Sydney's bubonic plague outbreak 1900-1910: a disaster for foreshore wildlife?

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ABSTRACT

The foreshore of Sydney Harbour includes extensive areas of protected native bushland that are an iconic and world-renowned feature of the Sydney landscape. Despite this vegetative cover, however, native small mammals are uncommon and the bushland is dominated by introduced Black Rats *Rattus rattus*. In particular, the Bush Rat *Rattus fuscipes* is absent yet remains abundant in comparable habitats to the north and south of Sydney; the last record of the Bush Rat near Sydney Harbour is from 1901. In this paper we explore the idea that the arrival and spread of bubonic plague in the port City of Sydney between 1900 and 1910 was a primary cause of the extirpation of Bush Rats around the harbour foreshore. The plague killed 181 people in Sydney during three major outbreaks, and also killed hundreds of thousands of rats and 52 native Australian mammals in the Moore Park Zoo. The ensuing hysteria and fear of plague resulted in a determined campaign to rid Sydney of rats, including the introduction of a rat bounty. This campaign led to the culling of a further 100,000 rats, both native and introduced, including "bush rats". We suggest that Bush Rats were wiped out from the harbour foreshore by the direct effects of the plague and the indirect effects arising from rat persecution to prevent plague, making the arrival of bubonic plague in the 1900s a disaster for Sydney's foreshore wildlife. If this hypothesis is correct, then future attempts to restore Bush Rats to the harbour foreshore will not be hampered by the cause of their absence, as Australia is currently free from plague.

Key words: *Rattus Rattus, Rattus fuscipes*, Bush rat, Black rat, alien species, local extinction

Introduction

The introduction of alien species is recognized widely to be a disaster for indigenous species. Alien species bring direct impacts such as predation and competition for resources as well as indirect impacts such as novel pathogens, parasites and hyper-predation effects. In some cases the impacts on local fauna are acute and devastating with the rapid loss of individuals, populations and species (e.g. Mooney 2005). In other cases, those native species that survive the initial invasion can suffer chronic impacts from alien species, which are typically greater than those caused by their indigenous enemies (Salo *et al.* 2007). In this paper we investigate evidence for a novel form of indirect impact upon native Bush Rats *Rattus fuscipes* in the bushland and built environments around Sydney Harbour resulting from the introduction of Black Rats *Rattus rattus* to Australia. Black Rats and Bush Rats are about the same size; both are ecological generalists and omnivorous, although Black Rats are considered to be mainly commensal with humans (Breed and Ford 2007). However, around Sydney Harbour the introduced species appears to have replaced the native Bush Rat sometime during the chronic phase of the invasion of Black Rats. Identifying the possible mechanism for this replacement is the focus of the present paper. We aim to understand what led to the local extinction of native Bush Rats from the foreshores of Sydney Harbour to guide efforts to reintroduce this species into Sydney Harbour National Park and other areas of native vegetation in future.

Historical evidence for Bush Rats and Black Rats around Sydney Harbour

Bush Rats are considered to have a predominantly coastal distribution, being found generally no further than 100 km from the coast with the except of the highlands of south-eastern Australia (Watts and Aslin 1981). Around Sydney, Bush Rats are abundant in Royal National Park to the south and in Ku-ring-gai Chase, Garigal and Lane Cove National Parks to the north (Figure 1). However, they appear to be absent from otherwise suitable environments in Sydney Harbour National Park (SHNP). The last record of a Bush Rat in or close to SHNP is a specimen in the Australian Museum collected from Maroubra in 1901. An email survey (October 2009) of mammal researchers who had been working in the Sydney region since the 1960s revealed no further records of Bush Rats around the harbour foreshore. The NSW Wildlife Atlas has no trap-based records of Bush Rats in SHNP. An extensive camera-based survey of the SHNP in 2010 also failed to reveal any records of Bush Rats (S. Martin, G. Cleary and P. Banks unpublished).

