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A pilot study for satellite-tracking Gadwalls *Mareca strepera* wintering in the Lea Valley, UK

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ABSTRACT

A pilot study monitored four overwintering Gadwalls fitted with satellite trackers in November 2018 at Rye Meads Nature Reserve, Hertfordshire. The research assessed the feasibility of a larger study investigating the range, movement and habitat preference of Gadwall utilising the Greater London wetland areas, and the suitability of fitting trackers using a glue-attachment method. Tracked birds varied in extent of movement. Two male Gadwalls remained largely sedentary, making use of the freshwater gravel lakes in the Lee Valley Regional Park. A pair-bonded male and female moved together, spending a number of weeks in the Lea Valley before moving 20 km to Hatfield Forest, Essex. This represented a change of habitat to a mature woodland with established lakes and ponds. We speculate that differences in movement between the male–female pair and other males may be attributable to mating effort and individual differences in migratory strategy. Considerable variation in the retention of trackers was seen, with one bird believed to have gradually removed the device through preening. Retrap data for one male showed overwinter weight loss that was higher than in any of 14 Gadwalls recorded previously. The cause of weight loss was unknown and we recommend further investigating the energetic costs of having a tracker fitted. Glue attachment may be unreliable for studies that require monitoring of Gadwalls for more than a few weeks, due to a high likelihood of attachment failure.

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The Greater London region of the United Kingdom is highly urbanised, with fragmented green spaces consisting of parks, wetlands and reservoirs that provide for recreational human activities such as walking, sailing, fishing and bird watching (Underhill & Kirby 1993). These spaces also support a complex array of ecosystems and species (London Wildlife Trust undated). Many wetland habitats have been created following historical sand and gravel extraction or for public water supply. Collectively, these wetlands form a large network of water space across Greater London.

The Lea Valley, Colne Valley, and south-west London water bodies are key areas of wetland resource in Greater London, attracting many species of wintering waterfowl. As a consequence, some sites are legally protected, with the Lea Valley and south-west London reservoir areas designated Special Protection Areas (SPAs) on the basis of their supporting internationally important migratory populations of waterfowl (Underhill *et al* 1993, JNCC 2001). The waterfowl assemblages at these sites can be a useful indicator of ecological quality, supporting their important status under the Water Framework Directive 2000/60/EC (European Communities 2000).

The dabbling duck species Gadwall *Mareca strepera* is a key member of waterfowl assemblages that make use of the Greater London wetlands. A small population of Gadwall resides year-round in the east and south-east of the UK. During the winter months, the numbers are bolstered by a significant influx of Gadwalls from breeding grounds in central and eastern Europe, Scandinavia and Iceland (Sterry 2004). The numbers of this species in the Greater London wetland areas, totalling 2674 individuals in the 2019/20 winter and with a five-year average of 2735, reach levels of national significance at some sites (five-year averages Lee Valley 624, Thames Estuary 408; Frost

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et al 2021). This confirms this wetland habitat as an important overwintering location for Gadwalls; research into their use of these sites has an important role in understanding the species and its conservation.

The life cycle of Gadwall is influenced by their need for specific types of freshwater wetland resources that are patchily distributed throughout the environment. Much research has been conducted that describes that life cycle on an annual basis, specifically the influence of breeding, moult strategy and migration on their activities and timing of movements (Lokemoen *et al* 1990, Clark *et al* 2005, Gehrold *et al* 2014). Research on habitat use has also been conducted within seasons; Briggs *et al* (2012) monitored the movement of Gadwalls within and around the south-west London reservoir complex to establish whether the boundaries of the SPA encompassed key Gadwall habitats and locations. That research used population counts and observational line-of-sight methods to investigate site use for feeding, roosting and refuge. The findings of Briggs *et al* (2012) included that Gadwalls adjusted their patterns of site use in relation to changing food resources and that their movements did not closely match the formally defined boundaries of the south-west London water-body complex.

Furthering our understanding of the use of the Greater London wetland habitat by overwintering Gadwalls requires monitoring their movements with a high degree of fidelity and in a way not limited by the extent of the researcher's line of sight. Satellite global positioning systems (GPS) provide the technology to capture such movements and open up the possibility of investigating the movement of Gadwalls both within and between the regions that make up the Greater London wetlands.

Tracking technology affords a more detailed understanding of the lives of animals and their patterns of behaviour, but carries costs and risks. Fitting of tracking devices to animals requires the capture, handling and attachment of a foreign object to the study species. This could potentially influence its behaviour and so invalidate any conclusions drawn. This is particularly an issue of concern when dealing with birds, due to their small size and body weights and their reliance on flight for their movements. Further, when dealing with waterfowl, the presence of an external object can impair streamlining as a bird moves through water during essential behaviours such as feeding. Over the past 20 years, much progress has been made in the design and development of tracking devices towards minimising the energetic costs and impact on animals to which they are fitted. Researchers in this field have proposed that tracking studies should report the potential impact of devices as standard practice, particularly in relation to waterfowl (Lameris & Kleyheeg 2017).

Although GPS methods can capture high-quality data, the cost of such studies can be prohibitively expensive. To assess the feasibility of a larger project to investigate movements, home range and habitat preference of Gadwall in the Greater London wetlands, we report here from a pilot study where GPS trackers were fitted to a small number of Gadwalls in the Lee Valley SPA. We describe the challenges in catching Gadwall and deploying trackers, summarise the movements of the birds tagged, and provide comment on the glue-attachment method and possible welfare considerations when fitting trackers to this species.

