Ecological Impacts of Australian Ravens on Bush Bird Communities on Rottnest Island

Claire Anne Stevenson

Murdoch University
School of Biological Sciences and Biotechnology
Honours Thesis in Biological Sciences

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Author: Claire Anne Stevenson

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Abstract

The Australian Raven *Corvus coronoides* is a predator of the eggs and nestlings of bush birds on Rottnest Island, Western Australia. Nest predation is a threatening process of island birds, and when combined with other threatening processes, such as habitat fragmentation and degradation, sustained nest predation can cause declines in bush bird communities. The terrestrial habitats on Rottnest Island have been historically fragmented through land clearing, so concern was raised by the Rottnest Island Authority regarding the impact of the Australian Raven on bush bird communities. The aims of this study were to describe the ecology of the Australian Raven on Rottnest Island, in particular the feeding ecology, and to evaluate how important bush birds are in the diet of the Australian Raven.

To determine the rate of nest predation by the Australian Raven, an artificial nest experiment was conducted over four months from August to November, over six study sites. The diet of the Australian Raven was analysed by laboratory examination of raven stomach samples. In addition, observational data collected at the study sites during the study period was used to quantify the behaviour, abundance and distribution of ravens, and compared to bush bird distribution on Rottnest Island.

During this study, ravens predated 20% of the artificial nests, indicating a high capacity for potential population impacts. Nest predation was confirmed by the presence of birds in the stomach contents of ravens from Rottnest, but plant material and invertebrates were found to be more important in the diet. The Australian Raven prefers the disturbed and urban habitat areas of Rottnest Island for feeding, roosting and breeding. Bush birds avoid these areas, and prefer remnant and revegetated areas.

The results of this study have identified the Australian Raven as a potential predator of nesting bush birds on Rottnest Island. However, restoration of island vegetation may be having a positive effect on bush bird communities that outweighs losses of eggs and nestlings to ravens. In view of these results, continued management of the raven population is recommended as a precautionary approach so that the impacts of nest predation on bush birds are limited. Meanwhile, the population dynamics of selected bush

birds can be assessed to confirm that they are recovering in response to habitat restoration programs.

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Chapter 1

Introduction

The 2011 Action Plan for Australian Birds (Garnett, Szabo and Duston 2011) lists 11.8% of Australian birds as threatened, with an additional 2.2% listed as extinct. Fifty-eight percent of the threatened or extinct bird taxa in Australia are found on islands (Burbidge 2010). Island birds are threatened by habitat destruction and modification, exploitation by humans (hunting), fire, introduced species and direct predation from vertebrate animals (Hopkins and Harvey 1989; Whittaker and Fernandez-Palacois 2007; Garnett *et al.* 2011). In addition, Australian bush birds are facing widespread decline (Barrett, Ford and Recher 1994; Recher 1999). The major threatening processes of bush birds are habitat fragmentation resulting from human management processes and the associated consequences such as fire, change in species assemblage, increased edge effects, increased competition and increased predation (Mac Nally and Bennett 1997). The coastal islands of Western Australia can provide sanctuary for plants and animals, including bush birds, from some of the events that threaten populations on the mainland (Burbidge 1989), but only if the islands themselves are protected from these processes.

Rottnest Island has had a long history of land clearing for agricultural and urban development resulting in substantial habitat loss and fragmentation of the remaining habitat. Subsequently, the avifauna of the island has changed dramatically with two bush bird species becoming locally extinct and several others declining. Several other species have invaded and colonized as the habitat has become suitable. One of the most successful colonizers has been the Australian Raven *Corvus coronoides*. The Australian Raven is listed by Barrett, Ford and Recher (1994) as a species that is 'tolerant of fragmentation and disturbance'. The proliferation of the raven from human induced causes may negatively impact on the ecology of other bush bird species (see Recher 1999). Bird species groups that have declined regionally since European settlement of Australia, and that have also declined on Rottnest Island, include whistlers (Pachycephalidae), thornbills, gerygones

(Acanthizidae), robins (Petroicidae) and small honeyeaters (Meliphagidae)(Catterall *et al.* 1998).

Nest predation is the greatest cause of nesting mortality in birds (Skutch 1966; Ricklefs 1969, Ford *et al.* 2001). Nest predation increases in fragmented habitats (Andren 1992; Piper and Catterall 2004), as the habitat becomes more exposed and as predators move in from neighboring areas. Bird populations in fragmented habitats that are subjected to extensive nest predation are unlikely to be self-sustaining (Schmidt and Whelan 1999). Avian predators have been identified as the most important nest predators of bush birds (Fulton and Ford 2001; Piper, Catterall and Olsen 2002; Zanette 2002). The Australian Raven has been identified as a predator of other bush bird nests (Major *et al.* 1994; Major *et al.* 1999; Fulton 2006), but I am unaware of any detailed study conducted into the effects of nest predation by this species.

1.1 What are bush birds?

The term bush bird, or woodland bird, arouses an image of a small, delicate, often non-descript passerine (song bird), but the category can be applied to all birds that occur in non-aquatic habitats such as woodlands, scrublands, grasslands, forests and heath. "Bush bird" also includes larger passerines such as bowerbirds, magpies and corvids; as well as terrestrial non-passerines for example quails, parrots, raptors, cuckoos and owls. For the context of this study I refer to a bush bird to include those species that prefer, for the most part, terrestrial habitats including vegetation fringing water bodies and coastal dunes and heath. I do not include shorebirds (waders), ducks, gulls, rails, herons and egrets as bush birds despite that these groups of birds may also use terrestrial habitats for foraging, nesting or roosting. I have selected six passerine bush birds resident on Rottnest Island as a focus for this study: White-browed Scrubwren *Sericornis frontalis*; Western Gerygone *Gerygone fusca*, Singing Honeyeater *Lichenostomus virescens*, White-fronted Chat *Epithianura albifrons*; Red-caped Robin *Petroica goodenovii* , and Golden Whistler *Pachycephala pectoralis*. These species have been identified as those of conservation concern (Saunders and de Rebeira 2009) on Rottnest Island.

1.2 Why is the Australian Raven a pest?

Invasive animals are those that have increased in their distribution and abundance as a result of 'human activities' (Olsen, Silcocks and Weston 2006). When the species has increased so significantly that it causes harm to the environment, other species, agriculture or infrastructure, the species is considered a pest. In Australia, the terms "invasive" and "pest" are often associated with introduced mammalian predators such as cats, foxes and rabbits. Native animals can also be considered pests when the '… changing land use has resulted in overabundant populations of some species or the concentration of gregarious species in a particular area' (Hart and Bomford 2006). In southwestern Australia, the Australian Raven has expanded its range and now occurs on Rottnest Island, where it has become both overabundant and concentrated.

The Australian Raven was identified as pest bird under the Rottnest Island Authority *Pest Management Plan* (2008) because it is a 'nuisance to visitors and island residents', in particular around the settlement area where it competes for human food scraps with Silver Gulls *Larus novaehollandiae* and peafowl. In addition, there is concern that the Australian Raven may be predating on the nests of bush birds on Rottnest Island. The *Pest Management Plan* identified the need for research into the diet of the Australian Raven, in particular through the analysis of stomach contents.

The long-term goal of the *Pest Management Plan* is: '*To have a sustainable population of ravens on Rottnest Island that feed on natural food resources instead of human waste*'. Rottnest Island Authority has initiated raven management by including processes to reduce access by ravens to human food scraps in the *Waste Management Plan*; by continuing education of the public and residents to deter interaction with ravens; and by targeted reduction in the raven population through culling. The outcomes of this study will be used to decide the future control methods and management initiatives of the Australian Raven on Rottnest Island.

1.3 Research Questions

The overall aim for this study is to describe the ecology of the Australian Raven on Rottnest Island. In particular, I will assess whether the Australian Raven is a predator of nesting bush birds on Rottnest Island, and how this impacts on bush bird communities.

Specific questions are:

1) What is the distribution of bush birds on Rottnest Island?
2) What is the abundance and distribution of the Australian Raven on Rottnest Island?
3) Does the Australian Raven predate on bush birds on Rottnest Island?
4) What is the feeding ecology of the Australian Raven on Rottnest Island?
5) How does predation by the Australian Raven impact on bush birds on Rottnest Island?

I use observational and experimental methods to investigate these questions. The research is presented here with each question answered in an independent chapter. The findings of each chapter are linked in the final Discussion (Chapter 6) where I will answer Question 5. The chapters are described below:

Chapter 2 — Reviews the history of Rottnest Island and describes the changes to the avifauna through a literature review of published surveys of Rottnest avifauna over the last 100 years;
Examines the current distribution of bush birds on Rottnest Island using observational data collected during this study and external data sources.

Chapter 3 — Introduces the biology and ecology, in particular the distribution and abundance, of the Australian Raven in the context of Rottnest Island using observational data collected during this project.

Chapter 4 — Investigates nest predation by the Australian Raven using an artificial nest experiment.

Chapter 5 Investigates the feeding ecology and the diet of the Australian Raven on Rottnest Island through observational data recorded during this study; Quantifies the analysis of stomach samples from raven specimens collected on Rottnest Island.

Chapter 2
Terrestrial Avifauna of Rottnest Island

2.1 Introduction and Aims

Since its occupation by European settlers almost 200 years ago, Rottnest Island has been coveted for its natural beauty and idealised lifestyle. As a result, the natural and anthropogenic histories are well documented. Many residents of Perth are sentimental about the Rottnest environment and its recreation opportunities. However, the island has not always been a place for locals and tourists looking to relax. Rottnest was formerly used as a pastoral lease, penal outpost and later a military base, which along with the more recent development of facilities for tourists, has considerably changed the composition of the flora and fauna species. It no longer resembles what would have been experienced by the first settlers in the 1830s.

In this chapter I summarize the history of Rottnest Island and examine how the changes to vegetation and landscape use have influenced the distribution and abundance of bush birds. The changes in the status of bush birds on Rottnest Island is examined through a review of the literature of previous bird studies and historical records, and is compared to recent surveys and observations.

2.1.1 Geography & geology

Rottnest Island is located 17km northwest offshore from Fremantle, Western Australia (Figure 2.1). The island has a temperate climate, with temperatures slightly lower than those recorded on the adjacent mainland, and an average annual rainfall of 563mm (Bureau of Metrology 2011). It is part of a chain of Quaternary limestone islands and reefs along the continental shelf opposite Perth, which also includes those in Cockburn Sound (Garden, Carnac and Penguin Islands) (Playford 1988) to the south, which were separated from the mainland approximately 7000 years ago (Glenister, Hassell and Kneebone 1959). Rottnest is the largest (1900 ha) of these island and measures 10.5km from east to west. It is predominantly open heath and dunes with 10% of the area occupied by large salt lakes separating the eastern and western parts of the island (Playford 1983).

2.1.2 History

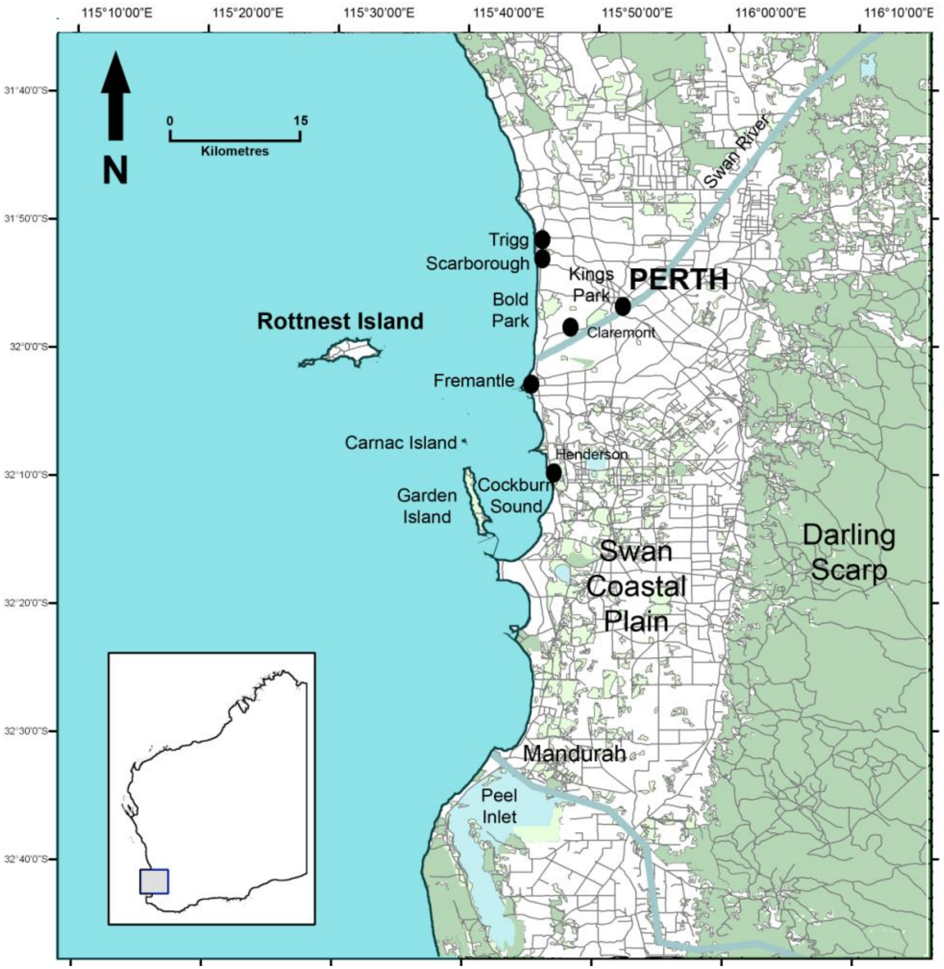
Archaeological evidence suggests Aboriginal Australians occupied Rottnest Island during the Eocene, but occupation ceased soon after Rottnest was separated from the mainland during the late Pleistocene (Playford 1988; Dortch 1991; Hesp, Murray-Wallace and Dortch 1999). The local Noongar name for the island is Wadjemup meaning 'place across the water' (Somerville 1976) and they maintain a spiritual connection to the island for ancient and recent events. The first Europeans to document Rottnest Island was the Dutch explorer Volkersen in 1658, and later followed by Vlaming in 1696-7 (Somerville 1976). It was not until settlement of the Swan River Colony in 1829 that Europeans also settled Rottnest. In 1831, privileged early pioneers were given allotments of land where agriculture was trialed, but these failed early on. From 1838 to 1904 the island was used as a penal settlement for aboriginal prisoners (Watson, 1998). The island was developed for tourism in 1907 (Joske, Jeffery and Hoffman 1995) and this has continued to be the main use of the island, with a short period as a military base during World War II. The establishment of recreational facilities included construction of roads, buildings, amenities, and a golf course northwest of the settlement. Increased visitation put pressure on fisheries and potable water supplies, but strict visitor permits limited most people to day visits.

The establishment of a military base during the 1930s and 1940s further changed the landscape with the construction of additional roads, a bituminised water catchment area at Mt Herschel, supplementary fresh water wells, extension of the airstrip, further clearing of the land for trenches and an increase in fires (Somerville 1976; Playford 1988). Recreation recommenced after the World War II with two major infrastructure projects having negative ecological impacts on interior wetlands. Road building during the 1970s utilised marl extracted from five of the eight swamps, turning them from fresh or brackish water to permanently saline lakes (Playford 1988; Saunders and de Rebeira 2009). Following this a road was constructed along the northern shoreline of Lake Herschel, removing significant foraging habitat for wading birds (Saunders and de Rebeira 2009).

Recent management of the islands terrestrial and marine habitats and fauna has been more favourable to the conservation of the biota. The Rottnest Island Authority Act 1987 includes in its functions the protection, maintenance and repair of the natural environment of the island. In 2009/10 over 356,000 people visited Rottnest Island, with 65% of visitors departing on the same day. The island infrastructure has changed significantly in the last twenty-five years to support day-visitation with the provision of multiple cafes, restaurants and take-away outlets, while the amount of overnight accommodation has remained unchanged. Over one tonne of waste is produced by visitors annually, and they require 164 kilolitres of potable water and over 500 million kilowatts of power (Rottnest Island Authority 2010). To offset the potential negative impacts this may have on island resources, sustainability and waste management plans have included the installation of a wind turbine and desalination plant, as well as the removal of waste to the mainland, replacing the onsite infill. Aquatic and terrestrial habitats are protected by signage, fencing or restricted usage of important ecological areas, and through visitor management and education. This change towards preservation for enjoyment instead of exploitation, reflects the change in attitude by the public, and subsequently governments, whereby natural habitats are valued for their aesthetic and economic value, that has been clearly evidenced over the last forty years (McCormick 1989).

2.1.3 Vegetation

Despite the close proximity and relatively recent separation of Rottnest from the adjacent mainland, the vegetation is markedly different. The differences in the flora have been influenced by the geology, wind exposure and soil structure (McArthur 1957; Storr 1962). Similar species compositions exist on the mainland where the environment is similar. For example, *Callitris preisii* remnants occur near Henderson and *Acacia rostellifera* scrub is found between Trigg and Scarborough. In comparison, Rottnest Island flora is lacking in the dominant tall eucalypt and banksia species of the Swan Coastal Plain, although fossil pollen records shows these were once



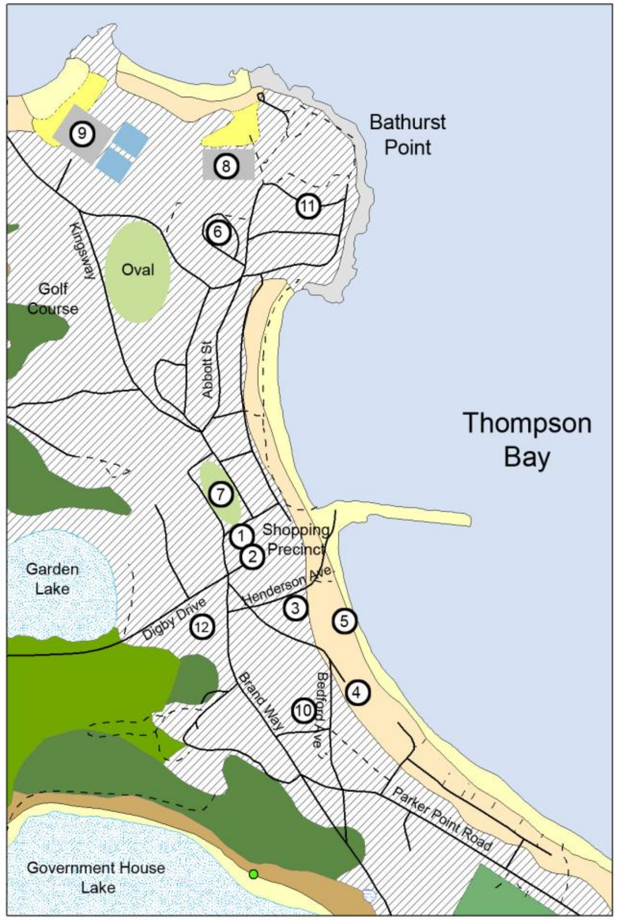


Figure 2.1: Rottnest Island in relation to adjacent Swan Coastal Plain showing key landmarks. GIS Imaging source used under WALIS Licence for the non-commercial use of land information

Figure 2.2a: Inset A Thompson Bay settlement with major roads and landmarks: 1) Bakery; 2) General Store; 3) Dome Café; 4) Hotel Rottnest; 5) Aristos Café; 6) Carolyn Thompson campground; 7) Heritage Common; 8) tennis courts; 9) desalination plant; 10) bike hire;

provided by the Government of WA, courtesy WA Museum. 2011. 11) Lancier Street cottages; 12) Fun park

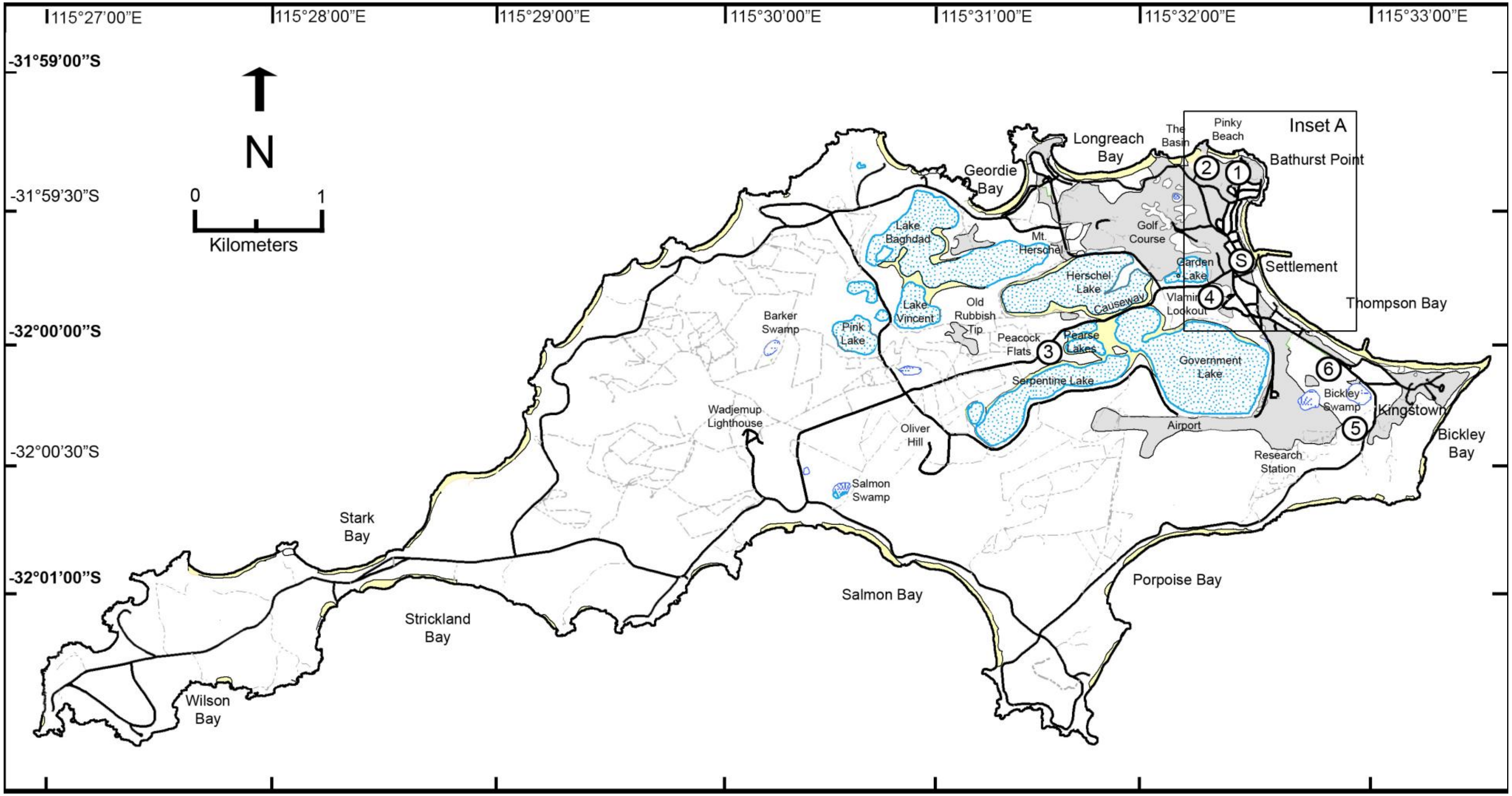


Figure 2.2b: Rottnest Island with topographical features and infrastructure, and study sites locations: 1) Bathurst Point, 2) tuart grove near The Basin; 3) Peacock Flats near rubbish tip site, 4) tuart grove near Garden Lake, 5) Bickley Swamp, 6) revegetation Parker Point Road, S) central Settlement. The urban areas are shaded grey. Figure 2.2a & 2.2b GIS Imaging source used under WALIS Licence for the non-commercial use of land information provided by the Government of WA, courtesy Rottnest Island Authority 2011 present (Storr, Green and Churchill 1959). Of these species, the Tuart *Eucalyptus gomphocephala* has been introduced deliberately, being trialed successfully as a timber crop and stands are still evident near the cemetery and Pinky Beach. The vegetation inventory lists 246 plants (vascular flora) of which 42% are exotic species, and are obvious around the urban areas (Rippey, Hislop and Dodd 2003). Moreten Bay fig *Ficus macrophylla* and Norfolk Island pine *Araucaria heterophylla,* as well as marlock *Eucalyptus platypus*, *E. utilis* and *Casuarina glauca*, have been deliberately established for aesthetic purposes, with the two former species visually dominating the settlement. West of the settlement, the island vegetation has been shaped drastically over the last two centuries by three major processes: the clearing of land by European settlers, changes in fire regimes and changes in Quokka *Setonix brachyurus* abundance. These processes appear to have subsequently modified the distribution and abundance of the bush bird species on Rottnest Island.

