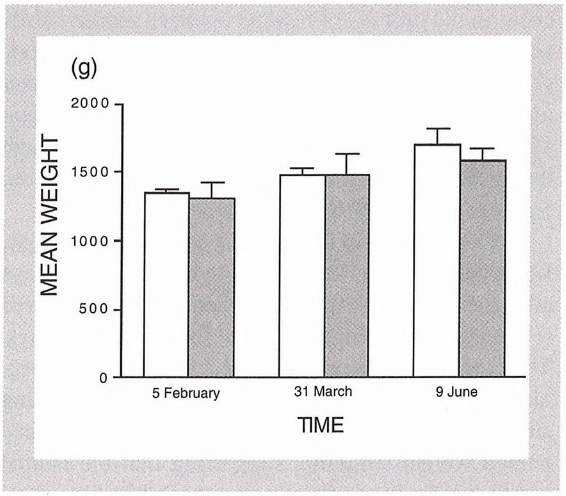

Figure 4. Mean weights (in g ± S.E.) of captive birds with (■, N = 4) and without (□, N = 3) collars related to time after fitting of collars (5 February).

equations with coefficients of determination of 0.128 and 0.326 for the two birds examined (see Table 4). Data were combined to give a single relationship which was then used to quantify time spent feeding for all birds. The standard deviation of the signal interval, and the ratio of the number of pulses received at short and long signal intervals were also assessed as independent variables but neither improved the predictive power.

In Study C, simultaneous visual and telemetric data were obtained for four of the 13 marked birds. However, sufficient data to produce a reliable equation were collected for only one of these. Number of pulses received at long intervals gave the highest coefficient of determination ($r^2 = 0.670$; see Table 4).

Effects of collars on behaviour and body condition of captive birds

Captive birds initially tried to displace their collars by lowering and shaking their necks, pecking at the transmitter and pulling at the aerial. On the second day after fitting they spent up to 18.5% of their time occupied in this behaviour, but it decreased to less than 5% within two weeks and to less than 1% within six weeks. The behaviour of marked birds was compared with that of the unmarked controls on three dates between two and seven weeks after fitting the collars. No significant or consistent differences ($P > 0.05$) were observed between marked and unmarked birds on any of the dates for any of the categories of behaviour (Fig. 3) nor were there significant differences in body weight (Fig. 4).

Effects of collars on behaviour and body condition of released birds

Observations of the behaviour of marked birds in the field during Study A were made over periods of up to four months after fitting the collars. No significant behavioural differences ($P > 0.05$) between those wearing collars and their nearest neighbours without collars were evident (Table 5). The high proportion of time spent trying to dislodge the collars observed in the captive birds was not seen in free ranging individuals, even only two days after the birds were caught and marked.

Focal samples of control and radio-marked birds in Study B showed that birds with collars fed for 78.6% of the time compared with 79.4% for the controls, and preening occupied 8.2% and 4.8% of time for marked and control birds, respectively. These differences were not significant statistically ($P > 0.05$).

In Study C observations of marked and unmarked birds revealed no significant differences in time allocated to feeding or preening ($P > 0.05$), though small, but significant, differences in time marked birds spent roosting ($P = 0.002$) and interacting with other birds ($P = 0.0009$) were detected.

Discussion

Temporary transmitter attachment

Thirty-eight brent geese were fitted with radio-transmitters attached to neck collars which were designed to fall off the birds after a few weeks. Of these, 16 geese

Table 5. Frequency of occurrence (Study A) and percentage of time (± S.E.; Study C) of six behaviour categories for free-living geese fitted with radio collars compared with their nearest neighbours.

	Study A		Study C	
Behaviour	Radio-collared geese (N)	Nearest neighbour	Radio-collared geese (% ± S.E.)	Nearest neighbour
Feeding	579	573	76.9 ± 19.6	77.8 ± 19.4
Vigilant	132	135	7.6 ± 5.9	9.3 ± 9.7
Aggression	5	3	0.2 ± 0.5	0.7 ± 2.0
Walking or running	49	51	6.4 ± 8.1	7.3 ± 11.1
Preening and similar behaviour	38	32	3.4 ± 11.1	1.4 ± 5.9
Roosting	1	10	1.7 ± 7.6	0.3 ± 3.4
Totals	804	804		

were subsequently seen without the neck collars suggesting an overall success rate of 42%. This is probably a too conservative estimate for two reasons. Firstly, in Study C, birds were not marked individually so it was not possible to know how many of the seven birds migrating with collars returned without the units the following autumn. If these birds are excluded, then the success rate rises to 52% (16 of 31). Secondly, although only three birds were seen to return to Study A without the collars, no birds were sighted with collars still attached in subsequent years. However sightings of an additional six birds from Study A were reported to us from other localities up to four years after they were marked (B. Ganter, pers. comm.). No information was available as to whether these birds were seen with radio collars, but if it can be assumed that the collars were already lost (which seems reasonable since an observer looking at a bird carefully enough to read a leg ring might also notice and report a radio transmitter if it was still attached), then the success rate increases further to 71% (22 of 31).