Methods

Study site and subjects

The area of interest was the Greater London wetlands, consisting of the Lea Valley (51°40'N 0°3'W), Colne Valley (51°34'N 0°29'W) and south-west London reservoirs (51°27'N 0°31'W). For this pilot study, fieldwork was confined to the Lee Valley SPA, situated in the north-east of Greater London and on the Hertfordshire/Essex border. The SPA covers a series of wetlands and reservoirs that occupy a 42-km stretch of the Lee Valley Regional Park, including a number of Sites of Special Scientific Interest (SSSIs), namely Walthamstow Reservoirs (51°34'N 0°3'W), Turnford and Cheshunt Pits (51°42'N 0°1'W), Amwell Quarry (51°47'N 0°0'W) and Rye Meads (51°46'N 0°0'E).

The study investigated overwintering Gadwalls in the SPA, this being a species contributing to the SPA designation. Previous surveys have indicated populations of this species of national and international significance in the Lee Valley SPA, with approximately 2% of north-west European Gadwalls found to be overwintering (JNCC 2001). For this research four Gadwalls were tagged in the Lea Valley and monitored using GPS tracking technology.

Tracking devices

The tracking devices used were GPS–GSM satellite transmitters supplied by Ornitela Ornithology & Telemetry Applications, UAB, Svitrigailos g, 11k-109, LT-03228, Vilnius, Lithuania. The model used was the OrniTrack T-15 solar transmitter, with 3D-

Table 1. Biometric details at first capture for the four adult Gadwalls tagged in this study.

Tag number	Sex	Wing length (mm)	Weight (g)	Tag weight as % of body mass
182371	Male	268	870	~2.1%
182372	Male	276	1050	~1.7%
182373	Female	255	860	~2.1%
182374	Male	272	830	~2.2%

printed extensions of 20 mm on each end of the tag. The tag weight was 18 g and its dimensions 96 × 25 × 14 mm. We followed guidelines specified by Kenward (2001) that the device should be less than 3–5% of the animal's body weight. With a weight range for Gadwall of 500–1250 g, the OrniTrack T-15 equates to about 3% of body mass for the smallest individuals and less than 1% of body mass for the largest. Table 1 shows tracker weights as a percentage of body weight for the four tracked Gadwalls.

Fieldwork and attachment method

Fieldwork was carried out at Rye Meads RSPB Nature Reserve, a site with a scrape where the water level can be controlled. Following unsuccessful attempts with a duck trap, the water level at this scrape was adjusted to provide a suitable area for baiting and trapping Gadwall. On the morning of 30 November 2018, prior to the reserve opening, four Gadwalls were caught there using a cannon net (Redfern & Clark 2001).

Trackers were fitted using a glue-attachment method, permission for which had been obtained through an application to the Special Methods Technical Panel (SMTP) via the British Trust for Ornithology (BTO) Licensing Team. The glue-attachment method for fitting tracking devices described by Kenward (2001) was followed. Each tracker was fitted to sit between the folded wings, two thirds of the way along the tertial feathers and just above the preen gland (Figure 1). All birds were also fitted with a standard BTO metal ring and a plastic colour ring with a two-digit inscription as a secondary method to aid field identification and data capture. Table 1 shows tracker and biometric information. The processing of birds to fit a device, apply metal and colour rings, weigh and measure took less than five minutes per bird. All birds were released together and on release spent a number of minutes on the water preening the GPS tag into the feathers.

Trackers were configured to collect data four times per day, once every six hours. This was an optimal setting to allow the collection of useful data points relating to movement whilst allowing the units to recharge and retain sufficient battery power to remain

Figure 1. Male and female Gadwalls with satellite transmitters fitted using the glue-attachment method. Images show placement of tracker two thirds of the way along the tertial feathers, above the preen gland.

operational. Data collection continued from the tagging date until 23 February 2019, by when the final tracker detached.

Habitat preference and choice were assessed through site visits by researchers to locations to which birds had been tracked. Broad habitat descriptions were recorded. It was not possible to identify specific aspects of sites that Gadwalls were making use of, unless they were still present. For places on private land that were not accessible to us, habitat descriptions were compiled from satellite images.

Results

Movements of tracked Gadwalls

Table 2 shows summary movement data from the four Gadwalls in this study. The almost identical movement patterns for the birds fitted with trackers 182372 (hereafter 72) and 182373 (73) indicated that they were a pair-bonded male and female. There was considerable variation between birds in terms of the distances moved and number of journeys. Journeys were defined as straight-line distances between consecutive GPS data fixes. The birds fitted with trackers 182371 (71) and 182374 (74) were both adult males. An estimated area of movement was calculated for each bird by measuring journey distances in Google Earth Pro (©2019 Google) and then calculating an area of movement, based on the geometric distances between the most distant points. These ranges are crude approximations and are sensitive to extreme data points and atypical flights. The following paragraphs describe the movement data obtained from each of the four Gadwalls tracked. Table 3 lists the sites visited by each bird and describes the habitat types found there.

Adult male Gadwall 71

This bird was the most sedentary of those tracked, remaining predominantly on the Rye Meads Nature Reserve and surrounding area. This bird made more use than any other of Glen Faba Lake (51°45'N 0° 1'E) and Stanstead Innings (51°47'N 0°0'E). This bird moved to Canons Brook (51°46'N 0°3'E), a wet area of meadows near Roydon in Essex and only 3 km from Rye Meads Nature Reserve, on 17 February. Sometime between then and 23 February, the tracker became detached from the bird. We have treated the final date the tracker returned fixes, 23 February, as the end date for data collection, although the tag might have been lost anytime after 17 February while the bird remained relatively settled in the Roydon area. This bird moved around an area of approximately 6.70 km^2 and its longest single journey was 3.5 km (Table 2).

Figure 2 shows a download of GPS tracking data between 30 November and 23 February for male 71. Lines on the satellite image indicate journeys between data points. The single movement towards Roydon, east of Rye Meads Nature Reserve, stands out as the only deviation from an otherwise neatly defined area of occupation for this individual. Almost all

Table 2. Summary of movement data for the four study Gadwalls, fitted with GPS–GSM tracking devices on 30 November 2018.

