

# Impacts of black rats *Rattus rattus* across an urban/bushland interface at Sydney's North Head

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## ABSTRACT

The black rat is among the world's worst vertebrate pests. Yet very little is known of its impacts or potential impacts on biodiversity in Australian ecosystems. In this paper we examine the impacts of black rats on biodiversity values at North Head, Sydney where a wildlife sanctuary is planned in an area with an abundant black rat population. We examined impacts on three key biodiversity elements considered flagships for the sanctuary concept: the endangered wattle *Acacia terminalis*, seedlings of which are vulnerable to rat grazing; the nests of small passerine birds which are vulnerable to rat predation; and the endangered population of long-nosed bandicoots *Perameles nasuta*, vulnerable to competition from black rats. Caging experiments using artificial seedling patches in recently burnt areas showed that rabbits or long-nosed bandicoots rather than black rats were the biggest grazing threat to *A. terminalis*. Similarly, although rats preyed on experimental artificial nests, nest predation was caused largely by other birds. An intensive trapping study showed a negative spatial relationship between black rats and long-nosed bandicoots at both macrohabitat and microhabitat scales in urban areas, suggesting some avoidance may occur. Thus rat impacts on sunshine wattle and birds nests currently appear to be small in comparison to impacts from other fauna, but an increase in the black rat population may heighten their impacts. It is also possible that black rats affect conservation values not measured here and the negative spatial interaction between black rats and long-nosed bandicoots warrants further investigation.

**Key words:** *Acacia terminalis*, bird nest predation, feral, *Perameles nasuta*, pest, Rodentia

## Introduction

This paper investigates the impacts of a population of introduced black rats *Rattus rattus* (Rodentia: Muridae) in native bushland at North Head at the entrance to Sydney Harbour, Australia. The black rat is an invasive pest species known the world over for its economic impacts on agriculture and its environmental impacts on native wildlife (Long 2003). The presence of black rats at North Head is of particular concern because of the conservation value of the area. North Head supports endangered populations of long-nosed bandicoots *Perameles nasuta*, little penguins *Eudyptula minor*, and sunshine wattle *Acacia terminalis*, along with an additional 119 species of native fauna (Skelton *et al.* 2003a). North Head also supports 159 species of exotic flora, 428 species of native flora and an endangered ecological community of Eastern Suburbs Banksia Scrub (Skelton *et al.* 2003b). Plans are currently under consideration to further protect the native flora and fauna in a sanctuary that would incorporate an existing National Park and part of an ex-military site. Black rats are probably the most abundant pest mammal species on the headland and, for the sanctuary to succeed, identification and management of the potential threats to the native flora and fauna are necessary. The aim of this study is to explore the potential impacts that black rats may have on species of conservation concern at North Head.

Around the world, black rats are responsible for the consumption of food stores and agricultural crops. They also forage on native vegetation. On average, black rats consume 10% of their body weight each day (Long 2003), making them potentially important in terms of their grazing pressure on endemic plants. Although they are omnivorous (Watts and Braithwaite 1978; Clark 1981, 1982; Watts 1995; Long 2003), a large portion of black rat diet may include leaves, stems, seeds and/or fruit (Norman 1970; Cox 1997). Importantly, the grazing of seedlings by black rats can negatively impact the population recruitment in some plants (Crawley 1983; Wilson *et al.* 2003; Brown 2005), and rodent grazing can substantially increase plant mortality (e.g. Hulme 1996). Moreover, when feeding on plants, rodents generally show preferences for younger seedlings over older plants (Ostfield *et al.* 1997). At North Head, there is concern over the potential impact of black rats on the recruitment of endangered plants (Skelton *et al.* 2003a), particularly sunshine wattle. Sunshine wattle is an acacia that occurs patchily within heathland. The major threat to this species is habitat reduction (NSW National Parks and Wildlife Service 2004a), but its seeds and seedlings may be vulnerable to rat predation, particularly in remnant heathland near urban areas. Black rats are known predators of sunshine wattle seedlings in commercial nurseries (C. Miller, pers. comm.). The first aim of this study is to determine the level of black rat foraging on sunshine wattle seedlings relative to other vertebrate grazers.

Outside Australia, the black rat's most devastating impacts have been as a predator of birds' nests (Norman 1970; Major and Gowing 1994; Long 2003). Nest predation by black rats has affected bird diversity on several islands (e.g. Campbell 1991; Pye *et al.* 1999) and, in some insular ecosystems, black rats have been identified as the foremost agent of bird extinctions (Long 2003). Nest predation is the primary cause of nest failure in some species (Ricklefs 1969; Armstrong and Pyke 1991), and although some birds also prey on the nests of sympatric species (Matthews *et al.* 1999), it is not known whether predation by feral black rats substantially adds to this "native" source of background nest failure. Within Australia, many bird species are increasingly restricted to less fragmented bushland areas due to clearing for agriculture. They have also been forced from urban areas by factors such as predation from domestic cats *Felis catus*, an absence of cover and/or nest sites, and from the relative increase of more aggressive bird species (Parsons and Major 2004). At North Head, there are at least 89 native bird species (Skelton *et al.* 2003a), and of these, at least 44 breed within the Sydney Harbour National Park, mainly in woodland, forest and heathland areas (NSW National Parks and Wildlife Service 2004b). The potential impact of black rat predation of birds nests at North Head is not known, so the second aim of this study is to evaluate and compare nest predation levels between urban and bushland habitats to determine whether black rats, which have typically been considered entirely commensal (but see Rose 2004), are impacting nest survival in bushland adjacent to urban areas.