Early European visitors described the island vegetation as a dense forest of cypress *Callitris preissii* interspersed with *Melaleuca lanceolata* and *Pittosporum phylliraeoides*, with *Acacia rostellifera* 'relatively uncommon' (Seddon 1983). Following settlement the eastern vegetation was rapidly cleared for the development of agriculture and establishment of dwellings. The western woodlands were cleared for firewood collection, with impacts intensified by grazing stock and an increase in the frequency of fires. Evidence from charcoal deposits found in the sediments of Barker Swamp (Backhouse 1993) suggest that prior to European settlement, major fires occurred on Rottnest only once every two centuries (Rippey and Hobbs 2003) most likely caused by lightning strike. Following settlement, fire frequency escalated to a weekly event with fire being used as a tool by Aboriginal prisoners to flush Quokka from vegetation during weekend hunts that occurred until the late 1800s (Somerville 1976). The last major fire in 1955 burnt two-thirds (1800 acres) of the island (Storr 1963; Pen and Green 1983), with a smaller fire in 1997 burning ninety hectares of heath between the centre and northern coastline (Rippey and Hobbs 2003). The vegetation on Rottnest has not had sufficient time to adapt to the rapid increase in fire events. Two species in particular, *Callitris preissii* and *Melaleuca lanceolata*, are extremely sensitive to fire and have been greatly reduced (Baird 1958; Rippey and Hobbs 2003), while *Acacia rostellifera* has thrived (Storr 1963) although inhibited by Quokka grazing.

Early observers did not document the Quokka density on Rottnest Island, but it is assumed that numbers were 'abundant' compared to mainland populations (Storr 1963). The establishment of crops and exotic herbivorous plants provided an additional food source for Quokkas, but hunting by aboriginal prisoners, vice-regal parties and later tourists, kept the population from proliferating (Storr 1963; Pen and Green 1982). In 1917 the species was declared protected and shooting was prohibited (Rippey *et al.* 2003). The population increased rapidly and by the early 1930s they had exploded, the increase coinciding with the observed fragmentation of *Acacia rostellifera* scrub (Storr 1963). Acacia, in particular its new suckers, are extremely palatable to Quokkas and within two years overgrazing can quickly remove this species from the matrix, where it is then replaced by fire resistant and unpalatable herbs and low shrubs (Storr *et al*.1959; Storr 1963).While land clearing and fires have removed the majority of the melalluca and callitris forests, over grazing by Quokkas has impeded the growth of acacia, leaving the dominant vegetation community of Rottnest Island as depauperate, schlerophyllous grassy heathlands (Rippey *et al.* 2003), a great contrast from the descriptions of early explorers.

In an effort to repair the habitats of Rottnest Island a management plan, the *Woodland Restoration Program*, has been implemented. In the past decade the program has planted over 242,000 trees in fenced plantations (Rottnest Island Authority 2009), with an aim to return the woodlands of the island to connect remnant woodland habitats and return Rottnest to reflect what was described by the first colonial settlers. Such drastic changes to the vegetation over the last two hundred years have impacted heavily on the terrestrial bird species that use these habitats, leading to the decline or local extinction of several habitat sensitive species. Other species have responded positively by increasing in both distribution and abundance. The change in status of bush birds on Rottnest and their current distribution is examined below.

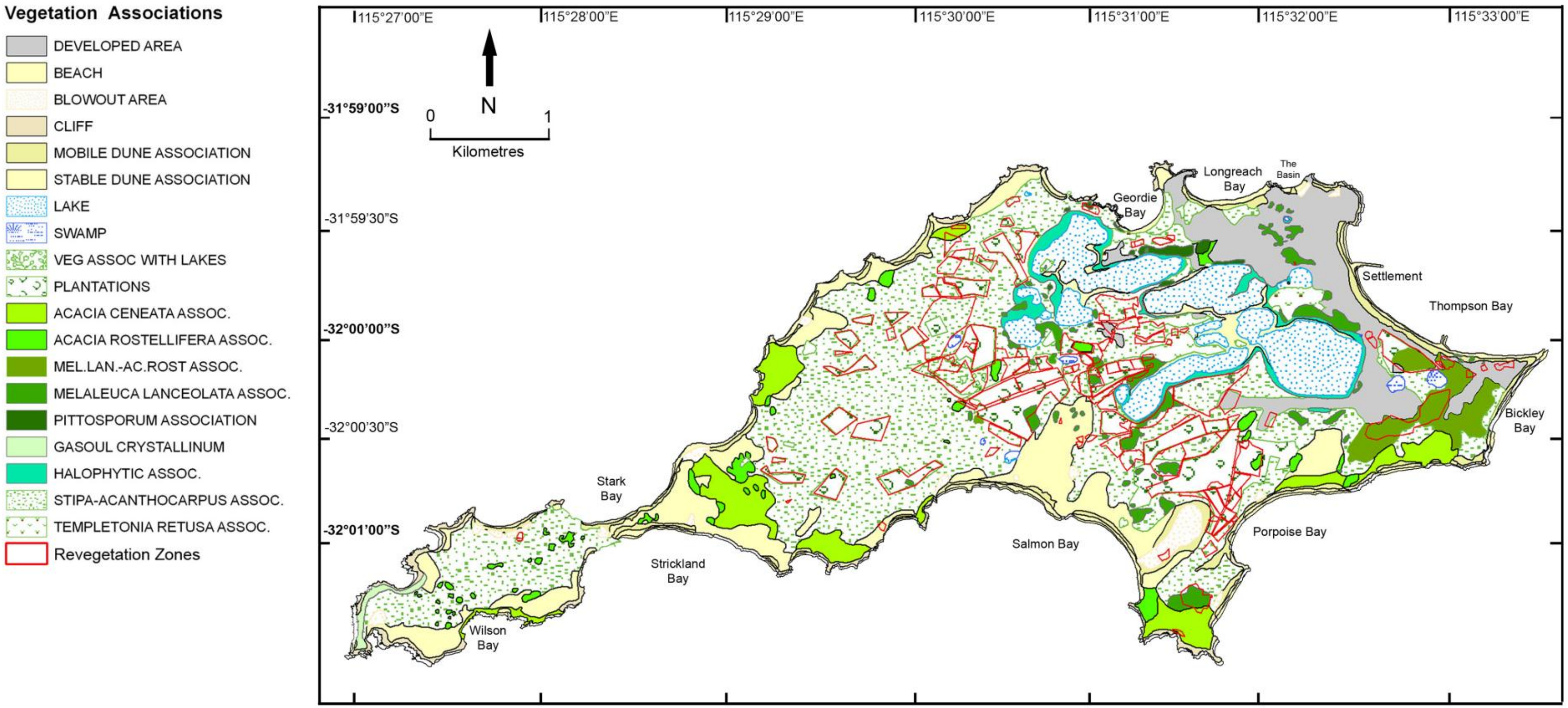


Figure 2.3: Major vegetation associations of Rottnest Island as of 2010. Revegetation plantations are outlined in red. GIS Imaging source used under WALIS Licence for the non-commercial use of land information provided by the Government of WA, courtesy Rottnest Island Authority 2011.

2.2 Methods

2.2.1 Literature review of avifauna

The Western Australian Museum does not hold a suitable series of specimens or observational data to establish a timeline of change of the islands avifauna. Of the 216 bird specimens lodged for Rottnest Island, 210 were collected prior to 1910. Single specimens were lodged in 1990 and 1970, with two exotic House Crows *Corvus splendens* collected in 2006. Several recent specimens were collected as part of this project. The majority of information on avifauna of Rottnest Island has been collated from field notebooks and observational records, and has been well documented since the declaration of the island as a recreational reserve. The first annotated list published was by Lawson (1904), with further lists by Alexander (1921), Glauert (1929) and Serventy (1938). Significant work was published by Storr (1965) and extensive long-term monitoring has been published by Saunders and de Rebeira (1985 – 2009). Most recently, Birds Australia WA group has published on their annual surveys of bush birds from 2000 - 2009 (Mather 2009).

I conducted a review of previously published field studies on bush birds of Rottnest Island. I combined the species lists and the status of each species from each author to illustrate the change in species status over time. The summary was tabulated and compared to my own observational data to give the current status of each species.

2.2.2 Study area and field observations

Six sites were selected at varying distances from the central Thompson Bay settlement (shopping district), with two sites each to the north, south and west (central) (Figure 2.2a; Figure 2.2b; Table 2.1). Due to the fragmentation of habitats on Rottnest it was not possible to replicate each habitat at all distances or in all directions. Sites were selected where adequate vegetation was available in a one hectare block. The sites were monitored over four survey periods: 6-10 September 2010(Trip A), 11-15 October 2010(Trip B) and 8-12 November 2010 (Trip C), and 1-5 August 2011 (Trip D); being the months of most active breeding for passerines on Rottnest Island (Storr and Johnstone 2004).

The presence or absence of bush birds was recorded during four surveys, monthly from August to November, of the six sites and the settlement district of Rottnest Island. Positive presence was recorded when birds were seen or heard at that site, with opportunistic observations recorded during transit between sites.

Site	Name	Zone	Latitude	Longitude	Distance from Settlement	Habitat Description
1	Bathurst Lighthouse	North	31°59`24"S	115°32`26"E	582m	Open grassland near tennis courts, surrounded by patchy stands of melaleuca, revegetated acacia, marlock and tuart.
2	The Basin	North	31°59`26"S	115°32`15"E	636m	Open tuart woodland, with thick grass and herbaceous understory, adjoining dense melaleuca and calitris stand. Lawn oval opposite.
3	Peacock Flats	Central	32°00`05"S	115°31`32"E	1539m	Low, open acacia swale with thick shrubby understory, on hill over-looking salt-lakes. Adjacent fenced revegetated stand of melaleuca.
4	Garden Lake	Central	31°59`52"S	115°32`13"E	285m	Steep rocky hill overlooking lake, with sparse, low acacia, and open tuart and melaleuca woodland to east.
5	Bickley Swamp	South	32°00`21"S	115°32`57"E	1392m	Dense melaleuca and calitris woodland with little understory, becoming open grassland nearing lake.
6	Thompson Bay	South	32°00`11"S	115°32`52"E	1051m	Open melaleuca and acacia woodland on sandy hill, with storm damaged vegetation. Medium height with patchy understory.

Table 2.1: Field site locations and habitat description with distance of each site from the central settlement area.

These observations were combined with data from bush bird surveys conducted by Birds Australian Western Australia group (2007 – 2009) and imported into *ArcGIS* 9.3 for Windows (ESIRI Australia Pty. Ltd.) to be mapped against vegetation complexes to assess habitat preferences of bush birds.

2.3 Results

2.3.1 History of the Rottnest avifauna

Paralleling the flora of Rottnest Island, the avifauna is also quite reduced, when compared to the adjacent mainland. A total of 131 species have been recorded for the island, including waterbirds and pelagic seabirds offshore (combined WA Museum specimen database and Birds Australia new atlas data: http://www.naturemap.dec.wa.gov.au [Accessed 15/10/11]). Fifty-five bush birds, have been recorded for the island, of which two are recently extinct (Table 2.2). Thirty-three species were recorded during observational surveys in 2010 and 2011.

Twenty bush birds are breeding residents of Rottnest Island, with nine of these species increasing in abundance and distribution over the last 100 years. Forty-five percent of terrestrial birds (25) recorded on Rottnest Island are considered vagrants, being only rarely or occasionally recorded. Another five species are migratory, only occurring on Rottnest Island at specific times. Five species have decreased, with two species, Indian Peafowl *Pavo christatus* and Australian Raven, being deliberately reduced through planned culling.

Decreases

There have been two local extinctions of bush birds on Rottnest Island: the Brush Bronzewing *Phaps elegans* and the Rufous Whistler *Pachycephala rufiventris* (Table 2.1). Both species suffered greatly with the loss of the acacia woodland habitats, with the bronzewing also being pressured from hunting for food (Saunders and de Rebeira 1989).

The last recorded sightings of Rufous Whistler on Rottnest were of single birds, by A.H. Robinson in 1922 and D.L. Serventy in 1925 (Storr 1965). On the adjacent Swan Coastal Plain, the Rufous Whistler is common in remnant woodlands and is able to traverse urban areas (Davis and Brooker 2008), while the Golden Whistler is almost absent (Storr and Johnstone 1988; How and Dell 1993). However on Rottnest it may have always been less common than the Golden Whistler (Lawson 1904). The reason for its extinction is most likely related to the removal of its preferred habitat, open forest and woodland, while the retention of acacia thickets and scrub habitats is more suitable for Golden Whistler (Storr and Johnstone 1988). The exact date of when the Brush Bronzewing became extinct on

Rottnest Island has not been recorded, however it is estimated to have been before 1929 (Glauert 1929; Storr 1965). The species was exploited for food in the early days of the settlement, with trapped birds sent to Fremantle for outgoing ships larders (Somerville 1976). The greatest change (decrease) in the population was likely to have occurred between 1877 and 1901 (Storr 1965). It was not listed by Lawson (1904) or Alexander (1921), and no museum specimens exist for this species from Rottnest. The species also declined significantly on the Swan Coastal Plain during the same period, and is now only recorded occasionally (Storr and Johnstone 1988).

The Rock Parrot *Neophema petrophila* has also declined through the removal of eggs and chicks for the avicultral trade (Storr and Johnstone 1998). These parrots were previously described in flocks of up to twenty-one (Storr 1965), therefore, although common they were never in large numbers, and are now more often seen singly and pairs (*pers. obs.* 2010) and should be of significant conservation concern.

The Australian Raven and Indian Peafowl have been reduced deliberately as part of the control of pest bird species on Rottnest Island. In 2009, Indian Peafowl were removed with the culling of female birds (Amalfi 2010). Three male birds have been retained and are restricted to the Thompson Bay settlement. In 2010 and 2011 I observed peafowl searching the area outside the bakery for scraps, and aggressively stealing food from tables at the hotel. Although the Australian Raven population increased rapidly during the first part of the last century, regular culls of ravens from 2009 to 2011 have reduced the population from an estimated 200 individuals to less than fifty birds in this period.

Genus species	**Common Name**	**Habitat**	**Status**	**Change**	**Year of first (+) or last (-) published record**	**Recorded Stevenson 2010/11**
Phasianus colchicus	Common Pheasant	W, H	Introduction	*Increased*	+ 1938	Y
Pavo cristatus	Common Peafowl	W, H	Introduction	*Decreased*	+ 1938	Y
Pandion haliaetus	Osprey	B	*Resident*	Increased		Y
Elanus caeruleus	Black-shouldered Kite	H	Vagrant	No change	+ 1985	
Haliastur sphenurus	Whistling Kite				*Unconfirmed*	?
Accipiter fasciatus	Brown Goshawk	H	Vagrant	No change	+ 1938	Y
Aquila morphnoides	Little Eagle		Vagrant	No change	+ 2009	
Haliaeetus leucogaster	White-bellied Sea-Eagle	B, S	Vagrant	No change		Y
Circus assimilis	Spotted Harrier	H	Vagrant	No change	+ 1985	
Falco berigora	Brown Falcon	W, H	Vagrant	No change		
Falco cenchroides	Australian Kestrel	W, H	*Resident*	Increase		Y
Falco longipennis	Australian Hobby	H	Vagrant	No change	+ 1985	
Turnix varia	Painted Button-quail	H	*Resident*	*Increased*	+ 2003[1]	Y
Vanellus tricolor	Banded Lapwing	H	*Resident*	*Increased*	+ 1938	Y
Columba livia	Domestic Pigeon	W	Vagrant	No change	+ 1965	
Streptopelia senegalensis	Laughing Turtle-Dove	W, H	*Resident*	*Increased*	+ 1938	Y

Streptopelia chinensis	Spotted Turtle-Dove	W, H	*Resident*	*Increased*	+ 1938	Y
Phaps elegans	Brush Bronzewing		*Extirpated*	*Decreased*	- 1929	
Calyptorhynchus latirostris	Carnaby's Cockatoo	W	Vagrant	No change	+ 1938	
Cacatua roseicapilla	Galah	W, H	*Resident*	*Vagrant to Resident*		Y
Trichoglossus haematodus	Rainbow Lorikeet	W	Vagrant	No change	+ 2009	Y
Glossopsitta porphyrocephala	Purple-crowned Lorikeet	W	Vagrant	No change	+ 1985	
Platycercus zonarius	Australian Ringneck	W	Vagrant	No change	+ 1965	
Neophema petrophila	Rock Parrot	B, S, W	*Resident*	*Decreased*		Y
Culculus pallidus	Pallid Cuckoo	W	*Migrant*	No change		
Cacomantis flabelliformis	Fan-tailed Cuckoo	W	*Migrant*	No change		Y
Chrysococcyx basalis	Horsfield's Bronze Cuckoo	W	*Migrant*	No change	+ 1965	Y
Chrysococcyx lucidus	Shining Bronze Ccuckoo	W	*Migrant*	No change		Y
Ninox novaeseelandiae	Boobook Owl	W	Vagrant	No change		
Tyto alba	Barn Owl	W	Vagrant	No change		
Apus pacificus	Fork-tailed Swift		*Vagrant*	No change	+ 1965	
Todiramphus sanctus	Sacred Kingfisher	W	*Resident*	*Increased*	+ 1938	Y
Merops ornatus	Rainbow Bee-eater	W, H	*Migrant*	*Increased*	+ 1985	Y
Pardalotus punctatus	Spotted Pardalote		Vagrant	No change	+ 2009	Y
Pardalotus striatus	Striated Pardalote	W	Vagrant	No change	+ 1965	Y
Sericornis frontalis	White-browed Scrubwren	W, H	*Resident*	No change		Y

Gerygone fusca	Western Gerygone	W	*Resident*	*Increased*	+ 1965	Y
Lichenostomus virescens	Singing Honeyeater	W, H	*Resident*	No change		Y
Anthochaera carunculata	Red Wattlebird		*Vagrant*	No change		
Epthianura albifrons	White-fronted Chat	S, W, H	*Resident*	No change		Y
Petroica goodenovii	Red-capped Robin	W	*Resident*	No change		Y
Pachycephala pectoralis	Golden Whistler	W	*Resident*	No change		Y
Pachycephala rufiventris	Rufous Whistler	W	Extirpated	*Decreased*	- 1938	
Colluricincla harmonica	Grey Shrike-thrush		*Vagrant*	*Vagrant no change*	+ 2009	
Rhipidura fuliginosa	Grey Fantail	W	Vagrant	No change	+ 1965	Y
Rhipidura leucophrys	Willie Wagtail	W, H	Vagrant	No change	+ 1938	
Grallina cyanoleuca	Magpie-lark	W	Vagrant	No change		
Coracina novaehollandiae	Black-faced Cuckoo-shrike	W	*Vagrant*	No change		Y
Lalage tricolor	White-winged Triller	W	Vagrant	No change		
Cracticus tibicen	Australian Magpie	W	Vagrant	No change		Y
Corvus coronoides	Australian Raven	B, S, W, H	*Resident*	Increased (recent decrease)		Y
Hirundo neoxena	Welcome Swallow	B, S, W, H	*Resident*	No change		Y
Hirundo nigricans	Tree Martin	S, W, H	*Resident*	*Increased*		Y
Zosterops lateralis	Grey-breasted White-eye (Silvereye)	W, H	*Resident*	No change		Y
Anthus australis	Australian Pipit	H	*Resident*	No change		

Table 2.2 : Literature review: Terrestrial avifauna of Rottnest Island as extracted from Lawson 1904, Glauert 1929, Serventy 1938, Storr 1965 (a, b, c), Saunders and De Rebeira 1985, Saunders and De Rebeira 1993, Mather 2009, Saunders and De Rebeira 2009; with incidence of occurrence during 2010 surveys. Categories and codes as per Saunders & De Rebeira 2009: Habitat codes: B = All coastal habitats (beaches, reef platforms, cliffs and offshore islets and stacks); H = heath (including golf course and airport verges); W = woodland (including settlement areas); and S = salt lakes and swamps. Status codes: Resident = species breeds on the island and remains there all year; migrant = species occurs on regular pattern each year; vagrant = species is recorded on the island occasionally, but there is no pattern to its presence. [1]Berry 2003. Taxonomy follows Johnstone (2010).

Increases

Twelve species have increased in abundance on Rottnest Island, with five species being recently recorded (Table 2.2) in the last eight years. Three of the newly recorded species, Little Eagle *Aquila morphenoides,* Spotted Pardalote *Pardalotus punctatus* and Grey Shirke-thrush *Colluricincla harmonica* are most likely vagrants. However the remaining two are being recorded on a more regular basis. Although it has not yet established itself permanently, the highly invasive Rainbow Lorikeet *Trichoglossus haematodus* is regularly observed around the Thompson Bay settlement and may be increasing in frequency. Painted Button-quail *Turnix varia* were observed at Rottnest early this century (Berry 2002) and are listed by Saunders and de Rebeira (2009) as '… now established as an uncommon resident'. However "quail" are noted to have been hunted by Governor Weld and E.H. Angelo c1869-75 and also by E.J Watson (1870-1939) (in Somerville 1976). It is possible these may have been Painted Button-quail (R.E. Johnstone[1] *pers. comm*. 2011). The appearance of Painted Button-quail on Rottnest Island coincides with the increase in the population in the Perth area (Berry 2002).

Banded Lapwing *Vanellus tricolor*, Galah *Cacatua roseicapilla,*, Spotted Turtle-Dove *Streptopelia chinensis* and Laughing Turtle-Dove *S. senegalensis* have colonised and increased on Rottnest Island following increases on the mainland (Storr and Johnstone 1998; Storr and Johnstone 2004). Other species, such as Rainbow Bee-eater *Merops ornatus*, Sacred Kingfisher *Todiramphus sanctus*, Australian Kestrel *Falco cenchroides*, Australian Raven and Tree Martin *Hirundo nigricans* have changed in status to that of breeding residents or increased in abundance, through the modification of the habitat in favour of these species (Saunders and de Rebeira 2009). Although the population of the Australian Raven on Rottnest Island has recently decreased through controlled culling, it benefited greatly from the changes to the island use, in particular the increase in food availability from waste generated by tourists, and Quokka carcasses. The changes in raven distribution and abundance are examined in detail in Chapter 3. The Western Gerygone was presumed to have established itself on the island around 1950,

[1] Ron Johnstone, Curator of Ornithology, Western Australian Museum, Welshpool WA

with Storr first observing them in 1955. The gerygone rapidly colonised all suitable habitats, favouring the plantations of tuarts (Serventy and Storr 1959), and by 1960 were noted to be more plentiful than Golden Whistler (Storr 1965), and is now one of the most commonly encountered bush birds on Rottnest.

2.3.2 Species of conservation concern

Seven species were identified by Saunders and de Rebeira (2009) to be of conservation importance. These being the Golden Whistler, White-browed Scrubwren, Western Gerygone, Red-caped Robin, White-fronted Chat, Singing Honeyeater and Rock Parrot. In addition, the Golden Whistler and Red-caped Robin has been proposed as an indicator species for the natural environment of Rottnest (Mather 2010). These species, with the exception of the Rock Parrot that does not nest in bush land, are used in this study as models for conservation of the bush birds of Rottnest Island. The distribution and abundance of these key species are examined below.

2.3.3 Distribution and abundance of bush birds

On Rottnest there is a strong preference by Golden Whistler, Red-capped Robin and Western Gerygone to occur in revegetated areas (Figure 2.3). This is supported by Birds Australia WA recorded increases, in particular in reforested areas, of Golden Whistler, Singing Honeyeater, Western Gerygone and Red-caped Robin during recent surveys (Mather 2009). With the exception of the Singing Honeyeater, passerine species strongly avoid areas that are disturbed including the Thompson Bay Settlement. During surveys in 2010 the only other passerines encountered in the settlement were resident species not regarded to be of concern, the Welcome Swallow *Hirundo neoxena* and Grey-breasted White-eye (Silvereye) *Zosterops lateralis*. A single Western Geryone was recorded in the settlement in August 2011. In comparison, the introduced Laughing Turtledove and invasive Australian Raven have a broader distribution, favouring the urban and disturbed areas (Figure 2.4).