Tag number	Date of device loss	Duration of device attachment (days)	Movement area (km^2)	Longest journey (km)
1823(**71**)	23 February 2019	86	6.70	3.5
1823(**72**)	23 December 2018	24	80.25	20.8
1823(**73**)	28 January 2019	60	80.25	20.8
1823(**74**)	7 January 2019	37	13.95	6.2

Table 3. Habitat descriptions for sites visited by tracked Gadwall.

Location	Habitat description	Birds recorded			
Rye Meads Nature Reserve	Small lakes restored for wildlife following gravel extraction. Embanked lagoons receiving treated water from sewage works. Reedbed habitats; developed scrub on embanked areas of lagoons.	71	72	73	74
Glen Faba Lake	Lakes created following gravel extraction. Reedbeds; several small islands containing developing woodland; grassland and scrub. Used for recreational angling.	71			
Stanstead Innings	Cluster of freshwater lakes and waterbodies restored for wildlife and recreational angling and sailing. Reedbed; marsh; meadow.	71	72	73	
Canons Brook	Small winding river with shallow pools and wet areas in grazed river valley. Grassland; marsh; fragmented woodland.	71			
Amwell Nature Reserve	Two freshwater lakes restored for wildlife following gravel extraction. Marsh; reedbed; woodland.		72	73	
Hatfield Forest Lake	Freshwater lake created in 17th century. Mature woodland; grassland; scrub and marsh.		72	73	
Takeley Scrapes	Attenuation ponds for Stansted Airport, two regular pools with artificial banks. Managed grassland and man-made site.		72	73	
Pincey Brook	Small winding river and flood meadow with large pools of open water with emergent vegetation edges. Marsh; restored wet grassland.		72	73	

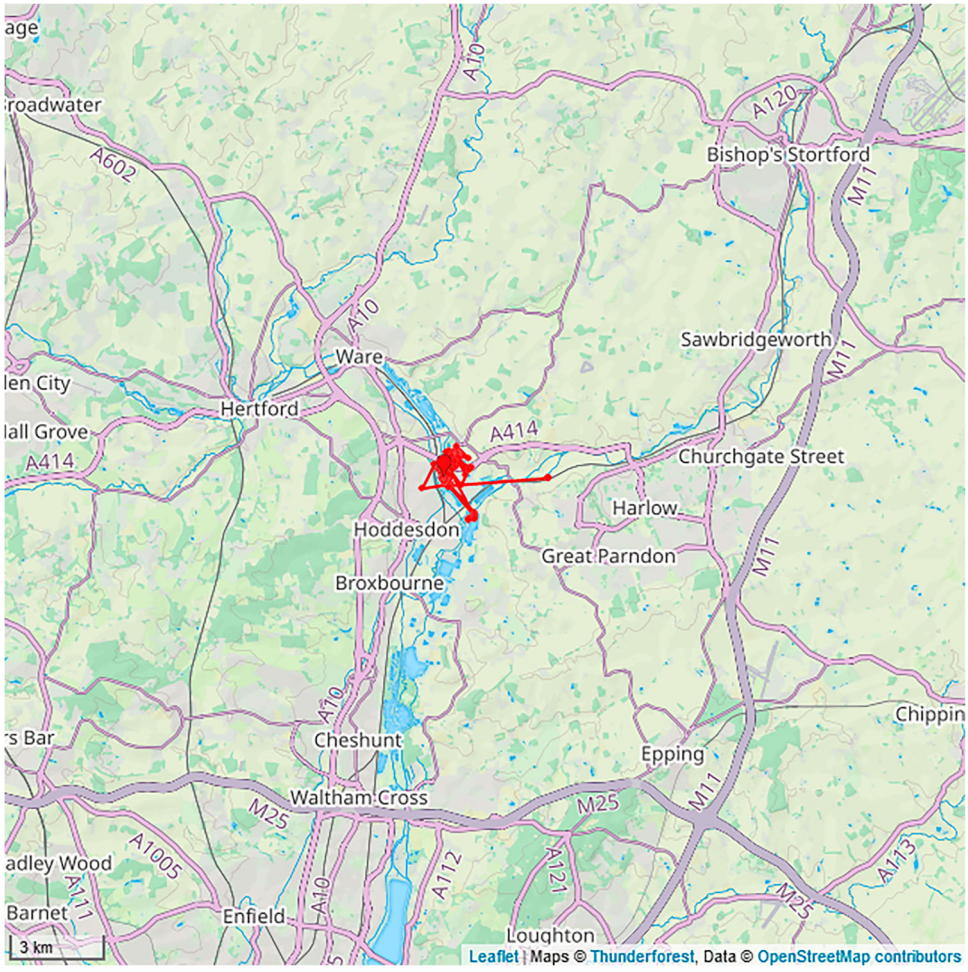

Figure 2. Movements of male 71, tracked from 30 November 2018 to 23 February 2019. Map data from OpenStreetMap under an Open Database License.

movement recorded for this bird was within the Lee Valley Regional Park.

Adult male Gadwall 72

Figure 3 shows a download of movements recorded for this adult male. Whilst being tracked, this male made movements almost identical to those of female 73, indicating they were pair-bonded. This bird, along with the female, was the most widely ranging, moving around an area of approximately 80.25 km^2. Its longest single journey was 20.8 km (Table 2). It remained at Rye Meads Nature Reserve between 30 November and 6 December, before moving to Amwell Nature Reserve 2.6 km to the north, where it appeared to remain between until 21 December. Sometimes its tracker did not transmit regularly, however, due to issues with battery recharging, and on 19 December no data fixes were obtained. We assume the bird made a similar movement to the female 73 and shifted to Stanstead Innings on that date. All previous movements had been within the Lee Valley Regional Park.