Interactions between black rats and native mammals at North Head are also of concern. Black rats have been implicated in the extinction of two native *Rattus* species on Christmas Island: *R. nativitatis* and *R. macleari* (Pickering and Norris 1996), and there is circumstantial evidence of negative spatial relationships between black rats and native rodents on mainland sites (Barnett *et al.* 1978; Downes *et al.* 1997; Capps 2001). Native rats are no longer present on North Head. The local population of long-nosed bandicoots shows a strong preference for open habitat areas close to urban development (Hughes 2002; E. Venstra, unpublished data). In contrast, black rats are most abundant in the native vegetation such as heath and woodland and less abundant in open areas (Cox *et al.* 2000; Miller and Puddephat 1996; Bray 1994). Little is known about direct interactions between bandicoots and rats, such as the existence of interspecies aggression or habitat partitioning. As such, the third aim of this study is to explore the potential for negative interactions between bandicoots and rats by directly examining their spatial associations at the macrohabitat and microhabitat scale.

We used a series of experiments to evaluate the impacts of black rats on some native wildlife and tested as the following predictions:

- If black rats are grazing sunshine wattle seedlings then seedlings with rat-only exclusion cages will suffer less grazing than uncaged controls.
- If black rats are the most significant predator of birds' nests in the area, a greater proportion of raided nests will have marks from rats than from other predators.

- If black rats are exerting more predation pressure on birds' nests in urban areas, a greater proportion of artificial nests in urban habitats will register rat predation than those in bushland habitats.
- If black rats and long-nosed bandicoots are segregating at a macrohabitat scale, the number of bandicoots captured per transect will be inversely related to the number of black rats captured per transect.
- If black rats and long-nosed bandicoots are segregating at a microhabitat scale, traps that have captured black rats will capture fewer bandicoots than those that have not.

## Methods

### Study site

The study site was Sydney's North Head (33°49'1" S, 151°17'50" E), adjacent to the suburb of Manly and 10 km east of the centre of Sydney. North Head is a 385 ha peninsula and forms the northern boundary to the entrance of Sydney Harbour. Annual mean precipitation is 1221 mm and this study was conducted following a period of severe drought throughout 2002 (rainfall was approximately 30% below average), although some recovery was evident in 2003 and 2004 (Bureau of Meteorology, unpublished data).

North Head supports a mosaic of natural vegetation and areas that have been highly modified for human use. The land falls under numerous tenures and the headland was first disturbed by Europeans with the establishment of a Quarantine Centre in 1832. This area is now under the jurisdiction of the Sydney Harbour National Park. By 1870, approximately 60 buildings were located in the Quarantine Station. The Roman Catholic Church cleared land for a Cardinal's Residence and Seminary in the late 19<sup>th</sup> century, a sewage treatment plant was established in 1916, and Manly hospital was built in 1917. North Fort military post (now a museum) was established in 1935 and a School of Artillery was built in 1945. Since the mid-19<sup>th</sup> century, urban residential and small scale commercial developments have proliferated on the sand spit connecting the North Head peninsula to the mainland (Figure 1).

Interspersed amongst the modified areas of North Head are patches of remnant natural vegetation, including areas of woodland, heath, shrubland and swamp (Chambers and Dickman 2002). One hundred and thirty five fauna species inhabit the area of which 14 are introduced (Skelton *et al.* 2003a), including the introduced European rabbit *Oryctolagus cuniculus* and the black rat. The introduced brown rat *R. norvegicus*, a potential competitor with black rats (Williams *et al.* 2003), is rarely recorded on the site, despite extensive surveys of the area (National Parks and Wildlife Service, unpublished data). The predator assemblage at North Head includes owls (southern boobook *Ninox novaeseelandiae*; barn owl *Tyto alba*; and powerful owl *Ninox strenua*) as visitors rather than breeding locals, feral and domestic cats and domestic dogs *Canis lupus familiaris*. Red foxes *Vulpes vulpes* are sporadic visitors to the headland (Banks 2004).





**Figure 1.** Aerial photograph of North Head showing patches of bushland interspersed with development. The lines indicate the location of 46 transects, yellow indicates transects classified as "urban" and red indicates transects classified as "bushland".

