Papers

Long-term health effects of harness-mounted radio transmitters in red kites (*Milvus milvus*) in England

G. Peniche, R. Vaughan-Higgins, I. Carter, A. Pocknell, D. Simpson, A. Sainsbury

In 1989, the Nature Conservancy Council and the Royal Society for the Protection of Birds commenced reintroduction of the red kite (*Milvus milvus*) according to International Union for Conservation of Nature criteria. Following 22 years of intensive effort, the red kite reintroduction programme has been a success with an estimated 1000 pairs now breeding in England. Post-release health surveillance is ongoing and has been achieved through radio-tracking, monitoring breeding at nest sites and pathological examinations of any red kites found dead. Tail-mounted radio transmitters were fitted from 1989 with harness-mounted radio transmitters being preferentially used since 2000. Since 2000, 180 individuals have been recovered for postmortem examination. Eighteen of these birds had previously had a harness-mounted radio transmitter fitted and four of these (22 per cent) had moderate to severe lesions associated with the presence of the harness and radio transmitter including chronic necrogranulomatous inflammation, deep muscular exposure and distorted muscular conformation. Failure to breed was also reported in two of these individuals over the preceding year(s), although it is not known whether the presence of the harness contributed to this failure. Duration of deployment may have been a significant factor in the formation of these lesions as those with lesions (n=4) had a statistically significant (P=0.009) longer duration of deployment compared to those without lesions (n=14). No lesions were reported in those red kites fitted with tail-transmitters.

THE red kite (*Milvus milvus*) was formerly widespread in the UK, but owing to persistent persecution the species became extinct in Scotland and England in the 19th century (Smart and others 2010). In 1989, a re-introduction programme was initiated by the Royal Society for the Protection of Birds and the Nature Conservancy Council (now Natural England, Scottish Natural Heritage and the Countryside Council for Wales). In England, red kites have been released in the Chiltern Hills, Cumbria, East Midlands, Yorkshire and Northumberland and the total red kite population has steadily expanded. There are currently estimated to be around 1000 breeding pairs of red kites in England.

Radio transmitters are used worldwide in many avian species to study habitat use, mortality, migration, home range and physiology (Amlaner and Macdonald 1980). The majority of reintroduced red kites have had radio transmitters fitted to provide valuable information on dispersal behaviour, home range, roosting sites and survival. In addition, radio-tracking can facilitate locating carcases for postmortem examination. This has allowed postmortem examinations to be undertaken on fresh carcases and helped to determine significant causes of mortality for the species (Carter 2007).

Two types of transmitter have been used during the red kite reintroduction programme: harness (or backpack) mounted radio transmitters and tail-mounted radio transmitters. The two types of radio transmitter are essentially the same item with different mounting systems. The harness-mounted radio transmitter typically consists of two loops of 6 mm Teflon ribbon encircling the body and passing through a spacer loop which lies along the breastbone (Fig 1). Each harness is individually fitted to each red kite using procedures described by Kenward (2001). Once fitted, these backpacks are intended to stay on for the life of the bird, potentially many years after the transmitter has ceased to function. Many raptor researchers prefer to use the harness attachment as the transmitter is centrally positioned and therefore less likely to affect the bird's balance, which allows an overall greater mass (29 g) and size than an asymmetrical mount (Kenward 2001). The harness attachment can therefore facilitate more effective radio-telemetry through allowing the use of transmitters with a longer battery life (Bedrosian and Craighead 2007).

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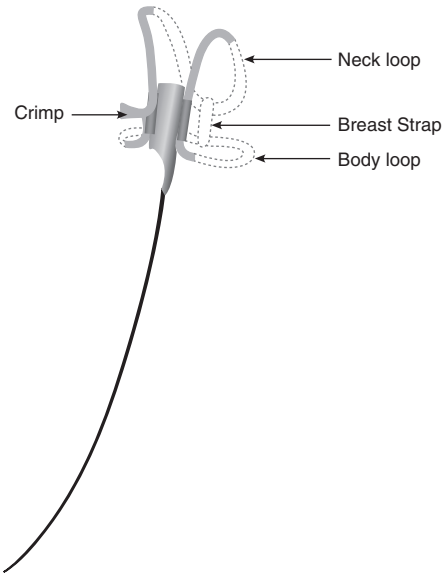

