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LIFE WADERS FOR REAL

Deliverable C2: The implementation and efficacy of predator monitoring and tracking

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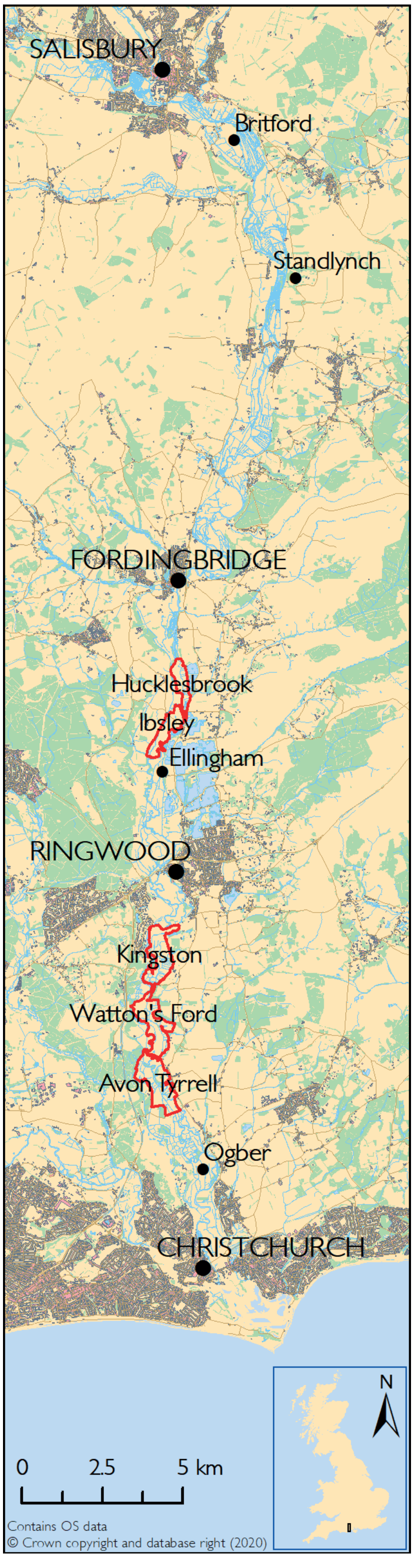
Game & Wildlife CONSERVATION TRUST

LIFE Waders for Real

Life



Preface

The Avon Valley (see map, left) has historically supported nationally important populations of breeding waders. However, in common with other lowland wet grassland sites throughout Britain, numbers of breeding waders in the valley have fallen dramatically since the early 1980s, with declines of 64% in lapwing, 75% in redshank and 97% in snipe. The valley is also designated for its wide range of habitats, an outstanding diversity of plants including several nationally rare species and many invertebrate species including dragonflies, grasshoppers and snails. The Game & Wildlife Conservation Trust has monitored wader numbers in the Avon Valley for over 20 years and our data on lapwing breeding success since 2007 show that low nest and chick survival resulting from high levels of predation is an important factor in the decline of this bird.

The aim of the LIFE Waders for Real project is to reverse the declines of breeding waders in the Avon Valley. The project is a partnership between farmers, landowners and the Game & Wildlife Conservation Trust, with input from Sparsholt College, Hampshire & Isle of Wight Wildlife Trust, Natural England and the Environment Agency. This builds upon agri-environment scheme management to implement additional habitat measures and trial methods of reducing predation pressure on wader nests and chicks.

Species recovery at local scales is no small task and it relies on many stakeholders working together to keep the 'cogs' of a conservation project like Waders for Real moving in the right direction. Success can only be achieved by un-locking enthusiasm, through building trusted relationships between land managers and advisors. Advice needs to be tailored, realistic and trusted to allow land managers and farmers on the ground to take ownership of their environmental goals alongside their day to day working practices.

Understanding species' requirements and measuring success is crucial to maintaining enthusiasm; providing an understanding of wider environmental issues and concepts, as well as the reasoning behind targeted conservation actions can go a long way in improving knowledge and crucially, participation. It is also essential for land managers to know what they are doing for wildlife is making a difference.

Introduction

Prior to the start of LIFE Waders for Real (hereafter W4R) in 2015, surveys at 6 to 7-year intervals had shown the number of Lapwing (Vanellus vanellus) in the Avon Valley to have declined by approximately 70% since 1990. Monitoring showed that local nest and chick survival were insufficient to maintain numbers without recruitment from elsewhere. However, it was unclear which predator species had the greatest impact. There is a large suite of potential predator species: mammalian predators including Red Fox (Vulpes vulpes), Badger (Meles meles), Feral Cat (Felis catus), Otter (Lutra lutra), American Mink (Neovison vison), Polecat (Mustela putorius), Stoat (Mustela erminea), Weasel (Mustela nivalis), Hedgehog (Erinaceus europaeus), Brown Rat (Rattus norvegicus); and avian predators including Heron (Ardea cinerea), Buzzard (Buteo buteo), Kestrel (Falco tinnunculus), Carrion Crow (Corvus corone), Rook (Corvus frugilegus), Jackdaw (Corvus monedula) and Magpie (Pica pica). However, elsewhere, the Red Fox (hereafter fox) has figured prominently in most detailed studies of predation on ground-nesting birds, especially Lapwing breeding in wet grassland habitats. Given GWCT's expertise with foxes and their control, we chose to focus on this predator.

Scope of this report

Here, we report on a key aim of the W4R project, which was to advance our understanding of fox ecology and management in river meadow habitats important for breeding wading birds, principally through GPS-tracking. We also describe ancillary research involving trail cameras and high seat counts to monitor fox activity on sites where foxes were tagged, and dietary studies. Due to the huge volume of biological material and monitoring data amassed during the project, much of it currently remains unanalysed, so we report only preliminary results. Once analyses are completed, the findings will be published in the scientific literature. Ultimately, we aim to assimilate the new knowledge to improve fox predation management to help conserve breeding wading birds, although we emphasise that foxes are one of many different predatory species that may impact on lapwing in the Avon Valley.

This LIFE report does not include details on:

- The monitoring of mammalian and avian predator activity on W4R hotspot sites, using mink rafts, ink-tracking tunnels, trail cameras and predator watches. See LIFE deliverable **D3: Report on the work carried out on the tracking and monitoring of predators.**
- Spatial analyses of tagged foxes around electric fences, and the impact of fox culling on the Bisterne Estate. See L**IFE deliverable E1: Technical publication on the direct and indirect predator control techniques for wader population stabilisation and increase, including implementation and efficacy of indirect measures.**
- Investigations into the diet of foxes throughout the Avon Valley. See **LIFE deliverable E1: Leaflet for wetland site managers summarising the Avon Valley results on fox density and diet.**
- In-depth analysis of fox movement behaviour and activity from GPS-tracking. This work will be reported in **LIFE deliverable E1: Scientific publication on fox movement ecology** and includes details of fox habitat use around breeding waders.

Managing fox predation

The fox is difficult to manage and a fundamental management decision is whether to (a) use lethal control measures to continually remove foxes that pose a threat, or might pose a threat; or alternatively (b) rely on physical barriers such as electrified fencing or water courses to prevent foxes from reaching vulnerable birds. Both well-established predation control techniques have merits and shortfalls, and both have been used successfully to improve the productivity of breeding waders in a variety of agricultural landscapes. Scaring foxes with audio or visual deterrent devices is another option (albeit with attendant risk of disturbing birds) and more recently wildlife wardens on reserves have strategically managed wet grassland habitats to try and influence the foraging behaviour of foxes and divert them away from important wader breeding areas. But which approach offers the best value for money in terms of delivering more waders, and what advice can we give to land managers to ensure their efforts are effective?

Filling knowledge gaps

To answer these questions, we needed a much clearer understanding of the lives of foxes on river meadows, and within the wider floodplain landscape, during the period that breeding waders are vulnerable. For this reason, the project invested heavily in novel fox tracking research, to learn more about their densities, habitat use, activity patterns and hunting behaviour in areas where waders once bred and still do. This will enable us to calculate the risk that foxes pose to breeding waders and, hopefully, to exploit new knowledge to design better wader breeding habitats, in which the chances of hunting foxes encountering nests and chicks are reduced.

