

Radio-tracking small aerial foraging birds: a preliminary study of the Sand martin *Riparia riparia*

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Abstract - A method is described for attaching radio-tags to small aerial feeding birds, illustrated with data from three Sand martins (*Riparia riparia*). The radio transmitters had no measurable effects on the subjects. Foraging range, and roost sites were recorded for a pair rearing chicks, which had a similar nest visit rate as a control pair in a neighbouring nest. The birds often foraged close to water, and the male used a larger area than the female. The pair roosted in agricultural crops several Kilometres from their nest, while the third bird (a mate guarding male) was found roosting in the burrow that it defended during the day. Some future applications of radio-tracking to small aerial foraging birds are discussed.

Introduction

Space use by breeding birds can be divided into two categories. Some birds exploit and defend relatively small exclusive territories, containing the nest site and sufficient food supplies. Others forage over much larger areas, often tracking ephemeral food patches, which are not defended. The latter often benefit from nesting and feeding in groups. Examples of the second category include seabirds, swifts and hirundines.

Despite extensive work on breeding birds at colonies, relatively little is known about where such individuals roost, forage or go when away from the colony. Radio-tracking facilitates studies where direct observation is made difficult by cover, distance or darkness, but it has seldom been applied to small birds (East and Hoffer 1986, Greig-Smith 1985, Hanski and Haila 1988, Jonstone 1992, Nygard and Einavik 1992, O'Connor *et al.* 1987). Although radio-tags have been used on hirundines (Brigham 1989), and on bats weighing less than 10 g (Lunney *et al.* 1985), the Sand martin is the smallest bird to be radio-tagged to date.

The Sand martin is the smallest hirundine species breeding in Britain (Cramp 1988). Sand martins nest in dense colonies with up to several hundred pairs (Hjeartaas *et al.* 1988, Jones 1986a, Petersen 1955, Stoner 1936) and are an example of social 'central place foragers' (Bryant and Turner 1982).

The aims of this study were to 1) assess the feasibility of radio-tagging Sand martins and 2) to illustrate the

type of novel information radio-tracking can provide for aerial feeding birds on foraging ranges and roost site selection.

Methods

The study site.

The study site was Barbush Sand Quarry (56° 12' N, 3° 59' W), central Scotland in June 1992. The Sand martin colony contained 516 occupied nests, occurring in subcolonies within 200-800 m of the River Allan. Criteria for assessing burrow occupancy followed Jones (1986a).

Radio-tags and radio-tracking.

Birds were caught using a hand net as they left their burrows, weighed, radio-tagged, marked with coloured dye and released within 5 minutes. A trial was carried out in which a radio-tag was glued (cyanoacrylate) between the shoulders of a Sand martin directly above the centre of gravity, following O'Connor *et al.* (1987) and Brigham (1989). The radio-tag fell off, or was removed by the bird within 24h so this technique was abandoned in favour of tail-clips.

Radio-tags were attached using miniature tail-clips (East and Hoffer 1986, Greig-Smith 1985, Johnstone 1992) such that they were hidden by the undertail coverts. Tail-clips weighed 0.3 g and consisted of two perspex plates clamped together using a pair of nylon bolts. The single stage SS-2 radio-tags (Biotrack,

Dorset, UK) weighed 1.0 g, resulting in a total package mass of 1.3 g. The 15 cm long external whip antenna projected from the tip of the tail. Only the central four tail feathers were contained within the clip so that the eight outer feathers could be spread as required. In Sand martins, the post-nuptial moult includes the tail (Turner and Rose 1989) so tags would soon be lost. However such an additional load on the tail may change the centre of gravity of the bird, potentially increasing flight costs or compromising manoeuvrability (Evans and Thomas 1992).

Information on nest attendance was collected for two hours during late morning (10-12 h) while birds were being radio-tracked. A neighbour's nest at the same stage was used as a control.