The reason for the local extinction of Bush Rats in SHNP is unknown, but possible causes have been proposed from as early as 1919. The museum collector, Charles Hoy, recorded the presence of Long-nosed Bandicoots *Perameles nasuta* in bushland at Mosman (around Taronga Zoo), but his accounts made no mention of Bush Rats from the area (although there is no evidence that he carried out

Pp 1033 - 1039. Paper in *Wildlife response to disasters*, the theme of the forum of the Royal Zoological Society of NSW in October 2009, edited by Chris Dickman, Daniel Lunney and Peter Banks. *Australian Zoologist* 2011 35 (4).

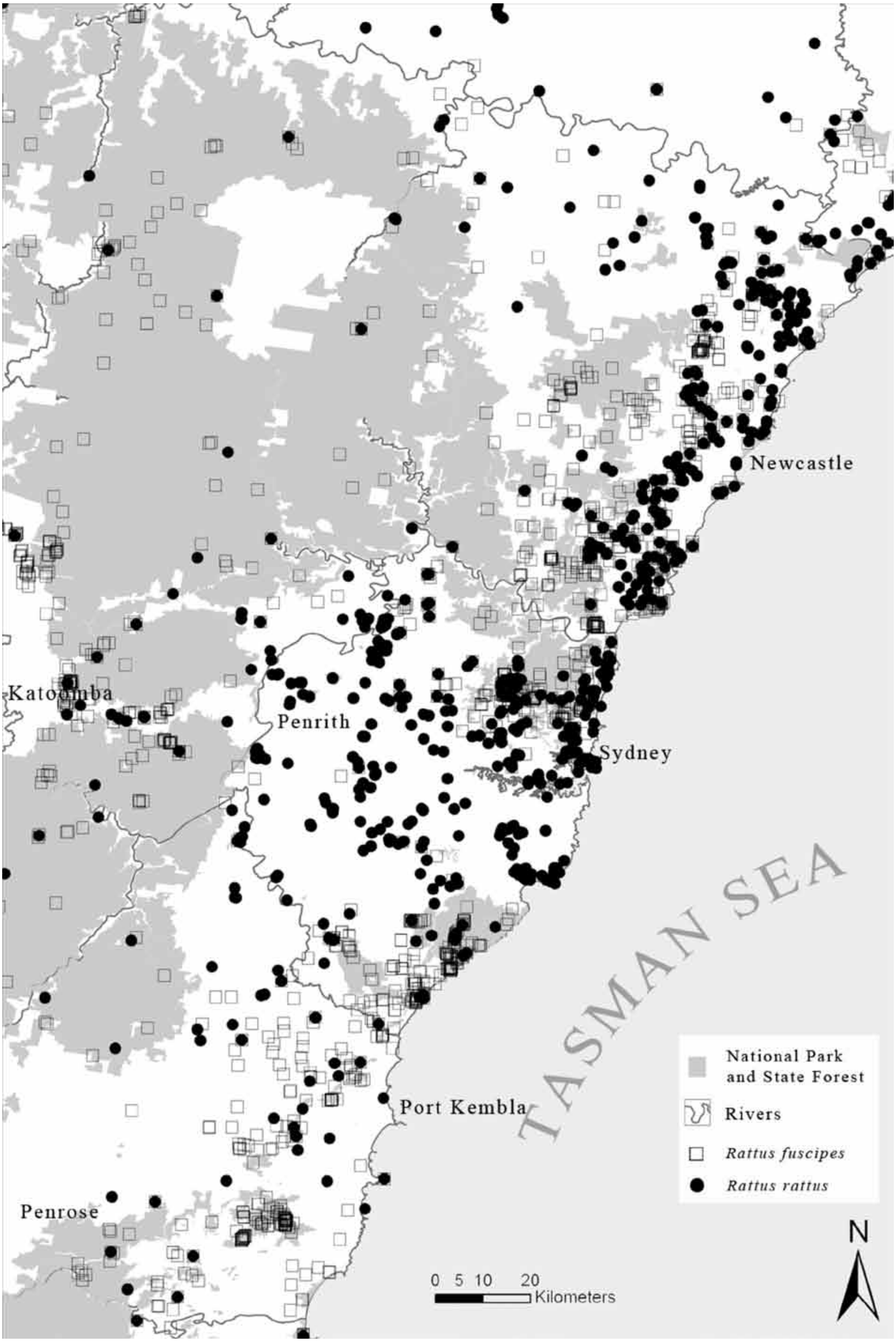

Figure 1. The distribution of Black Rats *Rattus rattus* (closed cirlces) and Bush Rats *Rattus fuscipes* (open squares) in the greater Sydney region, New South Wales. Data sourced from NSW National Parks and Wildlife Service Atlas of NSW Wildlife on 13/8/09.

extensive wildlife surveys in the foreshore vegetation as no other mammals were reported). Hoy suggested that bandicoots persisted in the area because of a lack of foxes and the isolation of Mosman's bushland. Elsewhere in Australia he often found Bush Rats to be very abundant, to the point of being a nuisance. But at Bulliac, near Gloucester, Hoy commented on the great abundance of introduced rats (Black Rats, based on his captures) and suggested that they had driven out the native rodents, even the large and semi-aquatic Water Rat *Hydromys chrysogaster* (see Short and Calaby 2001). The mechanism behind Hoy's suggestion is not clear from his writing, but it is likely that he was referring to competition for resources that led to the displacement of native rodents.

Black Rats (the Oceanic form - *sensu* Aplin *et al.* 2003) may have first entered Australia with the First Fleet more than 200 years ago, but their exact arrival date is unclear. Brown Rats *Rattus norvegicus* were the dominant rat in stores and warehouses in Europe up until the 1850s and are thought to be the species most commonly spread on ships at that time (King 2005). Black Rats became the major ship-borne species of rodent only after the 1830s-1850s (King 2005); for example, Black Rats first arrived on Christmas Island in 1901 despite earlier occupancy by European settlers (Wyatt *et al.* 2008). Sydney newspapers were reporting problems with rats as vermin from as early as 1804 (Anon. 1804), although the species involved is not certain. Nevertheless, there is clear evidence that by 1900 Black Rats were very abundant across the city of Sydney (Curson and McCracken 1989, see below).