The Avon Valley supports several large towns, many small villages, and a range of rural enterprises, including fish-farming and released-game shooting, all of which generate food resources that could be exploited by foxes. Similarly, unmanaged grass pastures, which can support high densities of small mammals, are prevalent in the very areas where vulnerable birds like Lapwing and Redshank (Tringa totanus) often breed. So, alongside the tracking work, we collected scats (faeces) to explore fox diet, predominantly in areas where foxes were tagged, but also from elsewhere in the valley when the opportunity arose.

We also analysed stomach contents of foxes culled during routine gamekeeping operations on the Bisterne Estate, home to the Watton's Ford and Kingston hotspot sites, and from other locations in the valley. Our assessment of fox culling data, and collection of fox carcasses, was enabled by building trusting relationships with local gamekeepers, who shared valuable material through their usual predator management activities, which weren't funded through LIFE. (For details on fox culling and fox stomach analysis, see the relevant publications listed above.)

Because lethal control of vertebrate pest species is controversial, understanding its limitations as a management option is important. An effective culling strategy requires prior knowledge about fox detectability using survey methods typically employed during and after fox culling operations, in order to understand how many foxes may remain in the control area. How detectable are the foxes that use wader breeding habitats, both within those habitats, and in adjoining habitats? To answer that we gathered data on the detectability of tagged foxes using: (a) point-counts from high-seats around sunset, and with thermal-imaging equipment at night, (b) with trail cameras and (c) by searching for their scats. Aside from their use in culling operations, understanding the limitations of these survey methods is important for wildlife managers when assessing fox predation risk.

Methods

Catching foxes and GPS-tracking

Catching and tagging foxes for research purposes falls under The Animals (Scientific Procedures) Act 1986 so this work was carried out under Home Office licence, with carefully planned field protocols and close scrutiny of progress by the Home Office Inspector. All foxes were caught and tagged by the Predation Manager (Mike Short) who is highly experienced in the live-capture and tagging of foxes.

Because cage traps are notoriously ineffective at catching adult rural foxes, we relied solely upon neck snares (DB snare, Perdix Wildlife Supplies, UK) for tagging (Figure 1). Contrary to widespread misconception, neck snares catch and restrain foxes without injury provided they are well-designed and carefully used (Defra 2012; Short et al 2012). The DB snare includes designed-in features both to facilitate fox capture, and to allow non-target species to self-release (Short et al 2012). Nevertheless, great care was taken to minimise risk of capture of Badger and Otter which also use the river meadows. Snares were set only in areas known to be occupied by untagged foxes, or to recapture specific foxes such as when a collar needed to be replaced. Strategically located trail cameras helped to guide snaring effort. Snare use and deployment was necessarily influenced by fox and non-target activity, and by water levels on river meadows: snares can only be set here when the ground is dry enough for snares to be tethered to secure ground-anchors. Snares were operated in accordance with the Defra Code of Practice on fox snares (Defra CoP 2012).

Captured foxes were quickly restrained and physically assessed prior to tagging. Foxes were never sedated, and the entire collaring procedure was conducted by the Predation Manager working alone. For captured foxes not requiring veterinary consultation by telephone (17/18 timed events), the average time to assess physical condition, fit a collar, and release the fox was 6min 13sec. All foxes were released where caught.

From 2017 onwards, at point-of-capture, we collected 23 fur samples from tagged-foxes and 26 fox scats found at capture sites, for subsequent DNA-analysis (genotyping). Successful amplification of fox DNA from these samples will confirm the number of individual foxes tagged: tags were recovered by remote drop-off and foxes were otherwise unmarked, so it's possible that some individuals were tagged twice in the same year, or in consecutive years. Further, genotyping of scats collected on tagging sites will (eventually) enable us to calculate the detectability of tagged foxes by scat searches, which is a commonly used fox survey method.

Choice of collar

Prior to the study, we researched the market for GPS-collars suitable for deployment on foxes. We chose a GSM-type collar (Tellus Ultra-Light, Followit) which uploads data directly to a computer server in scheduled transmissions via the mobile phone network. We field-tested two units on male foxes in July 2015, to ensure the GPS-technology and network coverage met our study requirements. These collars performed well, and we invested in 12 more units in subsequent years.

The collars are remotely programmable, but we programmed them initially to record a GPS-location every 10 minutes to provide adequate detail on habitat use and hunting behaviour. In some cases, we changed this to record once per hour to conserve battery life. When falling battery voltage indicated that little battery life remained, a remote drop-off mechanism could be triggered remotely, allowing the collar to be recovered and the fox allowed to go on without encumbrances. Some collars were recovered following the death of a tagged fox, such as after its shooting by a gamekeeper following dispersal from a study area. Successful collar recovery enabled re-use of collars, which were returned annually to the Swedish manufacturer for refurbishment, ready for use the following year.

Study sites

Although the W4R project largely focussed its activities on four hotspot sites (Hucklesbrook and Ibsley; Kingston; Watton's Ford and Avon Tyrrell) in the Lower Avon Valley, historically wading birds also bred on river meadows, all the way to Salisbury. However, since 1990, periodic bird surveys showed severe long-term declines, especially closer to Salisbury. We anticipated that environmental differences in the lower and upper valley, such as the availability of food resources and local fox culling pressure, might influence their population density and dynamics, so we tagged foxes at two representative sites at Britford and Somerley. Understanding any local differences in predator pressure between the upper and lower valley is important if the W4R project is to fulfil its long-term aim of recovering breeding waders throughout the valley.

(a) Britford, Upper Avon Valley, 2015-2017

All foxes were caught on a single landholding adjacent to the village of Britford just south of Salisbury. The site is bounded by the village to the west, and the main river Avon to the east, and the landscape includes small spinneys; rush dominated cattle-grazed-pastures; scrub patches; hay meadows; an ancient system of relict water meadows with associated herringbone drains, ditches and water carriers; and a commercial fish farming operation. Immediately downstream, the water meadows are maintained, grazed and managed in the traditional way, with the grassland periodically 'drowned' using an intricate system of hatches and sluice gates. The river meadows very rarely naturally flood at Britford, if at all. Hence, the landscape is broadly representative of other river meadows and land-uses in the Upper Avon Valley (Figure 2).

In the 1990's, Lapwing, Redshank and Snipe (Gallinago gallinago) all bred on the Britford water meadows; the last confirmed wader breeding attempt here was by two pairs of Redshank recorded in 2003 (GWCT, unpublished report). At the time of the study the relevant landowners were receiving Agri-environment payments through Higher Level Stewardship, to implement management options specifically designed to help breeding waders. However, none of these birds attempted to nest here during the study, although a single pair of Lapwing were observed using one meadow for several consecutive days in April 2017, suggesting the meadow was attractive enough for them to settle there.

There was no ongoing fox control effort by landowners at Britford which meant no premature loss of data from collared foxes by culling, provided they remained within the site. We tagged two male foxes at Britford in 2015 (the pilot-year); six adult males and three females in 2016, and five males and five females in 2017.

(b) Somerley Estate, Lower Avon Valley, 2018-2019

Foxes were caught on, or adjacent to, river meadows on the Somerley Estate, approximately 20km downriver of Britford, and home to the W4R's **Hucklesbrook and Ibsley** hotspot sites (Figure 3). Here, the river floodplain is much wider and wetter, and the river meadows are prone to winter and spring flooding. Some of them are managed as flood-marshes and provide low intensity grazing for horses, donkeys and cattle; others are managed for traditional hay crops (Figure 4).

The Somerley Estate includes historically important breeding areas for Lapwing and Redshank, and at the start of W4R, chick-rearing habitats were improved by creating wet scrapes; reinstating ditches; raising water levels and altering grazing regimes and stocking densities to enhance and diversify the meadow sward structure. Temporary electric fencing was used to protect nesting Lapwings, which enabled a unique opportunity to observe the movements of tagged foxes around fenced areas and to assess how fox-proof they are.

Foxes are routinely culled on the Somerley Estate in Autumn and Winter to prevent conflict with game and sheep management objectives, but the estate kindly agreed not to kill any foxes from the time that we set snares , until fox-tracking was complete in that year. We tagged four males and two females in 2018 and four males and six females in 2019.

