An investigation into the ecology and management of feral pigs (*Sus scrofa*) in the Macquarie Marshes, New South Wales.

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Abstract

Introduction

The Macquarie Marshes are one of the largest remaining inland semi-permanent wetlands in south-eastern Australia. They contain diverse flora and fauna, and provide important habitat for many colonial and migratory waterbirds. As a consequence, large areas of the Macquarie Marshes are listed as a Ramsar Wetland; a wetland of international importance. Feral pigs (*Sus scrofa*) are believed to be a key threatening process to the ecological integrity of this area. They are also believed to be a potential disease hazard and a significant impediment to surrounding agriculture. Despite considerable management efforts, feral pigs are abundant and widespread in the Macquarie Marshes. This project aims to provide a greater understanding of feral pig ecology and the effects of various management options on their abundance and damage to help refine future feral pig management in the region.

Diet

This study was undertaken to identify which wildlife species are being consumed by feral pigs in the Macquarie Marshes, and to determine whether collection date, collection site or feral pig demographics influence predation levels. Stomach contents were analysed from 58 feral pigs that were shot during a routine aerial shooting campaign in the Macquarie Marshes during May 2011, September 2011 and March 2012. Feral pigs were largely herbivorous, with plant material occurring in 100% of stomachs and making up 94% of the food material that was consumed. In contrast, animal material occurred in 31% of stomachs and made up the remaining 6%. Of the animal material that was consumed, vertebrate prey occurred most frequently and in largest quantities. Reptiles and amphibians, particularly frogs, were the most common. No threatened reptile and amphibian species were recorded, and neither were any colonial or migratory bird species, or their eggs. It is possible however that some food items such as soft bodied invertebrates (gastropods, annelids or larvae) and/or eggs of ground nesting species may be underrepresented in the diet, because they may digest more rapidly in the stomach compared to other food items such as grasses, roots and vertebrates. Notwithstanding, collection date was the only factor that significantly influenced wildlife predation levels, with vertebrate wildlife prey occurring more frequently and in larger quantities during September 2011 and May 2012, which were also the warmest months. Further investigations are required to determine the relationship between feral pig density and the damage to reptiles and amphibians, so that appropriate management and monitoring

actions can be developed. Stomach contents of feral pigs should also be analysed from additional months to more identify seasonal diet shifts. Unfortunately, this was not possible due to time and funding constraints.

Activity patterns

This study was implemented to assess whether season and/or management option influenced feral pig activity patterns in the Macquarie Marshes, using remote camera technology. During the study, 34 remote cameras were positioned at permanent monitoring stations, on four different properties (four different experimental treatments) in four different seasons (summer, autumn, winter, spring). A total of 287 feral pig passes were recorded, 72.1% of which were nocturnal (night), 21.6% were crepuscular (dawn or dusk) and 6.3% diurnal (day). Feral pigs were most active between 05:00pm and 07:00am. Very few feral pigs were recorded on camera during daylight hours and none were recorded between 12:00 noon and 04:00pm. The study confirmed that feral pigs in the Macquarie Marshes were primarily nocturnal irrespective of season or the local management approach. Evidence of bimodal activity patterns was also apparent, with the first peak in activity occurring at approximately ~09:00pm and the second lower peak in activity occurring at ~06:00am. Results should however be interpreted with caution as feral pig activity patterns may have already been influenced by historical management, general farming practices and/or illegal hunting activity. Nevertheless, the study indicates that remote camera technology may be useful for monitoring daily feral pig activity patterns in relatively inaccessible areas, as the results obtained in this study were consistent with numerous other national and international studies. A potential shortfall with remote camera technology is that unlike radio telemetry, little information is provided on distances travelled by feral pigs.

Bait attractants

This study was undertaken to assess the effectiveness of various bait attractants for their ability to enhance bait station visitation and bait-take by feral pigs in the Macquarie Marshes. During the trial, several different bait attractants including Carasweet®, meat meal, fish meal, vanilla and molasses (dry barley carrier), two common substrates (PIGOUT® and fermented barley) and a non-treatment (barley) bait were assessed. These bait attractants and bait types were trialled on four different properties, during two different seasons (summer and winter). The results demonstrate that none of the attractants tested (Carasweet®, meat meal, fish meal, vanilla or molasses) or commonly used bait substrates (PIGOUT® and fermented barley) were able to significantly outperform the non-treatment bait (dry barley). Despite this, Carasweet®, molasses, vanilla and fermented grain were consumed when they were discovered by feral pigs. All other attractants and the non-treatment received situations where feral pigs visited and did not eat. In addition, Carasweet® (4.3 ± 2.2 SE), molasses (3.33 ± 2.2 SE) fermented barley (2.10 ± 1.2 SE), meat meal (1.44 ± 0.09 SE) bait stations received a mean of ≥1 feral pig per station created, unlike the non-treatment which received a mean of 0.29 ± 0.20 SE feral pigs, per station. Non-significant results in the present study may have occurred because alternate foods were abundant during both trial periods and because the number of treatment replicates was relatively low. Hence, it is possible that the results are worst case scenario. Further investigations should be undertaken when conditions are drier and more suitable for baiting and trapping and a minimum of 32 replicates should be created for each attractant (Krebs 1999).

Management

The purpose of this study was to determine the relationship between index of feral pig abundance (number of feral pig passes per camera per night per site) and damage (ground rooting m^2), and to assess the efficacy of various management options for managing feral pigs in the Macquarie Marshes. Four agricultural properties were used as study sites, each site was assigned a different feral pig management option and the study was undertaken over two years. The management options were aerial shooting and toxic baiting (treatment 1 site), aerial shooting only (treatment 2 site), toxic baiting only (treatment 3 site) and no management (non-treatment site). Index of feral pig abundance (IOA) and damage were monitored using remote camera stations and permanent 500 metre line intercept transects, respectively. The results indicate that feral pig IOA and damage were significantly positively related (r=0.46, n=15, p=0.04) in the Macquarie Marshes, with higher mean number of feral pig passes, per camera, per night, per site equating to a higher mean level of ground rooting per site. It was also evident that aerial shooting was useful for rapid initial population reductions when feral pig IOA was already high. None of the management options tested were able to significantly reduce feral pig damage within each study site. However, the damage results may have been affected by site flooding, as some line intercept transects were inundated during some monitoring events. The mean cost per kill for poison baiting was $420.44 ± $145.56 (SE), and the mean cost per kill for aerial shooting was $56.42 ± $23.13 (SE). Both aerial shooting and poison baiting were likely to be affected by feral pig IOA, and poison baiting was also likely to be influenced by season. The greatest removal rate of feral

pigs from poison bait stations (75 ± 15% SE) occurred in January 2012 (summer). During future studies, each treatment should be simultaneously replicated on two or more properties that contain similar (high) levels of feral pig abundance. In addition, a minimum of sixteen permanent 500 metre line intercept transects should be created per site (Krebs 1999), and at least one round of poison baiting should be undertaken during hot and dry conditions. Unfortunately, this was not possible during the present study due to restricted site access, time and funding constraints, varying feral pig abundance throughout the region and above average rainfall.

In summary, this project was able to provide valuable results in regards to the ecology and management of feral pigs in the Macquarie Marshes, New South Wales. The knowledge gained will assist in the development of future feral pig management strategies. It will also provide a platform for future research in this complex system.

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Contents

Chapter 1 – Introduction

1.1 Feral pigs (Sus scrofa)

1.1.1 Australian history

It is believed that feral pigs (*Sus scrofa*) in Australia originate from domestic pig breeds (Berkshire, British Black, Large White and Tamworth) that either escaped, or were released, during early European settlement (Pullar 1950; Giles 1980; Tisdell 1982; Izac and O'Brien 1991; Choquenot *et al.* 1996; Gongora *et al.* 2004; Hone 2012). In some areas, piglets displaying dark dorsal stripes have also been found, which suggests that introductions of wild *Sus scrofa, S. celebensis* or *S. papuensis* have also occurred, because dorsal stripes are rarely seen in domestic breeds (Giles 1980; Pavlov *et al.* 1992; Pavlov and Edwards 1995; Choquenot *et al.* 1996; Hone 2012). Early feral pig populations were generally associated with settlement areas, although they have since spread throughout much of Australian through natural migration and deliberate translocation (Pullar 1950; Izac and O'Brien 1991; Choquenot *et al.* 1996; Caley 1997; Hampton *et al.* 2004; Spencer and Hampton 2005; Cowled *et al.* 2009). Hone (1990a) estimated there were 13.5 million feral pigs (95% CI between 3.5 and 23.5 million) spread over 38% of Australia. The distribution estimate has since increased to 45% and climatic matching suggests that there are many suitable areas yet to be colonised (Caley 1997; Anon 2005; West 2008; Cowled *et al.* 2009).

1.1.2 Biology/ecology

Behaviour

Feral pigs are highly adaptive and opportunistic creatures that can adjust their behavioural patterns to suit various climatic conditions, food availability and disturbance (Pullar 1950; Giles 1980; Caley 1997; Dexter 1998). Consequently, feral pigs have been able to colonise a variety of habitats throughout Australia (Choquenot *et al.* 1996). Feral pigs are however relatively heat intolerant, as they lack sweat glands, therefore permanent water and adequate shelter are essential habitat requirements in hotter conditions (Giles 1980; Saunders and Kay 1991; Caley 1997; Dexter 1998; Choquenot and Ruscoe 2003; Hampton *et al.* 2004; McLeod 2004; Campbell and Long 2009). During hot conditions, feral pigs often drink twice a day, wallow and spend a majority of the day in the shade to assist thermoregulation (Giles 1980; Saunders and Kay 1991; Campbell and Long 2009). Feral pigs also wallow in cooler conditions to relieve ectoparasite infection, although wallowing typically increases as temperatures rise (Bracke 2011). Feral pigs are restricted to shady habitats in warmer conditions, but will choose more food rich habitats when temperatures are milder (Giles 1980; Caley 1997; Dexter 1998; Choquenot and Ruscoe 2003; Twigg *et al.* 2005). Water is less important than cover in determining habitat preference in hot conditions, as feral pigs can travel a considerable distance (7km) in a short period to access water (Pavlov *et al.* 1992; Dexter 1998). Feral pigs use regular travel pads to water, preferred feeding grounds and bedding sites. Signs such as wallows, tracks, scats, fence crossings, rubbing and tusking that are found on such travel pads are useful for determining recent presence (Choquenot *et al.* 1996; Campbell and Long 2009).

Feral pigs are typically gregarious creatures that form groups known as mobs, or sounders in the USA. Mobs often contain 12 or fewer animals that are comprised of one or more sows and their piglets, young females, bachelor groups or other combinations (Giles 1980; Hone and Pederson 1980; Choquenot *et al.* 1996; Spencer *et al.* 2005; Twigg *et al.* 2005). Piglets usually stay with their mother until the next litter is due; thereafter they form their own groups (Giles 1980; Hone and Pederson 1980; Choquenot *et al.* 1996; Twigg *et al.* 2005). Males usually run in bachelor mobs until they reach 18 months of age; thereafter they become solitary only mixing with others during mating and at localised food resources (Giles 1980; Hone and Pederson 1980; Choquenot *et al.* 1996; Spencer *et al.* 2005; Twigg *et al.* 2005;)

Home range

Feral pigs have relatively defined home ranges and the size of their home range depends on factors such as resources, density and body mass (Giles 1980; Saunders and Kay 1991; Caley 1997; Dexter 1999; Saunders and McLeod 1999). Dexter (1999) also reported that feral pig home ranges in the rangelands decrease with increased air temperature. Therefore, summer home ranges in the rangelands are likely to be a compromise between the need to forage and the need to stay close to cover and permanent water (Dexter 1999). Annual home ranges can be as large as 43 km^2 for boars, 6.2 km^2 for sows and 1.13 km^2 for animals less than 12 months old (Giles 1980). Boars typically have larger home ranges than sows, because they are often heavier and thus they require more food. They may also have larger home ranges to maximise their chances of encountering oestrous sows that have small home ranges (Giles 1980; Saunders and Kay 1991; Caley 1997; Dexter 1999; Spencer *et al.* 2005; Spencer and Hampton 2005; Mitchell *et al.* 2009). The daily home ranges of feral pigs are much smaller than their annual home ranges, which usually falls between 0.7 – 1.4 km^2 (Choquenot *et al.*

1996; Dexter 1998). The daily home ranges of recently farrowed sows may be as small as 0.16 km^2, which may be 80% less than their usual daily home range (Saunders and Kay 1991; Choquenot *et al.* 1996).

Dietary requirements

Feral pigs are opportunistic omnivores, although their diet largely consists of vegetable matter such as foliage, stems, fruit, rhizomes, bulbs, tubers, seeds and fungi. They also consume animal material such as invertebrates, amphibians, reptiles, birds, mammals and carrion (Giles 1980; Baber and Coblentz 1987; Pavlov *et al.* 1992; Chimera *et al.* 1995; Choquenot *et al.* 1996; Taylor and Hellgren 1997; Anon 2005). Feral pigs typically change their diet according to season, particularly in the rangelands with grasses and forbs being consumed after rain events, and roots and animal material being consumed in drier conditions (Giles 1980; Baber and Coblentz 1987; Choquenot *et al.* 1996; Taylor and Hellgren 1997). Their body condition also improves when high protein green foods are available and declines when these foods become scarce (Giles 1980; Baber and Coblentz 1987; Choquenot *et al.* 1996; Dexter 2003).

Reproduction and lifecycle

Sows require high protein diets for successful lactation and young rearing. If crude protein intake levels fall below 15%, lactation may cease resulting in high piglet mortality (Giles 1980). Consequently, breeding is heavily influenced by the availability of high quality foods (Giles 1980; Hone and Pederson 1980; Caley 1993). In nutrient rich environments sows can breed throughout the year but in areas like the rangelands where resources are less reliable, breeding is often dependant on rain events and the subsequent flush of new growth (Giles 1980; Hone and Pederson 1980; Choquenot *et al.* 1996; Spencer *et al.* 2005). Giles (1980) reported that stomachs containing fresh green grass and forbs had higher crude protein levels (17.61% ± 0.73% SE) than those that contained root material (5.90% ± 0.47% SE). He also mentions that those containing animal material had crude protein levels as high as 33.5%. This may be why feral pigs tend to exploit fresh new growth when it is available and will switch to roots and underground foods when above ground quality vegetation dries off. It may also be why it is typically more common for feral pigs to supplement their diet with carrion during hot and dry summer conditions (Giles 1980).

Sows reach sexual maturity at 25 to 30kg, which usually occurs between 6 and 12 months of age (Giles 1980; Coblentz and Baber 1987; Twigg *et al.* 2005), whereas boars reach sexual maturity at 15 to 24 months of age (Choquenot *et al.* 1996). Fecundity generally increases with age and body size (Giles 1980; Spencer *et al.* 2005). Sows have a 21 day oestrous cycle and a 112 – 114 day gestation period. The average litter size for feral pigs is 5.6 piglets and piglets are often weaned by 2-3 months of age (Giles 1980; Coblentz and Baber 1987; Choquenot *et al.* 1996; Spencer *et al.* 2005; Twigg *et al.* 2005). Multiple paternity in sows can occur as they often copulate with different boars, which may increase genetic mixing (Spencer *et al.* 2005). Sows can produce two weaned litters within 15 months when quality food is plentiful, again highlighting the potential for population recovery after control efforts in good seasonal conditions (Choquenot *et al.* 1996).

1.1.3 Impacts

Environmental

Feral pigs cause a variety of environmental damage, although the extent of this damage is often difficult to quantify (Anon 2005). Some of the more recognised environmental damage caused by pigs includes predation, habitat degradation, competition and disease transmission, all of which are listed as key threatening processes under the Environmental Protection and Biodiversity Conservation Act 1999 (McLeod 2004; Anon 2005). Numerous authors have reported that feral pigs consume wildlife species such as small mammals, lizards, snakes, turtles, frogs, birds, crustaceans, insects and earth worms although the damage to these species is relatively unknown (Giles 1980; Coblentz and Baber 1987; Pavlov *et al.* 1992; Chimera *et al.* 1995; Pavlov and Edwards 1995; Taylor and Hellgren 1997; Cuthbert 2002; Fordham *et al.* 2006; Wilcox and VanVuren 2009; Jolley *et al.* 2010). Feral pigs also compete with native wildlife for resources and destroy native habitat by a number of means. The most obvious damage is likely to be ground rooting (Singer *et al.* 1984; Mitchell and Mayer 1997; Engeman *et al.* 2004; Mitchell *et al.* 2007). During this time, feral pigs turn over soil, logs and rocks with their strong cartilaginous snout in search of underground foods such as roots and invertebrates (Campbell and Long 2009; Hone 2012). Rooting usually occurs more frequently in areas where soil moisture persists such as moist gullies and creeks, and may be influenced by season (Hone 1988, 1995, 2002; Mitchell and Mayer 1997; Mitchell *et al.* 2007). Rooting is also usually more prominent when feral pig densities are higher (Hone 1988, 1995, 2002, 2006, 2012). Disturbance caused by rooting can promote weed establishment, alter vegetation structure and contribute to soil erosion (Singer *et al.* 1984; Pavlov *et al.* 1992; Choquenot *et al.* 1996; Hone 2002, 2012; Engeman *et al.* 2004; McLeod 2004; Mitchell *et al.* 2007; Campbell and Long 2009). Feral pigs may also facilitate the spread of root-rot fungus

Phytophthora cinnamomi; a soil-born water mould that produces a root infection in native plants causing them to wilt and die (Choquenot *et al.* 1996; Anon 2005).

Agricultural

Feral pigs are a significant impediment to agricultural productivity in Australia, and although it is difficult to attribute an Australia wide cost estimate on damage, Choquenot *et al.* (1996) reported it is likely to be in excess of $100 million dollars per annum. This figure may equate to more than $150 million today, based on a 2.6% annual rate of inflation and without accounting for population growth (RBA 2013). Such damage is likely to include crop consumption and trampling, lamb predation, competition for resources and damage to infrastructure (Pullar 1950; Giles 1980; Pavlov *et al.* 1981; Izac and O'Brien 1991; Caley 1993; Choquenot *et al.* 1996; Choquenot *et al.* 1997; McLeod 2004; Seward *et al.* 2004). Tisdell (1982) estimated that damage to grain crops alone was near $41.4 million during 1979-80. Caley (1993) estimated crop damage in the Douglas River region of the Northern Territory to be as high as 197kg of grain per adult pig, per season. In addition, Pavlov *et al.* (1981) and Choquenot *et al.* (1997) recorded average lamb predation rates at 18.7% and 29%, respectively. Choquenot *et al.* (1997) also reported that ewes lost more lambs when feral pig densities were higher, and implied predation rates increased with increased feral pig density. In addition, twin lambs were 6 times more likely to be preyed on than single lambs. Importantly, feral pigs are vectors of endemic diseases such as leptospirosis and brucellosis, and exotic diseases such as classical swine fever and foot-and-mouth disease that could seriously threaten wildlife, human and livestock health in the event of an outbreak (Pullar 1950; Giles 1980; Izac and O'Brien 1991; Pavlov *et al.* 1992; Pavlov and Edwards 1995; Choquenot *et al.* 1996; McLeod 2004; Seward *et al.* 2004). It was estimated that an outbreak of foot and mouth disease could cost Australia more than $3 billion in lost export and associated costs, even if it was eradicated immediately (Izac and O'Brien 1991). This may equate to more than $5.5 billion today (RBA 2012).

Social

Despite the negative impacts associated with feral pigs, they are also considered to be a valuable recreational and commercial resource (Pullar 1950; O'Brien 1987; Izac and O'Brien 1991; McIlroy 1995; Choquenot *et al.* 1996; Anon 2005). Feral pig hunting is popular in Australia and its flow-on effects can be valuable to local communities (O'Brien 1987; Choquenot *et al.* 1996; McLeod 2004; Anon 2005). Tisdell (1982) estimated there were around 100,000 pig hunters in Australia that spend an average of $447 per annum on pig hunting, which equates to almost $45 million a year in revenue (Tisdell 1982). Based on these estimates, annual revenue would equate to $140 million today; without an increase in the number of hunters (RBA 2013). Commercial harvesting of feral pigs began in Australia during 1980, and it is worth approximately $20 million per annum (McIlroy 1995; Choquenot *et al.* 1996; McLeod 2004; Anon 2005). Australia's feral pig meat comes from New South Wales, Queensland and the Northern Territory (Choquenot *et al.* 1996; Anon 2005). Commercial harvesters take field dressed animals to chiller operators where carcasses are purchased for up to $1.00 per kilogram (Choquenot *et al.* 1996). Hereafter, the animals are transported to a game meat processor in Sydney or Brisbane and the meat is exported to Europe as wild boar meat (O'Brien 1987; Choquenot *et al.* 1996).

1.1.4 Management techniques

Feral pigs are managed where they occur because of the damage they cause to agriculture and the natural environment, and because of their potential to spread numerous endemic and exotic diseases. In Australia, a variety of techniques are used to reduce feral pig damage including poison baiting, aerial shooting, hunting, trapping, Judas pig technique and fencing.

Baiting

Toxic baiting is commonly used in Australia, as it is one of the most cost-effective broad scale techniques available (Giles 1980; Hone and Pederson 1980; Hone 1983, 2002; McIlroy *et al.* 1993; McIlroy 1995; Cowled *et al.* 2006a, b, 2008a; Twigg *et al.* 2007). Toxins such as sodium monoflouroacetate (1080), yellow phosphorus and warfarin have been used in the past, although yellow phosphorus and warfarin are being phased out due to animal welfare concerns (McIlroy *et al.* 1989; Cowled *et al.* 2006a, b, 2008a; Twigg *et al.* 2007; Lapidge *et al.* 2009). This essentially leaves 1080 as the only registered alternative. However, 1080 is not without disadvantages, as it requires a relatively high dose which may impact non-target species should they consume bait, there is no antidote should accidental poisoning occur and 1080 ingestion by feral pigs can lead to vomiting (McIlroy 1983; Hone and Kleba 1984; O'Brien 1988; Sherley 2004; Cowled *et al.* 2008a; Lapidge *et al.* 2009).

Cowled *et al.* (2008a) identified sodium nitrite (SN) as a potential additional toxin. SN kills by methaemoglobinemia (blood oxygen deprivation), which leads to hypoxia, central nervous system depression and death. Feral pigs are highly susceptible to methaemoglobin forming compounds as they possess uniquely low levels of methaemoglobin reductase, which is the enzyme required for converting oxygen deficient methaemoglobin back to oxygen rich haemoglobin (Cowled *et al.* 2008a). Methaemoglobinemia caused by SN consumption is relatively fast (within 1.5 hours) and SN is accompanied by an effective antidote in methylene blue (Cowled *et al.* 2008a; IMVS 2010; Lapidge *et al.* 2009, 2012). An independent study undertaken by the Institute of Medical and Veterinary Science concluded "*the symptoms leading to death and duration of display of these symptoms would suggest that sodium nitrite satisfies a general understanding of what a humane poison would b*e" (IMVS 2010). However, until sodium nitrite becomes commercially available 1080 is the only registered toxicant for feral pig control in Australia, hence particular caution must be applied to minimise the risk to non-target species.

During feral pig baiting programs, non-poisoned free-feed baits such as grain, pellets, fruit or manufactured baits are offered at areas of recent or frequent feral pig activity (O'Brien and Lukins 1988; McIlroy *et al.* 1993; Caley 1994; Twigg *et al.* 2005, 2007; Cowled *et al.* 2006a, 2008a). Bait stations are checked daily for bait up-take and if the bait has been consumed by feral pigs it is replaced; if the bait has lost its attractiveness it is refreshed. Free-feeding is essential for best results and is undertaken until pig numbers plateau, which generally occurs at 10 – 15 days (McIlroy *et al.* 1993; Twigg *et al.* 2005, 2007). Thereafter, the non-toxic free-feed bait material is replaced with toxic (1080) bait material. Toxic baiting generally continues for 4 - 7 days or until toxic bait uptake ceases (Twigg *et al.* 2005).

Seasonal conditions have been reported to affect bait program efficacy and best results are often achieved when natural foods are scarce (Hone 1983, 2012; McIlroy and Saillard 1989; Caley 1994; McIlroy 1995; Choquenot and Lukins 1996). This is typically when it is hot and dry in the rangelands and tropical environments; or during autumn/winter in the highlands and Mediterranean climates (Hone 1983; O'Brien and Lukins 1988; Saunders and Kay 1991; McIlroy *et al.* 1993; Saunders *et al.* 1993; Caley 1994; Choquenot and Lukins 1996; Twigg *et al.* 2005, 2007). Bait station position also influences the success of poison baiting programs, with bait stations being most successful when they are established near fresh activity, within tree lines, on fire trails or near creek lines (O'Brien and Lukins 1988; McIlroy and Saillard 1989; Saunders and Kay 1991; McIlroy *et al.* 1993; Saunders *et al.* 1993; Caley 1994). Even when the pre-mentioned factors are considered, some pigs will not eat due to alternate food preference, neophobia to bait and lack of contact with bait (Hone 1983; McIlroy and Saillard

1989; McIlroy *et al.* 1993). Additionally, feral pig populations can recover to near pre-control levels one year after baiting if efficacy levels are insufficient (Hone and Pederson 1980), although rapid population recovery by feral pigs is common for other management techniques such as trapping and aerial shooting (Saunders 1993; Choquenot *et al.* 1996).

Aerial shooting

Aerial shooting is often used to manage feral pigs over vast and/or inaccessible areas (Hone 1983, 1990b; Saunders and Bryant 1988; Saunders 1993; McIlroy 1995; Dexter 1996; Choquenot *et al.* 1999). Aerial shooting is undertaken from a helicopter and it involves the use of a three or more person team including a pilot, a spotter who locates and records the number of pigs shot and stays vigilant for hazardous obstacles, and a shooter. Shooters must use appropriate firearms and ammunition, and must aim for the head or chest of the animal to ensure a humane kill (Sharp and Saunders 2004). Aerial shooting is species specific and it is capable of producing results equal to poisoning on a cost per pig basis when densities are high (Hone 1990b; Choquenot *et al.* 1999). In addition, aerial shooting is not particularly affected by seasonal conditions, although animals are may be located in the open during cool conditions (Hone 1983; Saunders and Bryant 1988; Saunders 1993; McIlroy 1995; Choquenot *et al.* 1996). The effectiveness of aerial shooting can however be affected by factors including dense vegetation, terrain and habituation by feral pigs to aerial shooting events (Hone 1983; Saunders and Bryant 1988; Choquenot *et al.* 1996; Dexter 1996; Campbell and Long 2009). Aerial shooting is also expensive when a low density threshold is reached, as it takes longer to locate and dispatch remaining animals (Hone 1983, 1990b; Saunders and Bryant 1988; Choquenot *et al.* 1999).

