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Visions of nature

For a young child, nature can be exciting, providing endless opportunities to play and discover its diversity. There are many ways to trigger and develop children's interest in nature. Regular visits to an interesting area, for instance, can spark a familiarity and a growing curiosity and knowledge about the place. A parent, a teacher or a friend might play an important role here, or even a book. The child's curiosity may be sparked by the experience of camping, hiking or cycling; or an encounter with a squirrel or a bird of prey, or maybe the smell and colours of grassland flowers on a summer's day.

Later in life, childrens' interests change. As they grow older they may find nature to be quiet and boring, the slow pace of change and the dominance of dull shades of, mainly, green and brown, may well be less attractive than the more exciting and colourful entertainments provided by computer games and television. By the time they have reached puberty, most have lost their interest in nature. But a minority carry this interest further, usually inspired by one of a couple of factors. Nature's aesthetic and emotional appeal may play a role; or curiosity to learn more about the animals and plants discovered in childhood.

An example of the first type of inspiration is the recently launched movie De Nieuwe Wildernis [The New Wilderness], about one of the Netherlands' most important wetland reserves, the Oostvaardersplassen. This overwhelmingly popular movie frequently evokes applause from the audience – a rare occurrence in Dutch cinemas. The images in the film are not just breathtaking: for many people they present a totally new view of nature in the Netherlands. Many viewers seem surprised that this is actually filmed in their own country. The stars of De Nieuwe Wildernis are the koniks and red deer, large groups of which roam the area. It covers the four seasons and the cycles of life and death in the Oostvaardersplassen and gives some good examples of how small ecosystems are interconnected in a larger ecosystem. It is, in many ways, a classical traditional documentary, based on beauty, drama, spectacle, and even a little humour. In this movie, nature is the theatre with the animals as its willing actors.

De Nieuwe Wildernis's vision of nature in the Netherlands, however, is one-sided, with a strong emphasis on aesthetics and emotions. The film largely ignores the ongoing debates about whether or not weaker animals should be given supplementary food in severe winters, left to perish or be culled; and whether or not the wolf should be introduced, or allowed to enter the area on its own, to complete the ecosystem. There is even a name for this kind of incomplete human-affected nature: 'novel ecosystem', illustrating that we are still not fully aware of its precise character.

The second type of inspiration can be illustrated by the ongoing Dutch mammal atlas project, which involves the work of many people, mainly volunteers. Publication of the end result, a new book on the distribution of wild mammals in the Netherlands, is in progress. The new mammal atlas demonstrates another way in which we can deal with, and relate to, nature around us. Early childhood contacts with nature can be followed up with further study, eventually leading to more or less systematic observation. The next logical phase is the interpretation of the data, with the ever-developing insights and discussions about the surveying methods and techniques used and how the results are interpreted. Finally, this can contribute to theories about, and also the practical consequences of, a particular aspect of, say, the biology of a species, the phylogenetic relationships within species groups or material flows within an ecosystem.

The realisation of the new mammal atlas of the Netherlands is the result of many enthusiasts surveying meticulously from day to day (and from night to night!) the spatial distribution and numbers of wild mammals. Opportunistic observations, targeted monitoring programmes, recorded traffic victims, bycatches in control programmes, hunting statistics, etc., have provided a further wealth of information. The Mammal Society and all the volunteers involved in its preparation have their hands full with of completing the atlas right now. We look forward to the results of their work.

What is it that drives us to accomplish such projects? Primarily of course it is curiosity, and when we channel this curiosity together, we can achieve a lot more than working alone, finding answers to questions and raising new ones. For example, we are curious whether certain species will be able to persist and what new species might arrive in the Netherlands. At present, fortunately, the state of the mammals native to the Netherlands appears to be generally positive. But there are still species, such as the common hamster and the bottlenose dolphin, which need special attention.

The contents of this issue relate to the more reflective vision of nature discussed above. Two papers are based entirely on observations of one single animal. The finding of a dead wolf on a roadside in the central part of the Netherlands generated a lot of media attention. The initial interpretation of this find had to be reconsidered after a thorough examination of the carcass. The use of state-of-the-art research methods allowed Gravendeel, de Groot & Kik et al. to properly reconstruct the wolf's origin; their examinations brought the authors to their surprising, new and final, conclusions, illustrating their open minds and sincerity. Another observation shows the same questioning spirit: Margry thinks it is likely that a taiga shrew, found outside its known habitat and distribution area in Norway, was dropped by a bird of prey.

Less spectacular, but of important practical use, is a new method, developed through experimentation by van Boekel for minimising mortality among shrews caught in traps as part of population surveys. Keeping them alive in their trap for as long as necessary, still can (and should) be improved. Van Boekel's experiments show how this can be done.

Van Adrichem et al. present the results of their research on brown rats in Amsterdam, showing that houses built before 1960 are more amenable to rats than more recently constructed houses, and that rats prefer urban green spaces. These and the other findings of this study are of practical use for the control and prevention of rats in urban environments, without the use of rodenticides. Dekker et al.'s study of Geoffroy's bats and how females of the species use the landscape led the authors to propose a number of practical recommendations for better protection of this rare species in the Netherlands. Finally, Hovens and

Rijkers investigate the origins of the Exmoor pony in England. They argue that Exmoor ponies may be considered as a wild type of horse, not a man-made breed. Most likely, these are not the final words on this subject.

The two – out of many! – ways of dealing with nature mentioned above are quite different. Roughly speaking, they could be spoken of as the emotional and the rational approach. Perhaps it should be considered as a challenge to confront, or even merge, the two approaches with each other. The emotional approach can be strengthened by paying attention to problems, facts, debate and solutions. Conversely, the rational approach can benefit if there is room for passion and commitment and, now and then, for some speculation.

Finally, we are happy to announce that two new editors, from very different backgrounds, have joined the board of *Lutra*. Marine biologist Meike Scheidat has dedicated most of her work to marine mammals, especially whales. She completed her PhD at Kiel University on the abundance, habitat use, behaviour and management of humpback whales in Ecuador. Maurice La Haye has been an expert on rodents for many years. He is currently working as a project manager at the Dutch Mammal Society and will soon defend his thesis on field experiments focussed on guaranteeing the survival of the common hamster in southern Limburg. Both Meike and Maurice are warmly welcomed to the editorial board!

Kees J. Canters and Ben Verboom


BRUINE RAT

Factors influencing the density of the brown rat (*Rattus norvegicus*) in and around houses in Amsterdam

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Abstract: The current strategy of the pest management department of the Public Health Service in Amsterdam is to identify causal factors in order to reduce the carrying capacity of pest populations and to minimise the use of pesticides. Rats have been controlled with rodenticides for decades, which has increased the survival of resistant rats. Rodenticide resistance has now been found in several rat populations in Europe. The main aim of this study was to establish the relationship between brown rat (*Rattus norvegicus*) occurrence in Amsterdam and a number of environmental and socio-economic factors. A second aim was to point out factors that can be managed by the local authorities as a next step towards prevention and pro-active, integrated pest management. The paper begins with a short overview of the biology of the brown rat, with an accent on diseases and habitat factors. The number of rat reports at the neighbourhood level during the years 2009-2012 is then related to 16 environmental and socio-economic variables including availability of water, availability of urban green space, sewer type, construction year of houses, property tax value, number of inhabitants and population composition. A generalised linear model was used; it had a negative binomial distribution and all candidate models were fitted with a maximum of five terms. The most significant terms were number of inhabitants, percentage of area occupied by urban green space, the percentage of houses with a construction year before 1960, and either the length of foul water sewer (separated sewer) or the length of combined sewer. Rats have a short generation time and can produce a large number of offspring. A rat population is therefore able to recover quickly from a reduction in number. It is therefore important to change the carrying capacity of the habitat in which rats are unwanted. This can be achieved by changing the amount of food and cover they can find. The results of the regression analysis suggest that houses constructed before 1960 and their gardens could be evaluated to see if there may be general solutions that would make them less amenable to rats. Furthermore, the results suggest that the structure of urban green space may be adapted to make it less attractive to rats; an example of this would be to replace evergreen shrubs with deciduous shrubs and to mow high vegetation near buildings more frequently. Moreover, the influence of waste near and in urban green space should be investigated. Finally, we suggest that the inspection and maintenance of sewers be continued and that this should include the connection between properties and the public sewer.

Keywords: brown rat, *Rattus norvegicus*, urban ecosystems, houses, rat reports, GIS, multiple regression, urban green space, construction year, sewer.

Introduction

Cities like Amsterdam provide diverse urban ecosystems with habitats for many animal species; these include mammal species, such as red squirrel (*Sciurus vulgaris*), common mole (*Talpa europaea*), western hedgehog (*Erinaceus europaeus*), red fox (*Vulpes vulpes*) and western polecat (*Mustela putorius*). In urban ecosystems, brown rats (*Rattus norvegicus*) have a role as collectors of edible garbage and as food for mammal and bird predators. Amsterdam (area 219 km^2) with its canals, old houses and parks provides potentially optimal habitat for the brown rat population.

The appearance of the brown rat in Europe was first described in the 18th century. In contrast to its scientific name *Rattus norvegicus*, the brown rat is thought to have originated in Asia. In the 18th century it spread rapidly throughout Europe and the rest of the world. Rats are highly adaptive and can nowadays be found in many different habitats and under diverse climatic conditions. Rats can be the vector of life threatening diseases and they can cause nuisance by spoiling and infesting food supplies and by leaving behind faeces and urine. Moreover, they can cause damage through gnawing items such as electric wiring and by digging in and undermining the structure of dykes. In Amsterdam the Public Health Service (PHS) collects complaints about rats in and around houses. Nuisance rats are mainly controlled using anticoagulant rodenticides, at the expense of the municipality. Nevertheless, the number of rat complaints remains quite constant. A study by Glass et al. (2009) in Baltimore shows that urban rat populations appear remarkably resilient to perturbation from even substantial population reduction.

The continued use of rodenticides over several decades has increased the survival of resistant rats. Rodenticide resistance has now been found in several rat populations in Europe (e.g. Baert et al. 2012, Runge et al. 2012, Buckle 2013). Although no rodenticide resistance was found in Amsterdam in a recent study, resistance has been found in other parts of the Netherlands (van der Lee et al. 2012). The current strategy of the pest management department of the PHS in Amsterdam is therefore to identify causal factors in order to reduce the carrying capacity of pest populations and, by doing so, to minimise the use of pesticides. The carrying capacity can be reduced by removing food sources and by modifying the habitat. The use of a variety of measures in combination in order to prevent the development of pests is known as Integrated Pest Management or IPM. In order to maximise the impact of such measures it is important to understand the ecology of rats in the city and the role of environmental and socio-economic factors.

The main aim of this study was therefore to establish the relationship between (nuisance) rat occurrence and environmental and socio-economic factors. More precisely, we studied which environmental and socio-economic factors determine the density of brown rat reports in and around houses in Amsterdam, and what is the role of: a. the presence of water and vegetation; b. the characteristics of the buildings and sewage systems; and c. human population characteristics. The second aim was to point out factors that can be managed by the local authorities as a next step towards prevention and pro-active, integrated pest management as an alternative to reactive pest control with the use of rat poison. Firstly, we present a short overview of the biology of the brown rat, with an accent on diseases and habitat factors.

Brown rat biology

Brown rats make burrows in places where the ground is neither too heavy or compacted nor too light and dry and preferably near cover such as shrubs (Twigg 1975). They live in territorial groups, making burrow systems (Cal-

houn 1962). The available literature on rat habitat preferences suggests generally that the brown rat prefers the proximity of water such as sewers, ponds and rivers. However, it can also be found in dry areas like waste disposal sites, stables and silos, dirty yards with dustbins, animal enclosures and slaughterhouses (Lore & Schultz 1989, Voigt 1995). In buildings the rat is mostly found in basements. The occurrence of anthropogenic waste seems to be the most important factor (Becker 1973).

There is also rat habitat beneath the streets, in the sewers. According to Bajomi (2013) sewage and drain systems are ideal foraging routes due to their more stable climate, they provide year round breeding without seasonal fluctuations and a minimal threat of predation. Twigg (1975) however, also mentions the negative factors of a sewer: flooding can drown most or all of the rats; many poisons and unpleasant substances are sent down the sewer and these present a hazard; and methane, which results from processes of decay, may also kill rats.

Like many species that thrive in urban environments the brown rat is a generalist. Schein & Orgain conducted an experiment with wild brown rats that were placed in cages and fed edible garbage commonly found in domestic refuse. The food offered ranged from grapefruit to cooked pork with bones. All types of food were at least partially eaten, but the rats especially preferred scrambled eggs, macaroni-and-cheese, cooked corn kernels, cooked potatoes and cooked oatmeal above the standard lab diet. From their data Schein & Orgain (1953) deducted that an average rat (250 gram) would require about 50 grams of moderately high caloric food per day.

In another preliminary analysis Orgain & Schein (1953) investigated the effect of a sharp reduction in the amount of garbage available to brown rats; they found that the population in a city block was completely eliminated within six months. The populations of the two city blocks that were used for reference were reasonably stationary.

Many wild city dwelling species, such as foxes, polecats, grey herons (*Ardea cinerea*), buzzards (*Buteo buteo*) and owls are known to eat rats. Predation by house cats (*Felis catus*) on brown rats primarily removes the juvenile proportion of the rat population and has little effect on the size of the adult population (Glass et al. 2009). Davis (1953) summarises in a review that the reproductive rate of brown rats in Baltimore is about 20 to 30 young weaned per adult female per year. The mortality of brown rats is not exactly known, but is approximately 0.90-0.95 per year.

Davis et al. (1948) argue that brown rats use regular runways to get from place to place and do not utilise the whole area. The home range may consist of a very narrow strip connecting a feeding and a harbourage area. Although they were not able to state their conclusions in terms of area, Davis et al. state that rats live for a long time within a limited area, the overall diameter of which seldom exceeds 30-45 metres.

According to a genetics study by Gardner-Santana et al. (2009) urban rats show strong site fidelity. They estimated a dispersal distance of urban rats of about 40-150 metres, although long distance movement of up to 11.5 km can take place. They furthermore estimated the mean density of rats, based upon capture rates and geographical extents of six locations, to be 0.007 ± 0.005 rats.m^{-2} (Gardner-Santana et al. 2009). Although brown rats have a limited home range, Gardner-Santana et al. (2009) found that city rat populations in Baltimore are not as isolated and as genetically structured as would be expected. Regular gene flow apparently takes place.

Diseases

Today in the Netherlands there are few cases of disease that are caused directly by the brown rat. Rats can be a carrier of the bacteria *Leptospira interrogans*. An infection with this bacterium can cause Weil's disease, a severe form

of leptospirosis. In the Netherlands (nearly 17 million inhabitants) there are around 30 cases of leptospirosis per year (RIVM 2012). One third of these cases are contracted abroad. Around 5% of all reported leptospirosis cases are fatal (RIVM 2000) but it is not specified how many of these cases are Weil's disease and what percentage is due to rats.

Rat bite fever is a rare infection, caused by the bacteria *Streptobacillus moniliformis* or *Spirillum minus*. It can not only be transmitted by rats, as the name suggests, but also by other rodents, carnivores and pigs. Transmission is not necessarily followed by infection and infection does not necessarily lead to serious clinical symptoms (Gaastra et al. 2009). There are few reports of this disease in the Netherlands

A hantavirus that can be transmitted by brown rats is the Seoul virus. We found no evidence for the presence of this disease in humans in the Netherlands.

Escherichia coli bacteria are normally found in the intestines of humans and animals. Shiga toxin-producing *Escherichia coli* (STEC) strains can however cause serious human gastrointestinal disease. We found no evidence in literature for the presence of STEC in free-living brown rats in the Netherlands.

Furthermore, there are some pathogens for which the transmission cycle depends on vectors, often arthropods, and hosts. In some of these cycles the brown rat can be one of several hosts. The vector (e.g. mosquito, sand fly, tick or flea) however, is the organism that transmits the pathogen. The role of rats in these cycles is often still unclear (Stojcevic et al. 2004, Johne et al. 2012).

Factors

Several studies have investigated factors that influence the occurrence of the brown rat in the urban environment. Most of these are from the United States (Gardner-Santana et al. 2009, Figgs 2011) and some are from Europe (Traweger et al. 2006, Sacchi et al. 2008), but to our knowledge no research has been done for the Dutch situation.

In Salzburg, three test areas were assessed for their ability to support brown rats by integrating habitat suitability modelling using GIS (Traweger & Slotta-Bachmayr 2005). Their habitat suitability model included the factors: buildings constructed between 1950-1979, waterways, compost heaps and type of settlement. According to Traweger & Slotta-Bachmayr (2005) food, vegetation, natural soil and shelter are essential factors for brown rat habitat. They also show that the type of settlement (inner city, garden settlement, apartment house settlement) influences habitat suitability for brown rats. Preventive management measures mentioned in this study are the improvement of building methods and the design of the entire city environment. This can include the limitation of access by rats to food and shelter, continuous monitoring of infestation signs and early use of suitable control measures. In another study in Salzburg (Traweger et al. 2006) the brown rat population was assessed by using live traps and hair sampling tubes in 71 discrete patches distributed within the urban area. The occurrence of rats was strongly influenced by vegetation, habitat modification and man-made impact in the area. Additionally, trapping points where disposal of waste or disposal of greens was present were dominant amongst the successful trapping points. Furthermore, it was mentioned that rats prefer natural soil and avoid stone and concrete. However, not all hard surfaces are problematic for rats. In Amsterdam the pavement is often surfaced with tiles and rats are known to make burrows underneath them. The sandy soil underneath block paved roads may also be used for burrowing.

In São Paulo, infestation by brown rats was closely related to access source (mainly the sewage system), then to food source (mainly accessible garbage and fruit trees) and then to shelter source (mainly wall cracks and dense bush) (Masi et al. 2010).

Methods

The pest management department of the Amsterdam PHS has, for many years, been collecting data on reports of sightings or evidence of rats ("rat reports") in and near houses in the municipality of Amsterdam (figure 1). Whenever rats are reported, the address and the postal code of the relevant location are registered and rat bait stations are placed at that specific location. These bait stations are removed when no more bait is taken. For every address in the Netherlands the geographical coordinates are known (Base Registry for Buildings and Addresses ('Basisregistratie Adressen en Gebouwen' = BAG)). We combined these datasets into a single file containing rat reports from the year 2009 to 2012 with geographical coordinates (figure 2). We now have a spatial representation of rat reports in and near buildings in the Municipality of Amsterdam which can be related to either spatial or non-spatial data on environmental and socio-economic variables. Most variables are available at neighbourhood level or can be converted to this level. We therefore used the number of rat reports in a neighbourhood in the years 2009-2012 as a response variable. All variables are listed in table 1. Environmental variables that were analysed were: availability of water; availability of urban green space; and sewer type. Furthermore, some socio-economic variables were analysed such as property tax value, number of inhabitants and population composition. Information on socio-economic variables was available from the Research and Statistics Service of the city of Amsterdam. Geographical data on water and urban green space were supplied by the Basic Information Service of the city of Amsterdam. Geographical data on the sewage system were obtained from 'Waternet', the water company of Amsterdam.

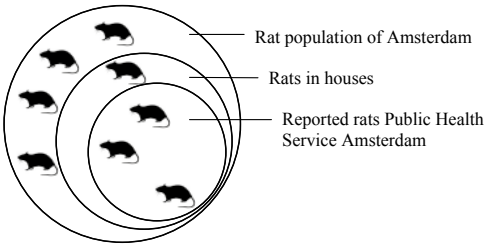

Figure 1. Schematic representation of the brown rat population in the municipality of Amsterdam.

