Use of Remote Cameras to Survey and Monitor Mammal Fauna Occurrence at Loch McNess and Lake Yonderup, Yanchep National Park, Perth, Western Australia (2011-2013)

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Summary

This study was conducted to address identified gaps in the understanding of the distribution, abundance and threats to native mammal species in Yanchep National Park.

Remote cameras were used at monitoring points at Loch McNess and Lake Yonderup with an aim to survey and monitor local native and introduced mammal species in Yanchep National Park, with an emphasis on *Hydromys chrysogaster* (Rakali or Water Rat), *Rattus fuscipes* (Bush Rat), *Isoodon obesulus fusciventer* (Southern Brown Bandicoot or Quenda) and introduced species *Rattus rattus* (Black Rat), *Mus musculus* (House Mouse), *Vulpes vulpes* (European Red Fox) and *Felis catus* (Feral Domestic Cat). Camera traps were installed in nine wetland and nine terrestrial sites around Loch McNess and Lake Yonderup over four seasons.

The number of visits per 100 trap nights was compared between terrestrial and wetland habitat, between seasons and between the 18 camera location sites. Most of the captured species showed a preference for terrestrial sites, with the exception of *H. chrysogaster*, which showed a preference for wetland habitat. *Rattus fuscipes* had a significantly greater preference for terrestrial habitat.

This study has contributed important information to the knowledge of the distribution of several native and introduced species on the Swan Coastal Plain, including *H. chrysogaster* and *R. fuscipes*. Both of these species were recorded within the study area, indicating that these two areas in Yanchep National Park are of great importance to these species, particularly the wetland habitat to *H. chrysogaster*. The survey would need to be continued on a regular basis to monitor changes in the fauna populations and the effect of declining water levels on native mammals.

Simultaneous use of wetland habitat by *H. chrysogaster* and introduced predators indicates a potential threat of predation to this species, especially by *V. vulpes* and *F. catus* in autumn and winter. This timing also coincides with a likely dispersal of juvenile *H. chrysogaster* from parents after weaning in summer. This indicates that late summer/ early autumn could be an optimal time to target predator control in order to reduce predation threats to *H. chrysogaster*. Simultaneous use of terrestrial habitat by *R. fuscipes* and introduced species indicates a potential for risk of predation by *F. catus* and *V. vulpes* on this species, which may increase during autumn and spring as reflected by high visitation rates during these seasons by these three species.

This study has also shown that conspecific and interspecific interactions occur across the study area, predominantly in the vicinity of Lake Yonderup, which may be a reflection of higher quality habitat and lower amount of anthropogenic disturbance at Lake Yonderup as compared to Loch McNess. This study has provided evidence of agonistic interspecific interactions between *R. fuscipes* and *R. rattus*. Both species prefer similar habitat, suggesting that territories of these two species may overlap resulting in direct competition for resources such as food, shelter and nest sites. In most interactions the introduced *R. rattus* was dominant over the native *R. fuscipes* - therefore it is important to learn more about the relationship between these two species in the study area in order to protect populations of *R. fuscipes*.

Management Recommendations:

1) Development of programs to control *Vulpes vulpes, Felis catus* and *Rattus rattus* based on an adaptive management approach.
2) Continuation of monitoring of native and introduced mammal species to determine changes in target species and introduced species (to assess predation and competition among species).
3) Continuation of survey on a regular basis at Loch McNess and Lake Yonderup to monitor changes in the fauna populations and the effect of declining water levels on native mammals.
4) Undertake targeted control of predators at all wetland sites where *Hydromys chrysogaster* are found (Wetlands 1-5 sites) and peak seasons (late summer / early autumn).
5) Investigate the use of vertical bait stations for *Rattus rattus* that reduces uptake by native rodent species.
6) Investigate the role of microhabitat integrity for maintenance of native species, particularly *Hydromys chrysogaster* and *Rattus fuscipes*.
7) Meet the performance targets relations to Protection of the Natural Environment as outlined in the Parks and Reserves of Yanchep and Neerabup Management Plan 76 (2012): *Continued persistence and no decline in the conservation status of threatened species*.
8) Implement further studies to determine threats to *Hydromys chrysogaster* (e.g. examine scats of *Vulpes vulpes* for evidence of predation)
9) Implement further studies to determine the impacts of *Rattus rattus* on populations of *Rattus fuscipes*.
10) Reduce threats to target native species by:
    - Incorporating protection of target mammal species and their habitat into prescribed burning plans.
    - Protecting habitat (e.g. weed control) and establishing / maintaining ecological linkages.
    - Ongoing monitoring of native species populations.
    - Assessing the effectiveness of predator control measures.
    - Determining seasonal trends of species abundance.
    - Determining the impacts of declining water levels / hydrological change at Loch McNess and Lake Yonderup.
    - Determining the importance of Lake Yonderup as refugia / alternative habitat for native species.

Introduction

Since European settlement, the abundance of native mammal species on the Swan Coastal Plain has declined significantly. Surveys conducted by early European settlers such as Gilbert (1839-43) and Shortridge (1904-07) recorded 33 species native to the region at the time of settlement (Kitchener *et al*., 1978). The next major survey conducted in 1977 – 1978 by the Western Australian Museum recorded 12 species (Table 1). The major factors considered to have contributed the decline in native species included introduced predators, changed fire regimes, loss of habitat (Kitchener *et al*., 1978).

More recent surveys by How and Dell in 1990s conducted in inner urban remnant vegetation patches on the Swan Coastal Plain (SCP) recorded only seven native and six introduced mammal species (How and Dell, 1993, 1994, 2000). One of the significances of this survey was that it did not record *Rattus fuscipes* (bush rats), *Hydromys chrysogaster* (water rat or Rakali) or *Pseudomys albocinereus* (ash-grey mice), all of which had been previously recorded in the 1977-1978 Western Australian Museum survey (How and Dell, 2000).

A study undertaken as part of the Gnangara Sustainability Strategy (GSS) investigated previous and current distribution of mammals on the Gnangara Groundwater System, and assessed potential impacts of predicted rainfall and groundwater declines on mammals (Valentine *et al*., 2009; Wilson and Valentine, 2009; Wilson *et al*., 2012). A general trapping survey was conducted at 40 sites, and targeted trapping was undertaken at wetlands for Rakali and *Isoodon obesulus fusciventer* (southern brown bandicoot or Quenda). Nine native and seven introduced terrestrial mammal species were recorded during the general survey. The most commonly captured native species was *Tarsipes rostratus* (honey possum). The study found that only eleven (nine recorded and two considered to be extant) of the twenty-eight historically recorded terrestrial native non-bat mammals still persisted in the area. Introduced species, including *Rattus rattus* (black rats), *Mus musculus* (house mouse), *Vulpes vulpes* (fox) and *Felis catus* (feral cat), were also observed. During the targeted trapping survey conducted in May 2008, a total of three male and three female *H. chrysogaster* were recorded, as well as *Rattus fuscipes* (bush rat) (Valentine *et al*., 2009, Wilson *et al*., 2012).

Use of infrared camera traps in fauna surveys

This study of mammal fauna at Yanchep National Park using infrared camera trapping was initiated in August 2011 to address identified gaps in the understanding of the distribution, abundance and threats to native fauna species in the National Park. The results of other recent studies suggest that the camera-trapping technique is a viable option for native mammal fauna surveys in comparison to live-trapping (De Bondi *et al*., 2010; Claridge *et al*., 2010). The technique has been developing over the last forty years (Claridge *et al*., 2010) and while it compares well to live-trapping in terms of species detection and costs, it is also a logistically easier sampling method. In addition the technique is also important for the detection of introduced species and predators. Unlike live-trapping, which demands extended periods of time spent by staff to monitor traps during field sampling, camera trapping equipment does not require constant supervision and can be used remotely for long periods of time. Remote camera trapping also negates the need to handle animals, therefore offering a less invasive sampling method which has ethical benefits (Claridge *et al*., 2010). Remote cameras are hardy, can be used in most habitats and are able to endure all types of climates (De Bondi *et al*., 2010).

In this study remote cameras were used at monitoring points at Loch McNess and Lake Yonderup with an aim to survey and monitor local native fauna populations and introduced species at Yanchep National Park, with an emphasis on *H. chrysogaster*, *R. fuscipes, Isoodon obesulus fusciventer* and introduced species *R. rattus*, *M. musculus*, *V. vulpes* and *F. catus.*

Target native species

The water rat or Rakali (*Hydromys chrysogaster*) is found throughout Australia and in Western Australia's south-west and north. As the name suggests *H. chrysogaster* lives in the vicinity of permanent bodies of fresh or brackish water (e.g. lakes, rivers, streams and coastal beaches) (Olsen, 1995; Morris, 2000; Olsen, 2008; Smart, 2009). Suitable habitat for *H. chrysogaster* includes areas with possible locations for burrows and nests (e.g. steep banks), logs, rocks or reeds for feeding areas and sufficient riparian and stream vegetation cover (Woollard *et al*., 1978). Rakali are mostly carnivorous, foraging in the water and also hunting on land (Strahan, 2004). The diet of this species consists of large aquatic insects, fishes, crustaceans, mussels, frogs, lizards, water birds and tortoises (Olsen, 2008; Woollard *et al*., 1978). *Hydromys chrysogaster* has partially webbed hind feet and a waterproof coat, and can be recognised by its large, long tail (227mm - 325mm) with a white tip, its somewhat flattened head and body, and small ears (Olsen, 1995). Usually *H. chrysogaster* is 231mm - 370mm in head and body size and weighs between 340g and 1275g (Olsen, 1995). Most rodents are nocturnal animals but the Rakali is mainly active at dusk and may feed in the day time (CSIRO, 2004).

Hydromys chrysogaster is highly susceptible to loss of habitat through the contraction and drying out of lakes either through filling and draining for alternative land use, decreasing rainfall/drying climate and hydrological groundwater changes. *Hydromys chrysogaster* are also susceptible to water quality degradation and predation by foxes and cats. Loss or reduction in size and quality of wetland areas would also affect the food resource for *H. chrysogaster* (Olsen, 2008; Woollard *et al.,* 1978). *Hydromys chrysogaster* is a Priority 4 Protected Species (Rare, Near Threatened) in Western Australia, requiring regular monitoring. Results from the GSS study conducted in 2007-2008 indicate that *H. chrysogaster* is present on the SCP, most likely in small populations. *Hydromys chrysogaster* was recorded at Loch McNess (6 individuals), Lake Goolellal (6 individuals) and Lake Joondalup (1 individual) (Wilson *et al*., 2012). At Lake Goolellal the 6 individuals were captured from 30 trap nights, indicating that a sizeable population may reside at this lake (Valentine *et al*., 2009). A study in 2009 surveyed for the presence of *H. chrysogaster* at 39 sites in the greater Perth area. The species was captured at only two sites, and there was indirect evidence of their presence recorded at a further four sites (Smart, 2009).

The bush rat (*Rattus fuscipes*) is native to Queensland, New South Wales, Victoria, South Australia and south-west Western Australia. *Rattus fuscipes* is a nocturnal animal and prefers nesting in dense forests under logs or rocks, which makes difficult to find. *Rattus fuscipes* can be recognised by its pointed head, round ears, short tail (105mm - 195mm) and dense soft fur. The bush rat weighs between 40g - 225g and is 111mm - 214mm in body size. The bush rat is an omnivore and eats fungi, grasses, fruits, seeds and insects (Lunney, 1995). The distribution of the Western Australian subspecies, *Rattus fuscipes fuscipes*, occurs close to the coast from Jurien Bay in the north to Israelite Bay in the south east, including offshore islands (Lunney, 1995). *Rattus fuscipes fuscipes* is considered to be sparsely distributed on the northern SCP, with specimen records limited to the coastal Yanchep area in 1975, and 1977–78 (Kitchener *et al.*, 1978).

On the northern SCP *R. f. fuscipes* appear to prefer mesic environments providing dense understorey and ground cover. Surveys conducted in 1975 and 1977-78 recorded *R. f. fuscipes* only near Loch McNess in Yanchep National Park (Kitchener *et al*., 1978). The GSS study in 2007-2008 recorded *R. f. fuscipes* only at Muckenburra Nature Reserve and Loch McNess and the highest trap success rate occurred at Loch McNess (29 captures per 100 trap nights) (Wilson *et al*., 2012). Results of several surveys indicate a preference for near-coastal habitats along the coastal strip on northern SCP. This area is largely proposed for urban development and is not considered a long term viable fauna habitat. Threats to this species include habitat loss, fragmentation, predation and inappropriate fire regimes (Lunney, 2008; Reaveley, 2009).

The southern brown bandicoot or Quenda (*Isoodon obesulus fusciventer*) occur in forest, woodland, shrub and heath communities on sandy soils with dense low vegetation (Reaveley, 2009). *Isoodon obesulus fusciventer* feed on invertebrates and subterranean material such as bulbs and fungi. Currently on the northern SCP this species appears to be sparsely distributed in areas of dense low vegetation that are associated with wetter riparian areas (Wilson *et al*., 2012). *Isoodon obesulus fusciventer* on the northern SCP are threatened by habitat loss, aridification, inappropriate fire regimes, loss of productivity, and predation pressure by foxes and cats (Reaveley, 2009). *Isoodon obesulus fusciventer* is listed as Priority 5 in Western Australia (Conservation Dependent Species).

On the SCP, *I. o. fusciventer* occur in a highly urbanised environment. Historically they were described as plentiful, but by the late 1970s were reported to be sparsely distributed (Kitchener *et al*., 1978). In recent times *I. o. fusciventer* are anecdotally reported to be in good numbers on the eastern SCP and Darling Scarp but the abundance has declined since a 1993 community survey, particularly south of the Swan Estuary in areas where urban expansion has occurred (Howard *et al*., 2012). Modelling indicates that *I. o. fusciventer* are more common in the higher rainfall areas of the SCP, close to waterways and in dense, low vegetation (Ramalho *et al*. 2013). In the GSS study conducted in 2007-2008 *I. o. fusciventer* were recorded from five of nine selected sites at Gnangara Lake, Little Badgerup Swamp, Neaves Road Nature Reserve, Twin Swamps Nature Reserve and Nowergup Nature Reserve in dense vegetation within riparian habitat (Wilson *et al*., 2012). In 1987-88 *I. o. fusciventer* were recorded in Yanchep National Park (Table 1) (Burbidge and Rolfe, unpublished data). The species has also been recorded in 2009-2013 at Lake Nowergup (K. Bryant, pers. comm). One individual was captured at the visitor centre in Yanchep NP as part of a Department of Parks and Wildlife survey in 2011, however it was likely to be one of two individual I. obesulus fusciventer that had been released in the area a few days prior as part of a translocation from a nearby development site (Moore, 2011). Incidental sightings of *I. o. fusciventer* have also occurred in wetland areas at reserves at Wilbinga and Pippadinny and northern end of Loch McNess (pers. comm. John Wheeler, 2014). The decline and status of *I. o. fusciventer* in south-eastern Australia indicate the sensitivity of this species to development in urban and peri-urban areas, and highlight the need to assess this species.

Table 1. Occurrence of native and feral mammals captured and/or sightings recorded at Yanchep National Park. Native mammal species are highlighted.

Mammal Species	1977/78 (Kitchener *et al*. 1978)	1987/88 (Burbidge and Rolfe, unpub. data)	2007/08 (Reaveley 2009; Wilson *et al*., 2012)	2011 (Moore, 2011)
Western grey kangaroo (*Macropus fuliginosus*)	X	X		
Western brush wallaby *(Macropus irma)*	X			
Brush-tailed possum (*Trichosurus vulpecular)*	X			
Bush rat (*Rattus fuscipes)*	X		X	X
Gould's wattle bat (*Chalinolobus gouldii)*	X			
Chocolate wattled bat *(Chalinolobus morio)*				
Lesser long-eared bat *(Nyctophilus geoffroyi)*		X		
Greater long-eared bat *(Nyctophilus timorensis)*		X		
Whites-striped freetail bat (*Tadarida australis*)		X		
Rakali *(Hydromys chrysogaster)*		X	X	
Quenda *(Isoodon obesulus fusciventer)*		X		X
Echidna *(Tachyglossus aculeatus)*		X		
Western quoll *(Dasyurus geoffroii)*				
Western pygmy possum *(Cercartetus concinnus)*				
Honey possum *(Tarsipes rostratus)*		X		
Fox (*Vulpes vulpes)*	X	X		
Ferret (*Mustela putorius)*	X			
Feral cat *(Felis catus)*	X	X		
Black rat (*Rattus rattus)*	X	X	X	X
House mouse (*Mus musculus)*	X	X	X	
European rabbit (*Oryctolagus cuniculus*)		X		

Study Objectives and Aims

The key objectives of this study were to:

- Identify the presence of fauna species and examine any seasonal differences. Help identify threatening processes and the impacts of these processes;
- Use this information to guide management decisions; and
- Use the results from this study to improve capacities for fauna and predator surveys.