On 21 December it moved around 20 km northeastwards to Hatfield Forest Lake (51°51'N 0°13'E) and then onwards to nearby Takeley Scrapes (51°52'N 0°15'E). On 23 December, the bird returned south to Hatfield Forest Lake and then visited Pincey Brook at Hatfield Broad Oak (51°49'N 0°14'E). Some commuting occurred to a small water body around 3 km to the north-west of Hatfield Broad Oak. The habitat in this area consists of mature woodland surrounding waterbodies. The tracker detached around 23 December.

This male showed a high fidelity to sites in the Lee Valley Regional Park for the first three weeks after tagging. The movement to the Hatfield Forest area, near Stansted Airport in Essex (51°53'N 0°14'E), took it outside the Lee Valley Regional Park.

Adult female Gadwall 73

The adult female was, along with male 72, the most wide-ranging of the birds tracked. This bird moved within an area of approximately 80.25 km^2 and its longest single journey was 20.8 km (Table 2). The

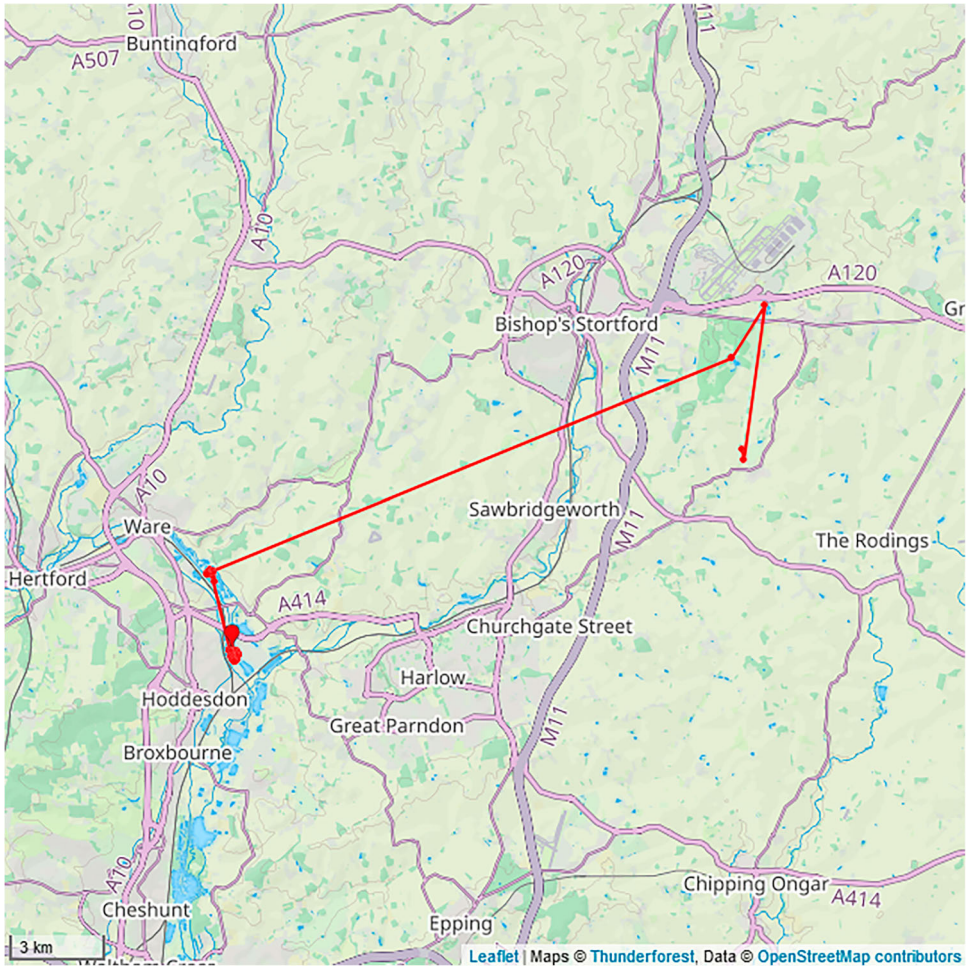

Figure 3. Movements of male 72, tracked from 30 November 2018 to 23 December 2018. Map data from OpenStreetMap under an Open Database License.

female made identical movements to male 72, remaining at Rye Meads Nature Reserve between 30 November and 6 December before moving to Amwell Nature Reserve, where it remained until 19 December, moving then to Stanstead Innings and staying there until 21 December (Figure 4).

On 21 December the bird moved around 20 km northeastwards to Hatfield Forest Lake and then to Takeley Scrapes, both sites in Essex. On 23 December it moved south to Hatfield Forest Lake and then to the water body at Pincey Brook at Hatfield Broad Oak, Essex. This period included some commuting to a small water body around 3 km to the northwest of Hatfield Broad Oak. The bird remained in the Hatfield Forest area, spending most of its time at Pincey Brook, for the remainder of the tracking period. This tracker transmitted the most regular data points and charged better than those fitted to the males. It detached sometime around 28 January.

Figure 4 shows an almost identical pattern of movement to male 72 from the tagging date until 23 December. After that date, additional data points were recorded for the female, with a tight cluster of movements in the Hatfield Broad Oak area of Essex. The female showed fidelity to sites in the Lee Valley SPA for the first few weeks of tracking and then a movement of 20 km to the Hatfield Forest area around Stansted Airport, followed by apparent fidelity to water bodies in that region for the remainder of the tracking period.

