Assessing European water vole (*Arvicola amphibius*) habitat suitability within Ae Forest, Dumfries and Galloway.

An undergraduate dissertation

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Abstract

The endangered European water vole is the fastest declining mammal in the UK. Conservation efforts for the species have largely failed to halt its decline over the past 60 years. Water voles are threatened in their native range by habitat degradation, fragmentation and loss combined with predatory pressure from the invasive non-native American mink. This study was devised in partnership with the The River Annan Trust to assess habitat suitability for water voles within Ae Forest. The River Annan Trust is responsible for improving the ecological state of the waterways within the River Annan Catchment, of which Ae Forest is a subsidiary. This study was devised to establish the suitability of Ae Forest to support a population of water voles. A field survey was conducted to establish baseline data on habitat suitability along 42 stretches of water within the forest. The majority of the surveyed stretches exhibited optimally suitable water vole habitat. Further research was conducted into the threats levied against the species within the forest. Desk based investigation methods revealed mink to be present in the forest, posing a significant threat to the survival of water voles here. Sensitive land management practices are in place within the forest in addition to mink control measures. It is a recommendation from this study that further research be conducted into the potential for forestry practices to pollute water vole habitats.

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Acknowledgments

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List of abbreviations

CBD	Convention on Biological Diversity
CEH	Centre for Ecology and Hydrology
FCS	Forestry Commission Scotland
FES	Forest Enterprise Scotland
INNS	Invasive Non-Native Species
IUCN	International Union for Conservation of Nature
LBAP	Local Biodiversity Action Plan
OS	Ordnance Survey
RAT	River Annan Trust
RADSFB	River Annan District Salmon Fisheries Board
RBMP	River Basin Management Plan
QGIS	Quantum Geographic Information System
QQR	Quinquennial Review
SWSEIC	Southwest Scotland Environmental Information Centre
UK	United Kingdom
UKBAP	United Kingdom Biodiversity Action Plan
UKFS	United Kingdom Forest Standard
WFD	Water Framework Directive
WVSG	Water Vole Steering Group

1. Introduction

1.1. The importance of biodiversity for ecosystem functioning

Biological diversity, or biodiversity, is widely accepted as being an essential prerequisite of healthy ecosystems (Baskin, 1994; Laurila-Pant *et al.*, 2015; Lefcheck *et al.*, 2015), and indeed the two are intrinsically linked. Loreau *et al.* (2001) and Hooper *et al.* (2012) highlight the worrying trend for humans to have an adverse influence upon ecosystems, through precipitating the reduction in biological diversity and subsequently changing important ecosystem processes. It is estimated that current global biodiversity loss is occurring at a rate 1,000 times greater than the natural background rate of species extinction (Pimm *et al*., 2014), and could reach 10,000 times this rate should those species presently threatened succumb to pressures levied against them (de Vos *et al*., 2015). One such species presently threatened within its native range is the European water vole (*Arvicola amphibius,* formerly *Arvicola terrestris*), upon which this study focuses.

1.2. *Arvicola amphibius* species description

The European water vole, an arvicoline rodent, is the largest vole species in the UK (McGuire and Whitfied, 2017). Adults typically measure between 140 and 220 mm in length from head to rump, and their tails can measure between 95 and 140 mm (The Mammal Society, 2016). Adult individuals weigh between 150 and 350 g, depending on the season and their sex (Meredith *et al*., 2013; Frafjord, 2016). There is little sexual dimorphism in the species, although healthy males will grow larger and heavier than healthy females (Frafjord, 2016). Water voles exhibit a wide range in pelage colour from chestnut brown to black, depending upon their location. Scottish and upland individuals typically possess darker colouration than lowland and southern conspecifics (SNH, 2018a).

Water voles bear a superficial resemblance to the brown rat (*Rattus norvegicus*), however the former is slightly smaller, has a rounder face, smaller, less-obvious ears, and a shorter, fur-covered tail (PTES, 2018). Brown rats typically present with a pointy face, large, protruding ears and long, scaly tails. The two are often confused due to their occupation of similar habitats (The Mammal Society, 2016) and are rarely seen at close proximity or for an extended period of time. **Fig. 1**, below highlights the anatomical differences between the two species.

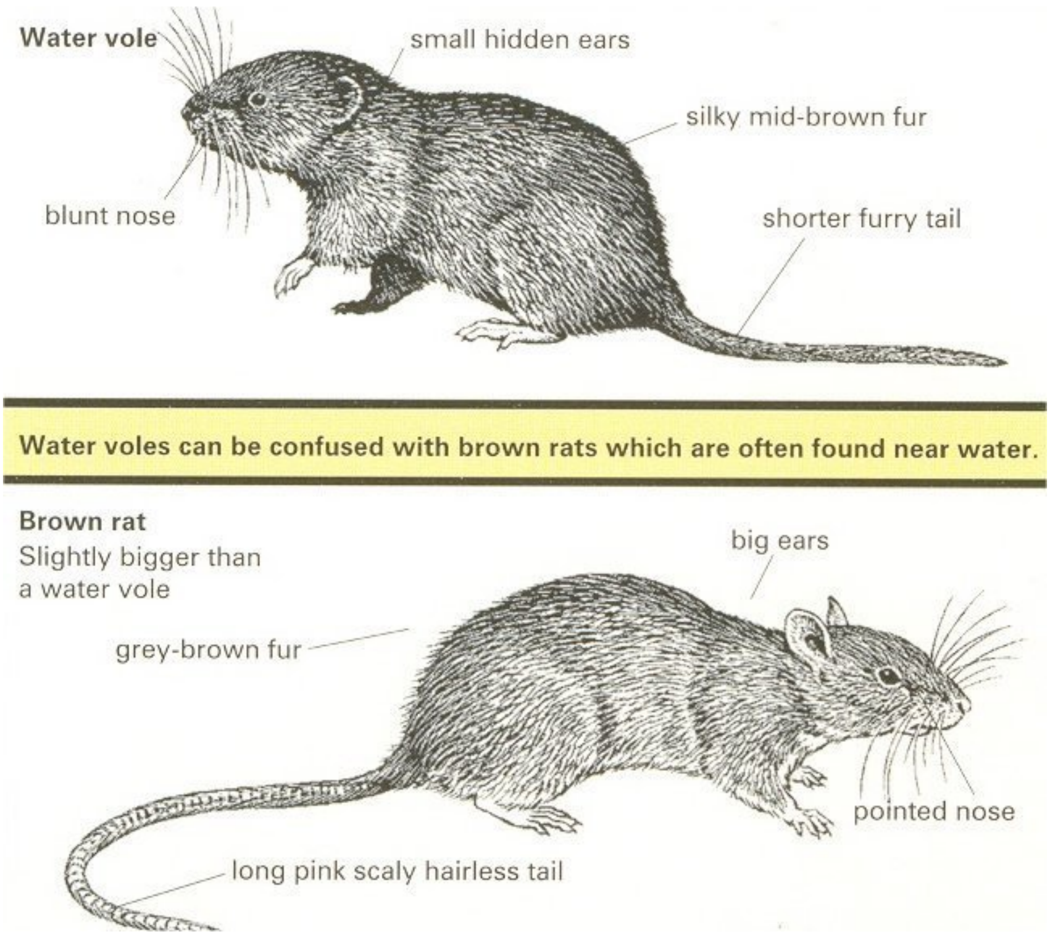

Figure 1. An illustration of the difference in appearance between the water vole and the brown rat. Image credit: Swallowfield Fishing Club (2011).

1.3. Ecology

1.3.1. Diet and field signs

The water vole's diet is largely herbivorous, consisting of a range of grasses, sedges, reeds, rushes and other leafy riparian vegetation throughout the growing season (Jefferies *et al.*, 1989). Typical favoured summer food sources include greater tussock sedge (*Carex paniculata*), willowherb (*Epilobium spp.*), loosestrife (*Lythrum salicaria*) and meadowsweet (*Filipendula ulmaria*) (Dean *et al.,* 2016). Throughout winter, when the species reverts to a largely fossorial existence, a carbohydrate-rich diet consisting of the roots and bark of willow (*Salix spp.*), as well as the tubers and rhizomes of herbaceous plants (Stewart *et al.*, 2008).

Analysis of faecal matter has identified 227 different plant species (Strachan and Moorhouse, 2006), showing their aptitude for dietary generalism. However, the species has been known to prey upon aquatic invertebrates, immature amphibians, crayfish and small fish on an *ad hoc* basis, particularly by females during gestation (PTES, 2018).

Characteristic water vole field signs include feeding platforms close to the water's edge littered with plant stems cut at a 45-degree angle, as well as excavated and nibbled tubers (PTES, 2015). Furthermore, specific latrines containing green-brown tic tac-shaped droppings approximately 10 mm long and 4 mm wide (Woodroffe *et al.*, 1990) are easily identifiable on the bankside during breeding season (Dean *et al.*, 2016). Water voles are easily startled and often difficult to see in the field, however their presence is readily identifiable by the characteristic 'plop' sound made as they dive underwater for cover (Strachan and Moorhouse, 2006).

1.3.2. Reproduction

Breeding season is known to be between March and October, and an adult female will produce up to five litters per season of between five and eight pups each (PTES, 2018). The young remain with their mothers for approximately one month before leaving their home nest to disperse into their own range (PTES, 2018). Those born in July may reproduce in the autumn, however most will not reproduce until after the first winter (PTES, 2018). This is especially so of the Scottish variant, which reaches the minimum threshold weight for sexual maturity much later than its southern conspecifics (Gow, 2007).

The typical lifespan for a water vole in the wild is just five months, due to their high mortality as a result of in-fighting, flooding and predation (Forestry Commission, 2017). However, individuals have been known to survive up to two years in captivity (The Mammal Society, 2016).

1.4. Colonisation history and genetic variation

The water vole has a complex genetic make-up and within its UK range has been referred to as a 'Celtic-fringe' species. This alludes to the distinct mitochondrial DNA differentiation between English and Scottish conspecifics, delineated almost exactly across the national border (Brace *et al*., 2016). Brace *et al.* (2016) hypothesise that such a genetic division occurred as a result of two distinct postglacial colonisation events, with the Scottish variant migrating from Iberia across the – now-flooded – Dogger Bank some 28,000 years ago followed by a second wave from Eastern Europe 16,000 years later. This second wave displaced the earlier migrants in most places below the border, creating what is now known as the 'Celtic-fringe'. Because of this this, and as mentioned previously, Scottish water voles are phenotypically different from their cousins below the border, exhibiting smaller size and a much darker pelage.

1.5. Range

1.5.1 Distribution in Britain

The water vole is distributed across much of mainland Europe and into Britain (Shenbrot & Krasnov, 2005). Prior even to the Roman occupation of Britain, water voles were a common sight along rural waterways (Lovegrove, 2008), and by the Iron Age the species' population is thought to have been as many as 6.7 billion (Lymbery, 2018). **Fig. 3**, below highlights the historical extent for the species across Britain.

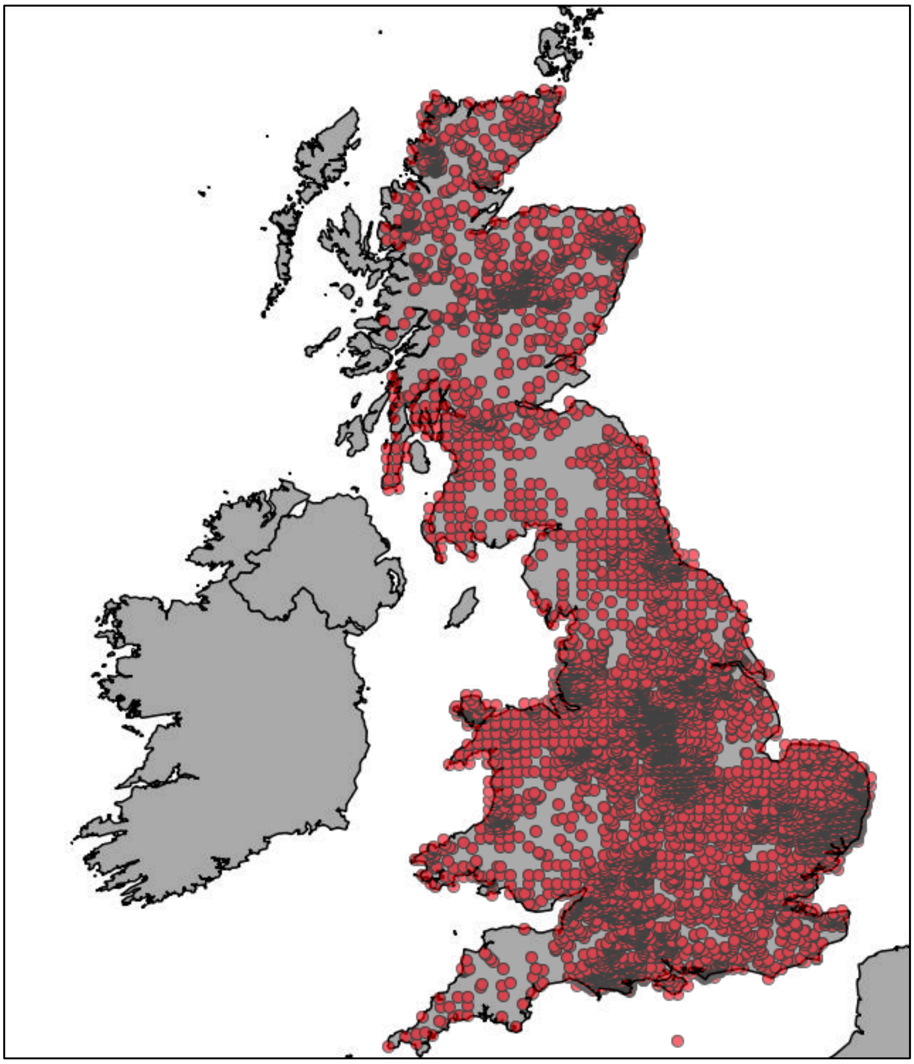

Figure 2. Recorded water vole distribution across the UK. Image credit: National Biodiversity Network (2017).

The majority of recordings are from lowland waterways rich with riparian and emergent vegetation (JNCC, 2010), however water voles can be found in habitats as diverse as reedbeds and ditches in upland moors (Aars *et al.*, 2001; Telfer *et al.*, 2001; JNCC, 2014). The species has also been documented to adapt to an entirely fossorial existence, persisting even in the non-aquatic urban grasslands of Glasgow's east end (Stewart *et al.*, 2017).

1.5.2. Distribution in Scotland

In Scotland, like much of the rest of Britain, lowland water voles have become marginalised as their habitats have succumbed to intensified agriculture and urbanisation. Such marginalisation is discussed in greater detail, below. As a result of the decline in lowland areas, much of Scotland's extant water vole populations are restricted to the smaller headwaters, moors and tributaries of upland rivers (SNH, 2018a), where they can thrive in the relative absence of habitat disturbance (Strachan and Moorhouse, 2006).

1.6. Species decline

Once common along British riverbanks, canals, drainage ditches and ponds, the water vole has endured both a rapid and profound decline over the past century. Indeed, the species has repeatedly been shown to be the fastest declining mammal in the UK (Barretto *et al.*, 1998; Telfer *et al.*, 2003; Strachan, 2004). It is estimated that since the Bronze age, water vole numbers in Great Britain have declined by 99.9 % (Jefferies, 2003), and over the past century alone the species has endured the most catastrophic population collapse of any mammal in the UK (SNH, 2014).

Although the evolutionary history of many mammalian species dictates that they undergo large, cyclical changes in population density, the water vole is not thought to be such a species (Jefferies *et al.*, 1989). Indeed, as an r-strategist, the species' high fecundity should more than account for natural predation levels (Meredith *et al.*, 2013). Therefore, the its decline in population as well as the rapid contraction of its range are indicative of debilitating pressures outwith the natural ecological cycle.

A series of national surveys between 1989 and 1998 found that nearly 70% of occupied sites surveyed in 1989 were abandoned by 1998 (Jefferies, 2003). Between 1989 and 1998, the population declined by some 88 %, from 7,294,000 to 875,000 across the UK (Jefferies, 2003). The Scottish water vole population comprises some 40 % of this (Raynor, 2005), the majority of which can be found in upland habitats.

The most recent national survey (2011-2015) conducted by the Wildlife Trusts highlights a 30 % decline in the water vole range over the past ten years alone (McGuire and Whitfield, 2017). The survey covers only England and Wales, omitting Scotland, and as such should be treated with caution when making inferences as to the state of Scottish water voles. The survey expresses confidence that despite conservation efforts over the past decade, water vole range is continuing to contract.

1.7. Threats to water voles

The threats to water voles are numerous, though it is thought that the introduction of American Mink (*Neovison vison*) in the 1920s for commercial fur farming, and their subsequent escape, proliferation and predation upon water voles is the main factor for the species' decline (Lawton and Woodroffe, 1991; Barretto *et al.*, 1998; Rushton *et al.*, 2000). Additionally, land use changes combined with ecologically insensitive modification of the riparian habitat have had a detrimental impact upon the species (Strachan and Moorhouse, 2006). These are of particular importance in the local context and will be discussed in greater detail below.