The fate of the remaining birds is of course open to speculation. It is likely that some may have returned to other wintering areas without being resighted; furthermore some may have died during the summer months and, if so, the possibility exists that the collar might have been a contributing factor. Future studies using this technique must consider the scientific worth against the risk to the birds involved.

Impact of collars on behaviour and body weight

Carrying the transmitters on neck collars had little impact on the behaviour of the geese in the three studies. The only abnormal behaviours observed were the attempts made by captive birds to dislodge their collars. Initially this accounted for 18% of their diurnal behaviour, but within two weeks they had habituated to the collars to the extent that less than 5% of their time was spent trying to dislodge them. In the field this habituation was apparently much quicker as no attempts to dislodge the collars were observed even two days after they were fitted. This difference between captive and free-living birds possibly arose because the latter dedicate approximately 70% of daylight hours to feeding compared to 25% for captive birds on a diet supplemented with grain.

As our studies were focused on feeding behaviour, it was important that this behaviour should not be altered by the use of collars. The proportion of time spent feeding by captive birds fitted with radio collars did not differ significantly from that of unmarked controls. Similarly in the field there were no significant differences in the time spent feeding between marked birds and their nearest unmarked neighbours. Elsewhere, geese fitted with neck collars were observed to spend more time preening than unmarked birds (Raveling 1969, Stock, Hofeditz & Eschkötter 1992) although this is not always the case (Johnson & Sibly 1989, Spray & Boyes 1992) and was not so in our work.

Stock et al. (1992) found that a captive brent goose, fitted with a collar, lost weight over the first 10 days after the collar was fitted, but then rapidly recovered to the prefitting weight over the following five days. The captive birds in our study were not weighed as regularly as in the study by Stock et al. to avoid handling stress, but over 158 days during spring all birds had gained weight similarly, suggesting that the annual increase in body condition was not inhibited by wearing radio collars.

Remote monitoring of feeding behaviour

For a time period chosen by the investigator, the ACTIV500 system provides the number of signals received at long and short intervals, and the mean pulse rate. Consequently, before embarking on the process of collecting visual and telemetric data to build the predictive equations, a researcher will need to decide how long that time period should be, and then which independent variable provides the most reliable interpretation.

In general shorter time periods (e.g. 30 seconds) provided better opportunities for collecting data for the equations. Geese feeding during the daytime have their head lowered for approximately 70% of the time and observations made over longer time intervals, for example 10 minutes, resulted in clusters of points around this value and few if any points of less than 60% or more than 80%. With such a narrow range of values for the dependent variable the resulting equations were poor. In contrast, although observations of short time intervals (60 seconds was used in Study A) still produced clusters of data within the 70% value, a much larger range of values was obtained for the dependent variable. This is because geese sometimes remained in alert postures for a minute or so and also occasionally fed continuously for the whole observation period. Of course, whatever observation period is used to produce the equations must then be maintained subsequently when night feeding is quantified remotely.

The process of deciding which variable to use is basically heuristic. Each variable provided by the ACTIV500 can be assessed and the final decision will rest on which one results in a high coefficient of determination.

All of our three studies were able to demonstrate a significant relationship between signal pattern and feeding behaviour, though the proportion of variation explained ranged widely. In Studies C and B, one and two birds, respectively were used to produce a single relationship which was then used to quantify feeding behaviour of all birds. This approach has the considerable advantage that the time spent in the field obtaining data to build the predictive equation is not long, but also the disadvantage that a transmitter sending poor quality or even erroneous data might not be detected.

In Study A, unique equations were produced for each bird. This was done because two brands of transmitter were used which had different long and short intervals, and because some transmitters were sending pulses at short intervals when geese were feeding while in others the opposite was the case. Field time devoted to assessing transmitter performance was therefore considerably longer than in Studies B and C, but the benefits were equations in which coefficients of determination were generally high and transmitters which were not functioning correctly were detected quickly.

The precision of this method to measure the feeding activity of brent geese was sufficient to quantify the amount of time that the birds allocated to feeding. However, greater accuracy might be more easily obtained in other applications in which the transmitters are subjected to greater changes in orientation between feeding and non-feeding positions. For example, when mounted as backpacks on golden plovers, transmitters were subjected to more motion and the resulting predictive equation had a coefficient of determination of 0.748 (Whittingham 1996).

Application of method

We used position-sensitive transmitters to assess the occurrences of night time feeding by brent geese in our respective study areas. For example, data on the incidence of feeding were collected from seven of the birds marked in Study A and combined with detailed quantification of feeding by two individuals. This revealed that on average 61% of the flock could be expected to feed each night on the saltmarshes adjacent to their roost, and that feeding intensity peaked at high tide (Lane & Hassall 1996).

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