Black rat - *Rattus rattus*
Norway rat - *Rattus norvegicus*
House mouse - *Mus musculus spec.*-complex

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Last update

17.03.2016

Brief description of the species/group of species: basic ecology and its relevance from an epidemiological perspective

The species in this review have been grouped due to their synanthropic nature. Both genera are highly adaptable to the human environment and have consequently spread worldwide. Their commensal nature requires methodological adaptations that make them suitable species for this review. Various pathogens have been identified previously with pathogen-specific methods (for reviews see Meerburg et al., 2009; Ulrich et al., 2009; Himsworth et al., 2013), but recently also using next-generation sequencing (Phan et al., 2011; Sachsenröder et al., 2014). The species were found to carry also non-zoonotic pathogens, such as herpesviruses (Ehlers et al., 2007) and papillomaviruses (Schulz et al., 2012), but here only pathogens with zoonotic potential are summarized.

***Rattus rattus*, *Rattus norvegicus* (Family: Muridae)**

Both species of the genus *Rattus* described in this review are classic examples of synanthropic species and have followed human activities worldwide. Their high adaptability in terms of food sources and habitat has led to a distribution throughout Europe. *Rattus norvegicus* (Berkenhout) is common in all European countries and only absent in regions with sparse human densities, namely Fennoscandia or parts of the Mediterranean (Mitchell-Jones et al., 1999). In contrast, *Rattus rattus* (Linneaus) has seen a decline in recent decades. It is still common in the Mediterranean, however is considered extinct in Fennocandia and can only sparsely be found in Great Britain, central and eastern Europe (Mitchell-Jones et al., 1999). This can mainly be attributed to the improvements in rodenticide/ anticoagulant formulation as well as the increasing expansion of *R. norvegicus* (v. Bülow, 1981). As in commensal rodents, the main habitat is associated with human settlements or food production and storage areas. *R. norvegicus* is native to Northeast Asia showing classic fossorial traits, but has adapted to a variety of secondary habitats (cellars, storage rooms, sewers, garbage dumps or farms). Non-commensal habitats in Europe are mainly associated with riverbanks. *R. rattus* is known to be an agile climber and where commensal it can often be found in elevated places such as the top floor of buildings, granaries, barns or trees, where they build their nests. Both species tend to live in groups ranging from <40 for *R. rattus* to around 60 individuals for *R. norvegicus* (Telle, 1966). Average densities for *R. rattus* in non-commensal populations have been shown to reach up to 36 ind/ha during abundance peaks for a montane population in India (Shanker & Sukumar, 1999). Population dynamics in commensal rodents are very different from feral, non-commensal populations. The commensal environmental conditions (constant food availability; moderated climate) often allow all-year breeding, which in turn can compensate increased mortality due to increased predation risk in the commensal environment (e.g. cats, dogs) (Pocock et al., 2004). In this scenario, the constant (e.g. storage) or occasional (e.g. yield) availability of superabundant food sources can consequently lead to high abundance. A classic example is the impact of food pulses of rat density due to the bamboo flowering in Southeast Asia (Htwe et al., 2010). The non-commensal forest populations of *R. rattus* in New Zealand, have also shown eruptive dynamics of which seasonal changes in food availability and predation seem to be the main drivers (Blackwell et al., 2003).

Rats contain a large number of zoonotic pathogens including different viruses, such as orthopox- and hantaviruses, and bacteria such as *Leptospira* spp., *Listeria monocytogenes, Salmonella* spp. and *Coxiella* spp. (Ulrich et al., 2009; Meerburg et al., 2009; Reusken et al., 2011). In addition, extended spectrum ß-lactamase producing *Escherichia coli* were detected in rats (Guenther et al., 2012). Furthermore, a novel hepatitis E virus genotype was described in Norway rats from Germany (Johne et al., 2012).