1.8. Legal status of water voles

Following decades of declining global biodiversity (Butchart *et al*., 2010), the United Nations 1992 Convention on Biological Diversity (CBD) was adopted by signatory parties to provide a legal framework by which to promote the conservation of biodiversity in the face of increased anthropogenic pressures (UN, 1992). Article 8 of the convention focuses on *in-situ* conservation, including the restoration of threatened species and habitats, as well as preventing the introduction and spread of invasive non-native species (INNS). INNS are reported to be at least partly responsible for 54 % of all known animal species extinctions over the past 400 years (EEA, 2012). In conjunction with the CBD the United Kingdom, as subject to European legislation, is party to Council Directive 92/43/EEC (the Habitats Directive). The Habitats Directive focuses on promoting biodiversity by legally obligating member states to ensure robust protection for those species and habitats of European importance (JNCC, 2014). While the Habitats Directive aims to protect species and habitats determined to be threated at a Europe-wide level, there is little provision for regionally or locally threatened examples. Thus member states must be responsible for the conservation of those species and habitats determined to be of local importance, which are not accounted for under the Habitats Directive.

Commissioned in the wake of the CBD, the UK Biological Diversity Action Plan (UKBAP) was created to extend upon the positive outcomes of the CBD and to work towards compliance with the Habitats Directive by describing the biological resources within the UK and setting out detailed guidelines to effect the conservation of these resources (JNCC, 2016). At its heart is a list of priority species and habitats at particular risk of overexploitation, decline or degradation, and a series of action plans and goals for each. Despite being classified least concern by the International Union for Conservation of Nature (IUCN) (Batsaikhan *et al.*, 2017), the water vole has experienced significant range contraction and decline within Britain. Thus the species is listed as a UKBAP Priority Species for conservation (JNCC, 2016).

While in England and Wales the water vole is afforded full protection under Schedule 5 of the Wildlife and Countryside Act 1981 (as amended), in Scotland the species is only protected with respect to its habitat under section 9(4) of the same Schedule (UK Government, 2017). As such, in Scotland the Act legislates against the intentional or reckless damage or destruction of any place which water voles use for shelter. Additionally, it is an offence to disturb any animal when occupying such a place or obstructing egress from and ingress to such a place (UK Government, 2017). The fifth Quinquennial Review (QQR) of Schedules 5 and 8 of the Wildlife and Countryside Act 1981 recommended the species be afforded full protection in Scotland in line with legislation across the rest of the UK (JNCC, 2008). In 2012, after a consultation period following the publication of the fifth QQR, the Scottish Government offered its support to this recommendation with a view to the species subsequently receiving full legal protection (The Scottish Government, 2012). As of April 2018, full protection for the species is yet to be awarded (SNH, 2018b).

1.9. Local context

The Dumfries and Galloway Local Biodiversity Action Plan (LBAP) highlights the need to conserve populations of characteristic species in the area with a view to improving overall biodiversity (Norman *et al.*, 2009). The current status of water voles in Dumfries and Galloway is unclear (Norman *et al.*, 2009) and is one such characteristic species afforded special attention within the LBAP. Whilst the Dumfries and Galloway County Mammal Report (2016) asserts the species population to be stable within the region, fewer than 50 sightings have been recorded per year. Additionally, more than half of the hectads within the Dumfries and Galloway contain no recordings since 2000 (Riches, 2016). It should be noted that a lack of recordings within these hectads is not necessarily indicative of the species being absent, but rather could represent a lack of surveying herein. Indeed, it is thought that upland areas, such as the Lowther Hills where Ae Forest is situated, may be the last refuge for the species (Aars *et al.*, 2001). However, due to the difficult nature of the upland terrain, such areas are also the most challenging to survey accurately.

1.9.1. The River Annan Catchment.

The Annan catchment encompasses approximately 950 km^2 (RADSFB, 2011) of river basin from the source of the river Annan near Moffat, through its many tributaries to the mouth of the river at Annan on the Solway Coast (see **Fig. 4**).

Figure 3. Map of the Annan DSFB Catchment, with Water of Ae highlighted. Adapted from RADSFB (2011).

The catchment is managed by RAT on behalf of the River Annan District Salmon Fisheries Board (RADSFB). RAT is a charitable organisation founded in 2010 with the broad aim of conserving the environment of the River Annan catchment (RAT, 2012). The trust’s remit extends to conducting research into, and the management of, native freshwater fish and their environments, as well as providing education on the river’s wider importance (RAT, 2012).

1.9.2. Water of Ae

The Water of Ae is a subset of the Annan Catchment, and covers 146 km^2 (RADSFB, 2011), incorporating upland moor, farmland, plantation forest and urban areas (CEH, 2012). One stretch of the Water of Ae, downstream of Goukstane Burn, has been designated 'bad' environmental status by SEPA (see **Fig. 5**), the only stretch designated such within the entire Annan Catchment (SEPA, 2016). Conducting an analysis of where improvements could be made to enhance water vole habitat may ultimately lead to the restoration of the watercourse to an acceptable ecological condition.

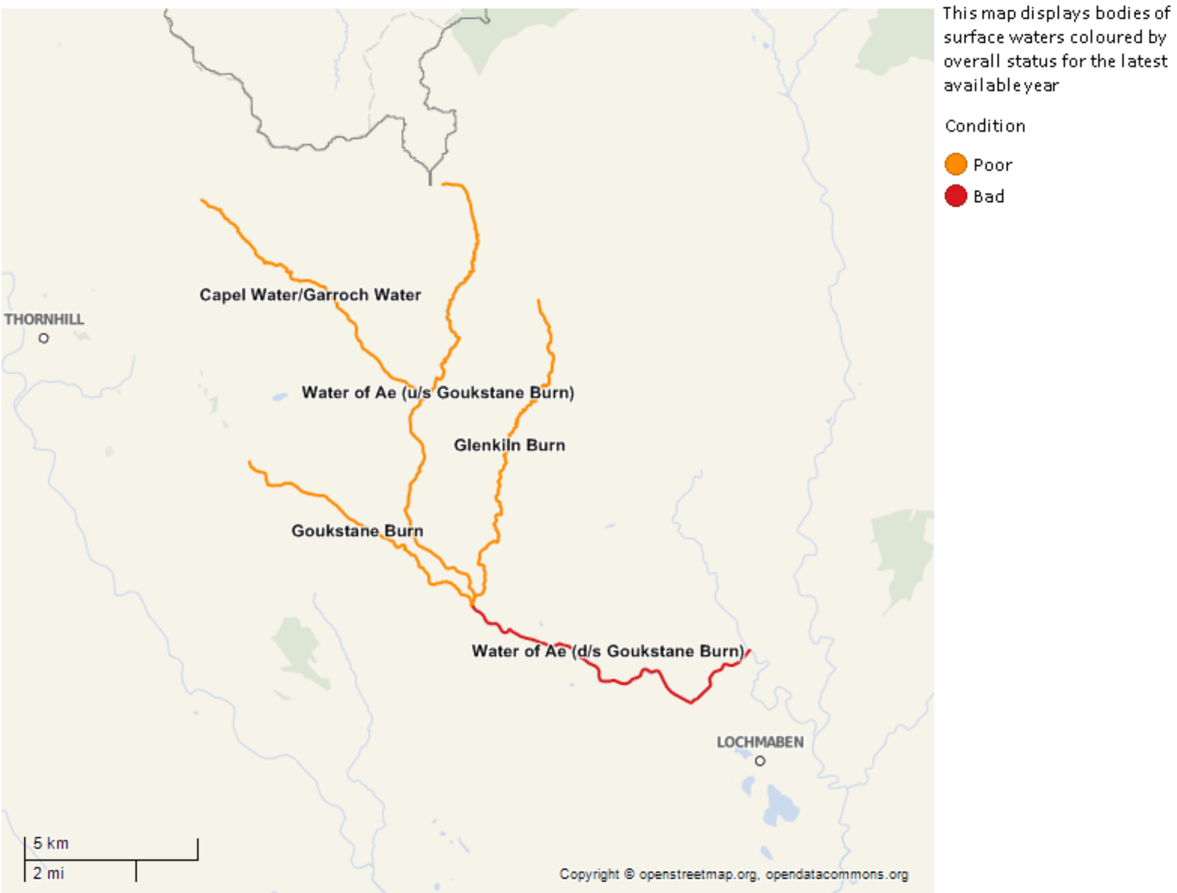

Figure 4. Overall status of surface waters within the Water of Ae Catchment (SEPA, 2016).

1.9.3. Ae Forest

This study focuses on Ae forest, more than 10,000 hectares (FCS, 2011) of predominantly coniferous upland plantation woodland in Dumfries and Galloway, some 15 kilometres north of Dumfries. After initial planting in 1929 the forest is now into its third rotation and is managed by Forest Enterprise Scotland (FES) for commercial timber production, electricity generation through the Harestanes wind farm (operated by Scottish Power) and varied recreation

(Duncan, 2017). The genetic makeup of the forest is largely monocultural, dominated by coupes of sitka spruce (*Picea sitchensis*) and, to a lesser extent, small stands of Japanese larch (*Larix kaempferi*) and Norway spruce (*Picea abies*) (Duncan, 2017). Riparian corridors are relatively scarce within the forest, comprising less than 5 % of individual coupes by area (Duncan, 2017). Tree species within these corridors consist of sparsely planted native broadleaves including willow (*Salix spp*.), birch (*Betula spp.*) and oak (*Quercus spp.*) (Duncan, 2017). The roots and bark of such species are excellent winter food sources for water voles (Strachan and Moorhouse, 2006).

The sporulating pathogen *Phytophthora ramorum* poses a significant threat to Japanese larch trees and has been identified within Ae Forest (Duncan, 2017). The pathogen has the potential to cause the widespread mortality of larch and other tree species, and hence substantial commercial and ecological losses (Forestry Commission, 2018). The threat of spread of *P. ramorum* has informed future plantation planning within the forest (Duncan, 2017).

While Japanese larch currently only comprises approximately 10 % of UK forest by area (Tubby *et al.*, 2017), it has an important role in supporting forest biodiversity. As one of the few coniferous trees to shed its needles in autumn, exfoliated stands of larch increase light penetration through the forest canopy, thus promoting the growth of a vegetated understorey (Fang *et al.*, 2014). It is estimated that by 2031 there will be a 50 % decline in standing larch within commercial forests as a result of pre-emptive felling to reduce the threat posed by the spread of *P. ramorum* (Forestry Commission Scotland, 2014).

As part of the Ae Forest Composite Land Management plan 2017-2027, no larch will be planted within the next ten years, reducing proportional cover by area to virtually 0 % (Duncan, 2017). Replacement by the more resilient Sitka spruce will result in almost universally closed coupe canopies throughout the year and may detrimentally impact the ability for understorey vegetation, and any co-dependent species, to thrive (Fang *et al.*, 2014).

Water voles have scarcely been reported within the River Annan catchment in recent years (RAT, 2010), and the last official recording within Ae Forest was in 2014 (SWSEIC, 2018). Considering the state of the species across Great Britain, more research should be conducted into the implications of a local decline.

2. Aims and Objectives

The research has been conducted as part of an honours year project of the BSc Environmental Science and Sustainability course at the University of Glasgow, Crichton Campus. As part of its commitment to promoting the conservation of biodiversity and the riparian environment within the Annan Catchment, RAT (in partnership with the University of Glasgow School of Interdisciplinary Studies) has devised a series of studies aimed at providing important information related to ecological restoration. This study has been devised to establish water vole habitat suitability within Ae Forest. The specific aims – posed as questions – are as follows and will be addressed in turn, below.

1. Is there evidence of water vole activity within Ae Forest?
2. What specific habitat conditions are required for water voles and do these exist within Ae Forest?
3. What are the key threats to water voles within Ae Forest?
4. What land management approaches are required to encourage and sustain a water vole population within Ae Forest? Do these conflict with existing management approaches?

The objectives of this study are to add to the knowledge on the state of water voles within the region, focusing on the capacity for the species to thrive along the county's waterways. Findings and subsequent recommendations will inform RAT on the state of riparian habitats within Ae Forest as well as to provide a baseline from which future conservation and management decisions can be made, both at local and wider-catchment scales.

4. Methodology

4.1. Overview

The study consists of a mixed methods approach to data collection. Research questions **1** and **2** utilise desk-based investigation methods in conjunction with a habitat field survey. Questions **3** and **4** rely upon desk-based investigation methods. The field survey methodology will be outlined first, followed by desk-based investigation techniques.

4.2. Review of previous study

In the research phase of the study, it emerged that a previous water vole habitat suitability survey had been conducted within the forest. An assessment commissioned by Forestry Commission Scotland (FCS) between September and October 2011 found that Ae Forest was largely unsuited to sustaining a viable population of water voles, due to its steep topography and overshadowing of the water courses by dense plantation woodland (Spray and Duffy, 2011). The assessment recorded no water voles or other fauna species during the survey. Five sites were deemed suitable for water vole habitation, due to their relatively slow flow and good bankside vegetation, however these five sites all lie outwith the Water of Ae catchment, to the northeast of the forest (Spray and Duffy, 2011).

The report gives no indication as to any specific surveying methodology used. In order to remain consistent with other national water vole habitat surveys, this study implemented the field methodology adapted from '*A Method for Assessing Water Vole Habitat Suitability'* (Harris *et al.*, 2009). This served to provide a robust and comprehensive impression of the suitability of multiple sections of waterway within the forest, which can be compared to other potential habitats across the country.

4.3. Habitat field survey

4.3.1. Study site

The study site encompasses predetermined areas of Ae Forest within the Water of Ae catchment. **Fig. 6**, below, highlights the extent of water watercourses contained both within Ae Forest and the Water of Ae catchment.

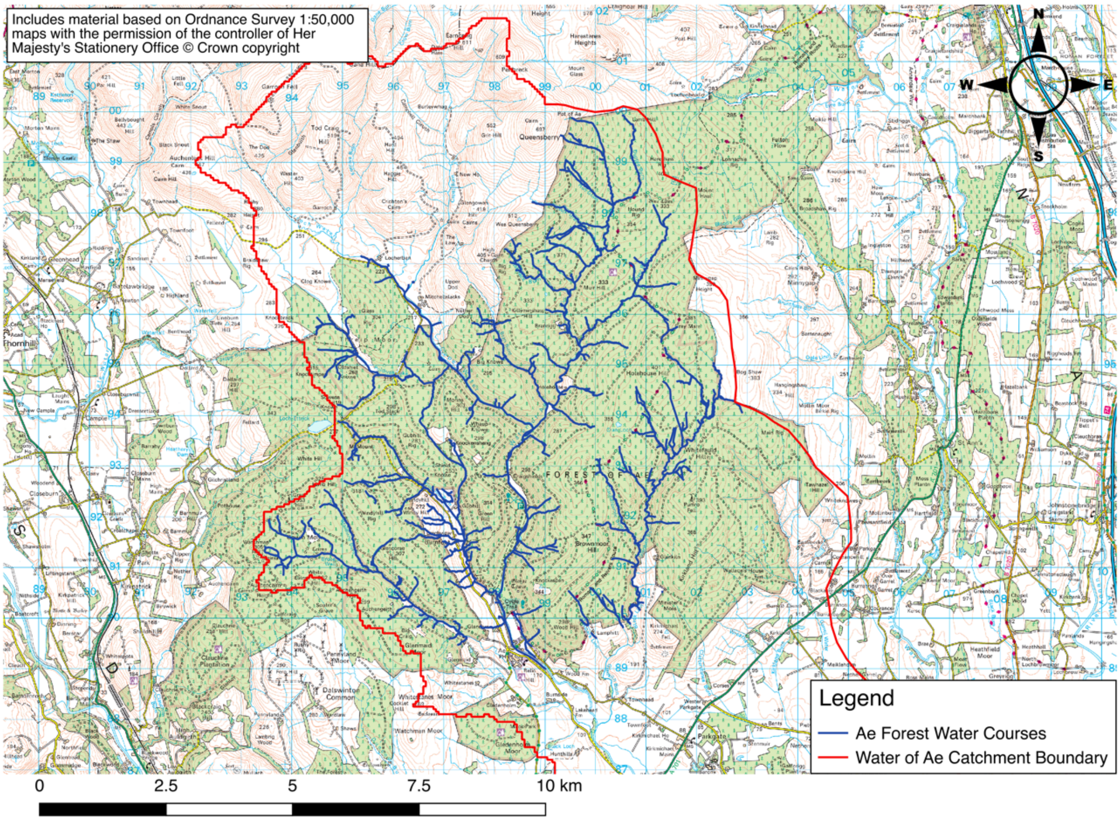

Figure 5. Overview of Ae Forest within the Water of Ae catchment. Adapted from Ordnance Survey (2018).

4.3.2. Experimental design and sampling strategy

An initial map of the forest and its waterways was constructed using Quantum Geographic Information System (QGIS) software. 1:25,000 scale raster tiles were downloaded from the Ordnance Survey (OS) OpenData repository covering the following 10x10 km grids: NX98, NX99, NY09. These covered the entirety of the section of the forest which lies within the Water of Ae Catchment. UK digital river network vector data were downloaded from the Centre for Ecology and Hydrology (CEH) database, and relevant watercourse sections within Ae forest were overlaid onto the OS tiles within QGIS.