Trapping

Trapping is useful in areas that are close to human habitation, or where non-target species exist at high densities (Choquenot *et al.* 1993; Saunders *et al.* 1993; Caley 1994; Choquenot *et al.* 1996). Trap designs vary greatly, although in Australia the three most common trap designs include panel, silo or box traps (Choquenot *et al.* 1996). All contain a one way entrance that enables animals to enter but prevents them from leaving. At the beginning of a trapping program, free-feed bait is deployed at areas of regular activity within a particular target area. Each bait station is checked daily for bait up-take. When bait is being taken regularly by feral pigs, a trap is assembled and the door is left open. Free-feeding continues until the number of individuals visiting and feeding from the trap reaches a plateau (7-10 days) (Saunders *et al.* 1993). Thereafter, the trap door is set and the trap is checked daily so captured animals can be disposed of humanely (Saunders *et al.* 1993). Many of the factors that affect baiting also affect trapping such as season, trap location, free-feeding and presence of fresh sign (Saunders *et al.* 1993; Caley 1994; Choquenot *et al.* 1996; Choquenot and Lukins 1996). Additional factors include behavioural pattern of an animal to a trapping mechanism, learned response to traps based on previous exposure and location of traps in relation to home range (Saunders *et al.* 1993). Caley (1994) also found that trapping success decreased as the distance from water increased in the dry season in the Douglas Daly region of the Northern Territory. If undertaken properly, trapping can provide population reductions of 62% and 81% (Choquenot *et al.* 1993; Saunders *et al.* 1993). Conversely, trapping can be expensive compared to aerial shooting and baiting, as it is labour intensive and good quality traps can be expensive (Giles 1980; Coblentz and Baber 1987; Saunders 1988; Choquenot *et al.* 1996). Other limitations are that trapping is less suitable for broad scale control, some animals cannot be captured and escapees become trap shy (Saunders *et al.* 1993; Choquenot *et al.* 1996)

Ground shooting and dogging

Ground shooting and hunting with dogs are popular recreational activities in Australia (McIlroy and Saillard 1989; Caley and Ottley 1995; McIlroy 1995; Choquenot *et al.* 1996; McLeod 2004). During ground shooting, hunters commonly walk through suitable feral pig habitat, sit near a favoured feed grounds or water points on dusk, or spotlight in open areas at night. Feral pigs are shot with an appropriate sized firearm when they are encountered. Ground shooting may be a useful mop up operation for targeting solitary animals that have evaded other techniques (Giles 1980; McIlroy 1995; Choquenot *et al.* 1996). However, Tisdell (1982) estimated that ground shooters only reduce the feral pig population by 15-20% per annum, which is unlikely to have any long term effect on the feral pig population.

During dogging, individuals use trained dogs that either catch and hold the feral pig or keep the animal at bay (Choquenot *et al.* 1996). The hunter then dispatches the animal using a knife or firearm. More recently, animal welfare concerns have arisen where hunting dogs are used to catch and hold feral pigs, and thus its use is under scrutiny. Hunting with dogs may be a useful for targeting remaining animals following other control techniques. Conversely, when pigs reside in large mobs or exist at high densities dogging is likely to have limited impact on the population and their damage (McIlroy and Saillard 1989; Caley and Ottley 1995;

Choquenot *et al.* 1996). McIlroy and Saillard (1989) found hunting with dogs in temperate highlands had limited effectiveness, where only 13% of pigs known to be in the area were removed. Barrett (1978) achieved a similar result (20%) in California. Caley and Ottley (1995) concluded that hunting with dogs in the Douglas Daly area of the Northern Territory was effective for removing solitary feral pigs after other control (88%), although its effectiveness was reduced to 9.2% when targeting mobs. A number of factors can influence the effectiveness of hunting with dogs including the skill of the hunter and the dog, vegetation, terrain and feral pigs previous exposure to dogging (McIlroy and Saillard 1989; Caley and Ottley 1995; McIlroy 1995).

Judas pig technique

The Judas technique aims to exploit the gregarious nature of certain pest animals. A radio collar is attached to a captured animal in the hope it will associate with other free-ranging animals when it is released (McIlroy 1995; McIlroy and Gifford 1997; Campbell and Long 2009). The radio collared animal can be tracked from the ground or by the air and its associates can be shot. This method is useful for highly social animal like feral goats that live in large groups, but may also be advantageous for feral pigs (McIlroy 1995; McIlroy and Gifford 1997). The Judas pig technique can be useful in the latter stages of a multi-technique approach to locate animals that have evaded other techniques (McIlroy 1995; McIlroy and Gifford 1997). McIlroy and Gifford (1997) reported that the most effective Judas animals were sows that belonged to the target area. Therefore, sows should be trapped from multiple sites in the target area before toxic baiting is undertaken (or aerial shooting or trapping). Those animals can then be released after poisoning to associate with any remaining animals (McIlroy 1995; McIlroy and Gifford 1997). The Judas pig technique may also be useful for targeting animals that belong to small populations in limited access areas (McIlroy 1995; McIlroy and Gifford 1997).

Exclusion fencing

Exclusion fencing is a non-lethal form of control that can be used to protect areas of high importance such as lambing paddocks and valuable crops (Giles 1980; Hone and Atkinson 1983; Reidy *et al.* 2008). Several fence designs have been tested for feral pig exclusion in Australia and overseas (Campbell and Long 2009). Hone and Atkinson (1983) reported that hinge joint fences were more efficacious than plain wire fences, and that stand off electrified wire (~30 centimetres above ground level) can make hinge joint fence almost pig proof (≥

93.7% affective). Reidy *et al.* (2008) evaluated the effectiveness of several electrified polywire fence designs for excluding feral pigs. It was reported that electrified fences could reduce feral pig incursions by 65% compared to non-electric polywire fences of the same design, and that two and three stand electrified polywire fences had 50% and 40% fewer incursions, respectively than a single electrified polywire fence. In addition, two strand electrified polywire fence reduced sorghum crop damage by 64% when compared to the two strand polywire non-electrified fence (Reidy *et al.* 2008). Some of the shortfalls with electric fencing are they are expensive to build and maintain, and thus they are usually only suitable for protecting small areas (Giles 1980; Hone and Atkinson 1983; Katahira *et al.* 1993; Reidy *et al.* 2008). It is often best to use electric fencing in conjunction with other techniques and it may be more cost effective to add a stand-off electrified wire to an existing fence, particularly if the existing fence if a hinge joint fence (Hone and Atkinson 1983; Reidy *et al.* 2008).

Recent developments

Manufactured poison baits have been developed for many pest species in Australia to reduce non-target risk, increase operator safety and enhance quality control (Cowled *et al.* 2006a, b; Lapidge *et al.* 2006, 2009). Currently, PIGOUT® is the only commercially manufactured feral pig bait in Australia. It is made of an omnivorous matrix that is wrapped in a cellulose skin, and in the centre of the bait is a hydrophobic 1080 core that provides a non-toxic buffer zone in the remainder of the bait. PIGOUT® is highly target specific and it can produce population knockdowns, equal to, or in excess of traditional baits (Cowled *et al.* 2006a, b; Lapidge *et al.* 2006, 2009).

Traditionally, feral pig bait is placed directly on the ground which may expose non-target species to poisonous substrates (Pavlov *et al.* 1992; Lapidge *et al.* 2006, 2009; Cowled *et al.* 2008a). Moreover, the 1080 dose required to control feral pigs is high, therefore non-target animals may be at risk should they consume bait (O'Brien 1988; Pavlov *et al.* 1992; Lapidge *et al.* 2006, 2009; Cowled *et al.* 2008a). As a result, several wild pig bait delivery devices have been created internationally to help reduce bait uptake by non-target species including the Boar-Operated-System (BOS™), the bucket feeder prototype and the Non-target Exclusion Device (NED) (Long *et al.* 2010; Massei *et al.* 2010). Many of these have been developed for delivery of pharmaceutical baits and most only hold a small amount of bait material, therefore they require daily bait replenishment (Long *et al.* 2010; Massei *et al.* 2010).

During 2006, the Invasive Animals Cooperative Research Centre (IA CRC) commenced the HogHopper™ project to develop a feral pig specific bait delivery device suited to Australian conditions. The HogHopper™ targets unique feral pig attributes such as reach, size, strength and feeding behaviour to prevent non-target species from accessing toxic bait. The HogHopper™ also holds enough bait to prevent daily operator maintenance. During its development, the HogHopper™ underwent stringent pen and field testing to ensure a highly efficacious and target specific product was created (Lapidge *et al.* 2009).

Modern approaches

In Australia, and internationally, eradication of established widespread pest species (the complete removal of all individuals) is rarely possible; except for isolated populations and on islands (Parkes 1990; Bomford and O'Brien 1995; Parkes *et al.* 2006). This is because rarely can the criteria required for successful eradication be met. In that, the removal rate must be faster that the rate of increase, immigration must be prevented and all reproductive animals must be at risk of the management technique (Izac and O'Brien 1991; Hone 1994; Bomford and O'Brien 1995; Parkes *et al.* 2006). Additional desirable criteria are the animals can be detected at low densities, cost benefit of eradication out-weighs continued management, and the socio-political environment is accepting (Bomford and O'Brien 1995).

Consequently, the focus of pest management has shifted towards damage management rather than pest animal eradication. Management programs also aim to integrate multiple management techniques over wider areas in a sustained fashion (O'Brien 1987; Parkes 1990; Braysher 1993; Hone 1994, 2007; Bomford and O'Brien 1995; Choquenot *et al.* 1996; Olsen 1998; Anon 2005; Reddiex *et al.* 2006; Campbell and Long 2009). Some of the best examples of coordinated and integrated multi-technique approaches are where managers have successfully eradicated feral pigs on islands and hence removed feral pig damage (Miller and Mullette 1985; Katahira *et al.* 1993; Cruz *et al.* 2005). Monitoring the effects of management on the apparent damage is also extremely important, as it enables manages to measure the short and long term management effects, hence permitting adaptive management (Braysher 1993; Hone 1994, 1995, 2002; Choquenot *et al.* 1996, 1997; Reddiex *et al.* 2006; Reddiex and Forsyth 2006). Adaptive management experiments are often necessary, because the systems in which pest animals occur are complex and the effects of pest management can only be hypothesised (Parkes *et al.* 2006). Appropriate sized target zones are also essential, because they can help to slow re-invasion and population recovery post management. This is why managers now try to coordinate management with their neighbours. More recently, molecular ecology has been used to help define population boundaries, hence develop more appropriate sized target areas (Hampton *et al.* 2004; Cowled *et al.* 2008b; Campbell and Long 2009). Braysher (1993) sets out the basic steps for developing strategic pest management programs. Since then this process has have evolved. Braysher *et al.* (2013) reports the most up to date set of guidelines, they are: define the problem (damage focused), determine management priorities (damage levels and focus areas), decide feasibility (economic, social and environmental), determine objectives (clear and measurable) develop the program (suitable techniques), implement the program (coordinated and strategic), monitor and evaluate (performance and operations), and refine according to program outcomes.

1.2 Feral pigs in the Macquarie Marshes

It is not known when feral pigs first arrived in the Macquarie Marshes, although they have been widespread in the area since 1896 (Hogendyk 2007). The Macquarie Marshes provide ideal habitat for feral pigs as they contain abundant food, water and extensive areas of dense cover. Giles (1980) estimated based on age structure and catch per unit effort, that feral pig densities were as high as 50 individuals per km^2 at Oxley station (south marsh) during 1973. However, Saunders and Bryant (1988) estimated the population was more likely to be 10 pigs per km^2. Regardless, the abundant feral pig population in the Macquarie Marshes is likely to be preying on various wildlife species such as frogs, turtles, snakes, lizards and waterbirds, damaging habitat by ground rooting, wallowing and trampling, competing with native species for resources and impacting water quality (Giles 1980; Choquenot *et al.* 1996; Brock 1998; Anon 2005). They are also likely to be impacting agriculture by preying on new born lambs, damaging and consuming crops and pasture, and spreading diseases such as leptospirosis (Brock 1998). Giles (1980) reported leptospirosis occurred in 19% ± 10% (SE) of animals tested during three consecutive years in the Macquarie Marshes. However, leptospirosis may also be prevalent in other species, particularly rodents (Caughley *et al.* 1998). As a consequence of the real and perceived impacts of feral pigs, they are listed as a primary threat to the ecological integrity of the Macquarie Marshes Ramsar Wetlands and their surrounds (NPWS 1993).

New South Wales National Parks and Wildlife Service implement a bi-annual aerial shooting campaign to help reduce the perceived damage feral pigs cause to biodiversity in the Macquarie Marshes Nature Reserve (MMNR); the program has been established since 1979 (Saunders 1993). The Central West and North West Livestock Health and Pest Authority undertake aerial shooting on adjoining private land when funding permits. On-ground efforts such as baiting and trapping are also undertaken on private land by landholders, although it is largely reactive and uncoordinated. Saunders (1993) implemented a two year study in the Macquarie Marshes to determine the effectiveness of aerial shooting for reducing pig numbers. He reported that aerial shooting could reduce the feral pig population by 80% in the first year and by 65% in the second year. However, the feral pig population was able to recover by 77% between control efforts.

Giles (1980) also reported, under good seasonal conditions, feral pig populations in the Macquarie Marshes can attain an annual exponential rate of increase (r) of 0.6 - 0.7, which is the equivalent to a maximum finite rate of increase (λ) of 1.82 – 2.0. This implies that the feral pig population in the Macquarie Marshes must be reduced by 50% in a short period of time for it to remain below pre-control levels one year after control. Similarly, Hone (2007) estimates that feral pigs have an annual maximum finite rate of increase (λ) of 2.1 under good seasonal conditions, and thus a population must be reduced by 52% to remain below pre-control levels one year after control. Choquenot *et al.* (1999) reported that the cost per kill during aerial shooting in the Macquarie Marshes increases exponentially once a low density threshold of 3 pigs per km^2 is achieved but above this threshold cost per kill was relatively consistent.

Giles (1980), Saunders and Bryant (1988) and Saunders (1993) demonstrate a need for a multi-technique, sustained management program in the Macquarie Marshes, if long term damage reductions are the objective. They also mention that aerial shooting (effective for broad scale control in difficult access areas) in combination with conventional on-ground techniques such as trapping or baiting will be essential. Of the more conventional on-ground techniques, toxic baiting may be most appropriate in the Macquarie Marshes (confirmed also by landholder support) as it is more cost effective than trapping for broad scale management (Coblentz and Baber 1987; Choquenot *et al.* 1996; Cruz *et al.* 2005). Toxic baiting is rarely undertaken in the Macquarie Marshes due to non-target concerns, although with the recent development of the HogHopper™ (a feral pig specific bait delivery device) the opportunity now exists to incorporate toxic baiting into a multi-technique approach. The HogHopper™ also helps to reduce operator maintenance, which makes it more appealing to end users and may increase the chances of broad scale adoption of the program in the future.

1.3 Aims and objectives

Given the above scientific literature, the aim of this project is to provide a greater understanding of feral pig ecology and the effects of various management options on feral pig abundance and damage to help refine future feral pig management in the region. The study has four main objectives:

Objective 1 – Undertake a dietary analysis of feral pigs in the Macquarie Marshes to determine which wildlife species may be at risk of feral pig predation, and to determine whether season, location or feral pig demographics influences predations levels.

Objective 2 – Assess feral pig activity patterns in the Macquarie Marshes using remote camera technology to determine whether season or management type influence activity patterns.

Objective 3 – Assess various bait attractants and bait substrates for their ability to enhance bait station visitation and bait-take by feral pigs in the Macquarie Marshes.

Objective 4 – Determine the relationship between feral pig abundance and damage (ground rooting), and to assess the efficacy of various forms of management to refine future management operations in the Macquarie Marshes.

Chapter 2 - Study site

2.1 The Macquarie Marshes

The Macquarie Marshes are situated in the rangelands of western New South Wales. They begin 50 kilometres north of Warren (31º 41’ 24” S, 147º 49’ 47” E) and continue north for almost 120 kilometres to finish near Carinda (Fig. 2.1) (Yonge and Hesse 2009; Ralph and Hesse 2010). The marshes are more than 200,000 hectares in size and are one of the largest remaining semi-permanent inland wetlands in eastern Australia (Kingsford and Johnson 1998; Fazey *et al.* 2006; Ralph and Hesse 2010). Approximately 18,000 hectares of the Macquarie Marshes is gazetted Macquarie Marshes Nature Reserve and the remainder is largely freehold land. During 1986, the Macquarie Marshes Nature Reserve was listed under the Ramsar convention as a wetland of international importance. An additional 583 hectares of freehold land was listed in 2000 (Kingsford and Thomas 1995; Kingsford and Auld 2005).

The Macquarie Marshes are comprised of a series of semi-permanent marshes, streams and lagoons as well as ephemeral wetlands that are inundated only during large floods (Kingsford and Auld 2005; Ralph and Hesse 2010; Ralph *et al.* 2011). Although local rainfall is important, the Macquarie Marshes rely heavily on in-flows from the Macquarie River, which generally occur during winter (Kingsford and Thomas 1995; Kingsford 2000; Ralph and Hesse 2010). The Macquarie River originates on the western side of the Great Dividing Range near Bathurst, and continues north until it reaches the Darling Riverine floodplain to form the Macquarie Marshes (Kingsford and Thomas 1995; Brock 1998; Kingsford and Johnson 1998; Kingsford and Auld 2005; Ralph and Hesse 2010). Some of the largest flows from the Macquarie River reach the Barwon-Darling River system, although it more commonly remains in the Macquarie Marshes Wetland (Kingsford and Thomas 1995; Kingsford and Johnson 1998; Kingsford 2000; Ralph and Hesse 2010). The area is mostly flat within the marshes and the soils are relatively uniform, largely consisting of grey-brown soils to black organic loams over grey clays (Brock 1998; Yonge and Hesse 2009).

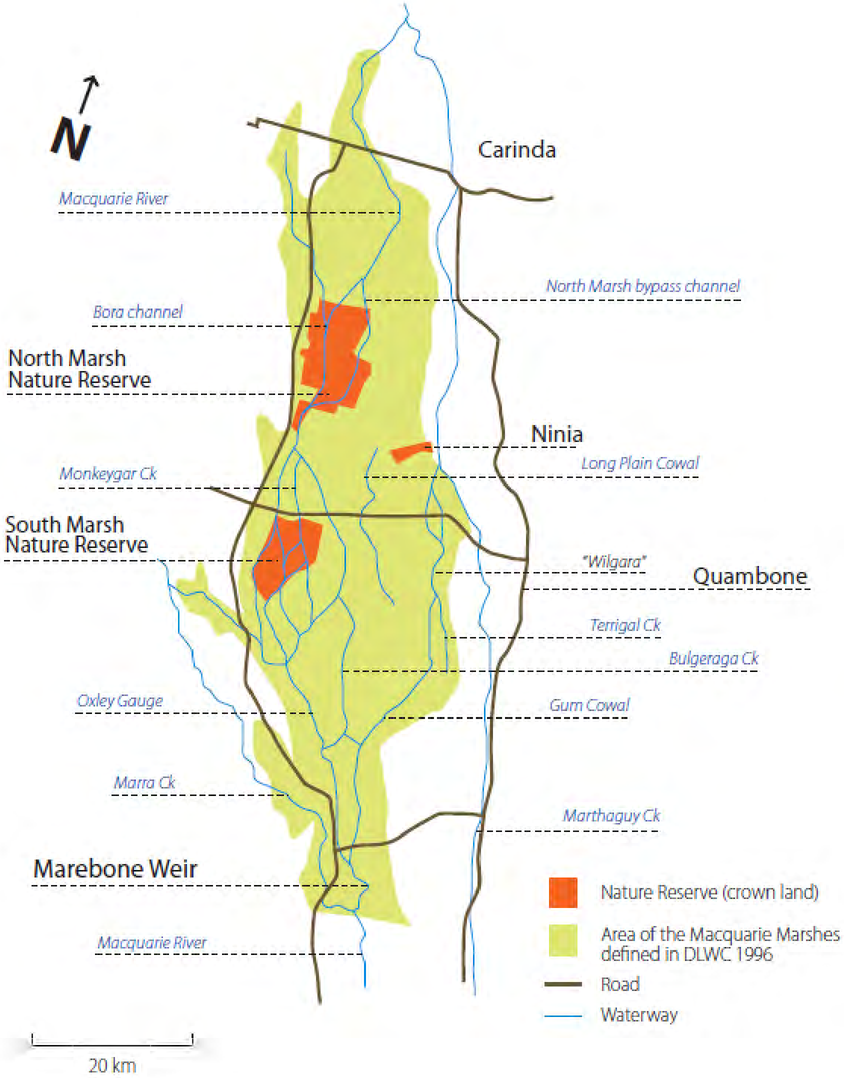

Figure 2.1 – Location of the Macquarie Marshes and associated Nature Reserves (Hogendyk 2007).

The Macquarie Marshes receives slightly higher mean rainfall and higher mean ambient air temperatures during summer (Table 2.1).

Table 2.1 – Summary of climatic data for Coonamble airport. Coonamble airport data was chosen as the airport was the nearest to the Macquarie Marshes (72km to the east) with the most comprehensive and up to date dataset (Bureau of Meteorology 2013).

	J	F	M	A	M	J	J	A	S	O	N	D
Mean max. temp. (°C)*	35	34	31	26	22	18	17	19	24	27	31	33
Mean min. temp (°C)*	20	19	17	12	7	5	4	4	7	11	16	18
Mean rainfall (mm)#	47	65	45	45	33	46	39	25	35	46	64	74

*1997-2012, # 1997-2013.

2.2 Study sites

This project was undertaken on four private agricultural properties that are situated in the central area of the Macquarie Marshes, between the North and South Macquarie Marshes Nature Reserves (30º 40′ 52″ S, 147º 32′ 49″ E) (Fig. 2.2). Giles (1980) assessed various aspects of the ecology of feral pigs at Oxley station, which is located south of the southern Macquarie Marshes Nature Reserve. The properties used in the present study were selected because they were similar in size and habitat, and because the landholders were willing to participate. Where possible, properties that were separated by distances >5km were selected to reduce the chances of feral pigs travelling from one property to another during the trial. Giles (1980) reported, using capture-mark-recapture, that the mean linear distance travelled by adult boars, adult sows and juvenile feral pigs within 12 months in the Macquarie Marshes was 3.7 ± 0.9 km (SE), 1.4 ± 0.4km (SE) and 0.6 ± 0.1km (SE) respectively.

Study sites 1 and 2 were approximately 4,500 and 2,000 hectares in size, respectively. Both contained semi-permanent wetlands and drier ephemeral wetlands and are primarily used for cattle grazing. Study sites 3 and 2 were approximately 2,500 and 2,800 hectares in size, respectively. Both are comprised of drier ephemeral wetlands and are primarily used for wool production. All four sites contained areas of intact remnant bushland. It was not possible to select four properties that contained semi-permanent wetlands, because all properties immediately adjoining the Macquarie Marshes Ramsar Wetlands (typically properties that contained semi-permanent wetlands) were subjected to routine bi-annual aerial shooting throughout the project, which would have confounded treatment/non-treatment objectives.

Historical feral pig management between each of the selected properties varied considerably, with site 1 being subjected to regular poison baiting up to three times per year (sodium monoflouroacetate and yellow phosphorus) and aerial shooting when funding permits. Site 2 was subjected to ground shooting and hunting with dogs up to twice per month, as well as aerial shooting when funding permits. Sites 3 and site 4 are subjected to ground shooting and hunting with dogs up to twice per month. Hunting activities were restricted at each site throughout project, although illegal hunting may have occurred on some occasions. Landholders may have also undertaken opportunistic shooting if feral pigs were sighted during daily activities. However, these activities are largely *ad hoc* and infrequent.

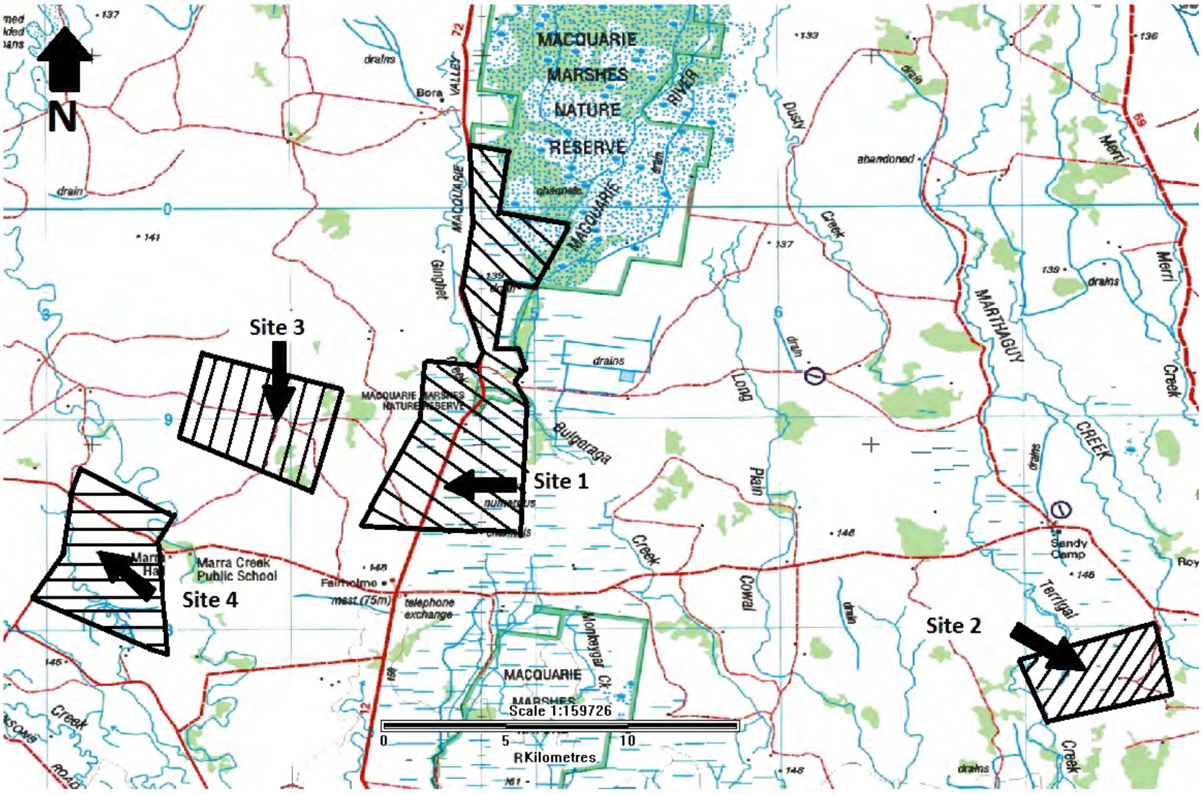

Figure 2.2 - Location of study sites used in relation to the north and south Macquarie Marshes Nature Reserves. The approximate target area within each study site is located in hatched areas (Geoscience Australia 2005).