***Mus musculus musculus*, *Mus musculus domesticus* (Family: Muridae)**

The general census in the nomenclature of the European *Mus musculus* (Linnaeus) complex is that two subspecies exist; the Western house mouse (*Mus musculus domesticus*) is distributed in the west and south, while the Eastern house mouse (*Mus musculus musculus*) is restricted to the east and north of the continent spreading into northern Asia (Auffray et al., 1990). Separating them is a narrow hybridization zone which stretches from Denmark south through Central Europe and the Balkans to the Black Sea coast (Burchot et al., 1993; Macholan et al., 2003). *M. m. musculus* is characterized by a longer tail (Tail/Body ~ 0.7) and darker ventral fur compared to *M. m. domesticus* (Tail/Body >1; light ventral fur). Their main habitat is almost exclusively associated with human structures and settlements, although feral populations in the wild are known from woodland (Fitzgerald et al., 1996) or hedges (Weisel & Brandl, 1993) and Australian grain growing regions (Singleton et al., 2005). Commensal populations live in groups with a defined territory, a dominating male and several females. Home ranges in these groups are generally small (<10m^2) (Pocock et al., 2004) and associated to food availability. Population dynamics of commensal populations are, in line with all commensal rodents, highly dependent on food availability and where sufficient reproduction can occur all year round with densities of >100 individuals within a single structure (Pocock et al., 2004). For non-commensal, feral populations, Fitzgerald et al. (1981) demonstrated considerably larger home ranges of up to 2.6ha in a New Zealand forest setting and suggested a similar exclusive territorial system as found in commensal populations. This generally results in lower densities compared to commensal populations. King et al. (1996) showed consistently lower population abundances trapped with a 1.8km trapping line (<15 individuals per 100 trapping nights) compared to commensal populations. Abundance peaks however do occur and can be attributed to increased recruitment due to favourable conditions (Brown et al., 2010).

In addition to *Mus musculus* spec. there are three additional species of the genus *Mus* in Europe (*Mus spretus* (Lataste), *Mus spirilegus* (Petenyi), *Mus macedonicus* (Petrov & Ruzic). All three live independent of human structures. They have been reported from a wide range of habitats including grassland, fields, orchards, woody edges or river courses (Mitchell-Jones et al., 1999). Methodologically these species have to be treated as non-commensal *Mus* spec.

The house mouse is known as reservoir of the Lymphocytic choriomeningitis virus (Ackermann et al., 1964). Additional viruses, such as cowpox virus, and bacterial pathogens, such as *Leptospira* spp. have been detected in house mice (Meerburg et al., 2009; Ulrich et al., 2009).

Recommended method(s) for most accurate population estimation

The gold standard to estimate population densities is live trapping (e.g., Sherman traps) and applying a capture-mark-recapture method (Seber, 1986; Jacob et al., 2002). It was first used by C.G.J. Petersen in 1896 and has been successfully applied to any different study aims (see Chapter 3.2.1) since. Population size can be estimated from four to five captures, but more visits can be made, especially if further information on survival or movement is desired. Animals are released and remain unharmed. Besides the possibility to monitor and identify a broad range of small mammal species accurately or to take additional samples, e.g. blood and tissues, live trapping is a time consuming, expensive and work-intensive process (Sibbald et al., 2006). For *Rattus* spec. a few pitfalls with CMR-studies have to be considered. *Rattus* spec. has been shown to exhibit a strong “new object” reaction (Cowan, 1974) indicating reluctance to newly setup traps. Additionally, handling of live individuals can prove difficult for the untrained and the use of anaesthetics can complicate application due to potential effects on the recapture rate of individuals (Prout & King, 2006). These aspects have to be considered when deciding on the most suitable method for *Rattus* spec. trapping.

Mini-review of methods applied in Europe

General reviews

A variety of methods have been used to estimate the abundance of small mammals (Schwarz and Seber, 1999; Sibbald et al., 2006). Auffrey et al. (1990) gives a concise review of the genus *Mus* and its distribution in Eurasia, which has since been expanded upon (e.g. Bonhomme & Searle, 2012).