Three Sand martins were caught in the same subcolony (Table 1). Only the pair provisioning nestlings was radio-tracked during daytime. All birds were also searched for at night throughout the lifetime of the radio-tags locate roost sites.

All radio-tracking was done using hand-held three element Yagi antennas and RX-81 receivers. The θ_{95} error arc (Springer 1979) of the antennas was $\pm 1.5^\circ$. During daylight, birds were monitored by an observer at each of two fixed vantage points near the nesting subcolony. The compass bearings of radio-signals

were simultaneously recorded from the vantage points every five minutes during each bout of tracking. These were then converted to locations on a 1:10,000 scale map of the study area. Four bouts of tracking were undertaken each day, each lasting 2 h and distributed over the day (early morning, late morning, afternoon and late evening). The pair provisioning nestlings were radio-tracked regularly during daytime for a period of 48 hour, over which the weather was warm, calm and sunny.

Analysis of radio-tracking data.

The degree of statistical independence between radio locations was evaluated by comparing colony attendance estimated from radio-tracking data with the nest attendance measured by direct observation over the same period. Both individuals attended the nest burrow between consecutive locations placing them some distance away. Therefore using a sample interval of 5 min, locations were considered independent following the 'rule of thumb' that the time taken to cross the home-range is equal to the time to independence (White and Garrot, 1990). Space use was quantified by using the grid-cell technique since this non-statistical range estimator makes few assumptions about the utilization distribution (White and Garrot 1990).

Table 1 - Capture and recapture details of Sand martins that were equipped with radio-tags.

Sex	Date tagged	Breeding stage	Initial mass (g)	Duration (Days)	Mass change on recapture (g)	No. burrow visits [§]	Subsequent behaviour
Female	8 th June	provisioning nestlings (1 st brood)	12.5	3 [*]	0	34 (21)	1 st brood fledged 2 nd brood attempted 39 days after being radio-tagged.
Male	9 th June	Mate nestlings (1 st brood)	13.0	14 [#]	+0.25	28 (23)	1 st and 2 nd broods fledged.
Male	24 th June	Mate guarding (2 brood)	12.5	5 [#]	-0.5		Mate deserted while attempting 2 nd brood.
Mean (\pm SD)			12.7 (0.29)	7.3 (5.9)	-0.1 (0.4)		

* Radio-tag not subsequently recovered.

Radio-tag removed on recapture.

§ Number of burrow visits recorded in two of hours observation during late morning (control birds in brackets).

Two variables are required to describe the use of space by an animal relative to a central place: direction and distance. The direction of the location estimates from the nest burrow were measured to the nearest 10° on the map of the study area. Locations that were less than 100 m from the burrow were considered to be at the burrow and had no bearing from it. Distances of locations from colony and river were measured to the centre of grid cells and rounded down to the nearest 100 m.

Since both members of the pair were tracked concurrently and the successive locations were independent, it was possible to measure the degree of interaction between the birds. A measure of static interaction can provide information on the degree to which two utilization distributions overlap, and also whether the shared area contains the least or most utilized parts of each range. The degree of static interaction was calculated using the 'Static' computer program of Doncaster (1990).

Simultaneous pairs of locations can also provide an estimate of dynamic interaction between a pair of animals. Positive dynamic interaction indicates two individuals occur close together more often than would be expected at random (mutual attraction), negative dynamic interaction indicates mutual avoidance (Doncaster 1990). A critical separation distance between pairs of locations of 150 m was used to include the eight cells surrounding the occupied cell. Dynamic interaction was calculated using the 'Dynamic' program (Doncaster 1990).

All statistical treatments follow Zar (1984).

Results

Radio-tag performance and accuracy of locations.