The sites furthest from the settlement (Site 3, Site 5 and Site 6) are also those that had the highest frequency of species of conservation concern, with the settlement showing a reduced diversity (Figure 2.5). These sites included well connected, though often sparse, woodland or grassland habitats. Conversely, Site 1 is severely fragmented, is in close proximity to accommodation and recreational areas, and had a species composition similar to the central settlement. The Singing Honeyeater was the only key species recorded at this site.

Singing Honeyeater and Western Gerygone were the most frequently recorded species over the sites visited, with the Singing Honeyeater recorded across all sites and the gerygone recorded most frequently. White-browed Scrub-wren and White-fronted Chat preferred habitats with suitable understory or dense vegetation. White-fronted Chat preferred vegetation fringing or near water (Site 5). Red-caped Robin and Golden Whistler preferred habitats with tall or dense woodland. The trend for Golden Whistler was particularly obvious at Site 3 where they were only recorded within a fenced area of mature revegetated forest, and not on the swale.

Evidence of breeding was recorded at Site 1, Site 4, Site 5 and Site 6 in 2010 and 2011. Red-capped Robin were observed feeding recently fledged young at Site 5 in September 2010, and Site 4 and Site 6 October 2010. Singing Honeyeater with begging young were recorded at Site 1 in October and November 2010, and at Site 2 in November 2010. Pairs of Western Gerygone were observed at each of Site 4, Site 5 and Site 6 in November 2010.

Figure 2.4 : Distribution of six bush bird species compared to two invasive species (Laughing Turtle-dove and Australian Raven). Data sourced from Birds Australian Western Australia group (open circles) and C.A. Stevenson (closed circles). Revegetation areas are outlined in red. GIS Imaging source used under WALIS Licence for the non-commercial use of land information provided by the Government of WA, courtesy Rottnest Island Authority 2011.

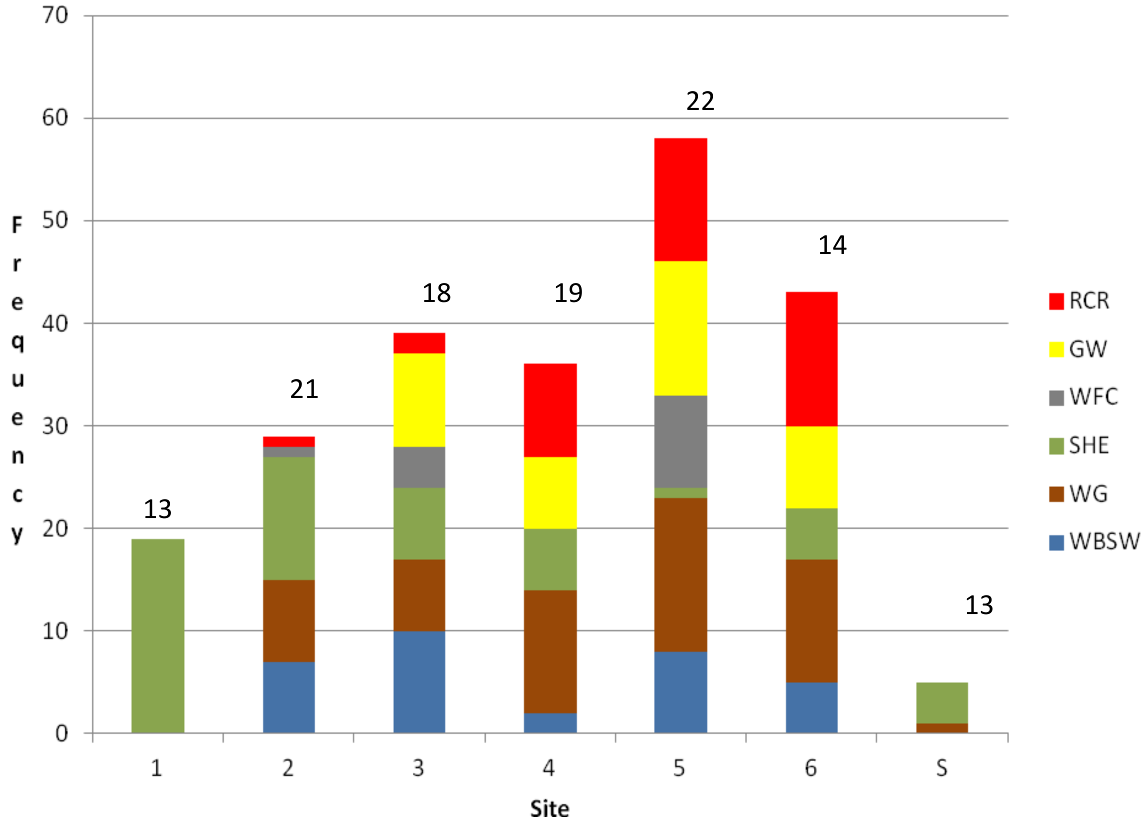


Figure 2.5: Combned monthly frequency and distribution by site of six bush bird species: RCR = Red-caped Robin, GW = Golden Whistler, WFC = White-fronted Chat, SHE = Singing Honeyeater, WG = Western Gerygone, WBSW = White-browed Scrubwren; by site: 1) Bathurst Lighthouse, 2) The Basin, 3) Peacock Flats, 4) Vlamingh Lookout, 5) Bickley Swamp, 6) Thompson Bay, S) Settlement. Total number of terrestrial bird species recorded for each site is given above.

2.4 Discussion

In the last 180 years following European settlement, Rottnest Island habitats have been drastically modified, in particular through the large-scale loss of woodland and forest vegetation. The loss and modification of habitats, as well as other threatening processes has subsequently changed the biodiversity of avian species, their abundance and their distribution on Rottnest Island.

The six bush bird species examined here are species of conservation importance and in some cases may be unique to Rottnest Island, as described below. The Golden Whister, White-browed Scrubwren, White-fronted Chat are also of concern on the adjacent Swan Coastal Plain (Recher and Serventy 1991; How and Dell 1993), while the Red-caped Robin is absent from much of the Swan Coastal Plain. The distributions of Golden Whistler and White-browed Scrubwren are reduced in the Perth area, with the whistler now almost entirely restricted to the heavily wooded areas of the Darling Scarp (Davis and Brooker 2008). White-browed Scrub-wren and White-fronted Chat are restricted in their distribution on the Swan Coastal Plain, and their preferred habitats may be threatened by rapid urban development. The populations on Rottnest Island may represent a safe-haven for these species, protected from further decline by their isolation.

In addition, three of these species differ morphologically or behaviourally from their nearest mainland populations. The Singing Honeyeaters of Rottnest Island has been proposed as a distinct species from birds of the mainland, based on the robustness of its appearance and differences in plumage colouration (Milligan 1911; Wooller *et al.*1985), but this recommendation has not been recognised in recent revisions of Australian avian taxonomy (Christidis and Boles 2008; Johnstone 2010). Similarly the Red-caped Robin and Western Gerygone have been suggested to differ from the mainland population (Saunders and de Rebeira 1985), as both differ in their calls when compared to birds in the southwest (Baker, Baker and Baker 2003a; Baker, Baker and Baker 2003b). Further research into the status of these population variants needs to be conducted to determine their true relationship to mainland populations.

The major threatening processes to island birds are in general anthropogenically derived processes being exploitation by humans: habitat loss, degradation and fragmentation; increased fire regimes; introduced species and direct predation (Whittaker and Fernandez-Palacois 2007). Hunting and the live trade of birds are now no longer threats to birds on Rottnest Island, but the other threats still remain. Habitat loss and fragmentation through land clearing and increased fire regimes has drastically altered the Rottnest landscape favouring some species, but causing the decline, and even local extinction, of others. The illustrated distributions of the six bush bird species highlighted in this chapter, show a strong preference in favour of remnant and revegetated sites, whereas introduced and invasive species prefer the urban and disturbed areas. Although only two species have been deliberately introduced to Rottnest Island, many other species have invaded or colonised from the mainland as the habitat has become suitable. The change to the species composition may increase predation on local species through the introduction of new predatory species (Andrén 1992).

The Australian Raven is a large, noisy and conspicuous bird and when in large numbers, its presence and behaviour attracts negative attention from island visitors. Not only is the species considered a pest, but anecdotal reports suggest that the raven may predate on nesting shorebirds and bush birds on Rottnest. The ecology of the Australian Raven has been examined in the Perth Metropolitan Area (Stewart 1994), where predation of bush bird nests was observed. However despite the well documented history of avifauna of Rottnest Island, little is known about the ecology and behaviour of the raven population. Also unknown is what effect raven abundance and distribution may have on other bush birds. In the next chapter I will review the ecology of the Australian Raven in the context of Rottnest Island.

Chapter 3
Biology and Ecology of the Australian Raven on Rottnest Island

3.1 Introduction and Aims

The increase of the abundance of the Australian Raven on Rottnest Island over the last century has been well documented, but little detailed study into the distribution or biology of the species has been conducted. For the most part, previous authors have simply commented on the raven's abundance without further investigation. In this chapter, I will quantify recent observations of ravens recorded during this project, and identify how ravens use the landscape by assessing their current distribution, abundance and population status on Rottnest Island.

3.1.1 Taxonomy of Australian corvids

Birds of the family Corvidae (the corvids) appear to have evolved from a forest-living ancestor out of Australia, which radiated out of the Australo-Papuan region into Asia during the late Oligocene and Miocene (Ericson, Irestedt and Johannsson 2003; Ericson, Johannsson and Ekman 2005). Monroe and Sibley (1993) list twenty-three genera comprising of 118 species, with a worldwide distribution including the northern hemisphere choughs (Pyrrhocorax), nutcrackers, jays, the rook and Eurasian magpies. The crows and ravens, genus *Corvus*, are all large to very large, black, grey or black and white birds, with strong legs and feet, large bills and wings (Goodwin 1976). There are five Australian native species of corvid, all belonging to the genus *Corvus* (*C. coronoides* Australian Raven; *C. tasmanicus* Forest Raven; *C. mellori* Little Raven; *C. bennetti* Little Crow; and *C. orru* Torresian Crow) (Higgins, Peter and Cowling 2006). The House Crow *C. splendens* occasionally occurs as an accidental visitor (ship assisted), including on Rottnest Island (Department of Agriculture and Food 2006). It has successfully been prevented from establishing in Australia. Three species are found in Western Australia: the Torresian Crow in the northern and northwest regions, the Little Crow in the arid regions and the Australian Raven of the southwest. There is a clinal decrease in size of the Australian Raven from east to west, with the southwestern subspecies *C. corronoides perlexus* being smaller in size than the nominate subspecies of eastern Australia (Rowley 1970). The south western subspecies may be elevated to a full species following molecular research (L. Jospeh[2] *pers. comm.* 2011).

3.1.2 Life history of the Australian Raven

Extensive research into the biology of Australian corvids, including the Australian Raven, was conducted principally by Ian Rowley in the 1960s, and published from 1967 to 1974. Observations of the biology, behaviour, habitat and ecology of corvids were collected during studies investigating predation on lambs by these species in southeastern Australia (Rowley 1973a; Rowley 1973b; Rowley, Braithwaite and Chapman 1973). Much of what is known of the biology and behaviour of the Australian Raven, and other Australian corvids, has been gleaned from these studies and is summarised below, except where acknowledged.

Australian Ravens reach breeding maturity at three years with eggs laid between May and October in Western Australia (Storr and Johnstone 2004). A large bowl-shaped nest is built by both sexes in a fork of the crown of the highest tree in the territory, but they will also use artificial structures (Rowley 1973b). The nest is constructed from sticks, twigs and rootlets being lined with bark, grass, wool and hair (Higgins *et al.* 2006), and may be reused with new material being added each year. Up to two to six eggs are laid on successive days and incubated for 19-20 days by the female only. The female broods the nestlings for the first two weeks, with both chicks and female being fed by the male. After this time both sexes will feed young up until fledging at around 40-45 days. Fledglings remain in or close to the nest tree at first, moving further and further away over the following weeks, and may remain in the territory for up to four months after which time they join non-breeding dispersive flocks. First year birds may return to their natal area the following year.

Raven pairs maintain territories of approximately 1200m^2. The territory is held by the male and is used all year round for feeding, roosting and breeding, and is defined by landscape features

[2] Dr. Leo Joseph Research Director & Curator, Australian National Wildlife Collection CSIRO Ecosystem Science, Crace ACT

such as ridges and forest edges. Both sexes defend the territory from intruding pairs and individuals, but will yield when swamped by large groups or flocks. Non-breeding birds form loose flocks that roost near the current nearest food source. This behavior has also been observed in communal Torresian Crows in urban Brisbane (Everinding and Montgomerie 2000; Everding and Jones 2004).

3.1.3 The Australian Raven as a pest

Like many species of corvid, the Australian Raven has adapted well to modifications made to habitats following European settlement and human disturbance (Goodwin 1976). The species is common in most habitats in the southwest, with the exception of heavily-wooded habitats (Storr and Johnstone 2004). Since 1960 the Australian Raven has increased greatly in numbers and breeding locations on the Swan Coastal Plain (Storr and Johnstone 2004) including Rottnest Island. Ravens are most commonly found in singles, pairs or small flocks, however large flocks form following breeding, making the species conspicuous and often gaining the attention of the public (Stewart 1997). Occasionally very large flocks of 100-300 birds will congregate at food-rich sites such as agricultural areas and rubbish tips. Complaints from the public motivated action to be taken regarding the increasing numbers of ravens in the Perth area, in particular due to their noise, scavenging and impact on other birds (Stewart 1997). More recently, local residents of southern suburban areas expressed concern over the perceived increase in raven numbers, the noise, destruction to property and predation on small passerines in residential gardens (Shurmer 2010). The Australian Raven is listed as a *Declared Pest of Agriculture* (Richardson 2009) and licensed extermination is allowable on private land in the southwest, but not in the Perth metropolitan, Mandurah or Bunbury areas (Department of Environment and Conservation 2007) where the species is protected under the *Wildlife Conservation Act 1950*. Culling of ravens in the Perth Metropolitan area is conducted informally as required, and is the responsibility of local councils under licence from the Department of Environment and Conservation. The Rottnest Island Authority conducts culls of Australian Ravens as part of the

Pest Management Plan, with 180 individual ravens being culled on Rottnest Island since 2009 (R. Priemus[3] *pers. comm.* 2011)

3.1.4 History of ravens on Rottnest Island

The Australian Raven is a recent arrival to Rottnest Island, establishing as a breeding resident in the last 100 years. As the species increased in numbers and distribution following land development and settlement expansion on the mainland, so too did it find suitable habitat in the modified Rottnest landscape. Lawson (1904) described the 'crow *Corvus corronoides'* as being only occasionally seen, so few that he assumed the birds observed were visitors from the mainland. By 1921 the species had evidently established on the island with Alexander listing them as common. Glauert (1929) noted 'hazel-eyed individuals' (juvenile birds) as well as adults, suggesting that the species was also breeding on the island. Nesting by ravens on Rottnest was confirmed by Storr (1965). By this time the raven population had increased greatly with Storr noting the culling of 222 individuals in 1958 and 100 additional birds shot in 1959. He states that the numbers of ravens was so great, that even following these large culls '.. it was hard to see any diminution in their numbers'. The reasons given for the cull in 1958/59 echo current issues, with a dislike for the species because of its noise and 'pilfering', and an assumption that it was predating on other bird life.

The filling in of the Rottnest landfill site in 2004 (Shortland-Jones[4] *pers. comm.* 2011), along with the implementation of covered bins, has reduced the food available for ravens (Saunders and de Rebeira 2009) and therefore raven abundance. Recent surveys have noted a continuing decline with 125 and 140 ravens recorded during a census of Rottnest birds in 2007 (Mather 2009). Subsequent surveys in 2009 recorded reduced numbers with 114 observed, but these surveys omitted the settlement area where the raven population was concentrated (Mather 2009). Mather commented that the 'high numbers [of Australian Raven] ... could be a threat to nesting shorebirds … and to nesting bush birds', yet no evidence was given.

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[3] Ron Priemus Ranger, Rottnest Island Authority, Victoria Quay, Fremantle

[4] Helen Shortland-Jones Rottnest Island Authority, Victoria Quay, Fremantle

Although there has been a continued and expressed concern by the public, researchers and local authorities, little is known about the demography and behaviour of the raven, other than recording its presence or absence. By documenting new observations taken over four months incorporating the raven breeding season (August to November), I hereby described in detail the current distribution, abundance and status of the Australian Raven on Rottnest Island.

3.2 Methods

3.2.1 Field Observations

Raven population sizes and territories were assessed by visually or audibly identifying the species, followed by pursuit and observation using binoculars by a single observer. Six predefined sites (Figure 2.2b Chapter 2) and the Thompson Bay settlement were surveyed daily for one hour per day over three days during each three monthly survey period (September, October, November 2010) and a follow up survey in August 2011. At least one morning, one midday and one afternoon visit were made to each site during each trip to avoid bias of observing the same site at the same time. Opportunistic observations were noted between sites at other locations. Individual ravens were noted each time they entered the site (frequency), their behaviour (i.e. foraging, perched, flying overhead) and the direction that they entered or departed a site. Notes were made of other ravens audible in the area but not occurring on site. Interactions between ravens and other avian species were also noted, including predation and any indication of breeding (i.e. pair bonding, nest building, mating). Locations of observations were marked using a GPS and the latitude and longitude recorded into a notebook. The data were imported into GIS software *Arcview 9.3* for Windows (ESRI Australia Pty. Ltd.) for mapping and analysis.

3.2.2 Laboratory analysis

The demography of the Australian Raven population on Rottnest Island was investigated by laboratory examination and dissection of specimens. Carcasses were obtained from authorised culling by Rottnest Island Authority Rangers in 2010 and 2011. Ravens were trapped from within the settlement, Bathurst Point and Signal Hill. Thirty-eight birds were culled in 2010, of which thirty were examined, with another twelve birds culled and examined in 2011. Following examination, the carcasses were forwarded to the School of Veterinary Sciences at Murdoch University, for identification of internal parasites. Whole stomachs were removed and preserved in 100% ethanol for examination of contents. These results are presented in Chapter 5.

Birds were aged and sexed following characteristics listed in the Handbook of Australian and New Zealand Birds (Higgins *et al.* 2006) (Table 3.1). The Australian Raven is sexually dimorphic, with adult males being larger than adult females. Both adult sexes have a bare area of abdominal skin, however only the female develops a true brood patch during the breeding period. The sex of each bird was determined by measurement and was confirmed in birds with visible gonads. Gonads were often undetected in juvenile or first year birds. Brood patch and developed gonads were noted when observed.

The colour of feathers, the eye and bare parts (gape and throat) change as ravens age. These soft parts gradually become black as they mature until becoming solid black in adults (Figure 3.1). Eye colour could not be used to determine age because the specimens were delivered frozen, and the eyes deteriorated.

Age/Sex	Eye	Gape	Throat	Plumage	Tarsus	Wing	Tail
Juvenile (J)	Dark Brown	Pink	Pink	Dull blackish-brown; wing in good condition, tail worn. Wing and tail feathers narrow.	-	325	214
First Year Immature (1)	Light Brown	Pink-black	Pink-black	Dull blackish-brown with contrasting glossy feathers; wing and tail sometimes very worn.	-	323-335	192-204
Second Year Immature (2)	Light Brown	Black-pink	Black-Pink	Blue-black, may retain few dull black-brown feathers, particularly on upper wing coverts.	-	-	-

Third Year Adult (3+)	White	Black	Black	Glossy blue-black. Wing and tail feathers broad and rounded.	55.6-70	310-361	170-205
Adult Male	White	Black	Black	Glossy blue-black	55.6-70	323-361	183-205
Adult Female	White	Black	Black	Glossy blue-black	56-61.7	310-344	170-198

Table 3.1: Morphological characteristics used to age and sex Australian Ravens on Rottnest Island with range for each age class, and ranges for adult males and females (Storr and Johnstone 2004; Higgins *et al.* 2006),

The plumage of juvenile birds is much less glossy than adults with a blackish-brown colour. These dull feathers are replaced with glossy blue-black feathers during each moult until reaching maturity at three years, where the plumage is all-over glossy blue-black. In addition, the characteristic elongated feathers on the throat (hackles) become denser and longer as birds mature. Ravens are also able to be aged on the shape of outer primaries and retricies, with adults having wider and more-rounded feathers. In this case it was often not possible to determine in the birds culled because the feathers were often damaged during the trapping.

Figure 3.1: Age characteristics of Australian Ravens from Rottnest Island showing changes in pallet, gape and throat colour as ravens mature. As the bird ages the amount of black on gape and throat, as well as the development of throat hackles, increases. Juvenile birds were identifiable by pink or red palate, gape and throat: A) juvenile gape B) juvenile throat; C) Immature gape; D) Immature throat; E) Adult 3+ gape; F) Adult 3+ throat.

3.3 Results

3.3.1 Distribution and abundance

Observational data from this project were compiled with historical observational data from Birds Australia WA to analyse the distributions of ravens over Rottnest Island (Figure 3.2).

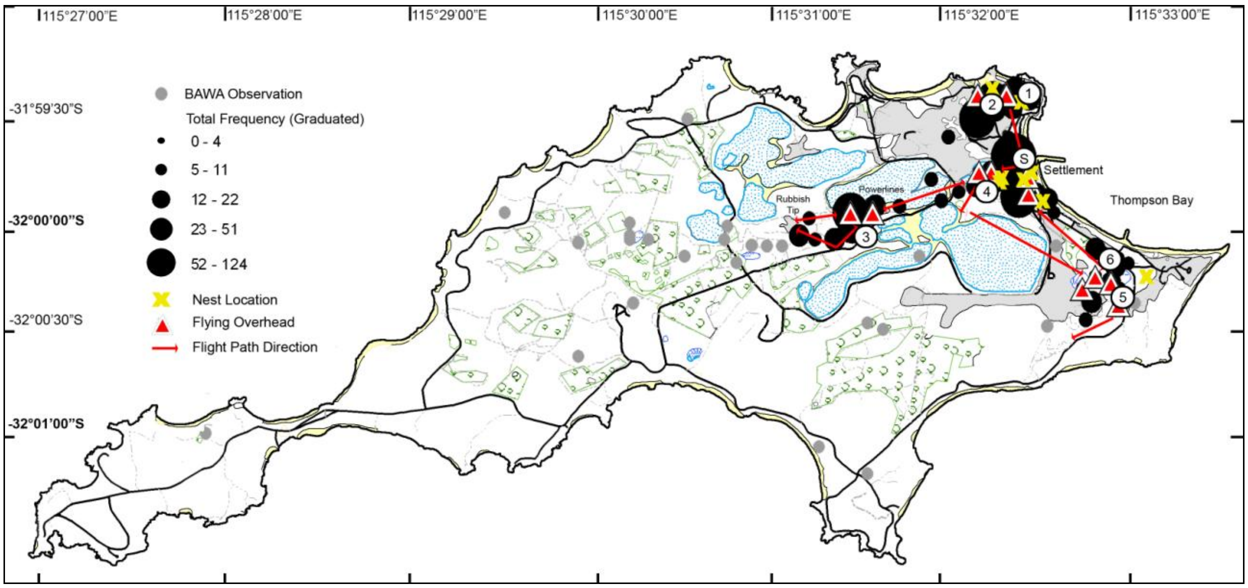

Figure 3.2: Distribution and total frequency of the Australian Raven on Rottnest Island including regular flight paths used between sites, and nest locations, with study sites: 1) Bathurst Point, 2) tuart grove near The Basin; 3) Peacock Flats near rubbish tip site, 4) tuart grove near Garden Lake, 5) Bickley Swamp, 6) revegetation Parker Point Road, S) central Settlement. The total frequency of ravens observed during all four surveys, was graduated to show the density over their distribution, with larger circles representing a higher total frequency. GIS Imaging source used under WALIS Licence for the non-commercial use of land information provided by the Government of WA, courtesy Rottnest Island Authority 2011. Data sources: Birds Australia Western Australia.

The distribution of the Australian Raven on Rottnest Island is concentrated in the east especially in the urban areas, and sparse in the western woodlands and grasslands (Figure 3.2). The ravens are centralised in the Thompson Bay settlement, in particular the shopping precinct outside the Rottnest General Store and a bakery. This area also consistently recorded the highest daily frequency of ravens (Figure 3.3). The area includes a cafe with alfresco dining, two fastfood outlets, a supermarket and bakery with outdoor seating. Ravens use the Moreton Bay fig trees in the area for roosting, preening and as a perch to visually survey the area. Other regular roosts include outside the Rottnest Lodge, on the hill behind the salt store and the large fig tree in the northeastern corner of the fun park. Ravens were observed regularly foraging on waste and remains of food left on tables, including on plates and cutlery, in the bakery precinct. Australian Raven and Silver Gull faeces were often present on tables and chairs. Ravens were also observed in and around tables at the Dome cafe and the Hotel Rottnest, but they were moved along quickly by staff or visitors. Bird netting surrounding Aristos Cafe overlooking the bay prevents the ravens and other birds from landing on tables and feeding on leftover food.