Were Bush Rats out-competed by Black Rats?

Competition theory predicts that two species with identical niches cannot coexist (Gause 1934). "Exploitation competition" occurs if one species exploits shared resources more efficiently than a second species and thus excludes it by a process of deprivation (Dickman 2011). Competition can also occur via "interference", in which one species aggressively excludes another from space and/or resources that they would otherwise use (Schoener 1983). These processes often characterize interactions between closely related species, but can occur also between ecologically similar species without a recently shared evolutionary history. For both forms of competition, small-scale exclusion of native species by their introduced counterparts is certainly possible, and provides a plausible explanation of why Black Rats have replaced Bush Rats in bushland close to urban areas around Sydney Harbour.

Evidence to support the suggestion that Black Rats are generically superior competitors is, however, equivocal. In Malagasy forests, for example, Black Rats were once thought to have replaced native nesomyine rodents through exploitation and interference competition (Goodman and Carleton 1996). However, at least one species of nesomyine rodent *Eliurus webbi* is now known to be affected negatively by logging of its forest habitat and to show no correlation with the numbers of Black Rats (Ramanamanjato and Ganzhorn 2001). Black Rat populations increase with the level of habitat disturbance, most notably in heavily logged secondary forest (Lehtonen *et al.* 2001), so that the probability of finding Black Rats increases with the decline in canopy cover caused by logging. Interestingly, Black Rats in Madagascar are less numerous in primary forests where native rodents occur in high numbers (Lehtonen *et al.* 2001). Thus disturbance potentially may play a role in providing Black Rats with a competitive advantage over other Malagasy rodents, but there is no clear evidence that they compete with the native species which are of a comparable body weight (*E. webbi* females: 85 g, males: 91 g; Black Rat females: 81 g, males: 98 g; Ramanamanjato and Ganzhorn 2001).