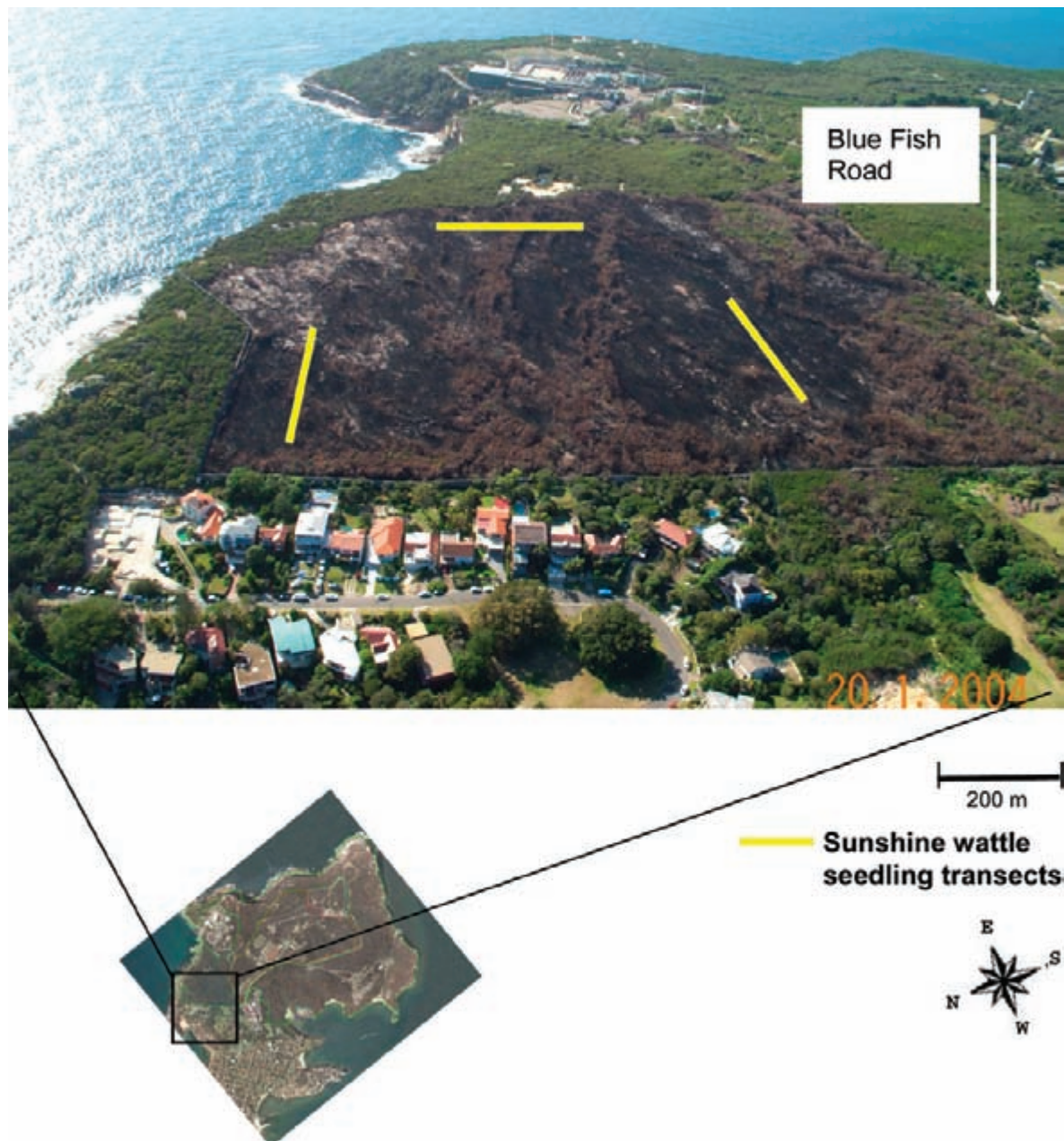
### Grazing of sunshine wattle seedlings

Rat grazing on the seedlings of the endangered sunshine wattle was measured in the field over 34 nights in July to August 2004. The study was conducted in a portion of the study area where sunshine wattle occurs naturally (Figure 2). This region was subjected to hazard reduction burning by the NSW National Parks and Wildlife Service (NPWS) eight months prior to this study, providing the habitat conditions under which sunshine wattle seedlings typically germinate and are at the greatest risk from grazing (Auld and O'Connell 1991; Benson and

McDougall 1996). Sunshine wattle seedlings ( $13.5 \pm 4.2$  cm in height) (Eastwood Nursery, Mangrove Mountain) were planted into seedling trays in the configuration outlined in Figure 3.