2.3 Key values

Vegetation

The Macquarie Marshes are situated in the Darling Riverine Plains Biogeographic Region (IBRA) (DSEWPC 2013). They contain diverse flora species and some of the most important of these include the river red gum *(Eucalyptus camaldulensis)*, coolibah *(E. coolabah)*, black box *(E. largiflorens)*, common reed *(Phragmites australis)*, lignum *(Muehlenbeckia florulenta)*, water couch *(Paspalum distichum)*, cumbungi (*Typha domingensis*) and river cooba *(Acacia stenophylla)* (Kingsford and Thomas 1995; Brock 1998; Kingsford and Johnson 1998; Kingsford and Auld 2005; Yonge and Hesse 2009; Office of Environment and Heritage 2012). The Macquarie Marshes also encompass a number of important vegetation communities including some of the largest common reed beds (tall grassland) in eastern Australia, the largest northern remaining river red gum community (forest/woodland) in NSW and the most southerly occurrence of coolabah in NSW (NPWS 1993; Brock 1998; Kingsford 2000). These vegetation communities, as well as lignum shrublands, cumbungi grasslands and water couch grasslands provide important habitat for numerous wildlife species including migratory and colonial waterbirds (Kingsford and Thomas 1995; Brock 1998; Kingsford and Johnson 1998; Kingsford and Auld 2005; DECCW 2010). The vegetation of the Macquarie Marshes also plays an important hydrological role by slowing water flow thereby reducing erosion and acting as a sediment trap by catching and trapping nutrient runoff (Prosser *et al.* 2001; Yonge and Hesse 2009; DECCW 2010).

Waterbirds

Kingsford and Porter (2009) ranked the Macquarie Marshes as the fifteenth most important wetland in eastern Australia (by mean (± SE) abundance of waterbirds). The marshes support 72 different waterbird species, 43 of which use the site for breeding (Kingsford and Thomas 1995; Kingsford and Johnson 1998; Kingsford 2000). Colonial waterbirds are most prominent, and those that use the site in the largest numbers include: great egret (*Ardea modesta*), intermediate egret (*Egretta intermedia*), little egret (*Egretta garzetta*), nankeen night heron (*Nycticorax caledonicus*), glossy ibis (*Plegadis falcinellus*), Australian white ibis (*Threskiornis molucca*), straw-necked ibis (*Threskiornis spinicollis*), little pied cormorant (*Phalacrocorax melanoleucos*) and little black cormorant (*Phalacrocorax sulcirostris*) (Kingsford and Thomas 1995; Brock 1998; Kingsford 2000). The Macquarie Marshes is also one of the select few places in NSW where magpie geese (*Anseranas semipalmata*) breed (Kingsford and Johnson 1998).

Many migratory birds that are listed under migratory bird agreements that Australia has with Japan (Japan and Australia Migratory Bird Agreement), China (China and Australia Migratory Bird Agreement) and South Korea (Republic of Korea and Australia Migratory Bird Agreement) use the Macquarie Marshes (Kingsford & Auld 2005; Office of Environment and Heritage 2012). These include the bar-tailed godwit (*Limosa lapponica*), Caspian tern (*Sterna caspia*), cattle egret (*Ardea ibis*), common greenshank (*Tringa nebularia*), common sandpiper (*Actitis hypoleucos*), curlew sandpiper (*Calidris ferruginea*), eastern great egret (*Ardea modesta*), glossy ibis, latham's snipe (*Gallinago hardwickii*), marsh sandpiper (*Tringa stagnatilis*), red-necked stint (*Calidris rufcollis*), sharp-tailed Sandpiper (*Calidris acuminata*), white-bellied sea eagle (*Haliaeetus leucogaster*) and the wood sandpiper (*Tringa glareala*) (MDBA 2010).

Other wildlife

Numerous aquatic and terrestrial wildlife species also reside in Macquarie Marshes including 131 bird species (in addition to its waterbirds), 8 native mammal species, 24 native fish species, 3 turtles species, 14 snake species, 39 lizard species and 15 frog species (Brock 1998; Office of Environment and Heritage 2012). Of these, the painted snipe (*Rostratula benghalensis*), red-backed button-quail (*Turnix maculosa*), superb parrot (*Polytelis swainsonii*) and Murray cod (*Maccullochella peelii peelie*) are listed as vulnerable under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999. The bush stone-curlew (*Burhinus grallarius*), Australian bustard (*Ardeotis australis*), cotton pigmy goose (*Nettapus coromandelianus*), black-necked stork (*Ephippiorhynchus asiaticus*) and painted snipe (*Rostratula benghalensis*) are listed as endangered under the NSW Threatened Species Conservation Act 1995. An additional 23 bird species, 5 bat species and 1 frog species are listed as vulnerable under the NSW Threatened Species Conservation Act 1995 (MDBA 2010).

Agriculture

The Macquarie Marshes are not only important for their ecological values, but they are also important for their agricultural values with industries such as grazing, irrigation and dryland farming being most common (Brock 1998). Agriculture began in the Macquarie Marshes during the 1830s and the area was largely used for sheep and cattle grazing (DECCW 2010; Office of Environment and Heritage 2012). Sheep were grazed on the surrounding drier ephemeral wetlands and cattle were grazed on the more frequently flooded semi-permanent wetlands (Brock 1998). Sheep and cattle grazing are still important in the Macquarie Marshes catchment today. It was estimated that livestock slaughtering's and products from the Macquarie Marshes region were worth $173 million during 2005-06 (DECCW 2010).

Irrigated agriculture began in the 1840s, shortly after sheep and cattle grazing, and it reached its peak during the early 1990s (DECCW 2010; Office of Environment and Heritage 2012). The most significant growth in irrigated agriculture occurred between 1980 and 1990 (Kingsford and Thomas 1995). Cotton is the dominant form of irrigated agriculture in the region, although the catchment supports irrigated vegetables, citrus, grapes, olives and roses (DECCW 2010). In 2000-01 it was estimated that the total output for irrigated agriculture in the Macquarie Marshes catchment was $255 million (DECCW 2010).

Cultural heritage

Fossil records indicate that aboriginal communities were present in the Macquarie Marshes over 30,000 years ago (Hogendyk 2007). Today more than 100 archaeological sites have been found including camp sites, burial and ceremonial grounds, scared trees and a number of rare oven mounds (NPWS 1993; Brookhouse 1999). The Macquarie Marshes were traditionally used by the Wailwan people, and because the wetlands provided such abundant natural resources (food, water, tools, shelter and medicinal items) they were able to occupy much smaller country when compared to those living in the surrounding drier regions (NPWS 1993; DECCW 2010).

Education

The uniqueness of the Macquarie Marshes, in regards to its flora, fauna and cultural heritage make it a popular and highly valuable educational resource for many school and university excursions (NPWS 1993). The Macquarie Marshes also attracts a considerable amount of scientific research. Projects that aim to reduce threats to the areas key values are encouraged (NPWS 1993).

2.4 Key threats

Several key threatening processes occur in the Macquarie Marshes and those of highest concern include water extraction/irrigation, grazing, inappropriate fire regimes and introduced plants and animals.

Water/irrigation

The Macquarie Marshes rely heavily on flooding from the Macquarie River to maintain ecosystem health (Kingsford and Thomas 1995; Brock 1998; Kingsford 2000; Kingsford and Auld 2005; Hogendyk 2007; DECCW 2010; Ralph and Hesse 2010). The volume and duration of these floods are important for sustaining macro-invertebrate diversity and semi-permanent wetland vegetation communities, which are essential for waterbird breeding (Brock 1998; Kingsford and Johnson 1998; Kingsford 2000; Kingsford and Auld 2005; DECCW 2010). Over the past 40 years, the Macquarie Marshes has experienced fewer flood events than it has in the past (Kingsford and Thomas 1995; Kingsford and Johnson 1998; Kingsford 2000; Kingsford and Auld 2005). It is believed that increased river regulation, including the establishment of the Burrendong Dam in 1967, and the subsequent increase in irrigated agriculture is largely responsible (Kingsford and Thomas 1995; Kingsford and Johnson 1998; Brookhouse 1999; Kingsford 2000; Kingsford and Auld 2005; Hogendyk 2007; Rayner *et al.* 2009; Ralph and Hesse 2010; Office of Environment and Heritage 2012). As a consequence, natural flows from the Macquarie River have diminished, which has contributed to avulsion and channel abandonment (Ralph *et al.* 2011). Many reed beds have been reduced, some wetland vegetation has been replaced with chenopod shrublands, and many river red gums have died (Kingsford and Thomas 1995; Kingsford and Johnson 1998; Kingsford 2000; Kingsford and Auld 2005; Yonge and Hesse 2009; DECCW 2010). Longer periods between floods have also contributed to the loss of organic matter and macro-invertebrate diversity and density (Kingsford and Auld 2005; DECCW 2010; Ralph *et al.* 2011) In addition, reduced flooding has meant that water bird colony sizes are smaller and breeding events are fewer than what may have occurred naturally (Kingsford 2000).

Grazing

Grazing by ungulate species such as sheep and cattle has been a major land use in Australia since European settlement (Jansen and Robertson 2001; Lunt *et al.* 2007). Grazing in wetland and riverine habitats is common in rangeland areas, as they provide valuable resources such as water and food (Jansen and Robertson 2001). Grazing may be important for maintaining species diversity when grazing pressure is low, although overgrazing can damage common reed and lignum during dry times or when new shoots are emerging (Brock 1998; Jansen and Robertson 2001; Hogendyk 2007; Lunt *et al.* 2007; DECCW 2010). Riparian and wetland vegetation provide essential habitat for wildlife and play an important hydrological role (Prosser *et al.* 2001; Ralph and Hesse 2010). Cloven hoofed animals such as cattle create pathways through reed beds and damage riparian vegetation which can contribute to erosion and increases turbidity (Jansen *et al.* 2001; Prosser *et al.* 2001; Hogendyk 2007; Lunt *et al.* 2007). High turbidity and increased nutrient runoff may also lead to algal blooms in the catchment (DLWC and NPWS 1996; Brock 1998; Prosser *et al.* 2001)

Inappropriate fire regimes

Australia is one of the most fire prone continents on Earth. As a result, many of its flora and fauna have adapted to cope with periodic fire patterns (Russell-Smith *et al.* 2007; Edwards *et al.* 2008). However, fire is believed to damaging to flora and fauna in the Macquarie Marshes when the marshes are dry (Brookhouse 1999; DECCW 2010). Fire can also damage property, grazing and cropping, livestock, humans and cultural heritage sites (Brookhouse 1999;

Russell-Smith *et al.* 2007). Since 1947, eighteen wildfires have been recorded in the Macquarie Marshes region (Office of Environment and Heritage 2012). The most common cause of fire in the Macquarie Marshes is lightning strike (Brookhouse 1999; Office of Environment and Heritage 2012). Historically, reed beds were burnt to increase nutritious growth for cattle grazing and national parks implement controlled burns reduce fuel load (Brookhouse 1999; Hogendyk 2007; DECCW 2010). Early European explorers, Sturt and Mitchell, also noted that the aboriginal people used fire for the growth of cumbungi and hunting in the Macquarie Marshes (Brookhouse 1999; Hogendyk 2007).

Weeds and pest animals

Many weed species occur in the Macquarie Marshes and those of particular concern include Bathurst burr (*Xanthium spinosum*), Noogora burr (*Xanthium pungens*), lippia (*Phyla canescens*) and African boxthorn (*Lycium ferocissimum*) (Brock 1998; Price *et al.* 2010; Office of Environment and Heritage 2012). Weed invasion is an ongoing problem and their management is difficult due to site inaccessibility (Brock 1997; Brock 1998). Numerous pest animal species also occur in the Macquarie Marshes including feral pigs (*Sus scrofa*), European rabbits (*Oryctolagus cuniculus*), European red foxes (*Vulpes vulpes*), feral cats (*Felis catus*) and common carp (*Cyprinus carpio*) (NPWS 1993; Brock 1997; Brock 1998; West 2008; Office of Environment and Heritage 2012). Factors such as predation, habitat degradation and competition by these species has probably affected waterbird numbers and contributed to the absence of many small mammals, reptiles, amphibians and fishes (NPWS 1993; Saunders *et al.* 1995; Williams *et al.* 1995; Choquenot *et al.* 1996; Brock 1997, 1998; Koehn *et al.* 2000; Saunders and McLeod 2007; Denny and Dickman 2010). Unlike some pests, feral pigs contribute to each of these factors. They may also facilitate the spread of exotic diseases in the event of an outbreak; therefore they are a particular concern (Brock 1998; Choquenot *et al.* 2005; Anon 2005).

Chapter 3 - The diet of feral pigs in the Macquarie Marshes, New South Wales.

3.1 Introduction

Feral pigs are opportunistic omnivores that have relatively high dietary energy and protein requirements (Giles 1980; Choquenot *et al.* 1996). If their crude energy intake falls below 5610 Kcal per day (20-35kg pig), they begin to rely on tissue energy stores and lose body condition. Sows can also cease lactation if crude protein intake falls below 15%, which can result in high piglet mortality (Giles 1980; Baber and Coblentz 1987; Choquenot *et al.* 1996). Consequently, feral pigs commonly change diet according to season as it is rare for the highest quality food items to be available throughout the year (Everett and Alaniz 1980; Giles 1980; Baber and Coblentz 1987; Thomson and Challies 1988; Pavlov and Edwards1995; Choquenot *et al.* 1996; Taylor and Hellgren 1997).

In the semi-arid zones, feral pigs actively seek new growth vegetation such as annual grasses and forbs after large rain events, as these plants are high in energy and protein (Everett and Alaniz 1980; Giles 1980; Baber and Coblentz 1987). In drier times feral pigs switch to underground plant storages (roots, rhizomes and tubers) and perennial plant foliage (i.e. saltbush), which are lower in energy and protein (Baber and Coblentz 1987). This may be why feral pigs are more likely to consume animal material to supplement protein intake in such times (Wilcox and Van Vuren 2009).

Despite feral pigs being omnivorous, animal material usually only makes up a small component of their diet (Giles 1980; Everett and Alaniz 1980; Baber and Coblentz 1987; Coblentz and Baber 1987; Thomson and Challies 1988; Chimera *et al.* 1995; Taylor and Hellgren 1997). Invertebrates such as earthworms (Baubet *et al.* 2003), moth and butterfly larvae, beetles, and carrion are most commonly consumed. Feral pigs also eat a diverse range of vertebrate wildlife species including reptiles, amphibians, birds, fish and mammals (Challies 1975; Giles 1980; Miller and Mullette 1985; Coblentz and Baber 1987; Thomson and Challies 1988; Chimera *et al.* 1995; Pavlov and Edwards 1995; Choquenot *et al.* 1996; Taylor and Hellgren 1997; McIlroy 2001; Anon 2005; Fordham *et al.* 2006; Wilcox and Van Vuren 2009; Jolley *et al.* 2010). In addition, feral pigs prey on domestic livestock species such as new born lambs and kid goats (Pavlov *et al.* 1981; Pavlov and Hone 1982; Choquenot *et al.* 1997). The impact of feral pig predation on native wildlife is particularly difficult to quantify. However, the added pressure on threatened or endangered species is likely to be damaging (Anon 1995; Chimera *et al.* 1995; Taylor and Hellgren 1997; Wilcox and Van Vuren 2009; Jolley *et al.* 2010).

In the Galapagos, on Isla Santiago, predation by feral pigs is thought to be a key contributing factor to the extinction of land iguanas (*Conolophus subcristatus*) (Coblentz and Baber 1987). They also threaten green sea turtles (*Chelonia mydas*), giant tortoises (*Geochelone elephantopus*) and dark-rumped petrels (*Pterodroma phaeopygia*) by damaging nests, and consuming eggs and hatchlings (Coblentz and Baber 1987; Taylor and Hellgren 1997). Across the Pacific Ocean, in the Mountains of New Zealand south island, feral pigs are implicated in the extinction of six endangered Hutton's shearwater breeding colonies. The two remaining colonies are the only two where feral pigs do not exist (Cuthbert *et al.* 2002). Two recent studies in the USA reported that feral pigs also consume small mammals, reptiles and amphibians. Wilcox and Van Vuren (2009) reported 40.5% (n=104) of feral pig stomachs in the oak woodlands of California contained vertebrate remains. Twenty different prey species were discovered and thirteen of these were mammals including 109 Californian voles (*Microtus californicus*) and 26 Botta's pocket gophers (*Thomomys bottae*). Jolley *et al*. (2010) reported 20.6% of feral pig stomachs (n=68) on Fort Benning Military Installation Georgia/Alabama contained reptiles and amphibians from five different species. Of these the spadefoot toad (*Scaphiopus holbrookii*) was consumed most frequently. It was estimated that feral pigs consume 3,533 spadefoot toads per km^2 per annum.

In Australia, feral pigs are believed to be the main reason why the Lord Howe Island woodhen (*Tricholimnas sylvestris*) did not occupy its potential range on Lord Howe Island (Miller and Mullette 1985). Feral pig and woodhen distributions on the island did not overlap, conversely they almost fit together perfectly (i.e. where pigs exist woodhen did not) (Miller and Mullette 1985). Fordham *et al.* (2006) also reported that feral pigs consume large numbers of northern snake-necked turtles (*Chelodina rugosa*) in Arnhem Land, northern Australia. During the study, 28 of 38 turtles with confirmed fates died, and 27 (96%) of these deaths were caused by feral pigs. This level of feral pig predation could threaten the continued existence of the northern snake-necked turtle in Arnhem Land, particularly if wet years become infrequent (Fordham *et al.* 2006).

Little is known about feral pig predation in the Macquarie Marshes, although it is a concern as many nationally and internationally important species utilise the site including painted snipe, black-necked stork, glossy ibis and cattle egret, as well as many others. Giles (1980) also conducted a broad dietary analysis of feral pigs in the southern area of the Macquarie Marshes and found feral pigs do consume a variety of vertebrate wildlife, such as reptiles and amphibians. Pavlov *et al.* (1981) and Pavlov and Hone (1982) reported significant differences in lamb predation levels between years and that boars were more likely to attack lambs than sows near Nyngan NSW, which is situated only 125 kilometres south of the Macquarie Marshes. However, in the Macquarie Marshes the influence of feral pig demographics or season on native wildlife predation is unclear, and this information may be highly useful for developing strategic and targeted feral pig management in the future.

This study was undertaken to determine whether collection site, collection date or feral pig demographics influence feral pig diet and related predation of vertebrate wildlife in the Macquarie Marshes. In addition, to identify which species are most at risk so they can be monitored to assess the effects of future feral pig management in the area. The null hypothesis is that collection site, collection date and feral pig demographics have little influence on feral pig diet and related wildlife predation levels in the Macquarie Marshes. The alternate hypothesis is that collection site, collection date and feral pig demographics do influence feral pig diet and related wildlife predation levels in the Macquarie Marshes.

3.2 Methods

3.2.1 Study site

The study was undertaken at sites 1 and 2, which are spaced 27km apart (Fig 2.2). Each site contains some of the most important semi-permanent wetland habitat on private land in the region. Site 1 adjoins a public Ramsar Wetland (the northern Macquarie Marshes Nature Reserve) and Site 2 encompasses 530 hectares of private Ramsar Wetland. Feral pig stomachs were collected during May 2011, September 2011 and March 2012 and the average maximum temperature for each collection month was 18ºC, 24ºC and 28ºC, respectively. The total rainfall was 38mm, 49 mm and 141mm, respectively (see Table 2.1 for historical averages). Refer to chapter 2 – Study sites for map and further site details.

3.2.2 Procedure

The animals chosen for sampling in this study were either all animals that were aerially shot on the property, or animals that could be accessed by quad-bike and a relatively short walk through swamps (<500m). Hence, they were not randomly selected. A total of 58 feral pig stomachs were collected and analysed during the study, of these 26 were male, 32 were female, 21 were juvenile (≤ 25kg) and 37 were adult (≥ 26kg). Feral pigs ≤ 25kg were weighed in the field (were possible) using a set of field scales (200kg capacity). Heavier animal weights were estimated. Approximately 10 feral pig stomachs were collected from each of the two sites (n=20) during May 2011, September 2011 and March 2012.

Unlike Giles (1980) where animals were ground shot and their stomach contents were analysed in the field, stomachs in the current study were taken from aerially shot animals and were analysed back at base. All feral pigs were humanely destroyed by Feral Animal Aerial Shooting Team (FAAST) accredited rangers from the Central West and North West Livestock Health and Pest Authorities (LHPA). Carcasses were located using four wheel drive motorbike and GPS waypoints that were provided by the LHPA. When a carcass was found, the weight and gender of that animal were recorded. A sharp knife was used to remove the stomach and cable ties were applied to the oesophagus and the small intestine to prevent leakage. Stomachs were placed in a large labelled garbage bag and were stored in a freezer at the research facilities until later analysis. Each stomach was thawed, weighed and its content was placed into a large white plastic sorting tray. Food items were macroscopically sorted into categories including grasses, forbs, roots, ferns, crops, frogs, lizards, snakes, turtles, birds, mammals, invertebrates and carrion, which is similar to the classification method used by Taylor and Hellgren (1997). Carrion was classified as animal remains that contained maggots and/or were displaying odour of bacterial decomposition (Wilcox and Van Vuren 2009). Animal material was identified to species level and the number of individuals present per species was counted where possible. No attempt was made to correct the data for differences in digestibility and/or fragmentation (Thomson and Challies 1988).

Data are presented and analysed as frequency of occurrence and proportional presence. Frequency of occurrence was calculated as the number of stomachs containing a particular food item compared to the number of stomachs collected. Proportional presence was calculated as the percentage estimate of each food category present per stomach by volume. Percentage estimates were converted using the following rank system (Table 3.1)

Table 3.1 – The system used to convert the visual estimate of the amount of each food category present per feral pig stomach as a percentage to a numerical rank score.

Proportional presence (%)	***Rank***
0	0
1 - 20	1
21 - 40	2
41 - 60	3
61 - 80	4
81 - 100	5

3.2.4 Statistical analysis

Plant material was analysed in their pre-mentioned categories. Conversely, animal material was pooled into three categories including vertebrates (live prey), invertebrates (live prey) and carrion. Analysis was undertaken separately for frequency of occurrence and proportional presence.

Between collection sites and collection dates

One way between groups multivariate analysis of variance (MANOVA) (Pallant 2005) was conducted to determine the effect of collection site on diet. Another one way between groups MANOVA was undertaken to determine dietary differences between collection dates. One way MANOVA were used as there was one multi-level independent variable (collection site or collection date) and more than one dependant variable (each food category). A series of one-way analyses of variance (ANOVA) (Pallant 2005) were then used to determine which particular food items varied for collection site and collection date. A series of one way ANOVA were used as there was one multi-level dependant variable (either collection site or collection date) and there was one independent variable (each food item separately per analysis).

Between gender and maturity level

A two way between groups MANOVA (Pallant 2005) was used to investigate the combined and separate effect of feral pig maturity level and gender on diet. A series of one-way ANOVA (Pallant 2005) were then used to determine which particular food items varied for maturity and gender. A two-way between groups MANOVA was initially used as there were two multi-level independent variables (maturity and gender) and more than one dependant variable (food categories). Thereafter, a series of one-way ANOVA were used as there were one multi-level dependant variable (either gender or maturity) and there were one independent variable (each food item separately per analysis).

3.3 Results

Feral pigs in the Macquarie Marshes are largely herbivorous, with plant material occurring in 100% of stomachs (n=58) and making up 94% of the food material that was consumed. Animal material occurred in 31% (n=18) of stomachs and made up 6%. The plant categories that occurred most frequently among stomachs were grasses (74%), roots (66%) and forbs (43%) (Fig. 3.2). These items also occurred in the largest quantities at 38%, 26% and 17%, respectively (Fig. 3.2). Of the animal material that was consumed, vertebrate prey occurred most frequently (21% of stomachs) and it was present in the largest proportion (3% of total food consumed) (Fig. 3.2).

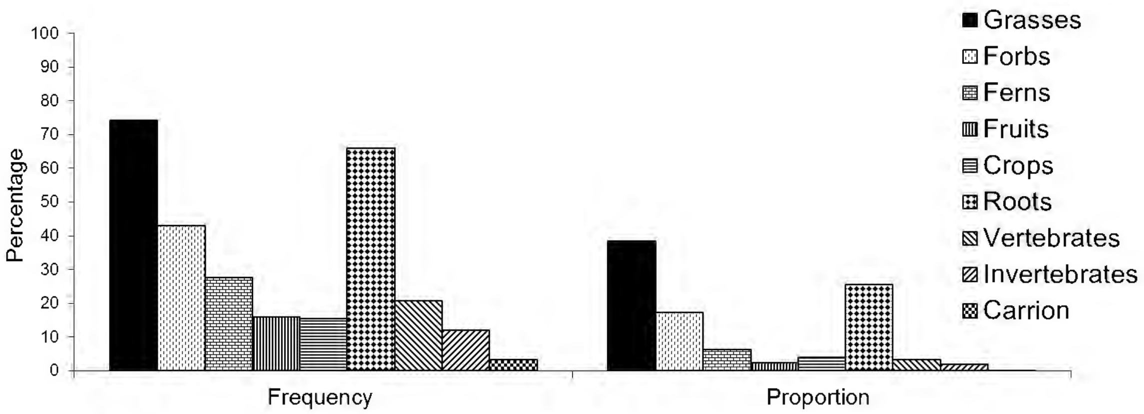

Figure 3.2 – Frequency of occurrence and proportional presence of food categories for all feral pig stomachs (n=58) collected during the study. Percentage frequency was derived by total number of stomachs containing each food item compared to the total number of stomachs collected. Percentage proportion was derived by the total rank score for each food item compared to the total rank score for all food items combined.

