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ORIGINAL RESEARCH

Eurasian beaver (*Castor fiber*) health surveillance in Britain: Assessing a disjunctive reintroduced population

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Abstract

Background: Numerous translocations of Eurasian beavers have occurred with little implementation of standardised health screening. Pre-release health screening enables the selection of individuals with the best survival prospects and reduces potential health risks, but this is by-passed during unofficial releases. Beaver reintroduction to Britain has been haphazard and currently disjunctive populations of varying status exist.

Methods: This observational cross section study investigated the health status of three beaver populations, with 90 live beavers tested for a range of pathogens comprising 56 from Tayside (unofficially released Scotland), nine from Knapdale (officially released Scotland) and 25 from Devon (unofficially released England). In addition, a further 32 cadavers were screened (25 from Tayside and seven from Knapdale).

Results: All beavers were in good physical condition, did not harbour any non-native disease or parasites of concern and demonstrated remarkably low levels of any disease or parasite exposure.

Conclusion: Beavers are establishing and adapting well to British landscapes and are not acting as reservoirs of significant zoonotic diseases. Official, licensed reintroduction programmes may appear overly convoluted; however, reputational damage of unofficial releases should be considered, along with the health and welfare of the animals involved and collateral damage to other wildlife, domestic animals and humans.

KEYWORDS
beaver, reintroduction, retrospective survey, wildlife disease

INTRODUCTION

The importance of animal health in conservation programmes is increasingly recognised as the success of any translocation or reintroduction can be significantly affected by disease. Despite this, the implementation and development of pre-reintroduction (e.g. robust disease risk analysis) and post-release (e.g. wildlife surveillance programmes) veterinary health programmes tend to receive less investment compared to other project aspects.[1] Although successful projects are well documented, many conservation reintroductions have failed (defined as lack of self-sustaining population establishment and/or failure to meet conservation objectives) for a variety of reasons.[2–6] Species reintroductions have occurred through uncoordinated releases or escapes from captive collections (e.g. wild boar, *Sus scrofa*, in England[7] and Eurasian beaver in Belgium[8]). In unplanned or unauthorised reintroductions, or those founded through escapes, baseline data (on the animals involved or ecological baselines on which they may impact) are lacking and so can present significant issues when attempting to assess either the suitability of founders or their environmental impacts.

Unofficial releases and potential escapees by-pass medical health assessments. In the normal course of events, pre-release health screening is essential to enable the selection of individuals with the best survival prospects and reduce potential health risks associated with any conservation translocation.[9] Along with the prevention of disease and parasite introduction at release sites, pre-release health checks ensure that any individual potentially unlikely to survive or to experience welfare challenges on release,

is identified.[10] Unofficial releases should still be assessed, health-wise, to determine whether they are coping with their release habitat and to assess whether they are carriers for significant pathogens for other animals and humans. The establishment of baseline species-specific health parameters and routine analyses of diagnostic samples allows informed decision-making and improvement in animal health and welfare.[11]

The range of pathogens that can be harboured by the Eurasian beaver has been previously reviewed along with pre-release health screening recommendations for beaver importation to Scotland.[10,20] Beavers can carry host-specific parasites that were previously present in Britain, but which died out with their demise, which include the beaver beetle *Platypsyllus castoris*, a stomach nematode *Travassosius rufus* and a specialised trematode or intestinal fluke *Stichorchis subtriquetrus*. These species have now all been recorded in wild beavers in Scotland.[10,21,22] Other parasites such as *Giardia* spp. and *Cryptosporidium* spp. are already present in British wildlife and domestic animals , therefore it is likely that beavers may also act as carriers. Like all other rodents, beavers may harbour common European rodent pathogens.[10,20] For any beavers of unknown origin, the presence of *Echinococcus multilocularis* and *Francisella tularensis* (the causative agent of tularaemia) would be of concern as these are notifiable diseases under EU law, significant zoonoses, not currently present in the UK and have been reported in Eurasian beavers in continental Europe.[20,23,24] Other significant diseases and parasites associated with beaver reintroduction (i.e. those which are Notifiable under EU Animal Health legislation and/or are likely to result in significant disease to domestic animals and humans) according to DEFRA (the UK Government's Department for Environment, Food and Rural Affairs) are considered to be *Cryptosporidium* spp., *Giardia* spp., *Leptospira* spp., *Mycobacterium bovis* (bovine mycobacteriosis) and *Salmonella* spp., which is supported by a recent peer-reviewed Eurasian beaver disease risk assessment.[20] Comparison of blood parameters measuring haematological and biochemical values for healthy beavers can also be valuable in assessing health status prior and after release.[25] From a health and biosecurity perspective, beavers are currently considered to present no greater risk to human, livestock or other wildlife health than any other native mammal, but ongoing vigilance and further data collection are warranted considering the very recent history of its reintroduction to Britain.[20]