Within each of three sites nine seedling trays were distributed approximately 20 m apart to simulate the patchy regeneration typical of the species. Sites were spaced ca. 200 m apart to provide some spatial independence given that rats on average move <200 m (V. Stokes pers comm.) within a nightly foray and home ranges on North Head are <1 ha (Cox *et al.* 2000). At



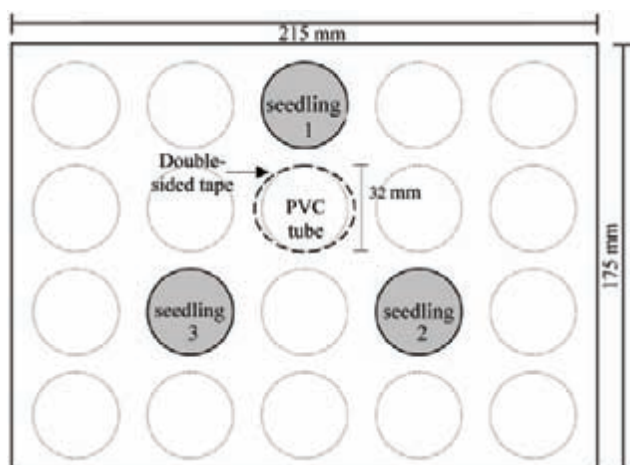


**Figure 2.** Aerial photograph of post-burn sunshine wattle heath community at Sydney Harbour National Park, used for *Acacia terminalis* seedling grazing experiment.

each site, three of the nine treatment trays were covered with rat-proof cages (300 x 300 x 350 mm; mesh size = 2.5 cm<sup>2</sup>), three procedural control trays were covered with similar cages, but had rat-sized holes (100 x 50 mm) cut into all four sides (Figure 4), and three control trays were set with no cages (Figure 5) (per Cohn and Bradstock 2000). The procedural control allowed rats access to the seedlings, but excluded larger potential grazers, such as the European rabbits and possums. Double-sided cloth tape was placed around a small plastic tube in the centre of each seedling tray to collect hair samples from visiting grazers (Figure 3). Hair samples were identified to species using morphological features following the methods in Brunner *et al.* (2002). The number of leaves on each seedling was counted before placing seedling trays in the field. Trays were buried in shallow holes to bring the seedlings level

with other plants. Seedlings were watered once a week when there had been no rainfall for the preceding 7 d. After 34 nights (which was deemed sufficient for grazing to have occurred), the seedling trays were removed and the number of leaves per seedling counted.

Treatment effects (i.e. cage, cage-with-holes, no cage) were compared using ANCOVA with treatment and site as the factors, and the initial number of leaves per seedling tray (i.e. total leaves for three plants) as the covariate. ANCOVA was chosen over analyses of proportional change because seedlings can grow during the experiment and proportional responses can be misleading (Packard and Boardman 1988). The assumption of homogeneity of slopes was confirmed by examining the covariate\*treatment interaction, which was then dropped from the analysis if  $p > 0.05$ .



**Figure 3.** Configuration of seedling trays for sunshine wattle grazing experiment: three seedlings arranged around a PVC tube with double-sided tape to trap the hairs of grazers.



**Figure 4.** Sunshine wattle seedling tray in exclusion cage with rat-sized holes cut into four sides (procedural control).



**Figure 5.** Sunshine wattle seedling tray without exclusion cage (control).

### Spatial relationships between black rats and long-nosed bandicoots

The spatial relationships between black rats and long-nosed bandicoots were evaluated using data collected from a 2002 survey of long-nosed bandicoots conducted by the NPWS (Lenehan and Banks 2002). During the survey, six cage traps (500 x 190 x 190 mm) with protective plastic

covers were placed 20 m apart in a total of 46 spatially-independent transects across the headland (transects were a minimum of 100 m apart) (Figure 1). Traps were baited with peanut butter and bread and checked daily at dawn, when they were re-baited and re-set. Trapping was conducted for five consecutive nights (1362 trap nights, accounting for closed and stolen traps).

The 46 transects were classified as either native bushland or disturbed urban habitats based on the relative proportion of native to non-native ("exotic") vegetation species. Although the proportion of exotic species does not encompass all forms of disturbance, it can be used as an indication of disturbance because many forms of human impacts contribute to weed proliferation (Saunders *et al.* 1991). The percentage of vertical cover by plant species (native and non-native following Robinson 1994) was estimated within 5 m x 5 m quadrats surrounding each of the six traps (see Hughes 2002). Transects were classified as "bushland" if the average vegetation composition along the trapline was  $\geq 70\%$  native ( $n = 20$ ) and "urban" ( $n = 26$ ) if exotic species comprised  $> 30\%$  of vegetation (Figure 1). One transect was re-classified as urban despite a high level of native species because it was directly adjacent to buildings of the sewage treatment plant.

The relationship between black rat abundance (total individuals per transect), habitat (fixed factor; "urban" or "bushland") and bandicoot abundance (fixed factor; total individuals per transect) at the scale of transect was compared by Generalised Linear Modelling, using the 34 transects where rats had been collected during the bandicoot census. At the trap point scale, logistic regression was used to explore the association between captures of rats (yes/no binomial response) and captures of bandicoots (yes/no binomial response).