The division in neighbourhoods is used for many purposes in Amsterdam; this is there-

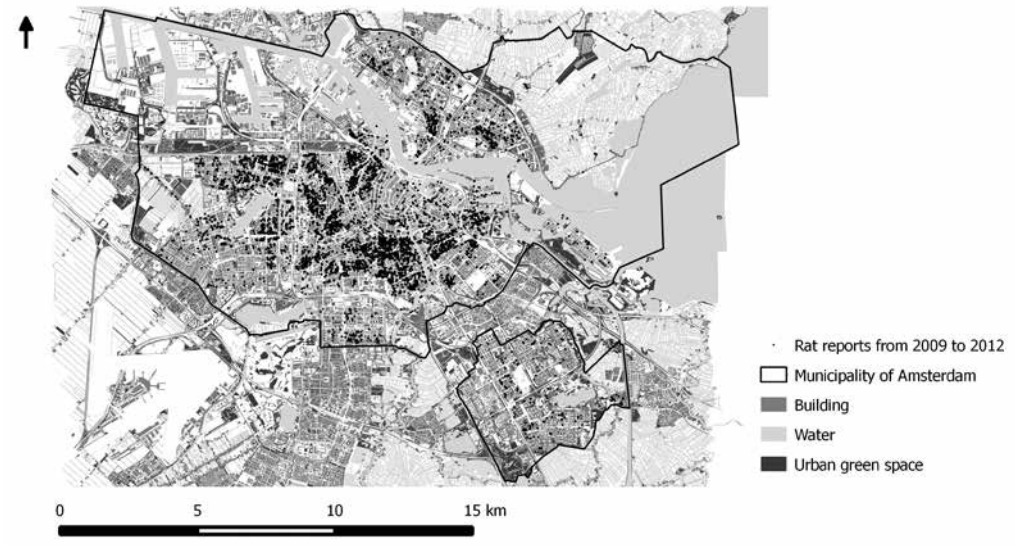

Figure 2. Locations of reported rats in the municipality of Amsterdam from 2009 to 2012.

Table 1. List of variables used in the statistical analysis.

	Variable	Unit	Transformation	Resolution	Source
1	% houses built before 1960	-	logit	neighbourhood	Base Registry for Buildings and Addresses
2	% surface water	-	logit	neighbourhood	Basic Information Service Amsterdam
3	% urban green space	-	logit	neighbourhood	Basic Information Service Amsterdam
4	building perimeter	$m.ha^{-1}$	-	neighbourhood	Basic Information Service Amsterdam
5	number of parcels	-	log	neighbourhood	Basic Information Service Amsterdam
6	% public housing	-	logit	neighbourhood	Research and Statistics Service Amsterdam
7	% non-western immigrants	-	logit	neighbourhood	Research and Statistics Service Amsterdam
8	% Western immigrants	-	logit	neighbourhood	Research and Statistics Service Amsterdam
9	human population density	$inhabitants.ha^{-1}$	log	neighbourhood	Research and Statistics Service Amsterdam
10	neighbourhood area	ha	log	neighbourhood	Research and Statistics Service Amsterdam
11	number of inhabitants	-	log	neighbourhood	Research and Statistics Service Amsterdam
12	property tax value	1000 euros	log	neighbourhood	Research and Statistics Service Amsterdam
13	street litter nuisance grade	-	-	neighbourhood combination	Research and Statistics Service Amsterdam
14	% combined sewer	-	-	neighbourhood	Waternet
15	length of combined sewer	km	-	neighbourhood	Waternet
16	length of foul water sewer	km	-	neighbourhood	Waternet

fore the most efficient level at which to take measures. The socio-economic variables were already available per neighbourhood. We calculated which percentage of the neighbourhood area was occupied by water or urban green space in order to be able to analyse these variables. We compared construction years of houses with rat reports to construction years of all houses in Amsterdam. We then calculated the percentage of houses per neighbourhood with a construction year before 1960 in order to use this factor in the statistical analysis.

The sewage system of Amsterdam consists of several types of sewer. In the city centre a large part of the sewer system is combined sewer (a combination of foul water sewage and surface water sewage). In newer parts of the city separated sewers (separate systems for foul water sewage and surface water sewage) have usually been installed. For each rat report we measured which type of sewer, combined or separated sewer, was nearest to the reported location. In addition, we calculated the total sewer length per sewer type and per neighbourhood.

The Research and Statistics Service also collects data on street litter. These data are available at management unit level for the cleansing department, which does not correspond to neighbourhoods. In the future, street litter monitoring locations will become available with coordinates (M. Heijnen, personal communication); however, for this study a dataset about street litter nuisance (1= much nuisance, 10= no nuisance) at the coarser spatial level of neighbourhood combinations was used, based on surveys from 2009 and 2011.

The data analysis was performed using R version 3.0.0 (R Core Team 2013). A generalised linear model with a negative binomial distribution and a logarithmic link was used to relate the number of rat reports to the environmental and socio-economic variables. Some skewed environmental variables were log transformed and percentages were logit transformed. All possible subsets were fitted using the R package 'glmulti' and the AIC criterion was used to select the most significant subsets. Where two variables were highly inter-correlated (r>0.75) one of the two was excluded from further analysis. 16 variables were finally selected (table 1).

In addition we compared the number of rat reports from 2010 and 2012 in order to exam-

Figure 3. a. Reports of rats from 2009 to 2012 per neighbourhood per hectare; b. Reports of rats from 2009 to 2012 per neighbourhood per 100 inhabitants.

ine the effect of variables in relation to either an increase or a decrease in number. We therefore subtracted the number of rat reports in 2010 from the number of rat reports in 2012. A generalised linear model with a normal distribution was used to relate the difference between 2010 and 2012 to the environmental and socio-economic variables (table 1).

Results

We first present the spatial distribution of rat reports across neighbourhoods. There are several options in relation to how these data can be displayed. Alternative hypotheses are that the number of rats per neighbourhood can be a function of: 1. neighbourhood area. 2. number of inhabitants; or 3. number of parcels. If the number of rat reports is mainly a function of neighbourhood area, we should display the number of reports per neighbourhood area (figure 3a); if the number of rat reports is mainly a function of number of inhabitants we should display the number of reports per number of inhabitants (figure 3b).

We compared construction years of all houses in Amsterdam with construction years of houses with rat reports. Figure 4a shows the number of houses in Amsterdam per construction year; and figure 4b shows the number of houses in Amsterdam with rat reports per construction year. These figures indicate that whilst many houses were built between 1960 and the present, the number of rat reports from houses constructed in this period was relatively low. We elaborated on this finding by classifying the construction years into construction periods and then calculating the houses with rat reports per period as a percentage of all houses per period (figure 5). This figure confirms that the percentage of rats reported from houses constructed between 1960 and the present is indeed lower than the percentage of rats reported from houses that were constructed in the periods before 1960. We calculated the percentage of houses per neighbourhood with a construction year before 1960 in order to use this factor in the statistical analysis.

We also measured which type of sewer, combined or separated, was nearest to the reported location per rat report. The number of rat reports near separated sewers is slightly lower than the number near combined sewers. There is however a significantly greater length of separated sewers in Amsterdam, than combined sewers. The number of rat reports from 2009 to 2012 per km of sewer is therefore much lower for separated sewers (1.1) than for combined sewers (5.2). For the multiple regression we calculated the total sewer length per sewer type and per neighbourhood.

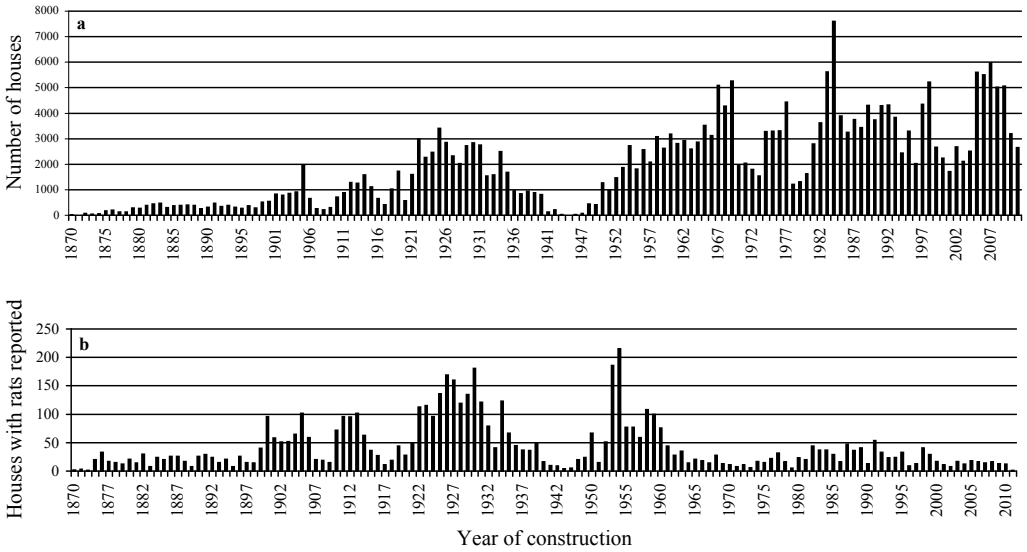

Figure 4. a. houses in Amsterdam per year of construction; b. houses with rats reported from 2009 to 2012 per year of construction. Houses with a construction year before 1870 (n=162) were left out of both graphs for readability.

Figure 5. Houses with rats reported from 2009 to 2012 per construction period as a percentage of all houses per construction period.

Table 2. Summary of general linear models, with -2 x log-likelihood and intercept of the models and with coefficients and *P*-values of the variables a to d, where a= number of inhabitants, b= percentage of area occupied by urban green space, c= percentage of houses with a construction year before 1960, d= length of foul water sewer and e= the length of combined sewer.

	Model	-2 x log-likelihood	*P*-value a	b	c	d	e
Three terms	1	2.433E+03	<0.001	<0.001	<0.001		
Four terms	2	2.426E+03	<0.001	<0.001	<0.001	8.090E-03	
	3	2.428E+03	<0.001	<0.001	<0.001		8.220E-03
Five terms	4	2.426E+03	<0.001	<0.001	<0.001	1.440E-01	3.380E-01
	Model	Intercept	Coefficient a	b	c	d	e
Three terms	1	-4.186E+00	9.551E-01	3.794E-01	2.437E-01		
Four terms	2	-4.510E+00	1.026E+00	4.466E-01	2.226E-01	-6.763E-05	
	3	-3.956E+00	9.134E-01	4.048E-01	2.194E-01		7.047E-05
Five terms	4	-4.311E+00	9.863E-01	4.383E-01	2.176E-01	4.771E-05	3.263E-05

The best regression model with three variables used was: number of inhabitants, percentage of area occupied by urban green space and the percentage of houses with a construction year before 1960 (table 2). The best models using more than three terms also contained these three variables. In addition to these three variables the length of foul water sewer or the length of combined sewer were also found to be significant. Due to the relatively large correlation (-0.52) between these sewer variables, adding both of these does not improve the model.

In addition, we compared the number of rat reports from 2010 and 2012 in order to examine the effect of variables in relation to either an increase or a decrease in number. A multiple regression with candidate models with a maximum of three variables gives foul water sewer as the only significant term in the best model (table 3).

Discussion

The regression analysis shows a positive relationship between the number of rat reports and the number of inhabitants. According to

Table 3. Summary of general linear models, with AIC (Akaike's Information Criterion) and intercept of the models and with coefficients and *P*-values of the variables a and b, where a= length of foul water sewer and b= street litter nuisance survey 2009 (1= much nuisance, 10= no nuisance).

	Model	AIC	*P*-value	
			a	b
One term	1	1960.2	1.31E-02	
Two and three terms	2	1961.00	1.12E-02	2.74E-01
	Model	Intercept	Coefficient	
			a	b
One term	1	4.86E-01	-2.09E-04	
Two and three terms	2	2.44E+00	-2.14E-04	-3.24E-01

model 1 (table 2) a neighbourhood with twice as many inhabitants as another neighbourhood would have almost twice as many (1.94 times) rat reports. The correlation with the number of inhabitants has two likely implications: firstly that more people means a higher chance that a rat is reported; and secondly that more people means more spillage of food and more waste, providing a higher carrying capacity for rats. The number of inhabitants is also a measure of area. While the number of rats per neighbourhood is expected to be a function of neighbourhood area, number of inhabitants, or number of parcels in the neighbourhood, these variables are too highly correlated to include them all. Number of inhabitants emerges as the one that explains most of the variation. However, it should be noted that our response variable is just an indicator for the total rat population of Amsterdam (see figure 1).

Another important factor is the percentage of houses with a construction year before 1960. Neighbourhoods with a high percentage of houses constructed before 1960 have more rat reports. For example, according to model 1 (table 2) neighbourhoods with 70% of houses built before 1960 have 51% more rat reports than neighbourhoods with 30% of such houses. Buildings constructed after 1960 are clearly less suitable for rats; it is either harder for rats to enter houses that were built more recently or these houses are less attractive, for example because there are no suitable hiding places.

Langton et al. (2001) found very similar results based on the 1996 English House Condition Survey. They also concluded that rat infestations are significantly more common in older properties, even after adjustment for other factors such as the presence of pets. According to them the reasons for this are not entirely clear, particularly in the case of outdoor infestations, but may relate to the maturity of the gardens and other habitat around the house; specifically in terms of well-developed, dense, vegetation providing better habitat for rats, rather than to the features of the houses themselves. Because in our case the decline was quite steep (figure 5), this suggests that the characteristics of the houses play a major role here. If the vegetation and other characteristics of the garden would be responsible for the decline, one would expect a more gradual decrease of rat reports.

The percentage of area occupied by urban green space also has a significant positive relationship with the number of rat reports. For example, according to model 1 (table 2), neighbourhoods with 40% of urban green space have 46% more rat reports than neighbourhoods with 20% of urban green space. Urban areas with shrubs or tall vegetation provide suitable habitat for the brown rat. It can therefore be expected that there will be a larger population of rats in areas with more urban green space. Traweger et al. (2006) also found (deciduous) trees, bank vegetation, vegetation with seasonal fruits and ruderal veg-

etation to be important descriptors for the terrestrial habitat of rats. Furthermore, rats seem to choose patches with organic debris, embankment and multilayer vegetation. One difference between the studies is that Traweger et al. (2006) caught brown rats in the entire city area, while we base our findings on rat reports in and around houses.

When either foul water sewer or combined sewer is added to the model, these variables have a significant effect. When both variables are added to the model they are not significant. The length of foul water sewer has a negative relationship with the number of rat reports, whereas the length of combined sewer has a positive relationship with the number of rat reports. This could indicate a difference in suitability of these sewer types for rats. Combined sewers and surface water sewers have to collect rainwater; these systems therefore contain storm drains (or surface water drains) which can provide free access for rats. Foul water sewers are not connected to surface water drains. So, although foul water sewers contain food waste, this type of sewer is difficult for rats to enter. Surface water sewers can be accessed, but these are probably not very suitable for rats because there is only little food available. It should be noted that although our results seem to indicate a difference in the suitability of separate sewer and combined sewer for rats, we found nothing on this subject in literature.

Another aspect that may explain the difference between the foul water sewage and the combined sewage, is that the combined sewage is, on average, older. It could therefore be that the combined sewage is in a worse condition than the separated sewage, with more cracks and more blind ends in which rats can find shelter. Employees of Waternet commented that the connection between a property and the public sewer is the responsibility of the property owner and that the private sewer of many old houses is therefore of poor quality. Cracks or displaced joints where rats can enter may occur at these locations. If this is the case, there may be an interaction effect between houses constructed before 1960 and the length of combined sewer. We did however not test for interaction effects.

Bajomi (2013) states that there is a relationship between surface rats and sewer rats; others however suggest the opposite (Channon et al. 2000, Gras et al. 2012). In our study surface rat reports seem to be related to the sewage type, which could indicate a relationship between surface rats and sewer rats.

We expected a positive relationship between street litter and the number of rat reports. Street litter can provide food as well as shelter for brown rats; however, we did not find a significant relationship. A reason for this could be that the available data were too coarse (combined neighbourhoods) or that the data were based on a survey of street litter nuisance instead of objective data on the amount of street litter. Another reason could be that there is in fact no relationship. However, as mentioned in the introduction, Orgain & Schein (1953) did find an effect of a sharp reduction in the amount of garbage on a population of brown rats.

In Traweger et al. (2006) running water was also preferred by rats. The study by Traweger surveyed rats in the whole urban area and not only in and around houses. Our analysis did not show that surface water is an important factor for rat reports in and around houses. This might be due to the fact that Amsterdam, with all of its canals, has plenty of surface water and therefore this may not be a limiting factor (figure 6).

We hypothesised that the trends in rat reports could also relate to environmental factors, while an alternative assumption is that the rat population is at carrying capacity. It appears that the difference between the number of rat reports in 2012 and 2010 is influenced by the length of foul water sewer. An explanation for this finding could be that in some neighbourhoods combined sewer has been replaced by separate sewer, and that this causes a decrease in the number of rats. This

Figure 6. Brown rat in Amsterdam drinking water and feeding on algae. *Photo: Jan Buijs.*

Figure 7. Building with adjacent evergreen shrubs and waste, which can provide cover and food for the brown rat. *Photo: Mark Nederveen.*

Figure 8. Brown rat in Amsterdam near green cover and waste. *Photo: Jan Buijs.*

makes sense because all the other variables are less dynamic and in a stable environment populations tend to be in equilibrium with their surroundings.

Our results only apply to the brown rat occurrence in and around houses. For other areas the data are scattered, owned by different commercial companies and often not freely available. The control of brown rats on commercial properties is not part of the legal obligation of the municipality. Rats on these properties are partly controlled through contracts with the PHS and partly by commercial pest controllers. In the public space rats are also controlled by the PHS, however not systematically. This may, in particular, lead to an underestimation of the total number of rats in the city centre; here there are many shops, restaurants and café's on the ground floor and fewer houses. However, our goal was not to estimate the total number of rats in Amsterdam, but to find factors that influence brown rat occurrence in and around houses.

Rats have a short generation time and can produce a large number of offspring. A rat population is therefore able to recover quickly from a reduction in number; for example as a result of poisoning. As a consequence, it is important to change the carrying capacity of the habitat in which rats are unwanted. This can be achieved by changing the amount of food and cover that they can find.

Conclusion and recommendations

The results of the regression analysis suggest that the number of rat reports in Amsterdam increases with: a. the number of inhabitants; b. the percentage of houses built before 1960; and c. the percentage of urban green. The results furthermore suggest that the number of rat reports decreases with the length of foul water sewer.

Based on these findings we recommend that houses constructed before 1960 and their gardens should be evaluated to see if there may be

general solutions that would make them less amenable to rats. Furthermore, we recommend that the structure of urban green space should be adapted to make it less attractive to rats. An example of this would be to replace evergreen shrubs with deciduous shrubs and to mow high vegetation near buildings more frequently (figure 7). Moreover, the influence of waste and especially food waste near and in urban green space should be investigated (figures 7 and 8). Finally, we recommend the continued inspection and maintenance of sewers and, in addition, to include the connection between properties and the public sewer in the inspections.