Once widely distributed across Britain, Eurasian beavers, *Castor fiber*, were thought to be generally extinct in England by the 12th century and 16th century in Scotland.[12,13] The sourcing of beavers for restoration to Scotland has been debated academically.[14–16] A government-sanctioned, scientific trial reintroduction (Scottish Beaver Trial, Knapdale, Argyll, Scotland, referred to in this publication as 'Knapdale') investigated the feasibility of beaver reintroduction in Scotland using wild Norwegian animals.[17,18] Outside of this official trial, a significant population (~114 active territories[19]) of wild-living beavers is also resident throughout the River Tay and Earn catchment, Perthshire, east Scotland (referred to in this publication as 'Tayside').

Two families of breeding beavers were reported on the River Otter, Devon, in February 2014 (referred to in this publication as 'Devon'). After a successful public campaign to see them remain in place, Natural England granted a 5-year licence to Devon Wildlife Trust in 2015. The River Otter Beaver Trial is a scientifically monitored trial reintroduction of Eurasian beavers and will conclude in March 2020. The Tayside and Devon populations have established outside of statutory procedures, through unlicensed releases and/or accidental escapees, therefore not subject to IUCN reintroduction guidelines and formal disease risk analysis.[20] Therefore, they are of unknown origin and health status with no baseline data collected on the originally released individuals. The aim of this study is to determine health status in free living beavers in Britain.

The data presented in this paper help to further our understanding of the potential disease risk of Eurasian beaver reintroduction to Britain.

METHODS

Following the Strobe guidelines,[26] an observational cross section study was undertaken. Data were examined from that collected from 2013 to 2019 in Tayside, Knapdale and Devon populations. A convenience sampling method was taken as detailed below.

Study areas

The 'Tayside' beavers include those found within the River Tay and Earn catchment that covers over 5000 km^2 (main River Tay ~193 km long), rising at Ben Lui, in Argyll, west Scotland, flowing into the North Sea at the Firth of Tay, Dundee, east Scotland.[27] The main land-use in the lowland part of the catchment area is intensive agriculture. Although unverified,[28] beavers are thought to have been present in this area for at least 15 years.

The 'Knapdale' beavers refer to those, established from the release of wild Norwegian animals in 2009, within the Knapdale Forest, Argyll, Scotland, the site of the original Scottish Beaver Trial (SBT).[10] This site is predominantly commercial conifer forest, but with multiple freshwater loch environments surrounded by mosaic of native broadleaf woodland, incorporating sites of special scientific interest for birds, lichens, dragonfly species and oak woodland. Wild beavers, including some originally imported Norwegian individuals and those born within the project were health-screened during September 2019 as part of an ongoing assessment of their health.

The 'Devon' beavers originated from the River Otter catchment in Devon, England, that covers 250 km^2 ris-