The specific aims of this study were to:

- Obtain information on the distribution and abundance of the population of *Hydromys chrysogaster* at Loch McNess and the use of Lake Yonderup and surrounding areas;
- To identify interactions between *Rattus rattus* and *Rattus fuscipes*;
- Obtain information on the timing of breeding and gain information on the distribution and abundance of *Rattus fuscipes*; and
- Obtain information on *Isoodon obesulus fusciventer*, which has not recently been recorded in the riparian areas of the lakes in previous surveys.

Methods

Study area

This study was conducted within Yanchep National Park (2,877 ha) in Perth, Western Australia, which is located 51 km north of Perth, within the Swan Coastal Plain (Figure 1). Yanchep National Park is situated on the landform known as the Dandaragan Trough. The area is made up of wind deposited (Aeolian) sediments and water deposited (alluvial) sediments. The park lies within the Spearwood and Quindalup dune systems. To the east of the study area, the land use is predominately state forest (mainly for pine plantation) and rural or semi-rural. Along the coast to the west of the study area, the major land use is urban development (DEC, 2012).

Yanchep National Park is a unique national park as it has been highly anthropogenically modified (approximately 10 ha has been cleared/highly modified). These modifications include an area of cleared land for recreational use, a golf course, koala enclosure, and heritage listed buildings. The park encompasses four wetlands, seven different vegetation communities and more than five hundred limestone caves.

The main threats to biodiversity within the study area are declining ground water levels in the Gnangara Mound superficial aquifer, introduced fauna species, changing climatic conditions (e.g. decreasing rainfall) as well as fragmentation of natural habitat due to urbanisation adjacent to the park boundaries. The primary sites in this study, Loch McNess and Lake Yonderup, are groundwater-dependent ecosystems that provide habitat to a variety of fauna species, and a decline in water levels and hydrological change form a major threat to these ecosystems (DEC, 2012; DOW 2011a).

Loch McNess is a conservation category wetland listed in the *Directory of Important Wetlands in Australia*, which is recognised for its high ecological and social values (DOW, 2011a). Loch McNess is at severe risk from possible drawdown as a decline in regional groundwater levels is causing a rapid decline in surface water levels (DOW, 2011a). Lake Yonderup is a situated to the south of Loch McNess and is recognised as a regionally significant (System 6) conservation category wetland and is listed on the *Register of the National Estate* due to its high ecological values (DOW, 2011b). It is a relatively undisturbed wetland and in 1995 was identified as a significant wetland for its undisturbed hydrologic regime and lack of seasonal variation in water level, rich invertebrate fauna and excellent water quality (WAWA, 1995; DOW, 2011b). However, water levels in Lake Yonderup have been declining steadily since 1995 (DOW, 2011b).

Pilot study

A pilot study using six cameras was undertaken from August 2011 to January 2012 (Figure 2, Table 2), to test the value of locations and as a preliminary survey. No lure was used during the pilot study. Surveys were undertaken at ten sites (Table 2, Figure 2), totalling 333 trap nights. Cameras were set to default settings, except for capture number, interval and sensor level, which varied in an attempt to identify optimal settings. Video settings were also employed in the pilot study, but as we did not have access to the correct software to view videos we did not use this setting for the main study.

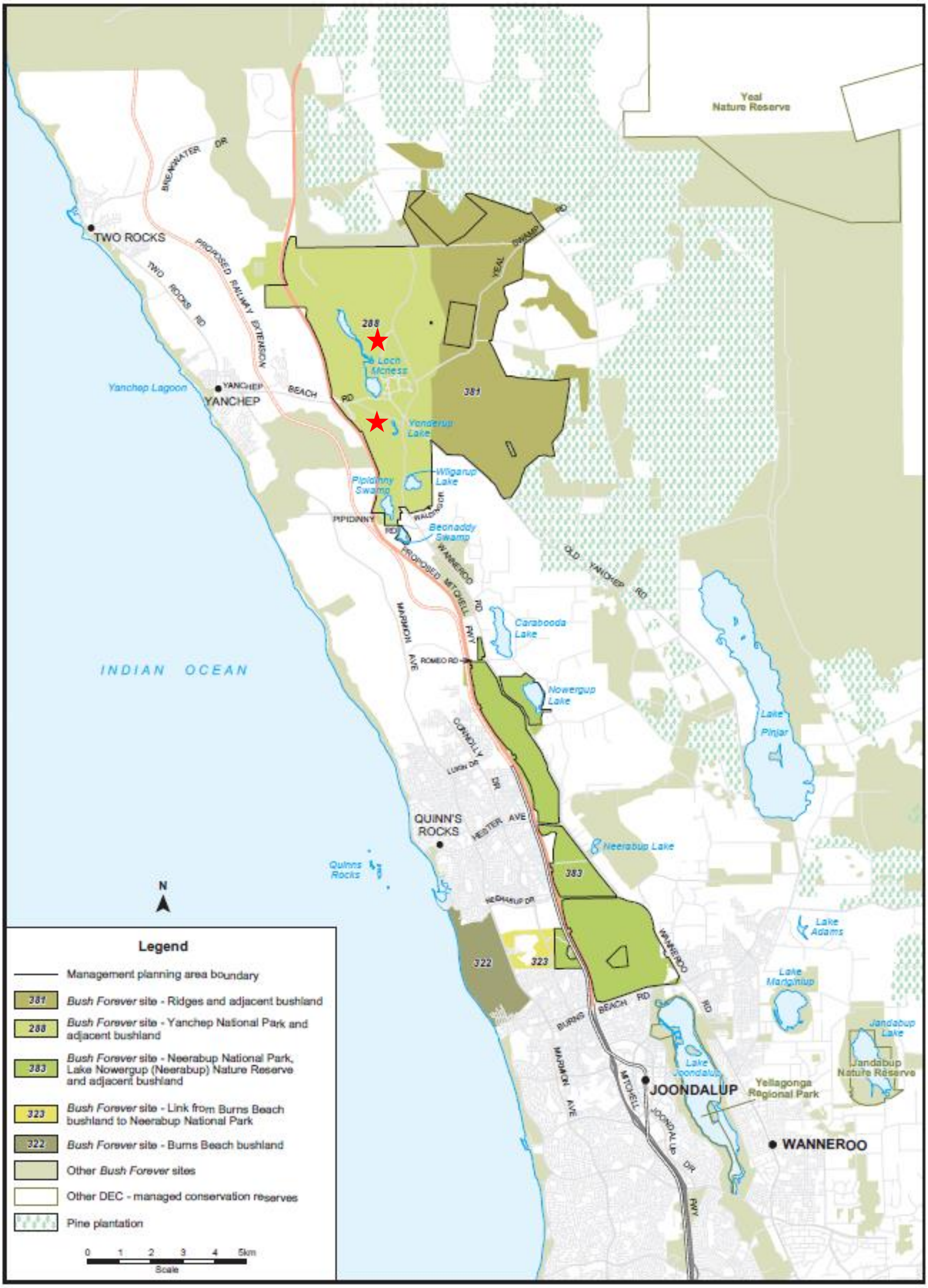

Figure 1. Distribution map showing Yanchep National Park, land tenure on the Northern Swan Coastal Plain and the location of Loch McNess and Lake Yonderup (red stars) (DEC, 2012).

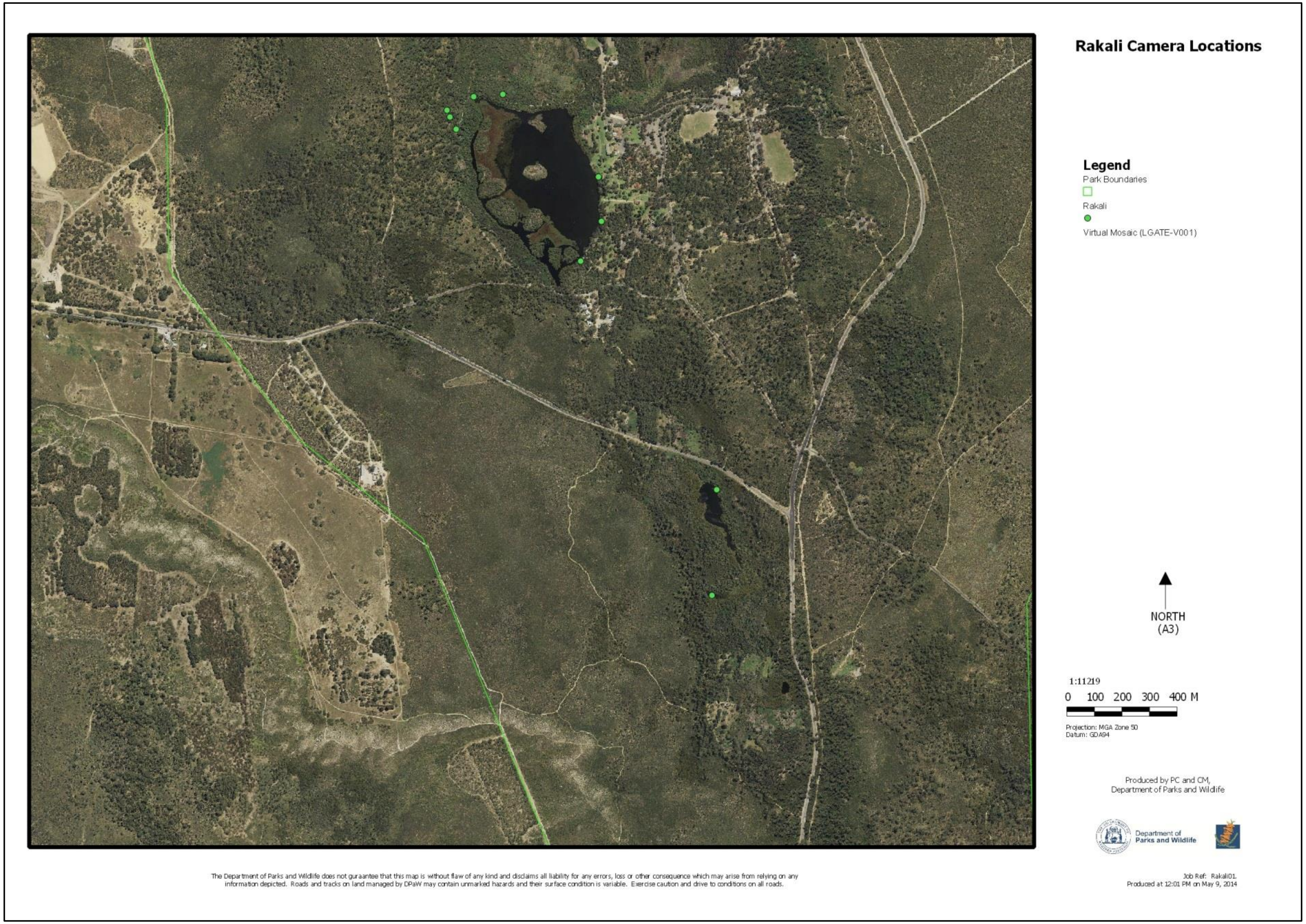

Figure 2. Location of fauna monitoring sites using camera traps in the study area for the Pilot Study in Yanchep National Park.

Table 2. Dates and locations of camera traps during the pilot study in 2011-2012.

Site	Set up dates	GPS coordinates	Location description
Bird Viewing Platform	29/07/11 - 03/08/11 08/09/11 - 28/09/11 22/08/11 - 05/09/11	S31° 32' 52.45" E115° 40' 55.59"	Under viewing platform on south east of Loch McNess, mounted on concrete pillar facing rocks on waterline under platform. Rakali scat, Freshwater mussels (opened and chewed), crayfish claw with incisor pattern found
Wetlands bridge	29/07/11- 03/08/11 05/08/11 – 17/08/11	S 31° 32' 34.8" E 115° 40' 39.36"	Under metal foot bridge to northwest of lake, attached to old wood pylon at southeastern side
Melalueca woodland	29/07/11 – 05/08/11	S31° 33' 35.53" E115° 40' 47.19"	Melaleuca woodland on northern side of Loch McNess, very little understory present
Ghosthouse 1	29/07/11- /06/08/11 09/09/11 – 24/10/11 14/11/11 – 28/11/11	S31° 32' 37.39" E115° 40' 37.2"	Tributary to northwest of Lake, mounted on Melaleuca in creek line, facing bank. Possible animal movement along bank edge
Ghosthouse 2	20/08/11 – 06/09/11 31/10/11 – 07/11/11	S31° 32' 35.66" E115° 40' 37.25"	Tributary to northwest of Lake, mounted on Melaleuca in creek line facing possible runnel on bank at northern end of wetland
Ghosthouse 3	20/08/11 – 06/09/11	S31° 32' 34.30" E115° 40' 37.60"	Tributary to northwest of Lake, mounted on fallen tuart tree at northern end of wetland
Lake Yonderup North	05/12/11 –12/12/11 19/12/11 – 10/01/12	S31° 33' 20.7" E115° 41' 11.8"	Mounted on star picket in water 1m from bank ,dense riparian vegetation
Lake Yonderup South	30/01/12 – 20/02/12	S31° 33' 33.9" E115° 41' 10.9"	Mounted on tree on banks of temporary tributary, facing west into wetland
Snake Island	19/12/11 - 05/01/12	S31° 32' 45.3" E115° 40' 56.7"	Small island adjacent to small boat jetties, mounted on star picket facing west across lake. Open fresh water mussels found in vicinity
Jetty	09/10/11 – 23/10/11 21/11/11 – 28/11/11 19/12/11 – 05/01/12	S31° 32' 49.2" E115° 40' 57.1"	Under large boat jetty on eastern edge of lake, mounted on pylon facing limestone wall

Main study - Camera trap locations

Loch McNess and Lake Yonderup were identified during the GSS study as being suitable habitat for target native animal species, with both Rakali and bush rats recorded in the vicinity of Loch McNess. Site selection in this study was influenced by sites that were in close proximity to water, the presence of dense understory, presence of potential feeding platforms and physical evidence of the presence of these species including scats and feeding remains. Logistical purposes were also taken into consideration, such as accessibility for personnel.

Camera traps were installed in both wetland and terrestrial sites at Loch McNess and Lake Yonderup, and sampled during summer (24 Feb-2 Mar 2012), autumn (8-17 May 2013), winter (20-30 June 2013) and spring (29 Oct-9 Nov 2012). In each of the wetland and terrestrial sites, nine camera trap locations were used (Figure 3, Table 3, Table 4). At Loch McNess there were six wetland and six terrestrial sites, and at Lake Yonderup there were three wetland and three terrestrial sites (Figure 3).

In the wetland sites, camera trap locations were chosen in the inundated wetland area (to target Rakali) (Figure 3, Table 3, Table 4). In the terrestrial sites, camera trap locations were chosen in the fringing vegetation immediately adjacent to the wetland but removed from the edge of the water (Figure 3, Table 3, Table 5). Due to technical issues it was not possible to have all cameras operational in each sampling period (Table 3).

The Lake Yonderup sites were located in or adjacent to a small pristine wetland which is perennial to the north but ephemeral at its southern periphery. The Loch McNess sites were located adjacent to a highly modified wetland and high usage walk trails. The area to the east of the loch is predominately a recreational area featuring irrigated lawns with natural vegetation to the north, west and south which is subject to impacts from weeds. The recreation area and walk trail receive high rates of visitation by tourists.

Table 3. Experimental design of the main study and the number of camera locations used in each season and site.