### Predation of birds' nests

We used artificial birds' nests and eggs to compare predation events by various predator species (e.g. Hartley and Hunter 1998; Hannon and Cotterill 1998; Matthews *et al.* 1999; Berry 2002). Artificial eggs and nests were created to mimic those of local honeyeaters (Meliphagidae), including the New Holland honeyeater *Phylidonyris novaehollandiae* and white-cheeked honeyeater *Lichenostomus leucotis*. Black rats commonly raid honeyeater nests (Armstrong and Pyke 1991; Major and Gowing 1994) and the most common cause of nest failure in the New Holland honeyeater is predation (Paton cited in Armstrong and Pyke 1991). Both species have clutches of two eggs and build cup-shaped nests constructed of small twigs and spider web (Armstrong and Pyke 1991; Morcombe 2003). Our artificial nests (70 mm outside diameter, 50 mm inside diameter, 30 mm deep and 40 mm outside) were constructed using halved tennis balls, covered with coconut fibre and lined with *Casuarina* needles, which were glued in place using a water-based building adhesive, and synthetic spider web was then bound around the outside of each nest (per Matthews *et al.* 1999) (Figure 6). A hole in the bottom allowed drainage and a thread of thin pliable wire was used to attach nests to tree branches. Nests were secured at 1 – 1.5 m above the ground, similar to the nest heights generally observed in honeyeaters (Morcombe 2003). Two artificial eggs, made from off-white non-toxic plasticine and rolled by hand to mimic honeyeater





**Figure 6.** Photograph of artificial honeyeater nest with two plasticine eggs, attached to a tree branch.

eggs, were placed in each nest and glued with non-toxic hobby glue. Because artificial nests may attract predators that hunt using visual cues rather than scent (Willebrand and Marcström 1988; Storaas 1988), and because rats probably hunt using scent (Major and Gowing 1994), bird odour was added to the nests in situ, using a water-based spray (two squirts). The odour spray was made by soaking bedding from a henhouse that contained nine domestic chickens *Gallus gallus* in water for two days.

Eight sites at North Head were used and were classified as either “urban” ( $n = 4$ ) or “bushland” ( $n = 4$ ) as described above. During July 2004, 20 artificial nests were placed at each site in individual trees approximately 20 m apart and left for eight nights, after which time they were checked for predation. Nests were considered depredated when at least one of the eggs was missing or showed predation markings. Predator type was identified from impressions left in the plasticine eggs according to Matthews *et al.* (1999) and by comparison with reference eggs from the Australian Museum; rat predation leaves two parallel lines in the plasticine (from incisors) whereas bird predation leaves triangular markings (from beaks).

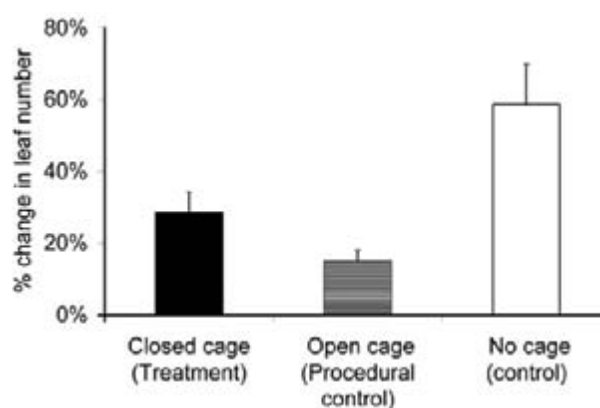
Initially, the glue used was too weak to withstand predation attack and both eggs were frequently missing from a nest, preventing identification of the predator. Therefore, a second experiment was conducted whereby two new eggs were glued into each nest using stronger superglue and re-sprayed with bird odour. After a further eight nights at the same location, the nests were removed and predation events and type recorded. Hereafter these experiments are labeled chronologically as “experiment one” (i.e. weaker glue used) and “experiment two” (i.e. stronger glue). Two-factor ANOVA was conducted for experiments one and two separately, using predator type (bird or rat) and habitat (bushland or urban) as the factors and the number of nests depredated per transect as the response.

In all tests,  $p \leq 0.05$  was considered significant. For non-significant results, post-hoc power analyses were used to determine  $\delta$ , the minimum differences between the means that ANOVAs were able to detect. For all power analyses,  $\alpha = 0.05$ ,  $\beta = 0.8$ .

## Results

### Grazing of sunshine wattle seedlings

There was substantial grazing pressure on sunshine wattle seedlings. Grazing intensity did not differ between the three sites (ANCOVA,  $F_{2,17} = 0.60$ ,  $p = 0.59$ ) nor was there any interaction between treatment and site, so this term was pooled with the residual variance (Underwood 1997). After 34 days, seedlings without cages (control) suffered 44% higher grazing damage than seedlings with open (procedural control) cages and 30% higher grazing than that of seedlings in closed (treatment) cages (ANCOVA,  $F_{2,17} = 7.53$ ,  $p = 0.06$ ) (Figure 7), indicating a cage effect. Double-sided tape produced five hair samples; three were from European rabbits and two were from bandicoots, but no black rat hairs were found suggesting that they were not entering cages. The grazers are probably therefore larger than the holes in the treatment control cages, and are most likely feral European rabbits and/or long-nosed bandicoots.