FIG 1: Harness-mounted radio transmitter used on red kites for radio tracking (illustration courtesy of Jeremy Sutherland, British Trust for Ornithology)

Tail-mounted transmitters are glued to the proximal end of the central tail feathers using procedures described by Kenward (2001). These radio transmitters are lighter (18.5 g) and have a shorter battery life (12 months) compared to the harness-mounted transmitters (which have a battery life of two to three years) and will be shed at the next moult. In comparison, the harness-mounted radio transmitter will remain intact and attached to the bird despite no longer performing a monitoring function.

Between 2000 and 2009, 142 red kites were fitted with harness-mounted radio transmitters (single cell TW-5, Biotrack). Tail-mounted radio transmitters (single cell TW-3, Biotrack) were fitted to 203 red kites from 1989 to 2000. Harness-mounted radio transmitters were fitted to either fully grown juveniles before release or nestlings over six weeks old. Tail-mounted transmitters were only fitted to fully grown juveniles in captivity before release. It was not possible to fit tail-mounted tags to nestlings in the wild because the tail is not sufficiently well grown in birds that have yet to leave the nest.

Several studies have evaluated the effects of harness-mounted radio transmitters on birds and the principle findings have included reduced survival in raptors (Burger and others 1991, Steenhof and others 2006) and other birds (Paton and others 1991, Cotter and Gratto 1995), increased energy consumption (as transmitter packages add mass and aerodynamic drag) (Pennycuik and Fuller 1987, Obrecht and others 1988), decreased agility (particularly important for raptors in relation to the procurement of food), decreased ability to compete for a territory and mate (Pennycuik and others 1989, Putaala and others 1997) and decreased productivity (Buehler and others 1995, Marzluff and others 1997). We could find only one report of disease associated with the prolonged use of harness-mounted radio transmitters in avian species. Foster and others (1992) reported that one spotted owl (*Strix occidentalis caurina*) died with subcutaneous abrasions caused by a harness three years after deployment. Sixteen owls were subsequently re-trapped one year after deployment to remove or replace transmitters owing to the development of abrasions under the transmitter or harness. In three cases, abrasions were believed to be life threatening and appeared to be caused by poor harness fit. Unfortunately, detailed pathological investigations including histopathology were not conducted in these cases.

In response to the detection of pathological findings in three red kites associated with harness-mounted radio transmitters between 2009 and 2010, we conducted a review of the postmortem examination results from all red kites fitted with radio transmitters in England during the reintroduction programme between 1989 and 2010. Here we discuss our pathological findings and the results of the review in relation to the current literature on the long-term effects on health of harness-mounted radio transmitters on birds and recommend further targeted surveillance.

Materials and methods

Pathological examination

Three free-living red kites found dead or dying in England in 2009 and 2010 were submitted for postmortem examination. Two carcases (693/09, 480/10) were refrigerated before examination and the third carcase (925/09) was frozen.

All three carcases were examined according to a standard postmortem examination protocol (Molenaar 2007). First, body condition was assessed by palpating the pectoral musculature over the keel and condition was graded (very good: keel palpated but well covered; good: keel easily palpated but smooth; moderate: keel easily palpated, pectoral muscles slightly sunken; poor: keel sharp to palpate, pectoral muscles sunken). Standard morphometric measurements were taken including bodyweight, wing length and tibiotarsal length. The skin, plumage and subcutaneous tissues were examined for abnormalities of size, shape, consistency and texture and external lesions were recorded. All internal organs were examined, both superficially and on their cut surface, and samples were taken from any lesions found. The remains of the carcases were archived frozen pending possible future examination.