The radio transmitters had a maximum range of 1.2 km and cell life of approximately 7 days. During daytime tracking, bearings could not be obtained on 5% of occasions for the male and 1% of occasions for the female. Sudden changes in signal strength suggested that this was due to birds being close to the ground where local topography blocked the signals, rather than to the birds being out of range. All locations were assigned to one hectare grid-cells. Measurement of error polygons indicated that 95% of the locations conformed to this level of accuracy, following the criteria of Kenward (1987). The remaining 5% percent were less accurate, but as outlying locations, contributed little to the utilization distribution. Since Sand martins are highly mobile, movement error may be an inevitable source of inaccuracy in the radio-locations. However, since

pairs of bearings from each individual were always recorded within a few seconds of each other, this was thought to be of little importance.

Effects of radio tags

Tagged birds behaved apparently normally. They flew with a mixed flapping and gliding gait typical of the species and could not be distinguished from other birds in flocks. When perching at the entrance of the burrows they were never seen to peck at the tags. Only small changes in body mass were shown between radio-tagging and recapture (Table 1), and no apparent damage to rectrices was observed.

The pair rearing chicks exhibited normal attendance behaviour just after tagging. They fed chicks at a broadly similar rate to a pair in a neighbouring nest used as a control (Table 1). The subsequent behaviour of the birds that were tagged is shown in Table 1.

Examples of what radio-tracking can reveal

1) Space use and habitat selection

The radio-locations obtained from the pair provisioning chicks, along with the locations of the subcolonies and the nearby river, are shown in Figure 1. The male and the female visited 69 and 39 one hectare grid-cells respectively.

On average the male showed little directional preference, while the female showed a strong preference for locations to the west of the subcolony (Figure 2).

For both male and female, over 70% of the locations occurred within 300 m of the burrow. There was no significant difference in the distance from the subcolony between the two birds (Mann-Whitney $W=22164$, $p=0.11$, male $n=154$ and female $n=148$). Distances from the subcolony at different times of the day (early morning, late morning, afternoon and evening) differed for the male (Kruskal-Wallis, $H=8.63$, $p<0.04$), but not for the female (Kruskal-Wallis, $H=5.74$, $p<0.13$). The male, was located further from the subcolony in late morning than in early morning (non-parametric Tukey comparisons, $Q = 2.912$, $p<0.05$).

The birds were located near the River Allan and over grassland and agricultural crops, when away from the colony. Birds were considered to be foraging most of the time when away from their nest burrow during daytime. Locations which placed the birds at their own subcolony were excluded from the sample, since such space use could be the result of the need to feed young rather than selection of habitat for foraging. Over the whole period that the birds were tracked, the male occurred significantly further from the river than