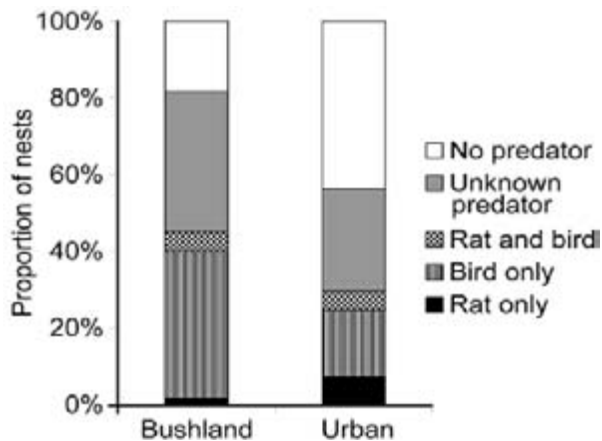


**Figure 7.** Mean percentage change ( $\pm$ SE) in the number of leaves on sunshine wattle seedlings before and after the grazing experiment: closed cages (treatment), open cages (procedural control) and no cages (control).

### Predation of birds' nests

The artificial birds' nests suffered rat predation across all transects, in both bushland and urban habitats, though each experiment suggests slightly different predation intensity by different predators. Overall, the level of nest predation from all sources was greater in the bushland compared with urban habitats. In the first experiment (weak glue), mean nest predation in bushland was  $82 \pm 6\%$ , compared with  $56 \pm 8\%$  in the urban habitats (Student's T-Test,  $p = 0.05$ ) (Figure 8) although the predator type was unknown in 46% of the instances where nests had been raided. In the second experiment (strong glue),  $73 \pm 13\%$  of nests in bushland areas suffered predation, compared with  $47 \pm 10\%$  in urban areas, although the difference was not significant (T-test,  $p = 0.12$ ) (Figure 9) and the predator type was unknown in only 7% of nests that suffered predation.

Birds and rats appear to be the only two predators of birds nests at North Head, although the proportion of unknown predators, particularly from experiment one, render this inconclusive. In the first experiment, predation rates differed between predator types (ANOVA,  $F_{1,12} = 13.57$ ,  $p < 0.01$ ), but an interaction with habitat (ANOVA,  $F_{1,12} = 5.10$ ,  $p < 0.04$ ) revealed that only nests in bushland habitats were preyed on by birds more than rats (Tukey's HSD test)



**Figure 8.** Percentage of nests in bushland and urban habitats where there was no predation, predation occurred but the predator type was unknown, predation by both rat and bird, predation by bird, and predation by rat (experiment one).

(Figure 10). Notably, rat predation did not differ between the two habitats. In experiment two however, bird predation on the artificial nests was greater than that by rats in both bushland and urban habitats (ANOVA,  $F_{1,12} = 22.95$ ,  $p < 0.01$ ) (Figure 11) but again predation by rats did not differ between habitats.

### Spatial relationships between black rats and long-nosed bandicoots

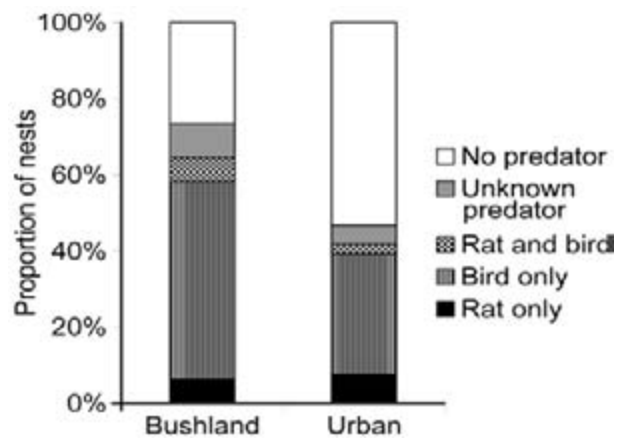
Black rats and bandicoots at North Head showed considerable spatial separation. At a larger, transect-scale in urban habitats, captures of long-nosed bandicoots were negatively related to captures of black rats, but the Rat\*Habitat interaction showed that the difference was most intense in urban areas whereas there was little relationship in bushland (ANCOVA,  $F_{1,29} = 4.85$ ,  $p = 0.04$ ) (Figure 12). At the smaller scale of individual trap points, captures of long-nosed bandicoots tended to be higher (63% of bandicoots captured) in traps where black rats were not caught ( $\chi^2 = 2.82$ ,  $p = 0.09$ ), but no significant habitat effect was detected ( $\chi^2 = 2.06$ ,  $p = 0.15$ ).