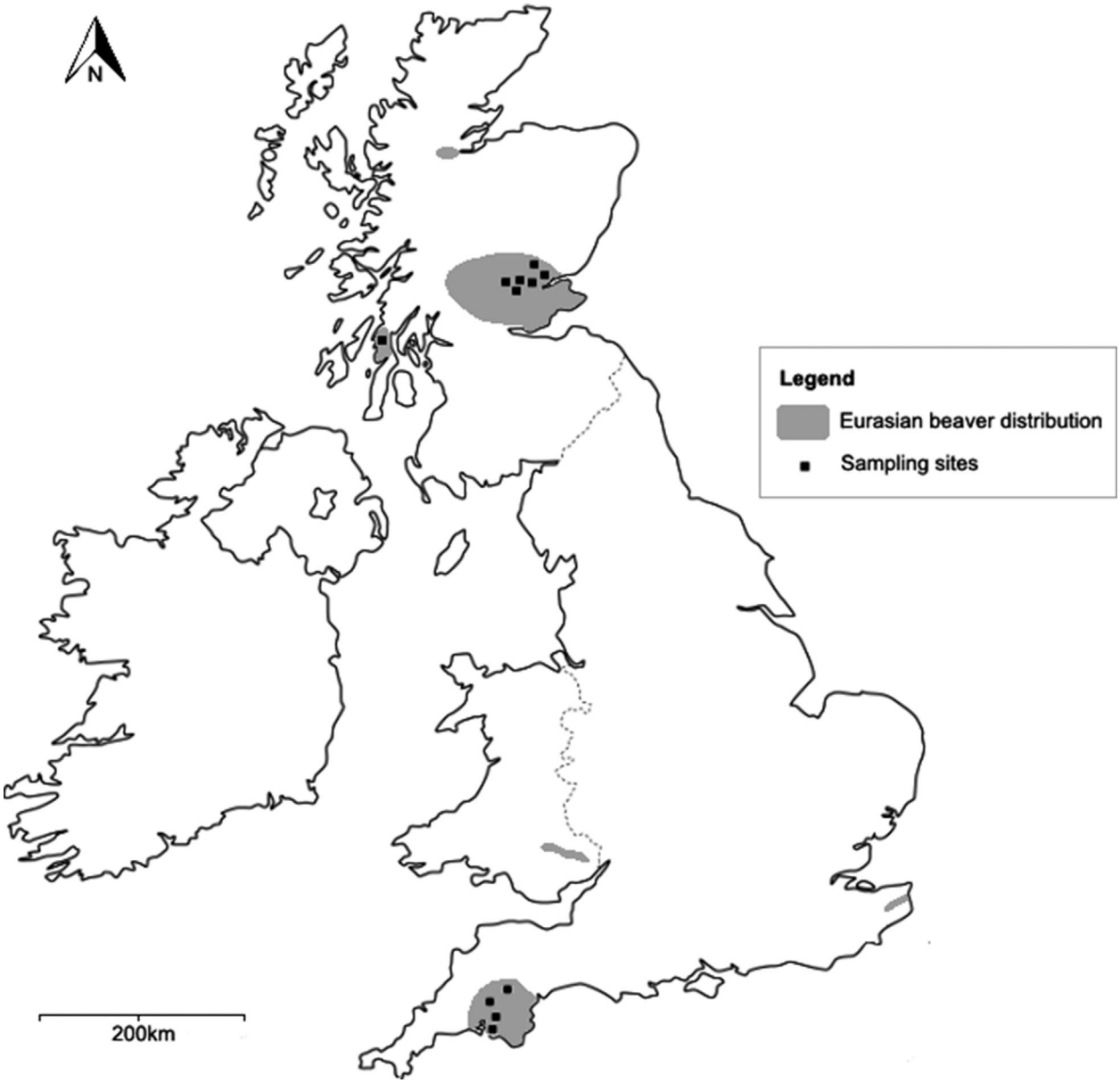

FIGURE 1 Distribution map of sampling locations

ing in the Blackdown Hills from a Cretaceous Upper Greensand scarp that rises to 275 m. It is predominantly a rural catchment with intensive agriculture in the southern end of catchment, with dispersed settlements. Half of the catchment is improved grassland, with 28% arable and horticulture, and 5% urban and suburban.[29] Beavers of unknown origins have been present from 2008, with known breeding in 2014 prompting a proposal by DEFRA to remove them. A successful campaign by local residents led to the Devon Wildlife Trust being granted a licence to run a 5-year trial to end in 2020.

Animals sampled and trapping methods

A live-trapping programme was carried out across the Tayside catchment from October 2012 until April 2014. All beaver handling, including transportation and re-release occurred under licence issued by Scottish Natural Heritage (licence numbers: 14529 and 148176). Trapping sites (Figure 1) were identified through beaver activity survey maps,[30] responses to land owner questionnaires about beaver presence and public reports of beaver field signs.[28] Additional trapping of beavers across Tayside catchment occurred in September and October 2017, 2018 and 2019 using techniques previously described.[10,19] Twenty one beavers were translocated during this time to reinforce the Knapdale population under licences issued by Scottish Natural Heritage (licence numbers: 103135 and 148511), while the remaining supplied translocation for projects in England. In all, 56 live beavers were examined from Tayside in this study. All beavers were fully health screened prior to any translocation event.