Prompted by postmortem examination findings, ancillary tests including bacteriology, mycology, parasitology, histology and toxicology were undertaken. All microbiological samples were stored at 4°C before submission to the laboratory. The samples were cultured on Columbia blood agar with 5 per cent horse blood for bacterial isolates and on Sabouraud's agar plates with chloramphenicol (QCM Laboratories) for fungal isolates. These were incubated at 37°C, in oxygen and observed after two and after five days. The different colonial morphologies were described as pure, predominant, mixed, confluent and scanty. Subcultured purity plates of pure and predominant colonial morphologies were Gram-stained for subsequent description of morphology and oxidase tests coupled with first-stage tables tests for both Gram-positive and Gram-negative bacteria (Cowan and Steel 1993). Tentative identifications were made using biochemical test kits (Api, bioMérieux) coupled with a program for Gram-negative bacteria and yeast species (Apiweb). For histological examination, sections were taken of a variety of relevant tissues and stored in 10 per cent buffered formalin. After fixation, samples were sent to Finn Pathologists where sections were cut at approximately 4 µm thickness, mounted and stained with haematoxylin-eosin and examined under light microscopy (x40, x100, x400 and x1000 magnification). For toxicological analysis, samples were collected of the liver, kidney and gizzard contents in glass vials, stored frozen and subsequently analysed using standardised analytical methods (Brown and others 2005) through the Wildlife Incident Investigation Scheme (Wildlife Incident Unit, Central Science Laboratory).

Review of pathological findings from red kites fitted with radio transmitters

The pathological findings from all red kites submitted to the Institute of Zoology since the inception of the reintroduction were reviewed. For all cases involving harnesses or tail-mounted transmitters, the presence of pathological lesions that were associated with the harness or tail-mounted transmitter (if any) were recorded.

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) (Version 19 for Windows) to present the mean, range and standard error (SE) for radio transmitter and harness weights as a proportion of bodyweight. A paired *t* test was used to compare (i) radio transmitter and harness weights as a proportion of bodyweight in red kites with harnesses and lesions, compared to those with harnesses without lesions and (ii) duration of harness deployment on red kites with lesions compared to duration of harness deployment on red kites without lesions. Statistical significance was assigned as $P<0.05$.

Results

Pathological findings from three red kites

In 2009, two red kites presented with chronic necrogranulomatous mass formation over points of contact with their harness-mounted radio transmitter. A third case was reported in 2010.

FIG 2: Adult female red kite 693/09. On the ventral midline, at the location of the t-bar of the harness, overlying the pectoral musculature, two raised lesions of inflamed granulation tissue with necrotic edges, incorporating the skin, were present

Case study 1

A harness-mounted radio transmitter was fitted to female red kite 693/09 in June 2004. This bird had been observed on June 29, 2009 and was reportedly perching and flying normally, although monitoring suggested failure to breed in 2009. On July 21, 2009, 693/09 was found trampled by cattle and in respiratory distress at NGR SE317482. The adult female was taken to the local veterinary surgeon, examined and euthanased owing to its respiratory compromise, abnormal conformation and severe lesions associated with the presence of the harness-mounted radio transmitter. On postmortem examination, this 1287 g female was in moderate body condition. Deep muscular exposure over the spine was evident in three focal regions, the largest being 20 x 12 mm with surrounding feather loss. Two raised lesions of inflamed granulation tissue with necrotic edges were evident on the dorsal midline, probably indicative of a chronic inflammatory process. Erythema surrounded the lesions and extended circumferentially around the body in line with the margin of the transmitter and harness.

On the ventral midline at the t-bar of the harness overlying the pectoral musculature, two raised lesions of inflamed granulation tissue were present. These were 55 x 45 mm in diameter, yellow-brown and easily removed from the underlying tissue bed. The ventral surface of this inflamed granulation tissue contained multifocal yellow raised furry rosette-like growths and surrounding erythema was evident. The centres of the lesions were composed of multiple fine filamentous white strands and powder. These lesions appeared to have pushed the pectoral muscles cranially and laterally, to cover the humerus and coracoid, resulting in abnormal conformation. The location of these lesions was directly related to the path of attachment of the harness and radio transmitter (Fig 2).

On histopathological examination, chronic inflammatory changes with secondary necrogranulomatous inflammation intra-lesional fungal hyphae and bacterial cocci, were reported. Mild multifocal pulmonary granulomas, focal, acute hepatic necrosis with mild haemosiderosis and moderate intestinal nematode infection were also present. *Aspergillus fumigatus* was cultured from the necrogranulomatous masses (Fig 3) caudal to the sternum and from the pulmonary granulomas. It is possible that the chronic inflammatory lesions associated with the harness and transmitter were a sufficient stressor to facilitate secondary *A fumigatus* infection.