Use of trail cameras

The cameras used for this LIFE deliverable, were separate to those used to monitor predator activity on hotspot sites, and whose deployment is described elsewhere. For us, the main purpose of using cameras was to guide snaring effort for fox-tagging, both by revealing any untagged foxes present and to assess risk of capture of non-target species, especially Otter and Badger, at potential capture sites (Figure 5). Therefore, cameras were not used systematically as elsewhere on the hotspot sites, rather in response to emerging fox location data. Once all available GPS-tags were deployed in a single field season, cameras were gradually relocated to provide good coverage across sites where foxes were tagged, and where we had permission to work. Camera locations were selected by the Predation Manager, who also maintained cameras.

Between 2016-2017, trail cameras (Ltl Acorn 5310 and Ltl Acorn 6310) were set at 30 different locations at Britford and maintained from March-July. Here, fox territories appeared to be contiguous and the eventual camera density was approximately one per 5 ha. Between 2018-2019, cameras were deployed at 69 different locations on the Somerley Estate and adjacent landholdings, to cater for geographically separate tagged-fox territories. Here, camera density was substantially less than at Britford, but cameras recorded images over a similar time period.

Aside from guiding tagging-effort, cameras were used to inform knowledge of fox diet and to reveal use of study sites by other mammalian predators. If they were located and accessible, cameras were deployed at fox breeding earths and denning areas, to record numbers of cubs and prey items delivered by adults.

Although cameras were not used optimally for this purpose, camera data will also provide an initial estimate of the detectability of foxes by trail cameras, which will be valuable in practical management. In all years, cameras were set to record three rapid consecutive pictures when a camera was triggered, to facilitate identification of individual tagged foxes. Camera records from 2019 are still being processed and analysing the huge volume of GPS data gathered during the project and marrying it with camera and high-seat data to calculate fox detectability, is an enormous and currently incomplete task and not a LIFE deliverable. To give some indication of what is required, cameras recorded a total of 153,427 images (not all of foxes) of which almost 40,000 remain unprocessed, and GPS-tags recorded 152,428 useable locations.

Fox scat collection

In 2017, between February-July we collected 163 fox scats at Britford. Scats were collected both opportunistically, and along a four-kilometre fixed transect route walked at two-week intervals. Because tagged foxes occupied multiple landholdings, scat collection effort was not uniform across the entire site. In addition to determining fox diet by macroscopic analysis, we took 88 faecal-swabs from a sample of those scats for DNA-analysis to reveal individual identities and gender to further inform density estimates. These swabs, along with a sample of scats and fur collected from tagged foxes, were sent to Umeå University in Sweden to be analysed by a team of geneticists experienced in fox DNA work. This analysis is still ongoing, so we are unable to report final genotyping results. These will appear in a future scientific publication.

Between 2018-2019, we collected 386 fox scats between March-July on the Somerley Estate and some adjacent landholdings. Scats were collected both opportunistically and by following multiple fixed transect routes of varying length, at 1 or 2 weekly intervals (depending on river meadow ground conditions, and perceived risk of disturbing nesting Lapwing) during the wader nesting period, in areas where foxes were GPS-tagged, and where we had permissive access. These samples are in frozen storage and will be swabbed for genotyping and analysed by either macroscopic or molecular methods if funds become available. (Insufficient resource was available to do this through the LIFE project.) If conducted, these analyses will further inform knowledge of fox diet and/or enable assessment of numbers of untagged foxes in areas where foxes were tracked (Figure 6).

Vegetation sampling

Mapped fox location data obtained between 2016-2018 suggested that foxes spent relatively little time in hay or silage fields when the vegetation grew tall. This is interesting because elsewhere wildlife managers on bird reserves are pioneering the use of long grass verges around the margins of short-sward wet grassland areas, with the aim of creating 'reservoirs' of small mammal prey, to divert predators away from sensitive Lapwing breeding areas (Laidlaw et al 2019).

Over a 2-week period at the start of June 2019, we conducted simple snap-shot surveys of sward height and structural density in 47 different fields (including hay meadows, silage grass fields, grazed pasture and marshland) occupied by tagged foxes on the Somerley Estate and some adjoining areas. Starting at the north-west corner of each field, we measured the maximum vegetation height and density using a dropped circular plate - Figure 7) 10 metres in from the field edge, and heading in an easterly direction, we repeated this every 10 paces, to generate 10 measurements. We repeated this procedure, starting at the north-east corner of the field and heading south, to generate a further 10 measurements, so that 20 vegetation height and density samples were taken in each field. For fields that weren't accessible (e.g. horse paddocks) we estimated the approximate vegetation height visually at a single point, or multiple points if the sward height was clearly variable.

We do not discuss the results of these surveys here, but vegetation data will be factored into detailed analyses of habitat use by tagged foxes and reported elsewhere.

High seat counts

Flood plain river meadows tend to be flat which restricts the safe use of firearms for lethal fox control. Thus, high-seats are commonly used to provide elevated positions for safe shooting opportunities. High-seats are also used by wildlife managers to monitor predator activity.

We conducted high-seat counts to survey areas where foxes were tagged. Counts took place at Britford in 2016 (May-June) and 2017 (March-June), and on Somerley in 2018 (May-June) and 2019 (April-June). The date periods reflected when foxes were tagged in each year. Where available we used high-seats that were already in situ on study sites for deer management, otherwise we used portable high-seats that could be carried into position and secured to a suitable tree to give the desired viewpoint (Figure 8). Portable high-seats were sited in locations where they might be placed by a gamekeeper during fox culling operations, always within a tagged-fox territory, and within both wet grassland habitats and adjoining farmland habitats. At each high-seat location, the facing direction and weather (wind speed and direction, temperature, cloud cover) at the start of the count were recorded. Counts were stopped if rain became heavy enough to compromise visibility.

There were two types of count: standard surveys that used only binoculars to detect foxes, and thermal surveys where both binoculars (typically 10x40) and a thermal imager (Pulsar Apex XD75 or Pulsar Helion XQ50F) were available. Standard surveys aimed to begin 60 minutes before sunset and finish 30 minutes after sunset, after which low light compromised visibility with binoculars. Thermal surveys either began at sunset or at the same time as standard surveys and finished 90 minutes after sunset. The last 60 minutes made sole use of the thermal imager for detection. A small number of surveys were conducted either during daytime hours or around sunrise rather than sunset.

Observers repeatedly scanned the viewable area with binoculars/thermal imager and recorded any foxes detected. As potential predators of waders, any Badgers and Otters detected were also recorded. For fox detections, data recorded included time of detection, how many were seen, age and sex (if obvious), any distinguishing features, activity type, and whether the fox was GPS tagged (with collar ID if visible). As shooting from high-seats is used as a lethal fox control method, observers trained in use of firearms assessed whether a detected fox would have been safe to shoot. Any records of untagged adult foxes were reported to the Predation Manager, to help guide snaring effort when animals were being tagged.

Key outcomes from the study of tagged foxes

Extent of tagging and captures

Between 2015-2019, snares were set for a total of 3,454 snare-days which resulted in 48 captures of 39 different foxes, of which two were juvenile and not tagged. Eight foxes were recaptured whilst still tagged, two of these deliberately to replace failing tags. Additionally, two captured foxes with recognisable physical features but without tags were believed to have been recaptures of individuals tagged previously, whose original tags were either pulled off, or remotely dropped off because of pending battery failure. Subsequent GPS-location data for both these foxes suggested they were indeed the same individuals, but we await confirmation following analysis of their DNA. The successful recapture of specific individuals demonstrates the unique value of snares as a wildlife management tool, which no other fox trapping device can match: rural adult foxes are innately wary animals, but because a snare only catches if it remains undetected, it is impossible for foxes to learn how to avoid them.

To reduce the risk of poor welfare outcomes as a result of long-term collaring, the attempted recovery of tags from foxes at the end of their tracking period either by remote drop-off, or by shooting, were agreed protocols in our Home Office project licence. A total of 37 foxes were tagged during the study, and we recovered 35/37 tags. Between 2016-2017, tags failed to remotely drop from three foxes resident at Britford. The Predation Manager and two other qualified persons spent a total of 62.5 hours in high-seats placed within their territories, armed with rifles, to try and recover their tags. One tag was recovered; the two other tagged foxes were never observed when the Predation Manager had a safe shooting opportunity. One of these two foxes was recorded by a farmer and then by a trail camera on the study site, in July 2019, >12 months after the last GPS fix was recorded.