Ongoing health assessment and trapping of beavers living wild (both original founders and offspring) in Knapdale, Argyll was carried out in 2019. In total nine

TABLE 1 Summary of live and cadaver samples obtained from River Tay catchment Scotland (Tayside = 81); Scottish Beaver Trial release site Knapdale, Argyll, Scotland (Knapdale = 16) and River Otter, Devon, England (Devon = 25)

Location of samples	Number of live samples	Number of cadaver samples
Tayside	56	25
Knapdale	9	7
Devon	25	0
Total	90	32

animals were trapped, physically assessed, and results included in this study.

The Devon beaver health assessment included initial full screening, under anaesthetic of five original population founders. As a condition of their remaining in the wild the Animal and Plant Health Agency (APHA) requested screening specifically for *E. multilocularis* (N = 4) owing to the UK's current free-status and the evidence of infection in beavers in parts of Europe and one captive beaver in England.[24] Ongoing assessment of additional trial animals occurred during annual trapping period (January to March 2015 and 2016). The main aims of these in-field assessments were to trap and tag new animals (kits born that breeding season or previously un-trapped individuals); check micro-chips and re-tag ear tags as required; collect samples for veterinary screening where possible and map population distribution and composition according to individuals trapped.

For all populations, beavers were live trapped using 'Bavarian' beaver traps by experienced personnel following described trapping protocols.[31,32] Traps were baited regularly and checked daily. Any beavers were restrained by experienced personnel using specialized equipment and re-released at point of capture.

A further 32 beaver cadavers, Tayside (N = 25) and Knapdale (N = 7), were examined at gross post-mortem and histopathology (Table 1).

Health screening

A physical examination of all live-trapped beavers (N = 90) and cadavers (N = 32) totalling 122 animals was carried out following methods described in the study of Goodman et al[10] including an assessment for external parasites. Body condition was assessed through palpation of the body (particularly of the spine and pelvis), assessment of tail condition (thick fat layer or not), and scored according to the standard rodent body scoring system adapted for beaver morphology (Table 2). Weight was measured via digital scales to the nearest 0.1 kg. Sex was established through the examination of the colour and viscosity of the anal gland secretions in live-trapped beavers and where present by examination the gonads in cadavers.[33]

A proportion of live trapped Tayside animals (N = 17), Tayside cadavers (N = 32) and the original Devon animals (N = 4) totalling 53 beavers underwent additional screening specifically for *E. multilocularis* as follows: radiographs of the chest and abdomen from a perpendicular, dorsoventral and lateral recumbency view were taken; abdominal ultrasonography was performed, with particular attention paid to the liver, for any signs of parasitic cysts of the intermediate stages of tape worms; and a thorough post-mortem examination where cadavers (N = 32) were presented including incising into liver, lung and other body organ parenchyma. For 21 live-trapped individuals classed as sub-adult and older from Tayside (N = 17) and Devon (N = 4), an additional minimally invasive laparoscopic examination of the abdomen was performed to further assess the liver and abdominal viscera for any signs of the intermediate stage of *E. multilocularis* or other pathology not evident on ultrasonography, radiography and physical examination.[34]

A total of 75 live-trapped beavers (Table S1) had some form of haematological analysis: 28 beavers underwent full analysis (packed cell volume/haematocrit, erythrocyte count, mean cell volume, mean cell haemoglobin concentration, mean haemoglobin concentration, total leucocyte count, neutrophil count, lymphocyte count, monocyte count, eosinophil and basophil count) using a Beckman-Coulter AcT 5 differential analyser (Beckman-Coulter UK Ltd, High Wycombe, Buckinghamshire, UK) on whole potassium EDTA blood according to manufacturer's guidelines; a further 22 were tested using a point of care analyser (i-STAT Zoetis UK Leatherhead, Surrey, UK) to assess haematocrit and haemoglobin levels; a further 25 animals, where insufficient blood was available for full analysis, had a blood smear and white cell differential count analysed. Haemoparasite screening was carried out on all 75 animals, following previous methods.[35]