Site	Season	Number of camera locations in use
Wetlands	Summer	8
	Autumn	8
	Winter	9
	Spring	7
Terrestrial	Summer	9
	Autumn	9
	Winter	9
	Spring	9

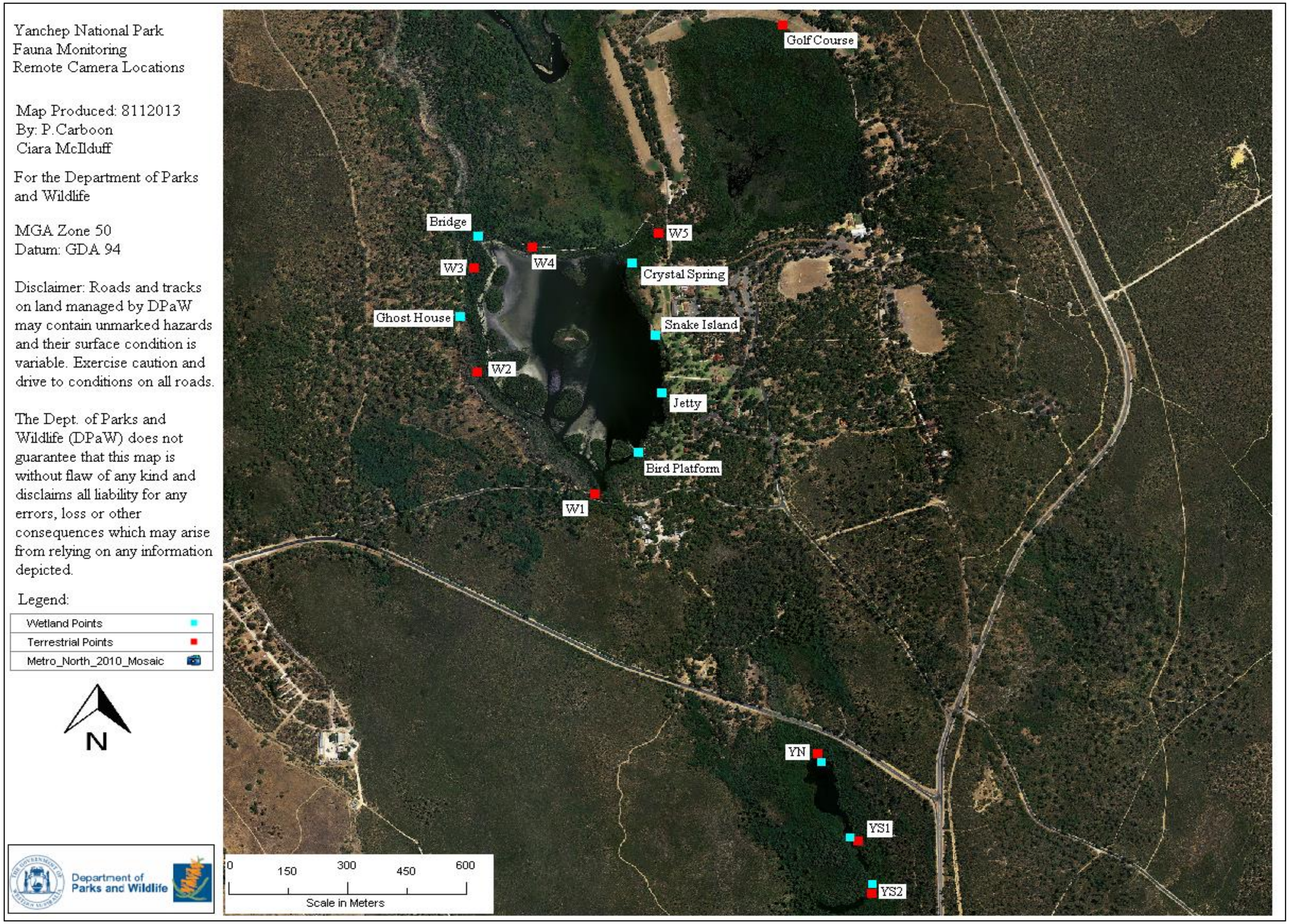

Figure 3. Location of terrestrial and wetland fauna monitoring sites using camera traps in the study area (Loch McNess to the north and Lake Yonderup to the south).

Table 4. Locations of camera trap sites in the wetland sites.

Site	GPS coordinates	Location description
Yonderup North (YN) (Entrance off Yanchep Beach Road)	S31° 33' 20.7" E115° 41' 11.8"	Mounted on star picket in water 1 m from edge, dense riparian vegetation.
Yonderup South 1 (YS1)	S31° 33' 33.9" E115° 41' 10.9"	Mounted on star picket 1 m from high water line, at northern end of temporary tributary, facing south into wetland.
Yonderup South 2 (YS2)	S31° 33' 34.1" E115° 41' 14.9"	Mounted on star picket 1 m from high water line, at southern end of temporary tributary, facing east bank.
Bird Watching Platform (Loch McNess South)	S31° 32' 51.1" E115° 40' 54.5"	Under viewing platform on south east of Loch McNess, mounted on concrete pillar facing rocks on waterline. Under platform Rakali scat found, freshwater mussels (opened and chewed), crayfish claw with incisor pattern.
Jetty (Loch McNess)	S31° 32' 49.2" E115° 40' 57.1"	Under large boat jetty on eastern edge of lake, mounted on pylon facing limestone wall.
Snake Island (Loch McNess)	S31° 32' 45.3" E115° 40' 56.7"	Small island adjacent to small boat jetties, mounted on star picket facing west across lake. Open fresh water mussels found in vicinity.
Crystal Spring (Loch McNess North)	S31° 32' 36.0" E115° 40' 57.3"	Major input for loch, continuous flowing water surrounded by dense riparian vegetation, situated between walk trail and road. Mounted on Agonis facing spring.
Bridge (Loch McNess NW)	S31° 32' 34.9" E115° 40' 39.5"	Under metal foot bridge to northwest of lake, attached to old wood pylon at southeastern side facing possible feeding platform, north-west aspect.
Ghost House	S31° 32' 36.4" E115° 40' 37.6"	Tributary to northwest of Loch McNess, mounted on *Melaleuca* in creek line, facing western bank.

Table 5. Locations of camera trap sites in the terrestrial sites.

Site	GPS coordinates	Location description
Yonderup North (YN)	S31° 33' 20.4" E115° 41' 11.4"	Mounted on Melaleuca in dense vegetation facing small clearing, 15m from high water mark.
Yonderup South1 (YS1)	S31° 33' 32.5" E115° 41' 09.5"	Mounted banksia tree, facing south in small clearing in dense vegetation, 10 m from high water mark.
Yonderup South 2 (YS2)	S31° 33' 34.5" E115° 41' 13.6"	Mounted on eucalypt open Eucalypt woodland adjacent to riparian vegetation, 50m from high water line.
Wetlands Walk Trail 1 (W1)	S31° 32' 55.6" E115° 40' 47.3"	Melaleuca, *Eucalyptus rudis* with dense understory of bracken fern and parrot bush, 10 m from walk trail, mounted on fallen Melaleuca, northern aspect.
Wetlands Walk Trail 2 (W2)	S31° 32' 43.6" E115° 40' 38.2"	Dense riparian vegetation, mounted 10 m from walk trail on Melaleuca, western aspect.
Wetlands Walk Trail 3 (W3)	S31° 32' 36.5" E115° 40' 38.6"	Dense riparian vegetation, mounted 5 m from walk trail on Melaleuca, eastern aspect.
Wetlands Walk Trail 4 (W4)	S31° 32' 35.2" E115° 40' 42.7"	Dense riparian vegetation, mounted on Melaleuca 2 m from track facing South-east.
Wetlands Walk Trail 5 (W5)	S31° 32' 17.0" E115° 40' 08.9"	Mounted in stand of Agonis trees adjacent to riparian vegetation, close proximity to walk trail and road.
Golf Course	S31° 32' 35.4" E115° 40' 57.3"	Small clearing in Banksia woodland adjacent to a winter stream on Third hole. Mounted on tree facing large log.

Data collection

Camera trapping

Two types of remote cameras were employed: Bushnell Trophy Cam and Reconyx Hyperfire (Figure 4). Remote cameras were used according to the guidelines set out in Department of Parks and Wildlife (previously the Department Environment and Conservation) Standard Operating Procedure 5.2 - Remote Operation of Cameras (DEC, 2011). Each site contained one camera and a bait/lure.

The wetland sites used a bait of sardines straight from the tin, and the terrestrial sites used universal bait made of sardines, oats and peanut butter rolled into balls.

Cameras were secured to a mature tree or star picket and positioned 0.2 – 1 metre above ground level. In some instances a small amount of vegetation was pruned to reduce false triggers from foliage movement. In most instances camera were set to default settings of 3 images per trigger with no time delay between triggers. During the preliminary study various settings were trailed to identify optimal settings for the main study. At the wetland sites cameras were mounted in or directly adjacent to the high water mark, and always within 1 metre of high water mark. At the terrestrial sites cameras were mounted between 5 and 20 metres from the high water mark.

Baits were placed 1-3 metres away from the camera and camera aspect varied between sites. The baits were smeared onto a log/branch line with the camera. Where possible the baits were placed in a small clearing to optimise the success of species identification.

Figure 4. A Reconyx camera set up at W2 camera location site (a) and a Bushnell camera set up at W1 camera location site (b).

The cameras were set up and calibrated on the first night and baits were set for four consecutive nights at the wetland sites and for four consecutive nights at the terrestrial sites, resulting in a total of 272 trap nights (128 trap nights for wetland sites and 144 trap nights for terrestrial sites). Trap nights differed between seasons: summer: 68 trap nights, autumn: 68 trap nights; winter: 72 trap nights; spring: 64 trap nights. The cameras were removed after four nights in order to recharge the batteries, swap memory cards and upload images. Due to the considerable number of images generated, false triggers, or images with no fauna present, were deleted. Species present on the remaining images were identified and data recorded into an excel spread sheet. Data recorded included date, time, camera, site number, species, confidence in ID, recorder and particular weather conditions.

Additional data recorded if possible included – age class of animal (adult, sub-adult, juvenile), sex, behaviour (e.g. consuming bait) and distinguishing features (e.g. loss of fur, markings). Species were identified using distinguishing features such as body size and shape, face shape and tail length.

A single visit (sighting) was defined as a recorded image of the animal at least 30 minutes apart from another recorded image of the same species. So for example, if an individual of the same species was recorded intermittently over an hour, this could result in a maximum of three visits (at 0 min, 30 min and 60 min). This arbitrary measure is considered an acceptable way to reduce the large number of images that may be generated using camera traps and is consistent with standard practice for this survey technique (DEC, 2011).

To facilitate comparisons between the number of visits between species and seasons the number of visits per 100 trap nights (number of visits/number of trap nights)*100) was calculated.

Interactions between individuals and species

Interactions between different species (interspecific interactions) and between individuals of the same species (conspecific interactions) were recorded at each site. Interactions were also classified as amicable interactions (behaviour that function to create or enhance bonds, or achieve mutual benefits between two or more animals, such as grooming) or agnostic interactions (behaviours that are aggressive, threatening or submissive, such as aggressive direct contact that aims to wound or challenge, or growling, lunging and submissive behaviour such as avoidance) (see Hill *et al*., 2014). This study defined a single interaction as when two or more individuals were captured together on the same image at least 30 minutes apart from another recorded image of the same combination of species. The dominant species of an interspecific interaction was defined as that species which excluded competing species from preferred habitat or territorial space (see Stokes *et al*., 2012).

Statistical analysis

An independent samples t-test was used to determine if there were significant differences for each species in the mean number of visits per 100 trap nights between wetland and terrestrial sites. A one-way ANOVA was used to determine if there were any significant differences between seasons in the mean number of visits per 100 trap nights for each species.

Results

Pilot study

Two native mammal species and three introduced mammal species were recorded during the 2011/12 pilot study, in addition to eleven identified native bird species (Table 6). Of the five mammal species that were recorded, *R. rattus* had the highest number of visits per 100 traps nights (8.5) with *H. chrysogaster* the second highest (7.0). *Vulpes vulpes*, *M. musculus* and *M. fuliginosus* had low number of visits per 100 trap nights (Figure 5).

Rattus rattus was recorded at three sites (Bird Viewing Platform, Ghost house 3 and Jetty), *V. vulpes* at two sites (Snake Island and Lake Yonderup South) and *H. chrysogaster* at two sites (Jetty and Bird Viewing Platform).

Table 6. Summary of visits from three seasons (winter, spring, summer) from the pilot study 2011/12. Visits = number of visits (with at least a 30 minute gap between events involving the same species). Sites = number of sites where species were sighted.

Mammals	**Visits**	**Sites**
Black rat *(Rattus rattus)*	23	3
Fox (*Vulpes vulpes)*	3	2
House mouse *(Mus musculus)*	1	1
Rakali *(Hydromys chrysogaster*)	19	2
Western grey kangaroo *(Macropus fuliginosus)*	2	1
Birds		
Australian white ibis *(Threskiornis molucca)*	20	2
Australian wood duck *(Chenonetta jubata)*	2	2
Bookbook owl *(Ninox novaeseelandiae)*	1	1
Carnaby's black cockatoo *(Calyptorhynchus latirostris)*	1	1
Great egret *(Ardea alba)*	8	1
Nankeen night heron *(Nycticorax caledonicus)*	6	1
Pacific black duck *(Anas superciliosa)*	248	5
Purple swamp hen *(Porphyrio porphyrio)*	46	7
Spotless crake *(Porzana tabuensis)*	9	1
Swamp harrier *(Circus approximans)*	3	2
Wedge-tailed eagle *(Aquila audax)*	1	1
Unidentified bird	2	2

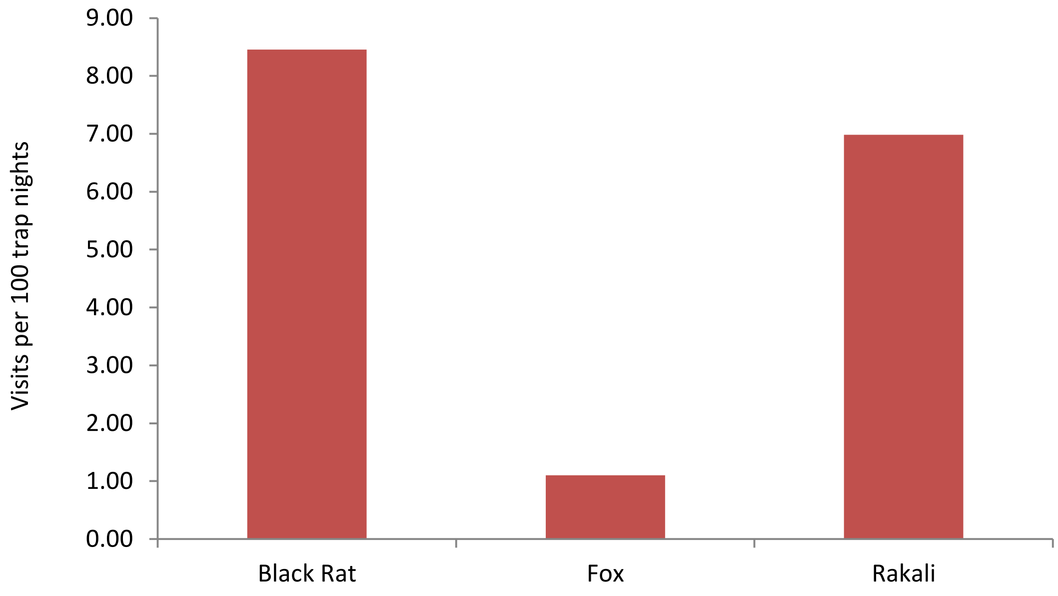

Figure 5. Number of visits per 100 trap nights of *Rattus rattus*, *Vulpes vulpes* and *Hydromys chrysogaster* during the 2011/12 pilot study.

Hydromys chrysogaster and *R. rattus* were captured in each of the three sampling periods (winter, spring, summer). The number of visits per 100 trap nights for *H. chrysogaster* was greatest in winter, followed by spring and the lowest number of visits was recorded in summer (Figure 6). *R. rattus* has the highest recorded visits per 100 trap nights in spring, then winter and the lowest number of visits in summer.