Between collection sites

A one way MANOVA showed a significant difference ($F_{9,48}$= 17.46, p <0.0001; Pillai's Trace = 0.77) in frequency of occurrence of food categories between sites 1 and 2. There was also a significant difference in proportional presence ($F_{9,48}$= 17.46, p <0.0001; Pillai's Trace = 0.59). When considered separately, it was evident that the differences for frequency of occurrence occurred within grasses ($F_{1,56}$= 33.42, p <0.0001), fruits ($F_{1,56}$= 11.58, p= 0.001), crops ($F_{1,56}$=

11.58, *p* =0.001) and roots ($F_{1,56}$= 17.05, *p* <0.001). Grasses, fruits and crops were more common among stomachs at site 2, whereas roots were common in stomachs at site 1 (Fig. 3.3).

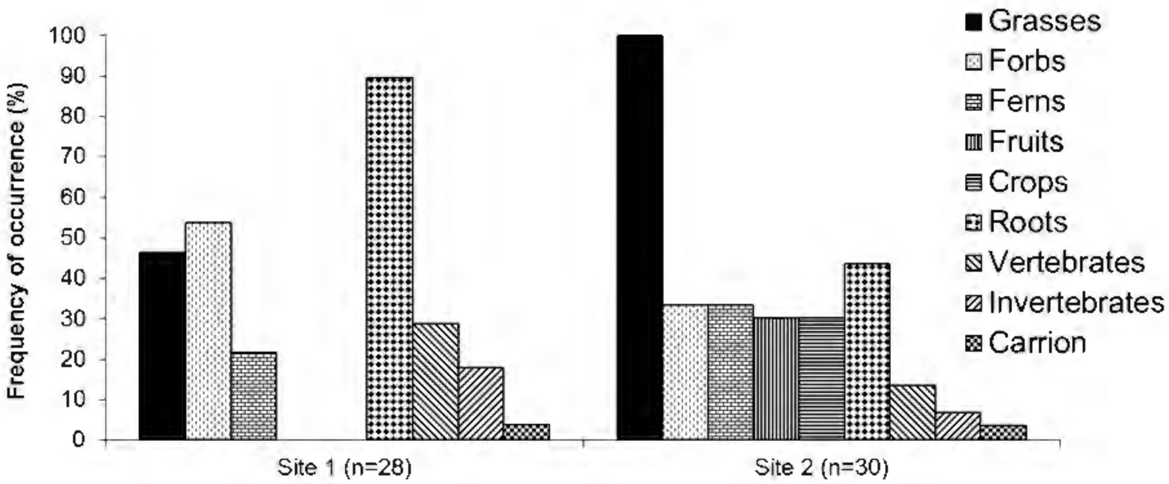

Figure 3.3 – Frequency of occurrence of food items in feral pig stomachs collected at site 1 (n=28) compared to those collected at site 2 (n=30). Percentage was derived from the total number of stomachs containing each food item per site compared to the total number of stomachs collected per site.

Differences in proportional presence were also found in grasses ($F_{1,56}$= 5.96, *p*= 0.018), fruits ($F_{1,56}$= 11.59, *p*= 0.001), crops ($F_{1,56}$= 7.95, *p*= 0.007) and roots ($F_{1, 56}$= 12.61, *p*= 0.001) (Fig. 3.4). No significant difference was found in frequency of occurrence ($F_{1,56}$= 2.05, *p*= 0.158) or proportional presence ($F_{1,56}$= 2.05, *p*= 0.158) of vertebrate prey between collection sites.

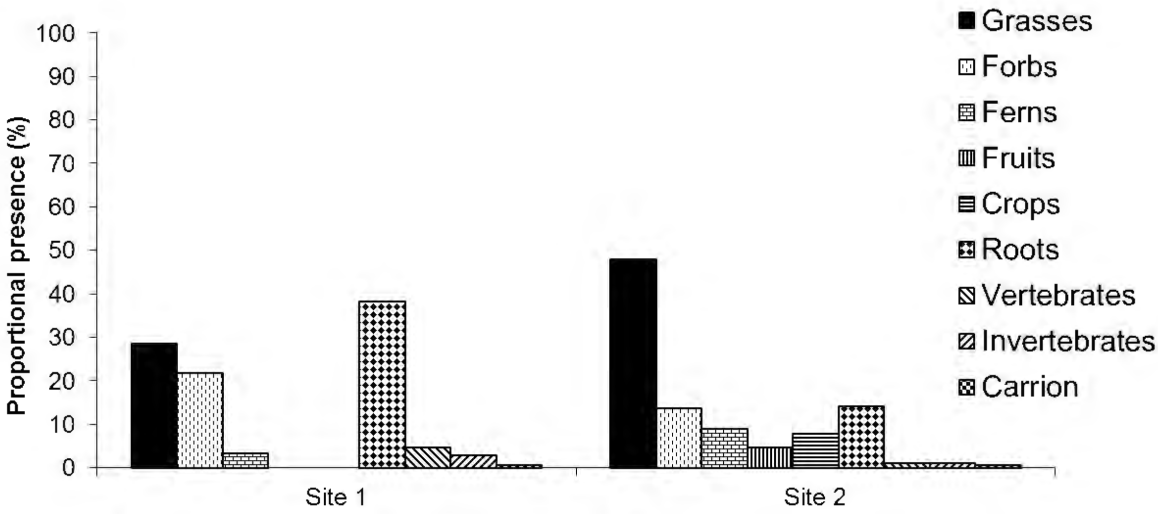

Figure 3.4 – Proportional presence values of food items as a percentage for feral pig stomachs collected at site 1 compared to those collected at site 2. Percentage derived from the total rank score for each food item per site compared to the total rank score (all food items combined) collected per site.

Between collection dates

A one way MANOVA identified a significant difference ($F_{18,96}$= 15.18, *p* <0.0001; Pillai's Trace = 1.45) in the frequency of occurrence of food categories between collection dates (Fig. 3.5). A significant difference ($F_{18,96}$= 6.89, *p* <0.0001; Pillai's Trace = 1.13) was also found for the proportional presence (Fig. 3.6). When looking at each food item individually (frequency of occurrence), it was evident that these differences occurred in ferns ($F_{2,55}$= 2.87, *p*= 0.002), fruits ($F_{2, 55}$= 14.74, *p* <0.0001), crops ($F_{2,55}$= 14.74, *p* <0.0001), roots ($F_{2,55}$= 7.34, *p*= 0.002) and vertebrates ($F_{2,55}$= 4.42, *p*= .017) (Fig. 3.5).

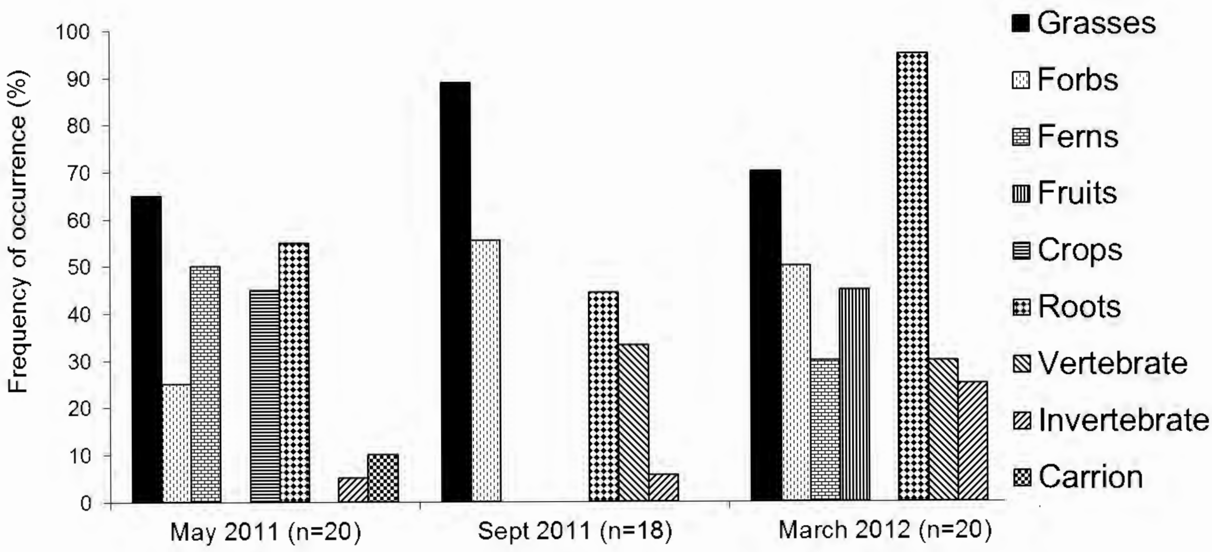

Figure 3.5 – Frequency of occurrence of food categories within feral pig stomachs collected during May 2011, September 2011 and March 2012. Percentage derived from the total number of stomachs containing each food item per collection period (both sites combined) compared to the total stomachs collected (both sites combined) per collection period.

Apart from ferns, the significant differences for proportional presence occurred in the same food categories grasses ($F_{2,55}$= 3.37, *p*= 0.042), fruits ($F_{2,55}$= 14.74, *p* <0.0001), crops ($F_{2,55}$ = 9.32, *p* <0.0001) and vertebrates ($F_{2,55}$ = 4.42, *p*= 0.017) (Fig. 3.6).

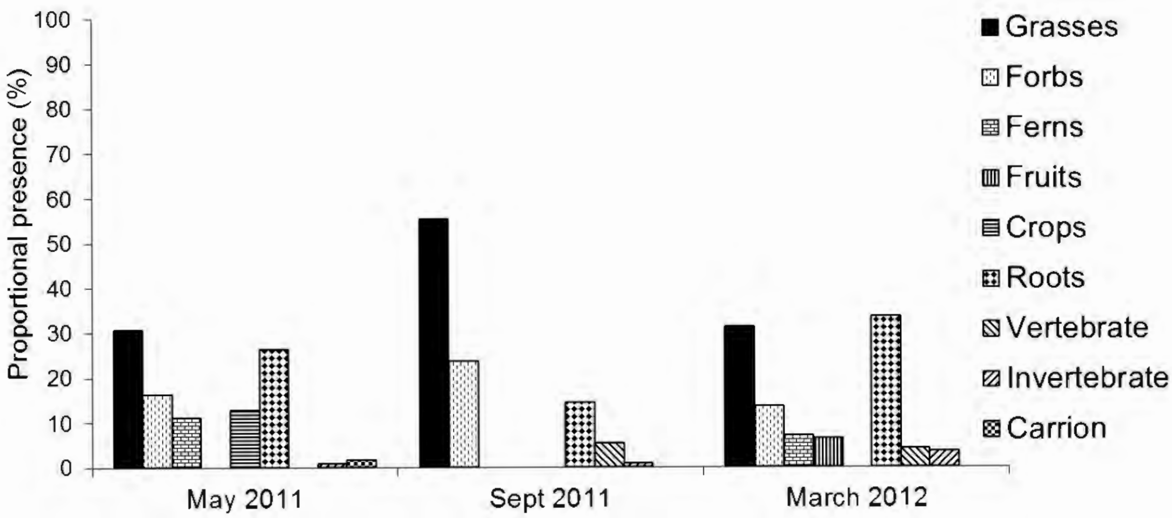

Figure 3.6 – Proportional presence of each food item found in feral pig stomachs during May 2011, September 2011 and March 2012. Percentage derived from the total rank score for each food item during each collection period (both sites combined) compared to the total rank score (all food items combined) collection period.

Feral pigs consumed more grasses in September 2011 than they did in May 2011 and March 2012 (Fig. 3.6). During the collection dates when grasses were consumed less, roots were consumed more and their overall diet was more diverse (Fig. 3.6). Importantly, vertebrate prey occurred in more stomachs and in larger quantities during the September 2012 and March 2012 (Fig. 3.6). No vertebrate prey was found during May 2011.

Between gender and maturity level

Two way MANOVA showed gender and maturity level in combination (≤ 25kg juvenile, ≥ 26kg adult) had no significant effect on the frequency of occurrence ($F_{9,46}$= 0.79, *p*= 0.624; Pillai's Trace = 0.13) or the proportional presence ($F_{9,46}$= 0.39, *p* = 0.936; Pillai's Trace = 0.07) of food items within feral pig stomachs. However, a one way MANOVA focusing on gender and maturity level separately showed there was a significantly difference ($F_{9,46}$ = 2.28, *p*= 0.033; Pillai's Trace = 0.03) in the frequency of occurrence of food items between juveniles and adults. A series of one way ANOVA identified that these differences occurred within grasses ($F_{1,54}$= 8.13, *p*= 0.006), forbs ($F_{1,54}$= 13.35, *p*= 0.001) and crops ($F_{1,54}$= 7.00, *p*= 0.011). In that, adult feral pigs consumed more grasses and crops, and juveniles consumed more forbs. Despite this, there was no significant difference in the frequency of occurrence or proportional presence of vertebrate prey items between males and females, or juveniles and adults (Fig. 3.7).

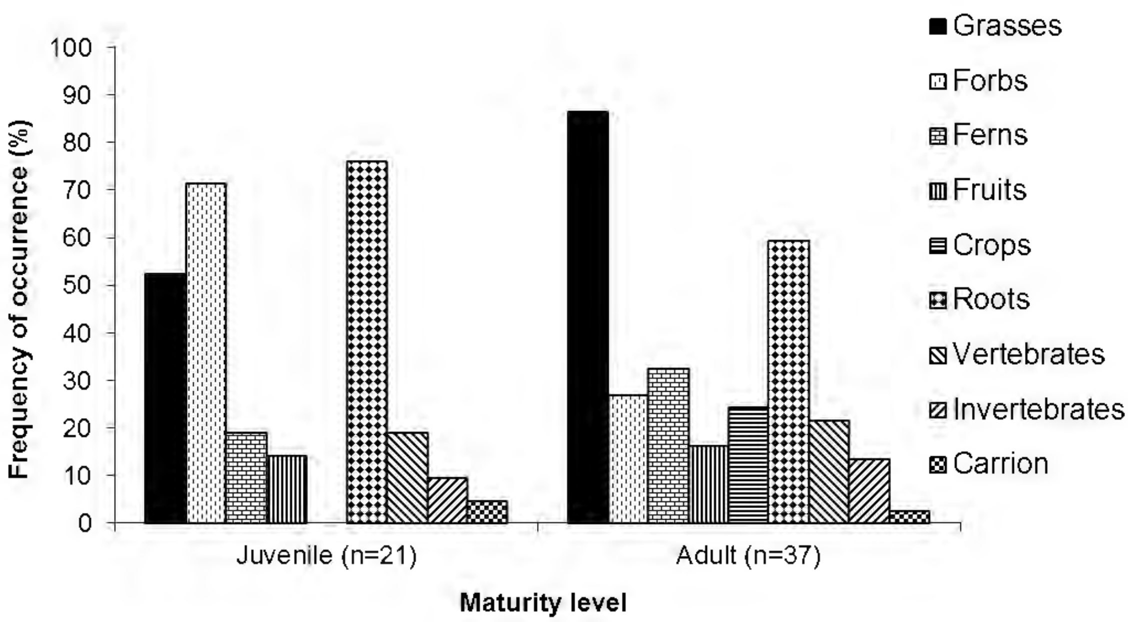

Figure 3.7 - Frequency of occurrence of each food category for juvenile (≤ 25kg) and adult (≥ 26kg) feral pigs. Percentage derived from the number of stomachs containing each food item (juveniles or adults) compared the total number of stomachs collected (juveniles or adults).

Animal material consumption

Animal material accounted for 6% of the total food material consumed by feral pig during the study, of which, 57% were vertebrate prey, 33% were invertebrate prey and 10% were carrion. Vertebrates also occurred most frequently in stomachs (n=12) compared to other invertebrates (n=7) and carrion (n=2). Five different vertebrate prey species were found, although barking marsh frogs (*Lymnodynastes fletcheri*) occurred most frequently and in the largest quantities (Table 3.2). Two additional frog species (*Litoria caerulea* and *Lymnodynastes tasmaniensis*) and two reptile species (*Pogona barbata* and *Denisonia devisi*) were also found (Table 3.2). Interestingly, all vertebrate prey was found during the September 2011 and March 2012 collection periods.

Invertebrates were found in 12% of feral pig stomachs (n=7). Of these earthworms occurred most frequently (n=5) and in the largest quantities (13 individuals). All earthworms were recorded in March 2012, apart from a single worm that occurred in September 2011. Carrion was found in 3.4% of feral pig stomachs (n=2) and only made up a small proportion of the food items present in those stomachs (Table 3.2).

Table 3.2 – Total number of animal items consumed (number of individuals), number of stomachs containing each item (stomachs), frequency of occurrence (Freq.) per species among the total stomachs collected (n=58). Also listed is the conservation status of each species under the NSW Threatened Species Conservation Act 1995.

Species	*# Individuals*	*Stomachs*	*Freq. (%)*	*Conservation status*
Vertebrates				
Eastern bearded dragon (*Pogona barbata*)	0.5	1	2	Not listed
Barking marsh frog (*Lymnodynastes fletcheri*)	15	6	10	Not listed
Green tree frog (*Litoria caerulea*)	2	3	5	Not listed
Spotted marsh frog (*Lymnodynastes tasmaniensis*)	1	1	2	Not listed
De Vis banded snake (*Denisonia devisi*)	1	1	2	Not listed
Invertebrates				
Fly larvae (*Calliphora sp.*)	1	1	2	N/A
Earthworm (Annelida)	13	5	9	N/A
Centrepede (*Cormocephalus sp.*)	2	2	3	N/A
Cockroaches (Blattodea)	3	2	3	N/A
Carrion				
Cattle *(Bos taurus)*	N/A	1	2	N/A
Bone fragments	N/A	2	3	N/A

N/A = not applicable

3.4 Discussion

The project demonstrated that feral pigs in the Macquarie Marshes were largely herbivorous, with vegetable matter occurring in 100% of the stomachs and making up 94% of the food material consumed. Animal matter was found in 31% of stomachs and it made up the remaining 6%. Vertebrate prey was found more frequently, and in larger quantities, than any other form of animal material (invertebrates and carrion) that was consumed by feral pigs.

Between collection sites

Feral pig diet varied significantly between collection sites, with grasses, fruits and crops occurring more frequently and in larger proportions in stomachs at site 2. Roots occurred more frequently and in larger proportions in stomachs at site 1. Other studies have reported (Giles 1980; Baber and Coblentz 1987; Thomson and Challies 1988; Taylor and Hellgren 1997) that feral pigs prefer to consume quality foods such as active growing grasses, fruits and crops when they are available, but will switch to lesser quality foods such as roots when they are no-longer available. Based on this, it is probable that feral pigs at site 1 consumed more roots than feral pigs at site 2, because these higher quality foods (grasses, fruits, crops) were less abundant. Alternatively, feral pigs at site 1 may have preferred to consume roots despite all foods being equally abundant at both areas, although it is unlikely. Unfortunately, it is not possible to know for certain as data were not collected on food item abundance during the study. Interestingly, there was no significant difference in the frequency of occurrence or the proportional presence of vertebrate prey items between sites, which suggests predation levels were relatively consistent between study sites, and perhaps throughout the Macquarie Marshes.

Between collection dates

Feral pig diet in the Macquarie Marshes differed significantly between collection dates. It was evident that stomachs contained significantly more grasses when they contained significantly less roots. In contrast, when stomachs contained significantly more roots, they contained significantly less grasses and their diet was more diverse. Giles (1980) also reported that feral pig stomach contents in the Macquarie Marshes reflected season with roots being consumed in the drier seasons and succulents being consumed during wetter times. It is probable that feral pigs in the Macquarie Marshes display similar dietary patterns to feral pigs elsewhere, where they consume grasses when they are available and switch to other foods of lesser quality, such as roots in between times (Giles 1980; Coblentz and Baber 1987; Thomson and Challies 1988; Taylor and Hellgren 1997). To further highlight this, grasses are seasonally abundant in the Macquarie Marshes whereas roots occur throughout the year. The more diverse diet also suggests the nutritional intake from roots is less than that of grasses therefore feral pigs may need to supplement their diet with additional food sources (Giles 1980). Baber and Coblentz (1987) reported that crude energy and crude protein levels in grasses are highest during active plant growth. This may be why grasses were most common in September 2011 (spring), which is when grasses in the marshes most likely to be actively growing, unlike in autumn (the other collection dates). Taylor and Hellgren (1997) also reported that grass consumption was highest in the semi-arid western zone of Texas, USA, in spring. There were also significant differences in the frequency of occurrence and proportional presence of ferns, fruits and crops in the present study. Again, feral pigs are likely to favour these when they are available, particularly fruits and crops, due to their high nutritional values. Fruits are high in digestible carbohydrates (energy) and crops, in this particular case, chick peas (legumes), are high in protein (Choquenot *et al.* 1996). Common nardoo (*Marsilea drummondii*) is a semiaquatic fern which becomes a dominant ground cover after flooding, hence becoming a readily available at particular times of the year (West 2007). However, it is regarded as low grade fodder and may be toxic to some animals including sheep and cattle; hence it is likely to be consumed when alternate foods are scarce (West 2007).

Importantly, there was a significant difference in the frequency of occurrence and proportional presence of vertebrate prey between collection dates. Vertebrate prey was only found in feral pig stomachs that were collected in September 2011 and March 2012, and no vertebrate prey was found in May 2011. In addition, the only vertebrate species that were found were reptiles and amphibians and most were nocturnal species. Therefore, it is not surprising that predation levels were highest when rainfall was above the average (+17mm September 2011 and + 116mm in March 2012) and when mean maximum temperatures were relatively high at 26ºC (Bureau of Meteorology 2012). Giles (1980) also reported in the Macquarie Marshes that frogs were the most common vertebrate wildlife species found in feral pig stomachs.

Between gender and maturity level

The demographic factors investigated during the study were feral pig maturity level (body size) and gender. These factors in combination had no significant effect on feral pig diet. However, when looking at them independently, it was evident that the frequency of occurrence of food items was significantly different between adults ($\geq$ 26 kg) and juveniles ($\leq$ 25kg). Adult male and female diets were similar, and juvenile male and female diets were similar, conversely adult and juvenile diets were different. Hence, gender had no influence. Adults consumed more grasses and crops, and juveniles consumed more forbs. Interestingly, there was no difference in the level of animal matter consumption between males and females or juveniles or adults. Therefore, predation of vertebrate prey is relatively consistent between demographic groups, unlike what was reported by Wilcox and Van Vuren (2009) that predation was more pronounced in females. Pavlov and Hone (1982) also reported that adult boars were the most frequently observed demographic group to attack lambs near Nyngan NSW. Results in the present study should be interpreted with caution because it is possible that a significant difference may occur between adult males and adult lactating or pregnant, females because lactating or pregnant females were not singled out during the analysis. Future studies should therefore investigate the diet of or lactating females in the Macquarie Marshes, as it is possible that they consume more animal material, particularly when alternate green foods are scarce, to increase protein uptake for successful lactation and young rearing (Giles 1980; Choquenot *et al.* 1996)

Animal material consumption

Many authors have previously noted that feral pigs do consume animal matter, although it generally only makes up a small component of their overall diet and it largely consists of either carrion or invertebrates (Everett and Alaniz 1980; Baber and Coblentz 1987; Thomson and Challies 1988; Chimera *et al.* 1995; Taylor and Hellgren 1997). During the current study, animal matter made up a small component of feral pig diet, although vertebrate prey occurred more frequently and in larger proportions than invertebrates and carrion. A variety of vertebrate prey species have been recorded in the diet of feral pigs both nationally and internationally. Those that seem most susceptible are slow moving, cold blooded ground dwelling and/or ground nesting (Coblentz and Baber 1987; Taylor and Hellgren 1997; Fordham *et al.* 2006; Jolley *et al.* 2010). During this study, frogs, snakes and lizards were the only vertebrate prey species recorded, and all of which possess the pre-mentioned high risk life traits. Jolley *et al.* (2010) recorded similar results in the USA, where reptiles and amphibians occurred in 20.6% of stomachs examined. In the present study, all but one prey species (bearded dragon) were nocturnal. Hence, the most commonly consumed prey are likely to be most active when feral pigs, that are also largely nocturnal, are most active (Choquenot *et al.* 1996). Of the prey species that were consumed, none are listed under the NSW Threatened Species Conservation Act 1995. Additionally, no colonial or migratory birds, or their eggs were found, which was also reported by Giles (1980). However, the Sloane's froglet (*Crinia sloanei*) is found in the Macquarie Marshes and it is listed as vulnerable under the NSW Threatened Species Conservation Act 1995. They also possess the same life traits as several species that were found in the diet of feral pigs in the present study. Hence, the Sloane’s froglet may be at risk and further investigations may be warranted.

Despite vertebrate wildlife species being recorded in the diet of feral pigs in the Macquarie Marshes in this study, and by Giles (1980), it does not necessarily mean that these species are being adversely impacted by this process at a population level. Banks (1999) implemented a study to test the predator limitation and doomed surplus hypotheses. That is, predation by introduced predators will either adversely impact the population, or have little impact because the predator may be consuming surplus individuals that would have died via other means regardless. Banks (1999) reported that the removal of the foxes (*Vulpes vulpes*) had no significant effect on native bush rat (*Rattus fuscupes)* in south-eastern Australia, and thus supporting the doomed surplus hypothesis. This may be what is occurring in the Macquarie Marshes, whereby feral pig predation may be a compensatory source of mortality rather than an additional one (Banks 1999). Therefore, further studies should be undertaken to determine influence of feral pig abundance on reptile and amphibian density and diversity.