A total of 53 live-trapped beavers had some form of serum/plasma biochemical analysis: 28 beavers underwent biochemical analysis (alanine aminotransferase, alkaline phosphatase, aspartate aminotransferase, gamma glutamyl transpeptidase, glutamate dehydrogenase, bile acids, total bilirubin, creatine kinase, blood urea nitrogen, creatinine, total protein, albumin, globulins, cholesterol, glucose, total calcium, phosphorus, sodium, potassium, chloride and amylase) using a Randox Imola clinical chemistry analyser (Randox Labs Ltd., Crumlin, County Antrim, Northern Ireland, UK) on a serum sample separated and refrigerated within 30 minutes of collection and analysed within 24 hours according to manufacturer's guidelines; a further 25 beavers underwent biochemical analysis (alanine transferase, alkaline phosphatase, bile acids, total bilirubin, blood urea nitrogen, creatinine, total protein, albumin, globulins, glucose, total calcium, phosphorus, sodium, potassium and amylase) on a heparinised plasma sample using an in-house analyser (Vetscan2 Zoetis UK Leatherhead, Surrey, UK) within 20 minutes of collection.

Additionally, specific serological and polymerase chain reaction (PCR) testing was performed

TABLE 2 Body condition scoring and methodology modified for beavers and based on methods for laboratory mouse, Mus musculus (Ullman-Culleré and Foltz, 1999). Body score determined through physical examination including palpitation of vertebral column, pelvis region and tail appearance

Body score	Description
1	Emaciated: skeletal structure extremely prominent, little flesh cover. Vertebrae distinctly segmented. Tail arch very prominent, with tail sunken on either side of midline, owing to low fat reserves
2	Poor: segmentation of vertebral column evident. Dorsal pelvic bones are readily palpated. Tail arch prominent, tail sunken, low fat reserves
3	Expected: vertebrae and dorsal pelvis not prominent, but palpated with slight pressure. Tail arch is visible, but tail is thick with good healthy fat reserves
4	Overweight: spine is a continuous column. Vertebrae palpated only with firm pressure. Tail arch not really visible, tail thick and more rounded
5	Obese: body is bulky. Bones disappear under flesh and subcutaneous fat layer. Tail is thick and rounded

including: an immunoblotting assay for *E. multilocularis* (N = 21)[36]; *Leptospira* serology (N = 48) (all serovars of pools 1–6) by means of the microscopic agglutination test carried out at the APHA central laboratory, Weybridge, Surrey, UK. As previously reported *Leptospira* spp. quantitative (q)PCR (N = 13) on urine (live beavers) or kidney samples (cadavers).[37] Testing for *F. tularensis* DNA by real-time (rt) PCR on clotted blood samples (N = 24) and cadaver liver samples (N = 5) at the National Veterinary Institute, Oslo, Norway (rtPCR ME07_110) with two animals tested additionally by serological tests at the National Veterinary Institute, Oslo, Norway using techniques previously reported.[38,39]

Gastro-intestinal parasitology testing included standard fresh smear evaluation, salt saturation flotation and sedimentation techniques followed by microscopy for coccidia, nematode, cestode and trematode oocysts for species identification and was carried out on a total of 114 beavers (84 live beavers and 30 cadavers) (Tables S1 and S2). In addition, acid fast staining was carried out on faeces after sedimentation and salt saturation for *Cryptosporidium* spp. in 104 beavers (74 live beavers and 30 cadavers) (Tables S1 and S2).[40] Finally, direct fresh sample evaluation (wet smear) followed by salt saturation and sedimentation was used to detect live and encysted forms of *Giardia* spp. in 103 beavers (73 live animals and 30 cadavers).[41]

Salmonella spp. microbial screening on faecal samples was carried out in a total of 105 beavers (75 live animals and 30 cadavers) using selenite enriched broth at 37C for 24 hours followed by transfer for growth on brilliant green agar for 24 hours again at 37C. *Yersinia* spp. microbial screening on faecal samples was carried out in a total of 71 beavers (41 live animals and 30 cadavers) using *Yersinia* spp. selective medium (CIN ThermoFisher Scientific) grown at 30C with species identified using mass spectrometry techniques. *Campylobacter* spp. on faecal samples was carried out in a total of 73 beavers (43 live animals and 30 cadavers) using *Campylobacter* spp. selective media supplements (Skirrow media ThermoFisher Scientific) cultured at 37C. Acid-fast bacterial screening for *Mycobacterium* spp. (such as *M. avium* subsp. *paratuberculosis*) was carried out on faecal samples in a total of 52 beavers (22 live and 30 dead beavers) via the Scottish Agricultural College (Consulting Veterinary Services, Scottish Rural College, Edinburgh, Scotland).

