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An assessment of the local impact of native predators on an established population of British water voles (*Arvicola terrestris*)

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Abstract

There is a considerable amount of literature on the diet and effect of feral American mink *Mustela vison* on the distribution and abundance of water voles *Arvicola terrestris* in Britain. Few recent studies, however, have attempted to examine the occurrence of water voles in the diets of native predators. Fox *Vulpes vulpes* scat and grey heron *Ardea cinerea* pellets were collected during winter 2003–2004 at a location known to contain a large number of water voles. These scats and pellets were subsequently analysed to determine the frequency of water vole occurrence in the diet of these opportunistic predators. Water vole remains were found in 30% of fox scats analysed and accounted for 13% of the total weight of scats. A total of 18% of heron pellets contained the fur of water voles in addition to the fur of four other rodent species. The potential role of native predators in the loss and fragmentation of site-specific populations of water voles in Britain is further discussed.

Key words: *Ardea cinerea*, *Arvicola terrestris*, *Mustela vison*, *Vulpes vulpes*, scat analysis

INTRODUCTION

The water vole *Arvicola terrestris* is arguably one of Britain's most threatened mammalian species. A considerable amount of effort has been devoted over the past 20 years in determining and alleviating the primary cause(s) of this species' dramatic reduction in distribution (Strachan & Jeffereies, 1993; Strachan, 1998). There is now little doubt that the cumulative loss and fragmentation of substantial areas of riparian and wetland habitat over the past 100 years has been the primary cause of the decline of the water vole (Lawton & Woodroffe, 1991; Jefferies, 2003).

Despite some initial controversy (e.g. Birks, 1990), the predatory impact of introduced American mink *Mustela vison* has also been strongly implicated in recent localized extinctions of water voles (Woodroffe *et al*., 1990; Strachan *et al*., 1998). Past European studies on the foraging behaviour of feral American mink have shown that water voles constitute a variable proportion of this predator's diet (Strachan & Jefferies, 1996; Strachan *et al*., 1998; Macdonald *et al*., 2002; Carter & Bright, 2003). Although there is now little doubt as to the potential impact of this non-native species on an already fragmented national population of water voles (Barreto, Macdonald & Strachan, 1998), no recent study has attempted to assess the localized impact of native predators on water vole colonies. A large number of British mammalian and avian species has been recorded as preying upon water voles (Strachan & Jefferies, 1993). Dietary studies on some of these predators (e.g. badger *Meles meles*, polecat *Mustela putorius* and kestrel *Falco tinnunculus*) have revealed that water voles seem to be taken infrequently and opportunistically (Cramp & Simmons, 1980*a*; Neal, 1986; Blandford & Walton, 1991).

Water voles contribute a relatively large proportion (>10%) of the diet of several European species including grey heron *Ardea cinerea*, barn owl *Tyto alba* and red fox *Vulpes vulpes* (Glue, 1974; Howes, 1979; Cramp & Simmons, 1980*b*; Love *et al*., 2000). Owing to the precarious situation that most water vole colonies are currently facing, it is essential that the foraging behaviour of native predators be assessed to determine the potential impact that these animals may have on the survival of water vole colonies. Evidence from several studies also suggests that water voles are highly susceptible to predation during the winter months (Stoddart, 1971; Woodroffe, 1988; Carter & Bright, 2003). The aim of this study was, therefore, to assess the impact of two common opportunistic predators (red fox and grey heron) on a substantial population of water voles at a wetland site in South Wales (U.K.) at this critical time of year.

METHODS

Study locations

The study was undertaken between November 2003 and January 2004 at the 300 acre (1.21 km^2) National Wetlands

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Centre Wales (NWCW), Carmarthenshire, South Wales. This location (grid reference SN 542 983) is a recently created, internationally important wetland reserve situated on the Loughor estuary, containing a wide diversity of wetland habitats (Forman, 2001, 2003).