The methodology outlined by Harris *et al*. (2009) requires each length of appropriate waterway and any other permanent water body to be surveyed within designated 1 km^2 sample plots. In order to avoid the experimental bias of selecting seemingly more appropriate or accessible sections of water course, sample plots were designated using the ‘random points along a line’ function within QGIS. The 1 km^2 OS grid square into which each point fell denoted the boundaries of each sample plot.

To avoid any overlap of data, each randomly generated point was programmed to be at least 1.5 km away from any other point in the forest. As demonstrated in **Fig. 7**, below, 1.41 km is the maximum possible distance between two points within a single 1 km^2 OS grid square.

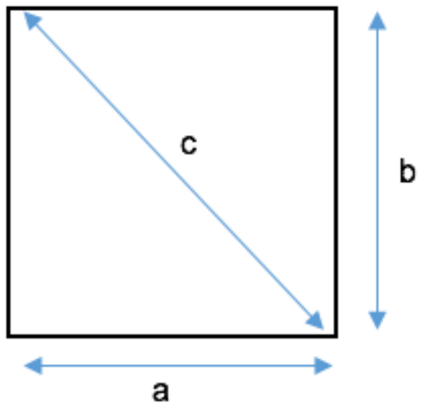

Figure 6. Calculating distances between randomly generated points.

Rearranging Pythagoras' theorem for c gives $c = \sqrt{a^2 + b^2}$. Where a and b are both equal to 1 km, we find the maximum distance across a sample plot to be 1.41 km. This was rounded up to 1.5 km for the purposes of inputting conditions into the QGIS random point generator. Additionally, this meant that surveying adjacent grid squares would be avoided, thus giving a wider range across the forest.

In total, six sample plots were selected across the forest watercourse network (**Table 1**). A map of these selections in the context of Ae Forest can be seen in **Fig. 8** below. It was decided that given time constraints and poor weather, between five and ten sample plots would be the maximum number conceivable achievable for this study. Originally, seven plots were chosen, however, persistent poor weather and access issues meant that this seventh plot had to be foregone.

Plot number	OS grid reference (1 km^2)
1	NY0192
2	NX9890
3	NX9690
4	NX9592
5	NX9894
6	NX9995

Table 1. Field survey sample plot grid references.

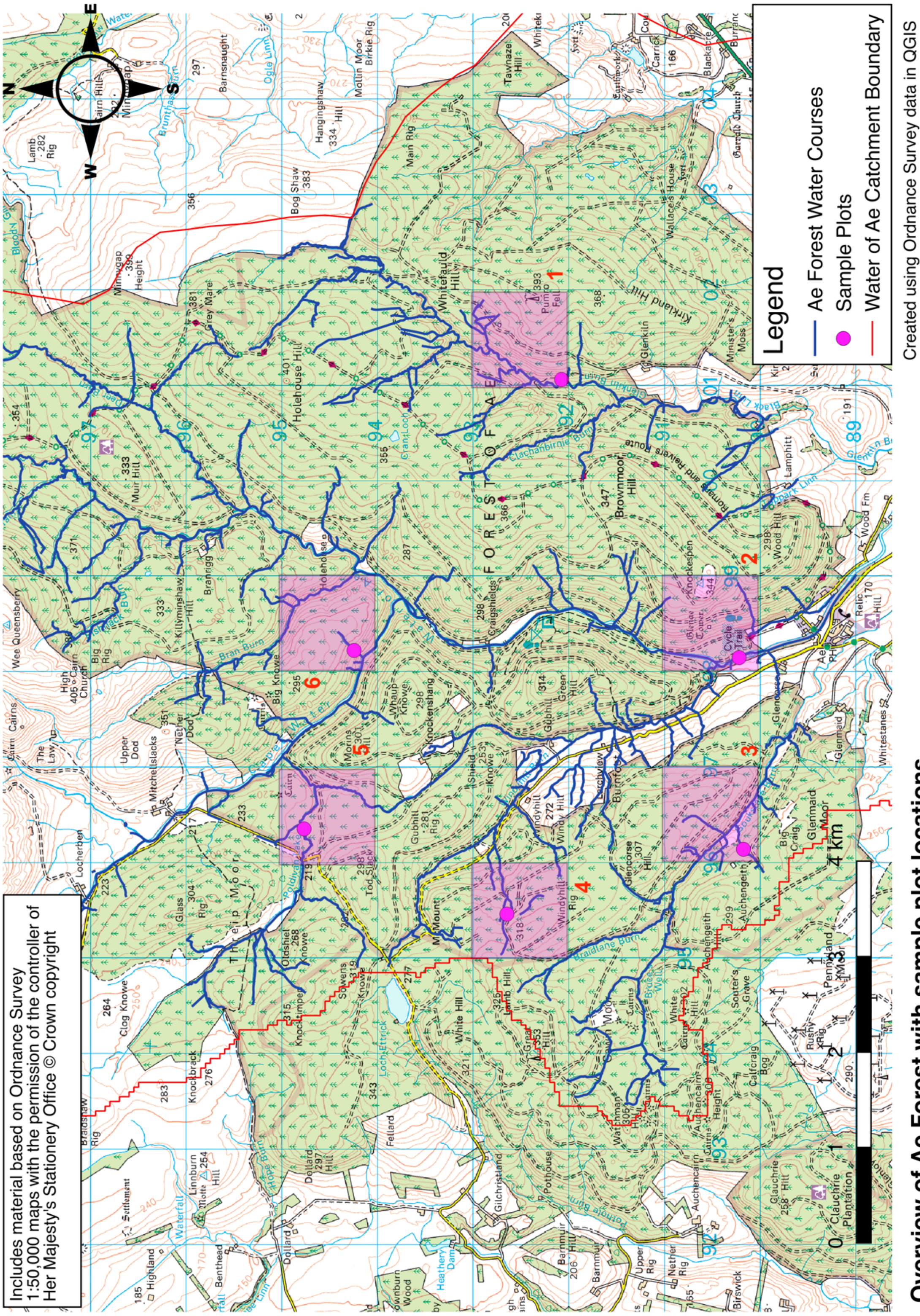

Figure 7. Overview of Ae Forest with highlighted sample plot locations. Adapted from Ordnance Survey (2018).

4.3.3. Survey methodology

Water vole habitat surveys should be undertaken between March and September, when riparian plant life is at is most abundant and the water table low enough to permit efficient study. This coincides with the water vole breeding season when they are most active and field signs most visible. Outwith this window, the seasonal dieback of plants easily identifiable as dietary constituents makes surveying more difficult.

The methodology outlined by Harris *et al.* (2009) evaluates habitat suitability within each sample plot. Linear watercourses were appropriately divided into stretches according to tributary or habitat type. Each stretch was surveyed individually, with the stretch number and direction of survey clearly indicated on a 1 km^2 OS map. Thus there can be degrees of habitat suitability within a single sample plot.

4.3.4. Sample parameters

The survey, conducted on foot along one side of each stretch, assessed ten known habitat parameters favoured by water voles. The water vole habitat suitability field sheet highlights the parameters assessed (see **Table 2**).

Each parameter was scored for either presence (1) or absence (0). A field sheet was filled in for each sample plot. The combined score out of 10 ultimately indicated the habitat suitability designation for each stretch (see **Table 3**). An in-depth guide to interpreting each parameter score is included in **Appendix A**.

Furthermore, notes on potential water vole field signs, adjacent land use and the physical characteristics of the water body within each stretch were taken for later reference. This information can be found in **Appendix C**.

WATER VOLE HABITAT SUITABILITY ASSESSMENT										
BACKGROUND INFORMATION						**Date**				
Site Location						**Grid Square Number**				
HABITAT SUITABILITY (Score 1 if feature present)	**Section number as indicated on map**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
[a] Well developed (>60%) bankside and aquatic vegetation that provides suitable food and cover										
[b] A good variety of food plants including favoured plants and winter food sources										
[c] Suitable refuge areas above extremes in water levels										
[d] Soft, earth banks suitable for burrowing (30° to 60° slope)										
[e] Water permanently present (water level stable and does not dry up)										
[f] Open water available for swimming										
[g] Ledge of berm present at or close to water level										
[h] Lack or damage or erosion to the banks										
[i] Slow flowing current or static water										
[j] Invasive non-native plant species absent										
HABITAT ASSESSMENT SCORE (Total score of features present)										
Habitat										
Bordering land use										
Dominant vegetation type										
Channel substrate										
Other Wildlife Records										

Table 2. Water vole habitat suitability assessment. Adapted from Harris *et al.* (2009).

Habitat Suitability Matrix		
Parameter score	**Suitability for water voles**	**Notes**
<3	Unsuitable	Water voles absent.
3-6	Sub-optimal	Occasional field signs for water vole.
7-10	Optimal	Water voles usually present.

Table 3. Habitat suitability matrix. Adapted from Harris *et al.* (2009).

4.3.5. Preparation and data collection

Prior to conducting the survey, permission was sought from FCS, which owns the land and forestry assets. The permission afforded vehicular access rights to and from the forest and survey sites via forest tracks and paths. An initial walkover of potential sample plots was conducted in November 2017 with Chris Stones of the RAT. This served to gain familiarity with the application of survey techniques and of the forest terrain. The forest's varied topography made access to the rivers and streams challenging; sections of steep hillside and areas of boggy floodplain meant careful planning was essential before conducting the field survey. Permission was initially granted until the end of January 2018, although this had to be extended for a month due to poor weather impeding survey progress. Out of necessity, this survey was conducted between December 2017 and February 2018, outside the seasonal surveying window (Harris *et al.*, 2009). The implications of this are discussed in below.

4.3.6. Data interpretation

After collection, the survey data for all stretches within each of the six sample plots were collated and presented in table form for simple interpretation. Given the nature of data collected as well as the relatively small sample sizes, it was unnecessary to conduct any descriptive or inferential statistical analysis. Thus the data are presented in their condensed form below and in their raw form in **Appendix B**.

4.4. Desk-based investigation

For each of the four research questions it was necessary to conduct desk-based investigation methods to complement the field survey. In researching each of the questions, access to relevant literature was granted through a range of digital journal repositories such as Elsevier, JSTOR, Web of Science and Wiley Online Library. Additionally, physical publications, such as Dumfries and Galloway LBAP and various ecology handbooks, were be consulted where appropriate. Personal communication with a range of professionals was invaluable for accessing detailed information on species records within national and Dumfries and Galloway contexts.

1. Is there evidence of water vole activity within Ae Forest?

Up-to-date data on vole activity within the Water of Ae Catchment was collected from Andy Riches (County Mammal Recorder) and from Mark Pollitt at the Southwest Scotland Environmental Information Centre (SWSEIC). These records were used to construct a dataset highlighting sections of the Forest within the Ae Catchment where water voles have historically and recently been identified and recorded.

2. What specific habitat conditions are required for water voles and do these exist within Ae Forest?

Prior to conducting the field survey, a desk-based study was undertaken to assess general water vole habitat requirements. This research focused on fluvial morphology (including gradient, flow rate, river width), dietary needs, availability of riparian vegetation, adjacent land use and predator-prey interactions. Relevant literature was consulted using the physical and digital means listed above. These were cross-referenced with data gathered using EDINA Digimap Ordnance Survey (OS) mapping tools as well as hydrological data from CEH. These were used to identify those sections of the catchment where fluvial geomorphology could be considered favourable to sustain water vole populations.

3. What are the key threats to water voles within Ae Forest?

Detailed information on universal threats to the species were amassed in consultation with RAT, and through a thorough review of relevant literature. These universal threats were cross-referenced with local data on riparian land use and prevalence of predators (primarily *Neovison vison*). Local data were acquired through conversation with the relevant stakeholders such as Dumfries and Galloway Council, FCS, RAT and SWSEIC.

4. What land management approaches are required to encourage and sustain a water vole population within Ae Forest? Do these conflict with existing management approaches?

This question was addressed in a similar manner, focusing on riparian land management for water voles in the commercial forestry context. A range of publicly available information on forestry management, including The Ae Forest Composite Land Management Plan 2017-2017, was used as a reference point for present and future approaches.

5. Is there evidence of water vole activity within Ae Forest?

Water voles demonstrate a range of characteristic field signs which allude to their presence in a given habitat. Under normal circumstances these field signs are easily identifiable, even to a relatively inexperienced surveyor. Such field signs include bankside burrow entrances, feeding stations, latrines and water voles (Strachan and Moorhouse, 2006). However, in upland areas rivers and streams tend to be more difficult to survey due to their relative narrowness combined with unforgiving terrain (Derbyshire Wildlife Trust, 2004).

In order to find physical evidence of water vole activity, a presence-absence survey should be conducted. However, due to the species' reversion to a largely subterranean existence during the colder months, surveying for water voles should take place between mid-April and September, when they are most active (Strachan and Moorhouse, 2006). The allocation and subsequent realisation of this project was such that a field survey was unfeasible during this time. Therefore, key habitat conditions will be used as a proxy by which to both infer where water vole activity is likely to be greatest and to serve as a guide by which to conduct future surveys in the catchment.

The habitat field survey conducted for question **2** highlighted potential potential water vole field signs.

Plate 1. Potential water vole burrow entrance. Note grazed 'lawn' and droppings.

Plate 1 was taken at stretch 8 of sample plot 2, and potentially shows the grazed 'lawn' and droppings indicative of a water vole burrow entrance.

Plate 2. Potential water vole feeding sign. Note 45-degree bite mark on stem.

Plate 2 was taken along stretch 6 of sample plot 3, and shows a partially chewed stem exhibiting the 45-degree bite marks characteristic of water voles.

6. What specific habitat conditions are required for water voles and do these exist within Ae Forest?

The water vole is a predominantly riparian species known to inhabit the soft, friable banks of slow-flowing water bodies (Richards *et al.,* 2014). Favoured aquatic habitats include streams, rivers, ponds, lakes, ditches, and upland marshes (Raynor, 2005; PTES, 2018). Habitat suitability is primarily a function of the preponderance of lush, bankside and emergent vegetation for food and cover as well as availability of slow-flowing water through which to swim and evade predation (Barreto, 1998; Strachan and Moorhouse, 2006).

Dispersing adults create complex bankside burrow systems, which often have multiple entrances both above and below the water surface as well as up to 3 m back from the water's edge (Dean *et al.*, 2016). **Fig. 8** shows the cross-section of a typical bankside burrow.

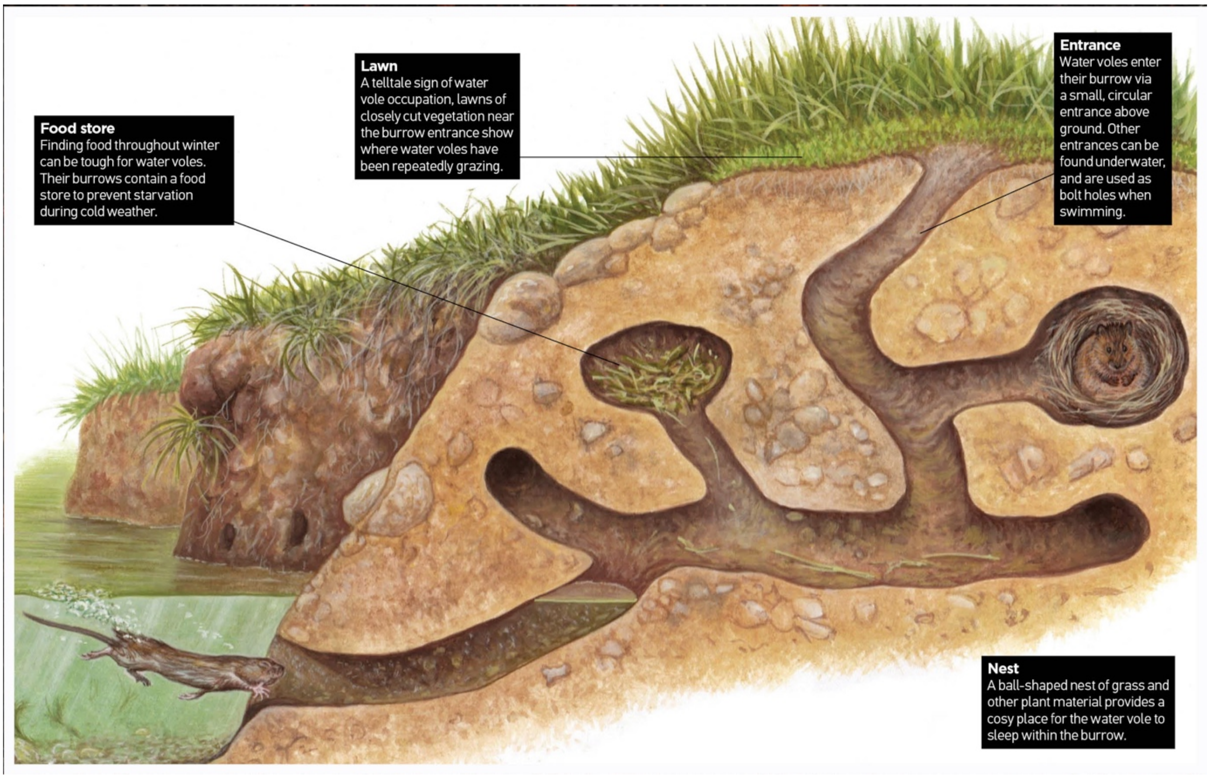

Figure 8. A cross-section view of a typical bankside water vole burrow. Image credit: Animal Answers (2018).