Additional factors that may have influenced the frequency of occurrence or proportional presence of food items in feral pig stomachs in the present study may be time of stomach collection, digestibility and stomach collection site. Stomachs were collected during the day, and because that food items generally only remains in feral pig stomachs for an average of 4 hours, it is possible nocturnal prey items may have passed through the stomach prior to the daytime stomach collection (Jolley *et al.* 2010). In addition, digestibility of food items was not taken into account in the current study, and neither has it been taken in to account during many other feral pig dietary studies (Everitt and Alaniz 1980; Baber and Coblentz 1987; Thomson and Challies 1988; Chimera *et al.* 1995; Taylor and Hellgren 1997; Fordham *et al.* 2006; Wilcox and Van Vuren 2009; Jolley *et al.* 2010). Isle and Hellgren (1995) used faecal analysis to compare the diet of feral pigs and collard peccaries (*Pecari tajacu*) in southern Texas USA, to determine niche diversity and overlap. They reported that the lack of diversity in the diet of feral pigs may have occurred because of the method of analysis, in that it only quantifies the indigestible food items. Hence, many highly digestible food items such as tubers and roots may be underrepresented in the diet of feral pigs during their particular study (Isle and Hellgren 1995). It is possible that a similar result may have occurred in the present study, whereby soft bodied invertebrates (gastropods, annelids and larvae) or eggs (bird and/or reptile) may have been under represented in the diet of feral pigs in the Macquarie Marshes when compared to more fibrous plant species, invertebrates with exoskeletons and/or larger vertebrate species. In addition, feral pig stomachs only were collected during routine LHPA aerial shooting programs. These aerial shoots are typically undertaken prior to waterbird breeding and nesting times to reduce perceived feral pig predation levels and to minimise human disturbance near active rookeries.

In summary, the study demonstrated that feral pigs in the Macquarie Marshes were largely herbivorous and that collection date was the only factor that specifically and significantly influenced vertebrate wildlife predation. In that, vertebrates occurred more in larger proportions and more frequently among feral pig stomachs during September 2011 and March 2012, which were also warmer months. Therefore, the study largely supports the alternate hypothesis that collection site, collection date and feral pig demographics do influence feral pig diet and related wildlife predation levels in the Macquarie Marshes, NSW.

Chapter 4 - Responses of feral pig activity patterns to season and management in the Macquarie Marshes, NSW.

4.1 Introduction

In Australia, feral pigs occur in a variety of habitats including alpine grasslands and forests, tropical rainforests, swamps and marshes, floodplains, dry woodlands, sub-tropical savannah and rangelands (Pullar 1950; Tisdell 1980; Choquenot *et al.* 1996). They do however require access to reliable water, food and shelter if they are to establish viable long-term populations. In warm conditions, feral pigs limit daily activity and spend most of their time in the shade (Giles 1980; Saunders and Kay 1991). If climatic conditions are particularly hot, feral pigs may visit water throughout the day to wallow and drink to avoid heat exposure (Giles 1980). Giles (1980) found that feral pigs confined in the open at temperatures ≥35ºC often died after 24 hours and summer temperatures often exceed 35ºC in the rangelands.

Feral pigs usually become active on dusk where they move from dense vegetation along worn travel pads to water and wallow (Giles 1980; McIlroy 1989; Saunders and Kay 1991; Caley 1997). Thereafter, they generally forage for several hours before becoming relatively sedentary (Giles 1980; Caley 1997). Feral pigs generally become active again shortly before sunrise, were they either return to water or move back to dense vegetation to rest (Giles 1980; Caley 1997). In cooler months, or climates, feral pigs sometimes continue to forage into daylight hours and may commence activity earlier in the afternoon (Giles 1980; McIlroy *et al.* 1989). Several international studies have also assessed home ranges and activity patterns of native wild boar, wild domestic pigs and/or their hybrids (Biotani *et al.* 1994; Massei *et al.* 1997; Russo *et al.* 1997; Keuling *et al.* 2008; Campbell and Long 2010). They report that they also display mostly nocturnal and crepuscular activity patterns, becoming active late in the afternoon and remain relatively active throughout the night before becoming relatively sedentary at sunrise.

Feral pigs may also adapt behavioural patterns according to human disturbance (Giles 1980; Saunders and Bryant 1988; McIlroy and Saillard 1989; Biotani *et al.* 1994; Choquenot *et al.* 1996; Dexter 1996; Russo *et al.* 1997; Keuling *et al.* 2008). The type of disturbance and its intensity may also influence behaviour to varying degrees, where more intrusive techniques such as dogging, aerial shooting and spotlighting may be more influential than passive techniques such as baiting. Therefore, feral pigs subjected to regular aerial shooting may become more nocturnal and hide in dense vegetation at the sound of an approaching helicopter (Saunders and Bryant 1988; Dexter 1996). McIlroy and Saillard (1989) also suggest that feral pigs in areas where wild dogs exist may be more difficult to capture with hunting dogs, as they may be more attuned to risk.

Implications of altered behaviour, due to season and management, may mean that some management techniques are more affective in some seasons, and some become less affective with repetition (Saunders and Bryant 1988; McIlroy and Saillard 1989; Dexter 1996). Saunders and Bryant (1988) suggested that aerial shooting itself may cause previously exposed animals to hide and/or live in dense vegetation. Dexter (1996) reported that feral pigs may be more difficult to find during aerial shooting programs in summer conditions, as they are often located under dense vegetation and are reluctant to move. Altered behavioural patterns in response to season or management also affect certain abundance/density monitoring techniques (Saunders and Bryant 1988; Dexter 1996). For example, aerial shooting programs that utilise aerial survey to monitor density may be less effective for detecting animals after aerial shooting programs (Saunders and Bryant 1988; Dexter 1996). A similar result may occur if spotlight counts are used to measure pest density/abundance when spotlight shooting is used as a management technique.

Giles (1980) reported feral pig feeding patterns in the Macquarie Marshes were generally nocturnal and/or crepuscular, and most crepuscular feeding activities (twilight) were confined to densely vegetated areas. Conversely, on one particular property, feral pigs were observed feeding during daylight hours in cooler conditions. Giles (1980) suggested this may have occurred because hunting was not permitted at this site. Saunders and Bryant (1988) reported that feral pigs in the Macquarie Marshes were unlikely to leave the study area because of aerial shooting, but they may adapt their behaviour to avoid detection. Despite some information being available on feral pig activity patterns in the Macquarie Marshes, the data are somewhat limited. This is because it is difficult to use radio telemetry collars in the Marshes, as large areas are often inaccessible (Giles 1980). Understanding feral pig behavioural patterns in the Macquarie Marshes may help to refine feral pig management and monitoring programs, which may in turn help to further reduce feral pig damage in this ecologically important area.

This study was implemented to assess whether season and/or management option influence feral pig activity patterns in the Macquarie Marshes by using remote cameras. The null hypothesis is that season and feral pig management options including poison baiting, aerial shooting and their combination do not impact feral pig behavioural patterns in the Macquarie Marshes. The alternate hypothesis is that season and feral pig management options including poison baiting, aerial shooting and their combination do influence feral pig behavioural patterns in the Macquarie Marshes

4.2 Methods

4.2.1. Study site

The study was undertaken at sites 1, 2, 3 and 4 (Fig. 2.1). Refer to Chapter 2 - Study sites for site details.

4.2.2 Procedure

Each study site received a different management option throughout the project. The managements were site 1 aerial shooting and toxic baiting (treatment 1 site), site 2 aerial shooting only (treatment 2 site), site 3 toxic baiting only (treatment 3 site) and site 4 no management (non-treatment site).

Baiting

During April 2011, HogHopper™s were positioned at all feral pig "hotspots" on each property. Hotspots were classified as locations with regular feral pig activity such as ground rooting, tree rubs, tracks and scats. Each hotspot was selected according to landowner knowledge and a subsequent site inspection. A total of 34 HogHopper™s were deployed which included 12 in treatment 1, six in treatment 2, eight in treatment 3 and eight in the non-treatment (a mean of one HogHopper™ per 343 ± 13 SE hectares). HogHopper™s are a light weight, aluminium, feral pig specific bait delivery device. They are designed to target unique feral pig feeding behaviour (lifting with snout), and morphological traits such as reach and strength. When in use, HogHopper™s must be anchored to the ground using a series of steel posts to prevent feral pig from overturning them during feeding (Fig. 4.1). Initially, HogHopper™s are set to the free-feed position, whereby the doors fixed partially open with a series of door stoppers, to encourage feral pigs to feed from the device. Thereafter, the door stoppers are removed so the doors can be fully closed for toxic baiting.

Figure 4.1 – Feral pigs feeding from a HogHopper™ in the Macquarie Marshes, NSW.

Feral pig free-feeding and poison baiting were undertaken in May/June 2011, August 2011, January 2012, June 2012 and November 2012. Free-feeding was implemented at the beginning of each program for approximately seven days, and toxic bait was deployed when the number of feral pigs visiting each bait station had begun to plateau (confirmed via motion sensing cameras). During toxic baiting, HogHopper™ doors were fully closed and each device was loaded with toxic PIGOUT® containing 72mg 1080 (sodium monoflouroacetate) per 250g bait or 1080-laced barley that contained 400mg/kg^{-1} of 1080. Toxic bait was only deployed at site 1 and site 3. Conversely, site 2 and the non-treatment site continued to receive free-feed bait material until bait uptake ceased at the poison bait sites.

Aerial shooting

Routine bi-annual aerial shooting was undertaken at sites 1 and 2 during May 2011, September 2011 and March 2012 (Table 6.1). All aerial shooting programs were undertaken from a Bell Jet Ranger by Feral Animal Aerial Shooting Team (FAAST) accredited rangers from the north-west and central west Livestock Health and Pest Authority (LHPA). During this time, feral pigs that were sighted were humanely destroyed using FAAST approved selfloading L1A1 rifles. Accredited shooters ensure humane destruction of feral pigs by providing two shots per pig, if necessary.

Activity index

Feral pig activity indices were recorded in August 2011 (winter), October 2011 (spring), January 2012 (summer) and April 2012 (autumn). During this time, remote cameras (Reconyx HC500 HyperFire semi-covert IR) were positioned at permanent independent monitoring stations for 10 days. One independent monitoring station was created for every HogHopper™ that was deployed; hence 34 monitoring stations were created in total. Monitoring stations were positioned >50 metres from each HogHopper™ facing areas likely to receive regular feral pig activity such as water points, travel pads or holes in fences (Fig. 4.2). Setting independent cameras within 50 metres may bias the results towards feral pigs that eat at bait stations, however monitoring at independent stations was undertaken between baiting programs, when HogHopper™s did not contain bait, to reduce this risk.

Figure 4.2 – A small group of feral pigs captured on camera at a permanent independent monitoring station.

Remote cameras were set to take three pictures per trigger with no time delay. Images were analysed for the total number of feral pig passes per camera, per night, per site (treatment), per collection (season) (Bengsen *et al.* 2011). Williams *et al.* (2011) found little difference in total number of identifiable feral pigs when remote cameras were set to 3 minute, 6 minute and 9 minute intervals between triggers. However in those studies, remote cameras were used to monitor feral pigs at bait stations, where pigs commonly remained for at least 30 minutes to feed. The current study aimed to capture feral pigs passing through the landscape during their normal daily activities, which may take seconds, hence why cameras were set to 3 images per trigger with no time delay. Each pass was classified as crepuscular (dawn and dusk), nocturnal (dark) or diurnal (light) and the time was recorded. The timing for each category (crepuscular, nocturnal and diurnal) was derived using remote camera images collected during each monitoring period and their associated time stamps, as well as actual observations where possible (see Fig. 4.3, Fig 4.4 and 4.5 for basic classifications). A confirmed pass was any instance where an animal passed within 10 metres of the remote camera. To prevent inflated pass estimates, individuals that made multiple passes within a 30 minute period were considered as one pass (Long *et al.* 2010).

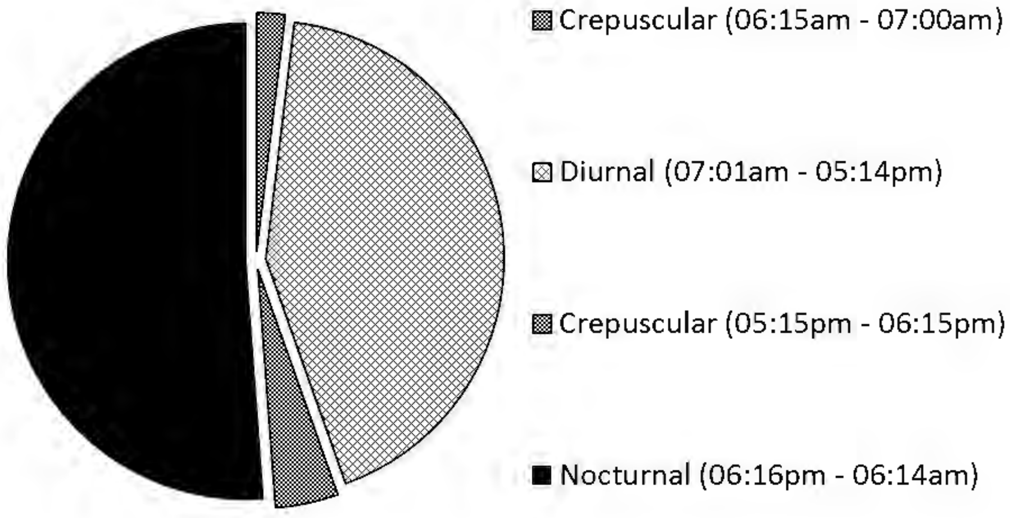

Figure 4.3 – Classification system and times used to determine crepuscular, diurnal or nocturnal activity patterns in winter and autumn (Australian Eastern Standard Time).

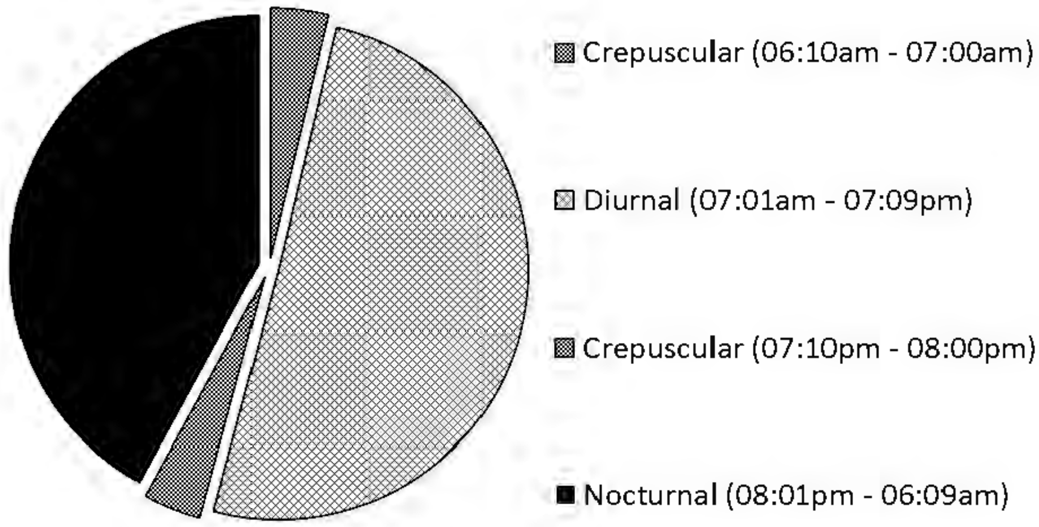

Figure 4.4 – Classification system and times used to determine crepuscular, diurnal or nocturnal activity patterns in spring (Australian Eastern Daylight Time).

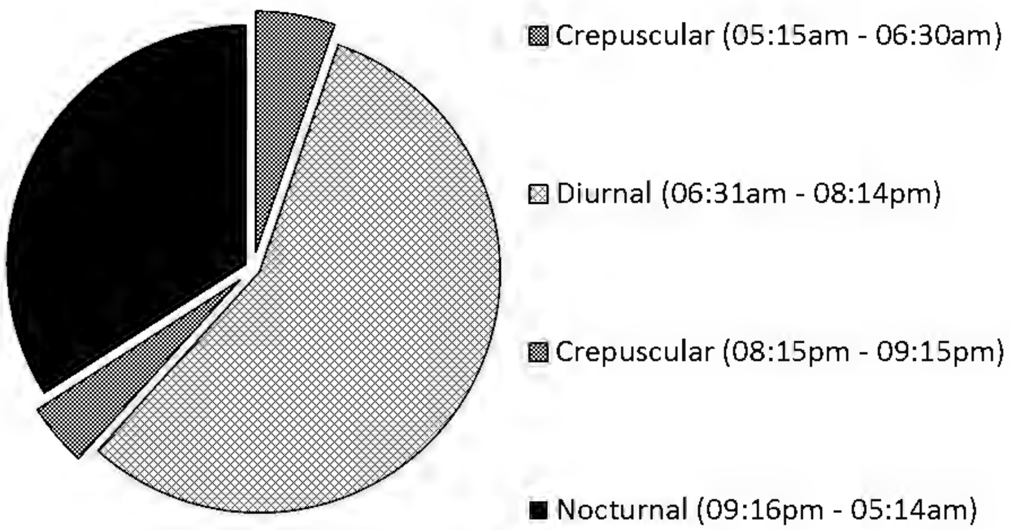

Figure 4.5 – Classification system and times used to determine crepuscular, diurnal or nocturnal activity patterns in summer (Australian Eastern Daylight Time).

4.2.4 Statistical analysis

General feral pig activity patterns

A one-way between-groups analysis of variance (ANOVA) (Pallant 2005) was used to determine whether there was a significant difference in the mean of crepuscular, nocturnal or diurnal activity displayed by feral pigs in the Macquarie Marshes. The data used were the mean number of feral pig passes per camera, per night, from all seasons and all treatment sites combined. A one-way between groups ANOVA was selected as there was one multi-level independent variable (activity category - crepuscular, nocturnal and diurnal) and one dependant variable (mean number of feral pig passes per camera per night).

Seasonal feral pig activity patterns

A one-way multivariate analysis of variance (MANOVA) (Pallant 2005) was used to determine whether mean level of feral pig activity was consistent between seasons in the Macquarie Marshes. The data used were the mean number of pig passes per camera, per night, per season (data from all treatment sites combined). One way MANOVA were used as there were a single multilevel independent variable (winter, spring, summer and autumn) and three multiple dependant variables (crepuscular, nocturnal and diurnal). A series of one-way ANOVA were then used to determine whether crepuscular, nocturnal or diurnal activity levels varied significantly within each season.

Management and feral pig activity patterns

A one-way MANOVA (Pallant 2005) was used to ascertain whether mean feral pig activity (crepuscular, nocturnal and diurnal combined) varied significantly between treatment sites (management) in the Macquarie Marshes. The data used were the mean number of pig passes per, camera per night, treatment area (all four seasons were combined). One-way MANOVA were used because there was a single multilevel independent variable (treatment 1 site, treatment 2 site, treatment 3 site and the non-treatment site) and three multiple dependant variables (crepuscular, nocturnal and diurnal). A series of one-way ANOVA were then undertaken to determine whether significant differences occurred between crepuscular, nocturnal or diurnal activity within each treatment site. In recognition that counts of feral pigs (passes per camera per night) varied between treatment sites (different level of feral pig abundance at each site), the same analyses were undertaken using the mean proportion of observations per site, per category (crepuscular, nocturnal and diurnal) in order to standardise the data.

4.3 Results

General feral pig activity patterns

Remote cameras were positioned in the field for 340 trap nights per season for four seasons; a total of 1,360 trap nights. They captured a total of 287 feral pig passes, of which 62 were crepuscular (occurred during twilight hours), 207 were nocturnal and 18 were diurnal. All passes were tallied on a 24hr time scale and are depicted in Figure 4.6. The graph shows a sharp increase in feral pig activity between 5:00pm and 9:00pm, which gradually declines throughout the night. No feral pig activity was recorded between 12:00 noon and 4:00pm. There may be evidence to indicate that feral pigs in the Macquarie Marshes display a bimodal activity patterns, with an initial peak at ~09:00pm and second, lower peak, at ~06:00am (Fig 4.6).

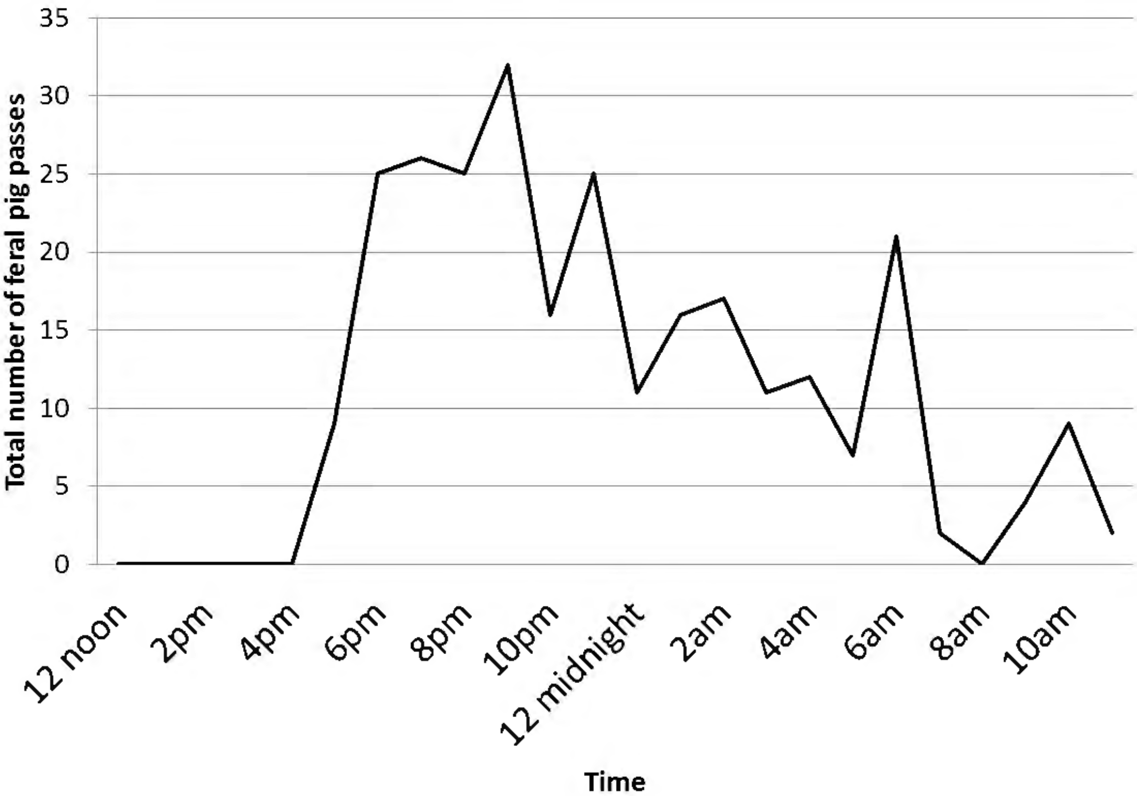

Figure 4.6 – Daily feral pig activity in the Macquarie Marshes NSW. Activity equates to the total number of feral pig passes recorded during each hour (rounded to the nearest hour) throughout the study.

A one way between groups ANOVA identified a significant difference ($F_{2,27}$= 34.54, p <0.001) between mean crepuscular, nocturnal and diurnal activity when the data for treatment sites and seasons were combined. Post hoc comparisons using Tukey HSD showed that nocturnal activity (0.15 ± 0.06 SE) was significantly greater than crepuscular (0.06 ± 0.01 SE) and diurnal (0.01 ± 0.01 SE) activity (Fig. 4.7). There was no significant difference between crepuscular and diurnal activity (Fig. 4.6).

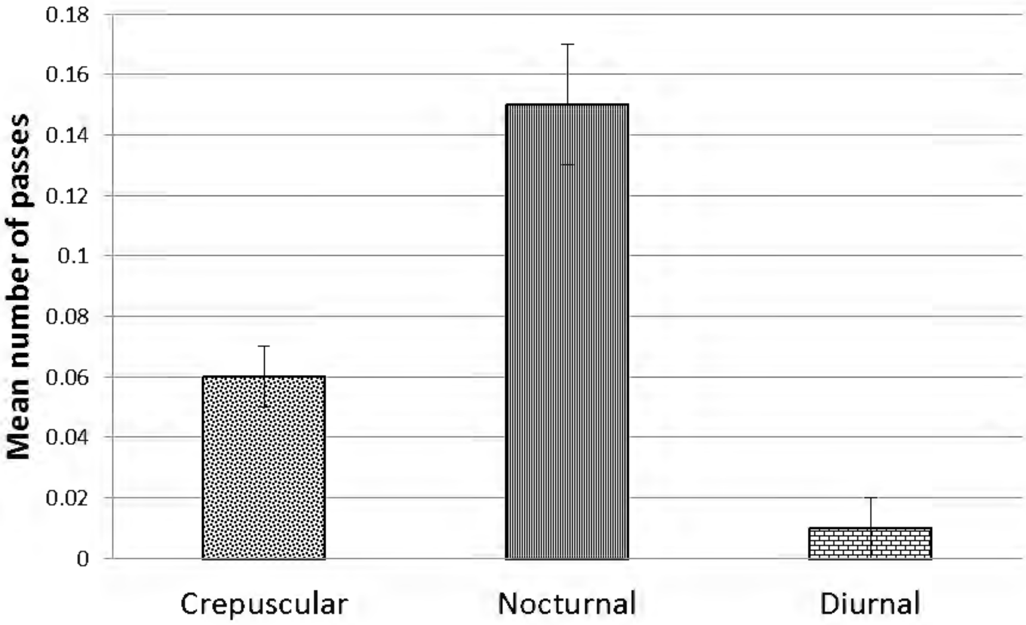

Figure 4.7 – Mean (± SE) number of feral pig passes per camera, per night for each activity category in the Macquarie Marshes.

It was evident that feral pigs in the Macquarie Marshes were largely nocturnal, to a lesser extent diurnal, despite there being more hours available within the diurnal activity category for feral pig passes, on average, within a 24 hour period (Table 4.1).

Table 4.1 – The mean number of feral pig passes within crepuscular, nocturnal and diurnal activity categories throughout the study comparative to the mean hours available per activity category over a 24 hour period throughout study.