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Samenvatting

Factoren die van invloed zijn op de dichtheid van de bruine rat *(Rattus norvegicus)* in en om huizen in Amsterdam

De huidige strategie van de afdeling Dierplaagbeheersing van de GGD in Amsterdam is om bij het optreden van een plaag of overlast veroorzaakt door dieren, factoren aan te wijzen die van invloed zijn op de dichtheid van de ongewenste soorten. Door beïnvloeding van die factoren kan de draagkracht van het habitat ter plaatse worden verlaagd en daarmee kan het gebruik van pesticiden

worden geminimaliseerd. Ratten worden al tientallen jaren bestreden met rodenticiden, waardoor de overlevingskans van resistente ratten is vergroot. Als gevolg daarvan komt er tegenwoordig in verschillende rattenpopulaties in Europa resistentie tegen rodenticiden voor. Het eerste doel van dit onderzoek was het vaststellen van de relatie tussen het aantal bruine ratten (*Rattus norvegicus*) en omgevingsfactoren en sociaaleconomische factoren. Het tweede doel was om factoren aan te wijzen die kunnen bijdragen aan de preventie van plagen en die ook kunnen worden beïnvloed door de betreffende instanties. De GGD in Amsterdam verzamelt al jaren de meldingen van ratten in en om huizen in de gemeente Amsterdam. Het aantal meldingen van ratten per buurt in de periode 2009-2012 hebben we gerelateerd aan 16 omgevings- en sociaaleconomische variabelen, waaronder beschikbaarheid van water, beschikbaarheid van stadsgroen, riooltype, bouwjaar van huizen, WOZ-waarde, aantal inwoners en bevolkingssamenstelling. Met een gegeneraliseerd lineair model met een negatief binomiale verdeling hebben we alle kandidaatmodellen met een maximum van vijf termen gepast op de data. De meest significante termen van de regressie waren het aantal inwoners, het percentage stadsgroen, het percentage huizen met een bouwjaar vóór 1960 en óf de lengte van droogweerafvoer óf de lengte van gemengd riool. Ratten hebben een korte generatieduur en kunnen snel veel nakomelingen voortbrengen. Daardoor kan een rattenpopulatie snel herstellen van een aantalsreductie. Als ratten ergens ongewenst zijn is het dus belangrijk om de draagkracht van het betreffende habitat te verlagen. Die draagkracht kan verlaagd worden door de beschikbaarheid van voedsel en beschutting te verlagen. De resultaten van de regressieanalyse suggereren dat bij huizen die gebouwd zijn vóór 1960 inclusief de bijbehorende tuinen, moet worden bekeken of er algemene oplossingen kunnen worden gevonden om deze huizen minder aantrekkelijk te maken voor ratten, zoals het dichten van gaten en het wegnemen van schuilplaatsen. Verder suggereren de resultaten dat de structuur van het stadsgroen zou kunnen worden aangepast, zodat deze minder aantrekkelijk wordt voor ratten. Zo zouden groenblijvende struiken kunnen worden vervangen door bladverliezende struiken en zo zou ook hoge vegetatie in de buurt van gebouwen vaker gemaaid kunnen worden. Verder zou de invloed van afval en vooral van voedselafval in en bij stadsgroen onderzocht moeten worden. Tenslotte lijkt het verstandig om door te gaan met de inspectie van en onderhoud aan het riool en om bij die inspectie ook de aansluiting van woningen op het gemeentelijke riool mee te nemen.

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The first wolf found in the Netherlands in 150 years was the victim of a wildlife crime

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Abstract: On July 4th 2013 a dead subadult female wolf-like canid was found by the roadside between Luttelgeest and Marknesse in the Noordoostpolder in the central part of the Netherlands. As the last observations of wild wolves in the Netherlands date back to 1869 the discovery of this animal generated a lot of media attention. European wolf populations have been expanding since the 1950s and the first packs recently established themselves in Germany in geographic proximity of the Dutch border, so natural re-appearance of the species in the Netherlands seemed likely. We investigated the taxonomy of the animal, its geographical origin, and its most recent history. Macroscopic and biochemical analyses of the dead animal convincingly showed that it was a purebred wolf, related to populations from eastern Europe. Bullet impacts and shattered fragments found in the chest and flank, and a discrepancy between the timing of the *post mortem* and *rigor mortis* intervals indicated that this wolf was shot prior to illegal transport to the Netherlands. The wolf fed on beaver in either the Carpathian mountains or the Eifel which is too far for the animal to have walked from by itself within the 24 hours needed to digest its last meal. These geographical areas are the only regions where haplotypes and $^{87}Sr/^{86}Sr$ isotopes retrieved from both the dead wolf and the beaver remains in its stomach co-occur. We therefore conclude that the first Dutch wolf found in the Netherlands in 150 years did not enter the Netherlands by itself but sadly proved to be the victim of wildlife crime.

Keywords: Canis lupus, Europe, haplotypes, isotopes, microsatellites, wildlife forensics, wolf.

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Introduction

On July 4th 2013, a large dead canid was found along the Uiterdijkenweg between Luttelgeest and Marknesse (RD-coordinates 191.1 - 528.6) in the Noordoostpolder in the central part of the Netherlands (figure 1). Although the wolf (*Canis lupus*) was once widespread throughout Europe, its natural range was reduced to approximately one third of its original size during the last centuries due to human persecution. Recovery of European wolf populations began during the 1950s when traditional rural economies declined and the need to kill wolves decreased (Boitani 2000). Currently, several main metapopulations in Europe exist from which wolves are colonising new territories from different directions (Stronen et al. 2013). The first metapopulation is formed by the approximately 2000 wolves inhabiting the Iberian Peninsula, of which 150 live in northeastern Portugal (Bessa-Gomes & Petrucci-Fonseca 2003). The second metapopulation originated from an expansion of the Italian Alpine population. That led to recolonisation of the western Italian and French Alps, recently followed by several new regions (Pyrenees, Jura, Vosges, Massif Central and Catalonia). This metapopulation now comprises about 800 animals (Caniglia et al. 2012, Fabbri et al. 2014). The third metapopulation consists of wolves from central Sweden that have expanded into southern Norway and contains at least 200 animals. The fourth metapopulation is formed by northcentral European wolf populations in Germany, Estonia, Latvia, Lithuania, Finland and Russia and currently encompasses over 3500 animals (Baltrunaite et al. 2013, Czarnomska et al. 2013). The fifth metapopulation is situated in the Ukraine. The sixth metapopulation is formed by wolves living in the Carpathian mountains that are situated in the Czech Republic, Poland, Romania, Slovakia and Ukraine. The seventh metapopulation is situated in the Balkans (Albania, Bosnia-Herzegovina, Bulgaria, Greece, Macedonia, Montenegro and Serbia). The numbers of animals of the last three metapopulations are not known.

Multiple fossil remains show that wolves lived throughout the Netherlands up to the

Figure 1. Dead wolf found by the road between Luttelgeest and Marknesse (Noordoostpolder) in the Netherlands on July 4th 2013. *Photo: Janneke van der Linde.*

Figure 2. Remains of dead wolf prior to section at DWHC and now deposited in Naturalis Biodiversity Center (RMNH.MAM.5000081). *Photo: Hugh Jansman.*

Pleistocene (http://www.geologievannederland.nl/fossielen/zoogdieren/wolf). Wolves are regularly mentioned in various historic documents, although a gradual decline set in once agriculture became more widespread. In some cases there were short-lasting invasions of wolves, as in the winter of 1233-1234 in the east of the Netherlands where buried bodies had to be protected to prevent them from being scavenged (Picardt 1660). In periods with low human population density wolves increased their distribution in the Netherlands, for example after the Black Death, and during the Eighty Years' War (1568-1648) (de Rijk 1985). In 1869, two wolves were caught in Schinveld (Limburg) in the south of the Netherlands (Flaton 1989). According to Okarma (2000), the last wild wolf of that century was observed nearby in Heeze (Brabant) in 1897. However, this record is disputed because by that time wolves had already been exterminated in the Ardennes and the Eifel.

From the beginning of the information campaign 'Wolves in the Netherlands' (http://www.wolveninnederland.nl) in 2008, claims of wolves and wolf tracks were reported on a regular basis. On and around 27 August 2011 actual sightings (and photographs) of an animal similar in morphology to a wild wolf were reported near Duiven in the east of the Netherlands. Following the media attention on wolves when a claim is reported, the number of wolf sightings or tracks increases, to decrease again to the normal level of approximately one claim per week in the months afterwards. Between 2011 and 2013, wolf sightings have also been reported in Belgium and Denmark, some documented by camera traps, all presumed to be the result of natural migrations from adjacent countries. In 2011 a wolf was filmed near Namur, in the Belgian Ardennes. In December 2012, a dead wolf was found in Denmark (Madsen et al. 2013). DNA analysis proved that this animal was born in Germany and had migrated at least 850 km (C. Nowak, unpublished data). In 2011, a wild wolf was photographed in the Westerwald in Germany, just 130 km from the Dutch border. This animal was accidentally shot in April 2012. DNA analysis showed that this animal was derived from the Alpine wolf populations. In April 2013, a wild wolf was photographed with a camera trap near Meppen in Germany, just 30 km from the Dutch border.

In 2012 a minimum of 14 wolf packs was living in Germany and in August 2013 a total of 23 packs was recorded. The nearest wolf pack is situated at approximately 150 km from the Dutch border and juvenile wolves commonly disperse over long distances (100-150 km, with some individuals dispersing up to 1500 km (Ciucci et al. 2009)). The increasing number of sightings along the Dutch-German border is therefore not surprising.

Detailed investigations on the remains of the dead canid found in the Noordoost-

polder were carried out to come up with (1) a sound taxonomic identification, (2) reconstruction of its geographical origin, and (3) its most recent history to assess whether this was the first wolf re-appearing in the Netherlands after 150 years or a victim of a wildlife crime.

Materials & Methods

Macroscopy

Section - After discovery the carcass was transported to Utrecht where it was sectioned (figure 2) and inspected by representatives of Alterra WUR, The Dutch Wildlife Health Centre and Naturalis Biodiversity Center. Blood, hide, skeleton, stomach content and tissue samples were frozen for further research.

Biochemistry

DNA analyses - Wolves and dogs are genetically very similar due to domestication of dogs from wolves, which only started ca. 40,000 years ago (Lindblad-Toh et al. 2005). Because of their recent history, wolf and dog can produce viable offspring in the wild. DNA analyses were carried out to obtain a sound taxonomic identification. For this purpose, DNA of the dead animal was compared with DNA from European wolves, dogs and wolf-dog hybrids, using a suit of genetic analyses. A first analysis consisted of Sanger sequencing of two overlapping fragments of the maternally inherited mitochondrial (mtDNA) displacement (D-)loop control region: one of 257 base pairs (bp) (Pilot et al. 2010) and one of 500 bp (Randi et al. 2000). This was done to reveal more about the taxonomic identity of the mother.

To investigate the taxonomic identity of the father, additional analyses were carried out with biparentally inherited nuclear microsatellites (Ostrander et al. 1993, Fredholm & Wintero 1995, Francisco et al. 1996) that have been used earlier to differentiate among wolves, dogs and wolf-dog hybrids (e.g. Caniglia et al. 2013). Two independent analyses were performed, using a similar set of markers (four shared loci FH2088, FH2096, FH2137, CPH5 from Fredholm & Wintero (1995) and Francisco et al. (1996)) but a different set of European wolves and dogs as references. Scores were visualised by a Principal Coordinates Analysis (PCA).

The first reference set (C09.250, C20.253, CPH2, CPH4, CPH8, CPH12, FH2004 and FH2079 from Ostrander et al. (1993), Fredholm & Wintero (1995) and Francisco et al. (1996), in addition to the four shared loci) contained profiles from domestic dogs (*n*=75; 63 crossbred dogs sampled in villages in the northern Apennines and 12 German Shepherd dogs) and three wolf reference populations (*n*=115; 79 animals from peninsular Italy, 10 from the Carpathian mountains and 26 from the Balkans). The second reference set (FH2001, FH2010, FH2017, FH2087L, FH2097, FH2140, vWF, FH2054, FH2161, PEZ17, DBX6 and DBX7 from Seddon et al. (2005), Shibuya et al. (1994), Fredholm & Wintero (1995), Francisco et al. (1996) and Cho (2005)), in addition to the four shared loci) contained profiles from domestic dogs (*n*=12), wolves from Germany and western Poland (*n*=49) and wolves from peninsular Italy (*n*=15).

Isotopes - Isotope analyses of strontium ($^{87}Sr/^{86}Sr$) were carried out on bone, hair and tooth enamel of the dead wolf and beaver bone remains in its stomach. These techniques have been developed for application in human and wildlife forensic applications to determine the origin and movement of suspects and animals (Bowen et al. 2005, Hobson & Wassenaar 2008). They could be applied to this particular wildlife forensic case as strontium isotope ($^{87}Sr/^{86}Sr$) values are highly correlated with the geology of particular areas (Evans et al. 2010, Voerkelius et al. 2010; figure 7C). Teeth enamel typically records the isotope signature of an animal's early life, while hair reflects the later life stages.

Results

Macroscopy

External investigations - The dead animal was a subadult, sexually mature female with a light-coloured coat (figures 1-2), indicating a European origin (Heptner & Naumov 1998, Okarma 2000). The dead animal had traces of a supracaudal gland ('violet gland'), which is lacking in most breeds of dog (Lloyd 1980). The tail was furry, as is characteristic for wolves, and the nails were quite long, which is suggestive of an outdoor life. Coat color and pattern resembled those of European wolves in all respects. No chip or visible remains of a collar could be found. Hairs on the back, shoulders, flanks and neck were ca. 50, 53, 57-29, and 82 mm long, respectively, and not in moulting stage. Hairs on the back of wolves from the Czech Republic and the Soviet Union are reported to range from 50-85 mm in winter (Peters 1993), indicating that the dead wolf was still in winter coat. The incisors showed slight wear on the sharp edges of the lobes, the canines had slight wear on the distal end of the posterior ridge, and the carnassials did not show any visible wear. This is all indicative of an age of at least 1.5 years and at most 2.5 years old (Gipson et al. 2000). Micro-CT scans of the right carnassial (figure 3) and microscopic inspection of thin slices of the root (Grue & Jensen 1979) confirmed that the animal was just over one year old when it died. This explains why it was not molting as this is often postponed in young animals. The stomach contained hairs, a spinal disc and part of the tail of a juvenile beaver (*Castor fiber*; figure 4), a regular part of the diet of wolves in central and northern Europe (Milne et al. 1989, Andersone & Ozolins 2004). The diameter of the spinal disc was 15 mm which corresponds with a first summer individual (Rosell et al. 2010). The dimensions of the scales on the tail were 8-9 by 3-4 mm, respectively (figure 4). Scales on the tails of beavers older than a year range from 11-15 by 5-6 mm of individuals deposited in the collection of Naturalis Biodiversity Center. Beavers remain in their natal territory until they are at least 20 months old (Campbell-Parker & Rosell 2013), thus this beaver was most likely consumed in close proximity to its parental lodge.

A total of three large scats (six subsamples) were found within less than 15 km from the dead animal on two different localities in the Kuinderbos (RD-coordinates 181.5 - 534) in July 2013. The scats were deposited in the middle of a path. Shape and size (length of 20 cm and diameter of ca. 4 cm) of the scats were very different from most fox scats. Morphological analyses based on cuticular hair patterns (Teerink 1991) showed that these scats contained hairs with a similar pattern to hairs of red deer (*Cervus elaphus*). The hairs were too short for an adult so originated from a juvenile or a domestically kept deer. Morphological identification keys are unsuitable for distinguishing juveniles from domestically kept deer. One of the scats not only contained hairs but also some bone and skin fragments, an ixodid tick, and a deer throat bot fly larva (*Pharyngomyia picta*). The hairs attached to the bone and skin fragments were identified as red fox (*Vulpes vulpes*). Eggs of the nematode parasite *Eucoleus aerophilus* were found in one of the scats. This worm belongs to the Capillariidae (Nematoda, Enoplida) and is often observed in the lungs of foxes and wolves in Europe. Eggs of *Spirometra* and *Alaria,* found in the intestines of the dead wolf (see below) were not observed in the scats.

Internal investigations - The animal was in excellent condition and only carried ripe proglottids of the tapeworm *Spirometra* sp. (Cestoda, Pseudophyllidea, Diphyllobothriidae) and the trematode parasite *Alaria alata* (Trematoda, Digenea, Diplostomatidae). This is indicative of a life in the wild. *Post mortem* analysis resulted in the discovery of three bullet holes in the hide, one of 4.5 mm in the flank, and two of 6 and 7 mm diameter in the chest (figure 5). A clear bullet trace was found in the tissue of the chest, in combination with multi-

Figure 3. Micro-CT-scan of the right carnassial of the dead wolf. The number of cementum annuli (indicated by the white arrows) corresponds with a second summer individual. *Photo: Dirk van der Marel.*

Figure 4. Beaver remains from the stomach of the dead wolf. *Photo: Kevin Beentjes.*

ple fragments of a copper-coated lead expanding bullet in the tissue of the animal's flank, indicating that the animal was shot twice. The dead animal had a fractured skull (figure 6), damages to the skin of the face (30 x 13 mm) and neck (76 x 14 mm), internal bleedings in the brain and thorax, torn muscles along the spine, and several damaged spinal discs, all

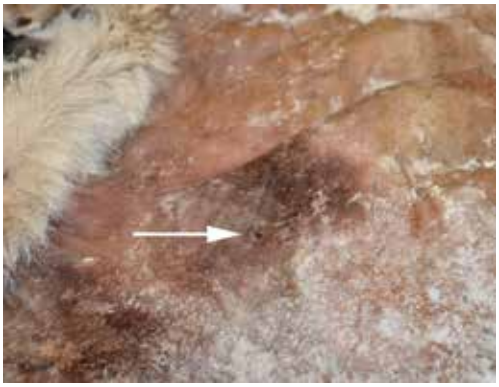

Figure 5. Bullet hole (indicated by the white arrow) in the middle of a dark colored bloodstain on the inner side of the hide originally enveloping the left chest of the dead wolf. *Photo: Marja Kik.*

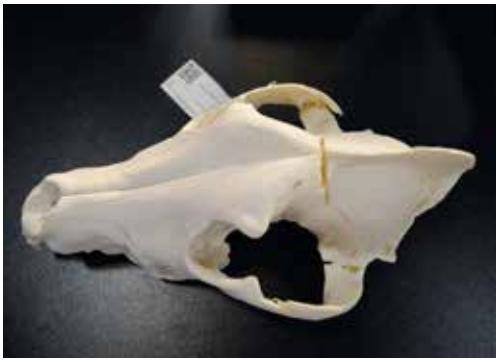

Figure 6. Re-assembled skull of the dead wolf showing multiple fractures. *Photo: Barbara Gravendeel.*

indicative of a collision by a car or heavy beating.

Biochemistry

DNA analyses - The mtDNA sequences obtained showed a 100% match with haplotype W1, commonly found in European wolves (Pilot et al. 2010, Baltrunaite et al. 2013; areas indicated in blue and red in figure 7A). As mtDNA is maternally inherited in wolves, this confirmed that at least the mother of the dead animal had been a wolf.

The PCA plot of the first set of microsatellite markers analysed (figure 8) shows that refer-

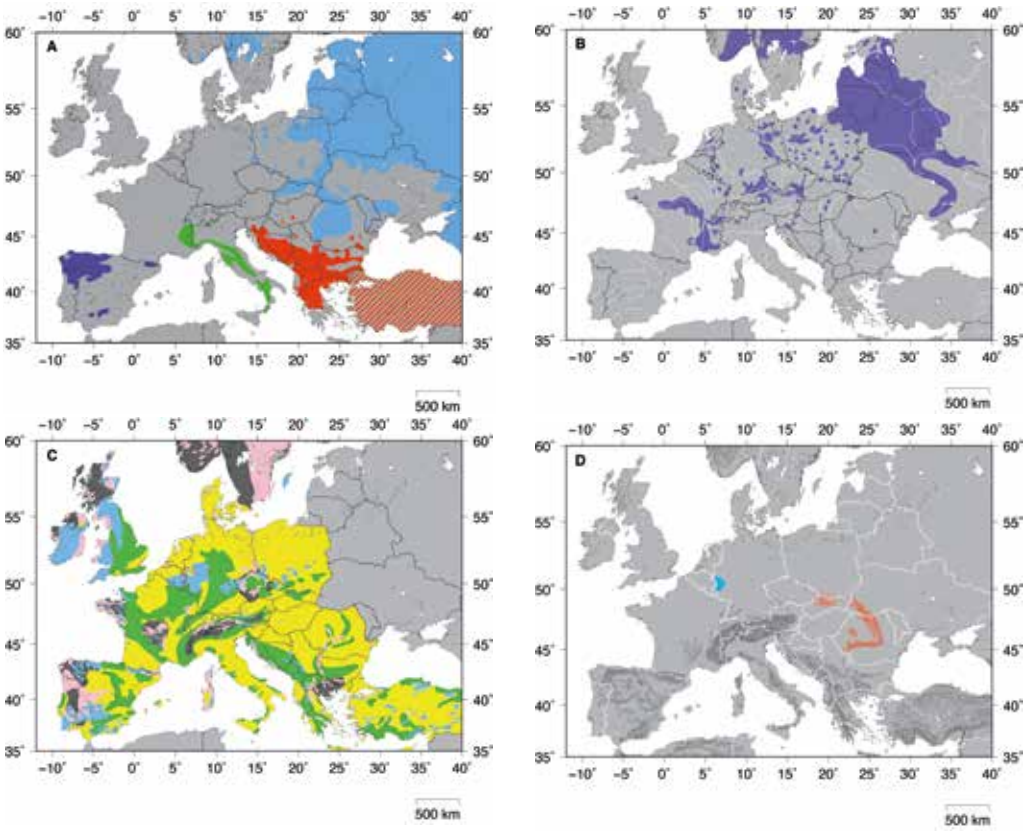

Figure 7.