Fig. 8 highlights the indicative 'lawn' of closely cut grass around the entrance to the burrow, which can be used to easily identify the presence of water voles (Strachan and Moorhouse, 2006). Burrow entrances are usually 4-8 cm in diameter, and slightly wider than they are tall (PTES, 2015). An individual typically forms a linear home range up to 300 m along a watercourse, which it will fiercely defend from rival conspecifics (Rushton *et al.*, 2000).

Perhaps surprisingly, water voles are ill-adapted to aquatic life. Although they are able to dive well to avoid predation, they are not strong swimmers (SWT, 2018). Unlike other aquatic mammals such as the Eurasian otter (*Lutra lutra*), water voles do not have webbed feet, are unable to use their tail as a rudder and their fur does not produce an oily secretion to prevent it becoming waterlogged (Meredith *et al.*, 2013). Because of this, it is not uncommon for water voles to drown when forced to remain in the water for extended periods or for entire nesting burrows to be washed out during episodes of high flow or flooding (Lawton and Woodroffe, 1991). Consequently, optimal habitat conditions require minimal seasonal variability in water level, to ensure their subterranean bankside burrows remain intact. In fact, such is the species' relative lack of adaptation to aquatic life, that in continental Europe – and parts of Scotland – they occupy exclusively terrestrial habitats, isolated from any focal aquatic environment (Batsaikhan *et al.*, 2016; Stewart *et al.*, 2017).

While dense and diverse bankside vegetation is preferable, tightly packed woody bankside plants and trees promote overshadowing which precludes the vegetative growth necessary to sustain a water vole colony. Furthermore, in upland areas relatively narrow stretches of water, typically less than 3 m in width (Field, 2009), are preferred to reduce visibility from predators.

Relatively deep bodies of water, around 50 cm, enable submersion as a means of predator deterrent and escape (Field, 2009). Invasive non-native plants such as Himalayan balsam (*Impatiens glandulifera*) are detrimental to water vole success as they compete for space with the native plants which make up much of the water vole's diet (Strachan and Moorhouse, 2006). Thus suitable water vole habitat must be absent of invasive species.

6.1 Field survey results

Results from the habitat suitability field survey found that 40 of the 42 stretches assessed were classified as exhibiting 'optimal' conditions. Two stretches were assessed to contain 'sub-optimal' habitat. No stretches were classified 'unsuitable'.

6.1.1. Sample plot 1 – NY0192

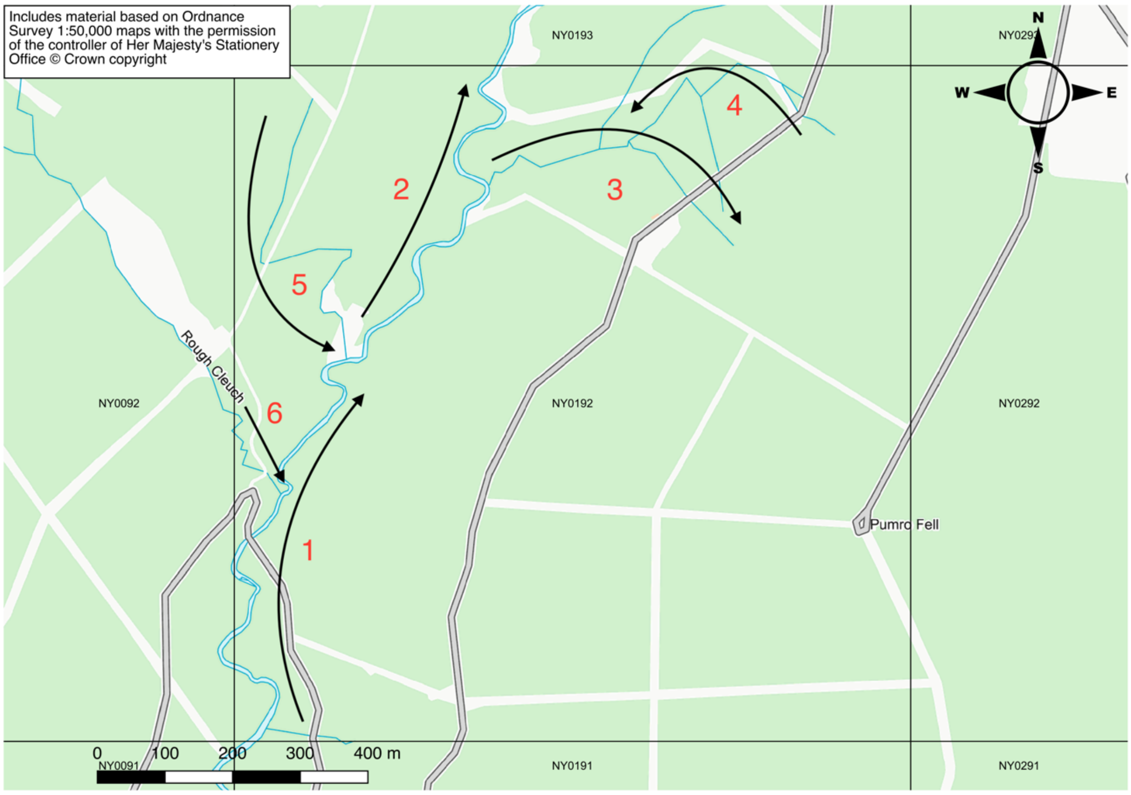

Figure 9. Overview of sample plot 1 with section numbers and direction of survey indicated. Adapted from Ordnance Survey (2018).

Habitat suitability score									
Sample plot 1 – NY0192									
Stretch	1	2	3	4	5	6	7	8	9
Suitability	8	9	9	9	7	5	-	-	-

Table 4. Habitat suitability score for each section within sample plot 1 – NY0192

All stretches within this sample plot, with the exception of stretch 6, were classified ‘optimal’ for water vole habitat suitability. Stretch 6 was classified ‘sub-optimal’ due to a combination of its fast current, lack of appropriate bankside berm and a lack of permanently present water for swimming. Adjacent land use included coniferous and mixed broadleaf woodland.

6.1.2. Sample plot 2 – NX9890

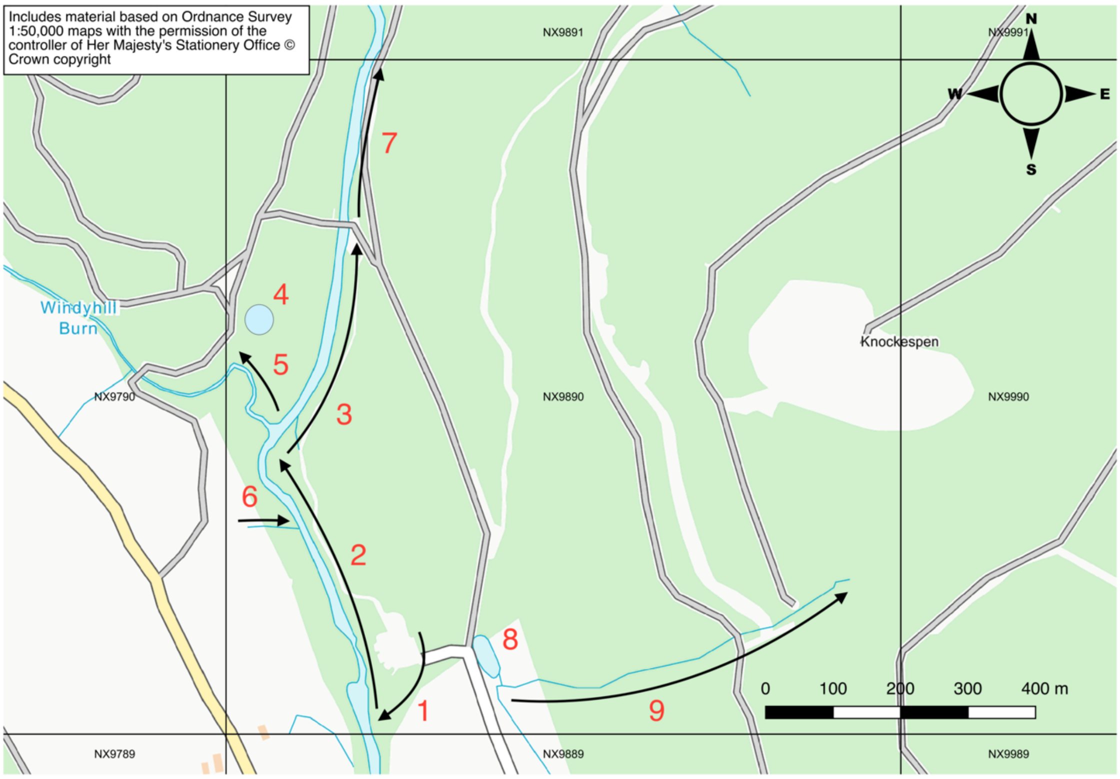

Figure 10. Overview of sample plot 2 with section numbers and direction of survey indicated. Adapted from Ordnance Survey (2018).

Habitat suitability score									
Sample plot 2 – NX9890									
Stretch	1	2	3	4	5	6	7	8	9
Suitability	8	8	8	8	9	8	8	10	9

Table 5. Habitat suitability score for each section within sample plot 2 – NX9890.

All stretches within this sample plot were classified 'optimal' for water vole habitat suitability. Adjacent land use included coniferous woodland, mixed broadleaf woodland, grassland and grazed land. Evidence of potential water vole activity was documented at stretch 8, in the form of bankside burrows and droppings (see **Plate 1**).

6.1.3. Sample plot 3 – NX9690

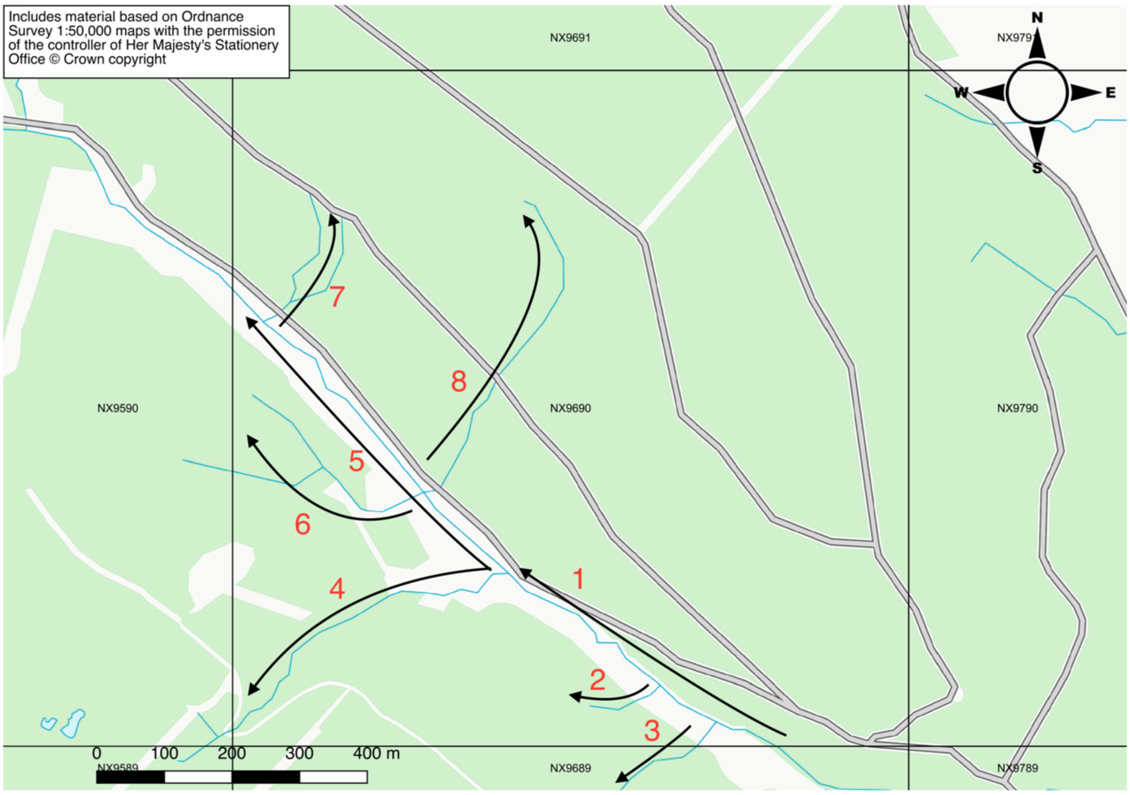

Figure 11. Overview of sample plot 3 with section numbers and direction of survey indicated. Adapted from Ordnance Survey (2018).

Habitat suitability score									
Sample plot 3 – NX9690									
Stretch	1	2	3	4	5	6	7	8	9
Suitability	9	8	8	8	9	10	7	6	-

Table 6. Habitat suitability score for each section within sample plot 3 – NX9690.

All stretches within this sample plot, with the exception of stretch 8, were classified 'optimal' for water vole habitat suitability. Stretch 8 was classified 'sub-optimal' due to its fast current, lack of bankside and emergent vegetation, and a dearth of readily available winter food sources. Adjacent land use included coniferous woodland, mixed broadleaf woodland, and heath. Evidence of potential water vole activity was documented along stretch 6, in the form of grazed vegetation (see **Plate 2**).

6.1.4. Sample plot 4 – NX9592

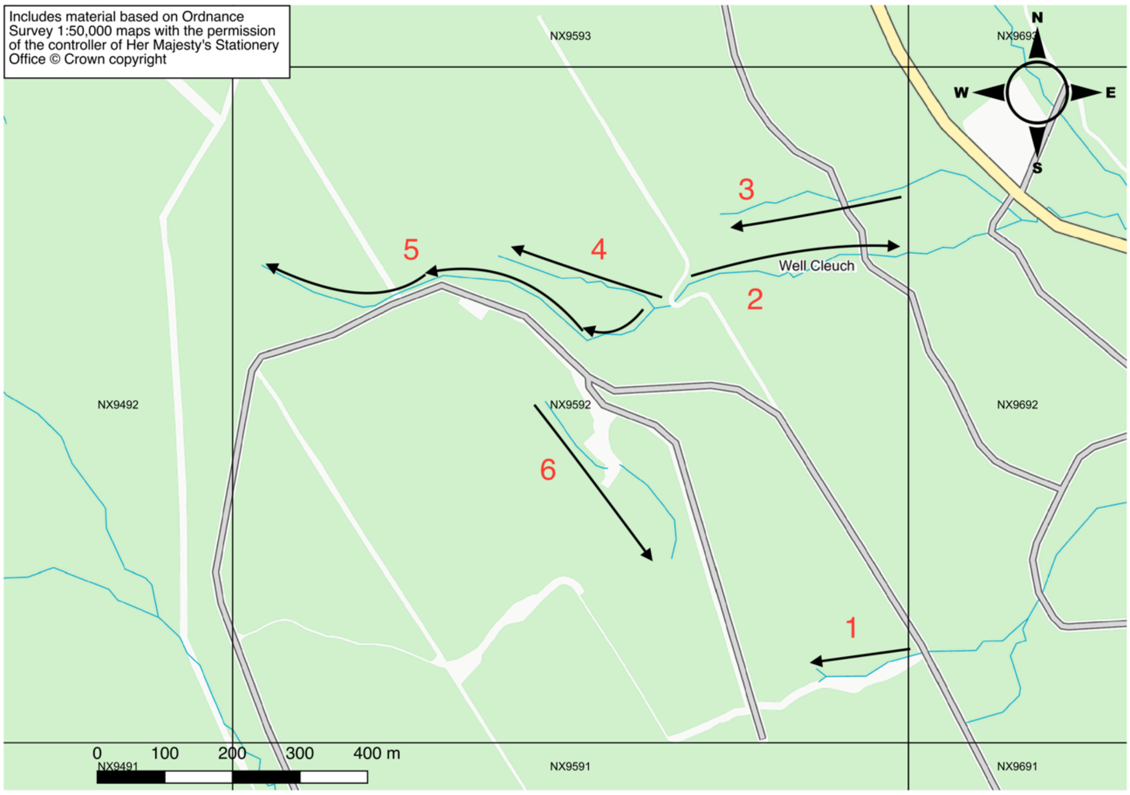

Figure 12. Overview of sample plot 4 with section numbers and direction of survey indicated. Adapted from Ordnance Survey (2018).

Habitat suitability score									
Sample plot 4 – NX9592									
Stretch	1	2	3	4	5	6	7	8	9
Suitability	8	9	10	10	10	9	-	-	-

Table 7. Habitat suitability score for each section within sample plot 4 – NX9592.