Recent work in the Galapagos Islands has confirmed the potential for the competitive superiority of Black Rats. There, the Black Rat has been linked to the extinction of four endemic species of rice rats; *Nesoryzomys swarthi*, *N. indeffesus*, *N. darwini* and *Oryzomys galapagoensis* (Hoeck 1984). Extinction was suspected to result from direct competition and disease that was spread by Black Rats. Surprisingly, in 1997, the largest of the previously listed extinct native rats, the Santiago Rat *N. swarthi*, was rediscovered living sympatrically with Black Rats on Santiago Island (Dowler *et al.* 2000). There was no evidence of strong spatial segregation, differences in home range size or temporal activity between the two species, but there was an increase in activity of the Santiago Rat pre-dawn and post-dusk in areas of high Black Rat density (Harris *et al.* 2006). This appeared to reflect the increased foraging effort necessary to compensate for the costs of interference competition from Black Rats, which are significantly larger than *N. swarthi* (Galapagos Black Rat males 183 g, females 141 g vs. *N. swarthi* males 115 g, females 91 g; Harris and Macdonald 2007).

In Australia, interactions between Black Rats and native rodents seem to differ from those in Madagascar and the Galapagos Islands. In general, Black Rats appear to have moved relatively little beyond close proximity to human habitation in all but a few localities (Dickman and Watts 2008). At Jervis Bay, on the south coast of New South Wales, Black Rats and native Bush Rats coexist on a macroscale, with Black Rats occupying some bush habitats (Stokes *et al.* 2009). The two species do compete: experimental removal of Black Rats led to increases in numbers of Bush Rat (Stokes *et al.* 2009). However, competition does not appear to be mediated via superior interference or exploitative ability on the part of Black Rats. Instead, competitive superiority appears to be conferred by the residency status of individuals - the animal that occupied space first determines which species would dominate. This prediction was confirmed in arena trials examining behavioural dominance in interactions between Bush and Black Rats; either species could win, with success being determined by the species that was introduced first (Stokes *et al.* 2007).

This body of work suggests that it is unlikely that Black Rats drove Bush Rats out of areas around Sydney Harbor because they are better able to exploit local resources or are more aggressive in interference competition. Although the vegetation in many areas of Sydney Harbour National Park can be considered highly disturbed, Bush Rats will also readily use disturbed and weedy habitats (W.

Gleen, G. Cleary and P. Banks, unpublished). Instead, it seems more likely that at some time Bush Rats lost their residency status in Sydney Harbour National Park, and this gave Black Rats an opportunity to establish and gain residency and a concomitant competitive advantage.

Black Rats, Bush Rats and the Bubonic Plague outbreak of the 1900s

The bubonic plague first entered Sydney sometime in late 1899 or early 1900. It was first reported in Sydney on 19 January 1900 (Ashton 1986) and rapidly spread throughout the central part of the city, including Darling Harbour and Haymarket and Redfern/Surry Hills (Curson and McCracken 1989, pp. 121-123). The epidemic was part of the third global pandemic of plague, the first being the "*Justinian plague*" in regions surrounding the Mediterranean Sea in the 6^{th} century, and the second being the "*Black Death*" in Europe in the 14^{th} century (Stenseth *et al.* 2008). In the middle of the 19^{th} century, plague began to spread through China and by the late 1800s it was sweeping through south-east Asia and causing heavy losses of life, including in towns and ports at which ships *en route* to Australia made port to take on supplies. Presumably, some of these ships took on plague-infected rats. Rapid urban development in Sydney in the late 19^{th} century led to poor hygiene in many parts of the city, with no sewerage system or rubbish facilities being in place when the plague arrived (Ashton 1986). These conditions would have favoured large populations of commensal Black Rats and hence great potential for the spread of plague.

Early in 1900, dead Black Rats began to appear around the wharf areas of the harbour foreshore, heralding much worse events to come (Curson and McCracken 1989). Within a few months, human cases of bubonic plague began to appear. In 1900 alone there were 303 human cases of plague; 103 people died. Plague outbreaks cycled approximately annually for 10 years, killing many thousands of Black Rats and 181 people in three major epidemics.