Raw GPS data include a proportion of records where the collar has failed to fix a location (timed out), as well as locations of dubious accuracy, recognisable from a variety of features (e.g. negative or outlier altitude values). After filtering these out, the total number of useable GPS-fixes was 75,103 for 21 foxes tagged at Britford, and 77,325 fixes for 16 foxes tagged on Somerley Estate.

Britford, Upper Avon Valley, 2015-2017:

In 2015, we tagged and tracked two adult male foxes at Britford from July-September primarily to assess the performance and suitability of GPS-collars, which performed well. Location data illustrated that these foxes occupied exclusive neighbouring territories which both included areas of river meadow, with a water carrier channel partially defining one territory boundary. One fox showed a shift in home-range use with regular excursions to an area of woodland which coincided with the releasing of juvenile Pheasants (Phasianus colchicus) here for game-shooting purposes in late-July.

In 2016, GPS-tracking of six males and three females between March-June showed fox density at Britford to be surprisingly high compared with our expectations from mixed farmland habitats and local game shooting estates. Whilst foxes were being tracked, simultaneous monitoring from high-seat locations, and with trail cameras, recorded as many untagged adult foxes using the same area. Location data showed that a local trout farm was a 'honeypot' area for tagged foxes, and 38/65 (58%) camera trap images of adult foxes carrying food/prey items on the study site, showed them to be carrying farmed Rainbow Trout (Onchorynchus mykiss) (Figure 9). We wondered to what extent this anthropogenic food resource was subsidising fox diet and contributing to the apparent high fox density. Two male foxes died whilst tagged, one from septicaemia, one from injuries consistent with a fight with a locally resident breeding pair of Mute Swans.

In 2017, we tagged five males and five females in the same area at Britford and tracked them between April-June. These ten foxes occupied two distinct fox territories (size = 32ha and 44ha) indicating a density of 13 tagged adult foxes/km^2. Genotyping of fox scats gathered here between March-May, detected the presence (at least once each) of a further 15 foxes using the same 76ha area. Because of the timings of scat collection, cubs were unlikely to be outside the earths, so these are assumed to be adult, providing a revised maximum density of 34 foxes/km^2 across this three-month period. Note that this is not a stationary density estimate: many foxes (both untagged and tagged) were detected from only one scat, so these genotype detections cannot be used to distinguish territory-holding residents from encroaching neighbours or transients that may have been passing through the site.

An MSc student (Naomi Sadoff) analysed undigested macroscopic prey remains from a sub-sample (50/163) of scats collected at Britford as part of her thesis (Sadoff 2017). Her results indicated that small mammals, especially Water Voles (Arvicola amphibius), were significant prey items, accounting for 61% of diet (Figure 10). Other prey items included Rabbit (17%), Bird (19%), Fish (2%), Unknown (1%). Given the obvious cluster of tagged fox locations around the fish farm, coupled with multiple images of foxes carrying trout, we were surprised that fish were scarcely detected in scats at all; it's probable that trout bones and scales dissolve during digestion to become visually undetectable in faecal remains. For this reason, we are exploring the feasibility of using molecular techniques including DNA meta-barcoding, e-DNA, and stable isotope signatures of different broad food resources to understand fox diet. However, from discussions with geneticists at Umeå University, and at Bournemouth University in the UK, it's apparent that molecular analysis of faecal matter is a similarly imperfect technique and may not provide any quantitative estimate of the importance of fish in fox diet.

In 2017, 3 males dispersed from the study site in April (Figure 11). This was surprising, because until then the main period for fox dispersal was considered in the literature to be autumn and winter. We speculate that these foxes dispersed as a result of social pressures and/or scarcity of food resources on the study site. One male periodically returned to the site after dispersing: from a fox management point of view this is interesting, as it reveals foxes using river meadows could regularly visit from afar; also that the resources supporting the fox density observed on the river meadows may include those available on neighbouring areas.

Somerley Estate, Lower Avon Valley, 2018-2019

In 2018, the Hucklesbrook and Ibsley hotspot sites were affected by severe flooding in March and April which greatly restricted fox tagging effort. Perhaps as a consequence of flooding, two tagged male foxes caught on Ibsley prior to the flooding, dispersed and settled on sites where we did not have permission to work or that were outside our area of interest; and a lactating female tagged on Hucklesbrook, barely used the flooded meadows where several pairs of Lapwing were breeding. For this reason, fox tagging effort was switched to the drier Ellingham Meadows (immediately downstream of Ibsley, and just north of the town of Ringwood) where we tagged two males and one female.

Fox location data from the two Ellingham males (who occupied the same territory) showed clearly that although the main River Avon broadly defined their territory boundary, it did not form a barrier, for they periodically crossed the river even when the channel was full. This implies that the river alone is an insufficient obstruction to impede the movement of foxes into sensitive wader breeding areas, or areas where they have previously been culled. Location data from these males showed regular activity in suburban areas around Ringwood (Figure 12). This behaviour exemplifies the adaptability of foxes and illustrates the broad range of anthropogenic food resources available at the rural fringe.

By good fortune, two pairs of Lapwing unexpectedly settled and nested on two separate river meadows also occupied by these two tagged males, and the W4R wader monitoring team erected two 8-strand temporary electric fences – a design used across hotspots in the valley – to protect their nests. GPS-tracking data showed that one of these fences was breached by a tagged fox, and trail cameras installed inside the other fence documented a breach by an untagged adult fox and a Badger. As a direct result of these observed breaches, the fence design and fence maintenance procedures used by the W4R team was revised for 2019.

In 2019, we tagged four adult males and six females, occupying 4 distinct territories that encompassed the Hucklesbrook and Ibsley hotspots, and tracked them from April-July. One tagged male and (we think) one previously tagged female occupying the Hucklesbrook hotspot, where breeding pairs of Lapwing and Redshank were being monitored, were recaptured and fitted with fresh GPS-collars to extend their tracking until all wader broods had fledged. Two males and two females occupying two territories on the Ibsley hotspot site, spent relatively little time on the river meadows, preferring permanent pasture, parkland, arable land, woodland and scrub habitats immediately adjacent to the river. At Hucklesbrook, two males and three females (two of which nursed litters of two and five cubs) occupied two adjacent territories that also encompassed adjoining farmland (Figure 13).

At Hucklesbrook, approximately one-third of each family territory (circa. 95 ha each) included river meadows where the habitat had been improved through W4R, and where 10 pairs of Lapwings fledged an average of 1.41 chicks per pair (Figure 14). That Lapwing breeding success was so good, despite high levels of fox activity around nesting areas, and no other predator management on this site, suggests optimum habitat conditions for breeding Lapwing and/or plentiful alternative food resources for fox's resident here in 2019.

On 15th April, a non-breeding adult female was caught and tagged on the Hucklesbrook hotspot. Overnight, this fox travelled approximately 25km, eastwards across the New Forest, before settling near Totton, a suburb of Southampton (Figure 15). She remained in that locality for ten days before travelling back to the Avon Valley, to the Kingston hotspot site where foxes are routinely culled. For lethal control, this illustrates from how far away immigrant foxes may originate, and why continuous culling might be required to maintain low fox density. It also indicates the scale at which we should attempt to understand how available resources determine fox population pressure.

This adult vixen occupied the Kingston and Watton's Ford hotspot site for ten days, before she was eventually detected by a trail camera and killed by the estate gamekeeper during normal fox culling operations. The camera that recorded this fox belonged to the gamekeeper; the fox was never detected by 20 other cameras maintained by W4R staff, in the same area, over the same period which provides an example of the poor detectability of a temporarily resident fox using this survey method.

The electric-fence design shown to be breached by tagged foxes in 2018 was modified for 2019. The 'improved' version included sturdier metal fence supports to give the wires extra height and tension, and vegetation around the wires was periodically trimmed by mechanical cutting with a battery-operated strimmer to minimise disturbance to nesting birds. Two of these fences were erected in areas occupied by six resident tagged foxes. These fences were deliberately set around parcels of river meadow used by tagged foxes (Figure 16) but did not surround any breeding waders. Although we obtained no evidence of fence breaches by tagged foxes, it is plausible that foxes may have been less motivated to breach the two fences because they contained no breeding birds.