All stretches within this sample plot were classified ‘optimal’ for water vole habitat suitability. Adjacent land use included coniferous woodland, mixed broadleaf woodland, peat bog and heath.

6.1.5. Sample plot 5 – NX9694

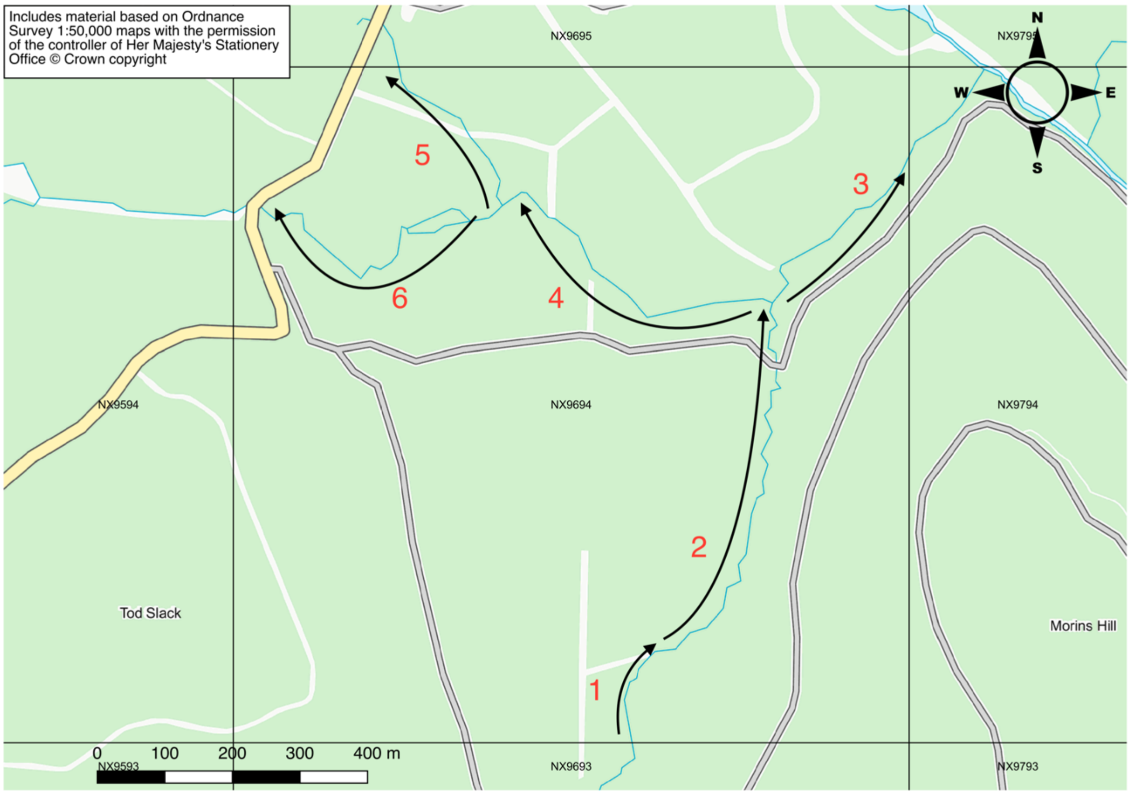

Figure 13. Overview of sample plot 5 with section numbers and direction of survey indicated. Adapted from Ordnance Survey (2018).

Habitat suitability score									
Sample plot 5 – NX9694									
Stretch	1	2	3	4	5	6	7	8	9
Suitability	9	10	9	9	9	9	-	-	-

Table 8. Habitat suitability score for each section within sample plot 5 – NX9694.

All stretches within this sample plot were classified 'optimal' for water vole habitat suitability. Adjacent land use included coniferous woodland, mixed broadleaf woodland, peat bog and heath.

6.1.6. Sample plot 6 – NX9894

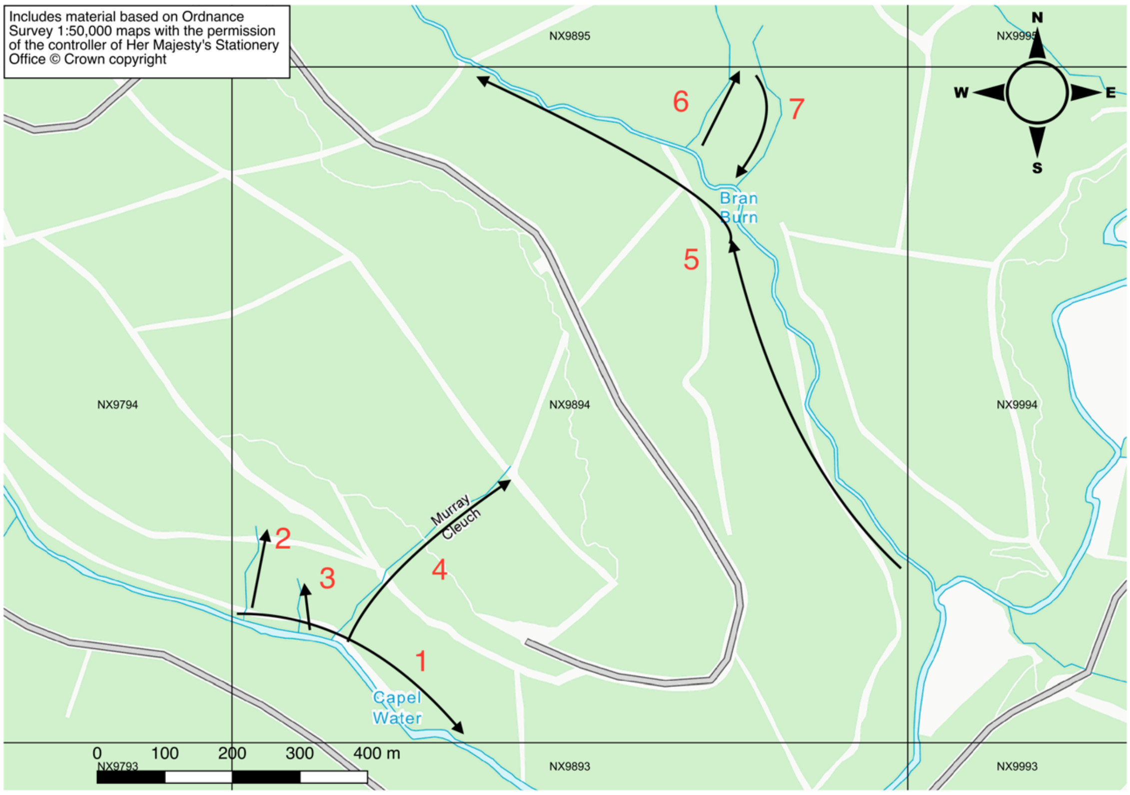

Figure 14. Overview of sample plot 6 with section numbers and direction of survey indicated. Adapted from Ordnance Survey (2018).

Habitat suitability score									
Sample plot 6 – NX9894									
Stretch	1	2	3	4	5	6	7	8	9
Suitability	9	7	7	8	9	9	9	-	-

Table 9. Habitat suitability score for each section within sample plot 6 – NX9894.

All stretches within this sample plot were classified 'optimal' for water vole habitat suitability. Adjacent land use included coniferous and mix broadleaf woodland.

6.2. Discussion and recommendations

The survey results suggest that a significant majority (95 %) of the total number of stretches assessed exhibit optimal water vole habitat suitability. There are, however, a number of limitations both with the habitat assessment itself and with the practical implementation of the methodology. As such, the results presented here should be treated with caution.

6.2.1. Ambiguity of parameter terms

Despite making use of the detailed guide to parameter designation (**Appendix A**), interpretation of each was inevitably subjective. Without the use of elaborate equipment, individual surveyors are likely to interpret such parameters as flow rate, water depth and the requisite amount of appropriate riparian vegetation differently. The guide to survey methodology makes no specific indication as to suitable flow rate window for the species, instead using the markedly ambiguous static, slow or fast flowing as a descriptor. There is no indication as to what is meant by each of these descriptors, or how to differentiate between them. No specific definition could be found in relevant literature to elucidate prior to conducting the field survey. Subsequently, however, it was found that water voles can persist in upland rivers exhibiting a gradient below 10 % (SEPA, 2005). River gradient can thus be used as a proxy for water flow rates. As the topography of surveyed areas constitutes ‘foothills with forest’ (Botham, 1998), many of the watercourses therein may exceed this threshold, hence rendering the habitat potentially unsuitable for water voles.

6.2.2. Suitability of survey methodology for upland use

When calculating the habitat suitability score, each parameter is attributed equal weighting. Certain parameters are in reality more influential than others in determining suitability, thus it is difficult to establish an accurate representation. Take for example parameter I – ‘slow flowing or static water’. Excessively fast flowing water (greater than 10 % gradient) may render a stretch unsuitable to sustain a water vole population. However, if every other parameter is present then the overall habitat score will be 9, and consequently categorised as being optimally suitable.

The survey methodology was adapted from Harris *et al.* (2009), where it was originally designed for use in wider, slower-flowing, lowland areas. As such these methods should be treated with some caution when implemented along steeper, narrower upland watercourses (Aars *et al.*, 2001). The FCS-commissioned 2011 survey suggested that the habitat conditions were unsuitable for water voles within the forest. That following the methodology outlined by

Harris *et al.* (2009) yielded results suggesting differently shows either that the parameters are open to interpretation, or that they are unsuited to upland areas. Thus, a more robust methodology which either applies a weighting to each parameter or which is altered for this specific terrain and accounts for gradient is necessary.

6.2.3. Bordering land use

The forest is divided into different blocks, each consisting of different age structure trees and and felling regimes (Duncan, 2017). This made for fairly heterogeneous riparian land use. Despite near-universal suitability of habitat, there did appear to be a vague correlation between of habitat suitability and bordering land use. Those stretches abutted by heath and peat bog tended to have higher suitability, as was the case in sample plot 4. Heath and peat bog habitats are preferred upland habitat for the species (Norman *et al.*, 2009). In future, a more rigorous statistical analysis of bordering land use in and habitat suitability should be conducted.

The project was not finalised until October 2017, after the recommended window in which to conduct habitat surveys had closed. This meant that the survey was conducted at a time when water voles live a predominantly subterranean existence (Stewart *et al.*, 2008). Over winter, faeces and food sources are mostly stored in underground galleries within the burrow system, where they decompose and radiate heat to keep the water voles warm (Cheshire Wildlife Trust, 2018). Though the project did not directly necessitate looking for voles proper, more readily visible field signs would have been useful to determine potential habitat suitability in marginal land.

Adverse wintry weather conditions posed a significant obstacle to data collection. Snow affected the ability to access some of the higher terrain within the forest as well as obscuring and compacting much of the riparian vegetation. Similarly, many of the water courses were swollen with meltwater, which could have artificially inflated both flow rate and stream depth. Furthermore, much of the in-stream vegetation would not have been growing vigorously at this time, so it was difficult to identify and interpret the preponderance of these emergent species. These factors may have negatively impacted data reliability.

During the field survey, multiple small water bodies were encountered that did not feature in the hydrological dataset provided by CEH. It was decided for the sake of consistency that any watercourse or body outwith this dataset would not be surveyed. However, as small ditches ponds and burns contribute some of the more hospitable upland water vole habitats (Aars *et al.,* 2001), many potentially suitable areas were disregarded.

A seventh sample plot was initially generated within the boundaries of Harestanes Wind Farm (NX9995). A notice period of one week, given in writing to Scottish Power, was required to gain entry and survey within this plot. Icy forest track conditions for much of the winter precluded entry to this more-elevated location on two occasions. Subsequent delays resulted in forest access permissions elapsing twice and the plot being necessarily abandoned. It would have been interesting to see how the felled radii around the turbines might impact water vole habitat suitability. Future research may wish to focus on this aspect and other potential wind farm implications.

7. What are the key threats to water voles within Ae Forest?

The primary threats to water voles in the general context are that of habitat degradation, fragmentation and loss as well as the threat from predation by the non-native invasive American mink (*Neovison vison*) (Strachan and Moorhouse, 2006). Water voles are susceptible to both changes in habitat and to altering ecological dynamics. In many cases populations can only exist both under optimal habitat conditions and in the absence of mink (Strachan and Moorhouse, 2006). Water voles and mink have only been observed to co-exist where habitat was suboptimal for the latter species, such as upland moors and in urban areas where the domestic cat (*Felis catus*) acts as a deterrent (Norman *et al.*, 2009). Water voles are also subject to other factors such as pollution, flooding and persecution (Broadmeadow and Nisbet, 2004). These factors may have a significant localised impact (Strachan and Moorhouse, 2006).

7.1. Habitat loss and degradation

In the years following the Second World War, The British Government introduced a policy of agricultural intensification. This policy, through a process of radical linearisation of riparian habitats, the loss of field margins, hedgerows and floodplain habitats, as well as the drainage of semi-natural grasslands and drainage ditches, resulted in significant changes to the delicate riparian ecosystems of which water voles are a part (Barreto *et al.*, 1998; Vickery *et al.,* 2001). These impacts have been compounded by the canalization and dredging of watercourses to produce heavily regulated channels, the maintenance of which has frequently been implicated in the fragmentation and loss of water vole colonies (Barreto *et al.*, 1998; Macdonald and Strachan, 1999; Strachan et al., 2003).

Water voles require wide, luxuriant riparian fringes, rich with herbaceous vegetation (Strachan and Moorhouse, 2006). inappropriate management techniques, such as overenthusiastic mowing of this vegetation not only reduces potential food supplies, but also the opportunity for the water vole to hide from predators (Telfer *et al.*, 2001). Bank protection measures such as installing metal or concrete gabions create an impermeable surface into which water voles are unable to burrow (Barreto *et al.*, 1998). Similarly, de-silting operations can remove in-stream vegetation which provides essential cover from predators (Strachan and Moorhouse, 2006).

Grazing of un-fenced riparian land by livestock can have various detrimental effects upon water vole habitat, through the removal of potential cover and food sources (Strachan and

Moorhouse, 2006). Additionally, poaching by livestock not only destroys potential food sources for water voles but can result in compaction, destabilisation and collapse of river banks to the point where they become unsuitable for burrowing (Barreto *et al.*, 1998). These management practices take a largely anthropocentric view on habitat priorities.

7.2. Meta-population dynamics

Water voles exist in fragile meta-populations made up of a number of small colonies (Strachan and Moorhouse, 2006). These meta-populations have been shown to collapse when faced with the combined pressures of habitat degradation and predation by mink (Barreto *et al.*, 1998). As water vole habitats become increasingly fragmented, neighbouring conspecifics are less able to disperse into and repopulate dwindling communities.

Ultimately, the ability of upland water voles to persist depends not only upon the presence of a suitable habitat or the absence of mink, but also the degree of isolation within meta-populations (Hanski, 1991). Thus the delicate balance of meta-population stability has become increasingly precarious as traditional water vole habitats are altered to suit largely anthropocentric needs (Barreto *et al.*, 1998).

7.3. Dumfries and Galloway land use

Historically, much of the region’s land has been used for agriculture, particularly the hill farming of cattle and sheep (Botham, 1998). In the early decades of the twentieth century, however, as economic and agricultural depression swept across the UK, swathes of farmland across Scotland were sold to the newly established Forestry Commission as a way of diversifying the rural economy. Today, approximately one quarter of Dumfries and Galloway is forested – the highest density of any UK region (DGERC, 2007).

7.4. Forestry impacts

The implications of increased forestry cover on the wider environment are well-documented and multifarious, though will not be discussed here. However, the practice has been identified as having the potential to degrade both water quality and the physical habitats within the freshwater systems that support water voles (Maitland *et al.*, 1990; Broadmeadow and Nisbet, 2004). Such degradation can occur for a number of reasons including flow regime changes, pollution, erosion and siltation. These will be further investigated below.

7.4.1. Shading from dense plantation

Water voles do not thrive along water courses where there is significant overshadowing from trees (Strachan and Moorhouse, 2006). While some shading can be beneficial for stabilising water temperature and obscuring water voles from predators (Johnson and Wilby, 2015), too much can be detrimental to the survival of understorey vegetation. This has the combined impact of reducing bankside stability – thereby promoting erosion – as well as limiting potential food sources for water voles (Scottish Government, 2009).

Ae Forest is managed by FES in accordance with both the UK Forest Standard (UKFS) and Solway Tweed RBMP (Duncan, 2017). Although many of the larger water courses within the forest have wide riparian borders, a number of the smaller burns were observed to be overshadowed by Sitka spruce and had sparsely vegetated banks. These smaller burns would not be considered suitable habitat for water voles. Were these areas devoid of plantation forest, it is conceivable that such burns would constitute suitable water vole habitat.

7.4.2. Flooding impacts

In addition to shading out understorey growth, forestry makes streams more susceptible to flash flooding (Ratnam *et al.*, 2014). Recently clear-felled areas promote surface water runoff, and consequently the receiving streams are rendered quick to rise and quick to fall. This volatility is non-conducive to sustaining healthy population of water voles, which are known to be ill-adapted to sudden and drastic changes in water level (Lawton and Woodroffe, 1991).