## Discussion

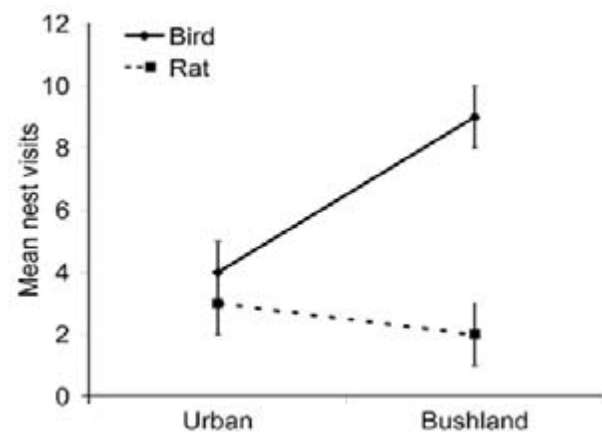
There are very few studies in Australia that have investigated the impact feral black rats have on native biodiversity. Based on the studies presented here of potential impacts of black rats on three key elements of North Head's biodiversity, rat impact may not be as dramatic as feared. Nonetheless a precautionary approach is still needed, particularly if population density of these rats increases, as it has the capacity to do (Rose 2004).

### Grazing of sunshine wattle seedlings

Although sunshine wattle seedlings were being foraged, it seems that black rats played only a minor role. Uncaged seedlings suffered significantly more foraging than seedlings with either full exclusion cages or those excluding larger foragers but not rats. The common brushtail possum *Trichosurus vulpecula* and the common ringtail possum *Pseudocheirus peregrinus* both forage acacia foliage (Irlbeck and Hume 2003). However, the presence of hairs from European rabbits and fresh diggings in the study site suggests that rabbits are probably the predominant grazer



**Figure 9.** Percentage of nests in bushland and urban habitats where there was no predation, predation occurred but the predator type was unknown, predation by both rat and bird, predation by bird, and predation by rat (experiment two).

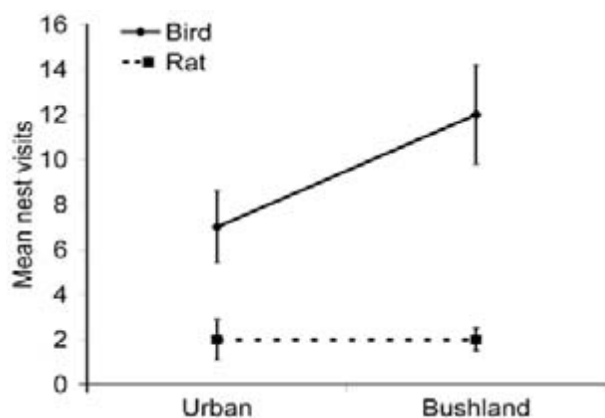


**Figure 10.** Mean ( $\pm$ SE) number of visits to a nest by habitat (urban and bushland) and predator type (bird and rat), experiment one.

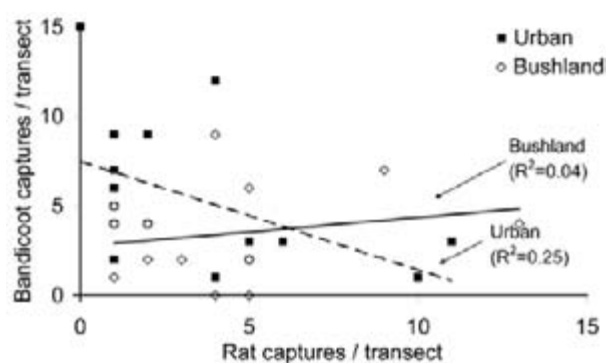
of sunshine wattle seedlings at North Head. Elsewhere, rabbits may limit full regeneration of *A. aneura*, *A. kempeana* and *A. papyrocarpa* (Barker 1987). Some seedlings without cages were stripped back to stems and a 30% higher level of foraging on uncaged seedlings suggests control measures of European rabbits may be necessary to improve recruitment of sunshine wattle seedlings. Although rats were present on the site (NPWS unpublished data), it seems they did not forage on the sunshine wattle seedlings under this experimental protocol. Further work is needed to resolve whether they impact on other components of post-fire regeneration such as seeds.

### Predation of birds' nests

Overall 63% of artificial birds' nests were visited by predators at North Head, with predation occurring in both urban and bushland habitats. We found no habitat differences in the total number of nests taken by rats, which contrasts with Matthews *et al.* (1999) who found that the number of birds' nests taken by rats was highest at the edges of small fragments ( $< 10$  ha) and almost non-existent in fragments greater than 100 ha. However, the areas of remnant bushland at North Head are only comparable in size to the smaller fragments studied by Matthews *et al.* (1999). High variances meant the relationship between predation rates and rat density was unclear, thus further analysis comparing nest success



**Figure 11.** Mean ( $\pm$ SE) number of visits to a nest by habitat (urban and bushland) and predator type (bird and rat), experiment two.



**Figure 12.** Numbers of rat captures and long-nosed bandicoot captures per transect in bushland and urban habitats, fitted with linear regression lines.

with rat density would better indicate the likelihood that recruitment of small birds would be negatively impacted by an increase in rat density.

Rats preyed on nests 58-77% less often than birds and, although rat predation is a markedly lower threat to nests than that from birds, it remains unclear whether the additive effect of black rat predation is biologically significant. Bush rats *Rattus fuscipes*, previous inhabitants of bushland at North Head (Skelton *et al.* 2003a), do not climb trees (Watts and Aslin 1981) and are thus unlikely to have imposed a significant predation pressure on aerial birds' nests. Evaluation of nest success following an experimental removal of black rats would better clarify this issue.