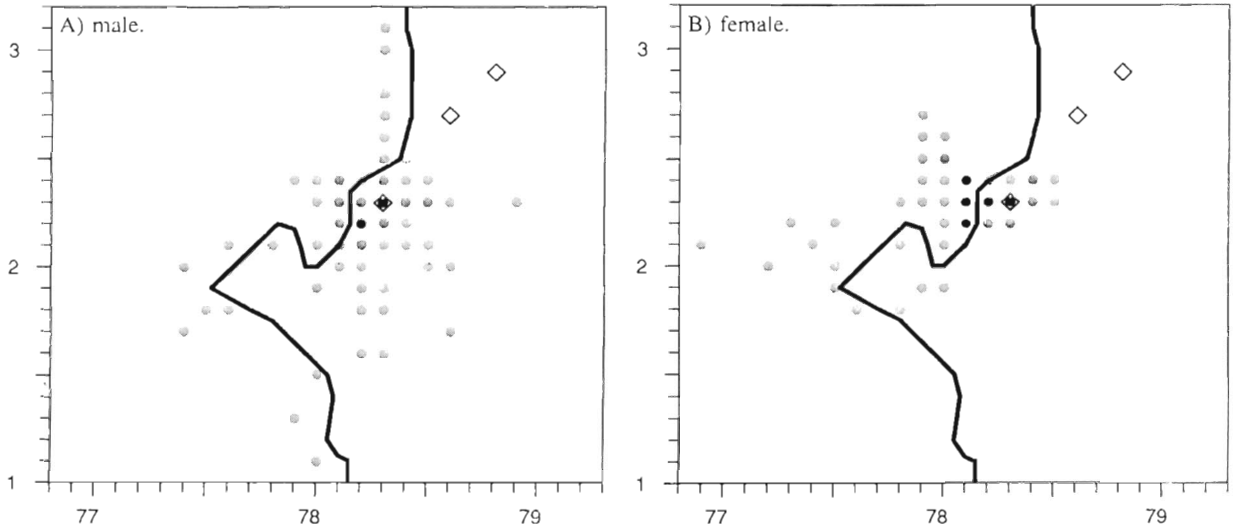


Fig. 1. Locations at which a pair of radio-tagged Sand martins were recorded, A) male n=148, B) female n=154. Black symbols represent >5% of the total number of locations. The diamond symbols represent subcolonies and the solid line the River Allan. Axes refer to km intervals within the 100 km grid square NN of the British national grid, north is the top of the figure. In both cases, the locations were concentrated around the subcolony containing the pair's nest burrow.

the female (Mann-Whitney $W=11676.0$, $p<0.001$, male $n=118$, female $n=114$). Both birds showed a significant tendency to be further from the river when they were at large distances from their nest burrow (male $r_s=0.27$, $p<0.01$, $n=118$; female $r_s=0.52$, $p<0.01$, $n=114$). Locations which placed the birds at their burrow were again excluded.

In contrast to its mate, the male visited other subcolonies; a behaviour which could be interpreted as seeking extra-pair copulations (EPCs). Of the occasions that the male was recorded closer to other subcolonies than to its own subcolony, 90% occurred in the afternoon and evening ($n=11$).

2) Interaction between the individuals

Of the 77 grid cells used by at least one member of the pair, only 29% were visited by both. Spearman's coefficient was used to test for a correlation between the utilization distributions of the pair, following Doncaster (1990). For the pair of Sand martins ranges, r_s was $+0.43$ ($p<0.05$). For ranges that overlap by the observed value of about 30%, a positive value for r_s indicates that the shared area contains the most utilized parts of each range (Doncaster 1990). Although male and female shared the most utilized parts of their home range, an analysis of dynamic interaction showed no tendency for the male and

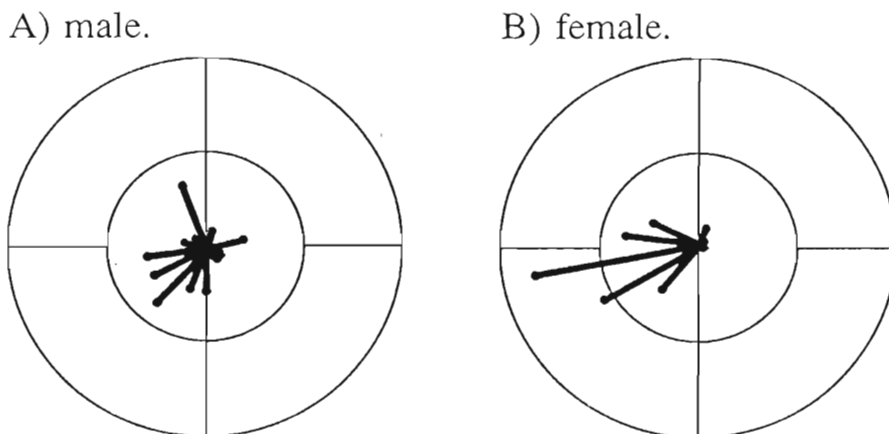


Fig. 2. Percentage of occasions on which birds were recorded in different directions from the nest burrow, bearings rounded to the nearest 10° . A) male ($n=118$), B) female ($n=114$). The radius of the inner circles represents 20 % of the total. North is towards the top of the figure. Locations placing the birds at the burrow were excluded.

female to be separated by less than 150 m more often than would be expected at random ($\chi^2=0.008$, $df=1$, $p>0.20$).

