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.

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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 18^{th} century. In contrast to its scientific name *Rattus norvegicus*, the brown rat is thought to have originated in Asia. In the 18^{th} 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 (Calhoun 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.

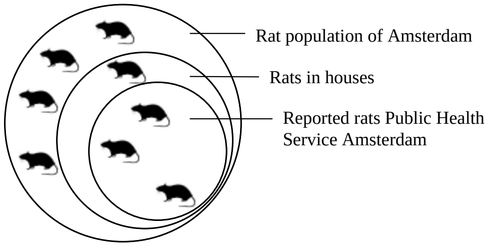

Figure 1. Schematic representation of the brown rat population in the municipality of Amsterdam.

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

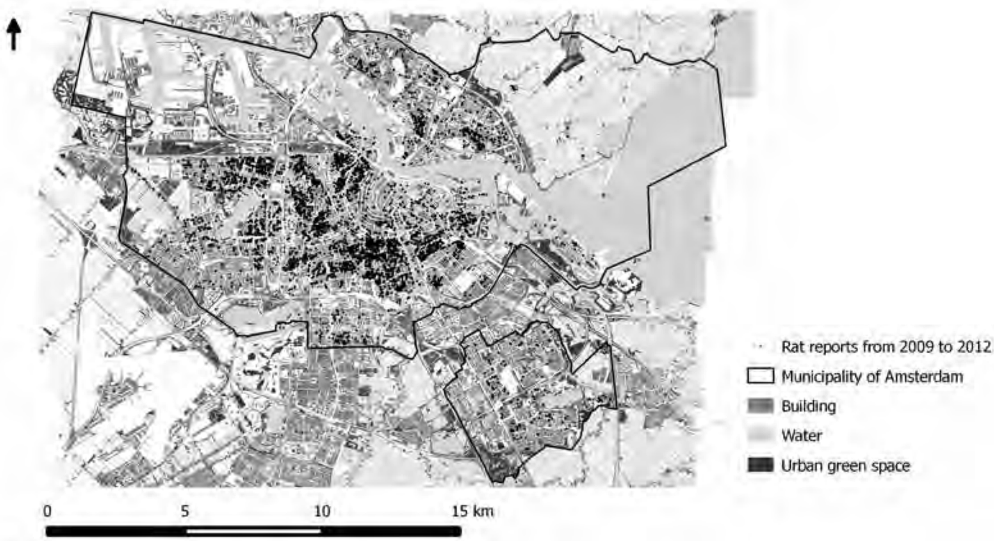

Figure 2. Locations of reported rats in the municipality of Amsterdam from 2009 to 2012.

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.

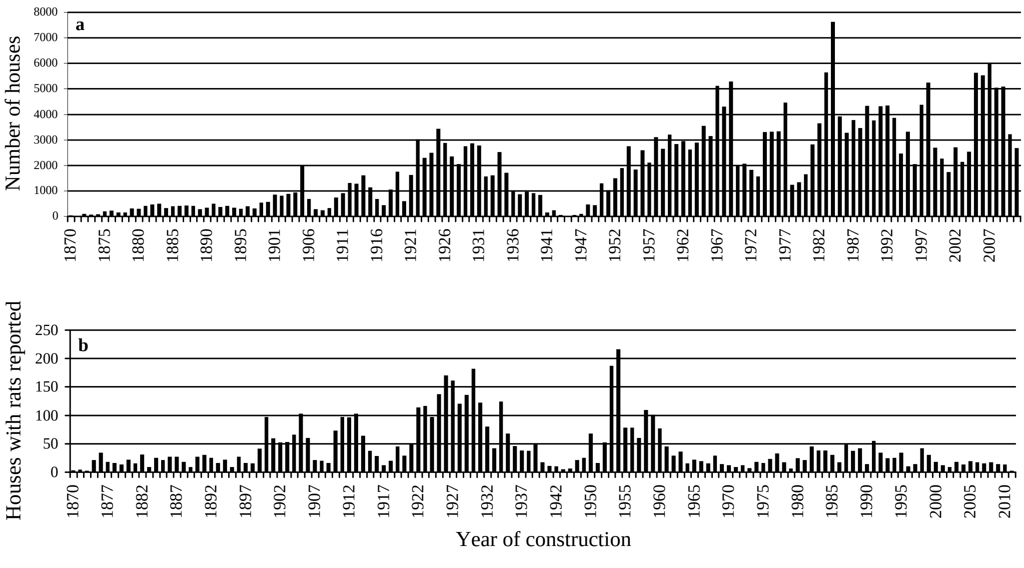

Figure 4. a. houses in Amsterdam per year of construction; b. houses with rats reported from 2009 to 2012 per year of construction. Houses with a construction year before 1870 (n=162) were left out of both graphs for readability.

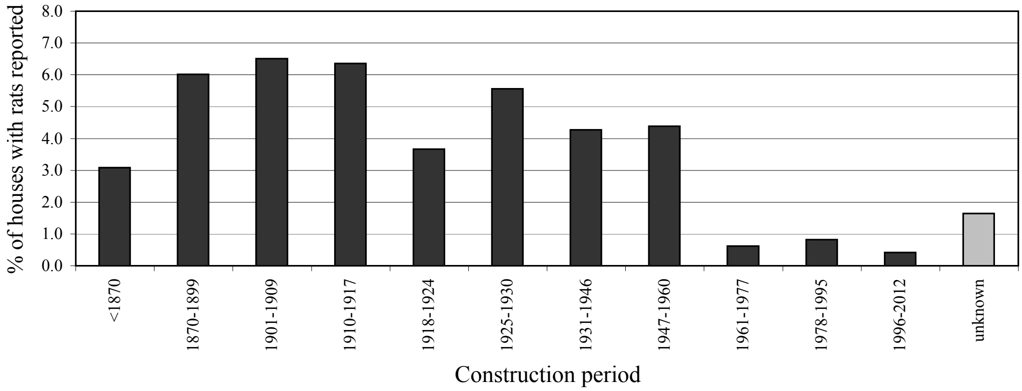

Figure 5. Houses with rats reported from 2009 to 2012 per construction period as a percentage of all houses per construction period.

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 vegetation 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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