Adult male Gadwall 74

Figure 5 shows all GPS data for male 74. This bird remained predominantly at Rye Meads Nature Reserve although it made some movements outside the reserve. Its longest single journey was 6.2 km (Table 2). Tracking data indicated it ranged south, east and west of Rye Meads Nature Reserve but no movements to the north of Rye Meads were recorded. All data points away from Rye Meads Nature Reserve were recorded at altitude, and at night, indicating this bird was in flight: the altitude range used to assess whether a bird was in

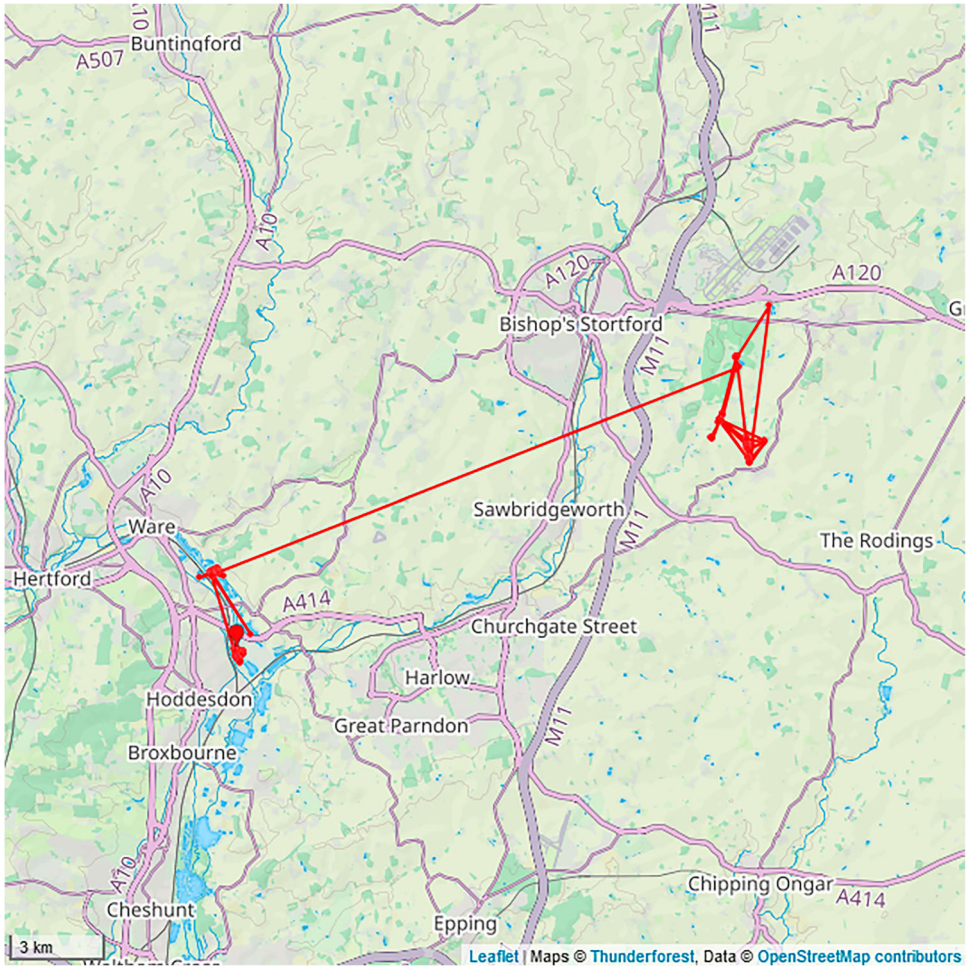

Figure 4. Movements of female 73, tracked from 30 November 2018 to 28 January 2019. Map data from OpenStreetMap under an Open Database License.

flight was 1–250 m. We hypothesise that this bird was travelling to other waterbodies outside the Lee Valley Regional Park, but these locations were not identifiable from the data points obtained. Alternatively, these fixes could have resulted from disturbance, or been erroneous. The area of movement for this bird, with its journeys outside the regional park, covered 13.95 km^2 (Table 2). We estimate that it actually occupied an area much smaller than this. This bird remained almost entirely within the boundaries of the SPA designation for the Lee Valley Regional Park. The transmission of data every six hours was insufficient to identify any other habitats utilised by this bird beyond Rye Meads Nature Reserve (Table 3).

Glue-attachment method for fitting trackers

Considerable variability was seen between birds in the durability of the glue attachment and the length of time trackers remained on individuals. The shortest time a glue-attached tracker stayed on a bird was 24 days, and the longest duration before loss of signal was 86 days (Table 2).

The dates of detachment for trackers (Table 2) are approximate, as it took a few days for the trackers to return sufficient data to indicate that they were stationary. Trackers 71 and 74 remained in a static position on land and were recovered after detaching. The remaining two were believed to have become detached and had drained of battery by floating panel-side down or in vegetation.

Supplementary field observations were attempted, to monitor birds fitted with trackers. The male–female pair, 72 and 73, were observed at Amwell Nature Reserve on 21 December, three weeks after tagging. The trackers appeared still to be fitted securely in position. Remote monitoring of tracker status and performance showed that the tracker fitted to the female was charging much more efficiently and returning data more consistently than the trackers