A. Distribution of wolf (*Canis lupus*) haplotypes (after Pilot et al. (2010), references in the appendix and Czarnoska et al. (2013)). Blue: areas where wolves have been found with the haplotype of the dead animal (blue dashed = no data); red: areas where a southeastern European haplotype is predominant but where a northern haplotype could occur as well (red dashed = no data); green: haplotype of populations in Italy and the French Alps where the haplotype of the dead animal does not occur; purple: haplotype of Spanish and Portugese populations where the haplotype of the dead animal does not occur either.

B. Distribution of beaver (*Castor fiber*) in Europe. The beaver retrieved from the stomach of the dead wolf had an eastern haplotype which occurs over large parts of Europe (Nowak, unpublished data).

C. $^{87}Sr/^{86}Sr$ isotope values currently known from Europe (after Evans et al. (2010) and Voerkelius et al. (2010)). Yellow: 0.70701 – 0.70900; green: 0.70901 – 0.71100; blue: 0.71101 – 0.71300; pink; 0.71301 – 0.72000; grey: 0.72001 – 0.78000.

D. Distribution of main European mountainous regions indicated in dark grey; the Carpathian mountains are indicated in red, the Eifel in blue. These regions are the only areas where the haplotypes of the wolf and $^{87}Sr/^{86}Sr$ isotopes retrieved from the dead wolf and the beaver in its stomach co-occur.

ence dogs and wolves plot separately. The dead animal is included within the Carpathian and Croatian reference wolf cluster. In line with the first analysis, in the PCA plot of the second microsatellite analysis (figure 9) the dogs are also clearly separated from the wolves and the dead animal is plotted amongst wolves. In conclusion, all assignment procedures led to the identification of the dead animal as a purebred wolf.

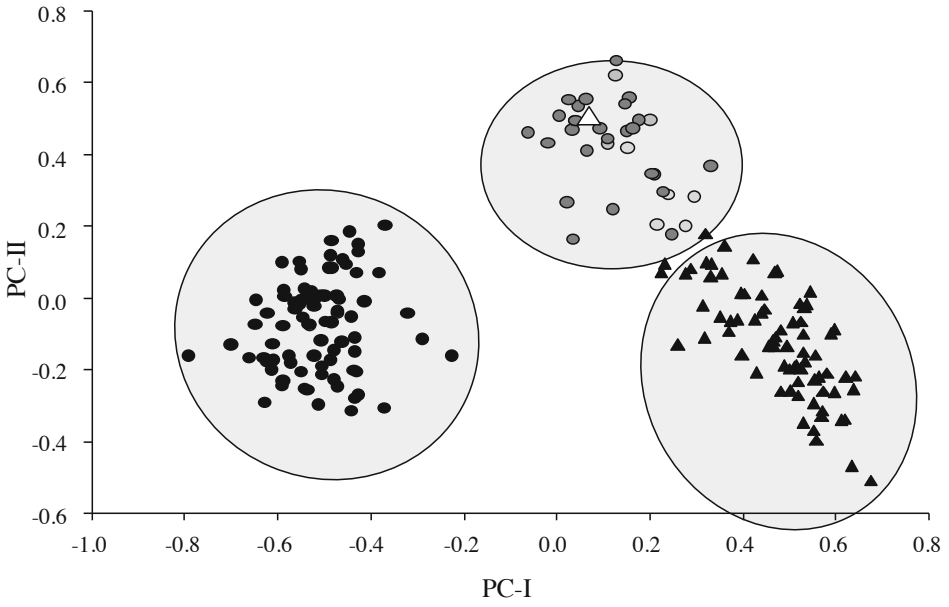

Figure 8. Principal Coordinates Analysis (PCA) plot of individual multilocus scores. Reference dogs (*n*=75; black triangles) and wolves (*n*=115; black and grey circles and white triangle) plot separately. Italian wolves (*n*=79; black circles) split apart from Carpathian (*n*=10; light grey circles) and Croatian wolves (*n*=26; dark grey circles). The dead animal (white triangle) is included within the Carpathian and Croatian wolf cluster.

Table 1. Details of the isotope analyses carried out on tissue samples of the dead wolf found near Luttelgeest, beaver remains found in its stomach, and three beavers from the Netherlands, Germany and the Czech Republic deposited in Naturalis Biodiversity Center (RGM) and Natural History Museum Rotterdam (NMR), respectively.

Species	**Origin**	**$^{87}Sr/^{86}Sr$ ± 2 standard error**
Beaver (RMNH.5000174)	In stomach of Luttelgeest wolf, 2013 Natural prey	0.716886 ± 0.000008 Spinal disc
Beaver (NMR9990-00842)	Czech Republic, 1992 Road kill	0.715446 ± 0.000010 Tooth
Beaver (58002CATB)	Germany, Bonn Year and cause of death unknown	0.708745 ± 0.000015 Tooth
Beaver (RMNH.MAM.55031.a)	The Netherlands, 2012, Arnhem, Drielsedijk Road kill	0.709006 ± 0.000009 Tooth
Wolf (RMHN.MAM.5000081)	The Netherlands, 2013, found along road near Luttelgeest	0.713420 ± 0.000011 Tooth 0.709033 ± 0.000012 Undercoat hair 0.709546 ± 0.000016 Guard hair

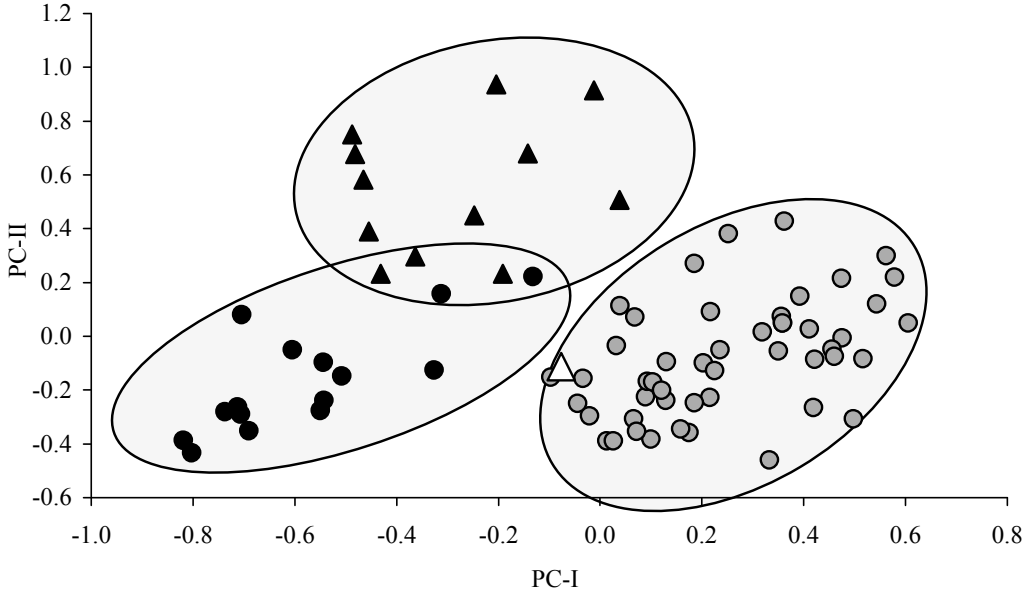

Figure 9. Principal Coordinates Analysis (PCA) plot of individual multilocus scores. Reference dogs (*n*=12; black triangles) and wolves (*n*=64; black and white circles and white triangle) plot almost separately. Italian wolves (*n*=15; black circles) split apart from German/West Polish wolves (*n*=49; dark grey circles). The dead animal (white triangle) is plotted on the outer edge of the cluster of German/West Polish wolves.

DNA sequences from the hypervariable mitochondrial control region retrieved from the beaver tail using primers employed by Durka et al. (2005) showed that this animal had an origin from eastern Europe (figure 10) or Germany (C. Nowak, unpublished data).

Genetic analyses were also performed to verify the producer of the scats analysed. DNA barcoding based on the same mitochondrial DNA fragment as used for taxonomic identification of the dead animal (Pilot et al. 2010) resulted in a DNA sequence that could be matched with red fox. As prey remains in the scat were morphologically identified as red fox, this DNA sequence may have been derived from the prey rather than the predator. In addition to the mitochondrial DNA, a total of seven loci (FH2004, FH2088, FH2137, CPH2, CPH12, FH2132 and U250 of Francisco et al. (1996), Fredholm & Wintero (1995) and Ostrander et al. (1993)) of the nuclear microsatellites produced from the dead animal could be amplified from the scats. These were all different from the alleles obtained from the dead animal (figure 11).

Isotopes - Values of $^{87}Sr/^{86}Sr$ of the dead animal's tooth enamel (0.713420 $\pm$ 0.000011; table 1) were well out of range of typical Dutch environmental isotope values (0.7085 - 0.7100; Font et al. 2012), suggesting that this animal was not born in the Netherlands. The hairs of the dead animal (both guard and undercoat hair), representing the last year of its life, had much lower values, which are in range of Dutch environmental ratios (table 1). The isotope ratios from the spinal disc of the beaver found in the wolf's stomach had the highest value of all (0.716886 $\pm$ 0.000008; table 1).

Discussion

Geographical origin - Currently, the packs of wolves occurring closest to the Netherlands

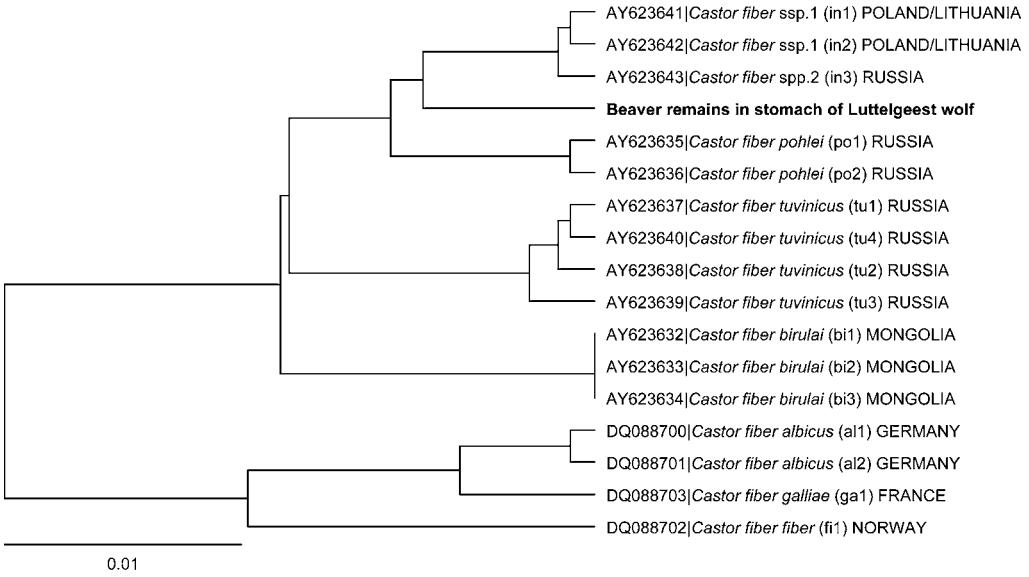

Figure 10. Unweighted Pair Group Mean Average (UPGMA) diagram of beaver (*Castor fiber*) mitochondrial Control Region haplotypes analysed. The remains of the beaver found in the stomach of the Luttelgeest wolf cluster with eastern European haplotypes.

live in northwestern Germany (federal state of Lower Saxony) (Groot Bruinderink et al. 2012). They belong to a larger population of wolves scattered mainly over eastern Germany and western Poland. Past sightings of wolves near the Netherlands were assumed to originate from this population, which Czarnomska et al. (2013) report to form the expanding western edge of a larger northeastern European population.

The mtDNA sequence obtained from the dead animal indeed fully matched with the most frequent haplotype occurring in the populations of eastern Germany and western Poland (haplotype W1 from Pilot et al. (2010)). Yet, in line with the hypothesis of a vast northeastern European population of wolves, Pilot et al. (2010) report the same haplotype to occur also (but less predominantly) throughout Fenno-Scandinavia and the Baltic States as well as in Belarus and Russia and the Ukrainian part of the Carpathian mountains (figure 7A). It is not unlikely that the same haplotype will also incidentally occur further south. Thus, based on its mtDNA data, the dead animal could have originated from an area ranging from Fenno-Scandinavia in the north up to south-eastern Europe.

Microsatellite markers typically show larger variation among individuals and populations. Unfortunately, at the time of this study no single reference set was available that included wolves from all over Europe. Two separate analyses were therefore performed to cover as many potential populations of origin as possible. The Principal Coordinates Analysis for one reference set, including Italian and German/West-Polish wolves, clearly separated populations from each other. The dead animal clustered weakly with the latter, as it is plotted at the outer edge of the cluster. Moreover, the dead animal showed several unique alleles, which have never been found in the German/West Polish population (C. Nowak, unpublished data). This makes it highly unlikely that the dead animal originated from this population. Czarnomska et al. (2013) also found individuals with unique alleles amongst the wolves sampled in western Poland, and suggested that these individuals

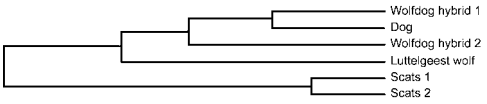

Figure 11. Unweighted Pair Group Mean Average (UPGMA) diagram of data obtained from seven nuclear microsatellites produced from the dead animal that could also be amplified from the scats found in the Kuinderbos. The data obtained show that none of the scats were produced by the dead animal.

represent immigrants from areas not covered in their analysis. Most likely it concerned immigrants from the northeast (Baltic States, Belarus, Russia), where larger populations occur that probably also contain a larger, but yet unmapped, genetic variation (Czarnomska et al. 2013). An analysis based on the other reference set used in our study suggests a different scenario. According to the other analyses carried out with microsatellites, the dead animal was included right in the middle of a Carpathian/Croatian cluster of wild wolves. A micro-array analysis including reference sets of all wolf populations occurring throughout Europe might shed further light on the origin of the dead animal.

Most recent history - The microsatellite differences found between the scats and the dead animal are sufficiently large to conclude that these cannot be linked (figure 11). Possible alternative producers were another wolf, a dog, a fox, or a wolf-dog hybrid. The fact that the scats contain red deer and red fox remains does not necessarily mean that only a wolf could have been the predator. Owners of wolf-dog hybrids commonly feed their pets locally shot deer or road kills and walk them in nature reserves where they are allowed to defecate freely. Dogs in the Netherlands are often walked off the leash and annually kill a lot of deer and other wildlife.

The isotope values obtained from the beaver remains found in the stomach of the dead animal strongly suggest that the wolf's last meal originated from a high $^{87}Sr/^{86}Sr$ catchment area. Such areas can be found in the Alps, the Carpathians, around some mineral springs originating from deep layers in the Eifel, the Pyrenees and in several smaller catchment areas in Europe (Voerkelius et al. 2010; figure 7C). All of these areas are mountainous, and too far away for the wolf to have walked to the Noordoostpolder in the Netherlands before digestion of its stomach contents. The remarkably large $^{87}Sr/^{86}Sr$ differences between the dead animal's tooth, hair and last meal suggest that it had roamed an area with significant regional $^{87}Sr/^{86}Sr$ variation. This would be in good (but not exclusive) agreement with geologically diverse areas such as the Eifel or the Carpathian mountains (figure 7D). This finding is in accordance with the eastern European haplotype derived from the tail tissue of the beaver retrieved from the stomach of the dead wolf (C. Nowak, unpublished data).

Beavers occur in large numbers in the northwestern part of the Carpathian mountains up to 500 m altitude due to successful reintroductions of Russian stock in the late 1970s in Poland (Carpathian Ecoregion Initiative 2001, Deinet et al. 2013) and in smaller numbers in the Eifel (figure 7B). The beaver was reintroduced in the latter region in the late 1980s with animals obtained from a farm in Popielno in Poland that imported its animals from Woronezj in Russia (Dalbeck et al. 2008). The clustering of the haplotype of the beaver remains retrieved from the stomach of the dead animal with Lithuanian/Polish/Russian haplotypes (figure 10) should therefore be interpretated with care as this animal could have been consumed in the Eifel. No $^{87}Sr/^{86}Sr$ isotopes studies have yet been carried out with beavers and we only sampled four specimens (table 1). Studies carried out with a larger number of replicates of different European deer species from various localities in Germany and the UK (Kierdorf et al. 2008, Sykes et al. 2006), however, showed that $^{87}Sr/^{86}Sr$ values obtained from the teeth of these herbivore species strongly correlated with the ranges of values known for differ-

ent geological areas. Strontium isotope values seem therefore very useful for assessing the provenance of animals of unknown geographical origin similar to humans for which this method has already been established (Bowen et al. 2005, Hobson & Wassenaar 2008). Ongoing analyses of water samples collected in December 2013 around beaver dens in the Eifel for isotope values of $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{207}Pb$ will hopefully shed further light on the geographic origin of the consumed beaver. These forensic markers are often used in combination to improve accuracy of assessing provenances (Kierdorf et al. 2008).

Migration distances of 1000 km are not uncommon for wolves as illustrated by the radio collared young German wolf 'Alan' that migrated from Germany to Belarus over circa 1000 km from start to end between 23 April and 26 September 2009, covering 1500 km in total (Schede et al. 2010). Wolves can cover great distances by running for hours at a rate of 8-9 $km.hr^{-1}$ (Mech & Boitani 2003). The dead animal could never have covered the distance of several hundred kilometres between the Eifel (where there is as yet no wolf population) or the Carpathian mountains and the Noordoostpolder in the ca. 24 hours needed to digest a juvenile beaver (Kelly & Garton 1997, Andersone & Ozolins 2004, Fuller et al. 2011). It was therefore most probably shot first and illegally transported to the Netherlands shortly afterwards.

Wildlife crime - All evidence suggests that a road accident was staged. This is, amongst others, known from the UK where farmers intentionally drive over badgers previously killed by shooting, snaring or poisoning because of a suspected infection with bovine TB (*Mycobacterium bovis*) to wipe out evidence of wildlife crime (BBC News 2012). We suspect a road kill might have been staged here as well for several reasons. First of all, no reports were made to the local authorities of a road accident in the Noordoostpolder that involved this particular animal. Secondly, the *post mortem* interval (i.e. the time that had elapsed between death and the discovery of the carcass) did not correspond with the time of *rigor mortis* (i.e. chemical processes in the muscles after death causing stiff limbs). The *post mortem* interval could never have been longer than twelve hours as the Uiterdijkenweg is a busy local road frequented by many commuters that claimed not having seen anything abnormal in the evening prior to the discovery of the carcass. The *rigor mortis* interval is estimated to have lasted at least 24 hours (DiNicola 2010). The dead animal lacked clear signs of *rigor mortis* when found in the morning of July 4th so this phase had passed. This means that the animal was moved from somewhere else after it was shot and run over or beaten up. The order of these events could not be deduced. No traces of tissue damage from freezing were observed during autopsy so the dead animal was not frozen prior to transport. As no clear signs of tissue decay were observed, the animal could not have been killed longer than two days prior to discovery (DiNicola 2010).