Capture-mark-recapture

A sound estimation of population density using capture-mark-recapture methods (CMR) is well established in population abundance estimation. The statistical models (Chao, 1987) have been and are still undergoing constant evaluation to adjust for departures from the underlying assumptions (see review by Schwarz, 1999). Heterogeneity in model parameters, especially in secretive small mammals has been shown to occur from a variety of known intrinsic or extrinsic sources. Observed variability in capture probability, violating the underlying conventional estimation assumptions, are often identified as a crucial pitfall in population density determination. Factors like species, age or gender can influence individual home ranges in relation to the layout of the trapping-grid (i.e. edge effects) often leading to high degrees of capture heterogeneity among individuals (Pledger and Efford, 1998). A much overlooked determinant of precision in CMR-studies, especially for small mammals, is the trap setup. A web-grid with varying trap-spacing improves the estimation of movement pattern within the trapping area and allows for accurate estimation of the effective trapping area reducing edge effects (Parmenter, 2003). Additionally, estimates of home ranges of target species should be incorporated into calculating the trap layout and spacing. More recently, spatially explicit capture-recapture statistics have been proposed to reduce edge effects altogether (Efford & Fewster, 2012).

Snap-trapping

This method is used regularly to estimate rodent abundance (Lidicker, 1973; Village and Myhill, 1990; Korpela et al., 2013). For *Rattus* sp. and *M. musculus* snap trapping has been widely applied as this is often part of eradication efforts and conservation concerns are of little importance, especially in urban areas. In commensal populations, where grid trapping might not be possible due to logistical constrains, trapping lines alongside human structures have been shown to yield good results (Pocock et al., 2004). In contrast, individuals in non-commensal populations show much greater home ranges (Clapperton, 2006) and therefore require an increase in trapping area and trap spacing. In general, trapping grids have been shown to be more effective compared to trap lines for areas where two or more species are present with one being subordinate to others (Weihong et al., 1999).

Tracking tunnels

Tracking tunnels will only allow determining an abundance index and can therefore be only interpreted relative to other tracking tunnel measurements. It nevertheless has the advantage to be less costly and less time consuming compared to the other methods mentioned in this review. In low density feral populations they can aid in determining the general presence/ absence of individuals (Innes et al., 1995) over large areas. In their work on feral *R. rattus* populations in New Zealand Blackwell et al. (2002) noted that tracking tunnel estimates should always be validated against a second density estimation method. Additionally, they suggested that the traditional 50m spacing between neighboring tunnels can be replaced by 100m spacing, reducing the work load as well as reducing the number individuals counted in single tunnels, consequently increasing the reliability of the index. It is suggested that tracking tunnels will more closely reflect actual densities when run as a consistent protocol in comparable habitats rather than just activity when applying them only occasionally.

Owl pellet analysis

The relative abundance can be estimated by analysing the diet of avian predators. As these birds cannot digest bones, claws, teeth and fur, they have to disgorge these components regularly. Therefore, large sample sizes of the prey can be easily identified to species level by examining jawbones, teeth or skulls from spit pellets (Love et al., 2000). In Europe the barn owl is mostly used for pellet analysis in small mammals as around 90% of its diet consists of rodents and shrews. The favoured roosting sites are in man-made constructions and pellets are therefore easier to find and decompose less rapidly compared to pellets from other owls (Glue, 1974). Further advantages of pellet analysis are low costs, the variety of prey species obtained, detection of rare species and the recognition of annual and seasonal changes of pellet composition. Since barn owls are nocturnal and the habitat of small mammals may differ from owl territories, certain prey species may be under-represented (Sibbald et al., 2006). Commensal rodent are not main prey item for barn owls. *Rattus* sp. has been shown to be an important secondary prey for barn owls in Britain although only mid-size individuals (<100g) will be preyed upon (Glue, 1974). *M. musculus* spec. only makes up for about 1% of the total vertebrate prey of the barn owl, although it is thought to be more important in areas where voles and shrews are absent or scarce (Glue, 1974).

APHAEA protocol (for harmonization at large scale)

For feral populations of *Rattus* sp. and *M. musculus* the APHAEA-protcol can be used with the following amendments:

- Depending on target species, specific snap traps (e.g. larger size for rats) have to be used
- For *Rattus* sp. the trap spacing has to be increased (20m recommended) to account for the generally larger size of home ranges

For commensal populations near human settlements and structures the proposed protocol is not appropriate. Here, due to logistical constrains the trap setting has to adapt to the local conditions. Rather than evenly distributing traps, trapping success is increased if rodent activity is taken into account. Traps have to be placed in locations where signs of activity are visible (runways, feces or burrow entrances). Trap numbers and spacing are up to the observer and can be distributed according to accessibility and expected trap success.