Scat and pellet collection

Before the study, all fox faeces (scats) and heron pellets from the study site were collected and disposed of. Fox scats were collected once per month over the study period (a total of 3 collection days) by walking along major linear features including hedgerows, ditches and paths. The total distance surveyed for scats was estimated at *c.* 16 km. Heron pellets were also collected once per month from pathways and bridges that had been previously identified as being regularly used by foraging herons. Scats and pellets were placed in individually labelled plastic bags and subsequently frozen at −17 °C until analysis could be undertaken.

Scat and pellet analysis

Scats and pellets were oven-dried at 70 °C for 48 h (Corbett, 1989), and their dry mass recorded. Each individual scat and pellet was washed separately through 1.7 mm, 600 μm and 212 μm sieves and the residues air-dried. Owing to the lack of hard prey remains in the heron pellets, a total of 30 individual mammalian hairs was selected (where present) from each pellet and all feather remains were discarded. These hairs were subsequently identified to species level using keys produced by Day (1966) and Teerink (1991). The constituents of each fox scat (positively identified by the presence of fox hair in each scat) were identified to the lowest possible taxon using keys produced by Corbet (1964), Day (1966), Teerink (1991), Yalden & Morris (1993), Brown *et al.* (1999), and a previously amassed reference collection of bones, fur and feathers.

The occurrence of each prey type was expressed as presence or absence within diet and % frequency of occurrence (the number of occurrences of that category ×100 divided by the sum of the occurrences of all the categories in the sample). Such methods have previously been shown to describe the relative importance of different prey types (Beja, 1991). Frequency of occurrence analysis is known to overestimate the importance of incidental prey and underestimate common prey types (Watt, 1995). Percentage weight contribution (%Wc) of each prey type was, therefore, calculated from the dry weight of each scat and the proportions of each prey type found therein. Prey types were assigned to the following categories: mammalian (rodents and lagomorphs), birds (passerine and non-passerine), invertebrates (coleopterans, annelids and arthropods), vegetation (grasses, fruits and seeds) and other (plastics, stones, food of human origin, other non-digestible items).

An assessment of the local impact of native predators and mink was undertaken by reviewing the available literature on this subject. Only those sources quoting specific numerical data were included in this review and national estimates of water vole predation were excluded on the basis that local trends would not be apparent in such sources. Statistical analysis of proportional data was conducted using one-way *G*-tests of homogeneity (including William's correction factor) as this method has greater robustness than more commonly used tests of homogeneity (Fowler & Cohen, 1990).

Table 1. Frequency of occurrence data of major prey types recorded in fox *Vulpes vulpes* scats ($n = 118$ scats) at the study site

Prey categories	Frequency of occurrence (%)
Mammals	89.8 ($n = 106$)
Birds	72.9 ($n = 86$)
Invertebrates	23.7 ($n = 28$)
Vegetation	91.5 ($n = 108$)
Miscellaneous	40.7 ($n = 48$)

RESULTS

Contents of fox scats collected at NWCW

A total of 118 fox scats was collected and analysed. Table 1 summarizes the frequency of occurrence of main prey types recorded over the duration of the study. Mammalian prey featured heavily in the diet of foxes foraging at NWCW with field voles *Microtus agrestis* frequently occurring in most of the scats collected at this site. Water vole remains occurred in 30.5% of fox scats collected at NWCW and contributed to 13% by weight of all scats examined at this site. There were significant differences in the occurrence of individual rodent species in the scats ($G_4 = 86.2$, $P < 0.0001$). Other significant prey at this location included rabbits *Oryctolagus cuniculus* and Rallidae (moorhen and coot) (Table 2).

Presence of mammalian fur in heron pellets

Of the 124 heron pellets collected and analysed, 47.6% ($n = 59$) contained mammalian fur. Five rodent species were identified. Frequency of occurrence data of this analysis is presented in Table 3.

Water vole fur was recovered from a greater number of heron pellets than any other rodent species. The proportion of fur of each rodent species recovered from heron pellets differed significantly ($G_4 = 25.1$, $P < 0.0001$).