FIG 3: Adult female red kite 693/09. The ventral surface of the inflamed granulation tissue when removed from the ventral midline contained multi-focal yellow raised furry rosette-like growths with surrounding skin erythema. When the inflamed granulation tissue was cut in cross-section, the centre was made up of multiple fine filamentous white strands and powder from which *Aspergillus fumigatus* was cultured

Case study 2

A harness-mounted radio transmitter was fitted to male red kite 925/09 in July 2005. Monitoring suggested failure to breed in 2008 and 2009 and this bird was last sighted in July 2009, perching with its mate near its nest site. On September 10, 2009, 925/09 was found dead beneath an electricity pylon at NGR NZ104642. On postmortem examination, this adult male weighed 750 g and was in poor body condition. Chronic, multiple, raised, focally extensive regions of inflamed granulation tissue with necrotic edges surrounded the path of the straps of the harness, with the greatest tissue reaction occurring at the points of maximal skin contact: on the ventral midline at the t-bar of the harness (Fig 4) and where the radio transmitter was attached over the dorsal midline (Fig 5). The largest of the two lesions beneath the dorsal radio transmitter mount was 32 x 44 mm. The presence of this inflamed granulation tissue on the ventral aspect had distorted the pectoral musculature to result in abnormal conformation. In addition, the harness appeared to have laterally shifted to the right, which would have placed excessive frictional contact on the skin and possibly would also have altered the flight capability of the bird owing to uneven weight distribution (Fig 4). This bird's harness-related lesions were similar to, although less severe than, those seen in red kite 693/09. Red kite 925/09 also presented with severe inter-digital erythema, extreme flexion of the digits, presence of semi-digested feed in the crop and congestion and moderate nematode infection within the large intestine. The interdigital lesions, extreme flexion of the digits and the bird's location beneath an electricity pylon suggested electrocution was likely to have been the ultimate cause of death. However, a severe *Porrocaecum angusticolle* nematode infection causing a partial obstruction of the large intestine and the presence of focally extensive regions of granulation tissue surrounding the harness indicate the bird's health was already compromised, which may have influenced the bird's propensity to die through electrocution.

Case study 3

A harness-mounted radio transmitter was fitted to female red kite 480/10 in June 2005. This female had successfully raised one chick in 2009 and had been observed feeding one chick in the 2010 season. On June 9, 2010, it was found dead at the base of an oak tree at NGR

FIG 4: The harness of red kite 925/09 was deviated to the right when observed in relation to the sternum (a) and at the ventral t-bar of the harness raised inflamed granulation tissue was evident. Haematoma formation and blood loss was evident over the right lateral body wall (b) where the harness had severely abraded the pectoral muscle

NZ061581. On postmortem examination, 480/10 was in moderate body condition and weighed 1209 g. At the point of attachment of the radio transmitter to the harness on the dorsal midline, loss of skin and muscle was observed and the vertebral column was visible. On the ventral aspect, at the t-bar of the harness, a focal raised yellow, firm lesion of inflamed granulation tissue 15 x 10 mm in diameter was present underlying the left lateral and right lateral straps of the harness. The pectoral muscle underlying the PTFE straps of the harness was firm and recessed 4 mm from the surrounding muscle. The oral cavity and crop contained pink flesh which weighed 80 g and appeared semi-digested. The trachea and syrinx also contained small boluses of semi-digested flesh. This bird appeared to have eaten a large meal and aspirated the contents into the trachea and syrinx, which possibly led to respiratory distress and death, although it is possible aspiration may have occurred agonally. However, given the moderate body condition of the bird, its successful chick rearing and the presence of semi-digested flesh in the crop, toxicity was suspected. The crop contents were found to contain 0.07 mg/kg carbofuran, consistent with carbofuran toxicity. Carbofuran toxicity was the likely ultimate cause of death, but the harness related disease was a significant secondary finding.