Near human activity traps have to be covered, for example with a mesh wire. This prevents accidents with humans, pet animals or other wildlife.

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Tables

See next page.

Table 1. Peculiarities of the species that modulate the methods to be used.

Characteristic	Observations
Distribution	*R. rattus* and *R. norvegicus* have large overlapping distributional ranges. However, morphological features allow for accurate species determination. For *R. rattus* three distinctly coloured types are known, generally considered as subspecies. *R. rattus rattus* is an all black type, *R. rattus frugivorus* brown dorsal and with white ventral hair with a distinct demarcation line and R. *rattus alexandrinus* has brown dorsal and pale grey ventral hair. These types do not affect features separating *R. rattus* from *R. norvegicus.* *M. musculus musculus* and *M. musculus domesticus* have been shown to exhibit morphological variation in for example mandible and skull size within their zone of hybridization (Mikul et al., 2010).
Population trends	*R. norvegicus* and *M. musculus* spec. are not endangered in their distributional range. They are considered pest species and often control measures are in place to combat local populations. Methods of abundance estimation can be disturbed by previous rodenticide applications. Information of previous pest control measures for the site of interest have to be obtained to accurately interpret population dynamics. *R. rattus* has seen a decline in some areas and local conditions need to be considered before trapping.
Density range	All suggested methods below are highly dependent on target species density (Parmenter, 2003). Especially, estimation of density from live trapping is often precluded or produces misleading results with few individuals are captured/recaptured. Here, commensal and non-commensal populations will exhibit marked differences in dynamics. In low abundance feral populations tracking tunnels are an ideal tool to identify areas where target species are present and they also have been used to estimate relative abundance Blackwell et al., 2002). In habitats where both, *Rattus* sp. and *M. musculus* spec. are present, rats have been shown to be the dominant species. *M. musculus* spec. is either absent from those areas or is present at lower abundances compared to habitats with no *Rattus* spec. present (Brown et al., 1996). In this context, eradication measures of *Rattus* spec. from a particular area can lead to an increase in an already present *M. musculus* spec. population (Witmer et al., 2007).
Main habitat	As commensal rodents, *Rattus* spec. and *M. musculus* spec. are mainly found in the vicinity of human settlements and structures. Within these, suitable habitat is often patchily distributed changing at a scale of just several meters. This arrangement is different from habitat and resources available to feral populations (Pocock et al., 2004), which requires methodological adaptation. Trap layout has to be adjusted depending on specific local conditions (e.g. Villafane & Busch, 2006).
Introduction-Releases	No intentional introduction of *Rattus* spec. and *M. musculus* spec. is known. All species are considered pests in most areas.
Detectability	For all species a rough estimate of general home range sizes has to form the basis for calculating the optimal trapping area and trap spacing. In urban populations, rats and mice tend to move shorter distances compared to feral populations, depending on the availability of food and shelter (Clapperton, 2006). Here trap spacing is often dictated by the structures used by species and has to be reduced compared to feral populations in order for the trapping to produce meaningful results. form the basis for calculating the optimal trapping area and trap.

Table 2. Classification of the different methods (all cited in this species' review, incl. the recommended method(s) for most accurate results) based on desirable characteristics for monitoring populations from an epidemiological perspective (1- very low, 5-very high). [1]=***Rattus sp.***; [2]=***Mus musculus***

Method	**Gold standard**[1,2]	**Snap-trapping**[1,2]	**Tracking tunnels**[1]	**Owl pellet anlaysis**[1,2]
Abundance / **D**ensity	A/D	A	D	A
Temporal / **S**patial trends	T/S	T/S	T/S	T
Precision	4	4	2	1
Seasonal independence	4	3	3	2
Visibility independence	5	5	5	5
Effort effectiveness	2	3	4	2
Ease of learning	*2*	4	5	4
Applicable at large scales	*2*	3	5	2
Useful at very low density	*3*	4	4	?
Useful at very high density	4	4	2	?