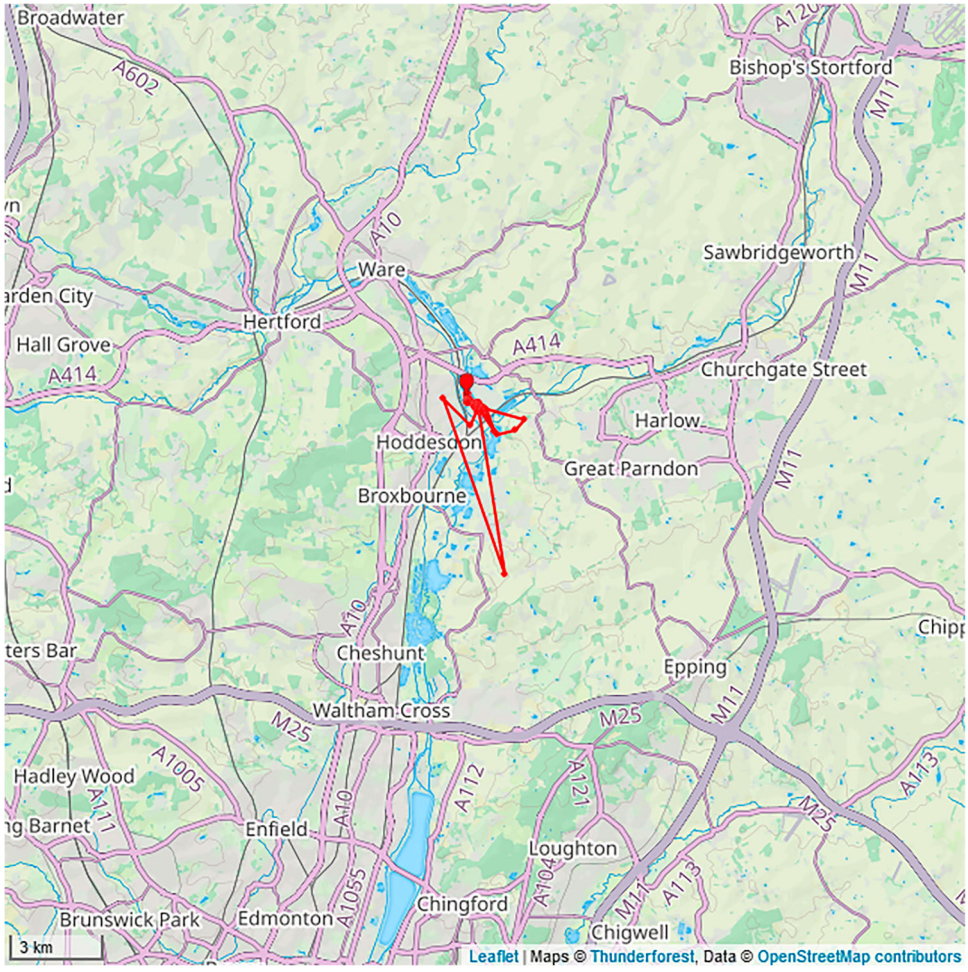

Figure 5. Movements of male 74, tracked from 30 November 2018 to 7 January 2019. Map data from OpenStreetMap under an Open Database License.

fitted to males. When the male–female pair were observed, it was noted that the male's longer scapular feathers were obscuring part of the solar panel, whereas the whole of the solar panel appeared to be exposed on the female (PR & TH, pers obs).

The behaviour of the pair in the field on 21 December 2018 did not suggest any adverse effects of the trackers; both birds were part of a foraging group. During observation the trackers were not interfered with by the birds (PR & TH, pers obs). These field observations gave no indication that trackers were having an adverse effect on normal flight, foraging and movement.

On 19 January 2019, male 74 was recaptured in a duck trap at Rye Meads Nature Reserve, after it had lost its tracker. The bird was assessed to be healthy and showing no ill effects from its time carrying a tracker. The bird had a small patch of feather regrowth at the site where the tracker had been glued (Figure 6). There were no signs of moult or feather regrowth anywhere else on the body, indicating the tracker had been pulled off rather than having fallen off. This assessment was made as its feather regrowth was consistent with that seen on a sample of two captive ducks, upon which the glue-attachment

Figure 6. Male Gadwall 74 on retrap at Rye Meads Nature Reserve, showing the placement site of the lost tracker and feather regrowth.

Table 4. Mean overwinter weight loss for Gadwalls retrapped at Rye Meads Nature Reserve between 1985 and 2019.

	n	Mean weight loss (g)	Range (g)
Male	7	67.86	30–130
Female	7	46.00	10–110
Total	14	58.75	10–130

method had been tested prior to its deployment on wild birds. The tests, to assess any potential negative effects on behaviour, using captive birds in a controlled environment, did not reveal any welfare issues but it was noted that trackers were gradually removed by the birds pulling out the feathers at the base of the quills through preening (PR, pers obs). Field observations of birds on water immediately after tagging suggested that the Gadwalls habituated to the tracker after an initial period of preening; similar observations have been reported in other waterfowl tracking studies (Roshier & Asmus 2009).

Male 74 when retrapped on 19 January 2019 weighed 640 g. This was 190 g lighter than when it had first been trapped, and tagged, on 30 November 2018. Biometric data for 71 Gadwalls trapped and ringed at Rye Meads Nature Reserve in the months of January during 1985–2019 showed weights for males between 550 g and 1050 g. The weight of male 74 was within the expected range for male Gadwalls for January and may be a normal weight for this time of year, given the overall harsher environmental conditions.

Biometric data for Gadwall trapped and retrapped at Rye Meads Nature Reserve during 1985–2019 were analysed to assess the range and mean of weight loss recorded for birds over winter at that site. Data were obtained for seven male and seven female Gadwalls with multiple records for weight over the winter months of a single season between October and March (Table 4). Of these 14 birds, 12 showed a weight loss as the months progressed and two gained weight. The average weight loss over winter was 58.75 g and the range 10–130 g. Male birds showed a greater average weight loss than females: males 67.86 g, females 46.00 g, though with a large overlap in range. These results provide a small sample with which to compare male 74, but indicate that the overwinter weight loss shown by this male was much higher than average, and beyond the previous range, for other male Gadwalls trapped at Rye Meads. The mean period between trapping and retrapping for this sample was 26 days, and the range 2–96 days, encompassing the 37 days that male Gadwall 74 carried its tracker. The two Gadwalls that showed a gain in weight over winter were both female; one gained 20 g and the other 50 g.