As in the earlier two plague pandemics, the social response to plague was one of fear and panic (Curson and McCracken 1989). Curson and McCracken (1989) described Sydney's reaction to the plague thus: "*It produced a frantic desire at both the public and private level for cleansing, disinfecting and rehabilitating areas much like the scourging of medieval times*". But unlike the earlier pandemics, an effective solution to the spread of plague was available. In 1898, French epidemiologist Paul-Louis Simond proposed the rat-flea-human theory of plague transmission, the idea that fleas infected with plague from biting diseased rats were responsible for spreading the disease to humans (Simond 1898). This idea was not immediately accepted, and remained controversial for several years until validated by others (Gauthier and Raybaud 1903). Nevertheless, Sydney's chief medical officer in 1900, Ashburton Thompson, knew of Simond's theory and showed considerable foresight in establishing a determined campaign to rid Sydney of rats to prevent the spread of plague. The government introduced a bounty of sixpence (~$AUD 4 in current value) for the body of every rat delivered to a furnace in Bathurst Street, Sydney. In addition, more than 3000 professional rat-catchers were employed (Figure 2); 3808 buildings were inspected and cleansed of rats, free rat poison was supplied to councils for distribution to the public, and sewers were fumigated with burning sulphur (Ashton 1986; Konkola 1992).

Figure 2. Professional Ratcatchers from "Views taken during Cleansing Operations, Quarantine Area, Sydney, 1900, Vol. IV / under the supervision of Mr George McCredie, F.I.A., N.S.W. Mitchell Library, State Library of NSW Call No PXE93/264

As a result of these activities, more than 17,000 rats were killed in houses, 27,548 were killed at a quarantine depot and 1423 dead animals brought in from around the harbour in the first few months of the campaign. In total, within 10 months of the first human case of plague being reported in Sydney, 108,308 rats were known to have been killed, a large but unknown number would have been killed by poison and fumigation, and rat persecution continued for many years as a result of the plague epidemic. The Sydney Harbour Trust was created in 1900 and was given power over all wharf and harbour foreshore areas (Lewis 1979). Many homes and outbuildings were demolished, fences knocked down, sanitary conveniences destroyed, and costly rat-proof seawalls constructed to prevent the entry of plague-bearing rats (Mitchell 1977). These activities helped to reduce rat numbers in the city area; although plague broke out again in 1921 and 1922 and resulted in the deaths of 10 people, the 'war' against rats had effectively been won (Cumpston and MacCallum 1926).

Were Black Rats the only rodents killed in the fight to contain the 1900-1910 plague outbreak? It is open to question just how selective the rat catchers were in ensuring that they captured only Black Rats. For example, Bush Rats and Black Rats are superficially very similar in size, colour and dimensions, and it is difficult for a layperson to tell them apart. Furthermore, the host specificity to Black Rats of the plague-carrying fleas was unknown at the time, and many rat catchers might have assumed that all types of rats were responsible for transmitting the disease. An instruction booklet issued to Sydney householders by the Department of Public Health, dated 1 March 1900, stated that "*All rats, therefore, must be exterminated as far* *as possible, and the attack upon them should be simultaneous in the healthy and infected neighbourhoods*." (Ashton 1986). Records from the Board of Health show further that "*bush rats were being sent to Sydney from country districts and the consignors receiving the capitation fee of 6d*" (Curson and McCracken 1989). In addition, there is photographic evidence that Water Rats and Brown Rats were caught up in the spree of rat killing (Figure 3). It is highly likely then that many Bush Rats were killed as part of the plague hysteria that swept Sydney in the 1900s, victims either of the imperative to protect human health, or perhaps also of the desire to collect bounties. Whatever the case, it is almost certain that plague would have had an indirect impact on the wildlife of the Sydney Harbour foreshore.