Media attention - Triggered by the coverage in the popular media, several people reported sightings to Staatsbosbeheer in the time period just before the dead animal was found. A putative wolf was seen in the Achterhoek in the eastern part of the Netherlands on the 8th of June about 80 km from where the dead animal was found. The animal chased a roe deer (*Capreolus capreolus*) at high speed for at least a hundred metres. Between June 15th and 18th three people reported having seen a living wolf near the Noorderring or Noordermidden road, just a few km north and west from Emmeloord in the middle of the Noordoostpolder, which is at approximately 20 km distance from where the dead animal was found. A woman reported to have seen a wolf when traveling by train from Amsterdam to Almere. Upon disembarking she verified her observation with the engineer who confirmed seeing the same animal. A local farmer saw a

wolf-like animal on the land of his neighbour in the Noordoostpolder and on his own fields later that day at only 15 m distance. Another farmer close by found wolf-like prints on his land during the period mentioned above. These observations fit in the usual pattern of wolf sightings and this study underlines how cautiously such reports need to be treated.

Obviously, these observations cannot possibly be from the animal found by the roadside between Luttelgeest and Marknesse, as this individual was still living elsewhere in Europe at that time. The sightings are all classified as so-called C3 observations according to internationally agreed criteria (Kaczensky et al. 2009), as they were not from an experienced person (C2 category) or accompanied by movies or photographs or DNA evidence from hairs, saliva samples, or scats (C1 category). The behaviour displayed by the observed animal(s) does certainly raise questions too. A solitary wolf in search of a territory or mate is usually very shy. It is possible that the observations were of a dog or dog-wolf hybrid. Another explanation could be that the observations were of another wolf or wolves. There is some anecdotal evidence that young wolves display curious rather than shy behaviour when confronted with humans. A military recruit in Germany was followed by three young wolves over a substantial distance in September 2012 (http://www.ndr.de/regional/niedersachsen/heide/woelfe241.html). Whether dispersing wolves, which are far older than these young animals, are still apt to display curious rather than shy behaviour is as yet unclear. In October 2012, multiple photographs were made of a wild wolf roaming the city of Uppsala in Sweden for an entire week (Radio Sweden 2012), indicating that wolves do not always avoid densely populated areas. A young wolf walked a distance of more than 700 km from Oslo in Norway to Karlskrona in Sweden in full daylight, passing villages and cities while people were passing by, all ignored by the wolf. Many photographs bear witness of this exceptional journey (Bovée 2013). Sightings of wolves in Germany are not uncommon, but usually occur around dusk or dawn, or in areas where wolves do not expect to encounter people.

Wolf management - The discovery of this dead animal in the Netherlands accelerated compilation of a special wolf management plan demanded by the Dutch government, specifying how to deal with the re-appearance of the wolf (Groot Bruinderink et al., in press).

Conclusions

Combined macroscopic and biochemical analyses of the dead canid found near Luttelgeest on July 4th 2013 showed that it was a purebred female wolf, just over one year old, of eastern European origin. Remains of shattered bullet fragments found in the chest and flank, and a discrepancy between the timing of the *post mortem* and *rigor mortis* intervals indicate that this wolf was shot prior to its appearance in the Netherlands. The carcass was still relatively fresh, thus it must have been driven from a distance that could be bridged within two days. It fed on beaver, most likely in either the Carpathian mountains or the Eifel, before it was shot and subsequently illegally transported to the Netherlands. These areas are the only regions where the haplotypes and $^{87}Sr/^{86}Sr$ isotopes retrieved from the dead wolf and the beaver remains found in its stomach co-occur. Ongoing analyses of additional $^{87}Sr/^{86}Sr$ and also $^{206}Pb/^{207}Pb$ isotopes will hopefully shed more light on the geographical region where the beaver was consumed. (Un)intentional illegal introductions of wildlife in the Netherlands are quite common (van Diepenbeek 2006, van der Hagen 2008). Detailed morphological, molecular and isotope analyses of the carcass and the stomach contents of the wolf helped to distinguish artificial from natural dispersal here, similar to earlier cases (Gravendeel et al. 2011). We advocate regular application

of wildlife forensic techniques when formerly extinct species re-appear.

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Samenvatting

De eerste in Nederland gevonden wolf sinds 150 jaar was het slachtoffer van milieucriminaliteit

De laatste wilde wolven (*Canis lupus*) in Nederland werden in 1869 waargenomen in Schinveld. Ruim 125 jaar later, op 4 juli 2013, werd een dood subadult vrouwtje gevonden op de weg tussen Luttelgeest en Marknesse in de Noordoostpolder. DNA-analyse wees uit dat het om een raszuivere wolf ging van Oost-Europese afkomst. Het laatst genoten maal bestond uit een bever die alleen in de Eifel of de Karpaten kan

zijn gevangen omdat dit de enige gebieden zijn waar $^{87}Sr/^{86}Sr$ isotopen en haplotypes van zowel de wolf als bever met elkaar overeenkomen. Beide gebieden liggen voor een wolf te ver van de Noordoostpolder vandaan om binnen een dag naar toe te kunnen lopen. Kogelfragmenten en slagsporen in de borstholte en flank, en een discrepantie in de periodes van lijkschouwing en lijkstijfheid, wijzen op afschot gevolgd door illegaal transport naar Nederland. Van natuurlijke remigratie was dan ook geen sprake.

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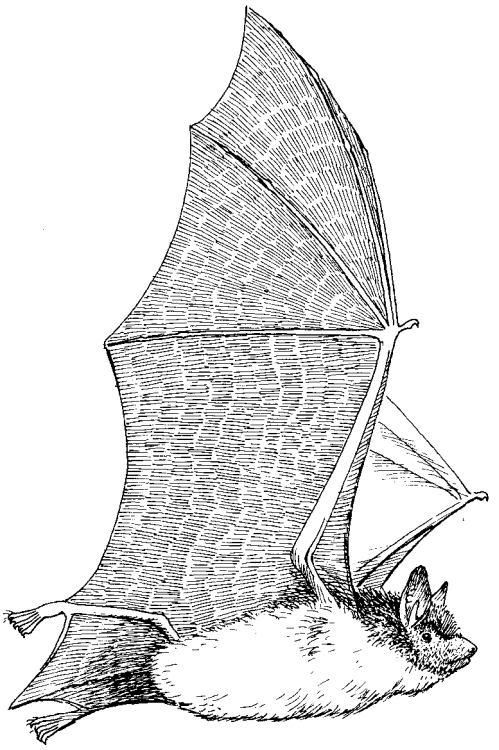

Habitat use by female Geoffroy's bats (*Myotis emarginatus*) at its two northernmost maternity roosts and the implications for their conservation

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Abstract: Geoffroy's bat (*Myotis emarginatus*) has four known breeding colonies in the Netherlands. Two of these are the known most northerly maternity roosts of the species. Both colonies have received Natura 2000 status. In order to collect ecological data needed to develop a management plan of these two sites, seven female Geoffroy's bats from these two breeding colonies were radio tagged and tracked during their foraging trips. The animals used woods, stables of cattle and sheep, and tree lanes, to a distance of up to 8 kilometres from the maternity roosts. The animals used tree lanes to fly from their roosts to the hunting areas, but also to forage. They spent the most time in woods (36%), stables (32%), and in tree lanes (29%), the remaining time (2%) was spent in urban areas, open fields and orchards. We did not observe any movement of individuals between the two colonies. The percentage of the night spent in stables was negatively correlated with outside temperature. Based on the ecology of Geoffroy's bats and the data gathered in the telemetry study, we propose a number of recommendations for protecting these two colonies. These include conserving the breeding colony buildings and adapting management practices in an area of 8 kilometres around the colonies. The most important of these management practices are: conserving tree lines, insect-rich stables and woods In addition, the Dutch and German authorities should cooperate in controlling development projects (construction of roads or estate development) and other projects that may affect these landscape structures.

Keywords: temperature, weather, stables, cattle, lanes, woodland, Chiroptera, Limburg, the Netherlands.

Introduction

Geoffroy's bat (*Myotis emarginatus*) is a rare species in the northern part of its range and was evaluated as "Vulnerable" in 1996 (IUCN 2007). For this reason, Geoffroy's bat was included in Annexes II and IV of the Habitat Directive, giving it a special protection status in the European Union. Recently, the conservation status of the species has improved throughout much of Europe: in the European Mammal Assessment of 2006 (Temple & Terry 2007) it was evaluated as being of 'Least Concern'. In the Netherlands, however, only two maternity sites are known and it is considered 'Vulnerable' (Zoogdiervereniging VZZ 2007).

After arousing from hibernation in April and May, the females move to large mater-

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nity colonies, where the young are born. During the time of this study, there were two large maternity roosts, and two very small roosts (<10 individuals) in the Netherlands. The two large maternity roosts are located within 2 km of each other near Echt, Province of Limburg, with one each occurring in the attics of the Maria-Hoop Monastery and Lilbosch Abbey (Vergoossen 1992, Verheggen 2001). These maternity roosts are surrounded by agricultural land and woodlands, and at the time of this study were occupied by 985 and 85 adult animals respectively during summer (Vergoossen et al. 2009). The buildings in which the colonies are located have been assigned a Natura 2000 status (Ministry of Agriculture, Nature and Food Quality 2003).

However, to conserve the maternity roosts, the foraging areas must also be protected. This requires an understanding of the distances flown and the habitat types used by the bats. We gathered these ecological data by radio tagging and tracking seven females from the maternity roosts during their foraging flights in May 2007.

Materials and methods

Bats were captured between 17 and 23 May 2007 on flight paths using mist nets on the terrain surrounding the two maternity roosts and at a stable in the village of Montfort that was found to be a foraging site in an earlier study (J. Regelink, unpublished results). The captured bats were sexed, weighed, their forearm length was measured, and their reproductive condition was assessed. Non-reproductive females or females in early stages of pregnancy received a 0.42 g radio-transmitter (Model LB-2, Holohil Systems Ltd, Carp, Ontario, Canada) which was glued onto the fur, between the shoulder blades, using surgical glue (Sauer Hautkleber, Manfred Sauer GMBH, Lobbach, Germany). The recommended transmitter to body weight ratio of 5% (Aldridge and Brigham) was not exceeded. After the glue had dried, animals were released by placing them on a tree or other elevated object, so that they could fly away.

Animals were tracked using a directional antenna (type Y-6, Televilt, Lindesberg, Sweden) mounted on a car, and a receiver (Communication Specialist, Orange, California, USA). Each team, consisting of a driver and a tracker, tracked a single animal by car and whenever possible used close approach telemetry techniques to verify the location of the bat. If this was not possible, radio-triangulation was used to provide point locations. The positions of the animal were determined by homing in, but if animals hunted in an area for a longer period, an attempt was made to pinpoint this site by triangulation or by circling the site. If animals were hunting in stables for longer periods, we attempted to get a precise location by observation or by triangulation on foot. When this was not possible, because areas were inaccessible, the whole area that could be encircled was classified as being used, accepting a lower resolution.

During tracking, locations of the animal were entered in a voice-recorder and a GPS. The location of the animal was classified by habitat type, classified as 'forest interior', 'stable', 'tree lane', 'orchard', 'urban' or 'open field'. Animal locations on a forest edge were classified as 'tree lane'. On the afternoon after each night of the fieldwork, the data were entered into a GIS and a spreadsheet. Stables that were used by the tracked animals were visited after the fieldwork period and their characteristics (type of cattle housed, type of flooring, and whether lights were left on or off at night) were recorded. Only animals that were tracked for more than two full nights were used in the habitat analyses.

We tested the effect of temperature, wind speed, and rainfall on the use of stables using Pearson correlation coefficients. Weather data was provided by Mr. Thieu Smeets (available from http://home.wxs.nl/~thieusm/limmet.htm) who maintains a weather station in Montfort. From his measurements, made at 10 minute intervals, we calculated sums (rain-

Table 1. Overview of the captures and days female Geoffroy's bats were tracked during the study in 2007. L: captured at Lilbosch. M: captured at Maria-Hoop. 1: 1st complete night tracked. 2: 2nd complete night tracked, ½: incomplete night. X: loss of transmitter.

Night of	L1	L2	L3	M1	M2	M3	M4
16 May	L						
17 May	1						
18 May	2	L	L				
19 May	-	1	1				
20 May	½	2	-	M	M	M	
21 May	½	-	-	-	1	1	
22 May	-	X	2	½	2	-	
23 May	X		-	-	-	-	
24 May			X	½	-	-	M
25 May				½	-	-	½
26 May				1	-	-	½

fall) or averages (wind, temperature) for the activity period of the bats, from 22:30 - 04:30 on the nights when bats were tracked.

The experiment was evaluated and approved by the Institutional Animal Care and Use Committee of Wageningen University as required by Dutch law (entry number 20070033). Exemption from the Dutch Flora and Fauna Act, which is required to capture and radio tag Geoffroy's bat, was given by the (then) Ministry of Agriculture, Nature and Food Quality.

Results

Four netting sessions resulted in the capture of ten female Geoffroy's bats. Of these, seven were radio tagged: three from the Lilbosch colony and four from the Maria-Hoop colony (table 1). Two tagged animals proved hard to track and could not be followed for two full nights. The data of these animals are included in the maps, but not used for habitat analyses. The animals lost the radio tags 4-6 days after tagging.

Two animals spent the day following capture outside the roost, one under a roof in Havert in nearby Germany, the other on the attic of a shed in Montfort in the Netherlands. One animal was caught near Maria-Hoop, but did not return to the colony at all. After two days, she was discovered roosting under an overhanging roof in Haaren, Germany. The next day, this animal roosted at a stable in Selsten, Germany.

All but one of the tracking days were dry. 4.4 mm of rain fell on the 18th of May in Montfort. The average temperature during the nights of the study ranged between 9.3 °C and 16.3 °C. Wind speeds remained below 1 Beaufort on all the nights of the study.

Spatial behaviour

During the study period, we were able to determine the emergence and return times of the 7 tagged animals a number of times. The radio tagged animals left the roost at 22:18 hours ± 0:12 sd (n=11), 44 minutes after sundown, and returned on average at 4:46 hours ± 0:14 sd (n=7), 53 minutes before sunrise.

Individual animals used similar flight paths and foraging areas on multiple days. Typically, after emergence from the roost, 2-3 stables were briefly visited during the commuting flight to the main hunting sites. A few times the tracked animals could be seen flying just under the canopy of tree-lined lanes,

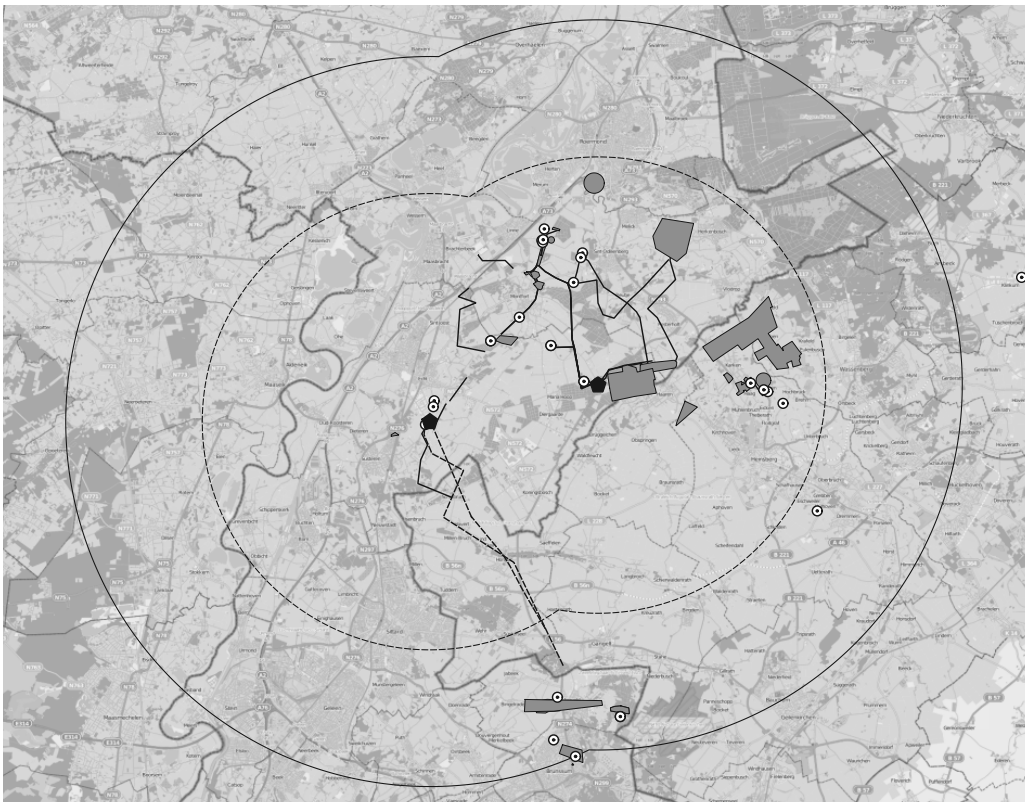

Figure 1. Overview of all certain (solid lines) and probable (dotted line) flying routes and foraging areas (polygons and dots) used by the seven tracked female Geoffroy's bats. The two houses represent the two colonies. The dotted circle has a radius of 5 kilometres, the solid circle a radius of 8 kilometres.

although they occasionally crossed tens of metres of open fields as well as two-lane roads close to the colonies. One of these roads (the N274), was crossed at multiple locations along a 3 km portion of the road that passed through a woodland, while the second road (the N572) was crossed where isolated tree rows intersected the road. The animals crossed at canopy-height. The animals spent large part of the night flying in several hunting areas, located in forests and stables. When returning to the roost in the morning, they often briefly visited stables *en route* again. The animals did not venture farther than 8 kilometres from their maternity roost (figure 1); three of the bats regularly foraged in Germany.

The tracked individuals of the two roosts remained loyal to the roost where they were captured, with the only overlap occurring on the foraging grounds. One bat from each roost used the same stable near Montfort and this included simultaneous use.

Habitat use

Between leaving the roost and returning to it, the animals we tracked spent 36% of the time in woodland, 32% in stables, 29% in tree lanes, and 2% of the time in villages, orchards or open fields. Animals from the Maria-Hoop roost used tree lanes less often as their roost borders woodland.

There were clear individual differences in habitat use and although the animals used roughly the same range on consecutive

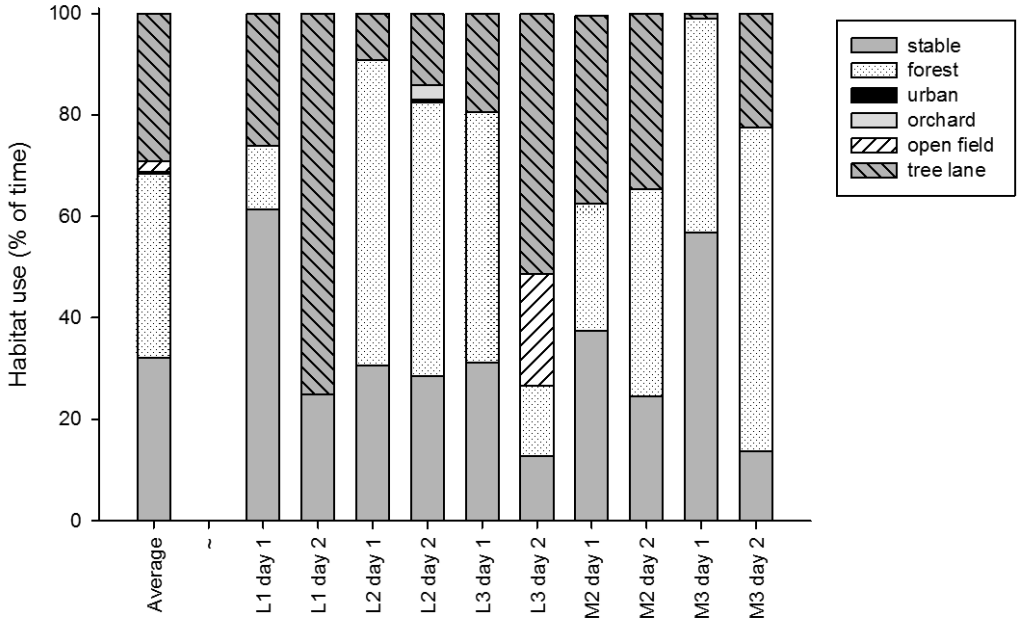

Figure 2. Habitat use by all animals and of individual animals per day, expressed as percentage of the time tracked.