Observations of flight direction recorded indicate that the ravens on Rottnest Island have regular flight paths that follow roads, manmade structures such as powerlines, and avenues of trees. There are three main flight paths the ravens use to traverse the island, usually being to or from the settlement. To the north, birds follow the tree-lined avenue of Abbot Street to access accommodation in the north of Thompson Bay and Bathurst Point. Birds traveling south follow Brand Way or Parker Point Road, crossing over bushland to the east of the airfield to access Bickley Swamp and Kingston Barracks. Ravens were also frequently observed to travel along Digby Drive, crossing over Vlamingh Lookout to Garden Lake, and then continue south to Bickley Swamp via Brand Way (Figure 2.2a Chapter 2). The major flight path to and from the settlement crosses Garden Lake, following Digby Drive across Herschel Lake and then follows the powerlines to the landfill site.

Despite continued culling of ravens during the survey period, the total daily average abundance of ravens increased from August to October (Figure3.3), with a decrease in November, presumably because birds start to leave the natal area in post-breeding flocks. The highest daily frequencies were observed in October towards the end of the breeding season. The decrease in observations of ravens at Bathurst Point (Site 1) in October was due to the movement of a family group. They were observed with a recently fledged

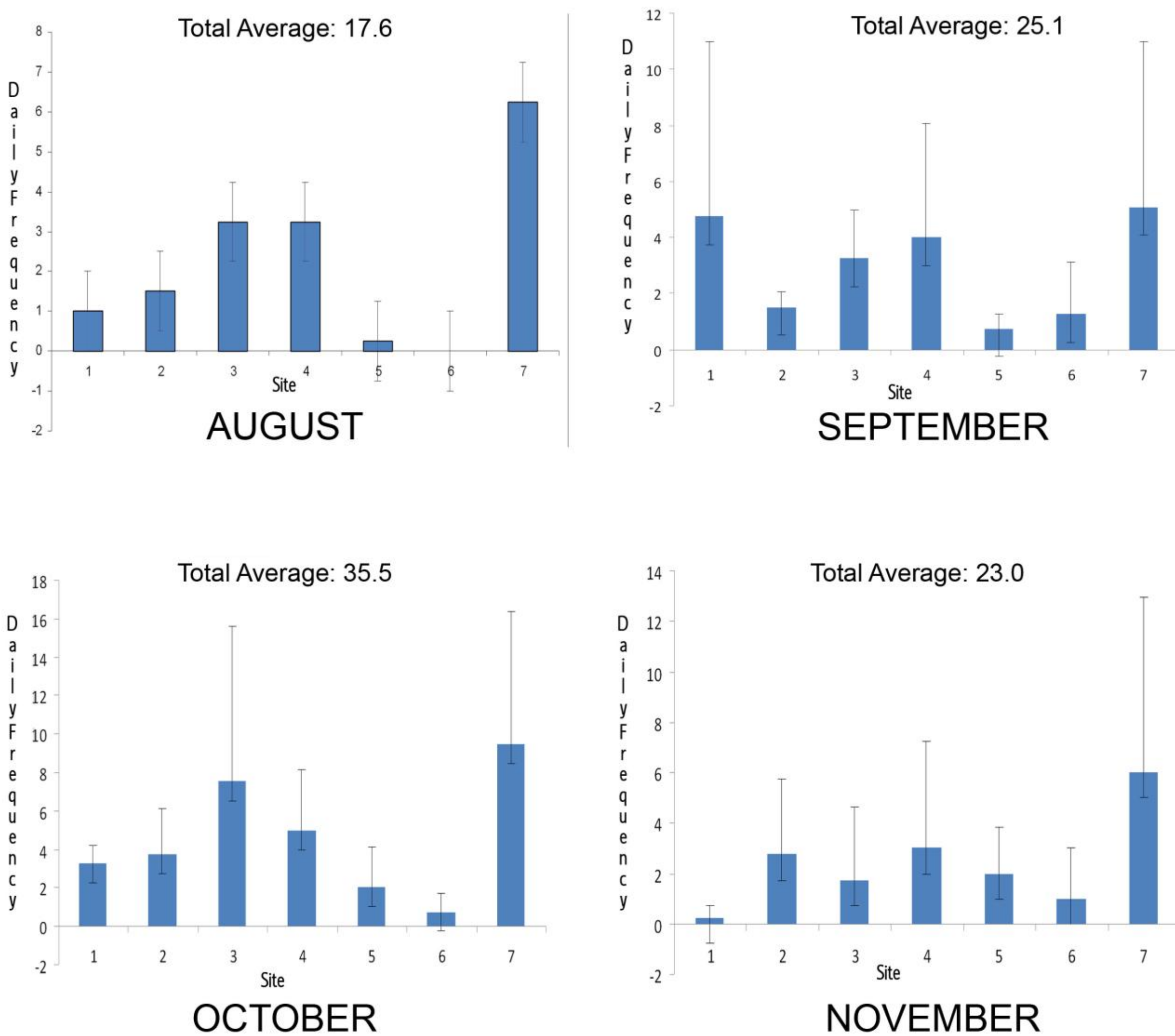

Figure 3.3: Means +/- standard deviation (σ) of daily frequency of raven sightings per month by site during the passerine breeding season August to November: 1) Bathurst Point, 2) tuart grove near The Basin; 3) Peacock Flats near rubbish tip site, 4) tuart grove near Garden Lake, 5) Bickley Swamp, 6) revegetation Parker Point Road, 7) central Settlement. Total monthly averages are given above.

young in September, but had moved out of the area during October, being absent in November. The highest daily average frequency of ravens was recorded in the central settlement, and close to the settlement (Site 4). The highest recorded single count of ravens was of eighteen individuals in the settlement area on 14 October 2010. High numbers of ravens were also recorded in the area in and around the rubbish tip site, along the powerlines at Peacock Flats (Site 3). Lower numbers of ravens were recorded further away from the settlement to the south near Kingston Barracks (Site 5 and 6), and where raven pairs had established territories (Site 2), excluding other ravens from entering the area.

3.3.2 Behaviour and activity

Figure 3.4 illustrates the breakdown of activity by the average number of ravens per day, per site. Ravens on Rottnest Island are highly mobile, with regular movement between sites. Peacock Flats(Site 3), which the powerlines run through, is adjacent to the landfill site and recorded the highest average number of ravens flying overhead per day as they move in and out of the settlement. This flight path crosses Garden Lake (Site 4) which recorded the second highest average number of ravens flying overhead. ‘Flying Overhead’ can be categorised into three behavioural types: in transit (flying high moving between sites); chase (chasing each other as territorial dispute or to obtain food, or mobbing predatory birds); and searching (flying low to inspect site or surveyor). Seven incidents of chasing were recorded by ravens over the project period, of which four involved ravens harassing or chasing off raptors (Osprey *Pandion haliaetus* and White-bellied Sea Eagle *Haliaeetus leucogaster*). In one instance ravens were observed to chase a pair of Australian Pelicans *Pelecanus conspicillatus*. Two incidents of chase due to a territorial dispute were recorded (The Basin and Bickley Swamp). In September 2010, two ravens were observed to chase a pair of Rock Parrots at Bathurst Point.

The settlement recorded the highest daily average number of ravens foraging and perching. Foraging and feeding ecology are explored in depth in Chapter 5. Perching includes roosting, calling and preening. Most often ravens were perched without other activity, and were assumed to be surveying the surrounding area.

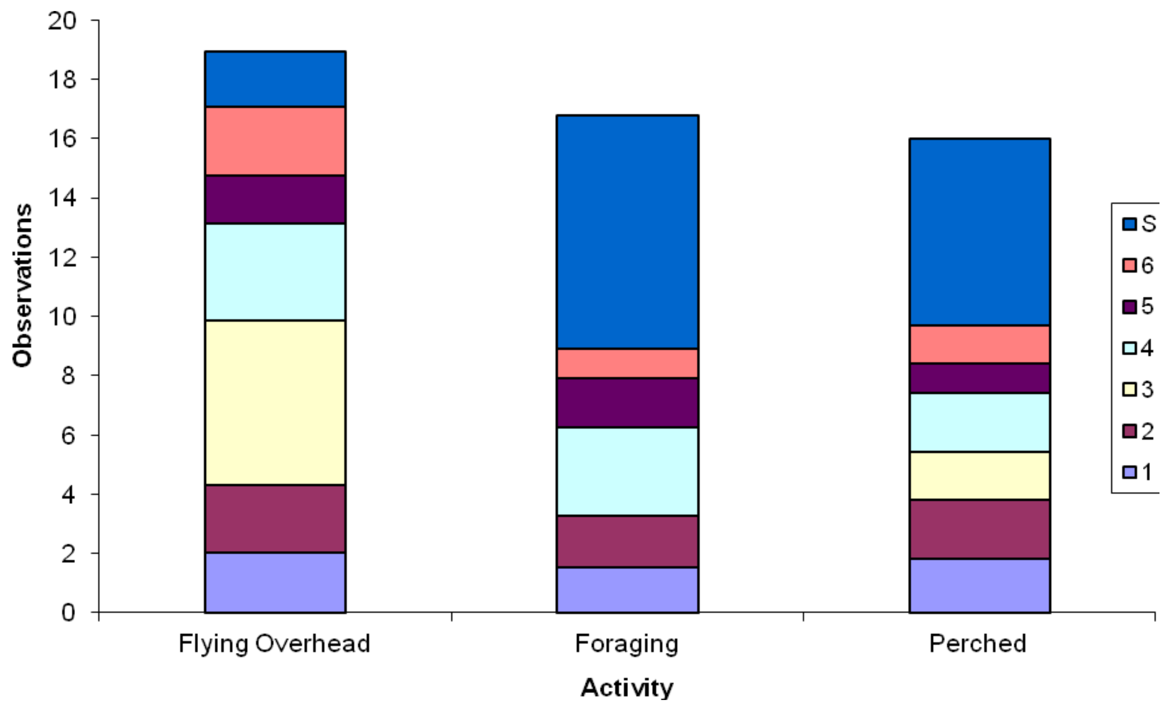

Figure 3.4: Average daily observations of raven activity proportioned by site: 1) Bathurst Point, 2) tuart grove near The Basin; 3) Peacock Flats near rubbish tip site, 4) tuart grove near Garden Lake, 5) Bickley Swamp, 6) revegetation Parker Point Road, S) central Settlement.

There were three incidents where ravens ate discarded food or rubbish left by visitors that they had taken to a perch. Five incidents were recorded where ravens were perched and calling in response to other ravens heard nearby. In four cases another raven then arrived in response to the calls. There were two incidents where perched birds called when the observer was detected, with another three incidents where a raven flying overhead landed to inspect the activity of the observer.

3.3.3 Breeding

Several disused and one active nest were found in the Settlement in 2010 (Figure 3.2). Three old nests were located in Norfolk Island Pines along Henderson Avenue, with additional old nests in tuarts near the cemetery on Digby Drive. A pair was observed actively defending a nest in a pine on the corner of Parker Point Road and Bedford Avenue, and defended the territory chasing other ravens out of the area until Henderson Avenue at which point they retreated. A pair of Osprey also had an active nest in tall pines on Bedford Avenue behind the Hotel Rottnest, and the ravens were frequently observed harassing osprey to the point where adult birds would abandon their nest platform. In some cases, returning Osprey with fish were prevented from landing by ravens dive-bombing and pulling at the tail feathers of the Osprey. Ospreys were seen to retaliate by flipping over mid-flight to present talons, or returning chase.

Two additional active raven nests were located north of the settlement. An active nest was found in a tuart near the tennis courts at Bathurst Point. A pair with a recently fledged young was observed foraging in the area during September 2010. The territory size of this pair was approximately 316m^2, and included the tennis courts, Carolyn Thompson campground and Lancier Street cottages. The juvenile bird was fed by the adults and frequently returned to the nest throughout the observational period. The group was observed again in October, but had moved to the accommodation area south of the tennis courts closer to the settlement. During this time the young bird was still being fed by the adults, and also picking up items by itself. The group was not seen in November, with a single bird being observed on only four occasions in the area. This bird entered the site from the tuart grove to the south, where another nest was located, and may not have been part of the family group observed in September and October. A second pair worked a nest in a tuart near the desalination ponds on Kingsway in October 2010, although no young were observed. The territory of this pair was approximately 575m^2, and included the desalination plant, football oval and campsite behind the Carolyn Thompson cottages. Territorial disputes between the nesting pair and another pair, occasionally involving a third bird, from The Basin area were observed in November, with the neighbouring birds chased out of the territory. No brooding behaviour was observed over the survey period from this pair. Only one nest was found to the south of the settlement, being a single disused nest in a tuart to the west of Kingston Barracks on Kingston Road.

3.3.4 Demographics

Forty-two Australian Raven carcasses were measured and examined internally to determine the age and sexual demographics of the population of ravens on Rottnest Island (Table 3.2).

Age and Sex	Juvenile	Immature 1	Immature 2	Adult	Breeding Adults	Male	Female	Unsexed
2010	10	4	7	10	8	7	13	10
2011	0	3	2	6	1	7	2	3
Total	**10**	**7**	**9**	**16**	**9**	**14**	**15**	**13**

Adult measurement and weight ranges:

Length (mm)	**Tail (mm)**	**Wing (mm)**	**Head-Bill (mm)**	**Tarsus (mm)**	**Weight (g)** N=14
411 - 480 (446)	178 - 201 (196)	238 - 340 (335)	92 - 100 (97)	59 - 62 (62)	437 - 620 (503)

Table 3.2: Demographics of Ravens of Rottnest Island from specimens. 42 Specimens examined in total. Birds that were unsexed were either juvenile birds with undeveloped gonads or where sex was unable to be confirmed on morphometrics. Average lengths and weights are shown in parenthesis.

Sex, age and breeding condition

Specimens were sexed using known morphological measurements (Table 3.2) for male and female Australian Ravens, and confirmed in adults that had advanced gonad development. There was a slightly higher incidence of female ravens to males in the sample, with a greater number of females collected during 2010 (43% of 30 birds), and a greater number of males collected in 2011 (58% of 12 birds).

There were a higher number of birds of non-breeding age in the sample, with 66.3% of the birds in 2010 being equally proportioned as juvenile or immature. In 2011 the age demographics varied with a reduced number of juveniles (8.3%) and an increase in immatures (41.7%) and adults (50%) sampled. Over half of the sixteen adult birds were identified to be in breeding condition, with four females with an obvious brood patch, and one with convoluted oviduct, and four males with enlarged testes.

Morphology

Adult ravens of both sexes from Rottnest Island were slightly smaller than the average size for the western subspecies *C. coronoides perplexus* as given by Storr and Johnstone (2004), although wing, tail and tarsus measurements were all within range. Juvenile birds were considerably smaller, with a length ranging from 401 to 450mm (average 422mm).

Weights

All raven specimens were defrosted, then weighed to two decimals places (of 100g) using a laboratory balance. During the weighing of the specimens from 2011, an error was identified in the calibration of the original balance used. The error was not consistent across all specimens and a corrective factor could not be applied. Since some specimens from 2010 had already been given to the School of Veterinary and Biological Sciences at Murdoch University for examination of parasites, not all specimens could be reweighed. The remaining specimens, three (2010) and eleven (2011), were reweighed using a second, calibrated balance. The average weight of these specimens was 503g, with a range of 437 – 620g in adult ravens. Male ravens were heavier than females, with the male(n=10) weight range from 470 – 620g, while females(n=3) were 437 to 472g.

3.3.5 Parasitology

On completion of laboratory examination of raven specimens, the carcasses were delivered to the School of Veterinary and Biomedical Sciences at Murdoch University where they were examined for internal parasites. The raven specimens from Rottnest Island were found to carry *Toxoplasmosis gondii*, however the results of this project are preliminary and confirmation was not available at the time of writing. Two parasitic worms were identified from the upper small intestine, a round worm Cestoda: *Hymenolepis* and a species of spiny-headed worm (Acanthocephala).

3.4 Discussion

The Australian Raven is one of the most abundant bush birds on Rottnest Island. The observations recorded during this survey illustrate that it is widespread over the island, with the population concentrated in the Thompson Bay settlement area.

Saunders and de Rebeira (2009) suggested a declining trend in the abundance of ravens following the closure of the landfill site in 2004. Culling of the species from June 2009 should have significantly reduced the population. No ravens were able to be identified individually using natural patterns or artificial tags. Therefore ravens were counted each time they entered a site, and represented as a frequency of occurrence or use of the site, rather than an individual count. Observations from a distance of the flight paths of ravens indicate that individual birds may return to a site multiple times during a one hour survey. It is therefore possible to count the same bird multiple times. Counts in the settlement give a more accurate indication of population size as birds were often perched or foraging on the ground, making it easier to count multiple individuals at the same time. From the observations made during 2010 and 2011, I estimate that the population size of the Australian Raven on Rottnest Island averaged approximately seventeen to thirty-six birds throughout the survey period, supporting the continuing decrease in raven abundance. Conversely, despite continued culls throughout the duration of the project, the numbers of ravens counted in the settlement did not decline significantly. This lack of decline and the high number of first and second year birds in the sample suggests that the raven population on Rottnest Island is supplemented by individuals flying across from the mainland, being at its lowest during winter and increasing following post-breeding aggregation. The high number of immature ravens may include non-breeding birds returning to their natal area the following year (Rowley 1973a). The presence of juvenile birds and multiple nests support the change in status of the Australian Raven from a vagrant to an established breeding resident on Rottnest Island.

Territory sizes calculated for two breeding pairs at Bathurst Point (316m^2) and the Basin (575m^2), were considerably smaller than territories of mainland pairs (approximately 1200m^2 Rowely 1973) with the smallest territories closer to the central settlement. Within and close to the settlement, disused multiple nests were found in adjacent trees, with less than 5m between of the base of nest trees. Colonial nesting has not been recorded for the Australian Raven, but the constant and abundant food supply may lead to 'swamping' of the territory whereby pairs will not be able to chase off multiple conspecifics (Rowley 1973a). Tuarts accounted for the majority of nesting trees, with one active and three disused nests found also in Norfolk Island pine. The preference for these tall species may also limit the number of available nesting sites, forcing pairs closer together and reducing territory size. Both the tuart and Norfolk Island pine are exotic species conspicuous in and around the settlement. The establishment of these trees on Rottnest has increased the suitability of the settlement area for breeding for ravens, and may also influence the distribution of ravens. Outside of the settlement, breeding pairs defending a territory may help to reduce the number of ravens at that site.

Ravens are highly mobile over the island landscape, using manmade features and structures to navigate to and from the centralised population in the settlement. Interestingly, even though the landfill site was closed in 2004, ravens are regularly attracted to the area. The elevation of the landfill site is not exceedingly high (12m), being between the higher points of Mount Herschel (20m) and Oliver Hill (23m). It is unlikely that ravens are attracted to the area as a vantage point. It is possible that the natural curiosity of ravens may associate the buildings and vehicles at the site with human activity and therefore the behaviour is habitual. However the high frequency of ravens visiting would suggest that this is unlikely to be a customary behaviour. More likely, there is an unidentified food source attracting the ravens to this location.

Unlike other bush birds of Rottnest Island (Figure 2.4 Chapter 2), the Australian Raven has a strong preference towards manmade structures, disturbed areas and the urban settlement, in particular favouring the bakery and fun park precincts for roosting and feeding. Ravens roosting near foraging areas may benefit through increased efficiency by using social foraging strategies in the local area (Everding and Jones 2004). Storr (1965) and Mather (2009) suggested that the Australian Raven is a potential predator of other birds. If this is so, could the distribution of ravens be an influencing factor in the distribution of smaller bush birds through predation on their nests and eggs? In the next chapter I will investigate the rate of predation by Australian Raven on bushbirds using a series of artificial nest experiments, and relate this to the distribution and frequency of ravens on Rottnest Island.

Chapter 4
Nest Predation by the Australian Raven on Rottnest Island

4.1 Introduction and Aims

Birds are the primary predator of other nesting birds (Fulton and Ford 2001; Piper and Catteral 2004) with corvids considered the most important of avian nest predators (Yahner and Cypher 1987; Buler and Hamilton 2000). In particular, corvid predation of nests may increase in proportion to the local abundance of corvids (Møller 1989) and where habitat is highly fragmented (Andrén 1992). This chapter investigates the rate of nest predation of ravens on bush birds using an artificial nest experiment, and examines how predation is related to the distribution and abundance of ravens in the fragmented landscape of Rottnest Island.

4.1.1 Nest predation by the Australian Raven

Nest predation of eggs and chicks has been recorded by American Crows *Corvus brachyrhynchos* (Hamus 1984), Common Raven *C. corax* (Avery *et al.* 1995), and Steller's Jay *Cyanocitta stelleri* (Hérbert and Golightly 2007). In Australia, Little Raven (Norman 1982; Kentish, Dann and Lowe 1995), Little Crow (Dorfman and Reed 1996) and Torresian Crow (Rowley and Vestjens 1973) have been recorded predating on the eggs and nestlings of other birds. The Australian Raven is adept at finding nests of other birds (Rowley and Vestjens 1973; Dorfman and Read 1996) and has been recorded predating on New Holland Honeyeater *Phylidonyris novaehollanidae* eggs (Major *et al.* 1994), nestling egrets (Baxter 1988), cormorants *Phalacrocorax sp.* (Dorfman and Reed 1996), and eggs of the threatened Hooded Plover *Charadrius rubricollis* (Maguire *et al.* 2011). In Perth, ravens have been observed predating on other birds including doves, ducks, honeyeaters, Willie Wagtail *Rhipidura leucogaster*, Australian Magpies *Cracticus tibicen* and parrots (Stewart 1997).

Australian Ravens on Rottnest Island have been observed to predate ducklings of the Australian Shelduck *Tadorna tadornoides*, chiefly when ducklings are being escorted from the nest site to the brooding area (Riggert 1977). Over 200 Australian Ravens were culled on Rottnest Island in 1958 '.. on the pretext that they were very destructive to birdlife, especially young Australian Shelduck ...' (Storr 1965). Storr examined ten of these carcasses for age, sex and weight, but unfortunately he did not examine the stomach contents to determine if the reasoning was substantiated. During my project, comments received from members of the public and Rottnest Island staff, indicated that there is a concern regarding the perceived predation of ravens on bush birds on Rottnest Island, but there is no published evidence.

4.1.2 Predation on Rottnest Island

Corvids may be wary to predate nests when an observer is present (Montevecchi 1976), making regular observations of active nest predation difficult. To investigate the effect that the Australian Raven population may have on nesting bush birds on Rottnest Island I designed a field experiment using artificially constructed false nests with a real egg as bait and clay egg to record the imprints made by predator mandibles or teeth.

Rottnest Island is a suitable study site for artificial nest experiments in that it is easily accessible, multiple sites can be monitored almost simultaneously, and the fauna, and therefore the potential predator assemblage, is well documented. There are five potential predators of nesting bush birds resident on Rottnest: the Dugite *Pseudonaja affinis*, Nankeen Kestrel, Australian Raven, House Mouse *Mus musculus* and Black Rat *Rattus rattus*. The Australian Raven is the most abundant nest predator resident on Rottnest Island. To further investigate how raven distribution and abundance may influence nesting bush birds, I designed an artificial nest experiment to monitor several sites at increasing distances from the settlement (Figure 2.2b Chapter 2), where the raven population is concentrated, and thereby determined the importance of the Australian Raven as a predator of bush birds on Rottnest Island.

4.1.3 Hypothesis tested

For this experiment, I developed three hypotheses:

1. If nest predation is related to the local raven population, then (i) predation should vary between sites and (ii) should be higher nearer the settlement, where the raven numbers are highest and decrease with distance from the settlement; and (iii) local estimates of raven abundance predation should be highest when more ravens are sighted nearby. I include the three components to this hypothesis because (i) and (ii) were easiest to measure, while (iii) was most informative but also the hardest to measure convincingly.

2. If nest predation is related to exposure of the nest, then more exposed nests should be predated compared to those partially-concealed or concealed.

3. If nest predation is related to nest type, then there should be a statistically significant association between nest type and predation frequency.