The occurence of water voles in the diet of mink and native British predators

The limited numerical data available for Britain on the local diets (frequency of occurrence) of local feral mink and named native predators is presented in Table 4. Data presented in Fig. 1 illustrate the proportion of radio-tracked water voles predated by specific predators (Woodroffe *et al.*, 1990; Jordan & Netherton, 1999;

Table 2. Frequency of occurrence and weight data of prey items recorded in fox *Vulpes vulpes* scats ($n = 118$ scats) collected from the National Wetlands Centre Wales

Prey category	Occurrence	% occurrence	Weight (g)	% weight
Rodents				
Field vole *Microtus agrestis*	66	55.9	42.46	32.3
Water vole *Arvicola terrestris*	36	30.5	17.2	13.1
Bank vole *Clethrionomys glareolus*	22	18.6	7.34	5.6
Brown rat *Rattus norvegicus*	6	5.1	2.32	1.8
Unidentified rodent remains	8	6.7	12.14	9.2
Lagomorph				
Rabbit *Oryctolagus cuniculus*	24	20.3	7.5	5.7
Brown hare *Lepus europaeus*	8	6.7	1.7	1.3
Birds				
Moorhen *Gallinula chloropus*	14	11.9	2.1	1.6
Coot *Fulica atra*	6	5.1	1.68	1.3
Unidentified rallidae	30	25.4	4.04	3.1
Mallard *Anas platyrhynchos*	12	10.2	7.94	6.0
Widgeon *Anas penelope*	2	1.7	3.88	3.0
Lapwing *Vanellus vanellus*	2	1.7	1.00	1.8
House sparrow *Passer domesticus*	2	1.7	0.02	0.02
Unidentified bird remains	20	16.9	3.32	2.5
Reptile				
Unidentified snake	2	1.7	1.34	1.0
Invertebrate				
Beetles (Coleoptera spp.)	10	8.5	0.06	0.5
Other arthropods	4	3.4	0.04	0.3
Annelid spp.	16	13.6	1.54	1.2
Vegetation				
Grasses	100	84.7	4.96	3.8
Fruit and seeds	8	6.7	4.06	3.1
Other				
Plastic	40	33.9	1.24	0.9
Stones	4	3.4	0.52	0.4
Miscellaneous	14	11.9	3.02	2.3

Table 3. Summary of the overall frequency of occurrence and ranking of rodent fur recovered from heron pellets ($n = 124$ pellets) collected over the duration of the study

Rodent species	% frequency of occurrence	Rank
Water vole	17.7 ($n = 22$)	1
Field vole	13.7 ($n = 17$)	2
Wood mouse	6.7 ($n = 12$)	3
Bank vole	4.8 ($n = 6$)	4
Brown rat	1.6 ($n = 2$)	5

Carter & Bright, 2003). Note that in Jordan & Netherton's (1999) study, no mink were present in their study site (see Fig. 1). The 'unknown mustelid' category refers to otter *Lutra lutra*, stoat *M. erminea* and some possible unconfirmed mink kills (Carter & Bright, 2003). Clearly, a significant number of water voles is taken locally by a variety of native species including various mustelids, domestic dog, barn owl and heron in addition to those consumed by feral mink.

DISCUSSION

My results clearly indicate that foxes at the NWCW have a highly varied diet and that field voles form a critical component of the prey base of this predator. Such findings are in agreement with numerous studies conducted on fox diet throughout Europe (e.g. von Schantz, 1980; Dyczkowski & Yalden, 1998; O'Mahony *et al*., 1999; Goldyn *et al*., 2003). Of particular interest, however, is the relatively high presence of water vole remains in the scats of foxes foraging at NWCW (see also Howes, 1979; Lloyd, 1980). This is unsurprising given the previously established functional relationship between the fox's diet and water vole availability in continental Europe (Weber & Aubry, 1993; Ferrari & Weber, 1995) and the fox's ability to home in on one particular prey type (Green, 2002). This finding does, however, emphasize the likelihood that foxes are consuming considerable numbers of water voles in Britain. Moreover, this study importantly demonstrates that water vole remains occur in fox scats at a frequency approximately equal to or greater than that recorded in most dietary studies on American mink in Europe (e.g. Sidorovich *et al*., 1998; Strachan *et al*., 1998; Macdonald *et al*., 2002; but see also Strachan & Jefferies, 1996). Extrapolating from biomass consumption calculations produced by von Schantz (1980), it is possible to estimate (albeit crudely) that an individual fox could potentially consume between 10 and 20 water voles per year. Although this value seems to be relatively low, any additional attrition to existing fragmented water vole populations may have potentially serious consequences for the long-term viability of water vole metapopulations