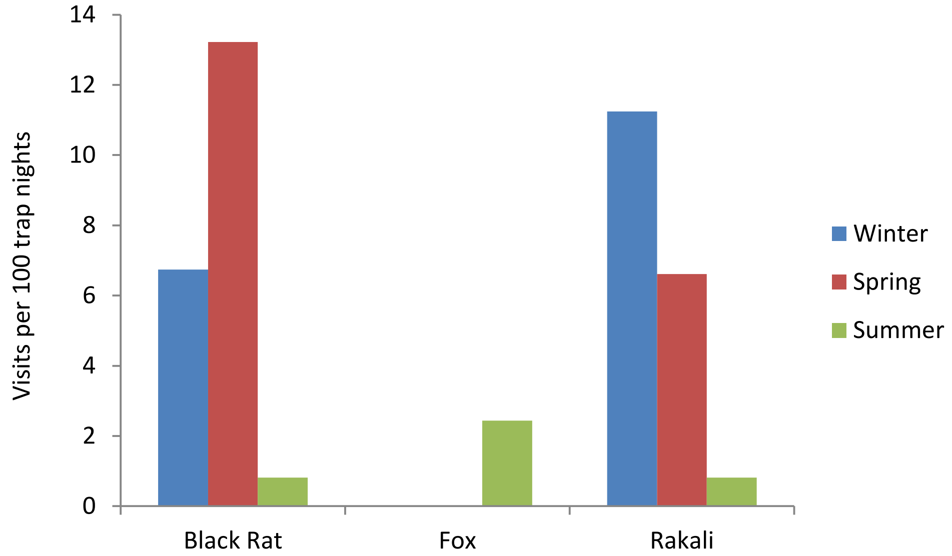

Figure 6. Number of visits per 100 trap nights of *Rattus rattus, Vulpes vulpes* and *Hydromys chrysogaster* to the 10 study sites in each season during the 2011/12 pilot study.

Main Study

Three native mammal species and four introduced mammal species were recorded during the 2012/13 main study, in addition to 15 identified native bird species and 2 reptile species (Table 7). *R. rattus* was the most abundant species with 341 total visits, followed by *R. fuscipes* with 243 recorded visits. *Rattus rattus* was present at all 18 sites in both wetland and terrestrial habitats during all four sampling periods, while *R. fuscipes* was present at 12 sites, at both habitats during all sampling periods (Table 7). The distribution of *V. vulpes* was also widespread, being recorded at 14 sites. *Hydromys chrysogaster* was recorded at six sites, a total of 24 times and was also recorded in both habitats and during all four sampling periods (Table 7, 8).

Table 7. Total number of sites (n = 18 sites total), target habitats (wetlands (W) and terrestrial (T)) where species were recorded during the 2012/13 main study.

Mammals	**Visits**	**Number of sites where recorded**	**Habitat**
Black rat (*Rattus rattus*)	341	18	W,T
Bush rat (*Rattus fuscipes fuscipes*)	243	12	W,T
Domestic cat (*Felis catus*)	57	7	W,T
Fox (*Vulpes vulpes*)	44	14	W,T
House mouse (*Mus musculus*)	100	9	W,T
Rakali (*Hydromys chrysogaster*)	24	6	W,T
Western grey kangaroo (*Macropus fuliginosus*)	8	3	W,T
Unidentified rodent species	145	13	W,T
Birds and reptiles	**Visits**	**Number of sites where recorded**	**Habitat**
Brown goshawk (*Accipiter fasciatus*)	1	1	W
Carnabys black cockatoo (*Calyptorhynchus latirostris*)	10	1	W
Fantail (*Rhipidura spp.*)	1	1	W
Grey fantail (*Rhipidura albiscapa*)	5	3	W,T
King's skink (*Egernia kingii*)	3	1	T
Little grass bird (*Megalurus gramineus)*	3	3	W,T
Native hen (*Tribonyx ventralis*)	17	1	W
Pacific black duck (*Anas superciliosa*)	12	4	W
Purple swamp hen (*Porphyrio porphyrio*)	49	6	W,T
Shingleback (*Tiliqua rugosa*)	4	3	T
Splendid fairy wren (*Malurus splendens*)	5	2	T
Spotless crake (*Porzana tabuensis*)	12	1	W
White breasted robin (*Eopsaltria Georgiana*)	8	3	T
White-browed Scrubwren (*Sericornis frontalis*)	2	2	T
White faced heron (*Egretta novaehollandiae*)	2	2	W
Willie wagtail (*Rhipidura leucophrys*)	1	1	W
Yellow billed spoonbill (*Platalea flavipes*)	1	1	W
Unidentifed skink species	8	2	T
Unidentified bird species	3	3	W,T

The occurrence of most target mammal species was concentrated in the terrestrial habitat, with the exception of *H. chrysogaster*, which was recorded at 5 wetland sites and 1 terrestrial site. *Rattus fuscipes* were recorded at 8 terrestrial and 4 wetland sites. *Mus musculus* was mostly recorded at terrestrial sites, while *V. vulpes* and *R. rattus* were recorded similarly at both wetland and terrestrial sites (Table 8).

In the same season, *R. rattus* and *R. fuscipes* were recorded at the same sites. In winter, *V. vulpes* was recorded at only one (wetland) site and *F. catus* was not recorded at all in winter. *Mus musculus* was not recorded at any sites in summer (Table 8).

Table 8. Summary of recorded images of target mammal species at the 18 study sites in the 2012/13 main study over four seasons (summer (S), autumn (A), winter (W), Spring (Sp)).

Site	***Hydromys chrysogaster***				***Rattus fuscipes***				***Felis catus***				***Mus musculus***				***Rattus rattus***				***Vulpes vulpes***			
	S	A	W	Sp	S	A	W	Sp	S	A	W	Sp	S	A	W	Sp	S	A	W	Sp	S	A	W	Sp
WETLAND SITES																					+	+		
Bird Watching Platform		+												+			+	+		+		+		
Ghost House Trail						+		+		+		+								+				
Crystal Spring			+	+				+																
Snake Island																			+	+	+	+		
Jetty			+												+		+	+	+			+		
Wetlands Bridge			+							+								+				+		
Yonderup South 1																		+			+			
Yonderup South 2						+		+												+	+			
Yonderup North	+	+	+		+												+						+	
																			+					
TERRESTRIAL SITES																								
Golf Course						+	+	+							+	+		+	+	+	+			+
Wetlands Walk trail 1										+							+		+	+	+			+
Wetlands Walk trail 2					+		+			+		+			+				+	+				
Wetlands Walk trail 3					+	+	+	+		+		+			+	+	+	+	+		+			
Wetlands Walk trail 4					+			+		+		+					+		+					
Wetlands Walk trail 5						+			+	+		+									+			
Yonderup South 1		+				+	+							+		+		+	+	+		+		+
Yonderup South 2					+		+	+						+	+	+	+		+	+	+			+
Yonderup North					+	+	+	+							+	+	+	+	+	+				
Total	**1**	**3**	**4**	**1**	**6**	**7**	**6**	**8**	**1**	**7**	**0**	**5**	**0**	**3**	**6**	**6**	**9**	**8**	**11**	**10**	**9**	**6**	**1**	**5**

Differences between terrestrial and wetland sites
There were a much greater number of visits per 100 trap nights for *R. fuscipes* at terrestrial sites (159 visits per 100 trap nights) than at wetland sites (10.9 visits/100 trap nights) (Figure 7(a)). In contrast, *H. chrysogaster* preferred wetland sites, with 18 visits/100 trap nights and only 0.7 visits/100 trap nights at terrestrial sites (Figure 7(a), Table 8).

There was a significant difference in the mean number of visits (per 100 trap nights) of *R. fuscipes* in wetland sites (M = 11.3, SE = 7.0) compared with terrestrial sites (M = 159.0, SE = 44.3); t = -3.3, p = 0.04) (Figure 7(b)).

Similar to *R. fuscipes*, all introduced mammal species were more common at terrestrial sites compared to wetland sites (Figure 8 (a), Table 8). *Rattus rattus* had the greatest number of visits of the introduced mammal species, with 140.3 visits per 100 trap nights to terrestrial sites and 108.6 visits per 100 trap nights to wetlands sites (Figure 8(a)).

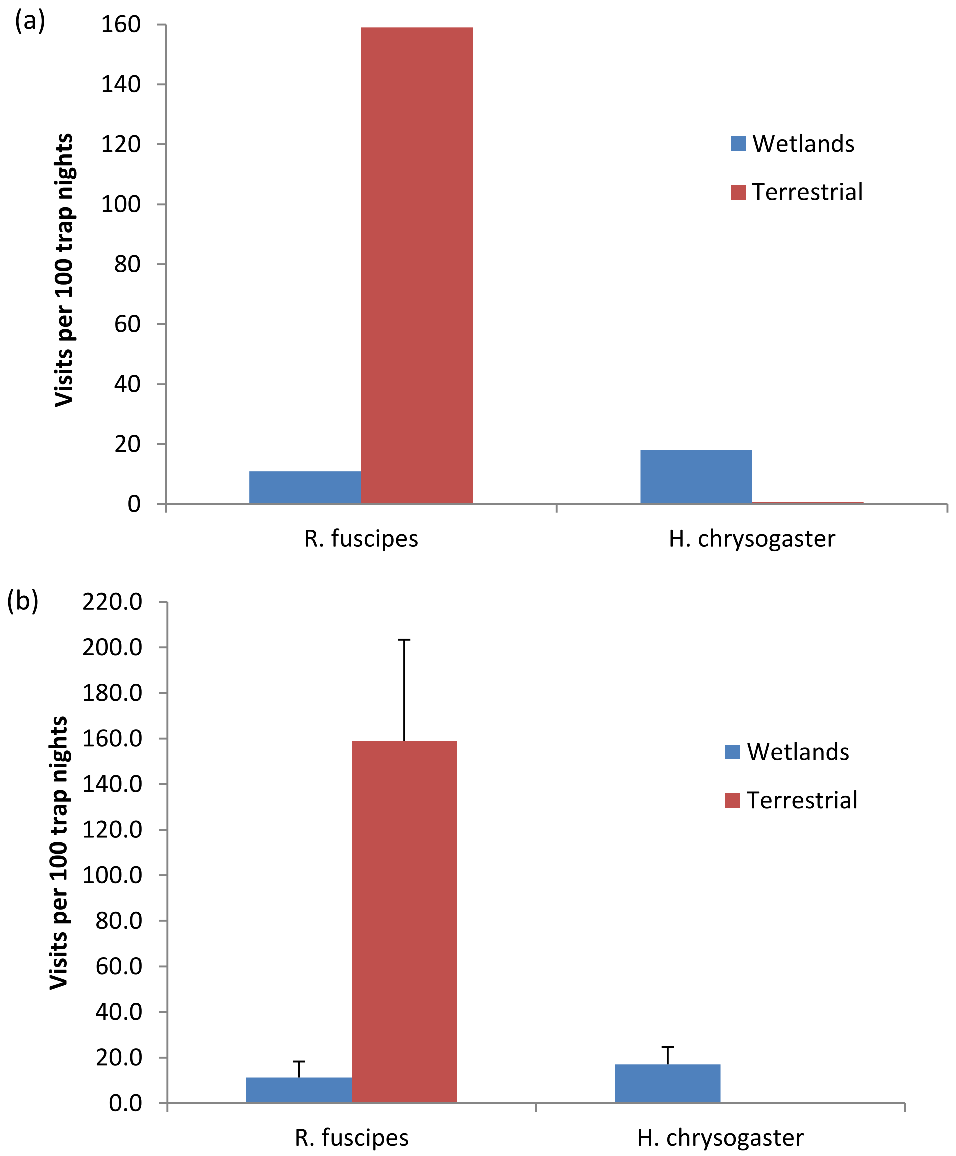

Figure 7. Total number (a) and mean (± SE) (b) of visits per 100 trap nights of *R. fuscipes* and *H. chrysogaster* to wetland sites (128 trap nights) and terrestrial sites (144 trap nights).

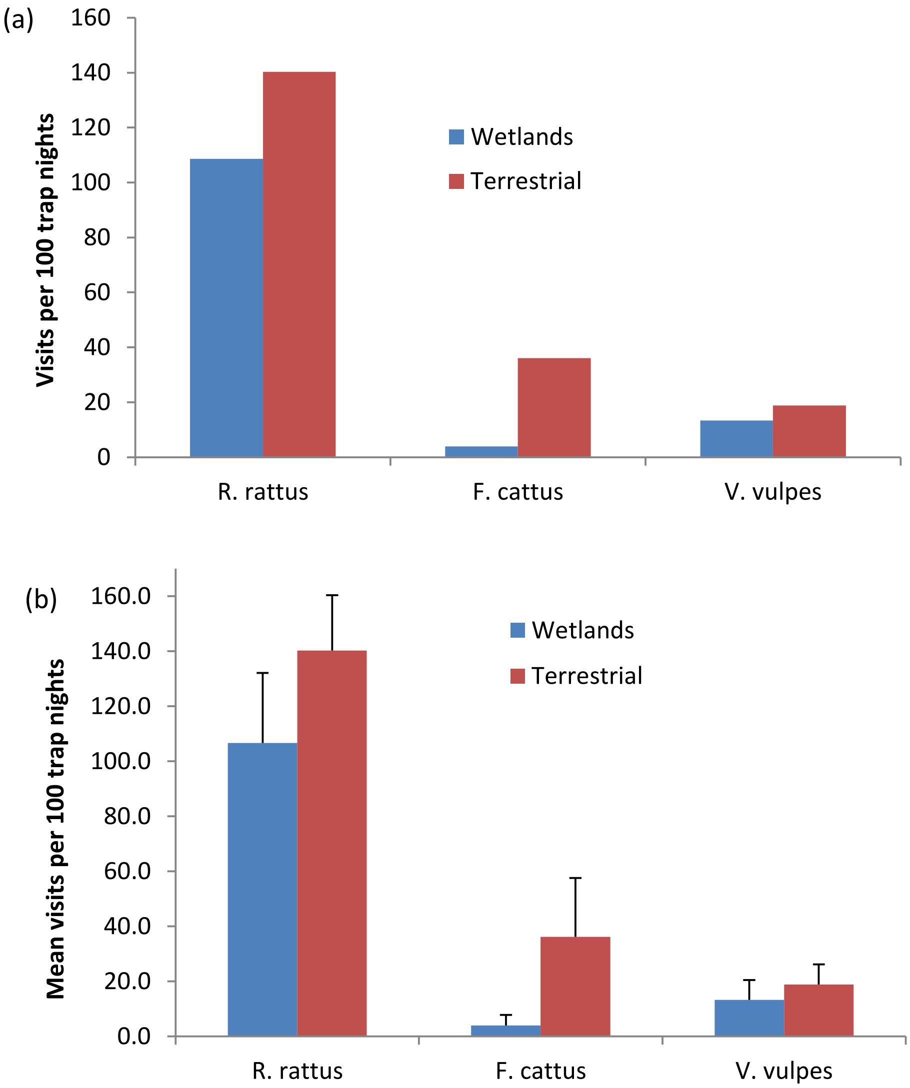

Figure 8. Total number (a) and mean (± SE) (b) of visits per 100 trap nights of *R. rattus*, *F. catus* and *V. vulpes* to wetland sites (128 trap nights) and terrestrial sites (144 trap nights).

Differences between seasons

When looking at differences between the four seasons, the number of visits (per 100 trap nights) by *Rattus fuscipes* to terrestrial sites were much lower during summer (10.6 visits per 100 trap nights) than during autumn, winter and spring (219.4, 216.7 and 169.4 visits per 100 trap nights, respectively) (Figure 9(a)). Visits to wetland sites were greatest for *R. fuscipes* in autumn (31.3 visits per 100 trap nights), followed by spring and summer; there were no records of *R. fuscipes* in winter for wetland sites.

There were no significant differences between seasons for the target species, with the exception of *V. vulpes* which had a significantly higher mean number of visits in autumn (M = 30.9, SE = 0.35) than in winter (M = 1.4, SE = 1.4); p = 0.69 (Figure 13(b)).

At wetland sites *Hydromys chrysogaster* were recorded the most during winter (36.1 visits per 100 trap nights) and autumn (21.9 visits per 100 trap nights) with few visits during summer and spring. While this species greatly preferred wetland sites, it was also recorded at terrestrial sites but only in autumn (2.8 visits per 100 trap nights) (Figure 10(a)).