4.2 Methods

4.2.1 Artificial nest experiments: uses and criticisms

Artificial, or false, nest experiments have been used successfully to assess corvid predation against various hypotheses including prey size (Montevecchi 1976), foraging memory (Sonerud and Fjeld 1987), edge effects and predator density (Andrén 1992), adverse conditioning (Avery *et al.* 1995) and sensory stimuli (Santisteban, Sieving and Avery 2002). In Australia, artificial nest experiments have been used to identify predators of nesting Scarlet Robin *Petroica goodnoviil* on Norfolk Island (Major 1991), to investigate the effects of Pied Currawong *Strepera gracilina* predation on nesting bush birds (Fulton and Ford 2001) and to investigate forest edge effects (Piper and Catterall 2004).

Artificial nest experiments have been criticised for their ability to accurately represent the predation rates on natural nests (Berry and Lill 2003; Moore and Robinson 2004). In particular that artificial nests are often more evenly and densely placed (Buler and Hamilton 2000); are more visible to predators (Santisteban, Sieving and Avery 2002); demonstrate a varying degree of attraction and detectability for a variety of predators (Roper 1992; Fulton and Ford 2003; Burke *et al.* 2004; Thompson and Burhans 2004) and often the potential predator assemblage is unknown (Weidinger 2001). In addition, corvids develop a search image to increase efficiency when searching for prey (Picozzi 1975; Yahner and Wright 1985; Sonerud and Fjeld 1987; Møller 1989; Bayne, Hobson and Fargey 1997) resulting in trap-lining (successful targeted search by a predator of experimental traps in one survey site resulting in the disturbance of all traps) of experimental study sites (Buler and Hamilton 2000).

To reduce the impact of some of the issues related to using artificial nests, authors have simultaneously monitored real nests (Wilson, Brittingham and Goodrich 1998), and utilised sticky traps or cameras to confirm predators (Major 1991; Thompson and Burhans 2004; Fulton 2006). However, the most commonly recommended approach is to create the artificial nests to be as realistic as possible (Martin 1987; Davidson and Bollinger 2000; Berry and Lill 2003; Villard and Part 2004) in both appearance and positioning, and to decrease the densities of artificial nests at each site (Buler and Hamilton 2000).

4.2.2 Artificial nest construction

The artificial nests were constructed to be as realistic as possible following illustrations and dimensions given in Storr and Johnstone (1998, 2004). The nests of five locally-occurring species were chosen as models for the nests: Laughing Turtle-dove, Golden Whistler, Singing Honeyeater, White-browed Scrubwren and Red-caped Robin, the last four also being listed as species of conservation concern on Rottnest Island (Saunders and de Rebiera 2009) (Figure 4.1). Because nests of the six species of concern are similar in appearance and size, I chose to include the Laughing Turtle-Dove as the fifth nest design to vary the artificial nests. The artificial nests were made by creating a frame shaped from plastic-coated gardening wire and aluminum wire. This was covered in a commercially available paperbark, as used for hanging baskets.

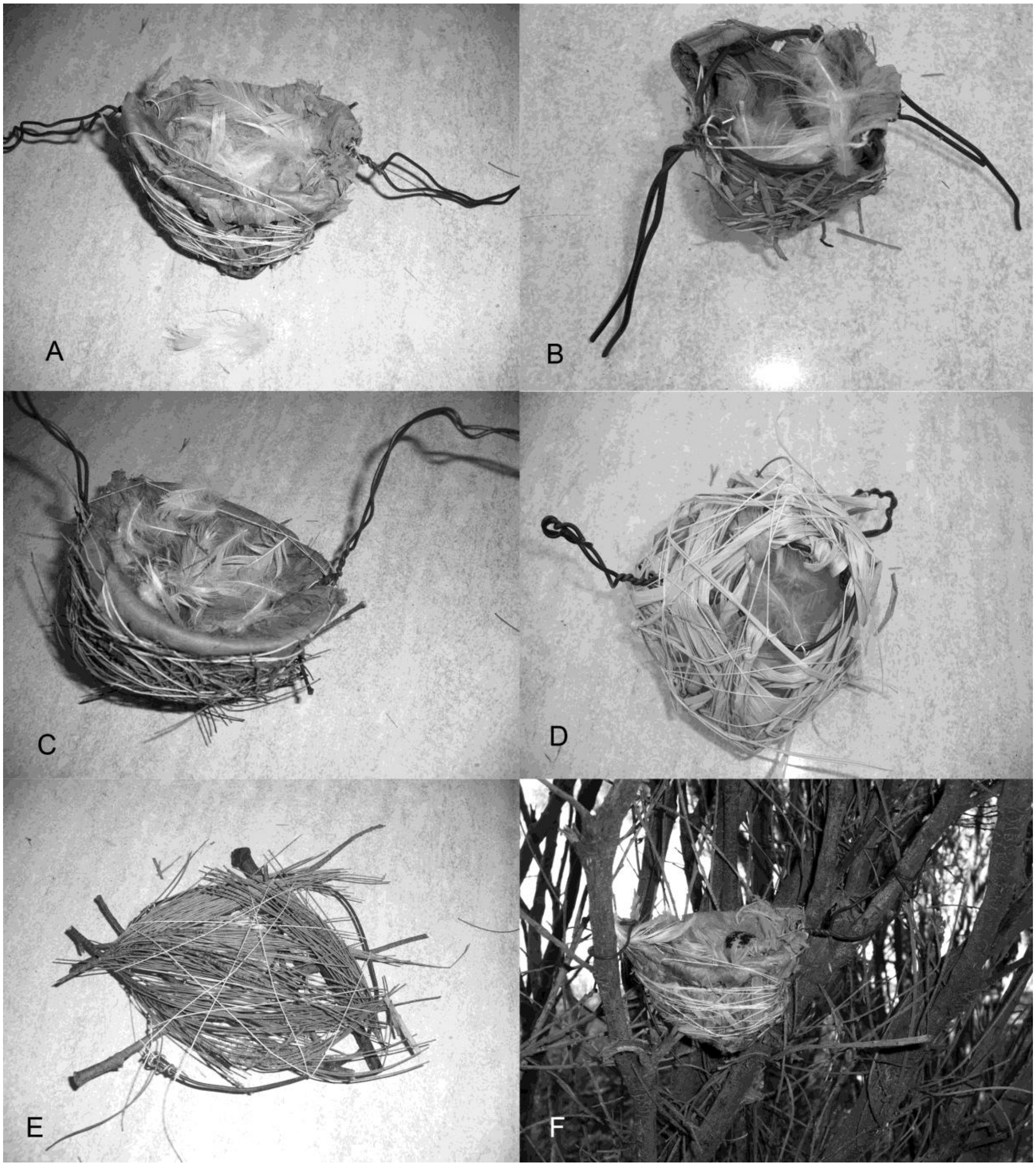

Figure 4.1: Artificial nest type construction: A) Singing Honeyeater; B) Red-capped Robin; C) Golden Whistler; D) White-browed Scrubwren; E) Laughing Turtle-dove; F) Nest placement at site.

The outside of the nests were decorated with a combination of craft raffia, cotton, sugar cane clippings and cleaned she-oak *Allocasuarina sp*. needles, and the inside lined with commercially available chicken feathers. A short wire loop was attached to the bottom of each nest for attaching the clay eggs. Wire extensions were added to the rim of each nest to support and attach the nest when placed in the field. The nests were aired outside prior to placement in the field to reduce human odours, and when not being used were stored together in a sealed box.

4.2.3 Artificial egg construction

Artificial clay eggs were created using *Super Sculpey* (available from Kirkside Product, Osborne Park) a non-toxic oven-bake clay. It was moulded to the size and shape of Japanese Quail *Coturnix japonica* eggs. This clay was chosen over others available for its ability to be baked solid. If an egg was found to be imprinted during inspection of the field sites, the egg, or parts remaining, were baked at 170°C for one minute, fixing the indentations and eliminating the potential to accidentally create other markings. However, care must be taken not to overbake the clay or it will become brittle and crack. Initially artificial eggs were attached with wire run through the middle of the egg and tied to the base of each nest. It was found that without anchoring the clay egg could be completely removed by predators and was therefore irretrievable. Further modifications to the false eggs were made to include a hard inner-core of which wire had been threaded through and then baked in an oven at 170°C for two minutes to harden the clay. An unbaked layer of sculpting clay was then wrapped around this core, before being fixed to the artificial nest with wire, making removal of the entire artificial egg more difficult for predators. Eggs were attached to the artificial nest prior to arrival at the field site and stored together with the nests. Latex gloves were worn when moulding artificial eggs to avoid transferring human-related scents to the eggs.

4.2.4 Bait eggs

Japanese Quail eggs were used as the bait egg for each artificial nest and were purchased fresh prior to each survey. Although quail eggs may be too large to adequately sample all potential predators (for example small mammals, Fulton and Ford 2003), and do not mimic the natural size or colour of the model species, I chose these as they were the only eggs available in the quantity and at the time required. There are only two small mammals present on Rottnest Island, the House Mouse *Mus musculus* and Black Rat *Rattus rattus*, of which neither were target species for this study. Small mammals readily imprint plasticine or clay eggs (Fulton and Ford 2003), and so detection of these species could be made using the clay eggs provided in each nest.

4.2.5 Site selection

A total of 143 artificial nests were set at six sites at varying distances from the settlement over four survey periods: 6-10 September 2010(Trip A), 11-15 October 2010(Trip B) and 8-12 November 2010 (Trip C), and 1-5 August 2011 (Trip D) (see Fig 2.2b Chapter 2); being the months of most active breeding for passerines on Rottnest Island (Storr and Johnstone 2004). Twenty-three of the total artificial nests (143) were those that had previously been predated and redeployed within the same site with a new quail and clay egg (see 4.2.6 below).

A single site for the artificial nest experiment was trialed within the settlement, 200m south of the shopping district. However, the nests were severely damaged or completely removed, and whole clay eggs were removed, making positive identification of predators impossible. Ravens were assumed to be responsible, in particular for the nest damage, but the site was very visible to visitors and human interference could not be eliminated.

To assess predation on ground nesting birds, I trialed sand pads on the shoreline of Government House Lake and Pearse Lake. However, these were disturbed by weather with wind blowing away quail eggs and rain washing away the sand pads, and this method was abandoned.

Five nests, one of each type, were distributed randomly at each site by dividing the site into a numbered grid and selecting five numbers using an online random integer generator (http://www.random.org/integers). The height, vegetation type and concealment of each nest were dependant on the quality and species of the vegetation available in that grid square. Notes were made at each nest of the latitude, longitude, vegetation species, height and if the nest was concealed, partially concealed or exposed.

4.2.6 Monitoring of artificial nests

Nests were monitored daily for four days for each of the four survey periods, being checked once a day. Artificial nests were inspected visually, with care being taken when approaching the nest position to avoid disturbance of any nest or clay egg remains that may have been dislodged from the position by predators. Where positive depredation was detected, the clay egg or any remains were removed and placed in an individual ziplock bag with a data tag enclosed. Notes were made on the condition of the quail egg and artificial nest. If the artificial nest was intact it was removed and replaced randomly within the site with a new clay and quail egg. Nests that were damaged were retained for repair. Imprinted clay eggs or clay parts were baked in an oven to preserve the imprints. Imprints were examined and identified using museum specimens. In an additional evaluation, I placed an artificial nest with a clay and quail egg in vegetation adjacent to the settlement shopping area, where the Australian Raven population was concentrated. I was able to record the technique and markings used by ravens to attack the artificial nest and eggs (Figure 4.2), and use these as guides to confirm the markings found on clay eggs to be those created by Australian Raven.

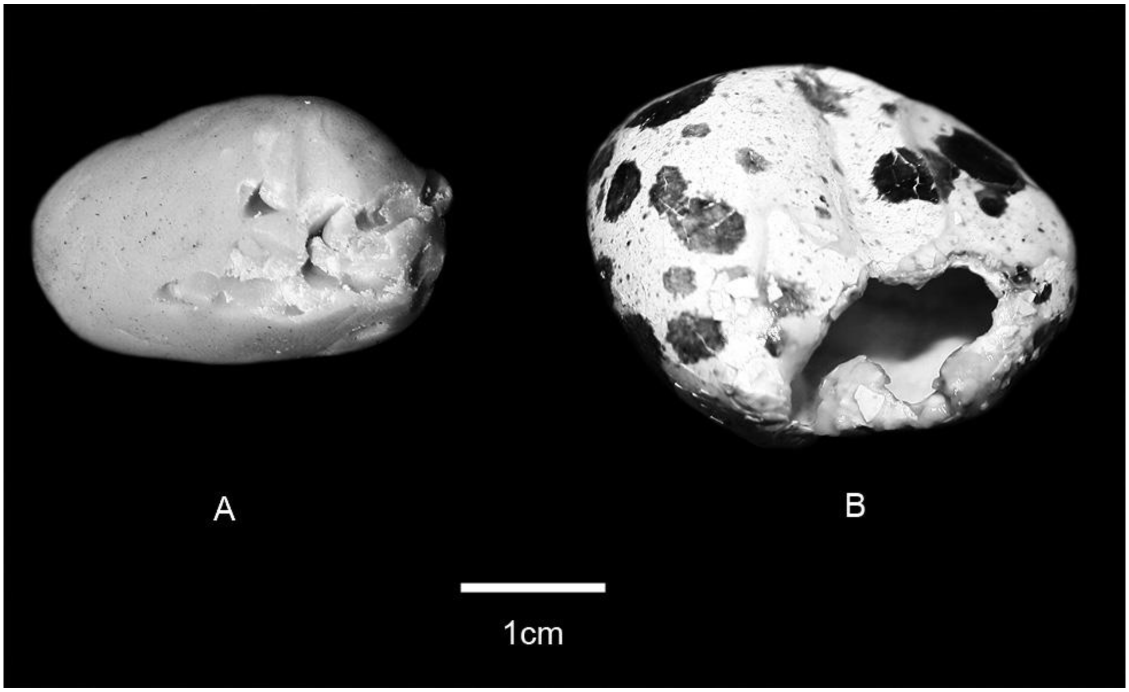

Figure 4.2: Imprints made by Australian Raven on clay egg (A) and Japanese Quail (bait) egg (B).

4.2.7 Statistical analysis

I used chi-squared contingency tables to test for associations between the frequencies of nests predated or not predated in relation to: 1) Site (1 - 6); 2) nest exposure (concealed, part-concealed and exposed) and 3) the false nest type used. In addition, I used linear regression to test if distance from the settlement was related to the level of predation at each site. Data were combined across all surveys for these analyses. All analyses were performed with *Statview 5* (SAS Institute Inc.).

I used Spearman rank correlation to test the final hypothesis that nest predation was related to the abundance of ravens seen near nest sites. I chose a rank correlation rather than a parametric one because I had no reason to believe that any relationship would be linear. Data from all trips and sites were combined. Correlations were calculated using *Statistica* for Windows Version 5.5 (Statsoft 1999).

4.2.8 Control – naturally occurring nests

Each site was searched thoroughly for existing active nests of bush birds which would be able to be monitored for breeding success. Evidence of breeding, such as a bird carrying nesting material or adult with dependent young, was noted when observed. Presence of disused or abandoned nests could not be used as the success of these nests was unknown.

4.3 Results

4.3.1 Identification of predators

Thirty-seven percent (55) of the total number of artificial nests (143) were predated over the survey period (Appendix I). Twenty-nine predated nests were able to be confirmed as being predated by Australian Raven based on the indentations left on the clay eggs (Table 4.1). Four other predation events were able to be identified as Quokka (4) and one of these also with indents of King Skink *Egernia kingii* (1). In one event, the false egg was not imprinted with the quail egg being found on the ground chewed open at one end indicating Quokka predation. However it is possible this was secondary predation by a Quokka. There were three events where the predator was positively identified as raven from indentations on recovered plasticine, but Quokkas were noted as secondary predators. In two of these events Quokkas were observed inspecting nest material and clay eggs on the ground, and in a separate event recovered clay was imprinted by raven, but the bait egg had been consumed by a Quokka. Eight positive predation events in September 2010 were unable to be identified as the clay eggs were not secured correctly and the entire false egg was removed by the predator. Identification of indents in four clay eggs were unable to be confirmed to species. In the remaining ten nests that were unable to be identified the clay egg was either ignored (5) or consumed (5) by the predator. Of the nests confirmed to be predated by ravens, 35% had been damaged, usually with partial nest construction material removed from the frame. Occasionally, all construction material had been removed.

Status	Raven	Other	Unidentified
Bait egg removed + clay egg intact	0	1	5
Bait egg removed + clay egg recovered/imprinted + nest OK	17	2	4
Bait egg removed + clay egg recovered/imprinted + nest damaged	9	1	0
Bait and clay egg removed + nest OK	2	0	8
Bait egg and clay egg removed + nest damaged	1	0	5
Total	**29**	**4**	**22**

Table 4.1: Status of nests predated by predator. Ninety-three nests not shown here were not predated (bait and false egg retained, and no nest damage).

4.3.2 Predation intensity

The average rate of nest predation over the total experimental period was 11.4% of nests (0.57 nests per site) per day. Predation rates were higher at Site 5, Site 6, Site 1 and Site 4 (Table 4.2). Predation peaked in November (Figure 4.3) at all sites except Site 2, even though abundance decreased in November. The increase in predation in November is attributed to high predation recorded at the southern sites, Site 5 (Bickley Swamp) and Site 6 (Thompson Bay) during that month (Table 4.2). Site 5 had 80% of nests predated on one day, with four nests being predated on the 11 November 2010, all having the bait egg removed and three of which the clay egg had been ignored. All five nests were predated at Site 6 over two days, 10 and 11 November 2011, and all of the clay eggs were retrieved from nests and positively identified as raven.

	Distance from	Trip D AUG	Trip A SEPT	Trip B OCT	Trip C NOV	Total Predation	Total No.	Average Daily Abundance (a)

	Settlement					(a)	Nests	
SITE 1	582m	0.5	1	0.25	1	11	25	2.31
SITE 2	636m	0	0.75	0	0	3	23	2.38
SITE 3	1539m	0	0.25	0	0.25	2	22	3.94
SITE 4	285m	0.25	0	1	1.25	10	26	3.81
SITE 5	1392m	0.5	0.75	1	1.25	14	25	1.31
SITE 6	1051m	0.5	0.25	0.75	1.25	11	22	0.75
Total Predation (b)		7	12	13	19	**51**		
Total Average Daily Abundance (b)		17.62	25.16	35.53	22.87			

Table 4.2: Average daily rate of predation (exclusive of 'other') by site for each month, with average raven abundance by site(a) and by month (b). Months of highest predation rate are shaded. Total Average Daily Abundance (b) includes raven abundance recorded from the Thompson Bay settlement.

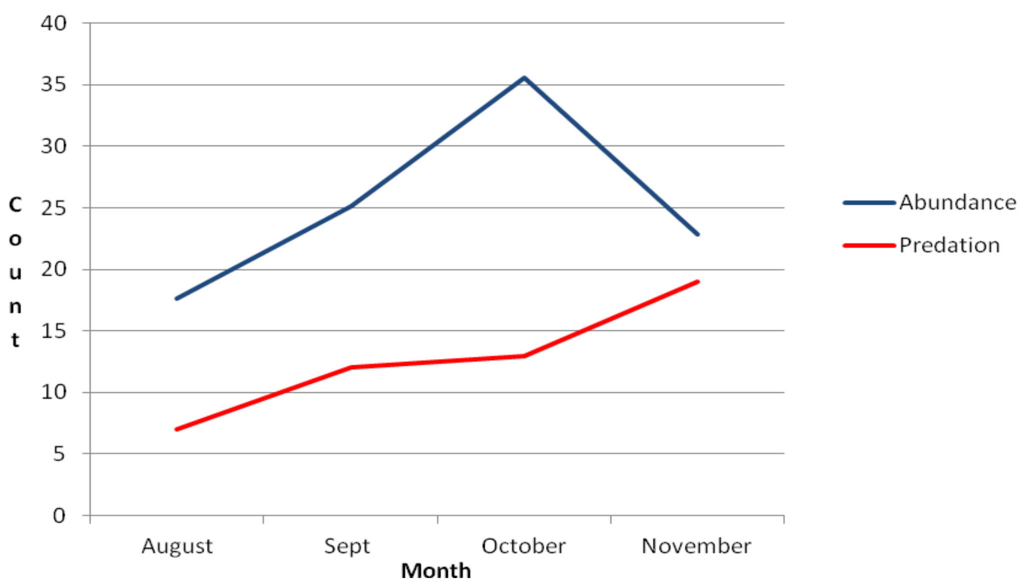

Figure 4.3: Total rate of predation compared to average raven abundance by month (Appendix II), exclusive of 'other' predation

Overall, very low predation was recorded during August 2011, with no predation was recorded at Site 2 and Site 3. Site 3 was the furtherest site from the settlement and recorded the lowest average daily predation frequencies, with 9% of nests predated over the four survey months. The highest average daily abundance of ravens was recorded at Site 3 and Site 4, and in lower abundance at Site 5 and Site 6 (Table 4.2).

4.3.3 Tests of specific hypotheses

Hypothesis 1(i) Predation versus site

Predation varied significantly across sites (χ^2_5 = 19.22, p = 0.0017), being lowest at Site 3 (13%). Site 4 and Site 1 recorded similar predation rates of 38% and 44% respectively. The sites with the highest predation rates were at Site 5 with a predation rate of 56%, and Site 6 (50%). The high predation rate at these sites is attributed to the unusually high predation intensity recorded in November 2010 (Table 4.2) (Appendix I and Appendix III).

Hypothesis 1(ii) Predation versus distance from settlement

Although predation differed significantly across sites, there was no relationship between distance from the settlement and predation rate (f = 0.049 (d.f. = 1,4), p = 0.8364, r^2 = 0.012) (Figure 4.4). High predation rates were recorded close to (Site 1 and Site 4) and further away from the settlement (Site 5 and Site 6).

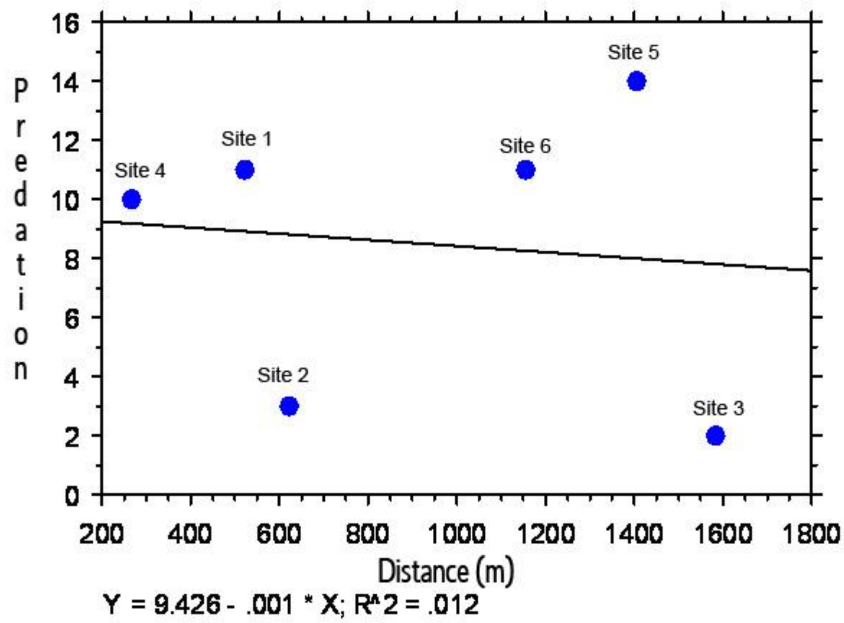

Figure 4.4: Linear regression test relating predation intensity to distance(m) of the site from the settlement.

Hypothesis 1(iii) Predation versus abundance

The total number of ravens observed nearby each site did not correlate with the incidence of nest predation (R = 0.04, t(N-2) = .39, p = 0.69). Site 3 recorded the lowest predation intensity but the highest raven abundance (Table 4.2). Whereas sites ranked highest for predation (Site 5, Site 6, Site 4 and site 1) varied in raven abundance.

Hypothesis 2 Predation versus nest exposure

Nest exposure was subjectively classified as either exposed (no vegetation cover, nest visible), partially-concealed (some vegetation cover, nest visible) and concealed (completely covered, nest not easily visible). Exposure was associated significantly with predation, with predation greatest in nests that were exposed (χ^2_5= 6.49, p = 0.039). Fifty-two percent of nests classed as exposed were predated. Partially-concealed and concealed artificial nests were equally predated (31%) (Appendix I and Appendix V).

Hypothesis 3 Predation versus nest type

Five different artificial nest designs were used at each site during each survey period (Figure 4.1). There was no significant association between the type of artificial nest used and predation (χ^2_4 = 4.76, p = 0.31) (Appendix I and Appendix IV).