At a local level, Ae Forest's typically saturated peat-gley soils intensify surface water runoff (Puhr *et al.*, 2000). This is compounded by the forest's relatively high altitude making it susceptible to snow, as was discovered in this study. Sudden thawing events have the potential to result in periods of high water flow which can severely impact water voles.

Climate change is likely to increase the frequency and intensity of sudden, heavy storms and precipitation (Trenberth *et al.,* 2003; Norman, 2009; Kendon *et al.,* 2014). The impacts upon water voles in Ae Forest will depend upon management of adjacent land to ensure surface water runoff is minimised, retarded and intercepted at the point of entry to the watercourse by dense riparian vegetation.

As Ae Forest has a mixed age structure across its constituent coupes, felling operations are in constant rotation. Tree felling results in nutrient runoff as well as sediment deposition from erosion, both of which have adverse impacts on water vole habitats (SNH, 2001).

7.4.3. Diffuse pollution effects

There is presently insufficient research into the impacts of forest-borne pollutants and on water voles (Strachan and Moorhouse, 2006). However, in accordance with the precautionary principle (Kriebel *et al.*, 2001) potential impacts upon the species should not be discounted.

Furthermore, there is little knowledge on the impact of water quality on water vole mortality or reproductive fitness (Strachan and Moorhouse, 2006). This is largely due to the fact that watercourses have no role in their reproductive cycle, and are used predominantly for transport and predator avoidance (Meredith *et al.*, 2013). However, while water voles maintain a largely vegetarian diet, they are known to eat aquatic invertebrates as well as immature frogs, crayfish and small fish on an *ad hoc* basis (PTES, 2018). Thus the impact of bioaccumulated toxins should be taken into account. Similarly, the influence of pollution on the water vole's physical habitat, through siltation and the contamination of riparian and emergent vegetation, must too be considered a threat to the species (SNH, 2001).

Pollution of freshwater systems poses a serious threat to the effective management of sensitive aquatic environments (SEPA, 2014). The primary threat in terms of pollution from forestry activity come from diffuse sources (Dunford *et al.*, 2012). Diffuse pollution describes those sources of pollution which may individually have only minor environmental impact but collectively and at a catchment scale can have a major impact (SEPA, 2014). In the forestry context these are largely driven by rainfall washing chemicals, nutrients and sediment into the local water environment (Dunford *et al.*, 2012).

Within Ae Forest, the main potential sources of diffuse pollution occur as the result of forestry operations. Pollution impacts of forestry on the freshwater system occur throughout the operative cycle, from planting to thinning to felling and restocking. Here, the differing impacts of the forestry cycle are addressed with regard to their impact on freshwater ecology, from which inferences can be made as to potential impacts upon water voles.

7.4.4. Surface water acidification

Commercial forestry has long been associated with surface water acidification and resultant negative impacts upon freshwater ecology (Nisbet, 2001; Dunford *et al.*, 2012). These effects are particularly pronounced in Dumfries and Galloway where the limited buffering capacity of the region's sedimentary shale and mudstone geology, combined with widespread forestation renders the fluvial system sensitive to acidification (Puhr et al., 2000; Dunford *et al.*, 2012).

Coniferous plantations have been shown to intercept – or scavenge – atmospheric pollutants such as sulphur dioxide, nitrogen dioxide, ammonia and nitric acid (Nisbet *et al.*, 1995). These pollutants are directly deposited onto the leaf surfaces, after which precipitation washes them into rivers and streams. Deposition of these pollutants within freshwater systems intensifies the acidification process (Fowler *et al.*, 2002), particularly in upland areas such as Ae Forest where a relatively high cloud immersion frequency has a compounding effect (Nisbet and Evans, 2014). Nitrogen accumulation in the freshwater environment can result in eutrophication, algal blooms an anoxic water conditions (Pretty *et al.*, 2003). This can reduce the presence of the emergent vegetation upon which water voles are dependent for cover.

Forestry further accelerates surface water acidification through the uptake of base cations from the soil (Nisbet and Evans, 2014). This in turn reduces the soil's buffering capacity, which, as has already been noted, is particularly limited within Dumfries and Galloway. Acidification of the soil as a result of base cation uptake and leaf litter accumulation results in the increased solubility and mobilisation of toxic heavy metals such as aluminium, lead and mercury (Muniz, 1990; Bobbink *et al.,* 1998; Hutchings, 2002). These elements are known to have debilitating impacts on aquatic wildlife (Demayo *et al.,* 1982; Balsberg-Påhlsson, 1989). However, the specific effect on water voles is little known, thus there is a need to conduct further research in this field.

7.4.5. Chemical leaching

Throughout the 1980s forestry management techniques involved the chemical thinning of standing stocks using the 'hack and spray' method of cutting tree bark and spraying the wound with glyphosate (Johnston *et al.,* 2003). This would result in the swift death of the treated tree, but chemical runoff from the treatment impacted upon non-target species (Tubby *et al.,* 2017). While this thinning technique has largely been abandoned since the early 1990s (Johnston *et al.*, 2003), renewed interest in chemical stump treatment using glyphosate to prevent fungal infection has the potential to redouble the impact on the surrounding aquatic environment through leaching into nearby watercourses (Ausden, 2008; Rötzer *et al.*, 2010).

7.5. Harestanes Wind Farm

No survey has been conducted since the construction and commissioning of Harestanes Wind Farm. The potential impact of this development should not be overlooked. Overall water quality has deteriorated within the catchment since 2013, such that now all five of the surface waters within Ae Forest are classified either 'poor' or 'bad' ecological status (See **Figs. 4** and **15**).

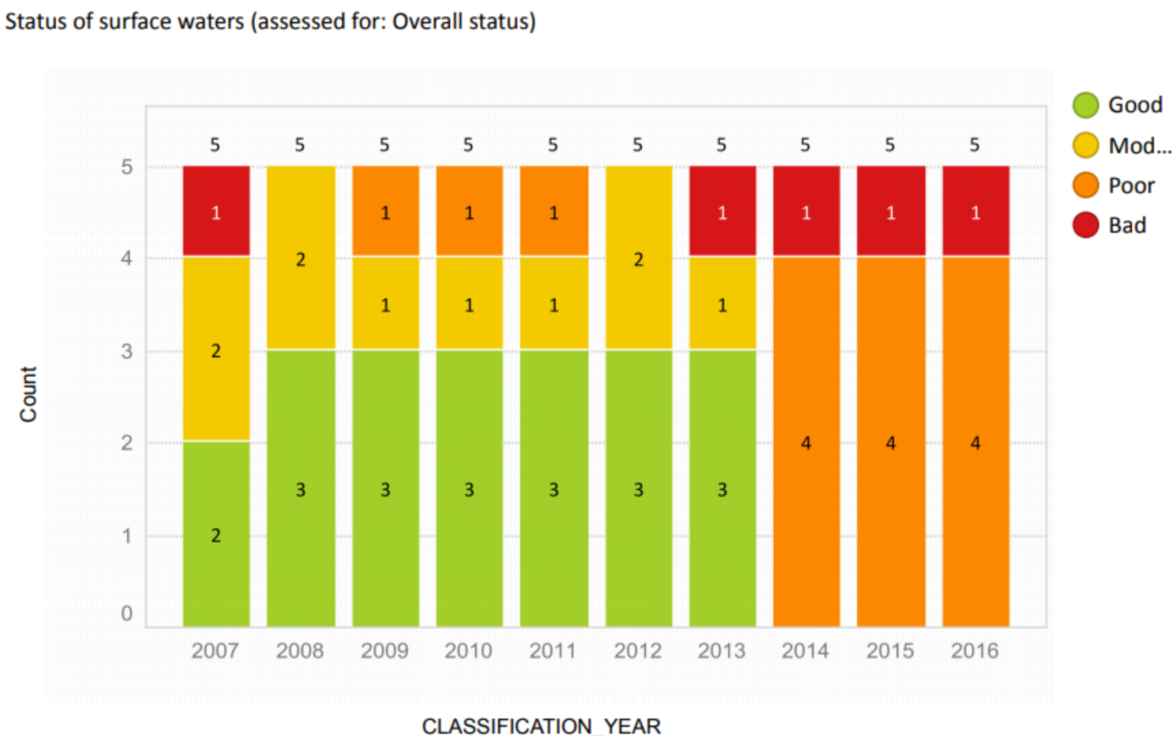

Figure 15. Annual changes to the overall status of surface water bodies within Ae Forest. (CEH, 2016)

Fig. 15 shows the decline in overall environmental status for the five surface water bodies of the Water of Ae that flow through Ae Forest. The most recent available data is for 2016. There is a clear indication that between the 2013 and 2014 surveys something to occurred to degrade the environmental status of the waters surface waters within the forest.

In each case, 'poor' and 'bad' status was designated for ecology value as a result of failing to meet the applicable biological, chemical or hydromorphological standard (Scottish Government, 2008). Ensuring good ecological quality requires the water to be unpolluted, with good physical structure of the banks and beds and good flows and water levels (SEPA, 2015).

The two-year construction of Harestanes Wind Farm, commencing in October 2012, coincided with the decline in water quality from 2013. Harestanes, in the upper reaches of the Ae Water Catchment, is one of Scotland's largest onshore wind farms comprising 68 turbines across a 20 km2 area of forest (Scottish Power, 2014). Maintenance buildings and 15 km of additional tracks, paths and trails were constructed around the site.

Laying forest tracks as well as transporting the heavy infrastructure into the forest must have had some impact on the freshwater environment. Furthermore, the felling of trees around the turbines might foster improved water vole habitat in areas adjacent to the turbines. It would be beneficial for further research to look into these potential impacts.

7.6. Predation

Water voles are subject to intense predatory pressure (Lawton and Woodroffe, 1991). Indeed, the species in Great Britain has evolved in tandem with a range of native predators such as grey heron (*Ardea cinerea*), the Eurasian otter and the stoat (*Mustela ermine*a) (Jefferies *et al.*, 1989). Nevertheless, as r-strategists, their prodigious fecundity more than compensates for ordinary levels of predation by native species (Meredith *et al.*, 2013).

Whilst no native predator is able to follow a water vole into its burrow, female American mink are able to do so due to their small size (Meredith *et al.*, 2013). Since the mid-20th Century, relentless predation by the introduced mink has sent the water vole into a spiral of population decline and range contraction from which it looks unlikely it will recover (McGuire and Whitfield, 2017).

7.6.1. American mink

Invasive non-native species (INNS) have been defined as those species 'whose introduction and/or spread threaten biological diversity or have other unforeseen impacts' (Defra 2008). INNS generally experience significant population expansion and self-sufficiency after initial introduction and naturalisation within a non-native range (Emerton and Howard 2008). Their deleterious impact on global biodiversity is considered to be second only to habitat loss in terms of impact on global biodiversity (Brooks *et al.,* 2006). Introduced to Great Britain from America in the 1920s as part of the fur trade, feral American mink have subsequently become established in the wild through a combination of inadvertent escapes and deliberate releases throughout the 1950s (Bonesi and Palazon, 2007). The species has no natural predators in the UK and is documented to have contributed to the decline in numerous native species, most notably the water vole (Lawton and Woodroffe, 1991).

Mink are most commonly associated with wooded and scrubby areas alongside rivers and streams, avoiding areas of open ground (Yamaguchi *et al.*, 2003). Ae Forest, which is largely covered in coniferous plantation, is thus an ideal habitat for the species. Mink are carnivorous and are able to hunt both on land and in water (Barreto *et al.*, 1998). They are an opportunistic predator, feeding upon fish, birds, mammals, amphibians and invertebrates, often killing more than they need for food (Hurníková *et al*., 2016).

The arrival of American mink has had an impact characteristic of invasive non-native predators in that they are able to counter the anti-predator behaviours evolved by the prey. Water vole anti predator behaviours are largely escape and distraction-based (Woodroffe *et al.,* 1990). The American mink is able to negate these behaviours, making water voles particularly vulnerable.

Water voles have a very high winter mortality rate – up to 70 % in some cases (Carter and Bright, 2003). Mink reproduce early in the season, between February and March (Macdonald and Feber, 2015), putting nearby winter-surviving water voles at risk of predation before they have had offspring of their own.

Previous studies conducted by Lawton and Woodroffe (1991) and Telfer *et al*., 2001 show that water vole populations remain fragmented in the long-term as a result of habitat predation by American mink. Consequently, individual water voles occupy only a minute fraction of available suitable habitats at any one time, experiencing high rates of extinction and recolonisation.

Mink have spread across Scotland, and now occupy all regions except the far north (Fraser *et al*., 2015). In Ae Forest, American mink have been recorded in 2014, 2015, and 2017 (see **Fig. 16**). Also presented here are water vole records since 2002. Due to the great distances to which mink can disperse, typically up to 40 km for adult females and 55 km for adult males (Oliver *et al.*, 2016), all water vole populations within Ae Forest are potentially at risk of predation and local extinction by the species (Bonesi and Palazon, 2007).

7.7. Persecution

The water vole has historically been the victim of persecution due to its superficial resemblance to the brown rat. Localised extinctions, particularly in urban areas, have been recorded as a result of poisoning by rotenticide (Strachan and Moorhouse, 2006). Given that Ae Forest is managed in accordance with the UKFS, which advocates water vole conservation, the risk of mistaken identity here is minimal.

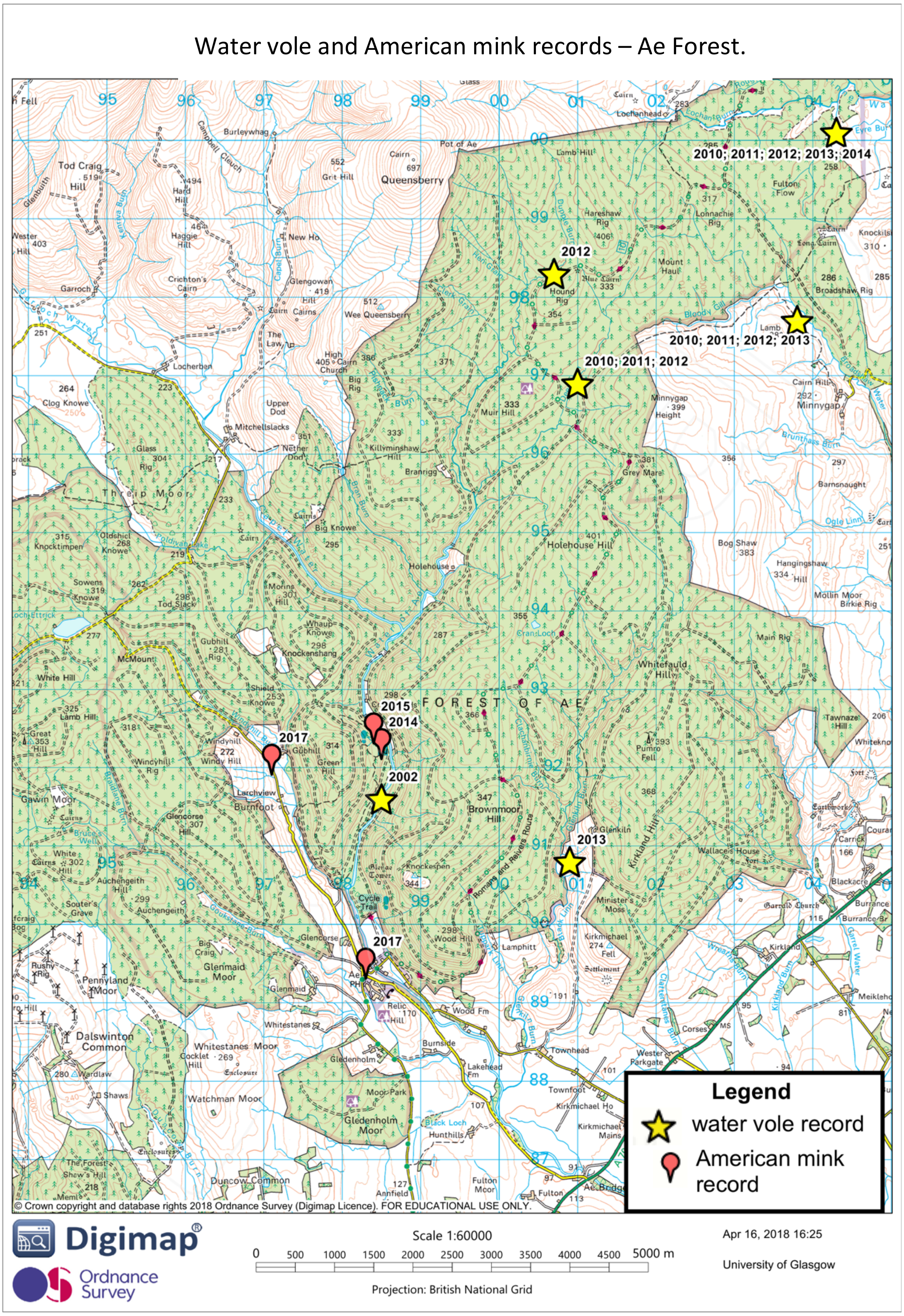

Figure 16. Water vole and American mink recordings in Ae Forest (Andy Riches, 2018).