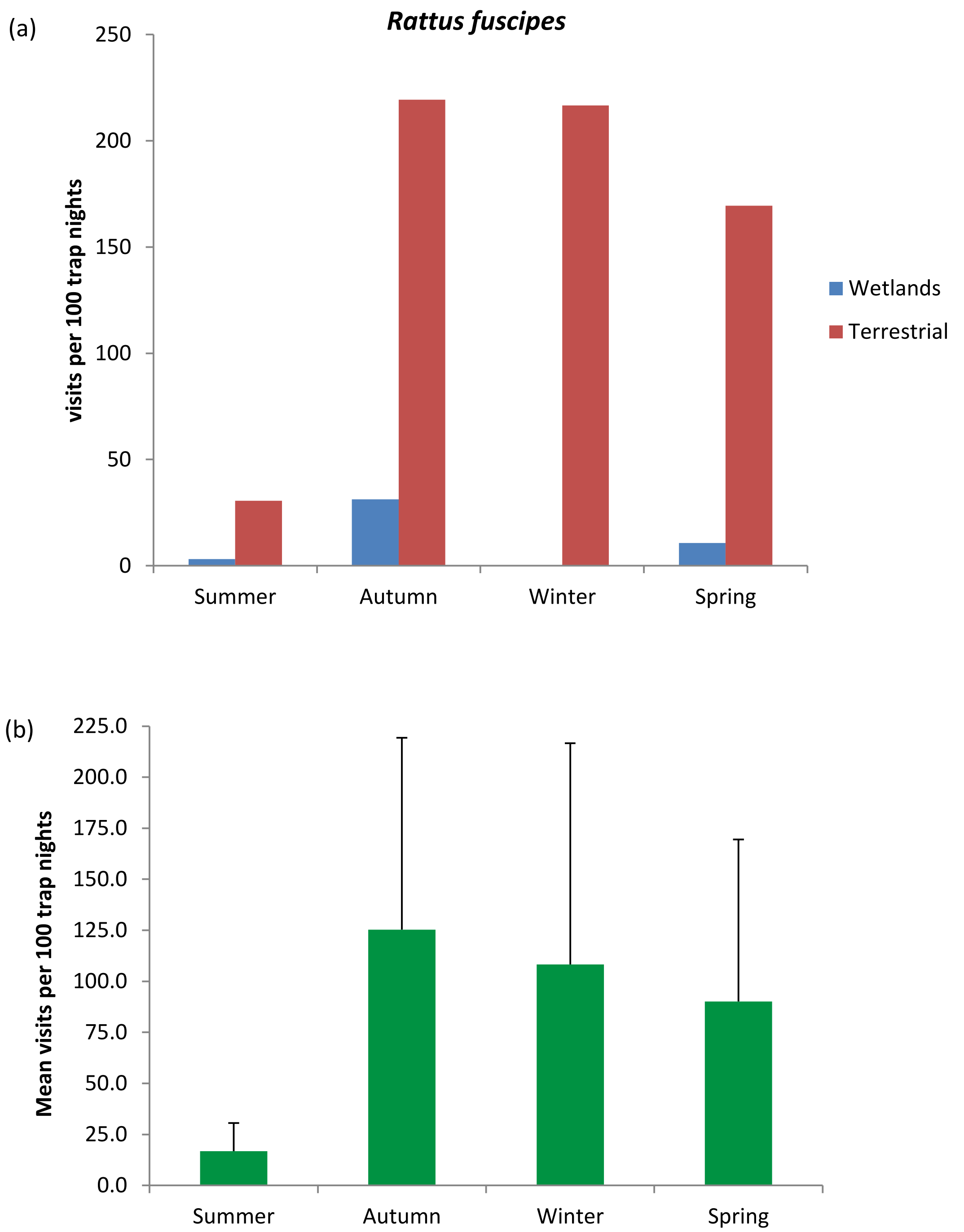

Figure 9. Total number (a) and mean (± SE) (b) of visits per 100 trap nights of *R. fuscipes* to wetland and terrestrial sites over four sampling periods (summer, autumn, winter and spring) during the 2012-2013 main study.

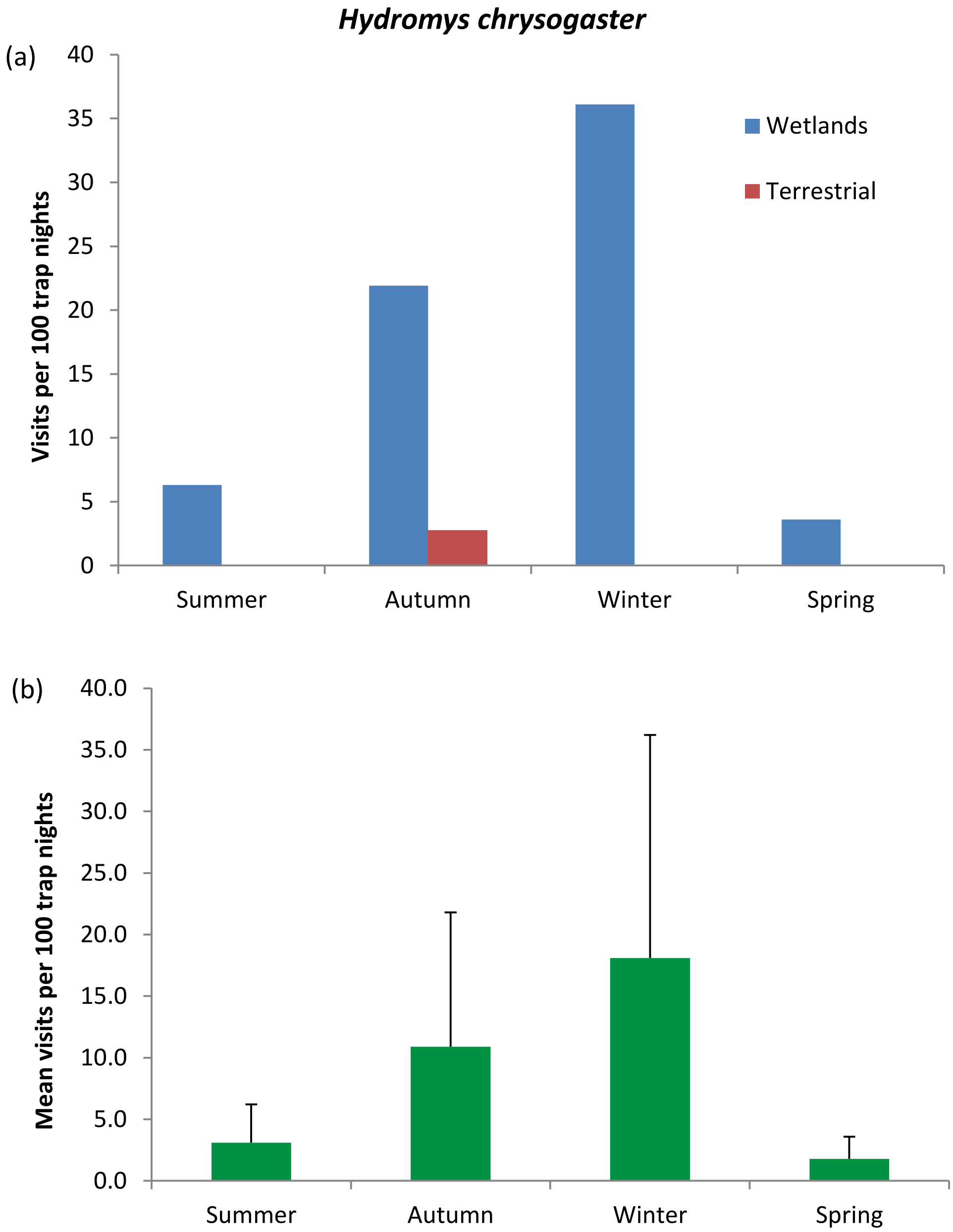

Figure 10. Total number (a) and mean (± SE) (b) of visits per 100 trap nights of *H. chrysogaster* to wetland and terrestrial sites over four sampling periods (summer, autumn, winter and spring) during the 2012-2013 main study.

Rattus rattus was the only species in the main study that was recorded in all four seasons for both terrestrial and wetland sites (Figure 11(a)). For three of the four seasons, *R. rattus* had a higher number of visits (per 100 trap nights) in the terrestrial sites. Only in autumn was there a greater number of captures in the wetland sites than the terrestrial sites. *Rattus rattus* had the highest number of visits per 100 trap nights in winter compared to the other introduced species.

Felis catus was not recorded in winter for both terrestrial and wetland sites, and was not recorded in summer at wetland sites. In autumn, *F. catus* was captured six times more at the terrestrial sites as compared to the wetland sites (Figure 12(a)).

In winter, the number of visits to terrestrial and wetland sites were very low by *V. vulpes* in winter (Figure 13(a)). *Vulpes vulpes* had the highest number of visits (per 100 trap nights) in autumn for both terrestrial and wetland sites (30.6 and 31.3 respectively), followed closely by terrestrial sites in summer. It was not recorded in wetland sites in spring, but was for terrestrial sites (13.9 visits per 100 trap nights).

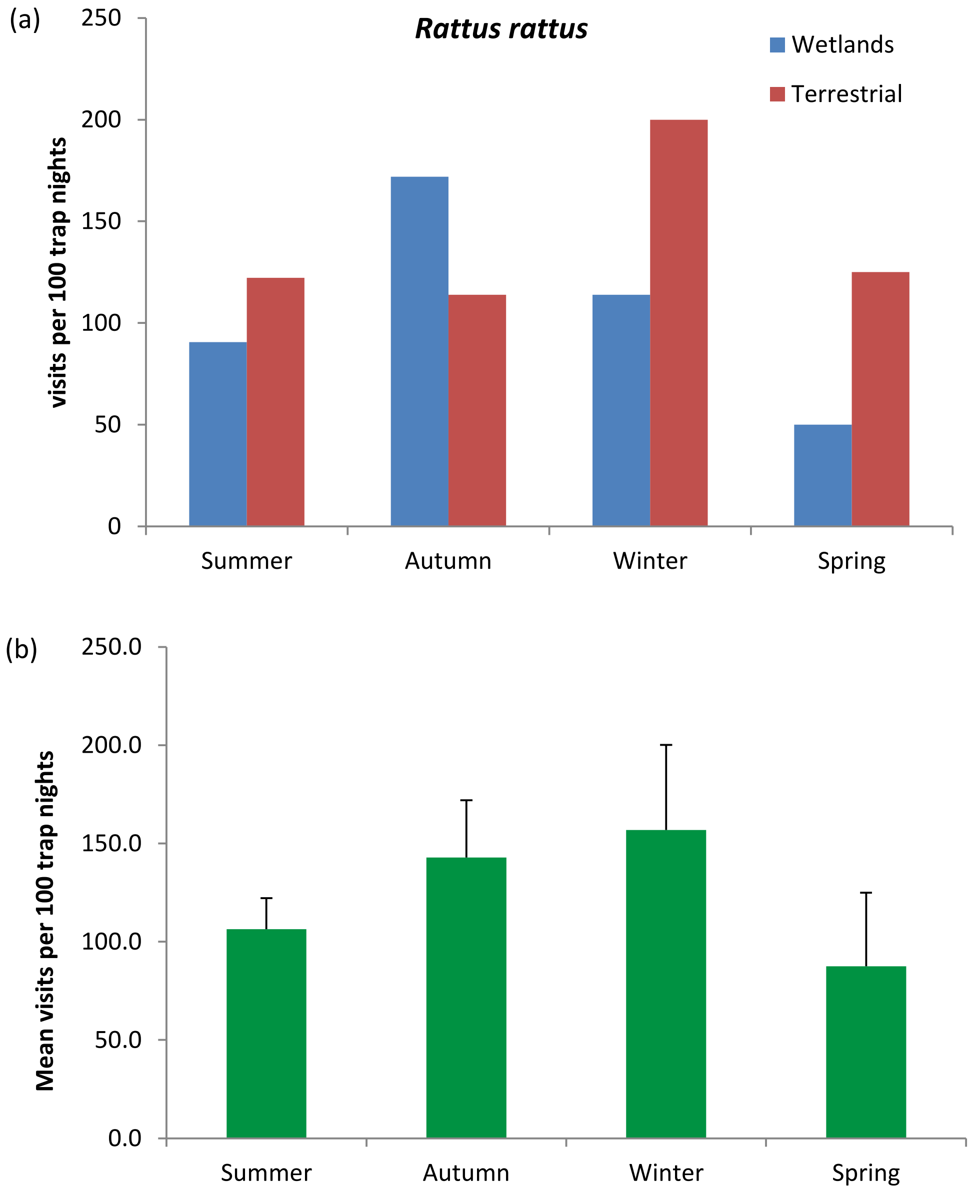

Figure 11. Total number (a) and mean (± SE) (b) of visits per 100 trap nights of *R. rattus* to wetland and terrestrial sites over four sampling periods (summer, autumn, winter and spring) during the 2012-2013 main study.

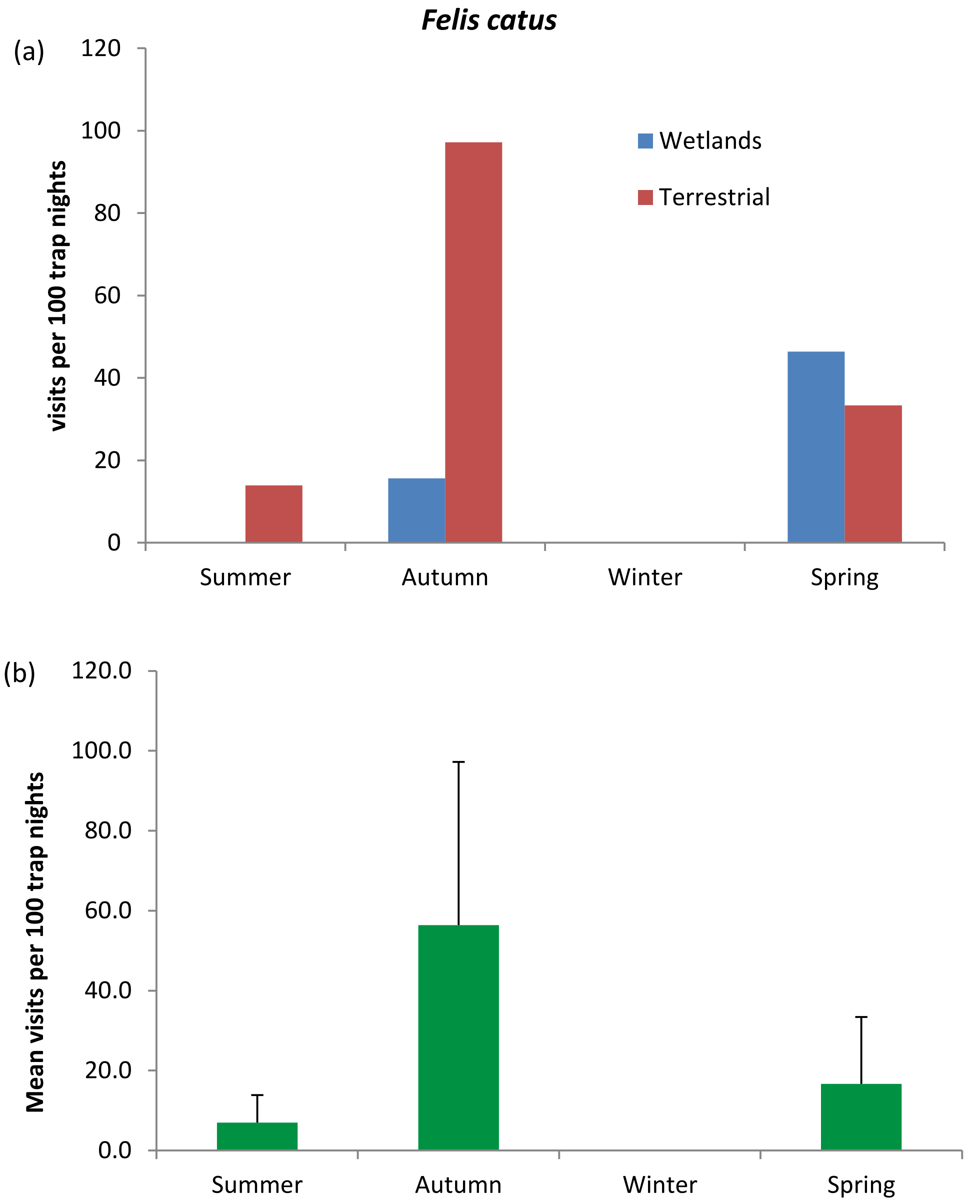

Figure 12. Total number (a) and mean (± SE) (b) of visits per 100 trap nights of *F. catus* to wetland and terrestrial sites over four sampling periods (summer, autumn, winter and spring) during the 2012-2013 main study.