3) Roost selection during the rearing period

The locations of roost sites chosen by the Sand martin pair with chicks are shown in Figure 3. On the nights of the 9th and 10th June, immediately after tagging, the female was located roosting in its burrow, while the male was not found within a 1 km radius. Both birds were located on the 12th June away from the colony, the first night that a search of the area surrounding the colony was carried out. The pair was found roosting together in a field of oilseed rape, (*Brassica napus*), 4.7 km from their nest burrow. On the following night they were located together in the same field, 50 m from the previous roost site. At dusk a few swallows (*Hirundo rustica*) foraged in the area, but there were no Sand martins visible and there was no contact calling or social interaction to suggest the presence of

a large communal roost. Both birds were again located roosting together on the 14th and 15th June. On these occasions the sites were in a field of wheat, (*Triticum aestivum*), 3 km from the subcolony, and in slightly different locations on each night. Again there was no suggestion as to the existence of a large communal roost. On the 16th June the birds were located together just before dusk. Fluctuating signals indicated that the birds were still active 2.7 km from the subcolony and heading in the same direction as the roost sites of previous nights. However they were not located after dusk despite an extensive search covering approximately 30 km², suggesting that the birds could have crossed the River Teith and the roost site was more than 6 km from the colony. On the night of 17th June, the last time the birds were searched for, neither was located. By then the chicks were 17 days old and only the male was feeding the brood. The second male was radio-tagged during mate guarding, and was recorded roosting at night in the same burrow that it defended during the daytime.