8. What land management approaches are required to encourage and sustain a water vole population within Ae Forest? Do these conflict with existing management approaches?

Water vole mitigation techniques can range from sensitive modification of the freshwater environment to the exclusion of predators from areas where water voles are present. These techniques are discussed below.

8.1. Sensitive modification of the freshwater environment.

Physical modification of the banks, beds and riparian habitat in freshwater systems has historically prioritised minimising flood risk and mitigating resultant damage (Barreto *et al.*, 1998). Usually these modifications have been for the benefit of agricultural or urban land use purposes and to detriment of the quality, extent and diversity of aquatic habitats (SEPA, 2015). Even today water courses are modified to increase their capacity to store and transport water downstream through dredging, straightening and reinforcing banks with concrete or steel, and the removal of obstructions that slow the flow of water. These practices aim to increase the speed at which water is transported away from areas of human significance, and largely serve anthropocentric goals.

The impacts of these – and other – management practices have been various, ranging from altering the fluvial geomorphology of a water course, to impacting its environmental status and even reducing native biodiversity (Strachan and Moorhouse, 2006). Water voles are one such native species negatively impacted by insensitive bankside management.

European Legislation in the form of the Water Framework Directive (WFD; 2000/60/EC), in combination with detailed local management plans laid out by SEPA, seeks to ensure good ecological status within freshwater systems. The Water of Ae is included within the Solway Tweed RBMP, which aims to limit and reduce the impacts of diffuse pollution from forestry operations (SEPA, 2015).

8.1.1. Riparian buffers

There are a number of ways in which a freshwater habitat can be sensitively managed for water voles, this incorporates managing both the in-stream water body as well as the bankside environment. This may be as simple as fencing off livestock from a margin of land to allow natural vegetative regeneration.

The establishment and retention of riparian buffers along a water course or body is an essential part of management water vole habitats. SEPA Riparian Vegetation Management Guidelines (2009) recommends leaving a vegetated buffer strip at least two metres wide on either bank of a watercourse, although more is preferable. Native broadleaf trees and varied herbaceous planting along the river and ditch banks provide diverse sources of food and cover from. In forested upland upland areas of high flow where erosion is prevalent, highly vegetated riparian borders act to stabilise bankside soil, preventing both erosion and siltation.

Where dredging and canalisation is essential, work should be conducted in phases so as to reduce the impact upon water voles. This would require at least one year to be left between modification activity on adjacent lengths of watercourse (Strachan and Moorhouse, 2006). Similarly, where possible, lateral channels and smaller tributaries should be left untouched to provide a refuge for remnant individuals, and to provide the basis from which new colonies can be revived (Derbyshire Wildlife Trust, 2004). It is beneficial to to retain as many features within the water course with water vole conservation value (Strachan and Moorhouse, 2006). In order to conserve fringes of emergent vegetation, modification work should be conducted from one side of the water course, where practicable (Strachan and Moorhouse, 2006).

In the context of Ae forest, many of the water courses are relatively narrow – mostly less than 3 m wide – and largely unaltered by engineering. Sample plot 5 of the habitat field survey was in an area of recently felled timber. Here there was a wide and diverse luscious fringe of riparian vegetation, making it ideal for a water vole population.

Due to the relatively steep topography within Ae forest and its propensity for sudden changes in flow – particularly over winter – erosion control is an important management priority, particularly in the lower stretches towards Ae village. Where bank erosion necessitates reinforcement, the use of metal sheeting, rock gabions and concrete should be avoided, particularly in areas known to harbour water vole populations (SEPA, 2008). There are a range of sympathetic bankside maintenance options which include the use of coir fibre bundles, willow withies and other natural materials which provide a sustainable food source and a permeable surface through which water voles are able to burrow (Strachan and Moorhouse, 2006; SEPA, 2008).

Many of the water courses within the forest follow the relatively steep topography of the area and as such river channels are largely straight and have few meanders. In this way, it would not be appropriate to use bankside reinforcement in these areas within the upper catchment.

However, areas where the slope of the water body is relatively shallow, such as towards Ae village, would be better suited to bank protection measures.

8.1.2. Wet ditch management.

The boggy and peaty terrain present in Ae Forest results in numerous wet ditches forming in due to surface water runoff. In the lower sections of the catchment management should incorporate trying to maintain a semi-natural, wide vegetative border as well as managing to retain as natural a water course as possible (Carter and Bright, 2003). In the lower sections of the catchment, wet ditches should be de-silted as infrequently as possible, ideally once every five years (Field, 2009). However, with regular harvesting operations likely to mobilise sediment upstream, this may need to be conducted at more regular intervals, or more appropriate upland erosion control methods need to be investigated. De-silting operations should be conducted only between mid-September and late January to enable dislodge plant material to quickly propagate downstream before spring (Field, 2009), although this will need to be done in consultation with the felling plans. At least 50 % of the in-stream vegetation should be left intact in order to maintain continuous availability of cover (Strachan and Moorhouse, 2006).

Non-woody bankside vegetation should be cut in rotation, once every three years, and at least a third of each wet ditch length should be left untouched so as to provide a suitable refuge for water voles (Field, 2009). Retaining in-stream braids is important to encourage the emergent vegetation growth which serves both as a food source and as natural cover from predators. Dredging can be beneficial in that during periods of high-flow re-suspended sediment suppresses aquatic plant growth and thus adversely affects the dependent wildlife.

Access across burns for timber forwarders and harvesters, is afforded by bridges made from compressed timber trunks and brash (personal observation). These create temporary changes to the water flow and should be removed once felling operations end. However, as felling in larger coupes can last months at a time, this could result in altered runoff for extended periods which may adversely impact upon water vole success downstream.

Where felling operations have recently taken place, water courses are at increased risk of pollution, both from nutrient and chemical leaching as well as increased sedimentation and turbidity. These risks can be minimised by adopting best practice techniques as outlined in the UK Forestry Standard (Forestry Commission, 2017). This recommends the creation of settling pools where surface water runoff is collected, and suspended sediments are allowed to settle on the bottom instead of entering the watercourse downstream. Additionally, temporary semipermeable dams can be employed to slow-down the flow of water from recently felled stands and to further collect dislodged sediment.

In sections where channelisation has removed natural meanders, habitat enhancement restoration can be implemented. Restoring the natural geomorphological and hydraulic features to a water course is beneficial to the entire aquatic ecosystem (Strachan and Moorhouse, 2006). Water voles, due to their susceptibility/sensitivity to habitat degradation and fragmentation, reap significant benefits from restored connectivity in the river system, including floodplain habitats, ponds, ditches, marshes and reedbeds (Barreto *et al.*, 1998; Carter and Bright, 2003).

8.1.3. Environmental ponds

The creation and maintenance of freshwater ponds and wetlands is an important element of ensuring a diverse and sustainable habitat for water voles. Ponds can serve as vital refuges for water voles during extreme flood or drought conditions when their usual bankside burrows might not be habitable (Lawton and Woodroffe,1991; Strachan and Moorhouse, 2006), and as such represent a valuable conservation tool for rivers known to spate, such as the Water of Ae. Modern forestry machinery makes the creation of ponds specifically designated for wildlife refuge relatively simple (Norman *et al.*, 2009).

8.1.4. Coupe thinning

While thinning is predominantly carried out for commercial purposes, such as to achieve a more profitable size structure by removing inferior specimens and to create more uniform stands (Rötzer *et al.*, 2010; Ratnam *et al.*, 2014), it can also be conducted to meet certain ecological goals. Thinning can lead to increased biodiversity. as improving light penetration through to the understorey and in riparian margins produces the standing deadwood necessary for many aquatic vertebrates (Smith *et al.*, 2007; Pollock and Beechie, 2014).

8.2. Management of American mink

The UK Water Vole Steering Group (WVSG) estimates that unless concerted efforts are made to reduce the impact of American mink then the majority of Great Britain's water vole colonies will become extinct within a few years (Strachan and Moorhouse, 2006). Indeed, in the absence of mink control water vole populations will crash, irrespective of any other management technique (Williams *et al.*, 2010). However, in isolation, removing mink from potential water vole habitat is not enough to prevent water vole decline. The UK WVSG recommends the concurrent removal of mink along with habitat restoration efforts and management to facilitate long-term protection of water voles (Strachan and Moorhouse, 2006).

Methods for mink control are varied, though focus is on the removal of mink from areas known to contain water voles or where habitats are suitable for water voles and their numbers have declined (Bonesi, *et al.*, 2007). Previous mink control efforts have relied upon speculative and non-targeted bankside trapping, resulting in, at-best, only sporadic captures (Reynolds *et al.*, 1994).

8.2.1. Mink trapping

Trapping is the most economically and time-efficient way of controlling mink populations. Live trapping followed by humane dispatch is considered the most effective method as it eliminates the risk of harm to non-target species (BASC, 2016). Due to their invasive nature and the adverse effect upon native wildlife, only lethal control methods are recommended (Bonesi and Palazon, 2007).

Modern methods utilise a Game Conservancy Trust (GCT) mink raft, which allows for both tracking and trapping functions. The benefit of using a mink raft over speculative trapping is that when monitoring it allows for trapping effort to be concentrated in areas where mink is known to exist Bonesi, *et al.*, 2007.

Mink rafts comprise a buoyant wooden platform upon which a tunnel is housed. The tunnel provides a dark cavity which is attractive to mink, and can be closed off to exclude larger, non-target species. During the monitoring phase the rafts are deployed at 1 km intervals along the water course. The tunnel is fitted with a clay-filled cartridge which takes clear footprints that can be used for positive mink identification. The raft is checked every week for signs of mink presence. If the presence of mink is confirmed then the clay plate is replaced by a live-capture trap, and trapping continues for a further two weeks or until the mink is caught (BASC, 2016). either a live-capture trap or an approved spring-loaded lethal trap as stipulated in The Spring Traps Approval (Scotland) Order 2011 (SSI 2011/393) is used. If caught alive, the captured mink is then cleanly dispatched by firearm. Mink trapping forms part of a wider control scheme aiming to exclude the species from a given territory to facilitate conservation of water voles or other threatened species (BASC, 2016).

Bonesi *et al.* (2007) found that mink must be excluded from an area for at least three consecutive months to facilitate a reduction in mink population below the threshold level 20 % of the carrying capacity. This is the maximum threshold level considered acceptable for water voles. Furthermore, the same study found that trapping during late dispersal and winter seasons was most effective for promoting long-term water vole population survival. This combats both the effect of dispersion of juveniles from the control area as well as immigration to the habitat from non-controlled areas. Trapping should focus on adult female mink as they are most likely to prey upon water voles due to their small size and ability to fit into water vole burrows (Bonesi *et al*., 2007). Additionally, trapping during the late dispersal stage in the mink life cycle reduces the numbers of mink at a time when the water voles are themselves dispersing (Strachan and Moorhouse, 2006). This is of particular importance to water vole conservation as the species has only a relatively short lifespan.

Juvenile mink have been shown to be particularly susceptible to trapping at the dispersal stage of their life history due to their inadequate knowledge of surrounding terrain, the physical stress of not having a territory and a resultant propensity toward malnourishment (Smal, 1991). Furthermore, trapping those individuals who have not yet reached sexual maturity precludes them from producing offspring and has a greater impact on long-term population control than trapping adults. It is also essential that mink control takes place annually, and systematically as opposed to opportunistically as has historically been the case (Bonesi *et al.*, 2007).

Within Ae forest, trapping of mink has already been conducted by RAT, and FCS, although records have not been updated or added to the Dumfries and Galloway mammal records. Recommendations from this report would be to encourage communication between the public bodies in order to paint a more representative picture of the spread and prevalence of mink within Ae forest, and to better inform future mink control activity.

Continued commercial management of the forest for timber will likely impact upon water vole populations. Given the presence of mink within the forest, temporary or permanent habitat loss of any species is inevitable. Thus it is important for any management plan to incorporate regular reviews of the approaches taken and methods involved, assuring that such are aligned with best practice for water vole conservation.

9.1. Conclusions

Field survey and desk based investigation methods identified evidence of water vole activity within Ae Forest. Data gathered from personal communication with SWSEIC as well as the County Mammal Recorder indicated a relatively wide range of locations where water voles had previously been recorded. The habitat survey identified potential water vole field signs, which may serve as evidence that water voles continue to survive within the forest, in the face of pressure from American mink.

The European water vole has a specific set of habitat requirements. The species prefers the soft, friable banks of richly vegetated and slow-flowing water courses. A habitat field survey was devised and conducted to assess the suitability of sections of Ae Forest to sustain a population of water voles. It was inferred that such habitat does exist within the forest, although limitations within the survey methodology meant the results should be treated with caution.

The main threats to water voles within Ae Forest are a combination of predatory pressure by American mink as well as pollution, sedimentation and acidification from forestry operations. It was recommended that further research be conducted into the impacts of forestry on freshwater habitats.

Land management approaches which help encourage and sustain water vole populations focus on the sensitive restoration and management of riparian habitats. Similarly, conducting mink eradication programmes are essential to encouraging water vole survival. Mink control programmes have been previously implemented within the forest; however, it is unclear whether they are still in operation. Ensuring the prosperity of water voles within Ae forest will depend upon the combination of mink control and sensitive riparian management.

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10. Appendix

10.1. Appendix A.

10.1.1. Habitat suitability interpretations

Interpreting the results

TABLE 1: WATER VOLE HABITAT SUITABILITY ASSESSMENT
(Score 1 if feature present)

[a] Well developed (>60%) bankside <u>and</u> aquatic vegetation that provides suitable food & cover

Score 1 here if:-

- At least one bank is covered with a strip of vegetation that is 2 m or more wide (from the water's edge) with very few/no sparsely vegetated or bare areas,
- At least 60% of the bank within 2-5 m from the water's edge is covered with a sward of tall grassy vegetation,
- Areas of tall grassy vegetation includes a mixture of grasses & herbaceous plants; and,
- There is a fringe of aquatic plants growing out of the water at the edge of the banks,
- Less than 10% of the bankside vegetation is trees and scrub.

<u>Notes</u>
When carrying out the survey early in the season (March, April and early May) it is important to take into account that the bankside vegetation may be shorter and less dense than it would be later in the season, as it has not grown up yet. In this case, it would still score a 1.

[b] A good variety of food plants including favoured plants and winter food sources
Score 1 here if:-

- The grass sward is tall and highly layered, including a mixture of grasses & herbaceous plants ,
- Stands of rushes, sedges or reeds are present,
- At least <u>three</u> different native herbaceous plants are present e.g. Willowherbs, Loostrifes, Meadowsweet, Common nettle, Hemlock Water Dropwort,
- At least one of the following is present; Elder, Bramble, Willow, Hawthorn or Flag iris.

<u>Notes</u>
The best sites for Water voles have banks that are covered with a tall, highly layered sward of grass that includes a diverse selection of flowering plants, including stands of Willowherb, Loosestrife, Meadowsweet, or nettles. The foot of the banks are often fringed with thick stands of rushes, sedges or reeds. Hawthorn, Willow, Elder, Bramble and Flag iris are preferred food sources in the autumn and winter.

Table 10 (Ctd. Below) Interpreting the results: Water vole habitat survey assessment. Adapted from Cheshire Wildlife Trust (2017) and Harris *et al.* (2009).

Interpreting the results

[c] Suitable refuge areas above extremes in water levels

Score1 here if:-

- There are high banks with suitable habitat well above the water level; **or,**
- Presence of backwater ponds, lakes, reservoirs or ditches with suitable habitat that is not subject to flooding;

Notes

Food, cover and burrow systems will be affected by fluctuating water levels. Suitable habitat above high water levels that act as refuge areas for water voles during flooding events are essential.

[d] Soft, earth banks suitable for burrowing (30° to 60° slope)

Score1 here if:-

- At least **one** bank is soft earth or silt that water voles can easily burrow into,
- The bank has an optimal slope (30 - 60°), neither too steep or too shallow, and is high enough to support a burrow system,
- There are no barriers to water voles accessing the banks from the water,
- The bank is not rocky or reinforced with material, such as metal, concrete, wood or boulders.

Notes

Water voles prefer sites with easily penetrable earth or silt –shored banks. Water voles can still burrow banks where brick or rock walls are present in front of earth banks if there are adequate gaps for the water voles to climb up and squeeze between to access the soft earth behind. Where this feature is present the site would still score 1. The bank does not have to be a smooth slope but may have some uneven areas or consist of a series of shallow shelves or ledges.

[e] Water permanently present (water levels stable and does not dry up

Score1 here if:-

- Water 1m or more in depth when water levels are normal i.e. deep enough for water voles to dive into and escape from predators
- Water levels do not fluctuate dramatically and the watercourse or waterbody is not at risk of drying out completely due to drought or seasonal changes

Notes

Periods of drought and low water levels are detrimental to water vole populations. Water voles dive in the water to escape from predators. Water voles have burrows under the water line and when these are exposed it leaves water voles particularly vulnerable to predators such as stoats and weasels.

[f] Open water available for swimming

Score1 here if:-

- There is an area of continuous open water (clear of vegetation) that is at least 15 m2 in extent and 0.5 m in depth.