Review of pathological findings from red kites fitted with radio transmitters

On review, an additional case of harness-related disease was found in an adult male red kite (530/07) found dead on May 19, 2007. A harness-mounted radio-transmitter had been fitted to 530/07 in 2004. This bird was found injured beside a road at NGR NZ036367. It was taken to the local veterinary surgeon and euthanased owing to its emaciated body condition and severe head trauma. On postmortem examination, this adult weighed 693 g and was in poor body condition. The harness of the radio transmitter was associated with

FIG 5: Adult male red kite 925/09. On the dorsal midline two raised lesions of inflamed granulation tissue were evident immediately caudal to the blue radio transmitter

inflamed granulation tissue over the spine and sternum. There was also haematoma formation over the right dorsal aspect of the skull and lateral to the right eye. Right intraocular haemorrhage and haemorrhage of the musculature overlying the right lateral cranium was noted. Haemorrhage was also noted in the right caudal pectoral musculature. The incapacity caused by the severe head trauma necessitated euthanasia. However, the bird was already emaciated which may have reduced its ability to avoid a collision. The significance of the lesions associated with the harness and radio transmitter in this case is difficult to determine, but they may have contributed to the emaciation.

In total, 228 red kites have undergone postmortem examination since the inception of the reintroduction programme. Harness-mounted transmitters began to be fitted to red kites for monitoring purposes in 2000 and of the 180 red kites examined after death between 2000 and 2010, 18 birds had a harness-mounted radio transmitter fitted. Four of these (22 per cent), all described above, had pathological lesions associated with the harness and radio transmitter. However, 142 red kites were fitted with harness-mounted radio transmitters between 2000 to 2009 and therefore 124 of these have yet to be recovered and examined. We have only undertaken one postmortem examination on a red kite fitted with a tail-mounted transmitter (226/97). This bird had no evidence of disease associated with the transmitter.

It is currently recommended that the total weight of a radio transmitter and its mount in proportion to bodyweight is used as a basis for advising on safe use. It is recommended that the radio transmitter and associated fitting devices should not exceed 2–3 per cent of bodyweight (Fuller and others 2005), while in larger birds with low wing-loading (large wing area relative to bodyweight) such as the red kite, others have recommended the radio transmitter and associated fitting device should be less than 5 per cent of bodyweight (Cochran 1980). The radio transmitter and harness weight (29 g) as a proportion of bodyweight in red kites 530/07, 693/09, 925/09 and 480/10 were calculated to be 4.2 per cent, 2.2 per cent, 3.9 per cent and 2.4 per cent, respectively. Therefore, the weight of the harness and radio transmitter of both 530/07 and 925/09 were above the maximal recommendation at the time of death if we use the recommendations of Fuller and others (2005). However, the weight of the harness and radio transmitter were well within the guidelines of Cochran (1980) which may provide a more appropriate reference for this species. In addition, both of these birds were in poor body condition at death and the transmitter weight would have been a lower proportion of bodyweight when the birds were healthy.

Of the 14 other red kites fitted with harness-mounted radio transmitters and examined after death, the mean transmitter and harness weight as a proportion of bodyweight was 4.82 per cent (SE: 0.83) at death. In nine cases, the transmitter and harness-to-bodyweight proportion was above the recommendations of Fuller and others (2005)

of 3 per cent of bodyweight. However, one of these birds was in poor body condition, five were severely autolysed and two were mummified and it is likely that autolysis and mummification would lead to loss in mass. Therefore, after removing those carcasses classed as severely autolysed and mummified, we re-calculated the radio transmitter and harness weights as a proportion of bodyweight for red kites both with and without lesions associated with the presence of the harness and radio transmitter. We found those with lesions had a range between 2.2 to 4.2 per cent with a mean of 3.15 per cent, standard error of the mean (SEM) 0.49 (n=4) and those without lesions, removing those birds which had conditions which may artefactually decrease bodyweight, had a range from 2.8 to 3.2 per cent with a mean of 2.96 per cent, SEM 0.07 (n=5). When comparing these two cohorts, it was evident that the current maximal weight recommendations for radio transmitters and harnesses of Fuller and others (2005) were exceeded in the cohort where pathological lesions were present. However, the difference was not statistically significant. Those with and without lesions were well within the guidelines of Cochran (1980).