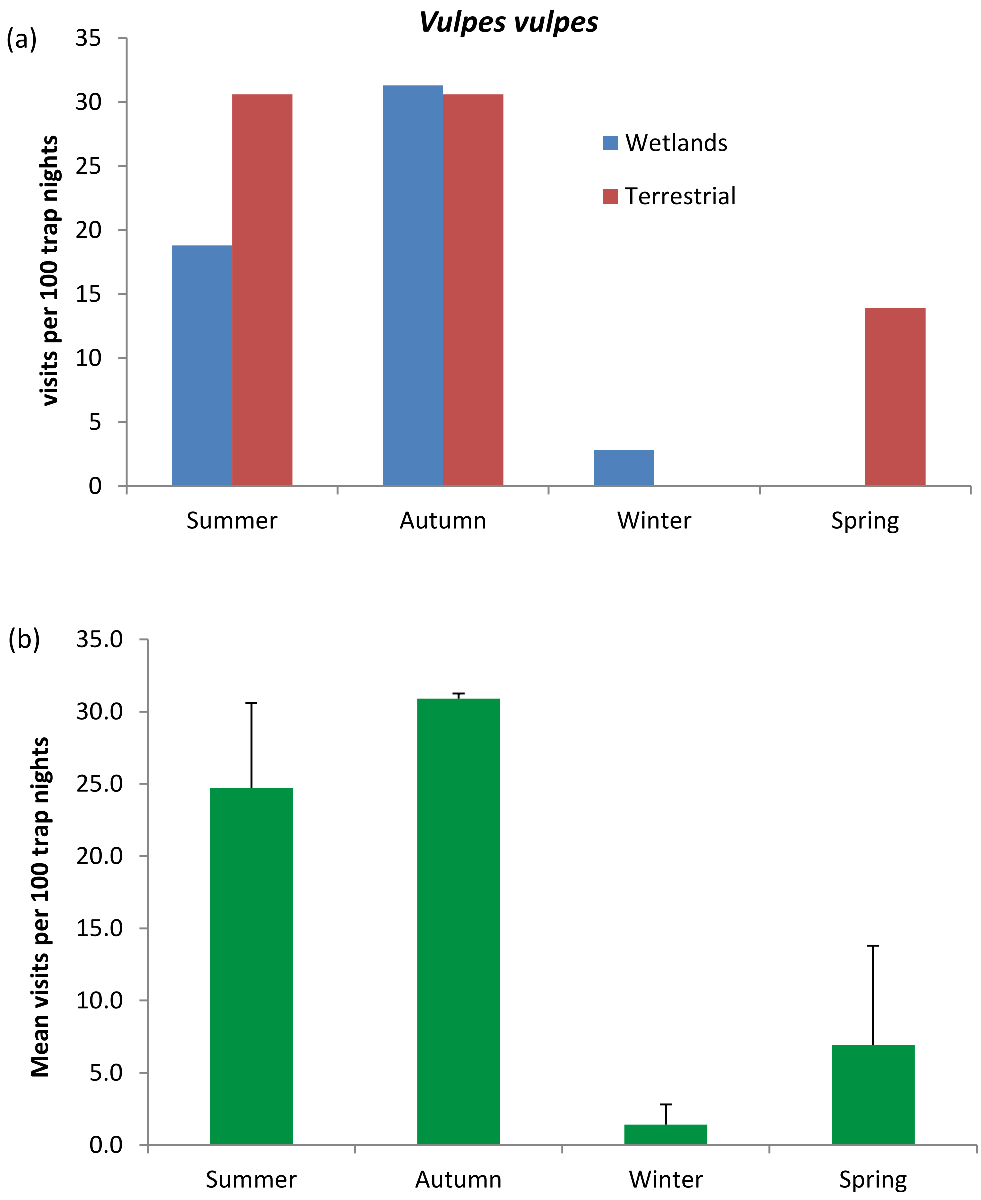

Figure 13. Total number (a) and mean (± SE) (b) of visits per 100 trap nights of *V. vulpes* to wetland and terrestrial sites over four sampling periods (summer, autumn, winter and spring) during the 2012-2013 main study.

Differences between individual sites

Of the terrestrial sites, Yonderup South 1 was the only site visited by *H. chrysogaster*, with the highest number of visits (per 100 trap nights) by *R. fuscipes* to Yonderup North, Wetlands 3 and the Golf course (Figure 14). Of the wetland sites, Yonderup South 1 had the highest total visits (per 100 trap nights) by *H. chrysogaster.* Ghosthouse trail was the site visited most frequently by *R. fuscipes* (Figure 15).

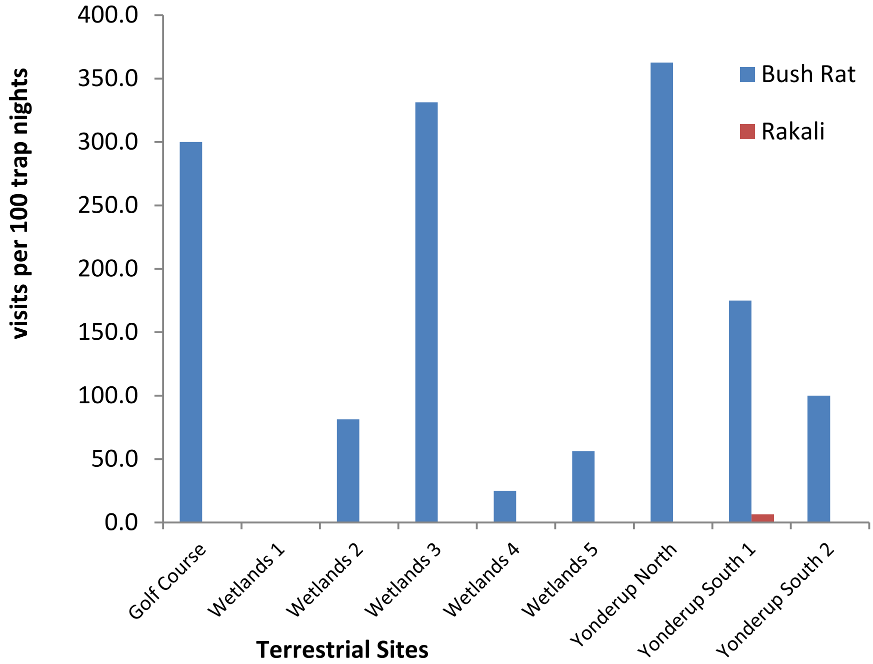

Figure 14. Number of visits per 100 trap nights of *R. fuscipes and H. chrysogaster* to the nine terrestrial sites during the 2012-2013 main study.

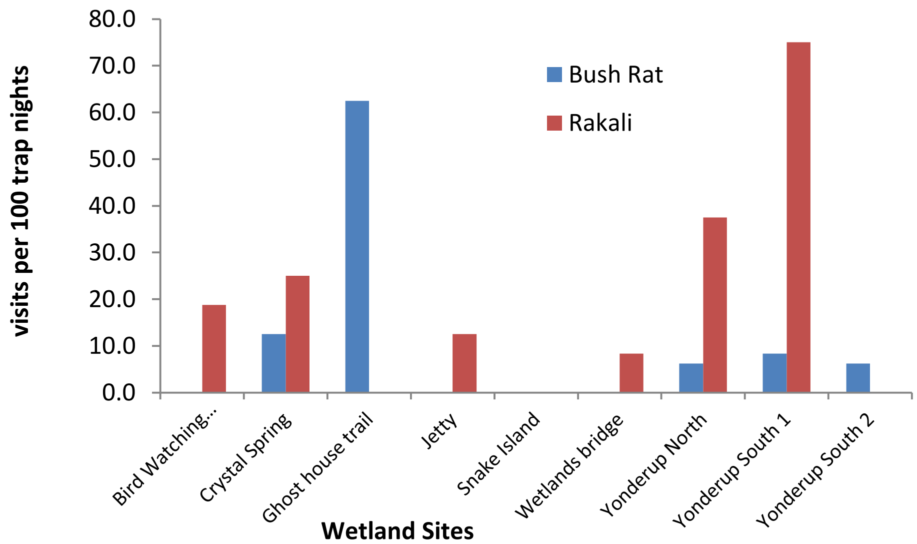

Figure 15. Number of visits per 100 trap nights of *R. fuscipes and H. chrysogaster* to the nine wetland sites during the 2012-2013 main study.

Of the terrestrial sites, Yonderup South 2 and Yonderup North were the sites with the highest number of visits (per 100 trap nights) by *R. rattus*. *Felis catus* was recorded only at the five Wetlands Walk trail sites, with the highest total number of visits recorded at Wetlands 5 (Figure 16). Jetty, Yonderup South 2 and Bird Watching Platform were the wetland sites where *R. rattus* were most often recorded (Figure 17). Ghosthouse trail was the only wetland site were all three target introduced animals were recorded (Figure 17), whereas three terrestrial sites (Wetlands 1, Wetlands 3, Wetlands 4) were visited by all three introduced animals (Figure 16). Of all individual sites, Snake Island, Wetlands 1, Wetlands 4 and Wetlands 5 received highest total number of visits by *V. vulpes* (Figure 16, 17).

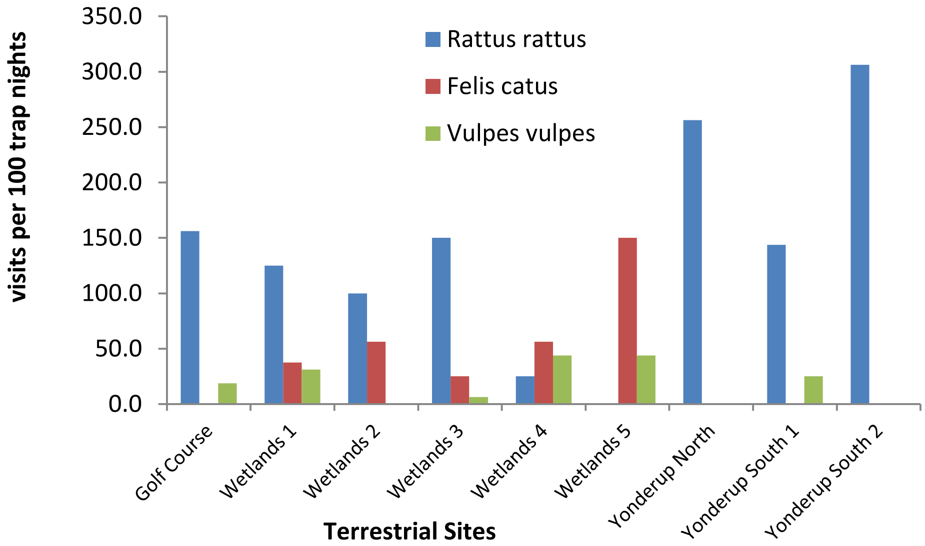

Figure 16. Number of visits per 100 trap nights of *R. rattus, F. catus* and *V. vulpes* to the nine terrestrial sites during the 2012-2013 main study.

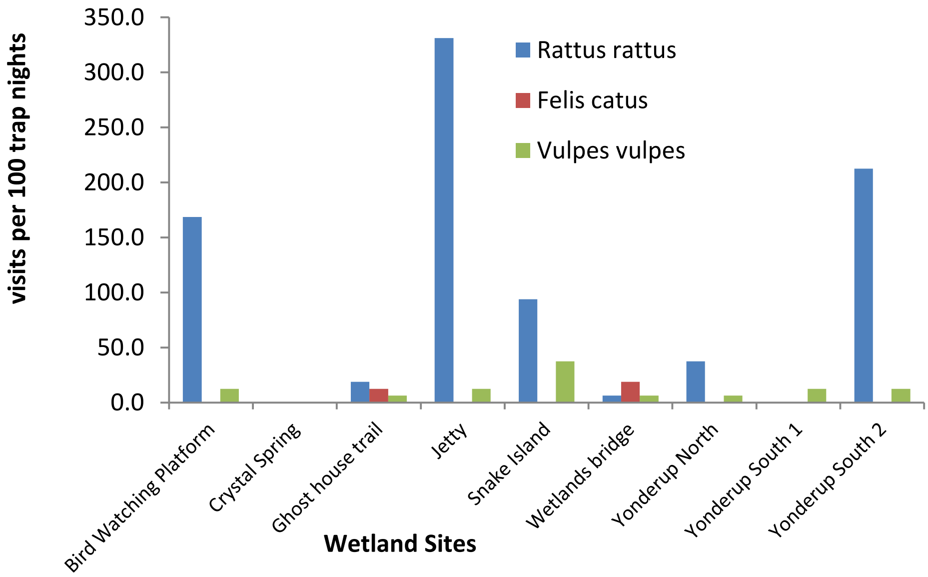

Figure 17. Number of visits per 100 trap nights of *R. rattus, F. catus* and *V. vulpes* to the nine wetland sites during the 2012-2013 main study.

Interactions between individuals and species

Conspecific interactions

A total of 40 conspecific interactions were recorded during the main study (Table 9). Interactions occurred when two or more mammal species were captured foraging or feeding together. Most conspecific interactions occurred during autumn and winter and at terrestrial sites, with the exception of three *R. fuscipes* interactions, which occurred during spring and three *R. rattus* interactions which occurred during spring and summer. Of the 40 recorded interactions, the majority of interactions (25) occurred at sites situated at Lake Yonderup. Conspecific interactions occurred at 10 of the 18 study sites.

Rattus fuscipes were recorded interacting on 15 occasions during autumn, spring and winter, and a family group of three was recorded at the terrestrial site Yonderup North in winter (Table 9, Figure 18(a)). This site had the highest number of bush rat interactions (8). Eighteen *R. rattus* interactions were recorded during all four seasons, including a family group of three individuals observed at the wetlands site Yonderup South 1 during the autumn survey (Table 9, Figure 18(b)). Yonderup South 1 recorded the highest number of *R. rattus* interactions. A pair of *H. chrysogaster* was recorded swimming and foraging at the wetlands site Yonderup North during the autumn and winter surveys (Table 9, Figure 18(c)).

Interspecific interactions

Six interspecific interactions between *R. fuscipes* and *R. rattus* were recorded (Table 10, Figure 18(d)). All observed interspecific interactions were agonistic and occurred at the terrestrial sites during winter and summer. Interspecific interactions were recorded at four of the eighteen study sites, and five of the six interactions occurred at sites situated at Lake Yonderup. Table 10 includes a brief description of each interaction and identifies the agonistic behaviours observed, including aggressive direct contact, lunging and submissive avoidance. *Rattus rattus* was the dominant species in four of the interactions, with *R. fuscipes* excluded from the site immediately following each interaction. In one of the interactions *R. fuscipes* was dominant, and the outcome of the last interaction was unclear as both individuals disappeared from the site simultaneously. However, it was observed that the *R. rattus* individual returned to the site first suggesting that it was the dominant species in this interaction.