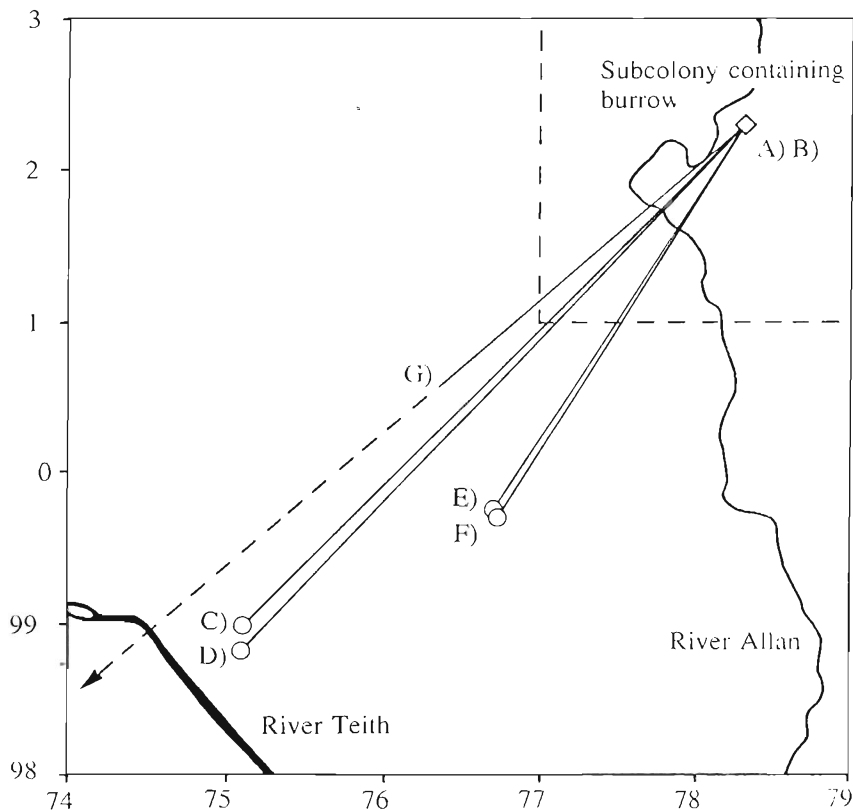


Fig. 3. Selection of roost sites by a pair of Sand martins during brood provisioning. A) and B) 9th and 10th June, nest burrow, female only, male not found. C) 12th June, oilseed rape (*Brassica napus*), male and female together. D) 13th June, oilseed rape (*B. napus*), male and female together. E) 14th June, wheat (*Triticum aestivum*), male and female together. F) 15th June, wheat (*T. aestivum*), male and female together. G) 16th June, still active just before dusk, male and female together, not found after dusk and probably crossed the River Teith. The square bounded by hatched line represents the area covered by Fig. 2. Axes refer to km intervals within the 100 km grid squares NS and NN of the British national grid, north is towards the top of the figure.

Discussion

1) Effects of tags

Radio-tags represented 10% of the mean body mass of the Sand martin (13 g), twice the widely recommended limit of 5 % (Cochran 1980). Accordingly, the minimum power required for level flight with and without radio-tags was derived using the programs of Pennycuik (1989). This indicated that a Sand martin of mean mass carrying a 1.3 g tail-mounted radio tag will incur a 15% increase in the power required for level flight. Since laying Sand martins (15 g) routinely incur a 27 % increase in minimum power, the additional load represented by the radio-tags fell well within that which Sand martins naturally experience. It is likely, however, that laying birds anticipate increases in flight cost associated with mass change and may adjust their physiology accordingly.

Only a few studies of small birds present quantitative results about the effects of radio tags (Brigham 1989, East and Hoffer 1985, Johnstone 1992). Studies on birds with high aspect ratio wings are also rare (Brigham 1989, Nygard and Einavik 1993). The effect of packages on the flight of such birds is of great importance since they are aerodynamically efficient, leaving relatively little scope for carrying additional loads, and also spend much of their time flying to collect food.

The present study suggests that the tail clips and associated change in centre of gravity caused no obvious problems to Sand martins. However, Wright and Cuthill (1990) have shown that subtle changes in provisioning rate may occur as a result of adding tail weights. Larger samples of birds and periods of observation would be necessary to test such changes in provisioning between tagged birds and controls.

Over the period that the birds carried radio-tags they showed on average only a slight decrease in body mass; consistent with the general decline in mass of the population during the breeding season (Jones 1986b). The pair provisioning chicks showed a slightly higher rate of nest attendance, in comparison with a neighbouring control nest. If the increase in wing loading due to the radio-tags caused a reduction in the mass of the prey bolus that birds could economically carry, burrow visits could become more frequent to maintain a constant rate of delivery to the chicks. The observed rates were, however, both within normal limits (Turner 1980) and the difference could be due to different demands of the broods or individual variations. Furthermore, the female successfully began a second clutch while tagged, indicating that radio-tags did not impair egg laying.

The results are consistent with tail mounted radio-tags having no major effects on Sand martins.

2) Space use and habitat selection

The use of radio-tracking techniques to determine foraging range and feeding locations by shags (*Phalacrocorax aristotelis*), a similarly highly mobile social 'central place forager', during chick rearing showed no significant sex difference (Wanless *et al.* 1991). But the radio-tagged male and female Sand martins commonly took different directions when foraging during the chick rearing period. They visited only 11% and 6% respectively of the area accessible within the maximum flight distance they used, which suggests a high degree of site selectivity. The bearings of the locations from the burrow suggested that the female concentrated foraging in the direction of the river, while the male showed much more variation. A previous study of predation strategies in aerial foraging birds recorded 75% of the feeding patches used by Sand martins to be over land and only 25% to be over or near water (Waugh 1978). Although the male showed a significant tendency to be further from the river than the female, the results from the present study recorded over 70% of the locations to be within 100 m from the river. A possible reason was that the local topography caused concentrations of insects along the river valley at the height favoured by foraging Sand martins (Waugh 1978). The birds being located further from the river at greater distances from the burrow, was almost certainly due to them taking a beeline flight paths to and from prey concentrations at different places along the meandering course of the river. This increased their probability of being located while overflying the intervening farmland.