This could be in the central channel of a ditch, canal, stream, brook or river, or close to the bank (within 2 m) of a pond lake or reservoir.

- The open water accounts for at least 10% of the water body.

Interpreting the results

[g] Ledge or berm present at or close to water level

- Just below the water level,
- At water level; **or,**
- Just above the water level.

[h] Lack of damage or erosion to the banks

Score1 here if there is no erosion or damage to at least 60% of the bank. Examples of damage which reduces suitability to water voles includes:-

- Overgrazing and poaching by livestock,
- Washed out banks due to flooding or fast currents,
- Recent management affecting the bank or vegetation,
- Bare earth or crumbling banks due to erosion from walkers/dog walkers.

[I] Slow flowing current or static water

Score1 here if:-

- There is no current; **or**
- Under normal conditions (i.e. during periods of flooding, immediately after heavy rains or periods of extended drought) the water flow is slow to moderate.

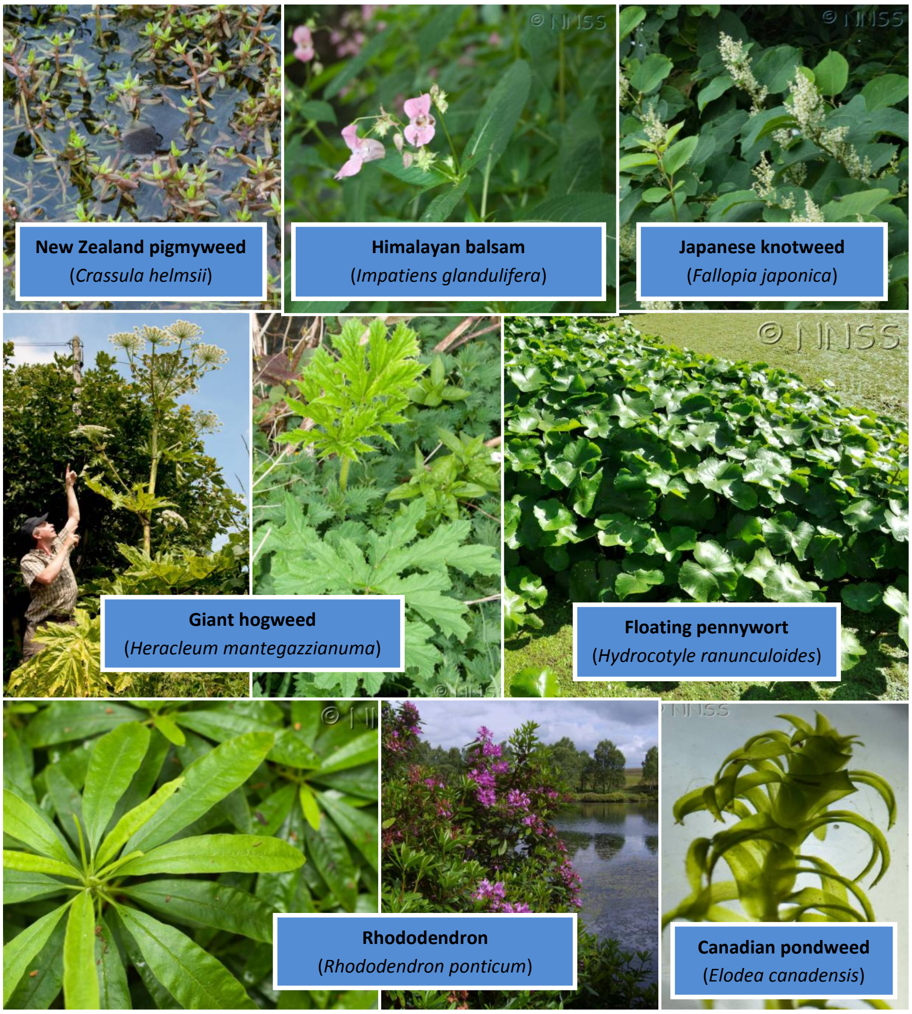
Notes

Water voles can swim, but are not well adapted to a life in the water and are not strong swimmers. They do not cope well with strong or rapid currents. To help gauge the speed of the current it may be useful to drop a twig or something similar into the channel and see how fast it travels downstream.

Interpreting the results

[j] Invasive non-native plant species absent (Japanese knotweed, Himalayan balsam)

If non-native plant species are not observed along the bank then Score 1. Score 0 here if any of the non-native invasive plant species pictured below are present along the bankside or within the water.



10.2. Appendix B.

10.2.1. Plot 1 survey sheet

WATER VOLE HABITAT SUITABILITY ASSESSMENT										
BACKGROUND INFORMATION					**Date**			01.12.17		
Site Location	PLOT 1 - Glenkiln Burn / Pumro Fell				**Grid Square Number**			NY0192		
HABITAT SUITABILITY (Score 1 if feature present)	**Section number as indicated on map**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
[a] Well developed (>60%) bankside and aquatic vegetation that provides suitable food and cover	1	1	1	1	1	1				
[b] A good variety of food plants including favoured plants and winter food sources	1	1	1	1	1	1				
[c] Suitable refuge areas above extremes in water levels	1	1	1	1	1	1				
[d] Soft, earth banks suitable for burrowing (30° to 60° slope)	0	1	1	1	0	0				
[e] Water permanently present (water level stable and does not dry up)	1	1	1	1	1	0				
[f] Open water available for swimming	1	1	0	0	0	0				
[g] Ledge of berm present at or close to water level	1	1	1	1	1	0				
[h] Lack or damage or erosion to the banks	1	1	1	1	1	1				
[i] Slow flowing current or static water	0	0	1	1	0	0				
[j] Invasive non-native plant species absent	1	1	1	1	1	1				
HABITAT ASSESSMENT SCORE (Total score of features present)	**8**	**9**	**9**	**9**	**7**	**5**				
Habitat	SR	SR	SR	SR	SR	SR				
Bordering land use	CW BW	CW BW	CW BW	CW BW	CW BW	CW BW				
Dominant vegetation type	TR H TG	TR H	TR H TG	TR H TG	TR H TG	TR H TG				
Channel substrate	CO GP	CO GP	CO GP	CO GP	CO GP	CO GP				
Other Wildlife Records										
Bracken, Digitalis, Juncus spp., woodrush, bramble.										

Table 11 Habitat Suitability Assessment: Plot 1

10.2.2. Plot 2 survey sheet

WATER VOLE HABITAT SUITABILITY ASSESSMENT										
BACKGROUND INFORMATION					**Date**		08.02.18			
Site Location	PLOT 2 - Car park and riverside				**Grid Square Number**		NX9890			
HABITAT SUITABILITY (Score 1 if feature present)	**Section number as indicated on map**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
[a] Well developed (>60%) bankside and aquatic vegetation that provides suitable food and cover	1	1	1	1	1	1	1	1	1	
[b] A good variety of food plants including favoured plants and winter food sources	1	1	1	0	1	1	1	1	1	
[c] Suitable refuge areas above extremes in water levels	1	1	1	1	1	1	1	1	1	
[d] Soft, earth banks suitable for burrowing (30° to 60° slope)	1	1	1	1	1	1	1	1	1	
[e] Water permanently present (water level stable and does not dry up)	0	1	1	0	1	0	1	1	1	
[f] Open water available for swimming	0	1	1	1	1	0	1	1	1	
[g] Ledge of berm present at or close to water level	1	1	1	1	1	1	1	1	1	
[h] Lack or damage or erosion to the banks	1	0	0	1	1	1	0	1	1	
[i] Slow flowing current or static water	1	0	0	1	0	1	0	1	0	
[j] Invasive non-native plant species absent	1	1	1	1	1	1	1	1	1	
HABITAT ASSESSMENT SCORE (Total score of features present)	**8**	**8**	**8**	**8**	**9**	**8**	**8**	**10**	**9**	
Habitat	SR	SR	SR	P	SR	SR	SR	P	SR	
Bordering land use	BW	BW CW	BW CW	BW CW	BW CW	CW	BW CW	BW G GZ	CW	
Dominant vegetation type	BR H TR	BR H RS TG TR	BR H RS TG TR	BR H RS TG TR	H TG TR	H SW TG TR	TR	RS TG TR	TR	
Channel substrate	GP SI	CO	CO GP	SI CL	CO	GP SI	GP	SI	GP	
Other Wildlife Records										
Potential water vole burrows at 8. Species-typical feeding lawn and droppings identified.										

Table 12 Habitat Suitability Assessment: Plot 2

10.2.3. Plot 3 survey sheet

WATER VOLE HABITAT SUITABILITY ASSESSMENT										
BACKGROUND INFORMATION				Date			08.02.18			
Site Location	PLOT 3 - Goukstane Burn			Grid Square Number			NX9690			
HABITAT SUITABILITY (Score 1 if feature present)	**Section number as indicated on map**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
[a] Well developed (>60%) bankside and aquatic vegetation that provides suitable food and cover	1	1	1	1	1	1	0	0		
[b] A good variety of food plants including favoured plants and winter food sources	1	1	1	1	1	1	1	0		
[c] Suitable refuge areas above extremes in water levels	1	1	1	1	1	1	1	1		
[d] Soft, earth banks suitable for burrowing (30° to 60° slope)	1	1	1	1	1	1	1	1		
[e] Water permanently present (water level stable and does not dry up)	1	1	1	1	1	1	0	1		
[f] Open water available for swimming	1	0	0	0	1	1	0	0		
[g] Ledge of berm present at or close to water level	1	1	1	1	1	1	1	1		
[h] Lack or damage or erosion to the banks	1	1	1	1	1	1	1	1		
[i] Slow flowing current or static water	0	0	0	0	0	1	1	0		
[j] Invasive non-native plant species absent	1	1	1	1	1	1	1	1		
HABITAT ASSESSMENT SCORE (Total score of features present)	**9**	**8**	**8**	**8**	**9**	**10**	**7**	**6**		
Habitat	SR	SR	SR	SR	SR	SR	SR	SR		
Bordering land use	BW	CW H	CW H	BW CW H	BW H	CW H	CW	CW		
Dominant vegetation type	BR SG TR	BR TG TR	BR TG TR	BR TG TR	H SG SW TR	H SW TG TR	TR	TR		
Channel substrate	CO	GP	GP	GP SI	CO GP	GP SI	GP SI	GP SI		
Other Wildlife Records										
Red-legged partridge startled at 4. Many rodent-like holes in bank of river at 6 – possibly field vole? Evidence of feeding on the riverbank at 6, including vegetation cut at a 45-degree angle.										

Table 13 Habitat Suitability Assessment: Plot 3

10.2.4. Plot 4 survey sheet

WATER VOLE HABITAT SUITABILITY ASSESSMENT										
BACKGROUND INFORMATION						**Date**		08.02.18		
Site Location	PLOT 4 - Well Cleuch					**Grid Square Number**		NX9592		
HABITAT SUITABILITY (Score 1 if feature present)	**Section number as indicated on map**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
[a] Well developed (>60%) bankside and aquatic vegetation that provides suitable food and cover	1	1	1	1	1	1				
[b] A good variety of food plants including favoured plants and winter food sources	1	1	1	1	1	0				
[c] Suitable refuge areas above extremes in water levels	1	1	1	1	1	1				
[d] Soft, earth banks suitable for burrowing (30° to 60° slope)	1	1	1	1	1	1				
[e] Water permanently present (water level stable and does not dry up)	1	1	1	1	1	1				
[f] Open water available for swimming	0	1	1	1	1	1				
[g] Ledge of berm present at or close to water level	1	1	1	1	1	1				
[h] Lack or damage or erosion to the banks	1	1	1	1	1	1				
[i] Slow flowing current or static water	0	0	1	1	1	1				
[j] Invasive non-native plant species absent	1	1	1	1	1	1				
HABITAT ASSESSMENT SCORE (Total score of features present)	**8**	**9**	**10**	**10**	**10**	**9**				
Habitat	SR	SR	SR	SR	SR	SR				
Bordering land use	BW CW	CW H PB	CW H PB	CW H PB	CW H PB	CW				
Dominant vegetation type	BR H SG TR	BR H SG TR	BR H SG TR	BR H SG TR	TG TR	RS SG TR				
Channel substrate	GP	GP	GP	GP SI	GP SI	GP SI				
Other Wildlife Records										

Table 14 Habitat Suitability Assessment: Plot 4

10.2.5. Plot 5 survey sheet

WATER VOLE HABITAT SUITABILITY ASSESSMENT										
BACKGROUND INFORMATION					Date		15.02.18			
Site Location	PLOT 5 - Tod Slack/Morins Hill				Grid Square Number		NX9694			
HABITAT SUITABILITY (Score 1 if feature present)	Section number as indicated on map									
	1	2	3	4	5	6	7	8	9	10
[a] Well developed (>60%) bankside and aquatic vegetation that provides suitable food and cover	1	1	1	1	1	1				
[b] A good variety of food plants including favoured plants and winter food sources	0	1	1	1	1	1				
[c] Suitable refuge areas above extremes in water levels	1	1	1	1	1	1				
[d] Soft, earth banks suitable for burrowing (30° to 60° slope)	1	1	1	1	1	1				
[e] Water permanently present (water level stable and does not dry up)	1	1	1	1	1	1				
[f] Open water available for swimming	1	1	1	1	1	1				
[g] Ledge of berm present at or close to water level	1	1	1	1	1	1				
[h] Lack or damage or erosion to the banks	1	1	1	1	1	1				
[i] Slow flowing current or static water	1	1	0	0	0	0				
[j] Invasive non-native plant species absent	1	1	1	1	1	1				
HABITAT ASSESSMENT SCORE (Total score of features present)	**9**	**10**	**9**	**9**	**9**	**9**				
Habitat	SR	SR	SR	SR	SR	SR				
Bordering land use	CW	CW PB	CW BW	CW BW	CW BW	CW BW				
Dominant vegetation type	H SG TR	RS TG	RS TR TG	RS TR TG	RS TR TG	RS TR TG				
Channel substrate	Si	Si	CO GP	CO GP	CO GP	CO GP				
Other Wildlife Records										
Buzzard flying overhead at stretch 4. **Badger tracks identified at stretch 4.**										

Table 15 Habitat Suitability Assessment: Plot 5

10.2.6. Plot 6 survey sheet

WATER VOLE HABITAT SUITABILITY ASSESSMENT										
BACKGROUND INFORMATION					Date			15.02.18		
Site Location	SAMPLE PLOT 6 – Murray Cleuch				Grid Square Number			NX9894		
HABITAT SUITABILITY (Score 1 if feature present)	Section number as indicated on map									
	1	2	3	4	5	6	7	8	9	10
[a] Well developed (>60%) bankside and aquatic vegetation that provides suitable food and cover	1	0	0	1	1	1	1			
[b] A good variety of food plants including favoured plants and winter food sources	1	1	1	1	1	1	1			
[c] Suitable refuge areas above extremes in water levels	1	1	1	1	1	1	1			
[d] Soft, earth banks suitable for burrowing (30° to 60° slope)	1	1	1	1	1	1	1			
[e] Water permanently present (water level stable and does not dry up)	1	1	1	1	1	1	1			
[f] Open water available for swimming	1	0	0	0	1	1	1			
[g] Ledge of berm present at or close to water level	1	1	1	1	1	1	1			
[h] Lack or damage or erosion to the banks	1	1	1	1	1	1	1			
[i] Slow flowing current or static water	0	0	0	0	0	0	0			
[j] Invasive non-native plant species absent	1	1	1	1	1	1	1			
HABITAT ASSESSMENT SCORE (Total score of features present)	**9**	**7**	**7**	**8**	**9**	**9**	**9**			
Habitat	SR	SR	SR	SR	SR	SR	SR			
Bordering land use	CW	CW	CW	CW	CW	CW	CW			
Dominant vegetation type	SG TR	TR BR	TR BR	TR BR	SG TR	TR TG	TR TG			
Channel substrate	CO	GP	GP	GP	CO	GP	GP			
Other Wildlife Records										

Table 16 Habitat Suitability Assessment: Plot 6

10.3. Appendix C.

10.3.1. Habitat information codes

HABITAT INFORMATION CODES							
Habitat		**Bordering land use**		**Dominant vegetation**		**Channel substrate**	
Ditch	D	Permanent/temporary grass	G	Bankside trees	TR	Not visible	NV
Pond	P	Mixed broadleaf woodland	BW	Bushes	B	Bedrock	BE
Canal	C	Conifer woodland	CW	Bramble	BR	Cobble	CO
Lake	L	Peat bog	PB	Herbs	H	Gravel/pebble	GP
Marsh/bog	MB	Arable crop	A	Submerged weeds	SW	Silt	SI
Stream/river	SR	Urban/industrial	U	Reeds/sedges	RS	Clay	CL
Reservoir	R	Park/garden	P	Tall grass	TG	Artificial	AR
Gravel pit	G	Heath	H	Short grass	SG		
		Fen	F				
		Cattle/grazed	GZ				
		Bank fenced	FN				

Table 17. Habitat information codes. Adapted from Harris *et al*., (2009).