We also conducted an independent samples *t* test to compare duration of harness deployment of red kites with lesions (which ranged between three and five years) and those without lesions (which ranged between one month and seven years). There was a significant difference (SD) in the duration of deployment in those with lesions (M=4.33 years, SD=0.98) and those without lesions (M=1.51 years, SD=1.76), $t(18)=2.97$, $P=0.009$.

With regards to survivability, initial analysis of data from radio-tagged birds suggests that there is no difference in survival rates in the first year (after which tail-mounted tags are lost) between birds fitted with different types of radio transmitter, although direct comparisons are difficult due to the differing circumstances and time periods in which tail-mounted and harness radio transmitters have been fitted to red kites in England.

Discussion

Four red kites fitted with harness-mounted transmitters were found to have moderate to severe pathological lesions associated with these devices detrimental to their survival, including raised inflamed granulation tissue (four birds), necrogranulomatous inflammation (two), loss of skin (two), deep muscular exposure (two) and distortion of muscular conformation (two). The greatest tissue reaction occurred at the points of maximal skin contact between the harness and the bird, on the ventral midline at the t-bar of the harness and where the transmitter was attached over the dorsal midline. These lesions probably led to the death of one bird and may have precipitated the death, due to other causes, of three other red kites. Although abrasions have been reported in spotted owls fitted with similar harness-mounted radio transmitters (Foster and others 1992), effects of this severity and magnitude have not previously been reported in red kites or other birds fitted with this type of harness and radio transmitter. Although the sample is small, the length of time that these birds had carried the harnesses was found to be a statistically significant factor in the formation of these lesions; those with lesions (n=4) had a longer duration of deployment of between three and five years, compared to those without lesions (n=14) with deployment of between one month and seven years.

The development of cutaneous and muscular lesions associated with the harness would have acted as a stressor to these birds and a potential route through which secondary infection could gain access. The additional stress may have predisposed these birds to the other diseases detected which included poor body condition (530/07, 925/09), nematode infection (925/09) and *A fumigatus* infection of the skin (639/09). *A fumigatus* is a ubiquitous fungal organism and the disease it induces, aspergillosis, is thought to be a disease primarily of the respiratory system. In rare situations, *Aspergillus* species may invade the gastrointestinal tract or disseminate from the respiratory system and invade other organs (Joseph 2000). Fungal infections of the integument are uncommonly reported problems in avian species, although *Candida albicans*, *Rhodotorula* species, *Microsporum gallinae*, *Aspergillus* species, *Rhizopus* species and *Mucor* species have been observed (Suedmeyer and others 2002). In raptors, aspergillosis typically occurs in immunocompromised or stressed birds and plaques or granulomas may be found in the nasal sinuses, trachea, syrinx, bronchi, lungs and air sacs. *A fumigatus* was cultured from both the necrogranulomatous masses and pulmonary granulomas in red kite 693/09. It is probable that the chronic inflammatory lesions associated with the harness and transmitter were a sufficient stressor to facilitate secondary *A fumigatus* infection.

Casper (2009) reviewed the general use of radio transmitters in birds. She reported that the causes of adverse impacts, when they occurred, were multi-factorial and related not only to the mass, size and shape of the device, but also to capture method, the handling time, the attachment method, food availability and the length of deployment. It is possible that one or more of these factors contributed to lesions found in the red kites. However, through reviewing the pathological findings from all red kites fitted with harness-mounted radio transmitters, we found that duration of deployment was a statistically significant factor for the presence of lesions and therefore should certainly be considered when evaluating the adverse impacts of harness-mounted radio transmitters on birds in future.