We discuss the movements of foxes around electric fences in much greater detail in **LIFE deliverable E1: Technical publication on the direct and indirect predator control techniques for wader population stabilisation and increase, including implementation and efficacy of indirect measures.**

Outcome from high-seat watches

Between 2016-2019, we conducted a total of 200 high-seat counts (Table 1), consisting of 138 standard counts and 62 thermal counts. 186 of the counts were conducted around sunset. 18 different observers were involved, but 60% of counts were undertaken by five full-time W4R staff members, the remaining counts were undertaken by students. Across the two sites we used 30 different high-seat locations. In total there were 261 detections of foxes, of which 66 were of tagged foxes. We also detected Badgers 21 times and Otter once. Of the 243 fox detections during sunset counts, 75% were detected after sunset, with 35% only made possible by using the thermal imager between 30 and 90 minutes after sunset. There were 15 thermal-imager-only detections of tagged Foxes. 69 fox detections were by observers who were firearms-trained, and who judged that in 35 instances it would have been safe to take a shot.

Sighting rates of foxes varied by year (Table 2). While this may reflect differing fox density at each site, the locations of high-seats, the height of vegetation within the field of view, and the observers were not the same in each year. The highest sighting rates, seen in 2018, were mostly due to one high-seat being located close to a cubbing earth and the repeated detection of a family group. Differences in sighting rate are therefore due to both availability of foxes to detect and the ability of observers to detect them from the high-seat locations. We compared the sighting rates of the two count methods to examine their relative efficiency. Summary statistics indicated that overall, detection rate where a thermal was available (mean = 0.95 fox/hr) were >50% higher than for standard counts (mean = 0.58 fox/hr). Across both methods, the sighting rate of foxes after sunset (mean = 1.15 fox/hr) was over four times greater than before sunset (mean = 0.26 fox/hr).

These data will be used in a later publication to estimate the detectability of individual tagged foxes using high-seats, scat surveys, and camera traps. Meanwhile, given the results, we recommend that wildlife managers begin their watches no earlier than sunset and use thermal imaging and/or night vision optics to maximise the probability of detecting foxes. Detection rates could potentially be further improved by using remotely controlled acoustic attractants to draw foxes towards high-seats, or to low vegetation areas where they can be more easily seen.

Management implications from preliminary results

We still have a large amount of biological material and GPS-tracking data to analyse, and new management recommendations borne from the five years of W4R fox research in the Avon Valley won't become clear for some time, especially the design of optimum wader breeding habitats to minimise predation risk. Any new recommendations will be dependent on analysis of fox habitat use, viewed alongside wader breeding success in improved and unimproved habitats. It is also likely that habitat improvement measures take time to mature and reach their full potential.

However, from visual assessment and preliminary analysis of GPS-locations, we know that foxes in the upper valley at Britford were living at one of the highest densities ever recorded in Britain, including those from urban areas. In 2017, fox location data combined with preliminary fox scat genotyping analysis, gave a potential maximum spring density estimate of 34 adult foxes km^2 between March-May. For comparison, a radio-tracking study on mixed farmland approximately 20km south-west of Britford, conducted during springtime in the late 1980's, estimated fox density at 1 adult fox km^2 (Reynolds et al 1995). We don't know the reason for this very high fox density at Britford, but clearly the landscape provides abundant food resources. Although we had no measure of small mammal (e.g. Microtus sp.) density here, they are likely to be abundant on lightly grazed relict water meadows that are no longer 'drowned' in the traditional way, and our dietary study highlighted the importance of Water Voles to foxes.

An ambition of the W4R project was to kick-start recovery of the breeding Lapwing population in the Avon Valley, by increasing fledging success on intensively managed 'hotspot' sites. This would in turn increase recruitment into the local breeding population and, hopefully, facilitate recolonization of former breeding sites where the habitat remains favourable. It should not be assumed that the high density of foxes observed at Britford caused Lapwings to stop breeding there, but increased levels of predation, as a result of no management, may have been a contributing factor. However, the exceptional density of foxes at Britford suggests that the risk of predation would be very high for any wading birds that chose to nest there. If Lapwing, and Redshank, are to stand any chance of properly recovering in the upper Avon Valley, then reducing the risk of fox predation should be a management priority.

In both years, location data at Britford revealed that some foxes lived and bred exclusively within river meadow habitats during the nesting period. This means that any lethal measures used to remove them must be effective within those areas, but this is challenging. Here, culling foxes by shooting is difficult due to the flat landscape and associated safety constraints, and tall vegetation and poor access reduces their detectability, even from high-seats. One recommendation from our high-seat counts would be for practitioners to make use of thermal imaging optics to increase fox detection rates. An alternative to shooting would be to use neck snares to catch and then humanely dispatch foxes. Although more effective in these conditions, snaring is labour intensive, risks non-target captures and carries some risks for captured animals – including foxes – that are exaggerated in unskilled hands. Also, snares should not be used in areas accessible to livestock, or when groundwater conditions prevent them from being tethered to secure ground anchors. Further, due to the high density of foxes in the upper valley, coupled with new knowledge from tagging that a fox regularly travelled to the Britford meadows from several kilometres away, the immigration rate of foxes into areas where they are culled is likely to be rapid (as we know it is at Bisterne), and an effective culling strategy will necessarily be laborious and costly; though that is not to say that it would not be possible. (Efficacy of lethal fox culling and fox immigration rates on the Bisterne Estate in the lower valley, is discussed in detail in **LIFE deliverable E1: Technical publication on the direct and indirect predator control techniques for wader population stabilisation and increase, including implementation and efficacy of indirect measures.)**

Non-lethal management options would also face practical difficulties at Britford. Effective use of temporary electric fencing to protect breeding birds would be constrained by the undulating network of herring-bone drains and ditches associated with water meadow management, and fencing could conflict with cattle grazing regimes. The cattle themselves are a vital management tool, and to an extent, they drive the retention of the ancient water meadow system between Salisbury and Downton. Here, water meadows have unique aesthetic, cultural and historic landscape value, and landowners are financially rewarded for conserving them through Agri-environment measures. Further, as the defining network of ancient water channels peculiar to water meadows provides the habitat used by Water Voles, and Water Voles are a key food resource, foxes may be highly motivated to find weaknesses and breach imperfect fences.

Conversely, foxes tagged at Somerley typically occupied territories which included river meadows, but which extended into farmland above the floodplain. For example, in 2019, 4/4 foxes tagged on the Ibsley hotspot site were caught on river meadows considered important for breeding Lapwing, yet their location data showed them to spend relatively little time here; the majority of their time was spent above the floodplain which presumably provided foxes with more important resources. Therefore, for birds nesting on the low-lying wet river meadows at Ibsley, we might expect the risk of fox predation to be relatively low. Further, from a lethal control perspective, opportunities for culling foxes on adjoining farmland habitats are much greater than when foxes live exclusively in river meadow habitats, as we saw at Britford.

It came as a surprise that breeding success of Lapwing on the Hucklesbrook hotspot site (where foxes were tagged) in 2019 was so high. Despite uncontrolled predator densities, including two family groups of foxes with litters of five and two cubs, ten pairs of Lapwing fledged an average of 1.41 chicks per pair, the highest recorded level of productivity across all sites in the Avon Valley during the project. Acting on tailored advice from W4R staff, the Hucklesbrook site manager aimed to produce optimum breeding habitat for Lapwing, principally by elevating water levels, and reinstating wet ditches on the flood meadows. The intention was to reduce access to mammalian predators and to disrupt their hunting behaviour; and to establish more abundant safe-feeding opportunities for foraging wader chicks, by creating multiple areas of invertebrate-rich soft mud within mosaics of mixed vegetation in which they could hide, especially from avian predators.

Direct observation of location data from Hucklesbrook indicates that tagged foxes still had access to these breeding areas, so why wasn't fox predation a problem? We think it may relate to abundant alternative food resources outside the floodplain, including inadequately protected domestic poultry on a local small holding, and plentiful wild Rabbits elsewhere in their territory. Also, the Predation Manager noted the strong smell of the marsh where Lapwing were breeding, and we speculate that stagnant water conditions (which can rot vegetation), coupled with odorous wet mud, may help mask the scent of vulnerable wader nests and chicks, thereby making them less detectable to foxes, who rely heavily on olfactory senses to locate prey.