Figure 3. A heap of rats, about 600 from "Views taken during Cleansing Operations, Quarantine Area, Sydney, 1900, Vol V / under the supervision of Mr George McCredie, FIA NSW, Mitchell Library, State Library of NSW Call No PXE94/265

It is also likely that Bush Rat populations were affected directly by the plague outbreak via infection from the disease itself. Accounts of Bush Rat deaths from plague are unknown and it is not clear whether they can carry the flea *Xenopsylla cheopis* that is responsible for spreading the plague in Australia. However, plague affects a wide range of rodents elsewhere in the world, occurring in the classic commensal rodent-flea cycle as well as sylvatic rodent-flea cycles (Stenseth *et al.* 2008). Plague transmission to other wildlife can also be airborne and via consumption of infected animals; few species are resistant to the disease. Native Australian animals in Moore Park Zoo, run by the Royal Zoological Society of NSW, were infected with the plague in 1902, including wallabies, kangaroos, quolls and possums, resulting in the closure of the zoo for four months (Strahan 1992). In 1907, the plague broke out in populations of the native rodent *Rattus tunneyi* on the sugar cane fields of Mossman in Queensland, although it failed to establish in the local human population (Curson and McCracken 1989). Presumably these Mossman rats caught plague from Black Rats in close proximity. Bush Rats and Black Rats can also live in close proximity to each other in an urban/bushland mosaic (e.g. Downes *et al.* 1997), with crossover from Black Rats providing opportunities for plague fleas to find new hosts in native rodents. This would have certainly been the case in areas around Sydney Harbour, where urban Black Rats would have been frequently in contact with Bush Rats in remnant native vegetation; this happens now on the northern suburban fringe of Sydney (P. Banks pers. obs). It thus seems highly likely that Sydney's Bush Rats were also affected directly by infection with the plague, contributing to their demise around the harbour foreshore.

If this reasoning is correct, why didn't Bush Rats return after the plague outbreaks had ended by the 1930s? By the late 1800s and early 1900s much of the harbour foreshore bushland had been fragmented by urban development. Historical photographs of Sydney's north shore from the Vaniman collection show extensive land clearing around North Sydney, Cremorne Point and Mosman. North Head was also isolated due to the extensive development of Manly. Benson and Howell (1990: 160) described the situation as this: "*The central spine, followed by Military, Spit and Bradleys Head Roads, is generally level and was cleared for houses in the nineteenth and early twentieth centuries. The wooded slopes of Mosman Bay were lost in the late nineteenth century as ferries and trams made Mosman's wooded shores a desirable residential address. Mosman is fortunate to have so much bushland, and particularly along its harbour foreshores. Such sites in other municipalities, particularly on the southern harbour foreshores and the lower Georges River, have been built out, but because they were required for military installations in the past, many of Mosman's bushland areas survived relatively unscathed to become part of SHNP when no longer required for defence*." Fragmentation of bushland would have destroyed network corridors for Bush Rats, resulting in isolation of populations at the time the plague swept through. We suggest that Bush Rats were unable to repopulate the Sydney Harbour foreshore due to urban development and fragmentation of the bushland. Vegetation on several of the headland areas (e.g. North Head) was also later cleared for military use during the early to mid 20th century with potential impacts on any residual Bush Rat populations. Bush Rats have a generally low dispersal rate and repopulate areas only very slowly due to their short movement distances (Peakall *et al.* 2006). By contrast, the urban areas likely sustained large populations of Black Rats (as they do today), thus providing a source of invaders able to move into bush areas. Given that residency appears to confer competitive advantage in rats, this likely would have prevented later reinvasion by Bush Rats.

Alternative explanations

Although there is strong circumstantial evidence that the plague outbreak resulted both directly and indirectly in the loss of Bush Rats from the harbour foreshore, other factors may have played a role. For example, Charles Hoy recorded Eastern Quolls *Dasyurus viverrinus* in Sydney in his 1919 journal (Short and Calaby 2001), and the species persisted in the metropolitan area until the 1960s when the last individuals seen on the Australian mainland disappeared from Nielsen Park (Caughley 1980). The impact of predation can be exaggerated by the fragmentation of habitats used by prey (Matthews *et al.* 1999), and it is possible that native quolls contributed to the extirpation of Bush Rats from fragmented parts of the harbour foreshore.