Where the red kites were in poor body condition, perhaps through an unrelated disease, as may have occurred in the case of 530/07, poor fitting of the harness may have contributed to the pathogenesis of the lesions. However, the lesions themselves may have debilitated the bird and given rise to poor body condition and we could not determine from the cases presented in which order these effects occurred. Weight loss, as a result of harness-related or another disease, could have caused the harness to become loose, which may in turn have increased the likelihood of harness slippage or the possibility of objects becoming lodged within the harness to cause tissue reaction, which would alter the frictional contact between the harness and bird. The harness weight as a proportion of bodyweight would also have increased, beginning to approach or exceed the recommended 2–3 per cent three of bodyweight (Fuller and others 2005). This change is likely to have increased energy consumption, as transmitter packages add mass and aerodynamic drag (Pennycuik and Fuller 1987, Obrecht and others 1988), which may have led to further weight loss and worsening of harness fit. Whether bodyweight loss gives rise to the lesions or the lesions themselves result in loss of bodyweight, it is clear that severe lesions occur due to changes in harness fitting. For example, in 925/09 the harness appeared to have laterally shifted to the right, which would have placed excessive frictional contact on the skin and possibly also altered the weight loading and flight capability of the bird owing to uneven weight distribution. These changes in frictional contact and weight bearing in turn may have led to the necrogranulomatous growths and subsequent muscular adaptation.

In a two-year study, Paton and others (1991) reported significantly lower survival and reduced nesting and fledging rates amongst female spotted owls (*Strix occidentalis caurina*) fitted with harness-mounted radio transmitters. In contrast, Foster and others (1992) compared eight locations in Washington and Oregon and found no annual differences in survival or body mass in spotted owls carrying radio transmitters compared to owls that were not carrying radio transmitters. However, the birds carrying radio transmitters were noted to produce significantly fewer young. Monitoring similarly suggested failure to breed in two of our red kites with pathological lesions associated with harnesses (925/09 reported failure to breed in 2008 and 2009 and 693/09 in 2009) and although the cause could not be determined, it is possible that the adverse effects of the transmitter were a contributory factor.

Although we have only recorded four cases of lesions associated with harness-mounted radio transmitters since the inception of the reintroduction program, it is reasonable to assume that some cases of harness-associated disease have gone undetected. It is well known that scanning surveillance programmes fail to detect a large proportion of dead animals and that the sample is biased (Wobeser 2006). Of the 142 red kites fitted with harness-mounted transmitters between 2000 and 2009, only 12 per cent have been found dead, and since annual survival rates are between 80 per cent and 95 per cent in England (depending on age) (Carter 2007), it would be expected that many more of these birds have died, some of which may have had pathological lesions associated with the harness, particularly those with a long duration of deployment.

In further investigations of pathological lesions associated with harness-mounted radio transmitters, crucial questions are how long it takes for lesions to develop after fitting and how long birds can carry harnesses before health is compromised. At present, red kites are not recaptured to monitor or remove harnesses and radio transmitters after their battery life has expired. This is primarily owing to the difficulties in targeting the harnessed birds and the perceived stress of recapture to both harnessed and non-harnessed individuals. However, it might be possible to address this question through investigations on ground-nesting raptors similarly fitted with harness-mounted radio transmitters, which can be more easily captured and monitored.

In response to the findings reported in this paper, Natural England and the British Trust for Ornithology have issued a specific postmortem examination protocol for wild birds with harnesses. This has been circulated to individuals and institutions that carry out postmortem examinations of wild birds. This initiative should assist in increasing our knowledge of the long-term effects of harnesses and radio transmitters fitted to wild birds.

Although only one red kite with a tail-mounted transmitter has been examined, no pathological lesions have been detected in red kites fitted with this transmitter type. However, owing to the positioning of the tail-mount, it is unlikely that the type of lesions described in this paper would occur as it is more likely that the feathers would simply fall out. The lack of individuals recovered with tail transmitters is likely a result of transmitter loss due to moult. Nonetheless, the lack of lesions is encouraging and suggests that for short-term monitoring (less than one year), a tail-mounted radio transmitter may be preferable. However, tail-mounted transmitters can only be applied when the bird has left the nest when their tail is fully grown and this, together with the capability to monitor only in the short term, may limit the use of tail-mounted transmitters in wild birds.

We have detected four cases of severe pathological lesions associated with harness-mounted radio transmitters in red kites and these lesions appeared to have occurred as a consequence of the length of their deployment. When considering the use of harness-mounted radio transmitters on birds in future, it will be important for the benefits, in terms of gathering useful information about the species, to be carefully balanced with the risks of adverse impacts on the birds. The use of harness-mounted radio transmitters should be closely monitored and further research to determine at what stage in the life of deployment the harnesses can become detrimental to the health of birds would be useful.

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