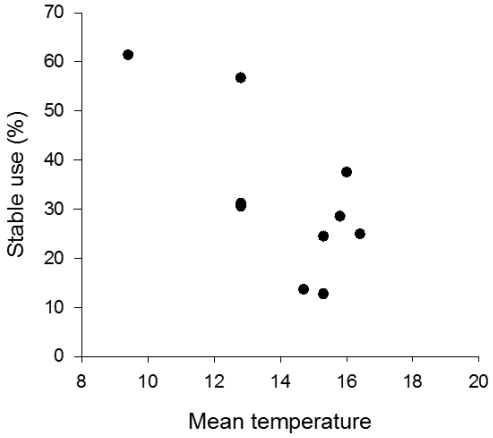

Figure 3. Use of stables and mean day temperature. Nightly use of stables was negatively correlated to night temperature (Pearson's correlation coefficient r=-0.70, P=0.02).

nights, some animals selected different habitats within these areas in the two nights they were tracked (figure 2). Nightly use of stables was negatively correlated to average temperature (figure 3; Pearson's r=-0.70, P=0.02).

Cattle were present in most (7 of 11) stables that were used, with one of these also housing sheep. One each of the remaining stables housed horses alone, sheep alone, horses and sheep together with the final stable containing only straw and machinery. All the stables had hard floors (concrete or tiles) where dung and straw is removed every few days, or had calves on straw in a corner. In 6 of 7 stables of which the owner could be interviewed, lights were kept off at night. The insides of stables and cowsheds were rich in insects, especially stable flies (*Stomoxys calcitrans*). We found no clear effect of the type of livestock housed on the amount of time a stable was used, but the stable used most and by several animals was a stable for cattle.

The animals hunted in several woodlands: Annendaalse Bos, Munningsbosch, 't Sweeltje, Taterbosch and a riparian woodland in Saefelen, Germany. The majority of these were mixed woods of Scots pine (*Pinus sylvestris*) and pedunculate oak (*Quercus robur*) crossed by open hiking paths. All but one of the woods used had a shrub layer of elder (*Sambucus nigra*), raspberry (*Rubus idaeus*) and rowan (*Sorbus aucuparia*).

Discussion

Only a small sample of the total population was studied: we tracked seven of the approximate 1000 animals inhabiting the two maternity roosts. However, the spatial patterns shown by these seven animals seemed to be similar to other Geoffroy's bats from these colonies that were observed using tree lanes and other linear elements as flyways, and woods and stables for hunting.

The insides of stables and cowsheds were relatively rich in insects, especially Diptera. They are sheltered from wind and rain and temperatures inside are usually higher than outside, especially when cattle are present. As such, stables may be an attractive foraging habitat for those species that can capture food by gleaning. Indeed, a large part of the diet of Geoffroy's bat in Germany and Belgium consists of insects that occur in stables (Krull et al. 1991, Moermans 2000, Steck & Brinkmann 2006, Kervyn 2012). The frequent use of stables and cowsheds by hunting Geoffroy's bats has also been found in other studies from the northern part of the species' distribution range (Krull et al. 1991, Brinkmann et al. 2001, Zahn et al. 2010). A study in southeastern Germany resulted in similar findings to our own study, with tracked females spending 24.5% of the time in cow stables (Zahn et al. 2010). In Baden-Württemberg tracked females from a maternity colony spent up to 90% of the night in stables, while the two males tracked did not hunt in stables at all (Brinkmann et al. 2001). The study by Krull et al. (1991) does not give figures that specify foraging times in different habitats. In France and Spain tracking studies have shown no use of stables (Huet et al. 2002, Flaquer et al. 2008), but these study sites had only one or two stables (personal communication M. Lemaire, L. Arthur and C. Flaquer). We found that bats made more use of stables on colder nights and this supports the idea that the use of stables is related to climatological differences: in colder climates, the relatively warm and insect rich stables appear to be a more attractive alternative to natural foraging habitats, such as forests and orchards, whereas in warmer areas this advantage of stables is less prominent or absent.

In line with this, the use of stables and cowsheds by foraging Geoffroy's bats may be more frequent in the cooler months of spring and autumn than in summer: in spring and autumn their energy requirements are higher, and the temperature and insect density in natural habitats are lower (see for example Scanlon & Petit 2008). As such the sheltered stables will be more attractive hunting habitat than woodlands and tree lanes during autumn and spring, although in these periods the animals can also conserve energy by using torpor during inclement weather. The inter-relationship between temperature and food availability and their effect on Geoffroy's bats' choice of different foraging habitats over different temporal scales is an interesting subject for further study. This could be explored further by building predictive energy budget models and testing these models by determining the use of stables in spring, summer and autumn, using telemetry or autonomous bat call loggers and gathering local, more precise weather data and quantifying insect availability in stables and in alternative habitats.

Our data indicate that the animals fan out from the roost sites, to a distance of up to (at least) 8 kilometres. This range is similar to the maximum distance of 7.5 km found by Brinkmann et al. (2001) and 8 km reported by Zahn et al. (2010). Krull et al. (1991), however, report animals foraging as far as 10 km from the roost. Given the small number of bats tracked in our study, we recommend a conservation buffer of 10 km around all roosts of this species in the Netherlands.

Conservation measures

This study provides information on the amount of time female Geoffoy's bats spend in

different habitats across the landscape around the only two known maternity roosts in the Netherlands. From the data gathered, several conservation measures have been proposed. Detailed plans are given in a separate Action Plan for Geoffroy's bat in the Netherlands (Dekker et al. 2008).

Geoffroy's bat uses tree lanes to commute between their roosts and foraging sites and for foraging. These lanes are important commuting routes and must be conserved. For commuting bats, these and other linear landscape elements are important in providing shelter from wind and predators, and provide orientation clues (e.g. Limpens & Kapteyn 1991, Verboom 1998). Even if the foraging areas and roosts are in prime condition, they will not be used if the animals cannot travel between them. Maintenance of tree lanes, especially the replacement of removed trees, is essential, to maintain connectivity across the landscape between foraging areas and roosts. The bats we saw during tracking flew in or above the canopy, and bats are sensitive to light during commuting (Stone et al. 2009). For this reason, streetlights in these areas should be placed sparingly. Attention needs to be given to providing bats with places to cross roads with substantial traffic (see Limpens et al. 2004).

Stables were an important foraging site. The stables used by the radio tracked animals mostly had livestock (and mostly cattle) housed on straw and an absence of lighting at night. It is vital for the wellbeing of maternity colonies to conserve these stables. Such stables are also used for hunting by common pipistrelle (*Pipistrellus pipistrellus*) (observations during our fieldwork), brown long-eared bat (*Plecotus auritus*) (Barataud 1990), grey long-eared bat (*Plecotus austriacus*) (Buys & Vergoossen 1997) and Natterer's bat (*Myotis nattereri*) (Simon et al. 2004). Stables can lose their value for foraging bats when insecticides or antiparasitic drugs are applied; this can reduce the number of insects, but also increases the risk of secondary poisoning. When stables are infested by insects that are harmful to the cattle, and must be treated, it is preferable to treat the cattle directly. The impact on bats can be minimised by treating stables early in the morning and by using insecticides that do not target mammals, such as pyrethrins. Other ways to minimise the impact on bats is by controlling insects using electrocution lights. We advocate avoiding deworming cattle with drugs that contain avermectins, as this compound remains active in dung for a long time, killing not only parasites, but also the insects inhabiting the stable (Ransome & Hutson 2000). Modern stables that do not have straw mixed with dung provide only few insects. This could become a problem, because "old-fashioned" stables seem to be becoming quite rare in the study area.

Woodlands used by the animals were mixed woods with a rich undergrowth. These woodlands should be conserved in this state. This can be done by retaining the undergrowth and leaving dead wood. The woodlands should be connected to tree lanes or other linear landscape structures, not only in the Netherlands, but also in neighbouring Germany.

Other studies have showed that *orchards* can also be an important habitat for Geoffroy's bats (Krull et al. 1991, Brinkmann et al. 2001, Zahn et al. 2010). There are very few orchards in our study area, but cultivation of these would surely benefit Geoffroy's bats, provided they are managed organically and are insect-friendly.

Conservation across borders. Three of the seven bats we tracked relied on areas in Germany for foraging and it is likely that the animals living in the Belgian maternity roosts close to the Dutch border have hunting areas in the Netherlands. For this reason, cross border landscape management plans are required that take the habitat requirements of Geoffroy's bat's into account. A first step could be to arrange meetings between bat specialists and local landscape planners and managers from Belgium, Germany and the Neth-

erlands. In such meetings, known data of maternity roosts can be compiled and shared and any planned construction or landscape management projects in the direct surroundings of the roosts in the three countries can be reviewed, with a view to ensuring that compensation and/or mitigation measures to minimise the effects of such projects can be formulated.

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Samenvatting

Ingekorven vleermuizen in Nederland: habitatgebruik en bescherming van de twee noordelijkste kraamkolonies

Ten behoeve van beheer van twee kraamverblijven met een Natura 2000 status, Lilbosch en Maria-Hoop, werd het habitatgebruik van de daar levende ingekorven vleermuizen (*Myotis emarginatus*) onderzocht. Dit gebeurde door zeven dieren uit te rusten met een kleine zender en deze te volgen tijdens foerageertochten.

De dieren gebruikten bossen, stallen en bomenlanen, tot 8 kilometer van hun kraamverblijf. Bomenlanen werden gebruikt om de foerageergebieden te bereiken. De dieren besteedden de meeste tijd in bossen (36%), gevolgd door stallen (32%) en bomenlanen (26%). De resterende tijd (2%) werd besteed in stedelijk gebied, boven weilanden of akkers, of in boomgaarden. Geen van de gevolgde dieren wisselde tijdens de studie van kraamverblijf. Het percentage van de nacht dat in stallen werd besteed was omgekeerd evenredig aan de buitentemperatuur.

Op basis van de verzamelde gegevens in deze en andere studies kon een aantal beheermaatregelen worden geformuleerd. Hoewel enkele honderden meters rond de twee kraamverblijven zijn aangewezen als Natura 2000 gebied, gebruiken de ingekorven vleermuizen een groter gebied. Het advies is daarom om de soort in een groter gebied te beschermen dan nu het geval is. Aanbevelingen voor het

beheer zijn het behoud van bomenlanen, stallen en bos, alsmede samenwerking aan beide zijden van de Nederlands-Duitse grens tijdens projecten die het landschap beïnvloeden, zoals wegen- en stedenbouw.

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Reducing shrew mortality in Longworth live-traps

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Abstract: During a four year field study period, several improvements were made to the method and mechanism of capturing shrews using Longworth live-traps, in order to reduce mortality after capture. The addition of extra food to the traps reduced mortality of common shrew (*Sorex araneus*) only slightly, indicating that insufficient food supply in the traps was not the main cause of death after capture. Mortality was largely reduced by checking all not-closed traps at every control round for signs of visits by shrews to the nestbox compartment and, subsequently, refilling these visited traps with food. Reducing the space beneath the treadle in the trap tunnel helped to lower shrew mortality further. The combined adaptations to the standard method and to the trapping mechanism reduced shrew mortality (both common shrew and water shrew, *Neomys fodiens*) by 83%.

Keywords: Longworth live-trap, common shrew, *Sorex araneus*, water shrew, *Neomys fodiens*, mortality.

Introduction

Longworth live-traps are widely used for capturing small mammals in many different biotopes (e.g. Bergers & La Haye 2000, Flowerdew et al. 2004). This type of trap consists of an entrance tunnel with the trapping mechanism and a nestbox in which nesting material and food can be placed. Trapping occurs when the animal steps on a treadle at the end of the tunnel. This causes the trapdoor at the entrance to fall down. The animal can make itself a secure place in the nestbox, which reduces stress, and food can be put in the nestbox to keep the animal alive until the trap is checked. However, mortality can be considerable in Longworth live-traps, especially for shrew species, which have a high metabolic rate compared to mice and voles (Rychlik & Jancewicz 2002, Taylor et al. 2013) and are more susceptible to stress.

De Onlanden is a nature reserve of about 25 km^2 near the city of Groningen, in the northern part of the Netherlands (figure 1). It has been designated as a water containment area by the Dutch government, as part of regional security measures against flooding. Therefore, over the past few years, De Onlanden has been drastically changed from a half-natural, extensively managed grassland biotope on peat soil into a wetland with large marshland areas and water levels that fluctuate greatly. Overall, the water levels in De Onlanden are now 30 to 70 cm higher than before.

Since 2009 the small mammal population in De Onlanden has been studied using Longworth live-traps. The aim of the study was to monitor the effects of the large and sudden biotope change on small mammal population, with special emphasis on the water shrew (*Neomys fodiens*). This study is still in progress and results will be published in the future.

The common shrew (*Sorex araneus*) has been abundant in De Onlanden during the study period and has often been captured in the traps. At first, using standard procedures for Longworth live-traps (Bergers & La Haye 2000), the mortality of this species after capture was high. During the research period a number of adjustments to the trapping procedure were tested in order to reduce the mortality of common shrews, and shrews in general, in Longworth live-traps. The results are described below.

Methods

Monitoring of small mammals in De Onlanden (53°10'N, 6°30'E) was carried out between 2010 and 2013 during the spring-summer period (end of May - end of September). Throughout the study, traps were placed in sets of two at ten points, approximately ten metres apart, along a straight line (trapline). At most locations in the study area, three traplines, 60 traps in total, were deployed. Distance between traplines was always at least 100 m, but usually they were placed much further apart. Since the main emphasis of the study was on water shrews, the traplines were mostly placed close to water, i.e. along the border of a ditch, pool or marsh area. The nestboxes of the traps were filled with nesting material (dry hay), and a piece of carrot and five living mealworms (*Tenebrio molitor* larvae) as food. Traps were left for two nights with the trapdoor mechanism inactivated, in order to let the mammals get used to the traps (prebait period). Next, another piece of carrot and approximately ten mealworms were added to the nestbox and the trapdoor mechanism was activated. Capture proceeded for three nights. Traps were checked every twelve hours, starting at dusk before the first night. So in total six trap checks were done. The described procedure was in accordance with the standard procedure for monitoring small mammals by live-trapping with Longworth live-traps used in the Netherlands (Bergers & La Haye 2000).

The small mammals captured in the traps, were weighed and marked (by clipping of the fur on the back) before release. Water shrews were not clipped, since this could negatively affect the water repelling properties of their fur, thereby reducing their fitness after release. Each trap that had been occupied was refilled with the standard amount of carrot and mealworms. Hay in the nestboxes was not refreshed on a regular basis after the prebait period, as described by Bergers & La Haye (2000), but only when considered necessary.

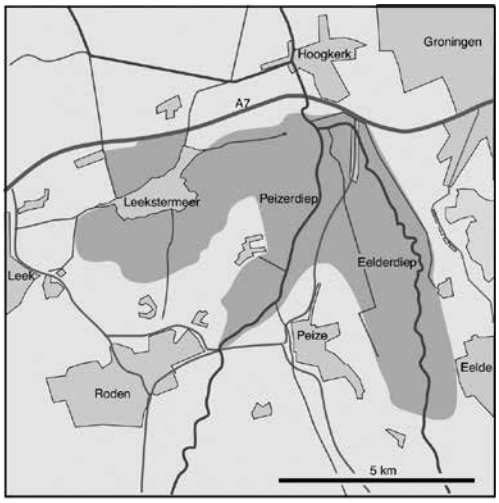

Figure 1. Location of De Onlanden (dark grey), the study area in the northern part of the Netherlands. *Map: H. Sips.*

Due to the constantly fluctuating water levels in the study area, traps could be flooded at any time during the prebait period or between two trap-checking sessions. In these cases the wet hay in the nestbox was refreshed. In the course of the study, modifications to the number of mealworms added to the trap as well as to the checking procedures were made. In consecutive years, these modifications consisted of: adding more mealworms to the traps, improving the checking procedure, and reducing the space beneath the treadle in the trap tunnels. Details of these modifications are described below, in the results section.

Results

The total numbers of captured shrews and other small mammals in De Onlanden in different years are given in table 1. In all years, large numbers of common shrew were captured, water shrew was captured mainly in the last two years, whereas pygmy shrew (*Sorex minutus*) was only very rarely captured throughout the study. Other small mammals were captured in relatively low numbers, com-

Table 1. Total numbers of captured animals, and of animals found dead in the Longworth live-traps per year for *Sorex araneus* (Sa), *Sorex minutus* (Sm), *Neomys fodiens* (Nf) and other small mammals (other); percentage dead = (dead/captured) x100.

Year	Total captured				Dead				Percentage dead			
	Sa	Sm	Nf	other	Sa	Sm	Nf	other	Sa	Sm	Nf	other
2010	147	3	0	22	19	0	0	1	12.9	0	0	4.6
2011	215	0	27	325	20	0	0	2	9.3	0	0	0.6
2012	211	0	119	93	12	0	4	1	5.7	0	3.4	1.1
2013	355	8	124	27	8	0	2	0	2.3	0	1.6	0

pared to shrews, except for 2011 when common vole (*Microtus arvalis*) was abundant. Very few field vole (*Microtus agrestis*), bank vole (*Myodes glareolus*), wood mouse (*Apodemus sylvaticus*), harvest mouse (*Micromys minutus*) and water vole (*Arvicola amphibius*) were captured.

In 2010 the standard method for monitoring small mammals that was described above was used. Mortality for common shrews in traps was 12.9% (table 1). In traps with dead shrews all the mealworms were eaten. Therefore, starvation was assumed to be the primary cause of this high mortality rate. In 2010 one common vole was found dead in the traps on a total of 17 captures of this species.

In order to reduce shrew mortality, in 2011 the standard amount of mealworms added to the traps after prebaiting was raised from approximately 10 to at least 20 per trap. Common shrew mortality decreased to 9.3% (table 1). Low numbers of water shrews were captured in 2011, of which none died. In this year, one common vole and one harvest mouse died when trapped, on a total of 246 and 16 captures, respectively.

In 2011 it was noticed regularly that nestboxes had been visited by a mammal without the trapdoor closing (figure 2). This occurred only at locations where common shrews were present. Apparently, these small mammals (and possibly pygmy shrews as well) were able to enter the nestbox by passing under the treadle, or by going over it without putting enough pressure on the treadle to release the trapdoor. All, or part of the mealworms in the nestbox could thus be eaten by the shrew, leaving the trap open for the next visiting shrew, which would have a reduced amount of food, or none, left when trapped. Mice and voles would not be affected by this lack of mealworms, since they can also feed on the carrot in the trap. Shrews however do not feed on carrot and would have a greater chance of dying by starvation when locked in an already visited trap. This might explain at least part of the continued high mortality of shrews in 2011, despite the extra amount of mealworms in the traps.