	Mean passes	*%*	*Mean hours*	*%*
Crepuscular	0.06	28	1.9	8
Nocturnal	0.15	67	10.3	42
Diurnal	0.01	5	12.05	50

Seasonal feral pig activity patterns

A one way MANOVA showed no significant difference ($F_{9,108}$= 1.67, p = 0.11; Pillia's Trace = 0.37) in the mean level of feral pig activity between seasons when dependant variables were combined (crepuscular, nocturnal and diurnal). However, when dependant variables were considered separately, nocturnal activity was significantly ($F_{3,36}$= 3.88, p= 0.017) lower in spring than it was in other seasons (Fig. 4.8). A series of one way ANOVA were then undertaken to determine whether differences occurred between mean crepuscular, nocturnal and diurnal activity within each season. A significant difference ($F_{2,27}$= 16.30, p <0.001) was identified in winter, with nocturnal activity (0.23 ± 0.04 SE) being greater than crepuscular (0.04 ± 0.02 SE) and diurnal (0.02 ± 0.02 SE) activity. Crepuscular and diurnal activity levels were not different. During spring, a significant difference was also apparent ($F_{2,27}$= 3.28 p= 0.05) with nocturnal activity (0.07 ± 0.02 SE) being higher than diurnal activity (0.01 ± 0.01 SE). There was no difference between nocturnal and crepuscular activity, or crepuscular and diurnal activity. During summer, there was no significant difference ($F_{2,27}$=1.95, p= 0.16) between crepuscular, nocturnal or diurnal activity (Fig. 4.8). In autumn, there was a significant difference ($F_{2,27}$=11.72, p <0.001) between activity categories, with nocturnal activity (0.20 ± 0.05 SE) being higher than crepuscular (0.07 ± 0.02 SE) and diurnal (0.00 ± 0.00 SE) activity. Diurnal activity and crepuscular activity were not significantly different.

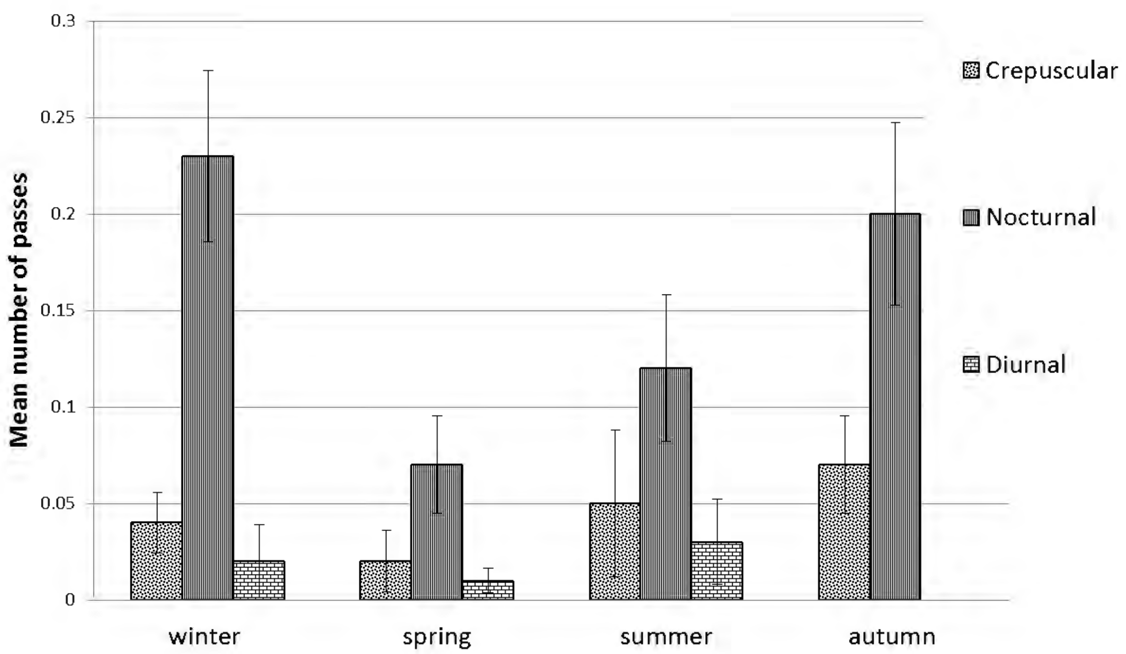

Figure 4.8 – Mean (± SE) feral pig activity with each activity category between seasons in the Macquarie Marshes.

Management and feral pig activity patterns

A one way MANOVA demonstrated that the mean level of feral pig activity recorded between treatment sites was significantly different ($F_{9,108}$= 2.56, *p*= 0.01; Pillia's Trace = 0.53) when dependant variables (crepuscular, nocturnal and diurnal) were combined. When dependant variables were considered separately, it was discovered nocturnal activity was significantly ($F_{3,36}$ = 6.85, *p*= 0.001) higher at the aerial shooting only site (Fig. 4.9). A series of one way ANOVA were undertaken to determine whether mean feral pig activity (crepuscular, nocturnal and diurnal) varied within treatment sites. There was a significant difference ($F_{2,27}$= 4.32, *p* = 0.024) between activity categories at the combined management site (treatment 1 site), with the nocturnal activity (0.09 ± 0.01 SE) being higher than crepuscular (0.02 ± 0.01 SE) and diurnal activity (0.02 ± 0.02 SE). Crepuscular and diurnal activity categories were not different. At the aerial shooting only site (treatment 2 site), a significant difference ($F_{2,27}$= 7.58, *p*= 0.002) was also identified, with nocturnal activity (0.34 ± 0.28 SE) being higher than crepuscular (0.08 ± 0.05 SE) and diurnal activity (0.03 ± 0.03 SE). There was no significant difference between crepuscular and diurnal activity. A significant difference ($F_{2,27}$= 4.12, *p*= 0.03) was found at the bait only site (treatment 3 site), where nocturnal activity (0.04 ± 0.01 SE) was significantly higher than diurnal activity, although there was no difference between crepuscular and nocturnal activity, or between diurnal and crepuscular activity (Fig. 4.9). There was a significant difference ($F_{2,27}$= 9.58, *p*= 0.001) in feral pig activity patterns at the no management site (non-treatment site), nocturnal activity (0.21 ± 0.15 SE) was significantly higher than crepuscular (0.09 ± 0.03 SE) and diurnal (0.01 ± 0.01 SE) activity, and there was no difference between crepuscular and diurnal activity. Hence, feral pigs were largely nocturnal within all treatment areas regardless of what form of management was being undertaken.

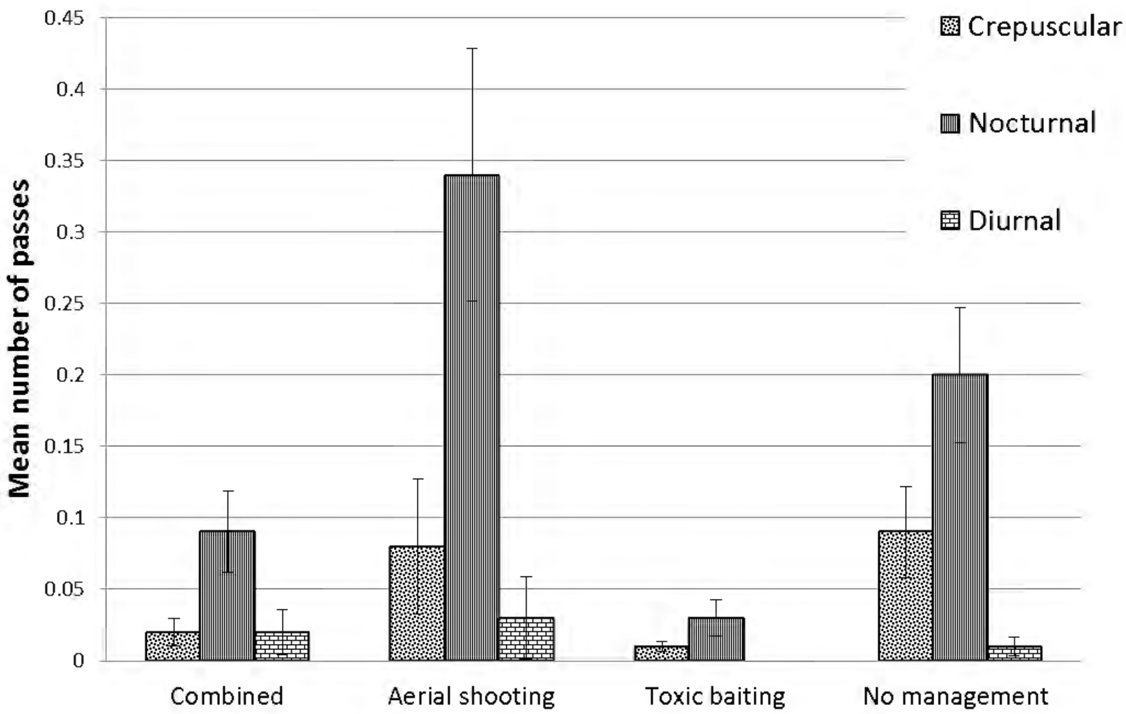

Figure 4.9 – Mean (± SE) Feral pig activity with each activity category between treatment sites in the Macquarie Marshes.

As counts of feral pigs (passes per camera per night) varied between sites throughout the study, analysis on the mean proportion of observations per treatment sites, per category (crepuscular, nocturnal and diurnal), were conducted in order to standardise the data. A one way MANOVA showed that the mean proportion of activity recorded between treatment sites was significantly different ($F_{9,108}$= 2.16, *p*= 0.031; Pillia's Trace = 0.15) when dependant variables (crepuscular, nocturnal and diurnal) were combined. It was evident there was a lower proportion of feral pig activity recorded at poison baiting only site (Fig. 4.10). However, when dependant variables were considered separately, the mean proportion of crepuscular ($F_{3,36}$ = 1.20, *p*= 0.135), nocturnal ($F_{3,36}$ = 1.05, *p*= 0.383) or diurnal ($F_{3,36}$ = 1.161, *p*= 0.338) activity was not significantly different between sites (Fig. 4.10). A series of one way ANOVA were undertaken to determine whether mean proportion of feral pig activity (crepuscular, nocturnal and diurnal) varied within treatment sites. It was discovered that nocturnal activity was significantly greater than diurnal and crepuscular activity at the aerial shooting and poison baiting site ($F_{2,27}$= 11.78, *p*< 0.0001), the aerial shooting only site ($F_{2,27}$= 17.32, *p*< 0.0001) and the poison baiting only site ($F_{2,27}$= 7.26, *p*= 0.003). There was no difference in the level of crepuscular and diurnal activity at these sites. There was a significant difference ($F_{2,27}$= 20.50, p< 0.0001) between all three activity categories (crepuscular, nocturnal and diurnal) at the no management site.

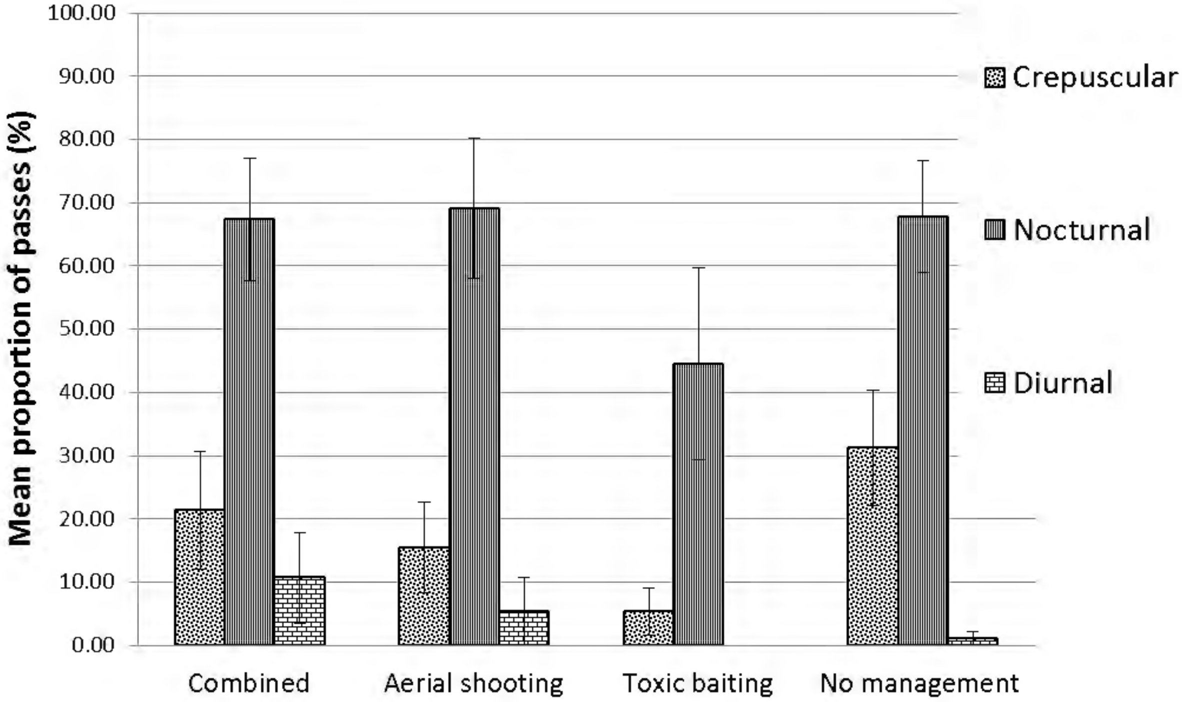

Figure 4.10 – Mean proportion of feral pig activity with each activity category (crepuscular, nocturnal or diurnal) between treatment sites in the Macquarie Marshes.

4.4 Discussion.

The study demonstrated that feral pigs in the Macquarie Marshes were largely nocturnal irrespective of the season or the management option, and that most activity occurred between 05:00pm and 07:00am. It also appears that remote imagery may be an effective alternative to radio telemetry or global-positioning-system collars for monitoring daily feral pig activity patterns in relatively remote areas. Giles (1980) found that feral pig activity in the Macquarie Marshes was largely nocturnal, although the data were largely observational as it was difficult to utilise radio telemetry in relatively inaccessible marsh country.

General feral pig activity patterns

Giles (1980) was able to utilise use radio telemetry to determine feral pig activity patterns at Yantabulla in north western NSW (rangelands), where it was reported that feral pig activity was mostly crepuscular. McIlroy *et al.* (1989) reported feral pigs were most active between 05:00pm and 01:00am and they were least active between 08:00am and 04:00pm in Namadgi

National Park, ACT (mountain and sub-alpine). Saunders and Kay (1991) reported a peak in activity between 07:00pm and 12:00 midnight at Sunny Corner in NSW (temperate highlands) and recorded very little activity during daylight hours. Caley (1997) reported that feral pigs displayed bimodal (two peaks of activity) activity patterns in the Douglas-Daley River region of the Northern Tertiary (tropical woodland habitat), with peaks in activity occurring between 04:00am and 06:00am and between 06:00pm and 08:00pm. During the present study, most activity occurred between 05:00pm and 07:00am, with activity generally declining throughout the night. Similar to what was reported by Caley (1997), there is some evidence to suggest that feral pigs in the Macquarie Marshes also display bimodal activity patterns, with the first peak occurring at ~09:00pm and the second smaller peak occurring at ~06:00am.

Internationally, Campbell and Long (2010) examined daily wild boar activity patterns using global-positioning-system collars in southern Texas, USA in mixed shrub rangelands, and reported wild boar were mostly nocturnal with peak activity occurring between 09:00pm and 04:00am. Nogueira *et al.* (2007) mentions feral pig activity in Hawaii generally peaks late in the afternoon, night and morning. In Tuscany Italy (sub-Mediterranean), Biotani *et al.* (1994) used radio telemetry and reported that wild boars were mostly active during crepuscular and nocturnal hours with peak activity occurring at 09:00pm; activity was particularly low between 09:00am and 04:00pm. On the Tyrrhenian coast in central Italy (Mediterranean), Russo *et al.* (1997) also use radio telemetry and reported that wild boars became active during daylight hours in the afternoon, but were primarily nocturnal. These national and international studies, in combination with the present study, suggest that feral pigs/wild boars and their combinations are largely nocturnal regardless of habitat or location. It also demonstrates that remote cameras can provide similar results to radio telemetry technology and global-positioning-system collar technologies, in regards to daily activity patterns. However, unlike radio elementary remote cameras have limited ability to provide distances moved by animals.

Seasonal feral pig activity patterns

The amount of feral pig activity recoded during each season was similar throughout the project; hence a similar number of feral pig passes per camera were recorded during winter, spring, summer and autumn. Feral pigs were primarily nocturnal throughout the year, although there was no significant difference between nocturnal and crepuscular activity in spring and summer. Nocturnal activity was greater than diurnal activity in all seasons, apart from summer where there was no significant difference between any of the activity categories. This is interesting, as it may be expected that feral pigs would become more nocturnal in summer to avoid high ambient temperatures. Giles (1980), Saunders and Kay (1991) and Caley (1997) reported feral pigs were rarely active during the day irrespective of season, although if they were active movements were generally confined to areas of thick vegetation. Similarly, diurnal activity in this study was typically recorded by cameras that were positioned in dense habitat. Caley (1997) reported that the evening activity peak was significantly greater during the early dry season (dry season in the Northern Territory runs from April/May until September/October). During the current study, nocturnal activity was significantly higher during winter and autumn, which also falls within the Northern Territory dry season. In contrast, McIlroy *et al.* (1989) reported no difference in the mean distances travelled by feral pigs during daylight and darkness in Namadgi National Park. Hone (1988, 2002) also mentions that feral pigs were sometimes sighted foraging during daylight hours. Such daytime observations may have occurred because of the cooler conditions in Namadgi National Park. Giles (1980) also observed feral pigs foraging during daylight hours in cooler conditions.

Russo *et al.* (1997) hypothesised that wild boar may have become active during afternoon daylight hours due to lack of food, and possible lack of human interference. Massei *et al.* (1997) reported that wild boars at high densities, in the same study area, foraged more intensively over a smaller area when food was less abundant and suggested this may be an adaptation to save energy and avoid starvation. In Germany, Keuling *et al.* (2008) mentions that diurnal activity was significantly higher in May and June (summer). In Texas, wild boars became more active with increased temperatures during the dormant and early growing season, which occurs from January to March (Campbell and Long 2010). Biotani *et al.* (1994) reported there was no significant change in wild boar activity between seasons in Tuscany. There was little evidence in the current study to suggest feral pig diurnal activity patterns were more pronounced in cooler months. Conversely, nocturnal activity was less pronounced in summer. A potential reason may be that it is lighter for longer during summer. In this study, it was generally dark between 06:15pm and 6:15am in winter, spring and between 08:01pm and 06:09am in autumn. Conversely, it was generally dark between 08:15pm and 4:15 am in summer, and thus less darkness hours were available. Other studies have reported, as quality foods become less abundant feral pig home ranges become larger to satisfy dietary requirements (Giles 1980; Caley 1997; Saunders and Kay 1991; Dexter 1998, 1999). Therefore, the need for feral pigs to forage over larger areas in summer combined with less hours of darkness may mean that feral pigs must continue to forage into daylight hours. However, this does not necessarily mean they will forage throughout the day, as no feral pig activity was recorded between 12:00 noon and 04:00pm, although it may mean they become active before and after dusk and dawn, respectively.

Management and feral pig activity patterns

The mean level of feral pig activity recorded between treatment sites was significantly different when the data for crepuscular, nocturnal and diurnal were combined. There were significantly more feral pig passes recorded at the aerial shooting site (treatment 2 site) compared to the other sites, and these passes were largely nocturnal. This may have occurred because more recordings were taken at this site (due to higher feral pig abundance), rather than because aerial shooting caused a higher levels of nocturnal activity. Therefore, future studies should select study sites with similar levels of feral pig abundance. Notwithstanding, in order to standardise the data, analysis were also undertaken using mean proportion of feral pig activity per category, per site. During this time, it was discovered that there was still a significant difference between sites when dependant variables were combined (crepuscular, nocturnal and diurnal); with a lower proportion of activity being recorded at poison only site (treatment 3). However, when crepuscular, nocturnal and diurnal activity was considered separately, the proportion of feral pig activity within each category did not alter significantly between sites. That is, a similar proportion of crepuscular, nocturnal and diurnal activity was recorded within all treatment sites.

Thereafter, all treatment sites were considered separately using both mean number of passes, per camera, per night and the mean proportion of passes per sight, per night, to assess the influence of various forms of management on crepuscular, nocturnal and diurnal activity patterns. The results for mean number of passes demonstrated that nocturnal activity was higher than crepuscular activity at all study sites apart from the bait only site (treatment 3 site), where crepuscular and nocturnal activity were similar. Nocturnal activity was higher than diurnal activity at all sites, whereas crepuscular and diurnal activity was similar in all sites. When focussing at the mean proportion of passes per activity category, it was discovered that nocturnal activity was significantly greater than crepuscular and diurnal activity at all treatment sites. In addition, crepuscular and diurnal activity were similar all sites apart from the non-treatment site where all activity categories were significantly different. Giles (1980) and Saunders and Kay (1991) mention that feral pigs could become more nocturnal in response to disturbance and/or hunting pressure. Giles (1980) reported that feral pigs were more likely to be seen foraging in the open on a property where hunting was not permitted. Several other studies have examined feral pig behavioural responses to various forms of management. Saunders and Bryant (1988) mention aerial shooting rarely caused animals to disperse outside their normal home range, although they may have learned to hide and avoid detection. McIlroy *et al.* (1989) examined the effectiveness of warfarin poisoning for managing feral pigs in Namadgi National Park and found no significant differences in mean distances covered in daylight or darkness. McIlroy and Saillard (1989) reported that hunting with trained dogs did not cause animals to disperse outside their normal home range, although they may have modified their behaviour to avoid detection. Dexter (1996) reported that helicopter shooting had no significant influence on hourly movement, variation in distance moved, or home range size before and after aerial shooting.

Internationally, Keuling *et al.* (2008) reported in Germany that hunting pressure had only a minor influence the daily activity of wild boars and that most shifts in activity were caused by season. Biotani *et al.* (1994) mentioned wild boars in Tuscany seemed to use open areas mainly at night, particularly when daytime temperatures were and hunting pressure were high. During the current study, feral pigs were most commonly nocturnal irrespective of management type. In addition, nocturnal activity was more common than crepuscular or diurnal activity at the no management site (non-treatment). It is possible that feral pigs were largely nocturnal due to previous exposure to recreational and illegal hunting, which is common throughout much of the region. Similarly, Dexter (1996) stated lack of statistical significance in his study may have occurred because feral pigs were already wary of human activity. It may also be possible in the present study that general farm duties such as mustering livestock and machinery use may have altered feral pig behaviour. Nevertheless, if feral pigs in the Macquarie Marshes are largely nocturnal, and they can learn avoid helicopter detection, as Saunders and Bryant (1988) suggest, it is possible that a residual learned population may exist in the area. This highlights the importance of using a sustained multiple management technique approach, so that animals that are missed with one management technique may be accounted for with another. Beneficial further research in the Macquarie Marshes may be to measure the effectiveness of remote cameras for monitoring habitat and resource (water points and cropping areas) utilisation.

Conclusion

The current study demonstrated that feral pigs in the Macquarie Marshes are largely nocturnal irrespective of season or management option, and that remote cameras can be a useful low labour technique for gathering information on daily feral pig activity patterns in relatively remote and inaccessible areas. This study largely supports the null hypothesis that season and various feral pig management options including poison baiting, aerial shooting and their combinations has little impact on feral pig behavioural patterns in the Macquarie Marshes.

Chapter 5 – An assessment of bait attractants for feral pig management in the Macquarie Marshes, New South Wales.

5.1 Introduction

Two of the more common techniques used to manage feral pigs in Australia are poison baiting and trapping (Choquenot *et al.* 1996; Hone 2012). Poison baiting is typically used in rural areas, because it is relatively cost effective and can be used to achieve large feral pig population reductions (Hone and Pederson 1980; Hone 1983; O'Brien and Lukins 1988; McIlroy *et al.* 1989; Saunders *et al.* 1990; Twigg *et al.* 2005; Cowled *et al.* 2006a). Trapping is more commonly used in areas that are close to human habitation or in environmentally sensitive areas, as it poses less risk to non-target species (Choquenot *et al.* 1993; Saunders *et al.* 1993; Caley 1994). Despite both techniques being highly useful, their efficacy can be influenced by numerous variables, and generally those that influence trapping success also influence poison baiting success. Variables reported to influence trapping and/or poison baiting success in Australia are: seasonal conditions, trap/bait station location in the landscape, free-feeding duration and bait attractiveness (Hone 1983, 2002; O'Brien and Lukins 1988; Saunders and Bryant 1988; Choquenot *et al.* 1993; McIlroy *et al.* 1993; Saunders *et al.* 1993; Caley 1994; Choquenot and Lukins 1996; Fleming *et al.* 2000; Twigg *et al.* 2005).

Trapping and poison baiting programs are generally most successful when alternative resources are scarce and when traps or bait stations are positioned near areas of fresh feral pig activity (Hone 1983, 2002; Choquenot *et al.* 1993; McIlroy *et al.* 1993; Saunders *et al.* 1993; Caley 1994; Choquenot and Lukins 1996; Twigg *et al.* 2005). Program efficacy is also enhanced when pre-feeding is undertaken for an extended period at the beginning of the program and when the bait substrates used are particularly attractive to feral pigs (Hone 1983; O'Brien and Lukins 1988; Saunders and Bryant 1988; McIlroy *et al.* 1993; Saunders *et al.* 1993; Caley 1994; Elsworth *et al.* 2004; Twigg *et al.* 2005). Even when the pre-mentioned factors are considered, several authors have reported that a proportion of the population will remain un-impacted, because they will not find bait, find bait and not eat or they will find bait and consume a sub-lethal dose (Hone 1983, 2002; Saunders and Bryant 1988; Choquenot *et al.* 1993; McIlroy *et al.* 1993; Saunders *et al.* 1993).

A bait attractant that could make bait substrates more attractive and palatable to feral pigs may be particularly useful for helping to reduce residual population size. An attractant that is highly pungent (increase discovery), highly palatable (increase bait-take), readily available (user access) and cost effective would be desirable. It should also be target specific to reduce uptake by non-target species, which may help reduce bait wastage and non-target species impact. One of the more common methods used to enhance the attractiveness of various grain baits is fermentation. This is achieved by submerging the grain in water for several days or weeks until it begins to swell and smell (Choquenot *et al.* 1993: McIlroy *et al.* 1993; Choquenot and Lukins 1996; Hone 2002). Fermentation helps to increase the pungency of the bait to maximise discovery by feral pigs. Twigg *et al.* (2005) reported that in the Kimberley region of W.A. the addition of Blood and Bone® could increase the uptake of fermented grain by feral pigs. Elsworth *et al.* (2004) assessed the effectiveness of various bait attractants for increasing uptake of grain, meat and bananas, but reported that none could significantly outperform the non-treatment substrates. Campbell and Long (2008) assessed various olfactory attractants on feral pigs in the USA and reported that apple and strawberry flavoured attractants were most appealing, although strawberry was more target specific. Subsequently, Campbell and Long (2009) tested strawberry flavoured baits to determine their target specificity to feral pigs and discovered collard peccary (*Pecari tajacu*), rodents (*Neotoma micropus* and *Sigmodon hispidus*) and cattle removed baits at a rate similar to, or greater than, feral pigs.