4.3.4 Active natural nests

During the surveys, several observations of adult birds with dependent young (Site 1, Site 4, Site 5 and Site 6) indicated that there had been recent successful breeding by bush birds (see Chapter 2). However despite intensive searching of all sites, no active nests of bush birds were located during the survey periods.

4.4 Discussion

The Australian Raven is a known predator of bush bird eggs and nests in Australia, and is a presumed predator on Rottnest Island, although there has been no documented evidence of predation on the island. The results of this experiment demonstrate that the Australian Raven is highly likely to be an active predator of bush birds on Rottnest Island. Overall 20% of nests suffered confirmed raven predation.

Raven predation of artificial nests varied across sites, but did not decrease with the distance of the sites from the centre of the Thompson Bay settlement, where the raven population is concentrated (Figure 3.2 Chapter 3). There was also no significant trend between raven abundance and predation intensity at each site. A range of ecological and behavioural factors, as examined in Chapter 3, explain these results. Site 3 recorded the lowest rate of raven predation and also recorded the highest raven abundance. Ravens recorded at Site 3 were most likely passing through the site in transit to and from the landfill area and not using Site 3 for foraging (Chapter 3). Although Site 2 was at a similar distance to the settlement as Site 1, it recorded lower predation intensity.

This can be explained by the presence of a territorial pair of ravens at Site 2 that excluded other ravens from foraging in the area. This behaviour has also been observed in the Common Raven (Avery *et al.* 1995). The high rates of nest predation at Site 5 and site 6 are explained below.

I addressed selected criticisms of artificial nests by the use of realistic nest models by varying designs to reduce the likelihood of ravens using a search image to deliberately target artificial nests. The lack of significance of nest type against predation intensity indicates that there was no bias towards artificial nests for predation. In addition, only five nests were present at each site at any one time and for only four days per month, reducing the time and density of nests available for ravens to develop a search image. However, the high predation rates and Site 5 and Site 6 in November 2010 indicate that some deliberate targeting of artificial nests by ravens did occur at these sites. I believe that in these cases one or more ravens were able to identify artificial nest locations by watching the observer inspect nests on earlier days.

One of the requirements when conducting field work on Rottnest Island was that I had to wear an orange high-visibility safety vest at all times while in the field. Corvids recognise individual humans (Bugnyar and Heinrish 2005) and may learn nest locations based on human activity (Thompson and Burhans 2004; Villard and Part 2004). While wearing the orange vest I would have been easily distinguishable from other humans in the area, and therefore able to be tracked by an observant raven (see 3.3.2 Chapter 3). A further criticism of artificial nest experiments is the lack of knowledge of potential predators. The fauna of Rottnest Island is well known, and five potential predators were identified. However, two additional predators were identified during this experiment that had not been considered, the Quokka and King Skink.

Quokkas are not considered to be a predator of nests and eggs as they are regarded as a browsing herbivore (Hayward 2005) foraging mostly on the ground. Quokkas are adept climbers (P. Mawson[5] *pers. comm*. 2010; R. Priemus[6] *pers. comm.* 2011) and may have been attracted to lower nests from human-related scent on the artificial nests. Quokkas were often encountered

[5] Dr Peter Mawson Principal Scientist, Species and Communities Branch, Department of Environment and Conservation, Kensington

investigating abandoned field equipment or luggage, presumably for food, as they readily take processed food from island visitors in and around the settlement. Another consideration is that Quokkas may have been secondary predators when nests were initially disturbed by ravens. It is unlikely that the Quokka would be a primary predator of bush birds during August to November when plant material is abundant (see Storr 1963).

Predation was also associated significantly with nest exposure, with nests that were more exposed being more likely to be predated. Nest exposure could be used to measure the health of a habitat, with denser vegetation providing greater concealment of nests and therefore better protection from predation by ravens.

The inability to find and monitor active breeding bush bird nests represents a lack of control in this experiment. However, successful breeding of bush birds was recorded at Site 1, Site 4, Site 5 and Site 6. These sites were also those sites where predation by ravens was highest. The audible calls of begging young when being fed by attending adult bush birds or alarm calls from brooding adults may act to attract or cause ravens to intensify their search effort at these sites. Similar behaviour was observed by Hamus (1984) of American Crows predating on brooding Spotted Sandpiper *Actitus macularia*.

While I believe that the results of this experiment do confirm the potential for ravens to predate on bush bird eggs and nestlings on Rottnest, they do not show that predation actually occurs. To confirm if the Australian Raven is a predator on bush birds nests, and to evaluate how important this food source is in the diet of the raven, I examined the stomach contents of raven specimens collected through the Rottnest Island Authority *Pest Management Plan*. The results of the examination of the stomach contents are presented in the next chapter.

[6] Ron Priemus Ranger, Rottnest Island Authority, Victoria Quay, Fremantle

Chapter 5
Feeding Ecology of the Australian Raven on Rottnest Island

5.1 Introduction and Aims

In Chapter 4 I demonstrated that the Australian Raven is a potential predator of nests of other bush birds. To further investigate the evidence for ravens predating on bush birds, and determine the importance of bush birds as part of the raven's diet, I recorded the foraging behaviours of ravens observed during the passerine breeding season (August to November), and confirmed the diet by examining and identifying the stomach contents of culled ravens from Rottnest Island.

5.1.1 Diet of the Australian Raven

Australian Ravens are general omnivorous scavengers, the diet consisting of small vertebrates (mammals, lizards, bird eggs and nestlings), invertebrates, seeds and fruit (Higgings *et al.* 2006). They are most often observed feeding on carrion, and human refuse (Storr and Johnstone 2004). The diet can change during the year in response to the availability of different food types, for example insects in spring and summer months, and seeds, fruit and meat during autumn and winter (Rowley and Vestjens 1972). The Australian Raven most often obtains food by searching on the ground, by turning bark, soil or leaf litter; and by actively predating on live vertebrates including other birds (Higgins *et al.* 2006). Food is generally eaten where it is found, unless feeding nestlings or if needing to soak the item in water. Occasionally food is cached (Higgings *et al.* 2006). Inedible objects are also consumed accidentally or deliberately, for example an Australian Raven at Murdoch University Western Australia was observed to ingest, and possibly cache, used cigarette butts (M. Calver[7] *pers. comm*. 2010).

Corvids do not have a crop, they have liquid faeces and regurgitated pellets are only rarely produced (Rowley and Vestjens 1972), therefore food items consumed by corvids are best

[7] Ass/Prof. Michael Calver, School of Biological Sciences and Biotechnology, Murdoch University, Murdoch

analysed using stomach samples obtained from deceased specimens. There have been two detailed studies published on the diet of Australian Raven, in both cases the authors quantified stomach samples as well as observing raven foraging activity. Rowely and Vestjens (1972) investigated Australian Ravens foraging in rural south eastern Australia, finding that flesh (as carrion) was the most significant component of the diet. Other bird remains accounted for 5% of the diet of ravens in their study, consisting of roadkill as well as nestlings and eggs. Stewart (1997) examined Australian Raven specimens from Rottnest Island, Kings Park and Claremont, finding that as well as meat, the diet of urban ravens consisted mainly of plant material (fruit, seeds, berries) and insects. On Rottnest, ravens feed readily on Quokka carcasses. The increase in Quokkas following their protection in (c1931) (Storr 1963), helped sustain the increasing raven population (Saunders and de Rebeira 1985).

5.2 Methods

5.2.1 Field observations

Using binoculars I recorded raven foraging behaviour as part of the routine surveys of six predefined sites and the Thompson Bay settlement (see Chapter 3). Opportunistic observations were recorded between sites at other locations. Locations of observations were marked using a GPS and the latitude and longitude recorded. The data were imported into GIS software *Arcview 9.3* for Windows (ESRI Australia Pty. Ltd.) for mapping and analysis.

5.2.2 Laboratory examination of stomach contents

Carcasses were obtained from authorised culling by Rottnest Island Authority Rangers in 2010 and 2011. Twenty-six raven specimens were used for stomach content analysis. The majority of specimens were collected from the settlement area (22), with three specimens collected from Bathurst Point and one from Signal Hill. In the first instance (2010) birds were trapped using cage crow traps and bread as a bait. Thirty ravens from this trapping period were autopsied for crop and stomach content, age, sex and reproductive condition. The use of bread compromised several of the 2010 stomach content samples and further culling, of twelve birds, was conducted in 2011 (May – September) without the use of a bait in the cage traps. The successful cage design was developed by Ron Priemus (Rottnest Island Authority). A medium sized cage, or Sheffield, trap was modified by inserting a Perspex shield to portion off the rear section of the trap behind which the bait was placed. The cage and bait were left open and accessible to the ravens to habituate the birds to enter the trap without being caught. After a few days, the Perspex barrier was put in place and the trap was armed allowing the birds to be caught without permitting them access to the bait. In some cases, the ravens were able to be trapped without either the Perspex shield or bait, with ravens entering the trap to inspect it (R. Priemus[8] *pers. comm*. 2011). Specimens were immediately frozen and later transported to the Western Australian Museum for dissection.

Stomach samples were removed from specimens during dissection for sexing (Chapter 3) and examined. Samples where the ravens had consumed bread used as bait in the trapping method were eliminated from further investigation. Twenty-six specimens were preserved and examined wet under a compound microscope. The contents were separated into either plant/seed, invertebrate, vertebrate, processed food, foreign object, and grit/debris (Table 5.1). Where tissue or meat material was unable to be identified, it was considered to be unknown meat.

To calculate the percentage weight for each category, each individual category from each sample was dried and weighed to four decimal places. And index of relative importance (IRI) (Hart, Calver and Dickman 2002; Armstrong and Booth 2005) was calculated from the percentage frequency of each food type (F) and the mean percentage volume of the total weight (V):

$$IRI = 100(FiVi / \sum_{i=1}^{n}(FiVi))$$

[8] Ron Priemus Ranger, Rottnest Island Authority, Victoria Quay, Fremantle

Where n = number food categories and *i* = the food category.

5.3 Results

5.3.1 Foraging behaviour and food sources

Foraging behaviour was most often observed in and around the settlement, in particular around the shopping precint, Heritage Common, the hill behind the salt store and fun park (Figure 2.2a Chapter 2). Important secondary foraging areas were the sports oval on Kingsway (Site 2), around the lakes and the hillside of Vlamingh Lookout (Site 4).

Ravens were most often observed feeding on the ground. Eighty-three percent of 'on ground' foraging activity (Figure 5.1) was recorded with ravens observed digging in lawned areas, digging in soil on the side of roads, in gardens and open woodlands, and searching paved areas under tables and seating. Ravens also foraged in leaf litter under vegetation (12%) and along the edge of Garden and Government House Lake shorelines (8%). When digging, ravens use their bill, either closed or opened, as a shovel to clear away leaf litter in a sideways motion, or to excavate shallow, narrow scrapes when foraging deeper. Co-operative digging, involving both adults and juveniles, was also observed, with one bird digging while the other stood or hunched close by, picking up items as they were uncovered.

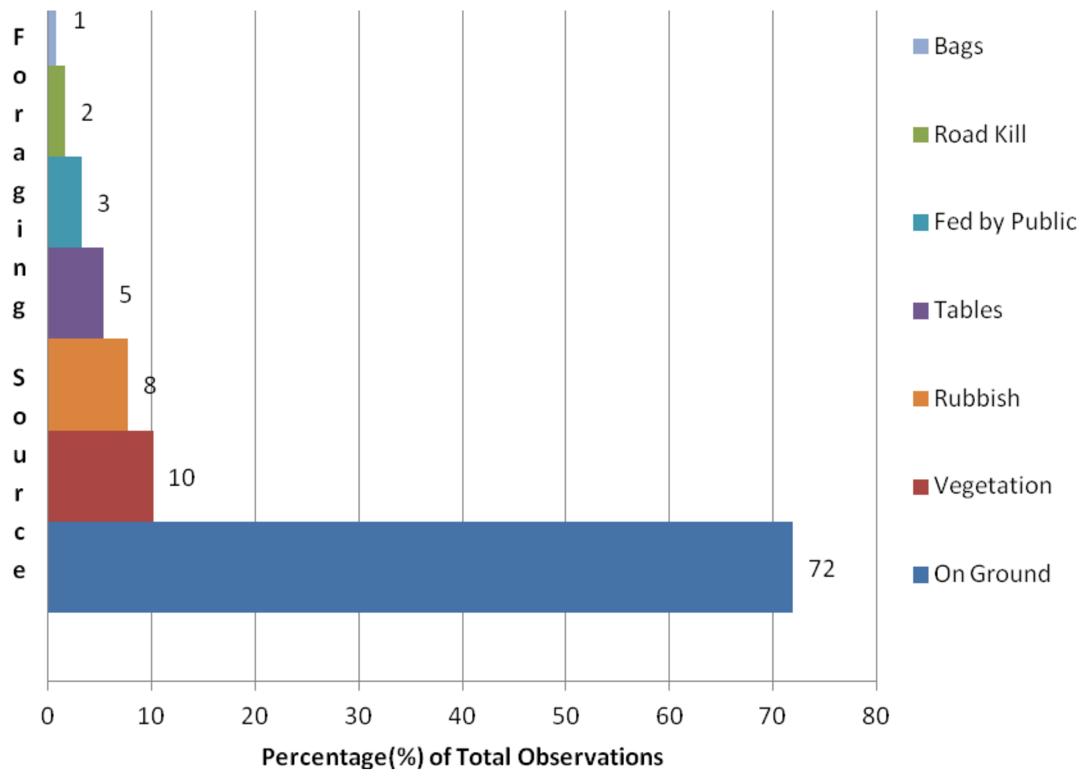

Figure 5.1: Sources of food in foraging Australian Ravens on Rottnest Island by percentage of total number of ravens observed(246) during the survey: Bags – shopping or luggage of visitors; Road kill – deceased vertebrates not killed by ravens; Fed by public – offered by visitors; Tables – unattended food or leftovers in eating area; Rubbish – bins or litter; Vegetation – feeding in or on trees and shrubs not including lawn; On ground – foraging under vegetation, on roadside, lakeside or lawned areas.

In the settlement, the leaf litter and area under the canopy of Moreton Bay figs were favoured ground foraging microhabitats, where ravens were observed feeding on ripened fruit and digging in the soil (Figure 5.2). During surveys in August 2011 Silver Gulls and Galah were observed waiting underneath fruiting Moreton Bay figs to pick up dislodged or dropped fruit from ravens feeding in the canopy of the same tree. Other than the Moreton Bay fig, ravens were recorded feeding on two additional vegetation types. A juvenile raven was observed tearing bark from a marlock on one occasion near the accomodation at Bathurst Point, however it was not seen to injest any parts of the plant. On three occassions in November 2010, ravens were also observed feeding on samphire *Tecticornia sp*. along the shoreline of the causeway between Government House Lake and Herschel Lake. I was unable to determine if the ravens were feeding on parts of the shrub or invertebrates that may have been on the shrub, but Rowley and Vestjens (1972) mention corvids feeding on succulent fruits in arid areas, and this behaviour may have been what was observed.

In the shopping precinct, ravens were observed searching under tables and chairs for rubbish and food dropped by the public. In addition, ravens were also recorded foragaing on tops of tables in alfresco eating areas feeding on uneaten food, wrappers and bevereages. In three instances, ravens approached patrons eating a meal to within 30cm. Unlike Silver Gulls also foraging in the area, ravens waited until food was dropped accidentally or patrons left before taking food. Gulls were observed to fly onto tables and plates still being used by patrons to steal food. In September 2010 a gull was observed to fly into the faces of patrons as they lifted food to eat, and flew at customers leaving with purchases from the bakery causing them to drop the food. The public were seen to deliberately feed ravens and gulls on two occasions. When a squabble over food occurred, gulls would concentrate in the centre, while ravens remained on outer edges of the gull flock, waiting for food to be tossed out during the frenzy. Ravens did not chase gulls with food, but would steal from and chase conspecifics to force them to drop food and rubbish. Rubbish including sauce containers, packaging, paper wrappers and softdrink cans, was taken from tables or outside bins. Either the item was carried to a perch or investigated as found. Ravens picked the item clean by holding it secure with the feet. Ravens were able to tear open plastic bags from overfilled residential rubbish bins, pulling items to the ground and carrying them off, abandoning them later. Similarily, ravens were observed to tear open plastic shopping bags and attempted to open other luggage left unattended on bikes or at tables (Figure 5.2).

Figure 5.2: Raven foraging behaviours: a) over flowing rubbish bins with bags that have been torn open; b) picking at discarded sandwich wrapper; c) drinking from glass on table outside bakery; d) tearing open unattended shopping bag on bike parked in shopping precinct; e) drinking from discarded soft drink can; f) digging in soil under fig tree in fun park.

Feeding on carrion (Banded Stilt *Cladorhynchus leucocephalus* and Crested Tern *Sterna bergii* carcasses) was observed on three occasions along the causeway between Herschel and Government House Lakes. None of the carcasses appeared to have been killed by ravens. The stilt carcasses were fresh and appeared to have died of impact trauma from collision with a vehicle or powerlines, while the tern had been dead for several days and had been eaten open by a larger predator, most likely a raptorial bird.

In addition to feeding behaviours, ravens were observed drinking on four occasions, obtaining fresh water from a dripping tap at the Bathurst Point tennis courts; and from rainwater collected on the road, accommodation gutters and pooled in the fork of a Moreton Bay fig tree behind the bakery.

5.3.2 Food types and importance

There was a high variety of food types in individual stomach samples with eighteen samples containing three or more food categories, most commonly including seed/plant material, invertebrate and grit/debris material (Table 5.1). Seeds and plants included seeds, seed husks, leaves, nuts, berries or fruit, fruit skin and fruit or plant pulp, and accounted for the highest total combined weight, greatest mean volume and had the highest frequency of occurrence across all the samples. Seed and plant material was also was ranked most highly using the IRI. Grit and debris were ranked second. However this material was considered to have been ingested unintentionally while feeding on other items. Similarly foreign objects, although ranked third, are not considered to be usually deliberately ingested. Included in the samples were paper wrappers, a sugar packet, foil wrappers and a small green bead. Invertebrate material was ranked fourth, although this food type accounted for the second highest frequency in the samples. The samples included heads and cerci (pincers) of earwigs (Order: Dermaptera), beetle elytra (wing casing), wings and legs (Order: Coleoptera), a land snail (Class: Gastrapoda), chitons (Class Polyplacophora), parts of unidentified pupae and pupae casings.

Food Category (*i*)	Seed/Plant	Grit/ Debris	Foreign Objects	Invertebrate	Vertebrate	Processed Food	Unknown Meat
Total weight (g)	12.7640	7.6681	3.3021	1.0906	1.9733	0.0879	0.0046
Mean % Volume of Total weight (W)	46.53	27.95	12.04	3.98	7.19	0.32	0.02
% Frequency of occurrence (F) (No. Samples)	88.46 (23)	76.92 (20)	26.92 (7)	80.77 (21)	26.92 (6)	23.08 (6)	3.85 (1)
IRI	**57.87**	**30.22**	**4.56**	**4.52**	**2.721**	**0.1**	**0.001**
Description	*Seeds, nuts, fruit and plant fibres*	*Particles of wood and shells; sand, fibres, rootlets and unidentified material.*	*Foil and paper wrappers, beads and plastic*	*Insect parts, larvae and casings, and molluscs*	*Bones, skin and feathers*	*Bread, pastry, processed nuts and meat*	*Unidentified meat*

Table 5.1: Index of relative importance: the total weight(g), percentage frequency, mean percentage volume and for each category of food type, proportioned by combined dry weight volume. Total weight 27.4335g (N=26).

Vertebrate material was found in six samples and was ranked of lesser importance. Four of these samples included feathers and bones; while one sample included two small unidentified vertebrae (possibly reptilian on size) and another with unidentified bone fragments. Only one sample was able to be identified to species, being a partial webbed foot and downy feathers of a duckling of Australian Shelduck (August/September 2010). Another sample was identified as a passerine nestling, based on small size of the bones and the presence of multiple unsheathed (pin) feathers (August/September 2010). The two remaining bird feather and bone samples were not able to be identified. Processed food was ranked insignificant, however was also identified in six samples. This included bread, pastry crusts, processed nuts (roasted hazelnut) and processed meat such as bacon.

5.4 Discussion

In the previous chapter I identified the Australian Raven as a potential predator on nesting bush birds. The presence of bird feathers, tissue and bones in the stomach contents of the ravens sampled, confirm that the Australian Raven does predate on other birds, specifically passerines and ducklings in this study. However, the vertebrate material identified also included reptilian bones, and was ranked less important than invertebrates and plant material. The relatively low frequency of bird material in the stomach samples suggests that birds are not an important component of the raven diet. In addition, no observations were made of ravens actively predating on birds during the survey period.

Seeds, fruit, nuts and plant material, in particular figs, were ranked the most important food category, and also had the highest volume and frequency of occurrence in the samples. Ignoring grit and debris that was most probably ingested while feeding on other foods, invertebrate material, in particular earwigs and beetles, was ranked the second most important food group. The high proportion of plant and invertebrate material in the samples is supported by the observations that ravens were most often observed foraging on the ground or in and around vegetation, where these food types would be expected to be found. The results from this study agree with raven stomach specimens examined by Stewart (1997) from Rottnest Island and the Perth Metropolitan Area, which also consisted mainly of plant and invertebrate material.

If the four foraging sources associated with human activity (bags, fed by public, tables and rubbish) are considered together, the combined value is 17% of total foraging observations, and is greater than vegetation sources. Human activity and accommodation on the island is centralised in the settlement, where the raven population is also concentrated (Chapter 3). It can be assumed that human activity provides a key foraging source, agreeing with the observations of Rowley (1973) that the Australian Raven roosts close to the nearest current food source.

Initially, culling was conducted at the discretion of the Rottnest Island Authority as indicated by the requirements of the *Pest Management Plan*. Ravens were trapped in the settlement as the concentration of the population in this area increased trapping success. It is possible that this created a bias towards sampling birds that had recently foraged within the settlement, where fewer bush birds occur. However, the observations of ravens collected during this project demonstrate that there is frequent movement of ravens in and out of the settlement (Chapter 3). I decided not to request specimens from the six experimental sites to avoid interference with the artificial nest experiment. Placing traps at the experimental sites could have potentially influenced the results of the artificial nest experiments by either attracting ravens to the area, or by removing ravens that may have been potential predators of the nests.

Although birds account for only a small proportion of the diet of ravens, the deleterious impacts on the populations of small bush birds cannot be ruled out. It is not possible to conclude if predation by ravens is a direct threat to any of the bush bird species on Rottnest Island, or if it is additive to other causes of decline such as habitat loss and fragmentation. It may be possible that ravens are acting as a compensatory source of predation on those individuals that may have otherwise died from other causes (e.g. Banks 1999). Therefore, there is a need to identify how to definitively test if raven predation is a threatening process of the bush birds on Rottnest Island, and if precautionary methods, such as regular culling, should be continued while awaiting an absolute resolution to the question. The importance of the raven as a nest predator of bush birds, and the management of the raven population on Rottnest Island is considered in the General Discussion.

Chapter 6
General Discussion

The motivation for this study was the concern from Rottnest Island Authority regarding the potential threat to bush birds from predation by ravens, and the need to identify the diet of the Australian Raven on Rottnest Island.

Rottnest Island is an important refuge for the conservation of bird species that are in decline on the adjacent mainland. The history of land clearing, increased fire regimes and urbanisation has impacted the avifauna of Rottnest, with several species declining since European settlement. Six bush bird species have been identified to be of conservation concern, of which two of these may be genetically different from mainland populations. Therefore there is a need to protect bush birds on Rottnest Island from further decline.

6.1 Outcomes from this study

During this study I used three approaches to answer the research questions: field observations, a field experiment and laboratory examination of specimens. The summarised outcomes for each question are given below, and detailed discussions for each can be found in the relevant chapters:

6.1.1 Question 1: What is the distribution of bush birds on Rottnest Island?

Observational data collected during this survey and external data sources illustrated that the majority of bush birds on Rottnest Island have a strong affiliation with remnant and revegetated areas, while avoiding urbanised and disturbed areas (Chapter 2).

6.1.2 Question 2: What is the abundance and distribution of the Australian Raven on Rottnest Island?

Observational data collected during this survey indicated that on Rottnest Island the Australian Raven has a strong preference for urbanised and disturbed areas, with the population concentrated in and around the Thompson Bay settlement (Chapter 3). Ravens use the settlement for foraging, roosting and nesting, but also travel widely over the island to forage, including to remnant habitats. Ravens show a strong preference for exotic trees for nesting and roosting.