Currently, we're unable to make fair comparisons of fox densities between Britford and Somerley, as there's been no equivalent genotyping of fox scats collected on Somerley. However, preliminary analysis of location-data from a family of four adult foxes with five cubs, occupying the Hucklesbrook hotspot site in 2019, provides a density estimate of 4.4 adult foxes/km^2, compared to 13 adult foxes/km^2 at Britford in 2017. This three-fold difference in fox density between foxes tagged in the upper and lower valley, likely reflects differences in the availability of food resources, fox culling activity/opportunities, or both.

Whilst GPS-tracking has documented the strict territoriality of most foxes resident around river meadow habitats, it has also revealed the surprising mobility of others. The adult female that travelled approximately 25km in one night from the Hucklesbrook hotspot to the outskirts of Southampton, and then back to the Avon Valley several weeks later, indicates the scale of movement of transient foxes who may threaten waders that breed here. Southampton and Bournemouth are two of the largest conurbations on the south-coast and may be important source areas of foxes that migrate into the valley, either temporarily or until they are culled by gamekeepers, as we saw on the Kingston hotspot site. But it's also feasible that foxes disperse here from other rural areas where abundant food resources, e.g. released game birds, enable them to breed well.

W4R has hugely increased our understanding of the ecology of foxes around river meadows, and future scientific publications will reflect this. Another legacy is a new collaboration between GWCT and Bournemouth University, with a PhD project to commence in September

2020 aiming to determine how regional resource dispersion and population dynamics of foxes affects the predation pressure experienced locally by wading birds that breed in the Avon Valley.

Acknowledgements

We are very grateful to the many landowners, farmers, gamekeepers and riverkeepers who supported this important research, and, ultimately, we hope it will help their collaborative efforts to increase the numbers of wading birds that breed in the Avon Valley. We give special thanks to James Whittle, John Levell, Kevin Peachey and Rupert Brewer. We thank all the GWCT students who helped with dietary studies and high-seat counts, and our Waders for Real colleagues - Lizzie Grayshon, Ryan Burrell, Andy Hoodless, but especially Jodie Case, for her endless enthusiasm for supporting our fox research.

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Table 1. Annual high-seat count survey effort and fox detections on Britford (2016-17) and Somerley (2018-19).

	2016	2017	2018	2019
Number of counts				
Standard	33	55	19	31
Thermal	0	18	10	34
Seat locations	11	10	5	9
Observers	7	7	7	9
Hours*	50.6	110.8	53.4	133.5
Before sunset	24.8	57.2	28.9	56.2
After sunset	11.8	52.1	24.5	67.2
Fox detections				
Total#	41	67	92	61
60-30 min before sunset	5	8	6	5
30-0 min before sunset	12	6	16	1
0-30 min after sunset	18	21	39	20
30-90 min after sunset	0	29	27	30
Tagged	13	26	12	15

*includes hours not on sunset counts
#includes foxes not detected on sunset counts

Table 2. Mean sighting rates (foxes detected per hour) in each year and across all years, showing difference between standard and thermal counts, and for sunset counts the difference before and after sunset.

	2016	2017	2018	2019	Mean
All times					
Standard count	0.81	0.37	1.58	0.33	0.58*
Thermal count	-	1.23	1.88	0.54	0.95
Before sunset					
Standard count	0.68	0.17	0.68	0.24	0.29*
Thermal count	-	0.17	0.90	0.00	0.21
After sunset					
Standard count	1.69	0.66	2.95	0.62	1.07*
Thermal count	-	1.20	2.53	0.91	1.27

*for comparison, mean is across 2017-2019 only as there were no thermal counts in 2016

Figure 1. We caught foxes in neck snares (left) and fitted them with GPS-collars (right) to explore their movement behaviour on and around the river meadows important for breeding wading birds. Between 2016 and 2019, we tracked 35 adult foxes during the birds' nesting season.

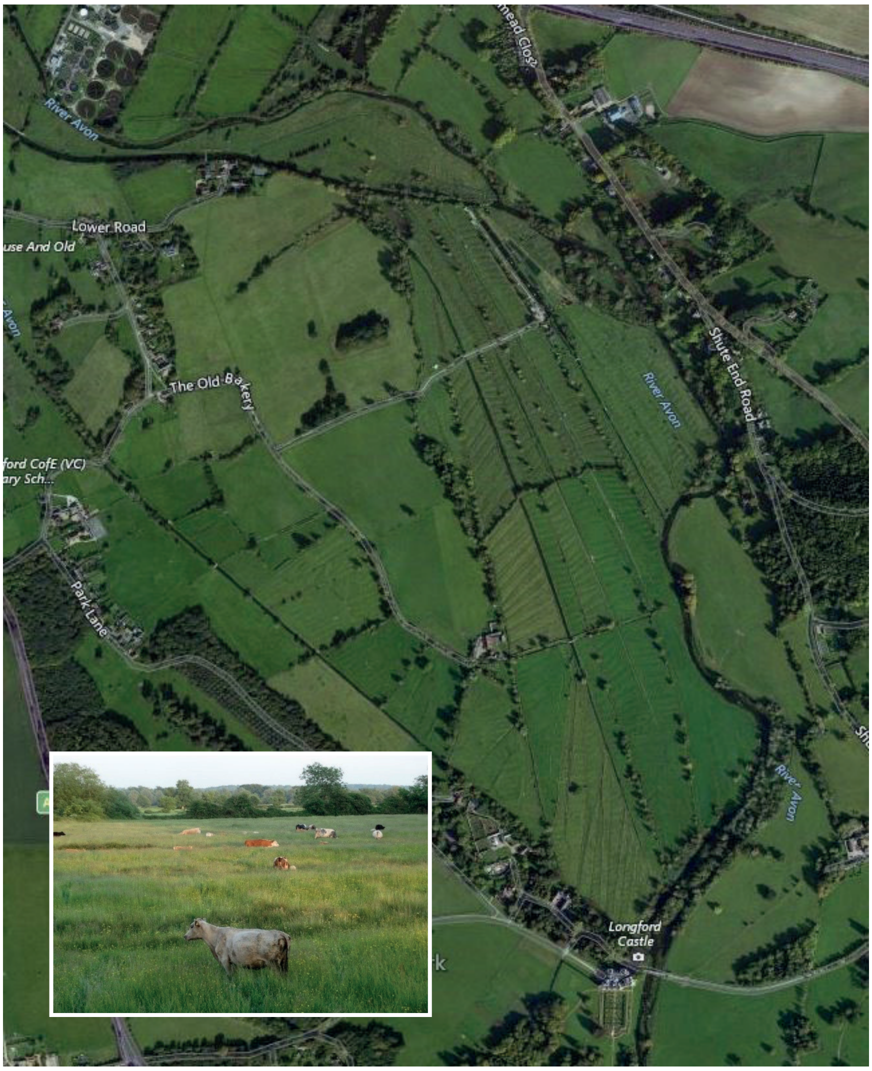

Figure 2. Between 2015 and 2017, we GPS-tracked 21 adult foxes caught on river meadows in the Upper Avon Valley at Britford. Here, the landscape is dominated by multiple enclosed pastures, including both relict and working water meadows grazed by cattle. The herringbone pattern of drains is apparent in both pictures. Waders used to breed on the Britford Meadows, but there are no records of Lapwing, Redshank or Snipe attempting to breed here since 2003. **Contains Bing imagery © Microsoft Corporation 2018.**

Figure 3. The red stars on the map mark the locations of our Britford study site in the upper Avon Valley, and the Hucklesbrook and Ibsley hotspot sites on the Somerley Estate in the lower Avon Valley. **Contains Bing imagery © Microsoft Corporation 2020.**

Figure 4. Between 2018 and 2019, we GPS-tracked 16 adult foxes caught on river meadows on the Somerley Estate, in the lower Avon Valley, where Lapwing and Redshank still breed. Here, the floodplain is much wider and wetter than at Britford, and the river meadows are prone to winter and spring flooding.

Figure 5. We used trail cameras (left) to help guide snaring effort for fox-tagging, both by revealing any untagged foxes present and to assess the risk of capturing non-target species. Cameras also revealed prey items carried by foxes, and images of tagged foxes will enable estimation of their detectability, which will be valuable in practical management.

Figure 6. We collected over 800 scats (faeces) during the project to investigate fox diet. We took DNA-swabs from a sub-sample of scats for genotyping, to identify the number of individual foxes with access to river meadows where foxes were tagged.