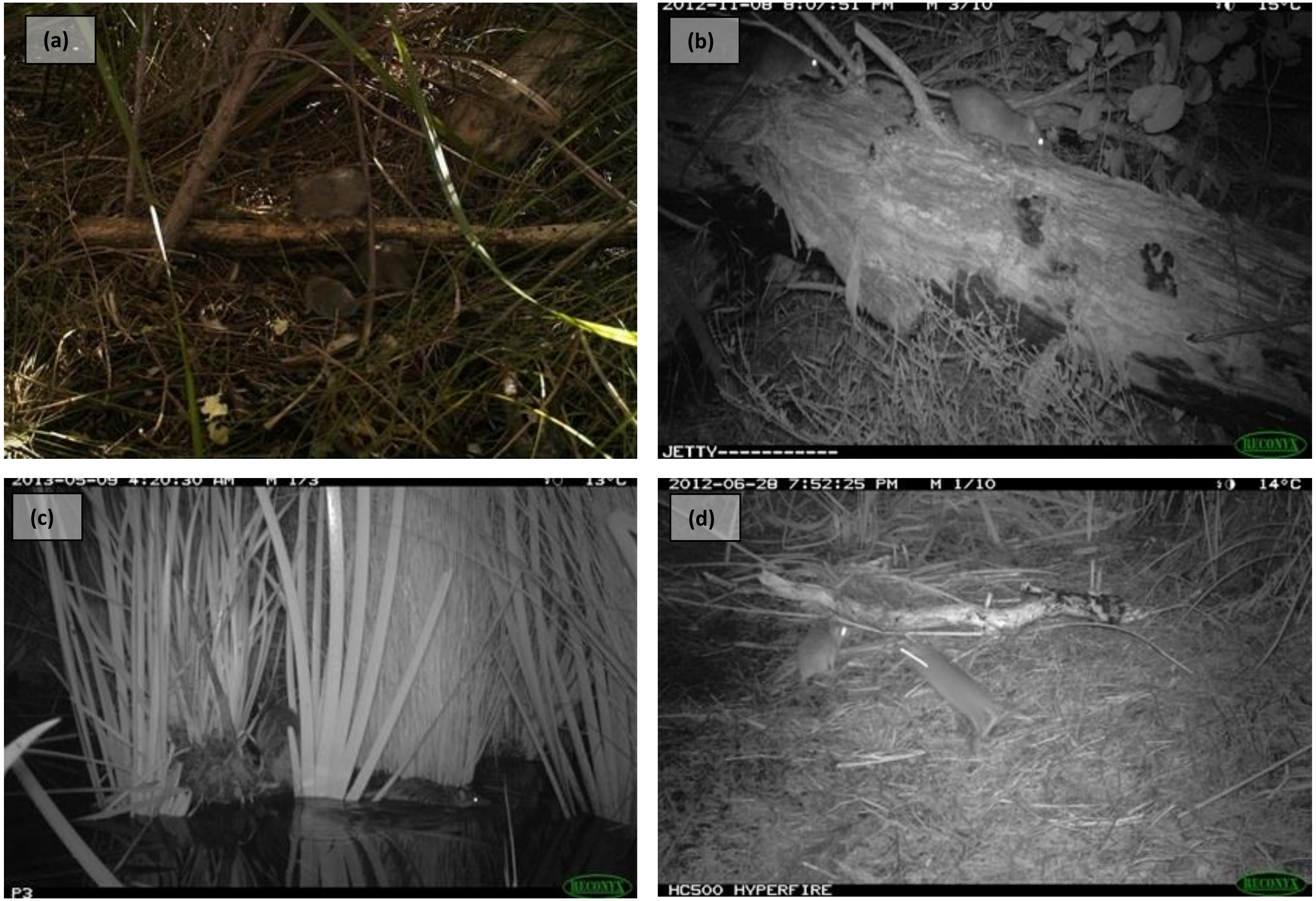

Figure 18. Images of interactions between: (a) three *R. fuscipes*, (b) two *R. rattus, (c)* two *H. chrysogaster*, and (d) *R. rattus* and *R. fuscipes*.

Table 9. Summary of 40 conspecific interactions between target mammal species at the 18 study sites during the 2012/13 main study.

Species	Season	Habitat	Site	Number of interactions	Number of individuals
R. fuscipes	Autumn	Terrestrial	Yonderup South 1	3	2
	Autumn	Terrestrial	Golf course	1	2
	Autumn	Terrestrial	Yonderup North	2	2
	Spring	Terrestrial	Wetlands Walk Trail 3	2	2
	Spring	Terrestrial	Yonderup North	1	2
	Winter	Terrestrial	Golf course	1	2
	Winter	Terrestrial	Yonderup North	5	2 (4 sightings); 3(1 sighting)
TOTAL				**15**	
R. rattus	Autumn	Terrestrial	Yonderup North	1	2
	Autumn	Wetlands	Yonderup South 1	7	2 (6 sightings); 3 (1 sighting)
	Spring	Terrestrial	Wetlands Walk Trail 1	1	2
	Summer	Terrestrial	Wetlands Walk Trail 3	1	2
	Summer	Terrestrial	Yonderup South 2	1	2
	Winter	Terrestrial	Yonderup South 2	2	2
	Winter	Terrestrial	Yonderup North	1	2
	Winter	Wetlands	Jetty	4	2
TOTAL				**18**	
F. catus	Autumn	Terrestrial	Wetlands Walk Trail 5	4	2 (kittens)
TOTAL				**4**	
M. musculus	Winter	Terrestrial	Wetlands Walk Trail 2	1	2
TOTAL				**1**	
H. chrysogaster	Autumn	Wetlands	Yonderup North	1	2
	Winter	Wetlands	Yonderup North	1	2
TOTAL				**2**	

Table 10. Summary of recorded images of interspecific interactions between *R. fuscipes* and *R. rattus* at the 18 study sites during the 2012/13 main study.

Season	Habitat	Site	Description of Interaction	Dominant Species
Winter	Terrestrial	Yonderup North	*R. fuscipes* forages prior to entrance of *R. rattus*; *R. fuscipes* retreats and repeatedly approaches bait and retreats displaying submissive avoidance behaviour, while *R. rattus* stands ground and continues to feed. Both individuals return intermittently to sight through the night.	*R. rattus*
Winter	Terrestrial	Yonderup South 1	*R. rattus* forages when *R. fuscipes* appears to chase off *R. rattus*; *R. fuscipes* returns about 1 hour later.	*R. fuscipes*
Winter	Terrestrial	Wetlands Walk Trail 3	*R. fuscipes* forages when *R. rattus* approaches *R. fuscipes* with aggressive lunging, the two individuals interact and fight on five occasions with *R. fuscipes* retreating to the undergrowth after each interaction. *R. rattus* remains at the site.	*R. rattus*
Summer	Terrestrial	Yonderup North	*R. rattus* presents first, *R. fuscipes* enters and fighting occurs; *R. fuscipes* retreats to undergrowth, *R. rattus* remains at site.	*R. rattus*
Summer	Terrestrial	Yonderup South 2	*R. rattus* is feeding, *R. fuscipes* approaches twice but retreats on both occasions. *R. fuscipes* returns 27 minutes later and moves lure and continues to feed for 15 minutes.	*R. rattus*
Summer	Terrestrial	Yonderup South 2	*R. rattus* forages as R. fuscipes approaches and fighting occurs; both individuals disappear from the site. *R. rattus* returns to the site after 20 minutes.	Unclear

Discussion

This study has contributed important information to the knowledge of the distribution of several native and introduced species on the Swan Coastal Plain, including *H. chrysogaster* and *R. fuscipes*.

Previous studies have recorded *H. chrysogaster* at Loch McNess (the GSS study), however this study has provided the first recording of *H. chrysogaster* at Lake Yonderup. These results highlight the importance of Lake Yonderup for this species, which is highly dependent on permanent water bodies. Studies should be implemented to increase our understanding of threats to Lake Yonderup and guide conservation management efforts in order to maintain its current condition.

Historically *R. fuscipes* have only been recorded sporadically across the SCP (Kitchener *et al*., 1978; Reaveley, 2009; Valentine *et al*., 2009; Wilson *et al*., 2012). The highest density recorded for the GSS study was in wetland vegetation at Loch McNess (Valentine *et al*., 2009). These findings are supported by results from this study as *R. fuscipes* was recorded at Loch McNess. This study also provides new information that *R. fuscipes* is also present at Lake Yonderup.

There have only been a few historical captures of *I. obesulus fusciventer* in Yanchep National Park, with Burbidge and Rolfe (Burbidge and Rolfe, unpublished data) recording the species in their 1987-88 survey and a more recent capture in 2011 (Moore, 2011). Similar to the GSS study, *I. obesulus fusciventer* was not recorded in this study at Loch McNess, nor was it recorded at Lake Yonderup. This species has been declining in numbers in the last 40 years and it appears to be sparsely distributed on the northern SCP. Given that it prefers dense low vegetation that is associated with wetter riparian areas, it is surprising that it was not captured in this study. Perhaps this is a reflection that the vegetation surrounding Loch McNess and Lake Yonderup is not dense enough. Perhaps also numbers are low enough that capture rates, via live-trapping or remote camera trapping, are just not adequate for detecting this species.

Introduced species found in this study were *R. rattus*, *V. vulpes*, *F. catus* and *M. musculus. Rattus rattus* was the most abundant species sighted, though the possibility of counting the same individual repeatedly needs to be taken into account. In the GSS study only 5 individuals were captured at Loch McNess whereas in this camera trapping study there were more than 359 sightings of *R. rattus*, however a direct comparison is not possible as this study was not able to record numbers of individuals of any species. The bait used during this study could have changed natural behaviour patterns of animals and influenced trapping rates (DEC, 2011).

There was a large number of unidentified species recorded in this study, mostly due to technical issues when using camera trapping, as well as a lack of expertise in species identification.

Main study

Differences between terrestrial and wetland sites

Most of the target mammal species in this study appeared to prefer terrestrial habitat, as there were greater number of visits per 100 trap nights recorded in the terrestrial sites. *R. fuscipes* showed a preference for terrestrial sites as there were a significantly higher number of mean visits per 100 trap nights to the terrestrial sites than to the wetland sites. *Rattus fuscipes* has a preference for dense understorey habitat / ground cover (Lunney, 1995) and wetland sites, which are situated close to the water, may be too wet and not have provided enough dense habitat for protection and food resources. This is further supported as the greatest number of visits by *R. fuscipes* to wetland sites occurred during autumn, when the lake water levels were lowest, with water contracting and exposing supplementary protection and possible food sources. This is particularly evident at the Ghost house Trail site (the wetlands site most preferred by this species) which contains no visible surface water by autumn and contains numerous fallen trees and dense low vegetation growth, which may provide protection not present at other times.

A study conducted in New South Wales found that *R. rattus* also preferred habitat with greater amounts of litter cover and forest habitat rather than open habitat with little litter cover, as it provided for food resources and protection from predators (Cox *et al*., 2000). In this study, a strong habitat preference was not displayed by *R. rattus* as it was recorded fairly equally in both terrestrial and wetland sites. This shows that *R. rattus* is less restricted in habitat utilisation than *R. fuscipes*. Also there is a possibility that *R. rattus* outcompetes *R. fuscipes* in the wetland habitat.

In contrast to the other species was *H. chrysogaster*, which had a preference for wetland sites and was only recorded at one terrestrial site. We would expect *H. chrysogaster* to prefer wetland sites given the species' reliance on water for its habitat and feeding requirements.

Differences between seasons

Several species were recorded in lower numbers in summer (*H. chrysogaster*, *R. fuscipes*, *F. catus*), but *R. rattus* and *V. vulpes* were recorded in high numbers in summer. *Rattus rattus* was recorded in all seasons in the main study in both terrestrial and wetland habitat, indicating that it is a very resilient species.

In both the pilot and main study, *H. chrysogaster* was recorded in highest numbers in winter (and autumn in the main study), with low numbers in summer and spring. This could be a reflection of the higher rainfall levels in autumn and winter, which would provide more suitable habitat and higher water levels of the Loch. It is unclear whether they retract to other areas or experience a population decline during the drier seasons. In addition, although breeding can occur throughout the year, most litters are born between spring and late summer (Olsen, 1995). With young suckling for four weeks and remaining with the mother for up to another four weeks (Olsen, 1995), the low numbers of *H. chrysogaster* in spring and summer may be a reflection of females with young restricting their movements and the length of time that they spent out foraging for food. The changing nature of Loch McNess, and the continual presence, even in low numbers, of *H. chrysogaster* at wetland sites which contain no surface water for extended periods of the year, suggests that this species may be adapting to impacts of declining water levels and increasing its dependence on non-aquatic food sources. Indeed, Smart *et al*. (2011) suggested that there are inconsistencies in the literature about the permanency of water that *H. chrysogaster* requires, ranging from *H. chrysogaster* being able to survive on dry land to it requiring permanent water (see references in Smart *et al*., 2011).

Simultaneous use of wetland habitat by *H. chrysogaster* and introduced predators indicates a potential threat of predation to this species. The highest number of visits per 100 trap nights to wetland sites by *H. chrysogaster* was recorded in autumn and winter. The highest mean visitation to wetland sites by *V. vulpes* occurred during autumn, and autumn is the only season that *F. catus* was captured at wetland sites. This timing also coincides with a likely dispersal of juvenile *H. chrysogaster* from parents after weaning in summer (Olsen, 1995). This indicates that late summer/ early autumn could be an optimal time to target predator control in order to reduce predation threats to *H. chrysogaster*. *Hydromys chrysogaster* has a low reproductive output compared to other rodent species and effective predator control measures at this time may be vital, as even low levels of predation on offspring may have a critical impact on the population (Smart *et al*., 2011).

Rattus fuscipes was recorded in very low numbers in summer (in the terrestrial and wetland sites) compared to the other seasons, which may be due to breeding in spring and summer. *Rattus fuscipes* can breed throughout the year, but tends not to breed in winter (Lunney, 1995; White *et al*., 1996). In South Australia White *et al*., (1996) found that there was a seasonal pattern in breeding activity for *R. fuscipes* with the production of young in spring and summer (October-February) with a peak in December. In autumn there can be a heavy mortality of individuals that have been sexually active during the previous 6-8 months (Lunney, 1995), however this was not the case in our study as autumn had the highest number of visits per 100 trap nights.

Simultaneous use of terrestrial habitat by *R. fuscipes* and introduced species indicates a potential for risk of predation by *F. catus* and *V. vulpes*, which may increase during autumn and spring as reflected by high visitation rates during these seasons by these three species. Results suggest that interactions between *R. fuscipes* and *R. rattus* may occur during autumn, winter and spring in terrestrial habitat when these species occupy the same habitat/niche simultaneously. However, recorded interactions between these species occurred during winter, as predicted, and summer when visitation to terrestrial sites by R. fuscipes was lowest (Table 10).

Differences between individual sites

All of the wetland sites where *H. chrysogaster* was recorded (Bird Watching Platform, Crystal Spring, Jetty, Bridge, Yonderup North and Yonderup South 1) are important sites for conservation of this species, especially the three wetlands sites at Lake Yonderup (Figure 3). The sites with the greatest chance of competition / interaction between *H. chrysogaster* and *R. rattus* are Bird Watching Platform, Jetty, and Yonderup North. There was some overlap between *F. catus* and *H. chrysogaster*, and therefore potential predation by *F. catus*, at the Ghost House Trail and Wetlands Bridge sites.

Wetlands Walk trail sites may hold the highest risk of predation for *R. fuscipes* as *F. catus* (and to a lesser extent *V. vulpes*) seem to prefer this area. This may be due to these sites being in close vicinity to opportunistic food sources, such as picnic areas and Yanchep Inn).

Targeted control of introduced predators in this area may reduce threats to *R. fuscipes*. Indeed, since the implementation of this survey, targeted trapping at Wetlands Walk trail 5, which recorded the highest total visitation by *F. catus,* has resulted in the capture and removal of three feral cats. In addition, since the initiation of this study, 1080 baiting has commenced, which has resulted in one known mortality of *V. vulpes* in the vicinity of the golf course.

Yonderup North, Golf Course and Wetlands Walk trail site 3 may be optimal sites for targeted control of *R. rattus* to reduce the risk of competition and aggressive interactions with *R. fuscipes* as these sites correlate as highest total visitation for both these rodent species simultaneously in terrestrial habitat.

Interactions between individuals and species

Results show that conspecific and interspecific interactions occur across the study area predominantly in the vicinity of Lake Yonderup. This may be reflective of the minimal anthropogenic disturbance at this site compared to Loch McNess where study sites are in close proximity to a high use walk trail and highly modified recreational area. The preference of Lake Yonderup for conspecific interactions may also be related to differences in habitat health and structural complexity, and it may provide a greater range of microhabitats, protection, access to food sources and a permanent water source (Cox *et al*., 2000). There is a need to investigate the role of microhabitat and structural integrity for native mammals in these two systems.

Interactions between conspecifics may indicate social behaviour and may provide evidence of courting and breeding timing. All observed conspecific interactions involved mutual feeding or foraging and can be considered amicable with the function of enhancing bonds or achieving mutual benefits (Hill *et al*., 2014). This study provides evidence of social interaction and breeding in *R. fuscipes*. Interestingly the record of a family interaction (two adults and one juvenile) of *R. fuscipes* at Yonderup North during winter contrasts with breeding activities of this species in South Australia where young are generally born in spring and summer (White *et al*., 1996). However, in south-eastern Australia, *R. fuscipes* is capable of breeding all year, but tends not to breed in winter (Lunney, 1995). As young become independent at 4-5 weeks (Lunney, 1995), it is likely that this family of *R. fuscipes* was a late breeding pair with its young.

Typically *H. chrysogaster* gives birth to young from September to January and juveniles remain with the female for up to two months prior to dispersal, but breeding can occur throughout the year (CSIRO, 2004). As this species is known to be solitary except when mating or caring for young, the presence of this pair indicates that they probably bred during autumn and winter in the study area.