6.1.3 Question 3: Does the Australian Raven predate on bush birds on Rottnest Island?

The results of the artificial nest experiment undertaken by this study demonstrated that ravens are highly likely to be nest predators of bush birds outside of the urban areas, even though predation is related to characteristics of individual sites rather than the distance from the Thompson Bay settlement (Chapter 4). In addition, bush bird nests that are not concealed by vegetation are more likely to be predated.

6.1.4 Question 4: What is the feeding ecology of the Australian Raven?

The examination of raven stomach contents in this study discovered the presence of bird feathers and bones, confirming that ravens are a predator of bush birds, including nestlings (Chapter 5). However, stomach content analysis also identified that plant material, especially fruits of the exotic Moreton Bay fig, and invertebrates are more important food preferences. Processed food was not found to be an important component of the raven diet during this study.

The results from this study determined that the Australian Raven is as a nest predator on Rottnest Island, but were less conclusive determining how important they were as predators. However, given that positive predation was recorded, both directly and indirectly, I cannot reject the proposal that raven predation is a threat to bush birds. The impact of raven nest predation on bush birds is discussed below.

6.2 Question 5: How does predation by the Australian Raven impact on bush birds on Rottnest Island?

I designed an experiment that strongly implicated the Australian Raven is a predator of bush birds. Raven predation may be additive to other sources of decline such as habitat fragmentation, or it may be compensatory, where ravens may be predating on individuals that would not survive otherwise.

I could not find any examples in the literature where corvids have been directly responsible for the decline or extinction of other birds. In addition, removal of corvid predators has been demonstrated not to have a positive effect the breeding success of other birds (Clark, Meger and Ignatiuk 1995; Parker 1984). Raven predation would have the most impact when acting with other factors, because in this situation even low levels of mortality could have a deleterious effect on bush bird abundance. Furthermore, when functioning as an addition to other threatening processes, raven predation may also influence the distributions of bush birds.

The low diversity of bush bird species within the settlement could be a result of the lack of suitable habitat, but the high density of ravens in this area may also indicate that raven abundance is a limiting factor. The habitat available for nesting within the settlement is poor. Bush birds attempting to nest within the settlement may be more exposed and therefore more likely to be predated by ravens. A high frequency of predation would not allow bush birds to establish in this area and they would have to move to areas outside the settlement where the habitat provides greater protection from ravens. This would be an example of interacting threats from habitat alteration and raven predation.

During this study raven predation was highest at sites where successful breeding of bush birds was also recorded. Therefore, ravens may be predating on the proportion of the bush bird nests that were already doomed not to survive (see Banks 1999; L.S. Mills 2007 p.p. 171-174) due to factors such as weather, nest exposure and food availability. In addition, bush birds and other groups of birds can compensate for predation by producing large clutches of young (for example Australian Shelduck) or additional young by re-nesting following nest predation. However this compensation is only successful if other non-predatory causes of mortality are also reduced. If raven predation is a limiting factor on the success of bush bird populations on Rottnest Island, then there should be an increase in bush bird populations following the reduction in raven abundance, as has occurred through the recent reduction by culling.

6.3 Recommendations for future research

Like many ecological field studies, this study encountered both spatial (distribution of sites) and temporal (replication of survey periods) limitations associated with the logistics of implementing the field methodology using a single-observer over a short period of time. However, the most important limitation was that there was a lack of background data with which to compare with the results of this study, and therefore to be able to identify if a reduction in raven abundance has influenced nest predation. There was no study conducted on the effect of raven predation on bush birds prior to the major cull in 2009. What has been presented here is the occurrence of raven predation after culling, when numbers had already been reduced. This limitation restricts the interpretation and relevance of this research to when raven numbers are controlled or reduced.

In addition, the success of nesting bush birds during 2010 and 2011 is unknown. However, increases in bush bird abundance was recorded by Birds Australia WA, illustrating that bush bird populations have been steadily increasing since 2007, prior to the culling of ravens in 2009. The fecundity of the species of bush birds on Rottnest is too low for noticeable changes in bush bird abundance following raven culling to have occurred at the time that this study was started.

Evidently, there is a need to reduce the uncertainty that exists regarding what the impact of raven predation on bush bird nests has on bush bird populations. I suggest that this can be achieved with two lines of enquiry:

1) a detailed investigation on bush bird nesting success, using experimental methods;

2) evaluate how bush birds, in particular those species of conservation concern, use the habitats on Rottnest Island.

Bush bird nesting success may be examined by locating and monitoring active nests to determine breeding success. However, care should be taken when developing methodologies for nest monitoring to avoid inadvertently alerting ravens, or other predators, to the locations of active nests, and therefore artificially increasing predation.

When investigating habitat use, particular attention should be made to identify the preferred nesting habitats of bush birds; and assess what factors make these habitats suitable for nesting (i.e. tree canopy density, vegetation composition, food availability). Such a study should include all areas in landscape to full understand how birds use all habitats (Catterall *et al.* 1998). White-fronted Chat prefer the open grassland areas, and revegetated woodland and forest may not be suitable for this species. In addition, the interactions between species could be examined. The Western Gerygone, like the raven, is a recent coloniser of Rottnest Island that quickly established as a breeding resident and increased greatly in its abundance and distribution. It would be interesting to explore if the gerygone competes with other bush birds for nesting and foraging resources.

Two species of conservation concern exhibit differences in morphology and call in comparison to mainland populations. The taxonomy of the Singing Honeyeater and Red-caped Robin of needs to be investigated to resolve the distinctiveness of the Rottnest Island populations compared to mainland populations. These species may be considered Evolutionary Significant Units (ESU) as outlined by Moritz (1994) where a '.. set of population has been historically isolated and, accordingly, is likely to have a distinct potential'. The ESU concept can be used to prioritize taxa for conservation where the existing knowledge of the taxonomy is deficient. Resolving the taxonomic status of the Singing Honeyeater and Red-caped Robin may help to elevate the conservation status of these species on Rottnest Island if they are found to be endemic taxa. I would suggest Rottnest Island Authority explore possibilities of this research using the relationships forged with the partners of this project, the WA Museum and Murdoch University.

Given that several bush bird species, two of which may be taxonomically distinct, on Rottnest Island have declined on the adjacent Swan Coastal Plain; there is a precautionary need to protect these species while the uncertainty of the effects of raven predation is reduced.

6.4 Recommendations for raven management

Given that there is some uncertainty about the probable impact of raven predation, I suggest that the precautionary principle is used to mitigate potential impact (see Calver *et al.* 2011). The 'principle of precautionary action' (Deville and Harding 1997) offers protection from impacts that may be harmful to the environment even though the evidence of harm has not been fully investigated or is not fully understood (Deville and Harding 1997). In this case, the bush birds of Rottnest Island must be protected where possible against nest predation by Australian Ravens, while further evidence is being collected to better understand the threat of nest predation.

The major cull of ravens on Rottnest Island in 2009 was the initial knock-down needed to reduce raven abundance. Although there is no data on nest predation by Australian Ravens prior to culling, the results of this study have demonstrated that predation intensity is moderate even at the current raven population size. There needs to be sustained management to keep the population at a lower level (Hart and Bomford 2006). Culling is often an ethically unpopular and expensive method of population management, and the benefits of culling may be limited. If ravens are removed, the Rottnest population could be supplemented from neighbouring mainland populations (see Harding, Doak and Albertson 2001). In addition the recruitment of young birds from breeding pairs could further supplement the population. I suggest that nest removal prior to egg-laying is also used to prevent ravens from breeding on Rottnest Island. Culling of breeding pairs with an established territory is not advised, as a territorial pair will prevent other ravens from foraging in that area (as observed at Site 2 during this study). An exception would be where ravens were identified as a direct threat to other birds (for example the raven pair nesting in the settlement that was observed harassing nesting Osprey). The removal of raven nests may be a simple and inexpensive method to help control the raven population on Rottnest Island. Preventing ravens breeding on Rottnest Island has two benefits:

1) Reduces population growth from recruitment of juvenile birds;
2) May reduce supplementation of the population from first and second year birds returning to Rottnest from the adjacent mainland.

While the removal of raven nests will prevent the raven population from naturally increasing, continued culling will further reduce raven abundance, and remove all age classes of raven from the population. Culling of ravens may be restricted by funding and time resources of Rottnest Island Authority staff. However, if ravens are not found to be a threat to bush birds, then these precautionary measures can be abandoned. If ravens are shown to be a significant threat to bush birds, measures to overcome the problem then become preventative, by negating a known risk, rather than acting in the face of uncertainty. In my opinion it is a far better option to take precautions to protect against raven predation, than to risk further losses of bush bird species on Rottnest Island through nest predation by the Australian Raven.

Reducing raven numbers may give bush bird populations the chance to increase and establish in new areas as revegetation matures and may also reduce competition in the remaining ravens for food on more important natural food sources (plant material and invertebrates). Reducing the raven population may also be justified to protect public health. Specimens examined during this study found evidence that ravens on Rottnest Island carry internal parasites that can infect and are potentially harmful to humans. Raven faeces were observed on chairs and tables, as well as ravens being in direct contact with cutlery and crockery in public eating areas. This presents a health risk to visitors and staff on Rottnest Island. Better management of these areas would reduce the risk of contamination to humans through contact with ravens.

6.5 Conclusion

The increase in bush birds and reduction in ravens documented in this study, suggest that the control methods initiated through the *Pest Management Plan* and *Woodland Restoration*

Program may already be influencing positive change on Rottnest Island. In addition, the greater proportion of natural foods over processed food in the raven diet, indicate that waste management methods are also effective. However, the overall findings of this study have substantiated the concern that the Australian Raven is a predator of the eggs and nestlings of bush birds on Rottnest Island.

I have also identified that there is some uncertainty in understanding the how raven predation impacts on bush birds on Rottnest Island. Therefore, I have recommended two avenues for future research on Rottnest Island, and two precautionary measures that should be undertaken while the research is completed:

Precautionary Measures

- Control of raven population through culling and nest removal
- Protect bush birds by continuing revegetation to connect habitats

Future Research

- Investigate breeding success and habitat use by bush birds
- Resolve taxonomic status of Red-caped Robin and Singing Honeyeater

Although this study has focused on eggs and nestlings of bush birds as the targeted prey, adult birds are more important when considering the conservation of a species. If a nest is predated, adult birds are able to produce more eggs, which then may be successful in being brooded to independence. Management of adult bush bird mortality, even if lower than nest predation (see Spencer and Thompson 2005), can be achieved in part by the provision of suitable habitat.

The State of Australia's Birds report (2006) stated that to be effective, the management of invasive species '… often needs to be integrated … with restoration of natural habitat'. Although not part of this study, the observations documented by Birds Australia WA give clear evidence of the benefits of the *Woodland Restoration Program*. There is a need to continue revegetation of the island, in particular, by connecting existing revegetation and remnant areas, so that breeding bush birds are not pushed into habitats where they would be more exposed to predation.

Finally, a commitment must be made to monitor the effectiveness of the control of the raven population. In particular, how important is raven predation to the nesting success of bush birds on Rottnest Island? Without this understanding, the efforts used to conserve bush birds may be misdirected at the control of ravens, and therefore the opportunity to conserve these species may be missed.

Appendices

Appendix I

Characteristics and placement of artificial nests and predation condition by nest number.

COUNT	SITE	TRIP	NEST NO.	DATE EST.	NEST TYPE	EXPOSURE	PREDATED	DATE PREDATED	PREDATOR	CONDITION
1	1	A	1	6/09/2010	RCR	Concealed	YES	7/09/2010	Quokka	Bait egg removed + false egg recovered/imprinted + nest OK
2	1	A	2	6/09/2010	SHE	Exposed	YES	7/09/2010	Unidentified	Bait egg and false egg removed + nest damaged
3	1	A	3	6/09/2010	LTD	Concealed	NO			
4	1	A	4	6/09/2010	GW	Exposed	YES	8/09/2010	Unidentified	Bait egg and false egg removed + nest damaged
5	1	A	5	6/09/2010	WBSW	Concealed	YES	7/09/2010	Unidentified	Bait egg and false egg removed + nest OK
6	2	A	6	6/09/2010	WBSW	Concealed	YES	7/09/2010	Unidentified	Bait egg and false egg removed + nest OK
7	2	A	7	6/09/2010	GW	Exposed	YES	7/09/2010	Unidentified	Bait egg and false egg removed + nest OK
8	2	A	8	6/09/2010	SHE	P/Concealed	NO			
9	2	A	9	6/09/2010	LTD	Exposed	NO			
10	2	A	10	6/09/2010	RCR	P/Concealed	NO			
11	3	A	11	6/09/2010	RCR	Concealed	NO			
12	3	A	12	6/09/2010	WBSW	Concealed	YES	8/09/2010	Unidentified	Bait egg removed + false egg recovered/imprinted + nest OK
13	3	A	13	6/09/2010	GW	P/Concealed	NO			
14	3	A	14	6/09/2010	SHE	Concealed	NO			
15	3	A	15	6/09/2010	LTD	Exposed	NO			
16	4	A	16	6/09/2010	LTD	Exposed	NO			
17	4	A	17	6/09/2010	GW	Concealed	NO			
18	4	A	18	6/09/2010	WBSW	Concealed	YES	7/09/2010	King Skink/ Quokka	Bait egg removed + false egg recovered/imprinted + nest OK

19	4	A	19	6/09/2010	SHE	Exposed	NO			
20	4	A	20	6/09/2010	RCR	Concealed	NO			
21	5	A	21	6/09/2010	LTD	Exposed	YES	7/09/2010	Unidentified	Bait egg and false egg removed + nest OK
22	5	A	22	6/09/2010	WBSW	Concealed	NO			
23	5	A	23	6/09/2010	GW	Exposed	YES	8/09/2010	Unidentified	Bait egg and false egg removed + nest OK
24	5	A	24	6/09/2010	RCR	Concealed	YES	9/09/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged
25	5	A	25	6/09/2010	SHE	Concealed	NO			
26	6	A	26	6/09/2010	GW	Exposed	NO			
27	6	A	27	6/09/2010	LTD	Exposed	NO			
28	6	A	28	6/09/2010	SHE	Exposed	NO			
29	6	A	29	6/09/2010	RCR	Exposed	NO			
30	6	A	30	6/09/2010	WBSW	Concealed	YES	7/09/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged
31	4	A	31	7/09/2010	WBSW	Concealed	NO			
32	5	A	32	8/09/2010	LTD	Exposed	NO			
33	5	A	33	8/09/2010	GW	Exposed	NO			
34	6	A	34	8/09/2010	WBSW	Concealed	NO			
35	2	A	35	8/09/2010	GW	P/Concealed	YES	9/09/2010	Unidentified	Bait egg and false egg removed + nest OK
36	2	A	36	8/09/2010	WBSW	P/Concealed	NO			
37	1	A	37	8/09/2010	WBSW	P/Concealed	NO			
38	1	A	38	8/09/2010	SHE	Exposed	YES	9/09/2010	Raven	Bait egg and false egg removed + nest damaged
39	1	A	39	8/09/2010	RCR	P/Concealed	NO			
40	3	A	40	8/09/2010	WBSW	P/Concealed	NO			
41	1	B	41	11/10/2010	WBSW	Exposed	NO			
42	1	B	42	11/10/2010	LTD	P/Concealed	YES	12/10/2010	Unidentified	Bait egg and false egg removed + nest damaged
43	1	B	43	11/10/2010	SHE	Concealed	NO			
44	1	B	44	11/10/2010	RCR	P/Concealed	NO			
45	1	B	45	11/10/2010	GW	Concealed	NO			
46	2	B	46	11/10/2010	LTD	Concealed	NO			
47	2	B	47	11/10/2010	SHE	Concealed	NO			
48	2	B	48	11/10/2010	RCR	P/Concealed	NO			

49	2	B	49	11/10/2010	GW	Exposed	YES	12/10/2010	Quokka	Bait egg removed + false egg intact
50	2	B	50	11/10/2010	WBSW	Exposed	NO			
51	3	B	51	11/10/2010	SHE	Exposed	NO			
52	3	B	52	11/10/2010	RCR	P/Concealed	YES	12/10/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
53	3	B	53	11/10/2010	GW	Concealed	NO			
54	3	B	54	11/10/2010	WBSW	Concealed	NO			
55	3	B	55	11/10/2010	LTD	P/Concealed	NO			
56	4	B	56	11/10/2010	RCR	Exposed	YES	12/10/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
57	4	B	57	11/10/2010	GW	Concealed	YES	12/10/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
58	4	B	58	11/10/2010	WBSW	Concealed	NO			
59	4	B	59	11/10/2010	LTD	Exposed	YES	13/10/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
60	4	B	60	11/10/2010	SHE	Concealed	NO			
61	5	B	61	11/10/2010	GW	Exposed	YES	14/10/2010	Unidentified	Bait egg and false egg removed + nest damaged
62	5	B	62	11/10/2010	WBSW	P/Concealed	YES	14/10/2010	Raven	Bait egg and false egg removed + nest OK
63	5	B	63	11/10/2010	LTD	Exposed	YES	14/10/2010	Unidentified	Bait egg and false egg removed + nest OK
64	5	B	64	11/10/2010	SHE	P/Concealed	YES	14/10/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged
65	5	B	65	11/10/2010	RCR	Concealed	NO			
66	6	B	66	11/10/2010	WBSW	Concealed	YES	15/10/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
67	6	B	67	11/10/2010	LTD	Exposed	YES	13/10/2010	Unidentified	Bait egg and false egg removed + nest damaged
68	6	B	68	11/10/2010	SHE	Concealed	NO			
69	6	B	69	11/10/2010	RCR	Exposed	NO			
70	6	B	70	11/10/2010	GW	Concealed	YES	14/10/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged
71	2	B	71	13/10/2010	GW	Exposed	NO			
72	1	B	72	13/10/2010	LTD	Exposed	NO			
73	4	B	73	13/10/2010	LTD	Exposed	YES	14/10/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged

74	4	B	74	13/10/2010	GW	P/Concealed	NO			
75	4	B	75	13/10/2010	RCR	Concealed	NO			
76	3	B	76	13/10/2010	RCR	Concealed	NO			
77	3	C	77	8/11/2010	SHE	P/Concealed	NO			
78	3	C	78	8/11/2010	LTD	Exposed	NO			
79	3	C	79	8/11/2010	RCR	P/Concealed	NO			
80	3	C	80	8/11/2010	WBSW	Concealed	NO			
81	3	C	81	8/11/2010	GW	P/Concealed	YES	11/11/2010	Quokka	Bait egg removed + false egg recovered/imprinted + nest damaged
82	4	C	82	8/11/2010	WBSW	Concealed	NO			
83	4	C	83	8/11/2010	RCR	Exposed	YES	11/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged
84	4	C	84	8/11/2010	LTD	P/Concealed	YES	10/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
85	4	C	85	8/11/2010	GW	Concealed	NO			
86	4	C	86	8/11/2010	SHE	Exposed	YES	9/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged
87	2	C	87	8/11/2010	RCR	Exposed	NO			
88	2	C	88	8/11/2010	LTD	P/Concealed	NO			
89	2	C	89	8/11/2010	GW	Exposed	NO			
90	2	C	90	8/11/2010	SHE	P/Concealed	NO			
91	2	C	91	8/11/2010	WBSW	P/Concealed	NO			
92	1	C	92	8/11/2010	LTD	P/Concealed	YES	9/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
93	1	C	93	8/11/2010	GW	P/Concealed	NO			
94	1	C	94	8/11/2010	RCR	Concealed	YES	9/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged
95	1	C	95	8/11/2010	WBSW	P/Concealed	NO			
96	1	C	96	8/11/2010	SHE	Concealed	YES	12/11/2010	Unidentified	Bait egg removed + false egg recovered/imprinted + nest OK
97	5	C	97	8/11/2010	GW	Exposed	YES	11/11/2010	Unidentified	Bait egg removed + false egg intact
98	5	C	98	8/11/2010	SHE	Concealed	YES	11/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
99	5	C	99	8/11/2010	WBSW	P/Concealed	YES	11/11/2010	Unidentified	Bait egg removed + false egg intact
100	5	C	100	8/11/2010	RCR	Concealed	YES	11/11/2010	Unidentified	Bait egg removed + false egg intact

101	5	C	101	8/11/2010	LTD	Exposed	YES	11/11/2010	Unidentified	Bait egg and false egg removed + nest OK
102	6	C	102	8/11/2010	SHE	Concealed	YES	10/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
103	6	C	103	8/11/2010	WBSW	P/Concealed	YES	11/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
104	6	C	104	8/11/2010	RCR	Exposed	YES	10/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest damaged
105	6	C	105	8/11/2010	LTD	Exposed	YES	10/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
106	6	C	106	8/11/2010	GW	Concealed	YES	11/11/2010	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
107	1	C	107	9/11/2010	LTD	Exposed	YES	10/11/2010	Unidentified	Bait egg removed + false egg recovered/imprinted + nest OK
108	4	C	108	10/11/2010	LTD	Exposed	YES	11/11/2010	Raven	Bait egg and false egg removed + nest OK
109	4	C	109	10/11/2010	SHE	Exposed	YES	11/11/2010	Unidentified	Bait egg removed + false egg recovered/imprinted + nest OK
110	5	C	110	11/11/2010	GW	Concealed	NO			
111	5	C	111	11/11/2010	WBSW	P/Concealed	NO			
112	1	D	112	1/08/2011	LTD	P/Concealed	NO			
113	1	D	113	1/08/2011	SHE	P/Concealed	YES	3/08/2011	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
114	1	D	114	1/08/2011	RCR	Exposed	YES	3/08/2011	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
115	1	D	115	1/08/2011	WBSW	Concealed	NO			
116	1	D	116	1/08/2011	GW	Concealed	NO			
117	2	D	117	1/08/2011	RCR	P/Concealed	NO			
118	2	D	118	1/08/2011	LTD	Exposed	NO			
119	2	D	119	1/08/2011	SHE	Concealed	NO			
120	2	D	120	1/08/2011	GW	Exposed	NO			
121	2	D	121	1/08/2011	WBSW	P/Concealed	NO			
122	5	D	122	1/08/2011	WBSW	Exposed	NO			
123	5	D	123	1/08/2011	GW	P/Concealed	YES	2/08/2011	Unidentified	Bait egg removed + false egg intact
124	5	D	124	1/08/2011	SHE	Exposed	NO			
125	5	D	125	1/08/2011	LTD	Exposed	YES	4/08/2011	Raven	Bait egg removed + false egg recovered/imprinted + nest OK

126	5	D	126	1/08/2011	RCR	Concealed	NO			
127	6	D	127	1/08/2011	RCR	Concealed	NO			
128	6	D	128	1/08/2011	WBSW	P/Concealed	NO			
129	6	D	129	1/08/2011	GW	Concealed	YES	2/08/2011	Unidentified	Bait egg removed + false egg intact
130	6	D	130	1/08/2011	SHE	Concealed	NO			
131	6	D	131	1/08/2011	LTD	Exposed	YES	3/08/2011	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
132	3	D	132	2/08/2011	LTD	P/Concealed	NO			
133	3	D	133	2/08/2011	RCR	P/Concealed	NO			
134	3	D	134	2/08/2011	WBSW	concealed	NO			
135	3	D	135	2/08/2011	GW	P/Concealed	NO			
136	3	D	136	2/08/2011	SHE	concealed	NO			
137	4	D	137	2/08/2011	SHE	concealed	NO			
138	4	D	138	2/08/2011	LTD	P/Concealed	YES	3/08/2011	Raven	Bait egg removed + false egg recovered/imprinted + nest OK
139	4	D	139	2/08/2011	RCR	P/Concealed	NO			
140	4	D	140	2/08/2011	WBSW	concealed	NO			
141	4	D	141	2/08/2011	GW	concealed	NO			
142	6	D	147	3/08/2011	GW	P/Concealed	NO			
143	5	D	148	3/08/2011	GW	Concealed	NO			

Site: 1. Bathurst Lighthouse; 2. The Basin; 3. Peacock Flats; 4. Vlamingh Lookout; 5. Bickley Swamp; 6. Thompson Bay. Trip: A – September 2010; B – October 2010; C - November 2010; D – August 2011. Nest type: RCR = Red-caped Robin; GW = Golden Whistler; LTD = Laughing Turtle-dove; WBSW = White-browed Scrubwren; SHE = Singing Honeyeater. Nest number 142 – 146 were nests trialed in the Settlement, not included in the analysis.