The independent tracking data collected in this study provides no information on the search paths of individuals. The collection of highly interdependent locations, for example by using Doppler radio direction finders (Angerbjorn and Becker 1992) would allow such detailed space use to be monitored. This would provide a more accurate picture of the economics of aerial foraging, as birds locate, exploit and subsequently abandon ephemeral prey patches.

3) Information centres

Nestling feeding by both parents provides an opportunity to investigate ideas generated by information-centre hypothesis. That is, roosting and other assemblies (including breeding colonies) could serve as information-centres, where individuals benefit by following successful ones to profitable feeding areas, particularly for unevenly distributed

resources (Ward and Zahavi 1973, Bayer 1982, Brown 1986). Radio tracking can provide a way to answer the question: do pairs co-operating to rear nestlings exchange information about the location of profitable prey patches?

As would be expected for a 'central place forager', the cells that were most utilized by each bird, were visited by both of them and were concentrated at and close to their burrow. Both birds must repeatedly have flown through these cells to deliver food to the chicks. The absence of any degree of dynamic interaction suggests that the birds were not using cues from each other or a third party to locate food.

4) Mixed reproductive strategy

The tendency for the male to visit more grid cells, and to be located on average further from the river than its mate, was possibly due to the male looking for potential extra-pair copulations (Riley 1992, Alves pers. obs.). Sand martin chasing behaviour shows its highest peak early in the morning, decreasing in the middle of the day and increasing again in the afternoon to reach another peak by evening (Jones 1986b). Fertile Sand martins could be located by males in a flock of foraging birds by a distinctive gait during flight (Jones 1986b). Radio-tracking Sand martins during the pre-laying and laying stages (when the males guard their mates) would give useful information about mate guarding and opportunities for extra-pair copulations when the birds are away from their nest burrows. This information is otherwise difficult to obtain.

5) Roost selection

Published information about roosting when away from the nest burrow during breeding is scarce in hirundines. In Sand martins, the females and sometimes the males roost in the nest burrow until the nestlings are 10 days old (Petersen 1955), after which there is no information. Huxley (1949) records House martins (*Delichon urbica*), Barn swallows (*Hirundo rustica*) and Chimney swifts (*Chaetura pelagica*) returning to ground level from a great height at dawn, suggesting the possibility of aerial roosting. However, Smart (1990) recorded House martins roosting in oak trees (*Quercus* sp) in June before a night of wet and windy weather. Common swifts (*Apus apus*) (Holmgren 1993) have been observed going into trees at dusk, and radio-tracked White-throated needletails (*Hirundapus caudacutus*) were also shown to be roosting in trees (Tarburton 1993). Records of

massive communal roosts of hirundines in Autumn during migration are widespread (Cramp 1988), sites usually being located in reed beds. Ford and Elphick (1993) observed the progressive formation of such a roost by swallows in maize (*Zea mays*) during August and September.

The use of roost sites in this study suggests an explanation for the absence of previous records of roosts away from the burrow during breeding. It is possible that single birds or pairs scatter into countryside surrounding a colony at dusk, and select separate locations in the highly abundant suitable sites represented by agricultural crops. Birds roosting in these situations would be impossible to detect without radio-tracking. These sites become increasingly rare during the late summer and autumn due to the harvesting of crops. This might account for the progressive formation of communal roosts after breeding when the birds became concentrated into remaining sites such as reed beds. The ability to locate roost sites many kilometres from the colony demonstrated by this study could open the possibility of monitoring the post breeding movements of individuals.

This pilot study suggests that there were no measurable effects on the behaviour, body mass and short term survival of Sand martins equipped with tail-mounted radio-tags. Thus the application of radio-tracking to such a small aerial foraging bird can provide useful information on foraging range, habitat selection and behaviour.

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