The Macquarie Marshes is an area where a feral pig bait attractant would be particularly useful, as alternate foods are often abundant. Therefore, it can be difficult to find bait substrates that are more attractive to feral pigs than what occurs naturally. No published data are available on bait attractants, or baiting procedures in the Macquarie Marshes, despite a number of authors recommending that poison baiting and/or trapping should be undertaken between aerial shooting events to reduce residual populations (Giles 1080; Saunders 1993). Therefore, this study was undertaken to determine whether bait attractants could be added to a traditional bait substrate (barley) to increase bait station visitation and bait-take by feral pigs, and ultimately enhance the effectiveness of feral pig baiting/trapping in the region. The null hypothesis is that bait attractants will have no influence on bait station visitation or active station rate by feral pigs compared to the non-treatment bait (dry barley) in the Macquarie Marshes. The alternate hypothesis is that bait attractants do influence bait station visitation or active station rate by feral pigs compared to the non-treatment bait (dry barley) in the Macquarie Marshes.

5.2 Methods

5.2.1 Study site

This study was undertaken at sites 1, 2, 3 and 4 (Fig. 2.2). The average daily maximum temperature recorded for January 2012 was 31ºC and the total rainfall was 101mm. The average daily maximum temperature recorded for June 2012 was 18ºC and the total rainfall was 38mm (Bureau of Meteorology 2012). Refer to chapter 2 – Study sites for a map and further site details.

5.2.2 Procedure

The HogHopper™ locations that were used in chapter 4 (activity patterns) were also used in the present study. Refer to chapter 4 – Procedure for details on bait station/HogHopper™ site selection and feral pig baiting procedures. Because only non-toxic bait was used in the present study, HogHopper™s were left in the free-feed position for the duration of the study (Fig. 5.2).

Figure 5.2 – Feral pigs feeding from HogHopper™ in the Macquarie Marshes. Doors are partially open and set to the free-feed position.

During the study, five different attractants were tested including Carasweet®, imitation vanilla essence (Queen), molasses, meat meal (GEMSCOTT), and fishmeal (SKSF). In addition, two common bait types, non-toxic PIGOUT® manufactured feral pig bait and fermented barley (hereafter fermented barley and PIGOUT® are referred to as attractants) and one non-treatment bait (dry barely) were assessed; equating to eight different experimental treatment groups. None of the treatment/non-treatment bait material was dyed green or blue, apart from PIGOUT® manufactured baits which are dyed green during the manufacturing process to reduce non-target species interest (Cowled *et al.* 2006b). All attractants were identified according to Australian studies (Elsworth *et al.* 2004; Cowled *et al.* 2006b; Twigg *et al.* 2007) and via personal communication with individuals involved in feral pig control.

Two attractants trials were undertaken, which included one in January 2012 and one in June 2012. During each study period, treatments were randomly assigned to HogHopper™s within each study site. As 12 HogHopper™s were assembled at site 1, four of the eight non-treatment/treatments were deployed twice at this site during each trial. Conversely, as six HogHopper™s were assembled at site 2, two non-treatment/treatments were not tested at this site during each trial. For each replicate, apart from PIGOUT® where 20 free-feed baits were deployed, approximately 10kg of dry barley was added to a 20 litre bucket followed by the attractant (100g Carasweet, 200ml Vanilla, 500g meat meal, 500g fish meal or no attractant for the non-treatment). The contents were then stirred using a clean mixing stick, the lid was fastened and the bucket shaken vigorously until the attractant was relatively evenly dispersed. The ratio of attractant to dry barley was selected according to label directions (Carasweet®) or via personal communication. The fermented grain was prepared by placing 60kg of dry barley in a large 100 litre container and submerging it in water for one month. Thereafter, the hard dry crust was removed and 10kg of the moist fermented barley underneath was shovelled into a 20 litre bucket. The attractants were deployed at their designated HogHopper™s (~5kg inside and approximately ~5kg outside) for 10 days during each trial (January 2012 and June 2012).

HogHopper™s were under constant motion sensing camera surveillance (Reconyx HC500 HyperFire semi-covert IR) for the duration of each trial. Remote cameras were positioned approximately four metres from each device (at chest height) and were set to one picture per trigger with no time delay. Remote cameras were used to count the total number of feral pigs per HogHopper™ per night. It was possible to identify individual feral pigs by size, gender, coat colour and mob affinity (Cowled *et al.* 2006a; Williams *et al.* 2011). Remote cameras were also used to determine the night of first visit and non-target species visitations.

HogHopper™s were checked every second day to determine bait-take and level of bait consumption. The bait was also replaced or refreshed during this time. Bait-take was classified as either no or yes (no = no obvious bait take by pigs, yes = bait take by pigs), which was also confirmed using remote cameras. Level of bait consumption was classified as untouched, low, medium or high, and was given a rank score according to the rank system below (Table 5.1).

Table 5.1 – Rank system for level of bait consumption used for statistical analysis.

Amount consumed	***Consumption level***	***Rank***
No obvious bait take	Untouched	0
Partially consumed outside HogHopper	Low	1
Completely consumed outside HogHopper	Medium	2
Completely consumed outside HogHopper and some inside	High	3

5.2.4 Statistical analysis

Bait station visitation

A one-way between groups analysis of variance (ANOVA) (Pallant 2005) was used to determine whether the rate of bait stations visited (number of stations visited compared to the total number of stations created) by feral pigs varied between trial dates (January 2012 and June 2012). A one-way between groups ANOVA was used because there was one multi-level independent variable (trail dates) and one dependant variable (stations visited).

Active bait stations

A one-way between groups analysis of variance (ANOVA) (Pallant 2005) was used to determine whether the proportion of active bait stations (number of stations with bait-take compared to the total number created) varied between trial dates (January 2012 and June 2012). A one-way between groups ANOVA was used because there were one multi-level independent variable (trail dates) and one dependant variable (stations with bait-take).

Pooled data analyses

Data from January 2012 and June 2012 were pooled and a series of one-way between groups ANOVA (Pallant 2005) were performed to determine differences in mean bait-take, station visitation, nights until visitation, level of bait consumption and number of feral pigs per attractant. A series of one-way between groups ANOVA were used as there was one consistent multi-level independent variable (attractant types) and one dependant variable (either mean bait-take, station visitation, nights until visitation, level of bait consumption or number of feral pigs per attractant).

Number of individual and bait consumption relationships

Correlation analysis (Pullant 2005) was used to determine the strength and direction of the relationship between the mean number of feral pigs present per bait station, per attractant compared to the mean level of bait consumption (rank score) per bait station, per attractant. The data used were directly comparable data that were collected throughout the trial for each attractant.

5.3 Results

Thirty four HogHopper™ locations were used during each trial, hence when trial 1 and trial 2 were combined there were 68 replicates. See Table 5.2 for treatment group sizes.

Table 5.2 – Total number of replicates per attractant during each trial period, and the combined total when trial 1 and trial 2 were pooled.

Attractant	*Trial 1 (January 2012)*	*Trial 2 (June 2012)*	*Combined*
Carasweet	5	5	10
Vanilla	4	4	8
Molasses	5	4	9
Meat meal	5	4	9
Fish meal	4	3	7
PIGOUT	4	4	8
Fermented barley	5	5	10
Barley (non-treatment)	2	5	7
Totals	**34**	**34**	**68**

Bait station visitation

A one way between groups ANOVA showed there was no significant difference ($F_{1,66}$= 1.53, *p*= 0.22) in the mean number stations visited between trials. However, Carasweet® and fermented barley received consistent and relatively high visitation rates at 0.60 ± 0.22 (SE) and 0.40 ± 0.22 (SE), respectively (Fig. 5.3). The remaining attractants received variable visitation rates between trials. All attractants received at least one visit per trial, apart from fish meal and dry barley (non-treatment).

Figure 5.3 – Mean (± SE) visitation rate for each attractant (number of stations visited compared to the total number of stations created) between trials.

Active bait stations

A one way between groups ANOVA demonstrated there was no significant difference ($F_{1,66}$= 0.58, p= 0.449) in the number of active stations (stations with bait-take by feral pigs) between trials. Carasweet® and fermented barley received the same active station rate as they did station visitation rate between seasons (Fig. 5.3 and Fig. 5.4). Hence, when feral pigs visited Carasweet® or fermented barley bait stations they also consumed bait. Feral pigs also consumed vanilla, molasses, meat meal and PIGOUT® baits, although there were times when feral pigs visited these stations and did not eat. No fish meal bait was consumed by feral pigs throughout the study.

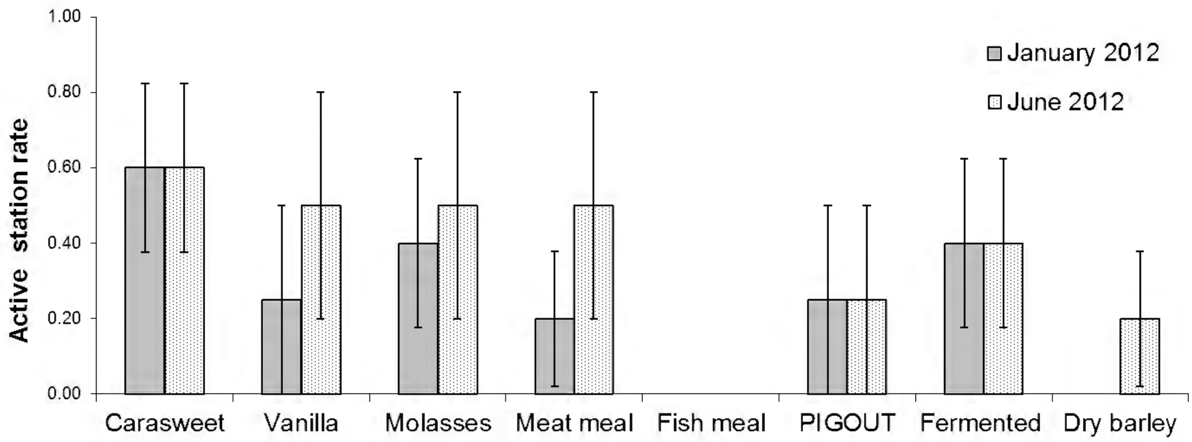

Figure 5.4 – Mean (± SE) active bait station rate for each attractant (number of stations with bait-take compared to the total number of stations created) between trials.

Pooled visitation and bait-take (January 2012 and June 2012)

The data for visitation and bait-take from trial 1 and trial 2 were pooled hereafter, because no significant differences were identified between trial dates. A series of one way between groups ANOVA showed there was no significant difference in station visitation rates ($F_{7,60}$= 0.56, p= 0.79) or active station rates ($F_{7,60}$= 1.27, p= 0.28) between attractants when the data were pooled. Carasweet® did however receive slightly higher station visitation and active station rates, which were also consistent (0.60 ± 0.16 SE). This meant that Carasweet® bait was consumed by feral pigs when it was discovered during both trials. Three additional attractants received equal visitation and active station rates which included vanilla, molasses and fermented barley (Fig 5.5). All other attractants had situations where feral pigs visited and did not eat (Fig 5.5). All attractants, apart from fish meal received higher visitation and bait-take rates than the non-treatment (dry barley), albeit not significant.

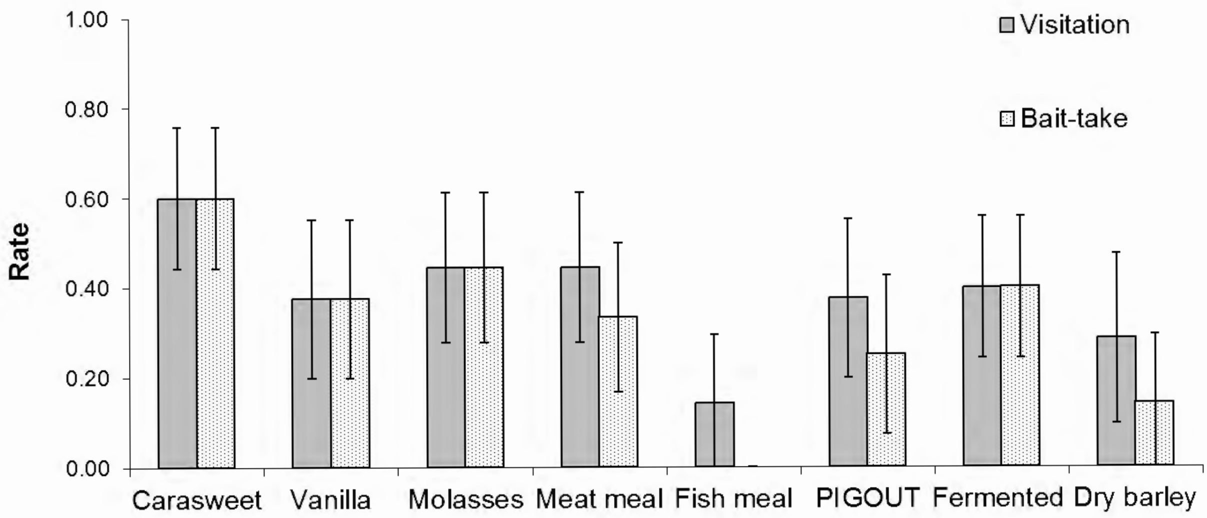

Figure 5.5 – Mean (± SE) visitation rate (number of stations visited compared to the total number of stations created) and active station rate (number of stations with bait-take compared to the total number of stations created) per attractant using pooled data from trial 1 (January 2012) and trial 2 (June 2012).

Nights until visitation

A one way between groups ANOVA showed there was no significant difference ($F_{7,60}$= 0.17, p= 0.10) in the mean number of nights until first visitation by feral pigs between attractants. Mean nights until visitation for all attractants was 1.7 ± 0.14 (SE) nights (Fig. 5.6). In addition, feral pigs typically continued to re-visit each station/attractant (apart from fish meal) when it was discovered.

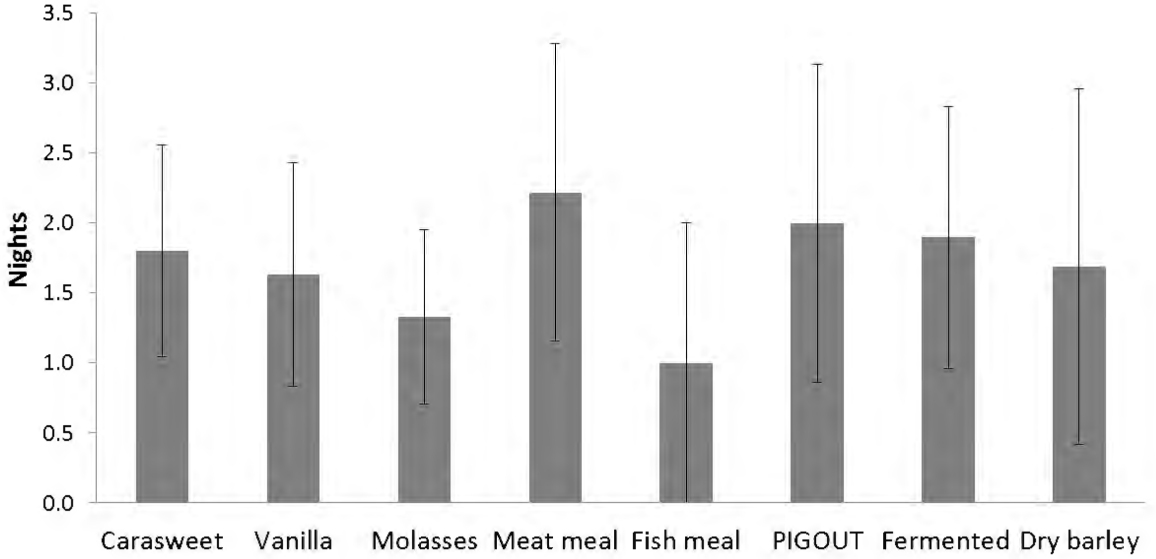

Figure 5.6 – Mean (± SE) nights until first visitation by feral pigs for each attractant.

Bait consumption level

Rank scores were assigned to every bait station during both trials (n=68); even those that did not receive bait consumption. Rank scores are derived from Table 5.1. A one way between groups ANOVA showed there was no significant difference in mean bait consumption (bait consumption levels) between attractants ($F_{7,60}$= 1.01, *p*= 0.43). Notwithstanding, Carasweet® received a higher mean consumption rank score 1.2 ± 0.36 (SE) than all other attractants (Fig. 5.7). In addition vanilla, molasses, meat meal, fermented grain and to a lesser extent PIGOUT® received higher, but not significant, mean rank scores than the non-treatment bait (dry barley).

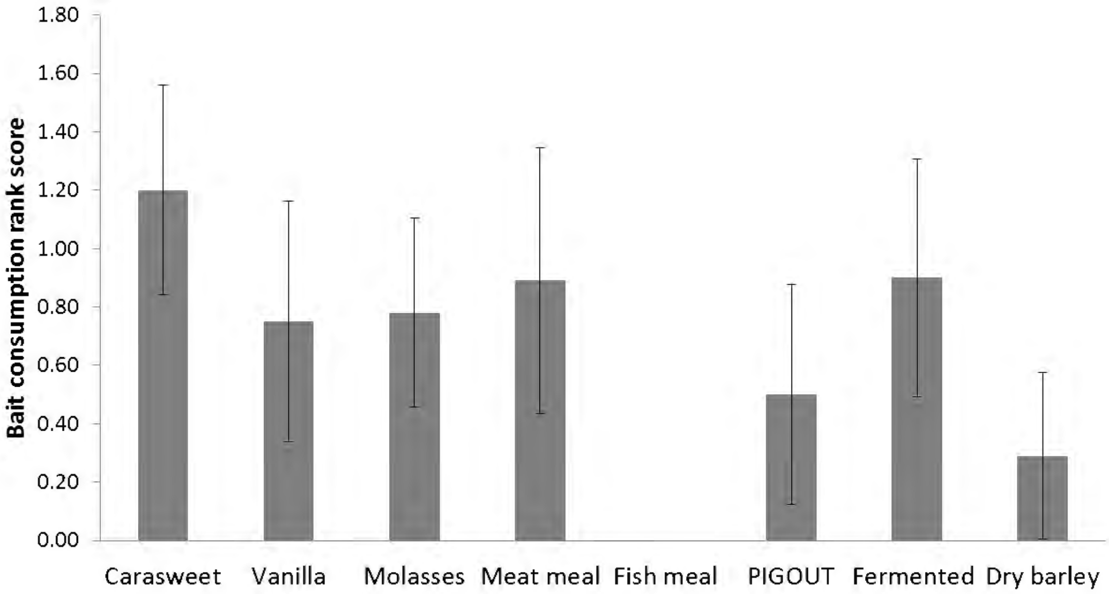

Figure 5.7 – Mean (± SE) bait consumption rank score (consumed by feral pigs) per attractant. All bait stations that were created for each attractant received a rank score according to Table 5.1.

Number of feral pigs

A total of 40 individual feral pigs visited bait stations during January 2012 and 81 individual feral pigs visited bait stations during June 2012; a combined total of 121. A one way ANOVA demonstrated there was no significant difference ($F_{7,60}$= 1.24, p= 0.30) in the mean number of feral pigs per station between attractants when the data were pooled from both trials. Carasweet® received the highest average at 4.3 ± 2.18 (SE) feral pigs per station. All other attractants, apart from fish meal, received higher average number of feral pigs per station than the non-treatment (dry barley), although it was not significant (Fig 5.8).

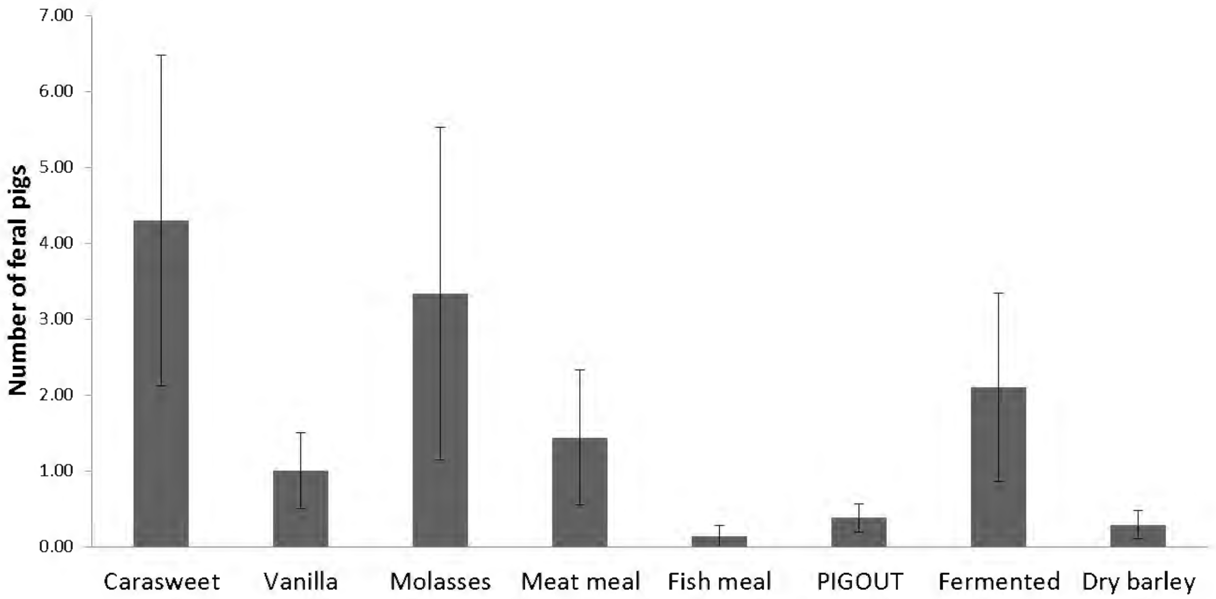

Figure 5.8 – Mean (±SE) number of feral pigs per station per attractant.

Number of individual and bait consumption relationships

Relationships between the mean number of feral pigs present per attractant, per station and mean bait consumption rank score per attractant, per station were assessed using a Pearson product-moment correlation coefficient. The results demonstrated a significant positive correlation between mean number of feral pigs present per station and the mean level of bait consumption (r= 0.82, n=8, *p*= 0.006), with a higher mean number of individuals per station equating to a higher level of bait consumption (Fig 5.9). The coefficient of determination (R^2) was 67.2%. Therefore, the mean number of feral pig per station explains 67.2% of variation in bait consumption by feral pigs.

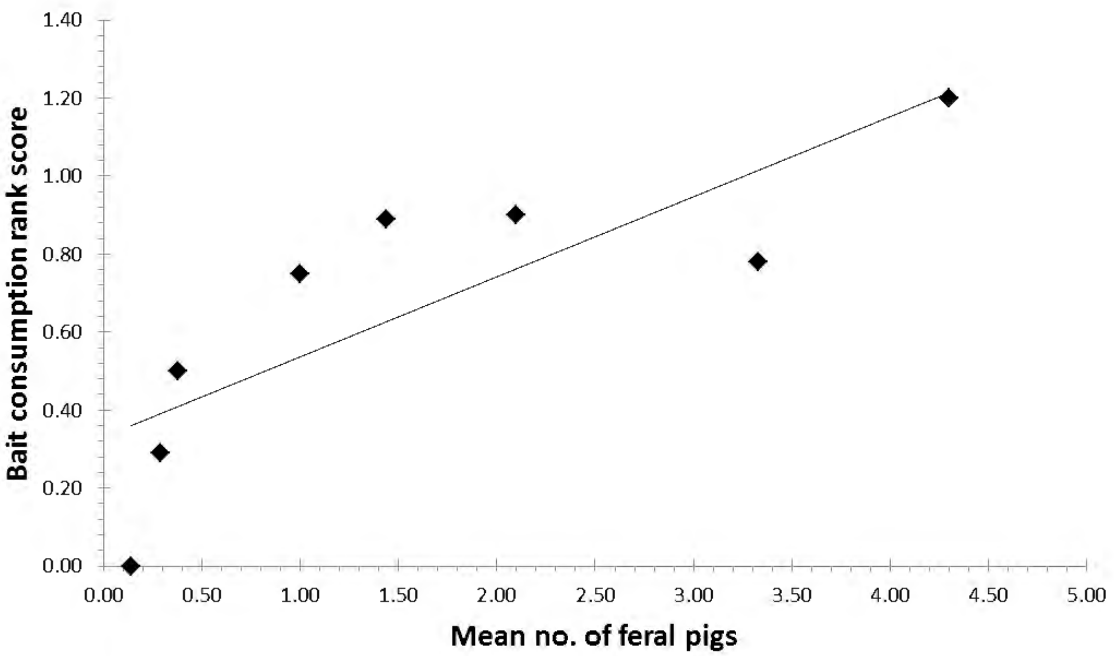

Figure 5.9 – Scatterplot displaying mean number of individual feral pigs per attractant per station compared to mean bait consumption rank score per attractant per station. The regression line (R^2 = 0.67) is shown.

Bait-take by non-target species

A total of 17 different species were recorded at bait stations during the trial. 13 of these species consumed bait from at least one station (or attractant) (Table 5.3). However, most bait that was consumed by non-target species was consumed off the ground in front of the HogHopper™, rather than within them despite the doors being partially open. The only species that were seen to consume bait from within the HogHopper™ were smaller birds such as apostle birds (*Struthidea cinerea*) and crested pigeons (*Ocyphaps lophotes*), which could fly in and out of the device relatively unrestricted, and foxes (*Vulpes vulpes*) which could reach bait with their slender snout. The only species seen to lift the HogHopper™ doors to access bait during the trial were feral pigs. Fish meal and PIGOUT® were consumed by the fewest number of non-target species (Table 5.3). Other attractants to record fewer non-target species than the non-treatment (dry barley) were molasses and Carasweet®.

Table 5.3 – List of species that consumed at least some bait material throughout the trial.