Discussion

Movements of tracked Gadwalls

This pilot study demonstrated the value of GPS–GSM satellite tracking for mapping movements of Gadwalls at a general level, in and around wetland habitats. GPS fixes were limited to four data points per day, which was sufficient to provide information regarding the birds' preferred locations (Table 3). It was insufficiently detailed to address specific aspects of the habitats Gadwalls were using, however, and how this influenced their movements.

The two males 71 and 74 stayed almost entirely within the Lee Valley Regional Park. Tracking data highlighted the importance of particular water bodies towards the north of the Lea Valley for these birds. It is noteworthy that, while both of these males were adults, they appeared not to be pair-bonded with females and at tagging they were solitary males. No field observations were recorded for them outside the GPS data fixes, so it is not possible to say whether they remained unpaired or paired with females at a later date, or whether their pairing status influenced their movements and behaviour. Unpaired males may be free of the time and energy costs that pair-bonded males have to invest in mate-guarding and searching for breeding sites and may be making trade-offs in energy usage by minimising costly long movements and remaining at foraging grounds when environmental conditions become challenging. However, male 74 showed considerable unexplained weight loss between tagging and recapture. The possibility of differences in energy budget between pair-bonded and solitary birds is worthy of further research.

The male–female pair 72 and 73 showed fidelity to sites within the Lee Valley Regional Park for several weeks after trackers were fitted, making use of Rye Meads Nature Reserve and Amwell Nature Reserve which are both key water bodies within the SPA. The pair then left the SPA, travelling north to the Hatfield Forest area, where they stayed for the remainder of the tracking period. A movement of this distance, about 20 km, was not unexpected but the change of habitat that this represented was surprising. Hatfield Forest is an old hunting forest consisting of mature woodland that differs considerably from the habitat type visited by these birds in the Lea Valley (Table 3). A restored river system at Pincey Brook was also used regularly, however, and habitat there resembled some aspects of the Lee Valley SPA. We visited this site and observed up to 10 Gadwalls, along with Teal *Anas crecca* and

Mallard *A. platyrhynchos*. The area also has features similar to the wet grassland habitat visited by male 71 (Table 3). Several movements made by the pair in Hatfield Forest were short commutes to small ponds around 18 m in diameter. This included movements made at night, possibly indicating nocturnal feeding. The difference in movement between this pair and males 71 and 74 led us to speculate that their behaviour might be linked to mating effort. Researchers considering a tracking study should note the likelihood of tagging pair-bonded birds and the issue of independence of data points this raises.

A key point of interest for this pilot was whether birds would move between areas of the Greater London water-body complex. We were interested to know if individuals moved between the Lea Valley, Colne Valley and the south-west London Reservoirs. Gadwalls may make such movements but insufficient data were obtained to answer this question. Recording no movements between different regions of similar habitat but recording movement to an area of dissimilar habitat, at Hatfield Forest, were both unexpected results.

All four birds spent several weeks around Rye Meads Nature Reserve, where they had been tagged. This is unsurprising due to the nutrient-rich treated sewage that flows through the lagoons at this site (White & Harris 2008). The preference of male 71 for Glen Faba Lake in the Lea Valley may reflect the similar conditions there of eutrophic water and readily available food, such as aquatic vegetation.

Previous research has suggested that Gadwall will move around the water bodies in their home range in response to food availability (Briggs *et al* 2012). Gadwall may be following a habitat-matching rule, where distribution and movements are influenced by the abundance of food items and the numbers of foragers exploiting the resource (Giraldeau & Caraco 2000). This would explain the numerous short journeys between different water bodies; they may have moved between sites as resources became locally depleted or more heavily contested by other foragers.

Surveys to estimate the abundance of food at different sites were not undertaken as part of this study. Future research could develop our understanding of the aspects of these habitats that are important by surveying abundance of food sources and changes relative to the movements of tracked birds. This would involve surveying sites whilst tracked birds are present and trying to identify whether there is a critical threshold of food availability and competition that prompts birds to move to a new patch.

Diverse habitats were visited (Table 3) and, beyond the presence of water bodies, no key features were identified that explained why they had chosen a particular site or how long they stayed. As suggested, birds may have been tracking food availability. We also considered that the pair 72 and 73 had not reached their final migratory destination. Gehrold *et al* (2014) used tracking studies of Gadwalls to show that paired individuals migrate together and make meandering multidirectional movements. They noted that birds often stopped and made use of wetland feeding grounds for a period of weeks, whilst neglecting numerous water bodies on route. Their conclusions were that final migratory destinations were influenced by individual differences in life history and by sites they had visited in previous years, perhaps even by their natal grounds. Interpreting the behavioural difference between the male–female pair and males 71 and 74 as individual differences in life history and migratory strategy would seem to account for the movement pattern of these birds. Movements to different habitats to those where they had been trapped meant that no terrestrial or riparian habitat features preferred by Gadwall were identified.

Increasing the number of data points per day would increase the fine detail of movement data and would be necessary if we are to understand better what prompted birds to change locations. More frequent downloads would also be required to investigate the behaviour of birds moving within a small area. Increasing the frequency of transmissions from trackers comes with costs, both financial and in terms of the demands placed on the battery of the tracker. Any future research utilising this approach needs to consider the trade-off between these factors and will ultimately be influenced by the research question. For this study, more frequent data points would certainly have shed light on important behaviours encompassed by protected sites, such as nocturnal feeding (Guilleman *et al* 2002). Future research incorporating surveys of fine-scale habitat data would also be needed to ascertain which environmental features were most important in influencing habitat preferences.