Figure 7. In June 2019, we conducted snap-shot surveys of sward height and density, to investigate whether vegetation height and structure influenced fox occupancy of 47 (predominantly grass) fields located within their territories.

Figure 8. We used strategically located portable high-seats to monitor fox activity on river meadows and in adjacent habitats. Seats were erected only in areas where foxes were tagged, to determine their detectability using this survey method. Between 2016 and 2019 we conducted a total of 200 high-seat counts using binoculars before and after sunset, and with thermal imagers at night.

Figure 9. In 2016, trail cameras at Britford recorded multiple images of foxes carrying trout scavenged from a local fish farm. We wondered to what extent this anthropogenic food resource was subsidising fox diet and contributing to the high fox density revealed by GPS-tagging.

Figure 10. In 2017, macroscopic analysis of undigested prey remains in fox scats collected at Britford, showed Water Voles and Field Voles to be important prey items. In the same year, trail cameras recorded numerous images of foxes carrying Water Voles (as above) and we found Water Vole remains at fox den sites.

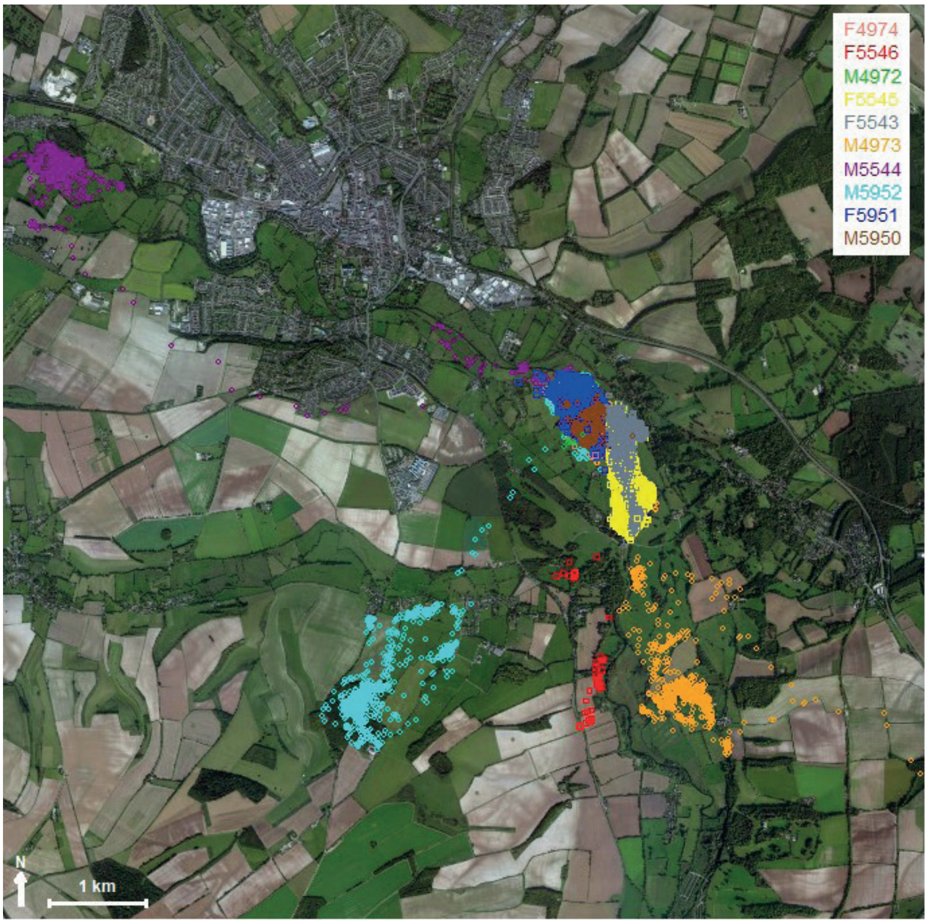

Figure 11. GPS-tagging showed that foxes were living at very high densities in the Avon Valley, just south of Salisbury. The coloured dots indicate locations of ten adult foxes tagged at our Britford study site in March-June 2017 (see key at top right; M=male, or F=female), recorded at 10-minute intervals. The locations of some individuals are partially masked by the sheer density of overlaid data. The purple, light blue and orange circles show the movements of the males that dispersed in April; the red squares show the movements of a female that left the study site and shed her collar within 24 hours of being tagged. **Contains Bing imagery © Microsoft Corporation 2017.**

Figure 12. In 2018, GPS-tracking of two adult male foxes, whose individual locations are shown as red and blue circles, revealed frequent incursions into the town of Ringwood. Their movements illustrate that at this site foxes whose territories include river meadows where waders breed must exploit food resources available in adjacent habitats, including suburban areas. The western edge of this fox territory is delineated by the main River Avon, but it did not form a barrier, and tagged foxes periodically crossed it by swimming. **Contains Bing imagery © Microsoft Corporation 2020.**

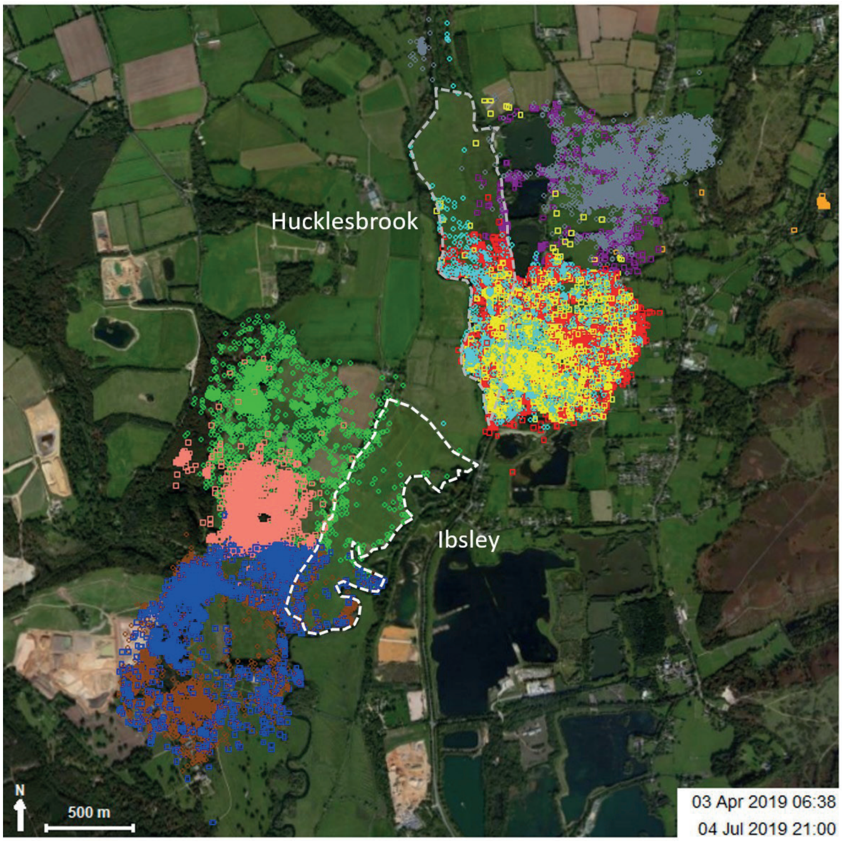

Figure 13. In 2019, two adult males (locations shown as green and brown circles) and two adult females (pink and blue squares) tagged on river meadows on the Ibsley hotspot site, spent relatively little time here, compared to the farmland, parkland and woodland habitats included elsewhere in their territories. Similarly, two territories belonging to five adult foxes occupying the Hucklesbrook hotspot site, also included farmland above the floodplain. This situation is quite different to Britford, where most foxes spent their entire time living in smaller territories on river meadows only. **Contains Bing imagery © Microsoft Corporation 2019.**