Artificial nest experiments suffer from methodological issues that constrain comparisons between predator types and an overall measure of nest predation (Willebrand and Marcström 1988). The artificial honeyeater nests used here suffered a much higher level of predation (63%) than predation rates of natural honeyeater nests (e.g. 45%: Armstrong and Pyke 1991; 42%: Berry 2001), which are raided by black rats more than by birds (Major and Gowing 1994). However artificial nests are thought to be more conspicuous than natural nests and may attract more visual predators such as birds (Storaas 1988; Willebrand and Marcström 1988; Berry and Lill 2003). The bird scent used in this study attempted to counteract this bias, but rain in the first few days may have diluted this control. The absence of parent birds at artificial nests to fend off predators may also lead to an overestimation of predation levels (Martin *et al.*

2000) although some researchers suggest parent activity may attract predators (Alerstam and Högstedt 1981; Greenwood 1985). Application of a non-water-soluble bird odour, along with placement of artificial parent birds at artificial nests may better resolve these uncertainties and clarify whether bird predation significantly affects honeyeater recruitment, as suggested by these findings.

### Spatial relationships between black rats and long-nosed bandicoots

Negative spatial associations were found between black rats and long-nosed bandicoots, particularly in urban habitats. Captures of rats and bandicoots showed a negative relationship at both the transect (macrohabitat) and trap (microhabitat) scales, however the mechanism generating these associations are not immediately clear. The macrohabitat scale associations concur with Chambers and Dickman's (2002) observation that bandicoots prefer ecotone habitats with cover adjacent to open foraging patches (see also Hughes 2002), whereas black rats prefer denser forest and heath with structural complexity (Bray 1994; Cox *et al.* 2000), a pattern that may be driven by competition between the two. There is some dietary overlap between the species: both species are consumers of invertebrates, fungi, and plant roots and shoots (Watts and Braithwaite 1978; Clark 1981 and 1982; Watts 1995; Moyle *et al.* 1995; Stodart 1995; Cox 1997; Long 2003); although bandicoots show preference for invertebrates and plant roots (Scott *et al.* 1999) whereas plant leaves and stem make up a large proportion of the diet of black rats at North Head (Cox 1997). But if the spatial pattern is generated by competitive exclusion, it may be interference competition from bandicoots. Hughes (2002) reported observations of a black rat approaching a bandicoot that was foraging in a heath habitat; the bandicoot emitted an alarm "honk", and the rat fled; the rat then reappeared and the bandicoot approached the rat aggressively, after which the rat departed and did not return. Thus bandicoots, which are five times the size of black rats may defend preferred foraging patches against black rats and may be the more dominant species of the two. More generally black rats may be poor competitors in bushland, being rarely recorded where native bush rats occur (V. Stokes, unpublished data; Capps 2001). At Bradley's Head, black rats occur only in bushland areas adjacent to Taronga Zoo, but not within the zoo where the much larger brown rats are dominant (Williams *et al.* 2003). However the black rats did not move into areas from which brown rats were removed and Williams *et al.* (2003) suggested that predation risk may drive the apparent preference for bushland areas. Because black rats can persist and reproduce in the bushland habitats of North Head (Rose 2004) which lack other rodents, their absence from other bushland habitats may be due to exclusion by the presence of remnant native rodents. Clearly this suggestion warrants further investigation, but the implication is that if the abundance of native small mammals declines, black rats may further invade bushland areas.

### Management Implications

Like most small rodent populations, the black rat population at North Head shows a strong innate capacity to increase (Rose 2004). Although black rats were not directly linked to substantial damage to sunshine wattle seedlings nor did they



have substantial additive impacts on nest survival in small passerines, an increase in their population size from current levels (approximately one rat per ha, Rose 2004) may heighten their impacts. A negative spatial relationship with endangered bandicoots, although appearing to be driven by bandicoots, warrants further exploration. It is also possible that black rats affect conservation values not measured here (through disease, parasites, attraction of predators) and if a sanctuary is created at North Head, supplemental feeding of other wildlife may fuel black rat population growth. These concerns, together with the population's high growth capacity, necessitate further investigation and ongoing monitoring. Exploitation of the population's dependence on juvenile recruitment for growth would be the most effective means of population suppression and control would be necessary in both urban and bushland habitats (Rose 2004).

Control of black rats cannot be conducted in bushland habitats without considering re-invasion from urban areas. In conjunction with population control, methods to limit black rat survival in urban areas, such as improved sanitation programs, rat-proofing buildings through blocking up holes and public education, may go some way to limiting the escalation of the black rat population.

This study also has implications for black rat invasion of similar bushland areas adjacent to urban areas. Evidence of a preference for fragmented bushland habitats (Rose 2004), together with indications of poor competitive abilities suggest the absence of black rats in bushland adjoining urban areas in some parts of Sydney (e.g. Kuring-gai Chase National Park) may not last if the residence of native rodents decreases.

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