Table 4. The local occurrence of water voles *Arvicola terrrestris* in the diets of named British predators

Predator	Frequency of occurrence (%)	County/area	Source
Otter	0.5	Somerset	Webb (1977)
	14	Deeside	Jenkins, Walker & McCowan (1979)
	2.8	Gwynedd	D. W. Forman (pers. obs.)
	5.9	Gwynedd	D. W. Forman (pers. obs.)
Mink	3.3	Devon	Chanin & Linn (1980)
	13	Central and southern England	Strachan *et al*. (1998)
Fox	20	Yorkshire	Howes (1979)
	30	Carmarthenshire	This study
Heron	91	England	Lowe (1954)
	17	Carmarthenshire	This study
Barn owl	12	Yorkshire	Glue (1974)
	15	Norfolk	Glue (1974)
	16	Somerset	Glue (1974)
	35	Kent	Glue (1974)
	14	Southern England	Love *et al*. (2000)

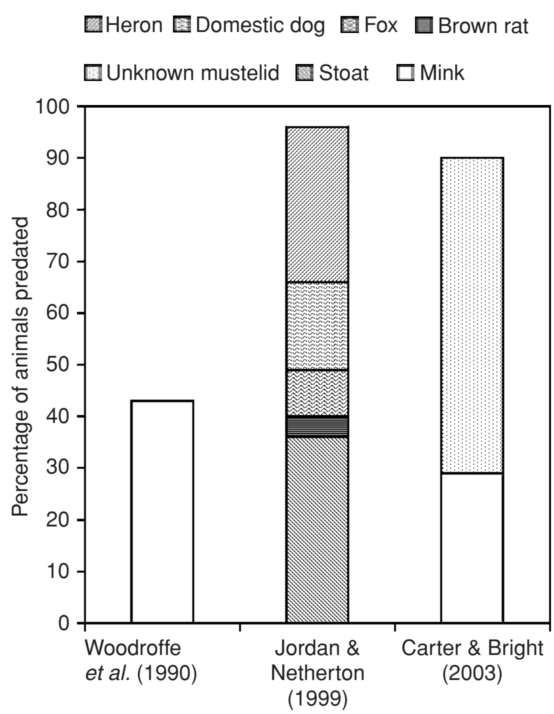

Fig. 1. Proportion of radio-tracked water voles *Arvicola terrestris* predated by specific carnivores recorded during three independent British studies.

(Aars *et al*., 2001). With the British fox population being estimated in 1995 to be in the region of 240 000 animals (Harris *et al*., 1995), the potential impact of the fox on isolated, low-density water vole colonies should not be underestimated, particularly in areas with low mink abundance.

Previous researchers on continental Europe have noted that the fossorial form of water vole spends a considerable amount of time underground during the winter period (e.g. von Schantz, 1980). Accordingly, the contribution of this rodent to the diet of continental mammalian and avian predators decreases during winter. In contrast, water voles at NWCW were active above ground all year round where suitable vegetative cover persisted (Forman, 2003). Such behaviour presumably increases the risk of predation in winter and may account for the high occurrence of water voles in the diet of both fox and heron at this location. Similarly, Carter & Bright (2003) recorded that the winter predation rate of water voles at a number of reedbed sites in England exceeded 60%, suggesting that animals at their study location were also active above ground during the winter.