Therefore, from 2012 on, at every control round the nestboxes of all traps were checked for signs of shrew visits. New mealworms (always at least 20) were added to the traps that had been visited. A record was kept of visited traps. In 2012, a total of 100 nestboxes were found to have been visited by shrews between two checking sessions without the trapdoor closing. Thus, on a total of 330 captures of shrews, approximately 23% of the shrews visiting a nestbox had not been captured on the first or subsequent entries. Common shrew mortality in 2012 was 5.7% (table 1), which was considerably lower than in previous years. In 2012 large numbers of water shrew were captured as well. Water shrew mortality was in the same range as of common shrew (table 1). Sometimes, the relatively large holes in the hay and large scats found in the tunnel of traps that had been visited, suggested that water shrews were also able to enter and leave

Figure 2. View inside a Longworth live-trap. The tunnel made in the nesting material is clear evidence that a mammal has visited the nestbox without the trapdoor closing. *Photo: W. van Boekel.*

the nestbox without the trapdoor closing, but no conclusive evidence was found for this. In 2012 one bank vole was found dead in the traps on a total of 20 captures of this species.

In 2013, the number of visits to nestboxes by shrews without being caught was largely reduced by adjustment of the trapping mechanism of the Longworth live-traps. By placing a piece of rubber (a section of bicycle inner tube was used) in a slit at the exterior of the tunnel next to the treadle (figure 3), the space beneath the treadle was reduced from the standard 13 mm to 8-10 mm, making it more difficult for shrews to pass under the treadle. The adjustment also helped to reduce the pressure needed to release the trapdoor when a shrew passed over the treadle. In 2013, at four out of 27 traplines small numbers (1 or 2 individuals) of pygmy shrews were caught, next to common shrews and water shrews. The pygmy shrews were probably still able to pass under the lowered treadle, but their presence, compared to the other shrew species, was too low to contribute significantly to the total numbers of visited nestboxes. In 2013, a total of 80 traps were visited by shrews without trapdoor closure on a total of 479 captured shrews. Thus, the adjustment of treadle height reduced the amount of non-captured shrews to 14% (cf. 23% in 2012). Common shrew mortality in 2013 was 2.3% and water shrew mortality was 1.6% (table 1).

Discussion

It is well known that the high metabolic rate of shrews makes them vulnerable to starvation when kept captured over longer periods with a limited food supply, as is the case in live-traps. However, in most reports on field studies using Longworth or other types of live-traps, mortality rates for captured shrews are not, or only summarily, mentioned (van Bemmel & Voesenek 1984, Bergers & La Haye 2000, van der Linden & van der Weijden 2011). Shonfield et al. (2013) give mortality rates of 10-93% for shrews in a review of 16 Northern American small mammal monitoring studies. In these studies no food suitable for shrews was added to the traps.

In field experiments, Bekker & Dekker (2009) showed that standard adding of food (mealworms) to Longworth live-traps had a larger positive effect on survival of captured common shrews than shortening the period between trap controls from 12 to 8 hours. In their experiments, the mean mortality of common shrew in Longworth live-traps permanently stocked with ten mealworms (D.J. Bekker, personal communication) and checked every twelve hours was 13.2%. This is comparable to the mortality of 12.9% found in the first year of this study.

In laboratory experiments, common shrews died within eight hours when left without food (Saarikko 1989). In the field this period may be shorter. The lower habitat temperature and probable higher activity level of the animal, compared to laboratory situations, will lead to a higher energy demand. The length of the survival period for a shrew after capture in a live-trap will thus depend on the amount of food and on the thermal conditions in the trap. In laboratory experiments, using metabolic cages at room temperature, Churchfield (1979) found that common shrews consumed,

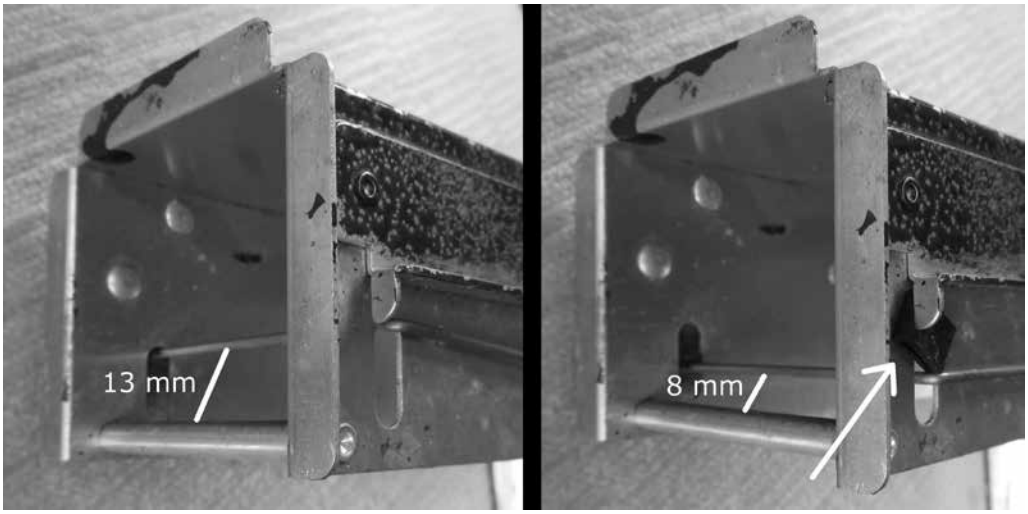

Figure 3. The space beneath the treadle in the tunnel of a Longworth live-trap is reduced from 13 mm (left) to 8 mm (right) with the use of a small strip of rubber inserted above the treadle on the outside of the tunnel (arrow on photo at the right). *Photo: W. van Boekel.*

on average, 8.3 g (mean wet weight) of bowfly (Calliphoridae) pupae per day. Using the energetic value of bowfly larvae of 8.4 kJ/g wet weight given by Rychlik & Jancewicz (2002), it can be calculated that on average the common shrews in Churchfield's study consumed 69.7 kJ food per day. The energetic value of mealworms given by Rychlik & Jancewicz (2002) is 10.5 kJ/g wet weight. The mean weight of the mealworms used in De Onlanden was 0.1 g (based on weighing 350 mealworms). The 10 or 20 mealworms added to the traps would therefore represent an energetic value of 10.5 and 21 kJ, respectively. Applying Churchfield's data to the situation in the present study, it can be concluded that theoretically an average common shrew that was captured in a trap containing 20 mealworms had enough food to sustain it for at least seven hours. Since it is likely that most shrews remained captured for periods (far) shorter than twelve hours, it can be assumed that the amount of 20 mealworms in the traps would be sufficient to cover the largest part of the energy demand of a common shrew after capture. Also, it is likely that the animal would be able to survive for several hours after depletion of the food in the trap, as mentioned above. For pygmy shrews, Churchfield (1979) found an average consumption of 4.9 g of bowfly pupae per day, indicating an energy consumption of 41.2 kJ/day for this species. Pygmy shrews in De Onlanden would thus theoretically have found sufficient food in the traps containing 20 mealworms to sustain them even when they remained captured for twelve hours. Churchfield (1979) found that food consumption by the large water shrews was low compared to common shrews. Water shrews ate 7.3 g of bowfly pupae per day, equivalent to an energy consumption of 61.3 kJ/day. Water shrews would probably also be able to survive for a longer period without food, compared to common shrews, due to their larger size. In general, shrews captured in De Onlanden in traps containing 20 mealworms had a good chance of surviving their capture. However, when the mealworms in the trap were eaten by a visiting shrew that was not captured, there might have been not enough food left in the trap for the next shrew.

Bekker & Dekker (2009) made no mention of the phenomenon of shrews visiting traps without capture. Usually, in field studies using Longworth live-traps, traps are quickly

checked for closed doors, without looking inside all traps to see if they have been visited. In this study it is shown that shrew mortality can be largely reduced by checking each trap at each control round for signs of visits by shrews and subsequently adding new mealworms to traps that have been visited.

Reduction of the space beneath the treadle largely improved the yield of the trapping mechanism of Longworth live-traps, thereby further reducing shrew mortality in the traps. In studies that focus on voles and mice, a high position of the treadle in Longworth live-traps is beneficial, since less traps will be occupied by (unwanted) shrews. In studies that aim at investigating all small mammals present in the field, Longworth live-traps with lower treadles would be more suitable, since this increases the chance of capturing shrews. Gurnell & Flowerdew (2006) mention the use of treadle ramps to prevent animals passing under the treadle of Longworth live-traps. However, it is still not clear whether these ramps are effective and reliable in field studies.

Dry hay, used in the present study as nesting material, has a better thermal insulating capacity than moist or wet hay. Due to the field conditions in the present study, most traps could not be kept dry over longer periods and the hay in the nestboxes was often moist or even wet. The effect of the condition of the nesting material on shrew mortality in the traps was not taken into account here. However, this effect can be assumed to have been small, since mortality was already reduced by 83% even though the overall condition of the nesting material remained constant. Each year, trapping was done in the summer period (June-August) when night temperatures generally are above 10 °C. Most likely, the effect of moist nesting material on survival of shrews will be larger in colder seasons.

Shrews are known to die easily in stressful situations. For instance, in the present study two lively common shrews died suddenly during the weighing procedure after capture (own data). There are, however, no indications that shrews died as a result of stress during captivity. In all the traps with dead shrews, no food was left and often clear signs of nest building activity in the tunnel part of the trap indicated that the shrew had been acting in a natural way. However, it cannot be excluded that animals became stressed after depletion of the food in the trap and that this contributed to the death of the animal.

Shrew mortality can also be reduced by increasing the frequency of control rounds. In studies focusing on shrews, the period between control rounds is often 2-4 hours (e.g. Churchfield 1984, Rychlik 2005). However, whether all shrews survive entrapment under these circumstances is mostly not clearly mentioned. If circumstances allow, a high checking frequency of the traps will be the best way to reduce mortality of all captured animals. In the present study, a high checking frequency was not feasible and would also have caused an unacceptable amount of disturbance in the nature reserve. However, the adaptations to the method and to the trapping mechanism presented here reduced shrew mortality considerably. The remaining trap deaths will probably have been caused by shrews being captured in traps that had been visited before by a shrew within the twelve hour period between two controls.

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Samenvatting

Verminderen van sterfte van spitsmuizen in Longworth inloopvallen

In het natuurgebied De Onlanden werd gedurende vier jaar de muizenpopulatie gevolgd met behulp van Longworth inloopvallen. In het eerste jaar werd de standaardmethode voor het vangen van muizen gebruikt. In de jaren daarna werd deze methode aangepast om de sterfte van spitsmuizen (gewone bosspitsmuis, *Sorex araneus*) en waterspitsmuis (*Neomys fodiens*)) in de vallen omlaag te brengen. De sterfte onder bosspitsmuizen was in het eerste jaar hoog door voedselgebrek. Toevoegen van extra voedsel in het tweede jaar leidde tot een geringe verlaging van de sterfte. Spitsmuizen bleken vaak onder de beweegbare drempel in de tunnel van de Longworth inloopvallen door te kruipen. Zo omzeilden ze het valdeurmechanisme. Ook als de spitsmuis wel over de drempel heen ging, bleek de val niet altijd dicht te gaan. Veel vallen werden zo door spitsmuizen, vooral bosspitsmuis maar mogelijk ook dwergspitsmuis (*Sorex minutus*), bezocht zonder vangst. Hierdoor was er geen, of te weinig, voedsel in de val voor de volgende spitsmuis die de val bezocht en deze wel dicht liet gaan. In het derde jaar van de studie werden daarom alle vallen, bij elke controle, nagekeken op bezoek van spitsmuizen (gangen in het hooi, keutels in de tunnel). Zo nodig werd de val bijgevuld met voedsel. De sterfte van spitsmuizen nam in dit jaar aanzienlijk af. Om de kans op bezoek van spitsmuizen aan vallen zonder vangst te verminderen werd in het vierde jaar de ruimte onder de drempel in de tunnel verkleind. Hierdoor nam de sterfte onder de gevangen spitsmuizen nog verder af. De gezamenlijke maatregelen leidden tot 83% lagere sterfte van spitsmuizen in de Longworth inloopvallen, ten opzichte van de standaardmethode.

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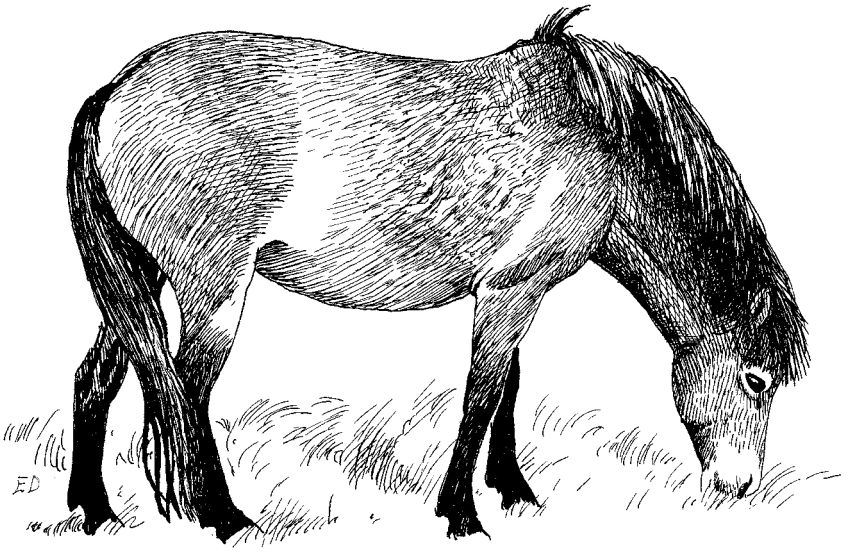

On the origins of the Exmoor pony: did the wild horse survive in Britain?

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Abstract: The Exmoor pony is considered the most primitive horse breed of Great Britain, but not a type of wild horse. In this article we draw upon historical descriptions, the literature on anatomical and morphological characteristics and on evidence based on mitochondrial DNA (mtDNA) and combine this with original analysis of the jaws and teeth of Exmoor ponies. Unlike elsewhere this wild pony type did not mix with other horse types on Exmoor. This leads us to argue that the Exmoor pony is not a 'man-made' breed, but a wild horse type with a separate history that has been uninfluenced by domestic horses.

Introduction

During the 1950s and 1960s, Speed (1951a, 1951b, 1956), Speed and Etherington (1952a, 1952b) and Ebhardt (1962) compared the bones and teeth of Pleistocene pony fossils with those of modern horse breeds and Exmoor ponies. They concluded that the modern Exmoor pony directly descends from the smaller Northern horse that lived in France and Britain during the Late Pleistocene. Unfortunately, these findings went relatively unnoticed by zoologists at the time. According to Groves (1986) British wild horses became extinct after the Pleistocene and Exmoor ponies descend from escaped domestic horses. Mohr (1971), on the other hand, argues that Exmoor ponies are partly descended from wild ponies that lived in Britain during the Late Pleistocene and partly from later imported breeds. The earliest discovered definitively British wild horse remains are estimated to date back to 8411 BC (Sommer et al. 2011).

In recent years the Exmoor pony has generally been described as the most primitive man made horse breed found in Britain (e.g. Aberle & Distl 2004, Cieslak et al. 2010) and the wild ancestors of domestic horses are regarded as being extinct (Warmuth et al. 2011). However, recent mitochondrial DNA (mtDNA) studies on the origin of horses have revealed new insights, particularly on the geographical distribution of different wild horse populations (Jansen et al. 2002, Cieslak et al. 2010). We argue in this paper that the Exmoor pony may directly descend from a wild type of pony population that lived in north-west Europe during the Late Pleistocene. The aim of this paper is to reconsider the true origin of the Exmoor pony, by focussing on specific anatomical, morphological and genetic characteristics, such as the jaws and teeth, coat colour, manes and mtDNA of Exmoor ponies and other horse types.

The recent history of the Exmoor pony

The presence of free ranging Exmoor ponies on Exmoor, England, was first described

in 1086 by tax inspectors of King William 1 (Morris et al. 1985). They reported that, besides their pack horses, some farmers around Exmoor owned 'unbroken horses' or '*Equi silvatici*' (the modern differentiation between the words 'pony' and 'horse' have no taxonomic relevance). Subsequent historical manuscripts (after 1617) refer to the Exmoor ponies as 'horse beasts', and describe how Exmoor pony foals were annually caught on Exmoor and sold into domestic service. In 1818 several local families started to breed 'pure bred' Exmoor ponies on small areas of moorland on the fringes of the old Royal Forest. Their herds were established with Exmoor ponies that were caught on Exmoor, and records show that the breeding of pure bred Exmoor ponies has continued right up until the present day (Baker 2008).

Anatomy: jaws and teeth

As far as we know Speed (1951a, 1951b), Speed & Etherington (1952a, 1952b) and Ebhardt (1962) are the only studies that analyse the bones and teeth of both Late Pleistocene and modern horse populations. These authors compared the bones and teeth of modern Exmoor ponies, Przewalski's horses, modern European horse breeds, fossils of Late Pleistocene north-western European ponies (up to approximately 102,000 to 6,500 years old) and ponies from Celtic graves (of ca. 2,250 years of age). They examined X-rays of lower jaws, molars and premolars and distinguished two horse types from north-western Europe in the Late Pleistocene. One was the larger Northern horse, which was (more or less) similar to Przewalski's horse. The larger Northern horse was adapted to a cold climate, whose optimal habitat is thought to be the steppe. Most of the Pleistocene horse remains from Britain and France were of this type. They also identified the smaller Northern horse. Remains of this smaller type were found in 21 excavation sites in the Mendip Hills, several other English and Scottish sites, in the Dordogne (France) and in Alaska (Speed & Etherington 1952a). According to Speed and Etherington (1952a) the smaller Northern horse probably migrated from America to Siberia during the Pleistocene and then subsequently it came to central and northern Europe via Asia Minor. It is presumed that it was once widely distributed and was well adapted to cold climates.

According to Speed (1951a, 1951b), Speed & Etherington (1952a, 1952b) and Ebhardt (1962), larger and smaller Northern horses, Przewalski's horses and Exmoor ponies have deep lower jaws with deeply rooted molars and premolars, set in a radial pattern (like the spokes of a wheel, see figure 1a). As these authors could not distinguish the bones, lower jaws, premolars and molars of the smaller Northern horse from those of modern Exmoor ponies, they concluded that the Exmoor pony was its only pure survivor in Britain.