This study provides evidence of agonistic interspecific interactions between *R. fuscipes* and *R. rattus*. Studies have shown these similarly sized species both prefer structurally complex forest habitat (Cox *et al*., 2000) such as the habitat found at Lake Yonderup where the majority of interactions occurred. Territories of these two species may overlap and direct competition between these species for resources such as food, shelter and nest sites may occur (Stokes *et al*., 2012). In most interactions *R. rattus* was dominant over *R. fuscipes*. Larger body size may provide *R. rattus* with a competitive advantage and allow dominance over the smaller *R. fuscipes*, (Stokes *et al*., 2012), which generally retreated after aggressive interactions. In addition to submissive avoidance and retreat behaviours *R. fuscipes* also displayed aggressive behaviour by approaching and lunging at *R. rattus* on numerous occasions.

Where introduced species are competitively dominant to native species occupying the same ecological niche, either by aggressive behaviour or better exploitation of resources, native species may experience reduced fitness, mortality and displacement (Stokes *et al*., 2012). Indeed, *R. rattus* is believed to be partially responsible for the extinction of many small mammal species, including *R. fuscipes*, from Western Australian coastal islands (Smart *et al*., 2011). By contrast, several studies have found that in habitats where both *R. rattus* and *R. fuscipes* are found, that the presence of *R. fuscipes* affected that of *R. rattus* (Barnett *et al*., 1978; Braithwaite and Gullan, 1978; Dickman, 1983). Cox *et al*. (2000) suggests that where *R. rattus* and *R. fuscipes* occur together, *R. fuscipes* is likely to persist at the expense of *R. rattus*. Stokes *et al*. (2012) also suggests that residency status of native species would present a competitive advantage and reduce the success of invasion by introduced species due to familiarity and defence of resources in established territories.

The occurrence of these aggressive interactions, despite the risks to each species, suggests that avoidance behaviour is not apparent between these two species. Many species whose habitats overlap have developed mechanisms to reduce aggressive interactions such as demarcation of territory with odour to demonstrate residency (Stokes *et al*., 2012). Recognition of these mechanisms may not yet have developed in *R. rattus* and *R. fuscipes* due to recent arrival of *R. rattus*, therefore each species does not recognise odour of the other and territories may overlap leading to increasing risk of interactions (Stokes *et al*., 2012.)

As previously mentioned, the bait used during this study could have changed natural behaviour patterns of animals and influenced the occurrence of interspecific interactions (DEC, 2011). Due to the sampling method used in this study there was an inability to distinguish individual animals. Further studies should be implemented to define population densities and spatial distribution of both species in order to determine if the *R. fuscipes* population is being detrimentally affected by the presence of *R. rattus*. In order to slow the invasion of *R. rattus* into undisturbed native habitat and minimise potential impacts on *R. fuscipes*, management actions to control this invasive species should be implemented.

Threats to Biodiversity

Loch McNess and Lake Yonderup are entirely a groundwater-dependent ecosystems which are being affected by falling groundwater levels (DOW, 2011a, b). Water Levels at Loch McNess have been declining over the last decade and have remained below the Ministerial Criteria absolute minimum level since November 2006 (Figure 19(a) and (b)) (DOW 2011a). Since December 2011 levels have declined to the point lake sediments are exposed and minimal surface water is present for several months in each subsequent year (Figure 19(b)). If declines in groundwater levels lead to a decrease in water levels in Loch McNess sufficient enough to alter the hydrologic regime of the lake, the once permanent water body could be changed to a seasonally inundated sumpland or, at worst, a seasonally waterlogged dampland (DOW, 2011a). The lake experienced the lowest water levels on written record during the summer of 2010/2011 (DOW, 2011a), which is particularly visible each year at the end of summer when lake sediments are exposed. Lake Yonderup water levels are also predicted to decrease further, putting further strain on the ecological values of Lake (DOW, 2011b). The water levels at Lake Yonderup south study sites are greatly reduced compared to Lake Yonderup north and the southern tributary is in a similar in state as Loch McNess as it is not permanently inundated.

H. chrysogaster and *R. fuscipes* are reliant on permanent water bodies (Kitchener *et al.*, 1978) and therefore the decline in water levels may have influenced the results in the camera trapping study 2012 compared to earlier studies. The survival of *H. chrysogaster*, in particular, is critically linked to the persistence and health of wetland ecosystems. This species will require careful management as climate change and decline in groundwater levels damages the viability of wetlands (Wilson and Valentine, 2009). Ecological changes already occurring as a result of decreasing water levels and associated changes to water chemistry include: degradation of water quality, particularly in Loch McNess; decline in vegetation health; some terrestrialisation of wetland areas; reduction in habitat for aquatic macroinvertebrates, fish and waterbirds; and a decrease in macroinvertebrate richness (DOW, 2011a, b). Acidification, elevated concentrations of arsenic, soluble iron and possibly other metals and significant shifts in the vegetation community are additional predicted consequences of continuing declines in water level (DOW, 2011a). Regular surveys should be undertaken to obtain a better understanding of the impact that declining water levels has on these mammals. In addition, further studies should be carried out to determine the importance of Lake Yonderup as a refuge for those species that are highly dependent on permanent water bodies.

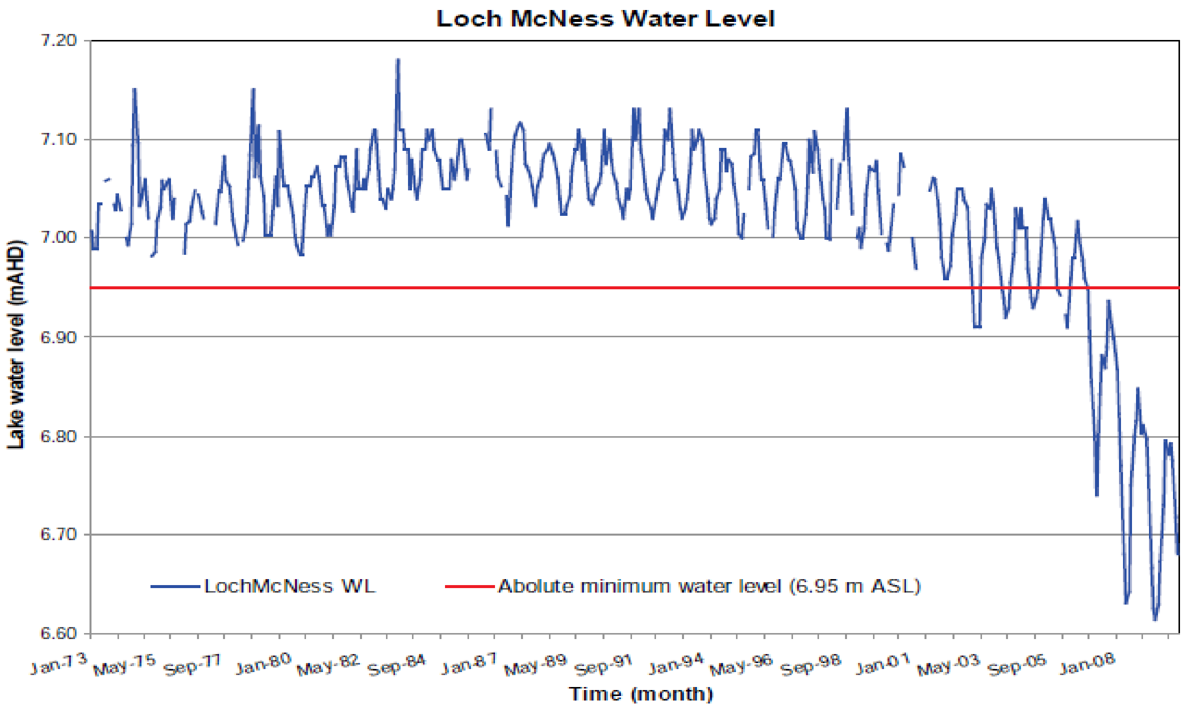

Figure 19(a). Water levels at Loch McNess 1973 – 2008 (DoW, 2011).

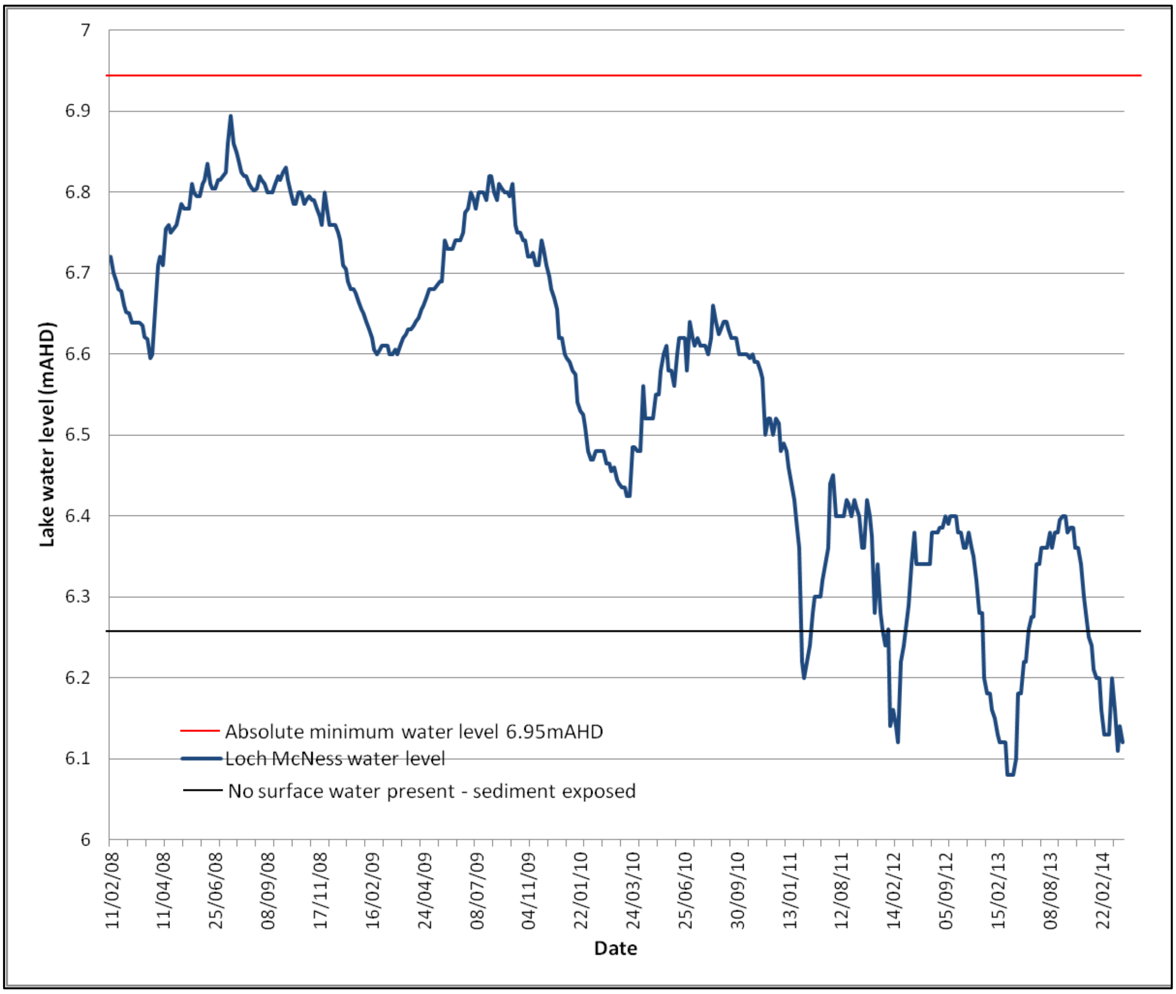

Figure 19(b). Water levels at Loch McNess 2008 – 2014 (Source: Ian Sorenesen, Yanchep National Park Volunteer Association, 2014).

Limitations of Study

Data collection methods

The use of camera trapping has pros and cons when compared to live-trapping techniques. Employing the camera-trapping technique for studies usually reliant on live-trapping would greatly reduce both the time and costs of the sampling period. This would enable limited funds to be used more efficiently for surveying these species on a greater spatial and temporal scale. Therefore the use of camera trapping could significantly increase both the range and reliability of information collected on terrestrial mammals, allowing for better-informed management decisions and actions. However, camera trapping has limitations, such as being unable to determine age, sex and life stage of the animal. Species identification may be difficulty if the animal is not captured wholly or at the right angle to determine distinguishing features. Furthermore it is difficult to determine if the same animal is captured repeatedly.

Technical related issues during this study included false triggers, over exposure and motion blur. We have therefore made several recommendations for possible future studies:

- Optimal camera setting is 3 pictures per trigger, cameras set 3 metres from the subject.

- Adjusting the sensitivity in order to reduce false trigger is not recommended as this may reduce ability to detect movements of warm blooded animal, particularly in summer (DEC 2011).
- False triggers were found to increase on sunny, windy days, therefore ensure the camera is secured to star picket or large tree to reduce movement.
- Setting the camera to night mode will increase the shutter speed and reduce the flash range but will also reduce motion blur (Reconyx, 2011).
- Programming the time delay options is not recommended as this may result in reduced success of species identification and large numbers of images that can be stored on memory cards (DEC, 2011).
- Several images per trigger at high resolution is recommended for fast moving animals, such as those targeted in this study, to increase the accuracy of identification by capturing tail length and face shape.

Volunteer involvement

The undertaking of this study was only possible due to the high level of volunteer involvement. However, studies that rely on volunteer involvement also have some innate limitations, including errors in species identification and data analysis, and a lack of resources for reporting. For future similar studies we would recommend that: data be collected and stored by volunteers with additional support required for data analysis (expertise required for more technical aspects); a standardised and detailed project outline/methods be used including location description and optimal camera settings; support and funding be provided for DPaW staff for adequate reporting; and possible collaborations with local universities (e.g. Honours projects) be investigated.

Management recommendations

From this study, we have made several management recommendations:

- Undertake targeted predator control at known sites (e.g. Wetlands 1-5 sites) and peak seasons (e.g. autumn) where there is the simultaneous presence of introduced and native mammals.

- Meet performance targets relating to Protection of the Natural Environment as outlined in the Parks and Reserves of Yanchep and Neerabup Management Plan 76 2012: *"Continued persistence and no decline in the conservation status of threatened species."*

- Implement further studies to determine threats to *H. chrysogaster*, for example examining scats of *V. vulpes* for evidence of predation.

- Implement further studies to determine the impacts of *R. rattus* on populations of *R. fuscipes*.

- Reduce threats to target native species by:
    - Incorporating protection of target mammal species and their habitat into prescribed burning plans.

- Protecting habitat (e.g. weed control) and establishing/maintaining ecological linkages.
- Ongoing monitoring of native species populations.
- Assessing the effectiveness of predator control measures.
- Determining seasonal trends of species abundance.
- Determining the impacts of declining water levels/hydrological change at Loch McNess and Lake Yonderup.
- Determining the importance of Lake Yonderup as refugia/alternative habitat for native species.

Conclusion

This study focused on the distribution and presence of native mammal species in Yanchep National Park with an emphasis on the native species *Hydromys chrysogaster* and *Rattus fuscipes*. Both of these species have been recorded within the study area, indicating that these two areas in Yanchep National Park are of great importance to these species, particularly to *H. chrysogaster*. The survey would need to be continued on a regular basis to monitor changes in the fauna populations and the effect of declining water levels on native mammals.

Some interesting information was gathered in this survey regarding the impact of introduced fauna on native fauna communities. This includes the simultaneous use of wetland habitat by *H. chrysogaster* and introduced predators, indicating a potential threat of predation to this species. This study has also shown that conspecific and interspecific interactions occur across the study area, predominantly in the vicinity of Lake Yonderup, which may be a reflection of higher quality habitat and lower amount of anthropogenic disturbance at Lake Yonderup as compared to Loch McNess. In addition, agonistic interspecific interactions between *R. fuscipes* and *R. rattus* were recorded. In most interactions the introduced *R. rattus* was dominant over the native *R. fuscipes* - therefore it is important to learn more about the relationship between these two species in the study area in order to protect populations of *R. fuscipes*.

It is vital to effectively protect the native fauna communities on the Swan Coastal Plain and to be able to implement reasonable and sustainable strategies regarding the management of introduced species. We recommend that a repetition of the study should be considered.

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