Approximately one in five heron pellets analysed contained water vole fur as well as the fur of a variety of other rodent species. This finding concurs with past studies from continental Europe that have investigated the diet of this predominately piscivorous species (Cramp & Simmons, 1980*b*; Peris, Briz & Campos, 1995). This is the first study to determine the frequency of water vole predation by British herons since Lowe's (1954) study in which 91% of pellets examined contained water vole remains. The digestive system of herons is extremely efficient and regurgitated pellets often contain only a variable proportion of the matter that the bird actually ingests (Strachan & Jefferies, 1993). Because of this it is possible that pellet analysis may overestimate the true occurrence of mammalian prey items in the diet of grey herons. Despite this potential source of error, it is clear that herons are extremely successful and skilful hunters (Lekuona, 2002), often returning to the same sites to forage (pers. obs.). Such behaviour is likely to have an acute and chronic effect on patch-specific water vole distribution and abundance. As water voles seem to be unable to assess predation risk from terrestrial predators (Carter & Bright, 2003), it seems unlikely that they are able to assess the risk of heron predation. The British population of herons is slowly increasing over time and is currently estimated at 14 000 breeding pairs (Crick *et al*., 2004). It is probable that the highly localized presence of a large number of these adaptable predators is responsible for a considerable amount of water vole predation that is, as yet, unquantified by any study to my knowledge (but see Jordan & Netherton, 1999). Studies should therefore be undertaken to investigate the long-term impact of this predator within the context of fragmented water vole populations. Such work should include assessing the viability and accuracy of different methodologies for determining the diet in herons (Carrs *et al*., 1997).

There seems to be a tremendous bias against mink within the scientific and popular press when appropriating blame for the loss of water vole colonies. Whilst I do not doubt the serious impact of this non-native predator within the British ecosystem, the cumulative role of our own native predators in localized water vole declines has, by and large, been overlooked. This study and data presented from previous studies clearly illustrate that generalist native predators consume significant numbers of water voles (when present). Whilst the relationship between these predators and rodents are historically established (cf. American mink), the potential reduction of water vole numbers in an already fragmented landscape could have serious implications for the recovery of local populations in the absence of mink as well as increasing the rate of colony elimination in areas where mink are present. Macdonald, Mace & Barretto (1999) modelled the persistence and extinction potential of an endangered British species (red grouse *Lagopus lagopus scoticus*) when exposed to native predators, stochastic events and invasive predators (e.g. mink). Their simulations revealed that small populations of endangered species can be extremely vulnerable to the impact of native predators when they are consumed at a constant rate, when predation occurs across all prey age classes and when prey populations are highly fragmented. It is highly probable that a significant proportion of water vole colonies within Britain experience these conditions at the current time. For example, it has been demonstrated that water vole predation by foxes remains constant when the voles are present at low densities (Artois & Stahl in Weber & Aubry, 1993; Ferrari & Weber, 1995) and that most water vole populations are small and highly fragmented (Jefferies, 2003). In the face of expanding British fox and, to a lesser extent, heron populations, tough choices concerning predator control may have to be made by conservation managers on a site-specific basis if local water vole meta-population structures are to persist.

Both Jordan & Netherton (1999) and Carter & Bright (2003) noted that a wide variety of mustelids and other predators actively predated water voles although the exact culprits were not always identified (Fig. 1). It is clear from data presented in Table 4 that water voles occur in the diet of otters and stoats at variable frequencies. It should be noted, however, that many studies investigating otter diet fail to identify mammalian prey to species level. It is possible, therefore, that the localized predation of water voles by otters is greatly underestimated. I have also encountered two instances over the past 2 years in which otters have dug out water vole burrows, presumably to obtain prey. Such active pursuit of water voles is not dissimilar to the behaviour of mink when observed foraging for water voles (Strachan & Jefferies, 1993). Owing to the diversity of native predators in Britain it would be prudent to examine, simultaneously, the diet and behaviour of each predator guild (including American mink) in conjunction with studies of water vole populations in a variety of habitat types. This type of study would allow the investigation of the relationship between interspecies competition, resource partitioning, local predator impact and the survival of water vole colonies. Such information would facilitate a greater understanding of some of the ecological mechanisms determining the survival of water vole colonies (Aars *et al*., 2001; Telfer *et al*., 2001).

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