Urban areas also have large populations of introduced predators, and these can similarly affect wildlife populations in fringing bushland. For example, domestic cats *Felis catus* were introduced to Australia by 1824 or earlier (Rolls 1969), with feral populations establishing soon afterwards (Dickman 1996). Cats were often introduced locally to control *plagues of mice, native rats and rabbits* in urban bushland (Rolls 1969; Long 1988). Although young rabbits appear to be preferred prey (Jones and Coman 1981), cats may consume two to three native animals a day, even when rabbits are abundant (Paton 1993). It is thus possible that cats assisted in the extirpation of Bush Rats around the foreshores of Sydney Harbour prior to any plague outbreak.

Red Foxes *Vulpes vulpes* are another candidate cause of the loss of Bush Rats from SHNP. They established in New South Wales towards the end of the eighteenth century, having spread from Victoria, although Hoy reported them absent from areas around Mosman in 1919 (Rolls 1969). Although foxes eat mainly rabbits when available, they do eat small rodents as supplemental prey, and these rodents may be naive to the risks associated with foxes (Banks 1998). However, experimental fox removal shows that Bush Rat populations are unaffected by fox predation when predation rates are low. Thus foxes seem an improbable cause for the absence of Bush Rats.

Rodents are also hosts for at least 60 other diseases, apart from plague, many of which may be carried by Black Rats and have the potential to adversely affect wildlife. Disease other than plague could potentially have reduced populations of Sydney's Bush Rats, although direct evidence is lacking. Two other native *Rattus* species endemic to Christmas Island, Maclear's Rat *Rattus macleari* and the Bulldog Rat *Rattus nativitatis* are thought to have been driven to extinction around 1908 by murid trypanosomes brought to the island by Black Rats which invaded in 1901 (Wyatt *et al.* 2008). The trypanosomes involved have only a mild effect on Black Rats and it is unclear whether the endemic *Rattus* died out from trypanosome infections or whether some other agent (e.g. plague, which was being spread throughout south-east Asia at the time) may have been involved.

Conclusions

It is unclear exactly what caused the local extinction of Bush Rats from the natural vegetation of the Sydney Harbour foreshore. Our contention here is that a combination of events surrounding the arrival of plague-infected Black Rats is the most likely cause. At the time of the outbreak, local populations of Bush Rats around the harbour foreshore were fragmented from the other national parks due to rapid urban development on the lower north shore for housing and farming. The urban areas of Sydney had a large resident Black Rat population, especially around ports, which undoubtedly facilitated the rapid spread of plague from infected stowaway rats, which arrived in 1900, one year prior to the last record of Bush Rats around Sydney Harbour. Bush Rats are likely to be highly susceptible to the plague - few species are resilient to the disease. At the same time the public reaction to the plague outbreak meant that Bush Rats were caught up in the frenzy to rid Sydney of rats. We contend that the combination of the direct effects of the disease and the indirect effects of the human response to the plague led to the demise of Bush Rats around the harbour where the plague outbreak was at its worst. Once Bush Rats lost their residency status in the isolated remnants of bushland, they could not reinvade because of fragmentation and their low propensity for dispersal. If this hypothesis is correct, then reintroduction of Bush Rat populations to harbour foreshore areas should not be constrained by the cause of their original demise. As far as records show, neither Bush Rats, nor any other Australian native species, acts as a reservoir for the plague and Australia remains plague free.

Acknowledgements

We thank Peter Curson for helpful discussions about the Sydney plague outbreak, and Sandy Ingleby, Adam Birnbaum, Tanya Leary, George McKay and Barry Fox for advice on records of Bush and Black Rats from Sydney Harbour. This work was supported by an ARC Discovery Grant (DP0881455) to PBB and an ARC Linkage Grant (LP100100600) to PBB and CRD.

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