Appendix II

Summary: Nest predation by trip

	Raven Attack	Unidentified Attack	Not Attacked	Other attacks	Total Number	Total Attacks	Avg. Abundance
Trip A	3	9	26	2	40	14	25.16
Trip B	9	4	22	1	36	14	35.53
Trip C	12	7	15	1	35	20	22.87
Trip D	5	2	25	0	32	7	17.62
	29	**22**	**88**	**4**	**143**	**55**	**55**

Trip A – September 2010; Trip B – October 2010; Trip C - November 2010; Trip D – August 2011

Appendix III

Summary: Nest predation by site

	Raven Attack	Unidentified Attack	Not Attacked	Other attacks	Total Number	Total Attacks
Site 1	5	6	13	1	25	12
Site 2	0	3	19	1	23	4
Site 3	1	1	19	1	22	3
Site 4	9	1	15	1	26	11
Site 5	5	9	11	0	25	14
Site 6	9	2	11	0	22	11
	29	**22**	**88**	**4**	**143**	**55**

Site: 1. Bathurst Lighthouse; 2. The Basin; 3. Peacock Flats; 4. Vlamingh Lookout; 5. Bickley Swamp; 6. Thompson Bay

Appendix IV

Summary: Nest predation by exposure

	Raven Attack	Unidentified Attack	Not Attacked	Other attacks	Total Number	Total Attacks
Exposed	12	12	23	1	48	25
Concealed	9	6	37	2	54	17
Part Concealed	8	4	28	1	41	13
	29	**22**	**88**	**4**	**143**	**55**

Appendix V

Summary: Nest predation by nest design type

	Raven Attack	Unidentified Attack	Not Attacked	Other attacks	Total Number	Total Attacks
RCR	7	1	18	1	27	9
GW	3	8	18	2	31	13
LTD	9	6	14	0	29	15
WBSW	4	4	21	1	30	9
SHE	6	3	17	0	26	9
	29	**22**	**88**	**4**	**143**	**55**

RCR = Red-caped Robin; GW = Golden Whistler; LTD = Laughing Turtle-dove; WBSW = White-browed Scrubwren; SHE = Singing Honeyeater

References

Alexander, W.B. (1921). The birds of the Swan River District, Western Australia. *Emu* 20: 150 – 168

Amalfi, C. (2010). Rottnest culls feral peacocks. Science Network WA, West Perth. http://www.sciencewa.net.au/index.php?/environment-and-climate/environment-and-climate/rottnest-culls-feral-peacocks.html

Andren, H. (1992). Corvid density and nest predation in relation to forest fragmentation: a landscape perspective. *Ecology* 73: 794 – 804

Armstong, G. and Booth, D.T. (2005). Dietary ecology of the Australian freshwater turtle (*Elseya* sp.: Chelonia : Chelidae) in the Burnett River, Queensland. *Wildlife Research* 32: 349 -353

Australian Bureau of Metrology (2011). Climate statistics for Australian locations: Rottnest Island. Australian Bureau of Metrology, Melbourne. http://www.bom.gov.au/climate/averages/tables/cw_009193.shtml and http://www.bom.gov.au/climate/current/annual/wa/summary.shtml

Avery, M.L., Pavelka, M.A., Bergman, D.L., Decker, D.G., Knittle, C.E. and Linz, G.M. (1995). Aversive conditioning to reduce raven predation on California Least Tern eggs. *Colonial Waterbirds* 18: 131 – 138

Backhouse, J. (1993). Holocene vegetation and climate record from Barker Swamp, Rottnest Island, Western Australia. *Journal of the Royal Society of Western Australia* 76: 53 – 61

Baird, A.M. (1958). Notes on the regeneration of vegetation of Garden Island after the 1956 fire. *Journal of the Royal Society of Western Australia* 41: 102 - 107

Baker, M.C., Baker, E.M. and Baker, S.A. (2003a). Songs of the Red-caped Robin Petroica goodenovii: a comparison of acoustic features in island and mainland populations. *Emu* 103: 329 - 335

Baker, M.C., Baker, M.S. and Baker, E.M. (2003b). Rapid evolution of a novel song and an increase in repertoire size of an island population of an Australian songbird. *Ibis* 145: 465 – 471

Banks, P.B. (1999). Predation by introducted foxes on native bush rats in Australia: do foxes take the doomed surplus? *Journal of Applied Ecology* 36: 1063 - 1071

Barrett, G.A., Ford, H.A. and Recher, H.F. (1994). Conservation of woodland birds in a fragmented rural landscape. *Pacific Conservation Biology* 1: 245 – 256

Baxter, G.S. (1988). Observations of predation on nestling egrets. *Corella* 12: 118 - 199

Bayne, E.M., Hobson, K.A. and Fargey, P. (1997). Predation on artificial nests in relation to forest type: contrasting the use of quail and plasticine eggs. *Ecography* 20: 233 239

Berry, P. (2002). Painted Button-quail at Rottnest Island. *Western Australian Bird Notes* 103: 26

Berry, L. and Lill, A. (2003). Do predation rates on artificial nests accurately predict predation rates on natural nests? *Emu* 103: 207-214

Bugnyar, T. and Heinrich, B. (2005). Ravens, *Corvus corax*, differentiate between knowledgeable and ignorant competitors. Proceedings *of the Royal Society: Biological Sciences* 272: 1641 - 1646

Buler, J.J. and Hamilton, R.B. (2000). Predation of artificial and natural nests in a southern pine forest. *The Auk* 117: 739 - 747

Burke, D. M., Elliott, K., Moore, L., Dunford, W., Nol, E., Phillips, J., Holmes, S. and Freemark, K. (2004). Patterns of nest predation on artificial and natural nests in forests. *Conservation Biology* 18:2 381-388.

Burbidge, A.A. (1989). The value of Western Australian island as biological reservoirs and the development of management priorities. In *Occasional Paper 2/89 Proceedings of a technical workshop Australian and New Zealand Islands: Nature Conservation Values and Management* Barrow Island, 17 – 24. Department of Conservation and Land Management, Perth

Burbidge, A.A. (2010). Australia's islands: biodiversity arks or rat-traps for future Dodos? In Kirkwood, J. and O'Connor, J. (Eds.) The State of Australia's Birds 2010: Islands and Birds. Supplement *Wingspan* 20: 2 – 3

Calver, M.C., Grayson, J., Lilith, M. and Dickman, C.R. (2011). Applying the precautionary principle to the issue of impacts by pet cats on urban wildlife. *Biological Conservation* 144: 1895 - 1901

Catterall, I.C.P., Kingston, M.B., Park, K. and Sewell, S. (1998). Deforestation, urbanization and seasonally interacting effects on a regional bird assemblage. *Biological Conservation* 84: 65 – 81

Christidis, L. and Boles, W.E. (2008). *Systematics and Taxonomy of Australian Birds*. CSIRO Publishing, Canberra

Clark, R.G., Meger, D.E. and Ignatiuk, J.B. (1995). Removing American Crows and duck nesting success. *Canadian Journal of Zoology* 73: 518 - 522

Davidson, W.B. and Bollinger, E. (2000). Predation rates on real and artificial nests of grassland birds. *The Auk* 117: 147 - 153

Davis, R.A. and Brooker, L. (2008). *Ecological Linkages and Urban Fauna at Risk on the Swan Coastal Plain, Perth, WA. Final Report to Perth Region NRM*. University of Western Australia, Crawley

Department of Agriculture and Food (2006). Unwelcome Rottnest visitors removed. *Biosecurity in Agriculture Newsletter* July 2006: 2

Department of Environment and Conservation (2007). *Prevention and Control of Damage by Animals in WA: Raven Corvus corronoides*. DEC, Kensington

Deville, A. and Harding, R. (1997). *Applying the Precautionary Principle*. Federation Press, Sydney

Dorfman, E.J. and Reed, J. (1996). Nest predation by corvids on cormorants in Australia. *Emu* 96: 132 – 135

Dortch, C.E. (1991). Rottnest and Garden Island prehistory and the archaeological potential of the adjacent continental shelf, Western Australia. *Australian Archaeology* 33: 38 – 43

Ericson, P.G.P., Irestedt, M. and Johansson, U.S. (2003). Evolution, biogeography, and patterns of diversification in passerine birds. *Journal of Avian Biology* 34: 3 - 15

Ericson, P.G.P, Jansen, A.-L., Johansson, U.S. and Ekman, J. (2005). Intergenetic relationship of the crows, jays, magpies and allied groups (Aves: Corvidae) based on nucleotide sequence data. *Journal of Avian Biology* 36: 222 – 234

Everding, S. E. and Jones, D.N. (2006). Communal roosting in a suburban population of Torresian Crows (Corvus orru). *Landscape and Urban Planning* 74: 21 – 33

Everding, S.E. and Montgomery, R. (2000). Movement and habitat use of the Torresian Crow in a subtropical suburban environment. *Emu* 100: 192 - 198

Ford, H.A., Barrett, G.W., Saunders, D.A. and Recher, H.F. (2001). Why have birds in the woodlands of Southern Australia declined? *Biological Conservation* 97: 71 – 88

Fulton, G.R. (2006). Identification of nest predators with remote cameras and artificial nests in extensive old growth woodland of south-western Australia. *Corella* 30: 35 - 39

Fulton, G.R. and Ford, H.A. (2001). The Pied Currawong's role in avian nest predation: a predator removal experiment. *Pacific Conservation Biology* 7: 154 – 160

Fulton, G. R. and Ford, H. A. (2003). Quail eggs, modelling clay eggs, imprints and small mammals in Australian woodland. *Emu* 103: 255-258

Garnett, S.T., Szabo, J.K. and Duston, G. (2011). *The Action Plan for Australian Birds 2010*. CSIRO Publishing, Canberra

Glauert, L. (1929). Contributions to the fauna of Rottnest Island No. I: Introduction and Vertebrates. *Journal of the Royal Society of Western Australia* 15: 37 - 48

Glenister, B.F., Hassell, C.W. and Kneebone, E.W.S. (1959) Geology of Rottnest Island. *Journal of the Royal Society of Western Australia* 42: 69 -70

Goodwin, D. (1976). *Crows of the World.* Cornell University Press, Ithica, New York.

Hamus, M.J. (1984). Crow predation on Spotted Sandpipers. *Journal of Field Ornithology* 55: 117 – 118

Harding, E.K., Doak, D.F. and Albertson, J.D. (2001). Evaluating the effectiveness of predator control: the non-native Red Fox as a case study. *Conservation Biology* 15: 1114 - 1122

Hart, Q. and Bomford, M. (2006). *Australia's Pest Animals: New Approaches to Old Problems. Science for Decision Makers. Revised Edition.* Bureau of Rural Sciences, Canberra. http://www.acera.unimelb.edu.au/materials/brochures/SDM-AustraliasPestAnimals.pdf

Hart, R.K., Calver, M.C. and Dickman, C.R. (2002). The index of relative importance: an alternative approach to reducing bias in descriptive studies of animal diets. *Wildlife Research* 29: 415 – 421

Hayward, M.W. (2005). Diet of the quokka, (*Setonix brachyurus*) (Macropodidae: Masupialia), in Western Australia's northern jarrah forest. *Wildlife Research* 34: 194 - 199

Hérbert, P.N. and Golightly, R.T. (2007). Observations of predation by corvids at a Marbled Murrelet Nest. *Journal of Field Ornithology* 78: 221 - 224

Hesp, P.A., Murray-Wallace, C.V. and Dortch, C.E. (1999). Aboriginal occupation on Rottnest Island, Western Australia, provisionally dated by Aspartic Acid Racemisation assay of land snails to greater than 50 ka. *Australian Archaeology* 49: 7 - 12

Higgins, P.J., Peter, J.M. and Cowling, S.J. (2006). *Handbook of Australian, New Zealand and Antarctic Birds. Volume 7: Boatbill to Starlings*. Oxford University Press, Melbourne.

Hopkins, A.J.M. and Harvey, J.M. (1989). Fire on offshore islands – problems and management solutions. In *Occasional Paper 2/89 Proceedings of a technical workshop Australian and New Zealand Islands: Nature Conservation Values and Management* Barrow Island, 83 – 97. Department of Conservation and Land Management, Perth

How, R.A. and Dell, J. (1993). Vertebrate fauna of the Perth metropolitan region: consequences of a modified habitat. In *Urban Bushland Management* (Ed. M. Hipkins) Australian Institute of Urban Studies: 28 – 47

Johnstone, R.E. (2010). Checklist of the Birds of Western Australia. Western Australian Museum, Welshpool. http://www.museum.wa.gov.au/research/research-areas/#terrestrial-zoology%2Fchecklist-terrestrial-vertebrate-fauna-western-australia [Accessed 31 August 2011]

Joske, P., Jeffery, C. and Hoffman, L. (1995). *Rottnest Island A Documentary History*. University of Western Australia, Perth

Kentish, B.J., Dann, P. And Low, K.W. (1995). Breeding biology of the Common Blackbird Terdus merula in Australia. *Emu* 95: 233 - 244

Lawson, F. (1904). A visit to Rottnest Island, WA. *Emu* 4: 129 – 132

Mac Nally, R.M. and Bennett, A.F. (1997). Species specific predictions of the impact of habitat fragmentation: local extinction of birds in the Box-Ironbark forests of central Victoria, Australia. *Biological Conservation* 82: 147 – 155

Maguire, G.S., Weston, M.A., Ehmke, G.C and Cullen, M. (2011). Returning the balance: managing threats to the Hooded Plover in Victoria. In *Proceedings of the 6th Biennial Australasian Ornithological Conference, James Cook University Cairns, 2011*

Major, R.E. (1991). Identification of nest predators by photography, dummy eggs and adhesive tape. *The Auk* 108: 190 -195

Major, R.E., Christie, F.J., Gowing, G. and Ivison, T.J. (1999). Elevated rates of nest predation on artificial nests in linear strips of habitat. *Journal of Field Ornithology* 70: 351 – 364

Major, R.E., Pyke, G.H., Christy, M.T., Gowing, G. And Hill, R.S. (1994). Can nest predation explain the timing of breeding season and the pattern of nest dispersion of New Holland Honeyeaters? *Oikos* 69: 364 – 372

Martin, T.E. (1987). Artificial nest experiments: effects of nest appearance and type of predator. *The Condor* 89: 925 - 928

Mather, S. (2009). The bushbirds of Rottnest Island. *Western Australian Bird Notes* 132: 1- 5

Mather, S. (2010). Birds Australia on Rottnest Island. In State of Australia's Birds 2010 Island and Birds. Kirkwood, J. And O'Connor, J. Eds. (2010). Supplement *Wingspan* 20: 14

McArthur, W.M. (1957). Plant ecology of the coastal islands near Fremantle, W.A. *Journal of the Royal Society of Western Australia* 40: 46 – 64

Milligan, A.W. (1911). Description of new *Ptilotis*. *Emu* 11: 124 – 125

Mills, L.S. (2007). *Conservation of Wildlife Populations: Demography, Genetics and Management*. Blackwell Publishing Ltd. Carlton, Victoria

Møller, A.P. (1989). Nest site selection across field-woodland ecotones: the effect of nest predation. *Oikos* 56: 240 - 246

Monroe Jr., B.L. and Sibley, C.G. (1993). *A World Checklist of Birds*. Yale University Press, New Haven

Montevecchi, W.A. (1976). Egg size and the egg predatory behaviour of crows. *Behaviour* 57: 307 - 320

Moore, R.P. and Robinson, W.D. (2004). Artificial bird nests, external validity and bias in ecological field studies. *Ecology* 85: 1562 – 1567

Norman, F.I. (1982). Eggs, egg-laying and incubation in the Chestnut Teal. *Emu* 82: 195 - 198

Olsen, P., Silcocks, A. and Weston, M. (2006). The State of Australia's Birds Report 2006: Invasive species. Supplement *Wingspan* 16: 4

Parker, H. (1984). Efect of corvid removal on reproduction of willow ptarmigan and black grouse. *Journal of Wildlife Management* 48: 1197 - 1205

Pen, L.J. and Green, J.W. (1983). Botanical exploration and vegetational changes on Rottnest Island. *Journal of the Royal Society of Western Australia* 66: 20 – 24

Picozzi, N. (1975). Crow predation on marked nests. *The Journal of Wildlife Management* 39: 151 - 155

Piper, S.D. and Catterall, C.P. (2004). Effects of edge type and nest height on predation of artificial nests within subtropical Australian eucalypt forests. *Forest Ecology and Management* 203: 361 – 372

Piper, S., Catterall, C.P. and Olsen, M. (2002). Does adjacent land use affect predation of artificial shrub-nests near eucalypt forest edges? *Wildlife Research* 29: 127 – 133

Playford, P.E. (1983). Geological Research on Rottnest Island. *Journal of the Royal Society of Western Australia* 68(1-2): 10 - 15

Playford, P.E. (1988). *Guidebook to the Geology of Rottnest Island.* Geological Society of Australia (WA Divison) and Geological Survey Australia, Perth

Recher, H.F. (1999). The state of Australia's avifauna: a personal opinion and prediction for the new millennium. *Australian Zoologist* 31: 11 - 27

Recher, H. and Serventy, D. (1991). Long-term changes in relative abundance of birds in Kings Park, Perth Western Australia. *Conservation Biology* 5: 90 – 102

Richardson, C. (2009). *Agriculture and Related Resources Act 1976: Declared Animals.* Agricultural Protection Board, South Perth. http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/vp/declared_animals.pdf

Ricklefs, R.E. (1969). An analysis of nesting mortality in birds. *Smithsonian Contributions to Zoology* 9. Smithsonian Institution Press, Washington

Riggert, T.L. (1977). The biology of the Mountain Duck on Rottnest Island, Western Australia. *Wildlife Monographs* 53: 3 - 67

Rippey, M.E., Hislop, M.C. and Dodd, J. (2003). Reassessment of the vascular flora of Rottnest Island. *Journal of the Royal Society of Western Australia* 86: 7 – 23

Rippey, M.E. and Hobbs, R.J. (2003). The effects of fire and Quokkas (*Setonix brachyurus*) on the vegetation of Rottnest Island, Western Australia. *Journal of the Royal Society of Western Australia* 86: 49 – 60

Roper, J. J. (1992). Nest predation experiments with quail eggs: too much to swallow. *Oikos* 65(3): 529-530

Rowley, I. (1970). The Genus *Corvus* (Aves: Corvidae) in Australia. *Wildlife Research* 15: 27 -71

Rowley, I. (1973a). The comparative ecology of Australian Corvids: II. Social organisation and behaviour. *Wildlife Research* 18: 25 – 65

Rowley, I. (1973b). The comparative ecology of Australian Corvids: IV. Nesting and the rearing of young to independence. *Wildlife Research* 18: 91 - 129

Rowley, I., Braithwaite, L.W. and Chapman, G.S. (1973). The comparative ecology of Australian Corvids: III. Breeding seasons. *Wildlife Research* 18: 67 – 90

Rowley, I. and Vestjens, W.JM. (1973). The comparative ecology of Australian Corvids: V. Food. *Wildlife Research* 18: 131 – 155

Rottnest Island Authority (2010). *Annual Report* 2009/10. Rottnest Island Authority, Fremantle

Rottnest Island Authority (2009). *Rottnest Island Management Plan 2009 - 2014*. Rottnest Island Authority, Fremantle

Santisteban, L., Sieving, K.E. and Avery, M.L. (2002). Use of sensory cues by Fish Crows Corvus ossifragus preying on artificial bird nests. *Journal of Avian Biology* 33: 245 - 252

Saunders, D.A. and de Reberia, C.P. (1985). *The Bird Life of Rottnest Island.* D.A. Saunders and C.P. De Riberia, Guildford

Saunders, D. A., and de Rebeira, C. P. (1989). Changes in species composition of the avifauna of Rottnest Island, Western Australia. In '*Australian and New Zealand Islands: Nature Conservation Values and Management*'. (Ed. A. Burbidge) pp. 73 – 81. Department of Conservation and Land Management, Wanneroo

Saunders, D.A. and de Reberia, C.P. (1993). *The Bird Life of Rottnest Island.* Second (revised) edition. Surrey Beatty and Sons, Chipping Norton, NSW

Saunders, D.A. and de Reberia, P. (2009). A case study of the conservation value of a small tourist resort island: Birds of Rottnest Island, Western Australia 1905 – 2007. *Pacific Conservation Biology* 15: 11 – 31

Schmidt, K.A. and Whelan, C.J. (1999). The relative impacts of nest predation and brood parasitism on seasonal fecundity in songbirds. *Conservation Biology* 13: 46 - 57

Seddon, G. (1983). The Rottnest experience. *Journal of the Royal Society of Western Australia* 66: 34 – 40

Serventy, D.L. (1938). Birds of the islands of Fremantle, Western Australia. *Emu* 37: 265 - 268

Serventy, D.L. and Storr, G.M. (1959). The birds of Rottnest Island. *Journal of the Royal Society of Western Australia* 42: 83 – 84

Shurmer, J. (2010). Too many ravens. *Comment News*. Community Newspaper Group, Perth. http://comment.inmycommunity.com.au/news-and-views/local-news/Too-many-ravens/7573585

Skutch, A.F. (1966). A breeding bird census and nesting success in Central America. *Ibis* 108: 1 – 15

Somerville, W. (1949). *Rottnest Island in History and Legend.* 4th Edition (1976). The Rottnest Island Board, Rottnest, WA

Sonerud, G.A. and Fjeld, P.E. (1987). Long-term memory in egg predators: an experiment with a Hooded Crow. *Ornis scandinavica* 18: 323 – 325

Spencer, R.J. and Thompson, M.B. (2005). Experimental analysis and impact of foxes on fresh water turtle populations. *Conservation Biology* 19: 845 - 854

Stewart, P.J. (1997). *Some aspects of the ecology of an urban corvid: the Australian Raven (Corvus corronoides) in metropolitan Perth.* BSc Honours Diss., Edith Cowan University

Storr, G.M. (1962). Annotated flora of Rottnest Island, Western Australia. *The West Australian Naturalist* 8: 109-124.

Storr, G.M. (1963). Some factors inducing change in the vegetation of Rottnest Island. *Western Australian Naturalist* 9: 15 – 22

Storr, G.M. (1965). The avifauna of Rottnest Island, Western Australia III. Land birds. *Emu* 64: 172 – 180

Storr, G.M., Green, J.W. and Churchill, D.M. (1959). The vegetation of Rottnest Island. *Journal of the Royal Society of Western Australia* 42: 70 – 71

Storr, G.M. and Johnstone, R.E. (1988). Birds of the Swan Coastal Plain and adjacent seas and islands. *Records of the Western Australian Museum* Supplement No. 28

Storr, G.M. and Johnstone, R.E. (1998). *Handbook of the Birds of Western Australia Volume I – Non-passerines (Emu to Dollarbird).* Western Australian Museum, Northbridge

Storr, G.M. and Johnstone, R.E. (2004). *Handbook of the Birds of Western Australia: Volume II – Passerines (Blue-winged Pitta to Goldfinch)*. Western Australian Museum, Northbridge

Thompson, F. R. III and Burhans, D. E. (2004). Difference in predators of artificial and real songbird nests: Evidence of a bias in artificial nest studies. *Conservation Biology* 18: 373-380

Villard, M. and Part, T. (2004). Don't put all your eggs in real nests. *Conservation Biology* 18: 371-373

Watson, E.J. (1998). *Rottnest Its Tragedy and Its Glory*. Frank Daniels Pty Ltd, Perth

Weidinger, K. (2001). How well do predation rates on artificial nests estimate predation on natural passerine nests? *Ibis* 143: 632 – 641

Whittaker, R.J. and Fernandez-Palacois, J.M. (2007). *Island Biogeography Ecology, Evolution, and Conservation.* Second Edition. Oxford University Press Inc., New York

Wilson, G.W., Brittingham, M.L. and Goodrich, L.J. (1998). How well do artificial nests estimate success of real nests? *Condor* 100: 357 - 364

Wooller, R.D. Saunders, D.A., Bradley, J.S., and de Reberia, C.P. (1985). Geographical variation in size of an Australian honeyeater (Aves : Meliphagidae): an example of Begmann's rule. *Biological Journal of the Linnean Society* 25: 355 – 63

Yahner, R.H. and Cypher, B.L. (1987). Effects of nest location on depredation of artificial arboreal nests. *The Journal of Wildlife Management* 51: 178 – 181

Yahner, R.H. and Wright, A.L. (1985). Depredation on artificial ground nests: effect of edge and plot age. *The Journal of Wildlife Management* 49: 508 - 513

Zanette, L. (2002). What do artificial nests tell us about nest predation? *Biological Conservation* 103: 323 - 329