Blind-sampled bronchioalveolar lavage fluid collected under general anaesthesia was investigated for standard microbiological culture and cytological examination, including acid-fast Ziehl-Nielsen staining for abnormalities or suspect acid-fast organisms including *Mycobacterium* spp. (Royal (Dick) School of Veterinary Studies, University of Edinburgh, Scotland, UK) on 14 live-trapped beavers. A total of 30 cadavers had lung tissue submitted for histopathological examination including acid-fast Ziehl-Nielsen staining for evidence of bacterial infections (Royal (Dick) School of Veterinary Studies, University of Edinburgh, Scotland, UK).

A total of 22 beavers were assessed by single channel electrocardiogram (ECG) under general anaesthesia.

All examinations and sample collections where laparoscopy, radiography or bronchoalveolar lavage occurred were carried out under general anaesthesia. Beavers were first transferred to burlap sacks, and via a face mask administered isoflurane in 100 per cent oxygen to induce general anaesthesia and then intubated and maintained on isoflurane while samples were taken.

Cadavers of beavers removed for management purposes or found as road kill within the Tayside catchment area were examined (N = 32). Standardised post-mortem examinations were undertaken within 2 days of collection[10] (Table S2). Standard radiographs (lateral and dorsoventral views) of the skull, chest and abdomen were taken and organ biopsies preserved in 10% buffered formal saline with subsequent histopathological examination.

RESULTS

In total 122 (live animals N = 90; cadavers N = 32) individual beavers underwent health screening with 56 of all animals being identified as female and 64 as male with two being unidentifiable at post-mortem due to the absence of reproductive organs through predation of the cadaver. All individuals were physically healthy, presented no obvious deformities, external parasites or obvious signs of disease.

Physical, physiological and histopathological examination

Four post-mortem beavers showed evidence of infectious disease (12.5% of post-mortems and 3.3% of all beavers tested). From these animals, evidence of pancreatitis and peritonitis was demonstrated in two with a fibropneumonia in another and an inconclusive result in a fourth. *E. coli* was isolated from two (one pancreatitis and one with fibropneumonia) and *Streptococcus gallolyticus* spp. *pasteurianus* isolated from a third animal with pancreatitis. These may have been post-mortem contaminants. The fourth animal had no specifically identified cause of death, although inflammation in multiple organs was seen but failed to culture a pure growth of bacteria from any one which was suspected to be due to the extensive degradation of the body post-mortem.

One beaver at post-mortem had mild abnormal incisor wear (3.1% of those examined at post-mortem and 0.8% overall) Abdominal ultrasound and laparoscopic examinations were unremarkable, with no indications of clinical disease, abnormalities or *E. multilocularis* infection. One Tayside individual was positive for *Cryptosporidium* spp. (3.3% of cadavers tested and 1% of all beavers tested). No other pathogenic bacteria (e.g. *Salmonella*, *Campylobacter*, *Leptospira*, *Yersinia* spp.) or parasites (e.g. *Giardia* spp.) were recorded in the beavers tested.

Haematology and serum biochemistry in those beavers sampled were all within normal published range for Eurasian beavers.[25] No blood parasites were evident in any beavers sampled.

No beaver examined showed evidence of abnormal ECG readings on rhythm or values.

The majority of beavers presented as cadavers for post-mortem showed signs of either shotgun pellet/bullet injuries that accounted for their death (59.4% of cadavers) or blunt trauma associated with suspected motorised vehicle collision (6.3% of cadavers) or other forms of trauma (suspected predation) (15.6% of cadavers). Five animals had an undetermined cause of death due to the significant post-mortem scavenging or decomposition of the carcass.

Parasitological examination results

Sixteen of the live tested Tayside beavers (19%) and four of the cadavers (13.3%) examined were positive for the beaver caecal trematode *S. subtriquetrus* meaning 17.5% of all beavers tested were positive overall. One of those tested demonstrated oocysts that could not be differentiated from the liver fluke *Fasciola hepatica*, and so infection with this pathogen cannot be ruled out in 0.9% of those tested.