In addition, Speed (1951a, 1951b), Speed & Etherington (1952a, 1952b, 1953) and Ebhardt (1962) argued that most of the modern north European horse breeds are partly descended from mares of the smaller Northern horse type, that were 'improved' by introducing Arabian and other types of stallions into the herds to replace the native stallions. According to them the Arabian horse was a type of wild horse, which no longer exists in its pure form in the present Arabian horses. This horse type had small premolars and molars in a shallow, lower jaw (Speed 1951a, 1951b). Figure 1b shows an X-ray of a lower jaw from a horse found in a Celtic grave from around 250 BC; its shallow jaw and small molars and premolars are, according to Speed (1951a, 1951b) and Ebhardt (1962), typical for Arabian horses. The presence of such a horse in a Celtic grave indicates that at this time the Celts already had horses whose appearance was very different from that of modern Exmoor ponies. Speed (1951a, 1951b), Speed & Etherington (1952a, 1952b, 1953) and Ebhardt (1962) concluded that, except for the Exmoor

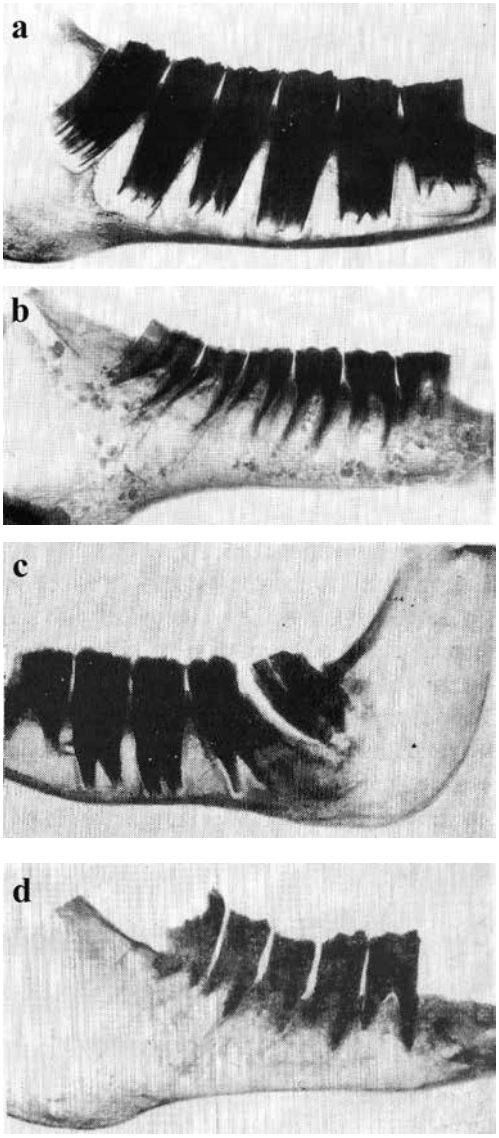

Figure 1. X-rays of a lower jaw of: a. a 4.5 year old Exmoor pony mare showing a deep lower jaw with deeply rooted molars and premolars, set in a radial pattern; b. an aged Arab-type stallion from a Celtic grave from around 250 BC, showing small premolars and molars in a shallow lower jaw; c. a Shetland pony, showing a short lower jaw with impaction of the 3rd and 2nd molars and; d. an aged 'Celtic' pony mare from Iceland, showing large teeth in a shallow jaw. The first two X-rays are taken from Speed & Etherington (1952b), the second two from Speed (1951a).

pony and the Przewalski's horse, all modern horse breeds are a mixture of original wild types. As a result the proportion of premolars and molars is often out of order to the available depth and length of lower jaws in modern breeds. This results in abnormalities, such as the impaction of the second and third molars (figure 1c) or large teeth in a shallow jaw (figure 1d). Such abnormalities are not found among Exmoor ponies or Przewalski's horses.

Although there is a lack of quantitative analysis in the work of Speed (1951a, 1951b) and Ebhardt (1962) these researchers mention having examined 'numerous horse skulls' (Speed 1951a) and 'a range of Celtic pony skulls, ancient and modern, from Iceland, Shetland, the mainland and Java' (Speed & Etherington 1952a). Boessneck et al. (1959) referred to Ebhardt's study material of horses and horse fossils as: 'an extensive collection of bones and X-rays of horse heads'. However, since there were only 50 Exmoor ponies extant in the world in 1945, the authors probably only examined a limited number of Exmoor ponies. In order to verify the lack of jaw abnormalities in Exmoor ponies, as mentioned by Speed (1951a, 1951b) and Ebhardt (1962), we dissected the lower jaws of 16 (four foals and twelve (sub) adults) deceased Exmoor ponies that were registered in the studbook of the 'Samenwerkingsverband Exmoorpony' (The Dutch Exmoor Pony Association). The molars and premolars in all the lower jaws were set in a regular radial pattern (figure 2) and all the (sub) adult Exmoor ponies had deep lower jaws (the lower jaws of foals become deep during the first year). The abnormalities that Speed (1951a) found in modern horse breeds were not present in any of the 16 lower jaws that we dissected. Two individuals had (pre) molars that were a little less deep rooted, similar to the X-ray of a lower jaw of a 2 ½ -year old Exmoor pony mare described by Speed (1951a). We believe that this may be a minor abnormality that sometimes occurs in natural populations.

Figure 2. Partly dissected lower jaw of a deceased adult Exmoor pony in 2012, showing a deep lower jaw with deeply rooted molars and premolars set in a radial pattern.

Morphology: coat colours and manes

DNA studies on coat colour variation in ancient, wild horse types show that most Siberian and European Pleistocene wild ponies were bay coloured, and probably dun, while a minority was spotted (Ludwig et al. 2009, Pruvost et al. 2011). This is consistent with Pleistocene drawings of wild horses in the caves at Lascaux and Chauvet, France: most of the horses in these drawings are bay dun (Pruvost et al. 2011). Colour mutations (chestnut, tobiano, sabino, buckskin and blacksilver) first occurred in Siberia and eastern Europe around 3000 BC, and strongly indicate horse domestication (Ludwig et al. 2009, Pruvost et al. 2011). Unlike most primitive European horse breeds (such as Shetland pony, Dartmoor pony, Icelandic horse and konik) Exmoor ponies lack these colour variations. They show a clear uniformity in coat colour, that is (dark) bay dun (figure 3a and b), similar to their free ranging ancestors in the early C19th (Baker 2008). Przewalski's horses are the only other remaining wild horse population that, to this day, have a uniform coat colour that is also bay dun (Pruvost et al. 2011).

Unlike Przewalski's horses, zebras and wild asses, Exmoor ponies have long pendulous manes (figures 3a and b). In Europe which has a predominant oceanic climate, pendulous manes might be advantageous as they allow rain drops to slide more easily down the coat. The recovery of a horse carcass from Yukon, Canada, estimated to be 26,000 years old, demonstrates that horses with long hanging manes already existed at the end of the Pleistocene (Harington & Eggleston-Stott 1996).

Genetics: mitochondrial DNA (mtDNA)

Recent mtDNA studies have revealed considerable new information on the maternal phylogeny of horses. Modern horse breeds appear to have maternally descended from a mixture of pre-domestic horse populations (e.g. Jansen et al. 2002). Aberle et al. (2007) showed that the mtDNA types of seven Exmoor ponies cluster almost entirely in one robust clade,

Figure 3. Exmoor ponies in a nature reserve in the Netherlands: a. Three year old Exmoor ponies in winter coat and; b. Three year old stallion, showing a deep lower jaw.

with low variability. Similar results were found by Vilà et al. (2001) and Jansen et al. (2002), who both found a low variation in the mtDNA sequences of Late Pleistocene Alaskan horses. They suggested this might be a feature of natural populations. The low level of diversity among Exmoor ponies may be due to a direct maternal link with a North-European wild pony type, but might also be due to a population bottleneck.

Cieslak et al. (2010) analysed mtDNA sequences from 207 ancient horse remains and 1754 modern horses, from Alaska to north eastern Siberia and Europe. Some mtDNA haplotypes were already widely distributed over Asia, Europe and Alaska, before the horse was domesticated. Other haplotypes were restricted to a geographic region before domestication, and their presence in a wild horse population indicates a period of isolation. The presence of some unique haplotypes in remains of Iberian Pleistocene horse indicates that the Iberian Peninsula was an ice-free refuge during the Pleistocene (Cieslak et al. 2010). In addition, Cieslak et al. (2010) found exclusive mtDNA haplotypes in remains of pre-domestic northern European horses (which they named B1 and F), that are still present in primitive European breeds, such as the Icelandic horse and Norwegian Fjord, but most frequently in the Exmoor pony (in 11 out of 17 samples; M. Cieslak, personal communication). One Exmoor pony sample (out of 17) had a haplotype (which they named X3) that probably was of a pre-domestic western European lineage as well, given the X3c2-sample from Shandon, Ireland from around ca. 25,624 BC (Cieslak et al. 2010). The presence of 11 (and probably 12) unique pre-domestic northern European haplotypes among 17 Exmoor pony samples, indicates that most Exmoor ponies are maternally linked to a wild north European pony type.

The five remaining Exmoor pony samples had haplotypes named I and D2e (Cieslak et al. 2010). Since the authors analysed relatively few ancient European horse samples, and the oldest horse remains with haplotypes I and D2e had a northern European origin, it is likely that these haplotypes also have a pre-domestic European origin. In summary, the mtDNA data indicate a separate history and a lack of influence of domestic horses in the maternal line of Exmoor ponies.

Discussion

During the Pleistocene, horses from colder climates inhabited the steppes and tundras of North Europe, Asia and Alaska, whereas horses from warmer climates inhabited the Iberian peninsula, and other ice-free refuges (Cieslak et al. 2010). The rising of the temperature after the Pleistocene could have created the conditions under which horse populations

from ice-free refuges moved northwards. However, this was probably not enough to enable them to make contact with the north European horse population, since at the same time the central European steppe gradually changed to forest vegetation, a biotope not liked by horses (Zeiler & Kooistra 1998, Birks 2005). Although horses were very rare in central Europe between 7,100 and 5,500 BC, remains of ancient wild horses indicate that wild horses were present in north western Europe and Iberia during this period (Sommer et al. 2011).

Even in the absence of a geographic barrier, such as a dense forest, other mechanisms, such as sexual imprinting (Irwin & Price 1999) are also likely to have prevented the fusion of colder and warmer horse types after the Pleistocene. In Mongolia, for example, Przewalski's horses and free ranging domestic horses remained different types (Orlando et al. 2013), in spite of them spending thousands of years in the same area. In and around the Hustai National Park owners of domestic horses often let them range freely (often not seeing them for several months (Hovens & Tungalaktuja 2005), but these horses have never formed or joined a harem group with the Przewalski's horses that were reintroduced in 1994 (N. Bandi, personal communication, director of Hustai National Park; J.P.M. Hovens, personal observations between 1994 – 2007).

Since the Pleistocene, Britain has always had open areas, which are a suitable horse habitat (Whitehouse & Smith 2010). The country was also connected to the North-European mainland until 7,000 BC (Sturt et al. 2013). Since wild horses inhabited the northern European mainland (northern France, Belgium, southern Sweden and northern Germany) during the 1,000 years before Britain was separated from the European mainland (Sommer et al. 2011), it is arguable that part of a Nordic population of wild horses lived and survived in Britain.

It is certain that horses of various types were crossbred by man during the period of domestication that started approximately 5,500 years ago (Cieslak et al. 2010). The British wild horse population, however, cannot have been mixed with other horse types until the Bronze period (2,000 BC), since Neolithic boats were not able to transport a living (wild) horse (Dent & Goodall 1962). Exmoor was relatively isolated until the C19th and wild horses were already recorded as being present on Exmoor as early as 1086. These two facts indicate that the Exmoor pony has remained largely separated from domestic horses and has retained its primitive features.

In view of the evidence (from different disciplines) that we have collected together here we conclude that the Exmoor pony is not a 'man-made' breed, but a wild horse type with a separate history that has been uninfluenced by domestic horses.

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Samenvatting

De herkomst van de Exmoorpony: Overleefde het wilde paard in Groot-Brittannië?

De Exmoorpony wordt doorgaans beschouwd als het primitiefste ponyras van Groot-Brittannië, maar niet als een ondersoort van het wilde paard. Op basis van historische bronnen, literatuur over anatomische en morfologische kenmerken, literatuur over mtDNA en eigen onderzoek aan kaken en tanden, blijkt echter dat de Exmoorpony een wild type paard is en geen door de mens gecreeerd ras. In tegenstelling tot elders in Europa, is deze ondersoort van het wilde paard in het Engelse Exmoor niet met andere paardentypen gekruist.

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A new record of taiga shrew (*Sorex isodon* Turov, 1924), from Sogn og Fjordane, Norway

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Abstract: The taiga shrew (*Sorex isodon*) has been known to be present in Norway since 1968, initially in the counties of Troms and Hedmark, and, more recently, in Sogn og Fjordane County. In the summer of 2011 a dead specimen was found outside its known distribution area in Sogn og Fjordane County, at an altitude of 800 m. This raises some questions, since the taiga shrew is known as a lowland species which prefers dense vegetation. One explanation for its presence at a high altitude is that it was dropped by a bird of prey after being caught at a lower altitude.

Keywords: Sorex isodon, taiga shrew, dusky shrew, distribution, Norway.

The known distribution area of the taiga shrew (*Sorex isodon*) extends from south-eastern Norway, northern Sweden and Finland through Siberia to the Pacific coast of Russia, Sakhalin and the Kuril Islands in the Sea of Okhotsk. As well as the preferred English name, taiga shrew, it is also known as dusky shrew (Wolsan & Hutterer 1998, Sulkava 1990, Sulkava 1999, Wilson & Reeder 2005). Records from Norway were previously limited to one location in the north of Troms County and locations in Hedmark County, close to the Swedish border (Sulkava 1999, van der Kooij & Solheim 2002a, 2002b, 2002c) (figure 1). Recently, several zoologists have recorded taiga shrews in Sogn og Fjordane County, further west in Norway (J. van der Kooij, T.C. Michaelsen and I. Byrkjedal, personal communication).

On 27 July 2011 a shrew was found on the path to the summit of the Tjuatoten, a mountain close to Dragsvik in Sogn og Fjordane County (61˚13'42 N, 006˚31'12 E) (figure 2). It was found at 800 m above sea level, on a slope where the vegetation was in transition from

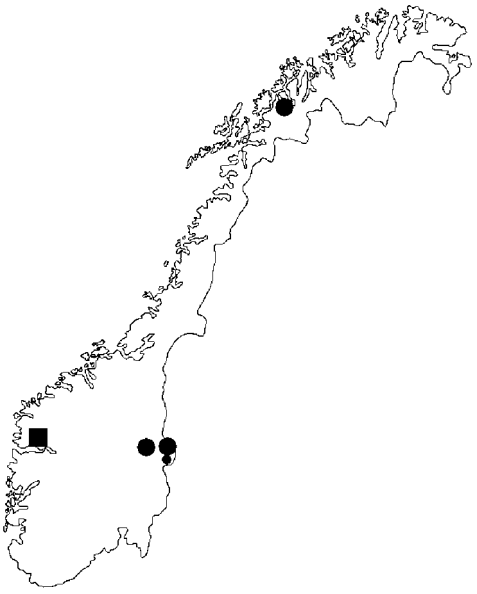

Figure 1. Distribution map of taiga shrew in Norway. Circles: localities known from previous records. Square: locality of the record from Dragsvik, to the north of the Sognefjord.

Figure 2. Locality of the record of the taiga shrew in Dragsvik. *Photo: Ingrid Margry.*

Figure 3. Preserved skin with the dark colour of the back gradually changing to a lighter grey-brown belly. *Photo: Ingrid Margry.*

forest to open area. The animal was remarkably large for a shrew and long hairs at the end of the tail showed it was a juvenile. The dark colour of the back gradually changed to a lighter grey-brown belly and the tail was clearly bicoloured (figure 3). The sex could not be determined. The animal was not quite fresh but has been preserved in alcohol.

Some measurements of the body and skull are listed in table 1 and compared with other taiga shrews and with the common shrew (*Sorex araneus*). The unicuspids gradually decrease in size and also the smallest unicuspid has a dark top (figures 4 and 5). The position of the foramen mentale of the mandible is a little posterior to the front edge of the first molar M_1 (figures 5 and 6). The rising part of the processus condylicus is much longer than the part that protrudes laterally (figure 7). The gradual change of colour on the flank, the length of the

Table 1. Body and skull measurements (mm) of the taiga shrew found at Dragsvik, Norway, compared with other taiga shrews and with common shrew. Measurements are according to van der Kooij (1999).

	Taiga shrew *Sorex isodon*	Taiga shrew *Sorex isodon*	Taiga shrew *Sorex isodon*	Taiga shrew *Sorex isodon* (*n*=?)	Common shrew *Sorex araneus* (*n*=?)
	Specimen from Dragsvik	Sulkava (1990) * = Ivanter (1976) ** = Skarén (1979)	van der Kooij (2002b)	van der Kooij (1999)	van der Kooij (1999, 2002b)
Total length	116	104-128 (*n*=19)	102-117 (*n*=8)		
Length of the tail	48.5	43-52 (*n*=19)	42-52 (*n*=9)		34-56
Head body length	67.5	59-83 (*n*=19)	56-74 (*n*= 9)		40-87
Hindfoot without nails	15	13.1-14.6 (*n*=19) 12.0-15.3 (*n*=?)*	13.7-14.5 (*n*=9)		10-14.5
Hindfoot with nails	16		15-16 (*n*=4)		
Length of the ear	9		6.4-8.8 (*n*=?)		6.2-8.0
Length of hairs on the end of the tail	8.5		1-9 (*n*=9)		
Condylobasal length	20.0	19.0-20.3 (*n*=15) 18.6-20.6 (*n*=?)**		18.6-20.6	17.7-20.2
Length tooth row I^1-M^3 // upper tooth row	9.08	8.5-9.2 (*n*=19) 8.0-9.4 (*n*=?)**		8.0-9.4	7.8-9.1
Width of the palatum	5.08	5.0-5.8 (*n*=19)		5.0-5.8	4.5-5.9
Width of the skull	10.25	9.2-10.2 (*n*=16)		9.4-10.3	9.0-10.3
Length tooth row I_1-M_3	8.31	7.8-8.5 (*n*=19)		7.8-8.5	6.6-8.7
Length of mandible	10.16				8.9-10.3
Special length of mandible	7.89			7.7-8.5	6.9-7.9
Height of the mandible	4.84	4.5-5,0 (*n*=19) 4.2-5.1 (*n*=?)**		4.2-5.1	4.1-4.9

hind feet and the characteristics of the skull confirmed the species as a taiga shrew (Sulkava 1990, van der Kooij 1999, van der Kooij & Solheim 2002b, Twisk et al. 2010). The specimen is now in the author's collection.

It is remarkable that this specimen was found in open land at a relatively high altitude. So far, taiga shrews have almost exclusively been found in moist and dense lowland vegetation. A good soil layer is a prerequisite. With their relatively broad front legs taiga shrews are considered to be real diggers (Sulkava 1990, van der Kooij & Solheim 2002a, 2002c, Twisk et al. 2010). During preparation of the skin of the Dragsvik specimen, haemorrhagic patches were noticed, especially on the left side of the body. The skull appeared to be broken in several places. These injuries suggest it is possible that this animal was taken by a bird of prey, and was dropped after a disturbance at this high altitude location.

In Norway records of taiga shrews are scarce, with isolated populations scattered over different parts of the country. The assumption is that the taiga shrew has a mosaic distribution in Norway with small local populations which may be vulnerable to extinction (van der Kooij & Solheim 2002a).

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Figure 4. Skull from the ventral side, clearly showing how the unicuspids gradually become smaller and also the smallest unicuspid has a dark top. *Photo: Ingrid Margry.*

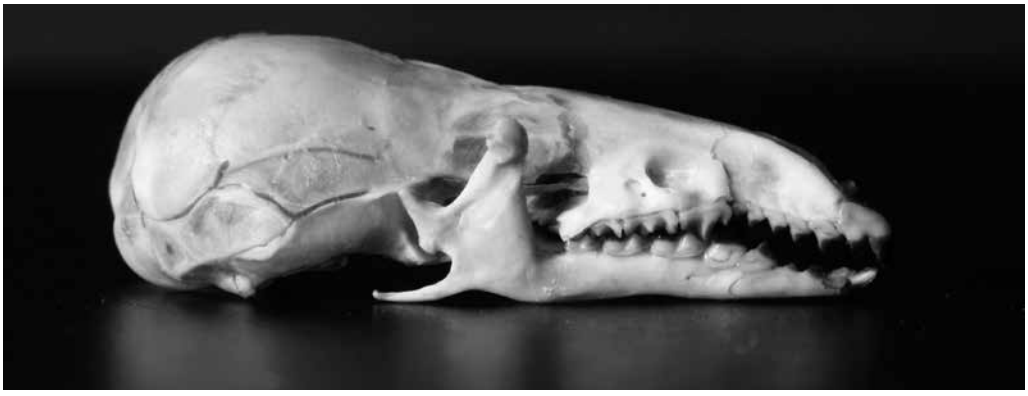

Figure 5. Skull, showing the same characteristics on the unicuspids from the right side. *Photo: Ingrid Margry.*

Figure 6. Right mandible with the backside of the incisor which reaches not further than the backside of the canine C_1. The foramen mentale is situated a little posterior to the front edge of the first molar M_1. *Photo: Ingrid Margry.*

Figure 7. Processus condylicus from the right mandible. The rising part is much longer than the part that protrudes laterally. *Photo: Ingrid Margry.*

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