Glue-attachment method for fitting trackers

There was marked variation in the period for which trackers remained attached, making the glue-attachment method potentially risky and unreliable. Trackers remained in place for between 24 and 86 days, producing a wide range in the quantity of data obtained for different individuals. As we sought to

investigate the movements of overwintering birds, an optimal study period for capturing tracking data would have been at least three months. Only male 71, which was one of our most sedentary individuals, retained a tracker for a period close to three months.

Some level of attachment failure or hardware failure should be anticipated, particularly for mobile species such as birds. Variance in the reliability of glue attachment between individuals, and the costs involved in GPS tracking studies, may preclude the use of this method if data are likely to be insufficient to meet the research aims. We suggest glue attachment is best suited to studies where data collection over a few days or weeks is sufficient to meet project goals. Other studies have shown that trackers can be retained for longer using attachment methods such as a backpack harness or glue attachment in combination with sutures (Roshier & Asmus 2009). However, these methods bring their own challenges and welfare considerations, including the level of invasiveness (Wheeler 1991). The study species, the demands of its habitat and its lifestyle are all factors to consider before using glue attachment. Waterfowl make use of terrestrial, riparian and aquatic environments, creating potentially greater stress and wear-and-tear on the materials used for fitting. Glue attachment may prove to be more reliable on species with less demanding lifestyles.

Considering bird welfare it appeared that, when recaptured in January 2019, male 74 had removed its tracker by pulling at the glued feathers, as was inferred from a similar feather regrowth pattern having been observed in the captive birds on which glue attachment had been trialled. Whilst feathers grow back quickly and are routinely moulted, it is unclear if glue attachment causes distress or irritation while the trackers are in place. Even if birds are largely untroubled by the presence of the tracker, a foreign object attached to the feathers is likely to capture the bird's attention during preening and the gradual removal of the device may be a consequence.

Further investigation is warranted on captive birds to determine any potential welfare impacts. The SMTP emphasise that tests must be in the study species and not substitute a comparison species, so tests on domestic ducks would not be valid. Researchers planning tracking studies should be aware of potential licensing issues and, at an early stage, should seek guidance on the requirements for trials and tests of attachment methods.

Species differ in their sensitivity to handling and other stressors when subjected to research manipulations (Kenward 2001). Even if glue attachment has minimal impact for Gadwall, this assessment cannot be generalised across all waterfowl species. Some species may be more robust and tolerant of this method, and of tracking studies in general, than others. Researchers should consider assessing impact through pilot studies or deployment under controlled conditions, such as monitoring the responses of captive birds. Both approaches were used for this project. Such investigations, in conjunction with the independent review of the information they garner by the BTO's SMTP, ensure that bird welfare remains paramount.

Measuring weight change may provide a useful means of assessing the impact and additional demands placed on animals by the attachment of trackers. In this pilot, comparison of weight change from a single tracked bird was made against a small sample of 14 others from local ringing records, with no systematic approach to obtaining and recording weight change in the comparison sample. Data points for weight were recorded as and when birds had been trapped, with some birds having their weight taken on dates only a few days apart and some after a much longer interval, up to 96 days. While the weight loss of male 74 seems extreme, caution must be urged before drawing conclusions about the significance of its weight loss and whether it can be attributed to the demands of wearing a tracker.

Evaluating welfare is difficult with so few data and field observations. We could draw a possible inference from the recorded feather regrowth and weight change that there was some effect on birds of carrying trackers. However, on balance we assess that carrying the tracking unit increases demands on the bird and birds may gradually loosen the unit through preening of the area of attachment. At the time of writing, none of the four birds had been reported anywhere else or found dead.

Conclusions

This study showed a mixture of movement and behaviour for tracked individuals, making it difficult to ascertain the key habitat features that are important for this species. Availability of food resources and the presence of competitors for those resources will likely have a significant impact and we believe that individuals may have been following a habitat-matching rule as they forage. Future research to assess this behaviour would require surveys of food abundance and changes relative to the movement of tracked birds. Such data could inform management

decisions regarding which food resources are critical and should be monitored longitudinally to anticipate the potential impact of environmental changes on Gadwall populations at these sites.

A larger sample is needed, with more frequent transmission from trackers, to develop our understanding of the movement of Gadwalls and their preferred habitats. With a small sample, it would be easy for the behaviour of individual birds to skew the data towards conclusions that might not represent the species as a whole. The pair 72 and 73 illustrated this well and their movements could be related to mating effort or to individual differences in migratory strategy.

Our experience was that having a budget and trackers is only half the picture. Trapping and fitting devices to certain bird species is not straightforward but requires extensive commitment of time and effort by a research team. Gadwalls proved extremely difficult to trap, despite a lot of experience and expertise from the ringers of Rye Meads Ringing Group and the Southern Colour Ringing Group. Birds were tagged at Rye Meads Nature Reserve, a site with considerable infrastructure for trapping and ringing, and even there numerous attempts were required to capture the study species. Trapping at other sites would likely prove even more difficult, as many old gravel-extraction reservoirs within the SPA provide little realistic opportunity for capture methods such as cannon netting.

Variation in the durability of the attachment method may influence the value of data collected and the validity of any conclusions. Glue attachment seems to be a more useful option for studies tracking more sedentary animals with less demanding lifestyles over an intended shorter study period, of the order of days or weeks. The choice of glue attachment for studies lasting months, or over indefinite periods, would seem unwise due to the likelihood of attachment failure.

We only indirectly assessed the welfare impact of the glue-attachment method, through a small number of field observations, comparison of feather regrowth patterns with captive birds, and comparison of weight change against a small sample of ringed birds. No firm conclusions regarding the impact of tracking devices and the glue-attachment method can be drawn from the data and we recommend further investigation into the potential welfare impacts and energetic costs of fitting trackers to Gadwalls. We hope the lessons learned from this pilot in relation to fieldwork challenges are of use to other researchers when designing and planning tracking studies.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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