One individual cadaver tested positive for *Cryptosporidium* spp. The individual was a subadult male, in good body condition and weight (14.3 kg). It also had a moderate burden of *S. subtriquetrus* intestinal trematodes but with no gross or histopathological evidence of an enteritis. Another female beaver tested positive for an *Eimeria* spp. coccidian parasite on faecal testing (1.1% of live beavers tested and 0.9% of beavers tested overall). The individual was a juvenile beaver (<1 year) based on criteria described in the methods section and was in good body condition (3.5/5) and weight (8.9 kg). The numbers of oocysts recovered were few (occasional oocysts seen). One live-trapped beaver was positive for the beaver fur beetle *P. castoris* (1.1% of live animals and 0.8% of all examined) but showed no evidence of fur loss or skin disease. No beavers tested positive for *E. multilocularis* or *Giardia* spp.

Bacteriological examination results

Two beavers were positive for *Yersinia frederikensii* on faecal sample testing (4.9% of live tested beavers and 2.8% of beavers tested overall), although neither showed signs of clinical disease on a physical examination, blood haematology or biochemistry assessment. No beavers tested positive for: *Campylobacter* or *Salmonella* spp. on selective culture; *Leptospira* spp. on serology or qPCR or *Franciscella tularensis* on RT-PCR or serology as described. No beavers were positive for acid-fast bacteria on lung washes or faecal analysis as described.

DISCUSSION

Given the large number of beaver translocations throughout Europe, relatively few have been robustly health screened.[42,43] Overall, the health of the beavers in Britain has been consistently positive with few if any pathogens recovered in this study. While the gender distribution of beavers sampled was roughly even the potential for bias in sampling is still present as beavers sampled were opportunistic (either killed and presented or entered humane traps). This may limit the findings to an unknown extent. However, the large number of animals sampled and ranges over which they were sampled both in time and geography would support their validity.

No evidence of significant zoonotic disease has been apparent with negative results for *E. multilocularis*, *Giardia* spp., *Francisella tularensis*, *Campylobacter*, *Salmonella* and *Mycobacterium* spp. supporting previous low disease risk assessments for significant zoonosis in beavers in Britain.[20] *Giardia* spp. has been reported in Eurasian beavers in continental Europe, and so vigilance for this organism, a potential water-borne zoonosis, is recommended.[44,45] Seroconversion to *Leptospira* spp. exposure has been seen in previous studies without clinical signs of disease, and subsequent results reported here suggest an absence of repeated exposure in the wild which fits with a wider picture of beavers not acting as an active reservoir for these potential pathogens.[37] These findings contrast with some case reports in the literature that suggest beavers are highly susceptible to disease with *Leptospira* spp. infections with

mortalities likely, suggesting other factors may have been at work in those published cases.[46,47] Two cases of *Y. frederikensii* are reported here on faecal culture in live-trapped beavers with no evidence of morbidity. Carriage of *Yersinia* spp. is common in rodents including beavers,[48] although no evidence of the potentially zoonotic species *Y. pseudotuberculosis* or *Y. enterocolitica* was isolated in this study which has been associated with mortalities in beaver reintroductions in other countries.[46] *Y. frederikensii* has been reported in freshwater fish (*Cyprinus carpio*) and occasionally enteritis in humans, and although it is essentially viewed as a freshwater environmental organism with world-wide distribution.[49,50] Haematological and serum chemistry analysis, serology, microbiological and parasitological assessments are all commonly used to determine disease/health status for a wide range of wild and domestic animals[51] and were within expected ranges for this species.[25]

Where mortalities were seen and thought to be associated with infectious disease in this study, two cadavers demonstrated sepsis associated with *E. coli* and one with *Streptococcus gallolyticus* spp. *pasteurianus*. *E. coli* is a common potential pathogen in a wide range of mammalian species and has been associated with sepsis in rodents, particularly those close to farms and may also be found in the digestive tract of healthy animals.[52] *S. gallolyticus* spp. *pasteurianus* has been identified as a pathogen associated with meningitis and premalignant and malignant colonic lesions in humans but its identification can be difficult, and it is often confused with *S. bovis* which is a ruminal micro-organism found in domestic cattle.[53,54] Both these findings suggest the possibility of infection of the beavers from domestic animals or wild rodents living close to farms and would reinforce the theory of synurbisation, that is the proximity of wildlife to humans and domestic animals increases the likelihood, they will become infected with potential pathogens including the above mentioned *Giardia* and *Leptospira* spp.[37,55]