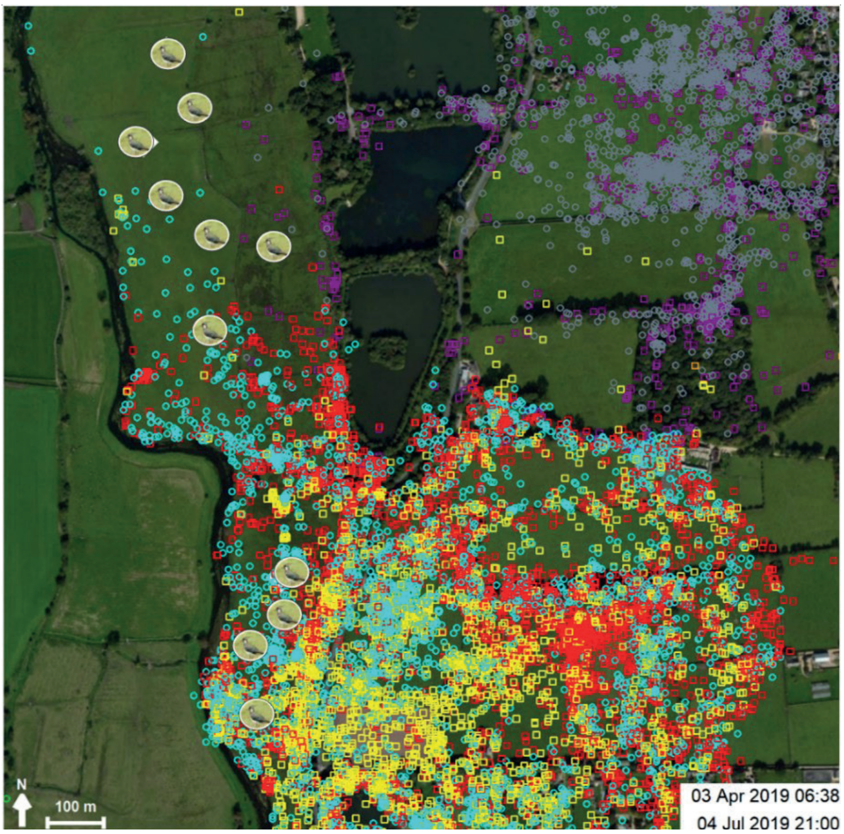

Figure 14. In 2019, GPS-tagging of 2 resident male and 3 female foxes occupying two neighbouring fox territories on the Hucklesbrook hotspot revealed intensive use of the river meadows. The small coloured circles represent the individual locations of tagged males, the coloured squares, females. Although the density of locations appears much less on the northern half of the river meadows, this does not necessarily reflect use by foxes, rather it reflects reduced tagging effort and the shorter period that the purple and grey foxes were tracked. 10 pairs of Lapwings, whose approximate locations are indicated by symbols on the map, fledged on average 1.41 chicks per pair. Contains Bing imagery © Microsoft Corporation 2019.

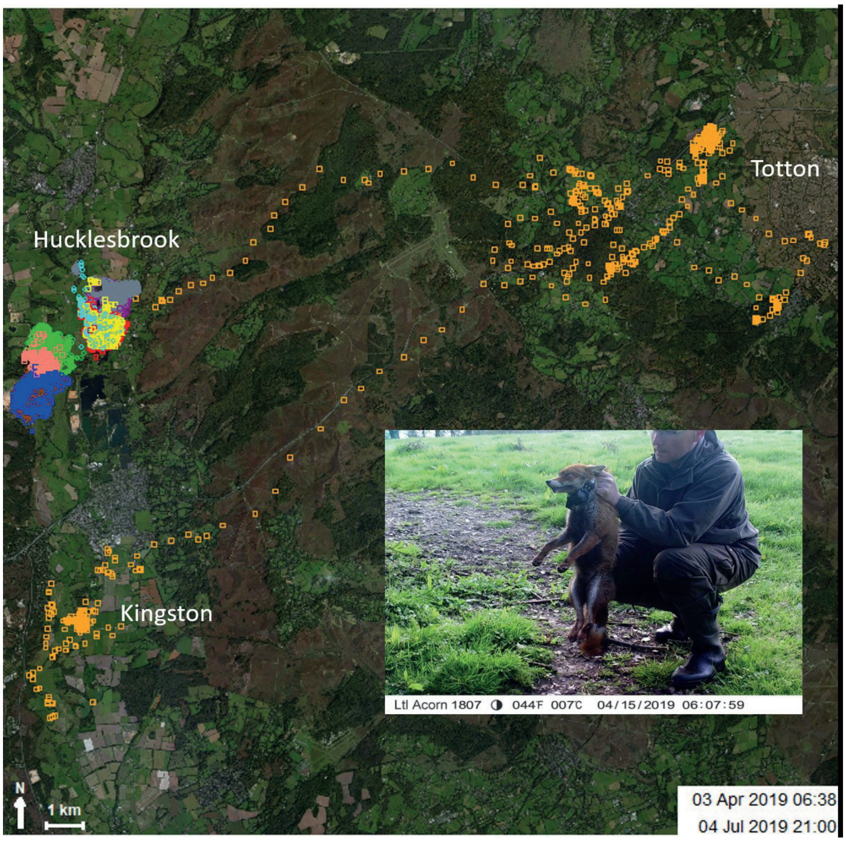

Figure 15. The coloured symbols show the individual locations of ten adult foxes tagged on the Hucklesbrook and Ibsley hotspot sites between April-July 2019. Nine of those foxes remained resident there (Fig. 13). The orange squares reveal the movements of a non-breeding female (picture inset) tagged at Hucklesbrook on 15th April. Shortly after release, she travelled eastwards to Totton near Southampton, before returning to the Avon Valley, where she was eventually killed 3 weeks later by a gamekeeper on the Kingston hotspot site. This suggests the geographical scale at which we should consider how available resources must determine fox population pressure. Contains Bing imagery © Microsoft Corporation 2019.

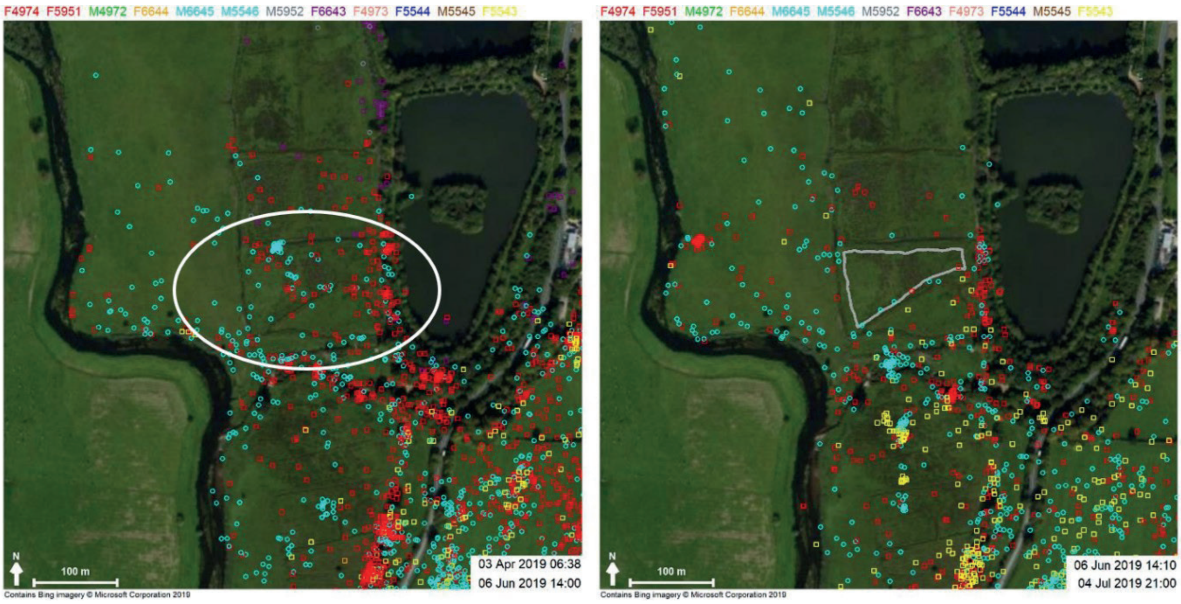

Figure 16. In 2019, we constructed an 'improved' electric fence around a parcel of river meadow at Hucklesbrook in regular use by tagged foxes. The coloured symbols within the white circle on the map on the left show the locations of tagged foxes until 6th June. The map on the right shows the location of the electric fence (drawn as a grey line) that was erected on 6th June, and the locations of tagged foxes thereafter until 4th July. Although we obtained no evidence of the fence being breached by tagged foxes, it's plausible they didn't try, as the fence did not protect any breeding birds **Contains Bing imagery © Microsoft Corporation 2020.**