A number of beavers tested in this study were positive for the host-specific parasite, *S. subtriquetrus*, which has previously been recorded in Scotland (Tayside catchment[21] and Scottish Beaver Trial[10]). This species is frequently reported in beaver populations throughout Europe[56] and is not considered a risk to humans, livestock or other wildlife and may be considered as a commensal enteric parasite. Intermediate host species (aquatic snails) have been demonstrated to be fully functional when infected.[57] While these host-specific parasites may not be of significant concern, this should not underestimate the risk of unwanted parasite introduction in unscreened or illegally introduced hosts. One case could not rule out the possibility of *Fasciola hepatica* liver fluke based on oocyst morphology. This raises the possibility that the Eurasian beaver can act as an aberrant and occasional host to this parasite which is ubiquitous in northern Europe, which would support findings in Polish beavers[58] and work in other semi-aquatic rodents such as capybara, *Hydrochoerus hydrochaeris*.[59]

One post-mortem of a shot individual tested positive for *Cryptosporidium* spp., a potential zoonosis and domestic animal pathogen. The animal was in good body condition (3/5) with no evidence of an enteritis, although it also had *S. subtriquetrus* intestinal trematodes in the caecum. Beavers in continental Europe have previously tested positive for *Cryptosporidium* spp. as the organism survives well in wet conditions and is a ubiquitous parasite of mammals.[45] Again, this raises the possibility that beavers can act as a vector of zoonotic disease, although the low incidence 1% of all animals tested (one out of 104 beavers) suggests that they are not a significant source of the parasite in the wild.

One live-caught individual tested positive for *Eimeria* spp. coccidial parasite (1.3% of all live caught animals and 0.9% of all beavers tested) at a low level (occasional oocysts seen). The individual was a subadult female from Knapdale in good body condition and weight with no signs of diarrhoea or obvious clinical disease. Coccidia are common in young animals including rodents. They uncommonly cause clinical disease in immune-competent animals and have high host specificity and so are unlikely to act as potential pathogens to other species.[60]

No significant ectoparasites were noted in the clinical examination of the pelage of 122 beavers. *P. castoris* was identified in one case (the so-called beaver beetle) which is not considered an important pathogen to beavers or other animals and has been previously reported in Britain.[22]

One beaver at post-mortem (0.8% of all beavers examined) was identified with a mild dental abnormality (abnormal wear of the incisor teeth). The adult male beaver was from Tayside, in good body condition (3/5) and weight 21.6 kg. The cause of death was determined as a rifle shot to the chest. Mild dental (incisor) wear abnormalities have been reported in beavers in Scotland before, and those seen so far do not appear to be associated with poor body condition.[61]

There are complex legal, socio-economic and management issues surrounding unofficial beaver releases in Britain which are outside the scope of this study. From a biological perspective current beaver populations sampled are predominantly free from disease and composed of individuals that are successfully breeding and apparently well adapted to the environment. This may be described as a case of 'luck' rather than proactive planning and has resulted in significant resources being required to answer a range of uncertainties to establish health and genetic status. Official, licensed reintroduction programmes may appear overly convoluted, and governments, statutory nature bodies and conservation NGO's may be considered slow to implement reintroductions as conservation tools. However, the application of the appropriate checks, planning and risk mitigation are necessary to ensure the potential of a reintroduction to succeed. The sudden reappearance of beavers, ahead of pragmatic management and conflict resolution frameworks have generated negative attitudes towards the species and persecution in Scotland

(similarly in Belgium[8]). The reputational damage of illegal animal releases to viable reintroduction processes should be considered, along with the health and welfare of the animals involved in any future prospective species restoration projects.

To assess suitability for release, it would be recommended that any pre-release health assessment should be carried out with specialist veterinary support and refer to current published baseline parameters.[10,25,35] These individual assessments should include physical examination, full haematology and serum biochemistry, parasitology and bacteriology and general serology. Any individuals testing positive to host-specific parasites, and/or common wildlife disease already present in British wildlife [62] should not be automatically excluded from any release, although their fitness upon release and likely welfare status assessed on a case by case basis. Any individuals testing positive for Notifiable agents/diseases such as *E. multilocularis*, or *F. tularensis* should not be released, and the Animal and Plant health Agency contacted.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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