Species	*Carasweet*	*Vanilla*	*Molasses*	*Meat meal*	*Fish meal*	*PIGOUT*	*F. Barley*	*D. Barley*
Australian raven *Corvus coronoides*	***X***	***X***	***X***	***X***	***X***	***X***	***X***	***X***
Apostle bird *Struthidea cinerea*	***X***	***X***	0	***X***	0	0	***X***	***X***
Crested pigeon *Ocyphaps lophotes*	***X***	***X***	***X***	***X***	0	0	***X***	***X***
Australian magpie *Gymnorhina tibicen*	0	***X***	0	***X***	0	0	0	0
Magpie-lark *Grallina cynoleuca*	0	***X***	0	0	0	0	0	0
Galah *Cacatua roseicapilla*	0	***X***	***X***	***X***	0	0	0	0
White-winged chough *Corcorax melanorhamphos*	***X***	***X***	***X***	***X***	0	0	***X***	***X***
Emu *Dromaius novaehollandiae*	***X***	***X***	0	0	0	0	***X***	***X***
Wood duck *Chenonetta jubata*	0	0	0	0	0	0	***X***	0
Swamp wallaby *Wallabia bicolor*	0	***X***	0	0	***X***	0	***X***	***X***
Red fox *Vulpes vulpes*	0	0	0	0	0	***X***	0	0
Feral pig *Sus scrofa*	***X***	***X***	***X***	***X***	0	***X***	***X***	***X***
Sheep *Ovis sp.*	0	***X***	0	0	0	0	0	0
Cattle *Bos taurus*	***X***	***X***	***X***	***X***	0	0	0	***X***
Total species	***7***	***12***	***6***	***8***	***2***	***3***	***8***	***8***

X = consumed at least some bait.
0 = not observed to have consumed bait.

General pricing

During the study, dry barley was purchased at $24.00 per 30 kilogram bag ($8.00 per 10 kilogram of non-treatment material). Fermented barley does not cost additional funding, but it does take the longest to prepare. All other attractants despite costing an extra $1.00 - $3.00 per 10kg can be deployed immediately upon mixing. In addition, free-feed PIGOUT® can be purchased as a ready-made shelf stable product.

Table 5.4 – Average cost to prepare 10kg of barley containing the required amount of attractant.

Attractant	*Cost of attractant + 10kg barley ($8)*
Carasweet	$10.60
Vanilla	$9.50
Molasses	$8.67
Meat meal	$8.56
Fish meal	$9.00
PIGOUT® free-feed	$2.53 per bait (250g)
Fermented barley	$8
Barley	$8

5.4 Discussion

The feral pig bait attractants used in this study did not significantly outperform the non-treatment bait (dry barley) in regards to bait station visitation, bait-take, nights until visitation, level of bait consumption or number of individuals per station in the Macquarie Marshes, New South Wales. However, alternate foods were abundant at the time of each trial due to above average rainfall. Consequently, the results are likely to be worst case scenario and further investigations may be required in drier conditions.

Visitation and active stations between trials (January 2012 and June 2012)

Numerous authors have demonstrated, or suggested, that season influences bait station visitation and bait-take by feral pigs (Hone 1983, 2002; McIlroy *et al.* 1993; Saunders *et al.* 1993; Caley 1994; Choquenot and Lukins 1996; Fleming *et al.* 2000; Twigg *et al.* 2005). Choquenot *et al.* (1990) conducted a feral pig baiting trial in the rangelands of western NSW after heavy rain, and suggested bait consumption and poison program efficacy may have been reduced as a result. Choquenot and Lukins (1996) also reported in the rangelands that bait-uptake by feral pigs decreased as pasture biomass increased. Hence, in such areas bait uptake is likely to be greatest in hot dry conditions when pasture is scarce. Conversely, McIlroy *et al.* (1993) and Saunders *et al.* (1993) reported bait-uptake by feral pigs in the hill country of south eastern Australia was greatest in late autumn, when pigs are located at lower elevations and when alternate foods are scarce. The change in diet between seasons is likely to be related to changes in growing conditions, and thus the availability of certain vegetation species. Interestingly, in the current study there was little difference between bait station visitation or bait-take between seasons, despite these trials being undertaken in two very contrasting seasons (summer and winter). Differences would be expected based of previous studies, although it is possible that little difference was detected because alternate foods were abundant during both study periods. The area received above average rainfall during the summer of 2012. If alternate foods were scarce during one of these seasons, it is possible that the results may have been different. Therefore, an additional attractants study should be undertaken in the Macquarie Marshes during hot and dry conditions. Nevertheless, the results from the current study, in combination with results from various other Australian rangeland studies (Giles 1980; Hone 1983; Choquenot *et al.* 1990), indicate that season may be used as a guide for determining when baiting or trapping should be undertaken, although the ultimate decision should be based on alternate food availability (particularly new growth grasses and forbs). This may vary within seasons from year to year, as rainfall in the Australian rangelands is sporadic (Giles 1980).

Pooled visitation and bait-take (January 2012 and June 2012 combined)

No significant difference in bait station visitation or bait-take was identified between bait attractants when the data were pooled, despite the larger treatment group size. Unfortunately, it was not possible to increase the number of replicates per attractant due to restricted site access, and for logistical reasons. It is estimated, using a power analysis (Krebs 1999), that 32 replicates would be required to detect an observed difference of 0.46 between the number of active Carasweet® (treatment) and non-treatment bait (barley) stations.

Despite non-significant results, some interesting findings occurred, in that Carasweet®, molasses, vanilla and fermented grain were consumed by feral pigs when they were discovered. Conversely, PIGOUT®, meat meal, fish meal and dry barley (non-treatment) received at least one situation where feral pigs visited and did not eat. Saunders and Bryant (1988) had limited success in the Macquarie Marshes during on-ground baiting and trapping exercises and believed this was likely due to insufficient pre-feeding. Hone (1983) estimated that 23% of feral pigs in a target site near Hillston, western NSW, did not eat poisoned bait and suggested this may have occurred because of bait shyness, insufficient free-feeding or lack of contact with bait. Choquenot *et al.* (1990) also implemented a poison baiting program in western NSW and achieved an average feral pig abundance reduction of 61% with *ad libatum* poisoning and stated reduced efficacy may have been because alternate foods were abundant. In the hill country of south-eastern Australia McIlroy *et al.* (1989), Saunders *et al.* (1990), Choquenot *et al.* (1993), Saunders *et al.* (1993) and Hone (2002) reported between 1.1 and 20% of feral pigs remained after trapping and baiting programs. They suggest this may have occurred because animals may not have found bait, animals may have preferred to consume alternate foods or because of bait/trap shyness.

In the current study, it is possible that feral pigs were present in each area that did not visit attractants (bait stations), or that feral pigs were not present in the immediate area of some the attractants and did not visit, as independent remote monitoring cameras were not used. However, bait stations were positioned near regular activity where possible and each trial was undertaken for 10 days to try and reduce this risk. It was possible to confirm instances where animals visited attractants and did not eat using remote cameras. Based on conclusions from previous research, it is unlikely that this occurred because of bait shyness as bait shyness is normally a learned behaviour derived from past bad experiences (Choquenot and Lukins 1996). Therefore, it is more likely to have occurred because alternative foods were more appealing than the bait used. Hence, it is possible that attractants that received equal visitation and bait-take results in the current study (consumed whenever they were found) were more attractive and palatable to pigs than those with unequal visitation and bait-take results. Investigations when alternate foods are scarce may be beneficial as the results may vary. This is also when landholders are most likely to implement management based on their previous experiences (landholder communications).

Nights until visitation

There was no significant difference in the number of nights until first visitation for each bait attractants. Bait stations were visited by feral pigs at an average of 1.7 ± 0.14 (SE) nights post setting. In addition, the number of feral pigs that were attending bait stations sometimes increased over each 10 day trial period. Saunders *et al.* (1993) and McIlroy *et al.* (1993) experienced similar results, whereby feral pig numbers continued to increase for 10 – 15 days. This result highlights the importance of an extended pre-feeding at the beginning of a trapping and baiting program to ensure a larger proportion of the population is exposed.

Level of bait consumption

The level of bait consumption also seemed to increase over time, although it is not known whether more feral pigs were consuming a similar amount of bait or whether some animals began to consume more bait. It is possible that both occurred. During the study, there was a significant positive relationship ($r= 0.82$, $n=8$, $p= 0.006$) between the mean number of feral pigs per station, per bait attractant and the mean level of bait consumption (rank scores) per station per attractant. Therefore, bait-uptake was higher when more feral pigs were present irrespective of the attractant or bait being used. Interestingly, the mean number of feral pigs per station, per attractant explains 67.2% of variation in bait consumption. The remaining factors may include palatability and bait familiarity (Hone *et al.* 1985; McIlroy *et al.* 1993; Saunders *et al.* 1993). Hone *et al.* (1985), McIlroy *et al.* (1993) and Saunders *et al.* (1993) reported increased bait consumption over time and hypothesised that individuals consumed more bait with increased exposure. This again highlights the importance of an extended pre-feeding period at the beginning of a program, to ensure high level of bait up-take prior to poisoned bait deployment. It may also help reduce the risk sub-lethal poisoning, which could leave bait adverse animals in the residual population. Carasweet® produced an average level bait consumption rank score of 1.2 ± 0.36 (SE) per station, which accounts to a mean low – medium bait consumption level. However, this is likely to be an underestimate as all stations were included in the analysis for each attractant, even those that were not visited. It is possible that such situations may have occurred because there were no feral pigs residing nearby at the time of testing, or feral pigs may have found alternate foods more appealing. All attractants received slightly higher (but not significant) average bait consumption rank scores than the non-treatment, apart from fish meal. As with many of the other factors that were assessed, the possibility of a type II error may exist. In that, no significant difference between attractants was detected even though one may be present. This may have occurred is due to the low number of replicates per attractant.

Number of feral pigs

A total of 121 individual feral pigs were recorded at bait stations when both trials were combined. Attractant locations were randomly assigned, and thus it was rare for the same attractant to be positioned at the same location in both trials. When the data for each trial were combined, the mean number of feral pigs per station created was 2 ± 0.5 (SE). There was no significant difference in the mean number of feral pigs per station between bait attractants. However, the attractant that received the largest average number of individuals per station was Carasweet® at 4.3 ± 2.2 feral pigs. Other attractants that received averages ≥ 1 animal per bait station were molasses (3.33 ± 2.2) fermented barley (2.10 ± 1.2), meat meal (1.44 ± 0.09) and vanilla (1 ± 0.5). This is because these attractants were generally visited by groups of animals where the others, particularly PIGOUT®, were often visited by lone animals. Cowled *et al.* (2006a) also utilised remote cameras in Welford National Park near Longreach in the rangelands of south-western Queensland to confirm feral pig visitations during a PIGOUT® feral pig baiting trial. They recorded 49 feral pigs feeding at four stations (12.5 feral pigs per station), although unlike the present study, they did not include stations that were created and not visited by feral pigs.

Non-target bait-take

The number of non-target species to consume bait was generally high for all attractants. Conversely, very few non-target species consumed bait from the fish meal and PIGOUT® stations. Cowled *et al.* (2006b) also reported PIGOUT® was more target specific than other commonly used substrates such as grain or meat. Other attractants in the current trial that received bait-take by fewer non-target species than the non-treatment were molasses and Carasweet®. Various bird species, particularly galahs, crested pigeons and apostle birds consumed bait most frequently, although most of this bait was consumed off the ground in front of the HogHopper™s. Hone *et al.* (1985) reported numerous bird species visited grain feed trays near Warren NSW (approximately 130km south of the current study site), but galahs and crested pigeons were the only birds observed to consume grain. These particular species consumed similar amounts of grain irrespective of whether it was dyed or un-dyed, although intake was variable between years, seasons grains and times within seasons.

McIlroy *et al.* (1993) reported numerous non-target species consumed free-feed wheat and pellets when the bait was uncovered, which included: birds, foxes, feral dogs (*Canis familiaris*), rabbits (*Oryctolagus cuniculus*), common wombats (*Vombatus urinsus*), macropods (*Macropus giganteus and M. rufogriseus*) and cattle. When baits were covered with forest floor litter, there was no significant difference in bait discovery by target or non-target species. Meat baits were not used in the current trial, although Hone and Pederson (1980) and Fleming *et al.* (2000) reported that surface laid meat baits are often consumed by non-target species such as foxes and birds (raptors and corvids). Consequently, few baits may be left for feral pigs. Losing bait to non-target species can add to management program costs, impact program efficacy as less bait material will be left for feral pigs, and during toxic baiting may increase non-target impacts. Fortunately, the HogHopper® restricts non-target species access during baiting. Therefore, bait can be delivered primarily to feral pigs, particularly when the doors are closed, even if the bait is equally attractive to non-target species. However, if a HogHopper® cannot be used this trial demonstrates that PIGOUT® may be a safer alternative than barley-based baits in the Macquarie Marshes. Dyeing grain green may also help reduce attractiveness to some bird species without impacting bait-take by feral pigs (Bryant *et al.* 1984). Although as previously mentioned, Hone *et al.* (1985) reported galahs and crested pigeons (species that also consumed grain in the present study) consumed similar amounts of dyed or undyed grain, therefore its effectiveness may be limited.

General pricing

All feral pig bait attractants used in the trial were relatively inexpensive, costing an additional $1.00 - $3.00 per 10 kilograms of dry barley (i.e. 10kg barley $8.00, 10kg barley mixed with 100g Carasweet® $10.60). There were no significant differences between baits containing attractants and the non-treatment (dry barley), however fermented barley, PIGOUT® and barley containing the various attracts commonly outperformed the non-treatment bait (dry barley) when looking at descriptive statistics alone. Therefore, the low price of the attractants may warrant their use, particularly if the bait substrate can be sourced at a low cost. If price is an issue it would be preferable to soak or ferment barley as there is no additional cost. If a HogHopper™ cannot be used it may be more cost effective (less wastage) and less harmful to non-target species to use PIGOUT®.

Conclusion

The trial showed little difference between the attractants tested and the non-treatment bait (dry barley) in regards to visitation, bait-take, nights until visitation and level of bait consumption in the Macquarie Marshes NSW. Unfortunately, alternate foods were abundant at the time of both trials, which may have influenced the results. Notwithstanding, the results support the null hypothesis in that bait attractants had little influence on bait station visitation or active station rate by feral pigs compared to the non-treatment bait (dry barley) in the Macquarie Marshes.

Chapter 6 - The effects of different management options on feral pig abundance and damage in the Macquarie Marshes, NSW.

6.1 Introduction

Feral pigs are one of Australia's most significant vertebrate pest species as they not only cause adverse agricultural and environmental impacts, but they can potentially spread exotic and endemic diseases that could threaten wildlife, livestock and human health in the event of an outbreak (Izac and O'Brien 1991; Choquenot *et al.* 1996; Anon 2005; Hone 2012). Consequently, feral pigs are often managed where they occur and in Australia this is often achieved via poisoning, hunting, trapping or aerial shooting (Choquenot *et al.* 1996; Anon 2005; Hone 2012).

Historically, the aim of many pest management programs has been to remove as many of the target species as possible, and very little time was spent monitoring and evaluating the effects of management on the perceived damage or the target species (Parkes 1990; Braysher 1993; Bomford and O'Brien 1995; Choquenot *et al.* 1996; Olsen 1998; Reddiex *et al.* 2006; Reddiex and Forsyth 2006; Hone 2007, 2012). However, in many situations density and damage relationships are not well understood, and it may be possible in some situations to significantly reduce pest abundance without significantly reducing damage. This may occur when only a small proportion of the population is causing a majority of the damage (Parkes 1990; Braysher 1993; Bomford and O'Brien 1995; Olsen 1998; Parkes *et al.* 2006; Hone 2007). As a consequence, the focus of many modern pest management programs has shifted towards targeted damage management (Parkes 1990; Braysher 1993; Hone 1994, 2007, 2012; Bomford and O'Brien 1995; Choquenot *et al.* 1996; Olsen 1998; Braysher and Saunders 2003; Reddiex *et al.* 2006; Reddiex and Forsyth 2006). Izac and O'Brien (1991) specifically discuss the history and implications of feral pig management in Australia, and discuss the feasibility of eradiation. They report, that with current technology feral pig eradication is technically impossible, therefore a cost benefit approach in regards to damage management may be the most suitable strategy.

Defining the damage, may not be as simple as it may seem, particularly with regard to feral pigs in natural ecosystems, because their damage in these areas is not well understood (Izac and O'Brien 1991; Choquenot *et al.* 1996; Anon 2005). Ground rooting is probably the most well studied and visually obvious (measurable) form of feral pig damage in natural ecosystems (Hone 1988, 1995, 2002, 2012; Choquenot *et al.* 1996; Mitchell and Mayer 1997; Anon 2005; Mitchell *et al.* 2007a, 2007b). Ground rooting by feral pigs is a form of ground disturbance that can favour some plant species (often weeds), change vegetation species composition, alter soil properties and reduce macro-invertebrate density (Alexiou 1983; Singer *et al.* 1984; Hone 1988, 1995, 2012; Bowman and McDonough 1991; Choquenot *et al.* 1996; Mitchell and Mayer 1997; Engeman *et al.* 2004; Anon 2005; Mitchell *et al.* 2007a, 2007b; Campbell and Long 2009; Taylor *et al.* 2011). In addition, ground rooting can reduce the amount of pasture that is available for native and domestic grazers (Hone 1980, 2006). Ground rooting has also been reported to be positively correlated with feral pig abundance (Hone 2002, 2012).

Large areas of the Macquarie Marshes have been listed as a Ramsar wetland; a wetland of international significance (Kingsford and Auld 2005). Feral pigs have been present in the Macquarie Marshes for over 100 years (Hogendyk 2007). Saunders and Bryant (1988) estimated the population was more likely to be 10 pigs per km^2. As a consequence of their high densities, feral pigs have been subjected to various forms of management in the area for many years, although little is known about the effects of this management on the feral pig damage. Aerial shooting is a favoured technique in the Macquarie Marshes, because it can be used to cover large inaccessible areas and it is relatively time and cost efficient. It is also less affected by seasonal conditions, unlike more conventional techniques such trapping and baiting (Hone 1983, 1990b; Saunders and Bryant 1988; Saunders 1993; McIlroy 1995; Dexter 1996; Choquenot *et al.* 1999). In contrast, aerial shooting can be compromised by dense vegetation, which occurs throughout much of the region (Hone 1983; Saunders and Bryant 1988; Choquenot *et al.* 1996; Dexter 1996; Campbell and Long 2009). Saunders (1993) reported that aerial shooting in the Macquarie Marshes could reduce feral pig populations by 80% in the short term, although the population was able to recover by 77% after one year. In addition, Giles (1980) indicates feral pig populations in the Macquarie Marshes can attain a maximum finite rate of increase (λ) of 1.82 – 2, which infers that the feral pig population must be reduced between 45% and 50% in a short period of time in order for it to remain below pre control levels one year after control. Both authors recommend conventional techniques such as poison baiting or trapping should be undertaken to help reduce residual feral pig populations between aerial shoots. Saunders (1993) also suggested that bi-annual aerial shooting may be beneficial. Despite interesting results in regards to population reductions, little information is provided on effects of management on damage, or feral pig density and damage relationships.

Therefore, this study was undertaken to determine the relationship between feral pig abundance and damage (ground rooting), and to assess the effectiveness of various feral pig management options for managing feral pigs in the Macquarie Marshes. The null hypothesis is that there is little difference between management options for reducing feral pig abundance and damage in the Macquarie Marshes. The alternate hypothesis is that there is a significant difference in the effectiveness between various management options for reducing feral pig abundance and damage in the Macquarie Marshes.

6.2 Methods

6.2.1 Study site

The study was undertaken at sites 1, 2, 3 and 4 (refer to chapter 2 for additional site details and map) (Fig. 2.2). The average annual rainfall for the area is 483.9mm and the Macquarie Marshes also receives water via inflows from the Macquarie River. During the study, the site received above average rainfall 493mm (2011) and 580mm (2012) and several large in-flows from the Macquarie River. The summer average maximum and minimum temperatures are 33.9ºC and 28.1ºC respectively and in winter are 17.6ºC and 13.3ºC (Bureau of Meteorology 2012).

6.2.2 Procedure

See chapter 2 for site selection criteria. Each site was allocated a treatment/non-treatment (feral pig management approach) based on historical feral pig management of that property and landholder permission, hence the experimental treatments were not randomly allocated. The management undertaken was:

Site 1 (treatment 1 site) - aerial shooting and toxic baiting;

Site 2 (treatment 2 site) - aerial shooting only;

Site 3 (treatment 3 site) - toxic baiting only;

Site 4 (non-treatment site) - no management.

Study sites 3 and 4 (non-treatment) were largely comprised of ephemeral wetlands (only inundated during the large floods). Unlike sites 1 and 2 which encompassed areas of semi-permanent wetland (often hold water for extended periods). Therefore, they were not matched sites which may complicate results. Unfortunately, it was not possible to select four properties that contained semi-permanent wetlands because all properties immediately adjoining the Macquarie Marshes Ramsar wetlands (typically properties that contained semi-permanent wetlands) were subjected to routine bi-annual aerial shooting, which would have confounded treatment/non-treatment objectives.

Site set up

The HogHopper™ locations and independent monitoring stations that were used in chapter 4 (activity patterns) were also used this section of the study (refer to chapter 4 – Procedure for details on bait station and independent monitoring site selection). However, a 500 metre permanent line intercept transect (Greenwood and Robinson 2006) was also created ~50 metres from each HogHopper™ and its direction was randomly selected. Line intercept transects (Greenwood and Robinson 2006) were used to monitor feral pig damage (ground rooting) and an independent monitoring stations were used to obtain an index of feral pig abundance (feral pig passes per camera). The spatial non-randomness of the independent monitoring stations in the landscape should not be considered a fault, as it was the feral pigs within the area that were the subject of sampling by the monitoring stations not the area itself (Bengsen *et al.* 2011).

Damage monitoring

The 500 metre long line intercept transects were walked twice (April and August) annually. During this time, GPS coordinates were taken whenever a transect intercepted an area of ground rooting. The area (m^2) of ground rooting was also estimated. The information was used to determine the average level of ground rooting per kilometre, per property throughout the project, which provided a measure of feral pig damage. This information was used to determine the effects of each treatment/non-treatment on feral pig damage.

Index of feral pig abundance

Motion sensing cameras (Reconyx HC500 HyperFire semi-covert IR) were positioned at permanent independent monitoring stations for 10 days in April and August each year (2011 and 2012). They were set to three pictures per trigger, with no time delay. All images were analysed for the number of feral pig passes per, camera per night, per site (Bengsen *et al.* 2011). A confirmed pass was any instance where an animal passed within 10 metres of the remote camera. To prevent inflated pass estimates, individuals that made multiple passes within a 30 minute period were considered as one pass (Long *et al.* 2010). These data were used to determine total number of feral pig passes, per night, per site throughout the trial, which was assumed to be an index of feral pig abundance (IOA), as opposed to an absolute abundance estimate. Hence, it is assumed that a greater level of passes per camera, per night, per site would also equate to a higher feral pig population abundance level. The data were used to determine the long term effects of each treatment/non-treatment on feral pig IOA.

Poison baiting

Feral pig poison baiting was undertaken in May/June 2011, August 2011, January 2012 and June 2012 (Table 6.1). An additional round of poison baiting was undertaken once the project was completed, during November 2012 as a mop up operation for the landholders. Refer to chapter 4 – Procedure for baiting procedure. Motion sensing cameras were used throughout the entire baiting process to identify individual feral pigs (coat patches, colour, size, mob affinity); bait-take was also recorded (Cowled *et al.* 2006a; Williams *et al.* 2011). The data were used to determine the immediate effects of baiting on the feeding feral pig population.

Aerial shooting

Routine bi-annual aerial shooting was undertaken in treatment 1 site and treatment 2 site, during May 2011, September 2011 and March 2012 (Table 6.1). Refer to chapter 4 – Procedure for aerial shooting procedure. Motion sensing cameras were positioned at independent monitoring locations for approximately 11 days during each aerial shooting event (five days each side of the aerial shoot) to gather an IOA before and after aerial shooting. This information was used to determine the immediate effects of aerial shooting on feral pig IOA.

Table 6.1 – Dates when aerial shooting, poison baiting and monitoring events were undertaken during the project.

Date	*Aerial Shooting*	*Poison Baiting*	*Monitoring*
Apr-11			X
May-11	X		
Jun-11		X	
Aug-11		X	X
Sep-12	X		
Jan-12		X	
Mar-12	X		
Apr-12			X
Jun-12		X	
Aug-12			X
Total	**3**	**4**	**4**

Cost effectiveness

Throughout the project, records were kept on the number of feral pigs removed per management technique within each treatment/non-treatment area. During poison baiting, feral pigs were assumed to have been killed if sufficient toxic bait material had been consumed and the animals never returned to that bait station thereafter (confirmed via remote imagery). Carcass searches were also undertaken, although carcasses were rarely found due to the dense vegetation present at each site. The basic cost of each item is presented in Table 6.2. The resources used such as bait, ammunition, helicopter hire and fuel. Hours spent undertaking each management activity were also recorded. The data were used to determine the cost per kill for each management technique within each area throughout the project.

Table 6.2 – Basic cost for each budget item during the project. These data were used to calculate cost per kill.

Budget item	*Rate*
Labour	$35 per hour
Helicopter hire	$1050 per hour (inc. fuel)
Free-feed barley	$0.66 per kg
Ammunition	$1.00 per round
Carasweet® barley	$0.93 per kg
1080 barley	$2.66 per kg
Non-toxic PIGOUT®	$2.53 per bait
Toxic PIGOUT®	$3.03 per bait
Diesel fuel	$1.55 per litre
Diesel fuel usage	0.17L per km

6.2.5 Statistical analysis

IOA and damage relationships

Correlation analysis (Hone 1988; Pallant 2005) was used to determine the strength and direction of the relationship between feral pig IOA (mean number of pig passes, per night, per site) and damage (mean area m^2 of ground rooting per kilometre per site). The data used in the analysis were directly comparable as they were collected during each concurrent IOA and damage monitoring phase (i.e. IOA and damage data collected at treatment 1 during April 2011 were plotted against each other).

Effects of management options on feral pig IOA

A one-way between groups analysis of variance (ANOVA) (Pallant 2005) was undertaken to determine whether feral pig IOA was significantly different between treatment areas before the project commenced (April 2011). The data used were the mean number of pig passes per camera, per night, per site for 10 consecutive nights within each treatment/non-treatment area before management. Similar analysis were undertaken to determine whether feral pig IOA was significantly different between treatment groups when the project finished (August 2012). A series of one-way between groups ANOVA (Pallant 2005) were also undertaken to determine whether feral pig IOA within each treatment/non-treatment area altered significantly throughout the project. The data used in these analyses were the mean number of feral pig passes, per camera, per night, per site over 10 consecutive nights during April 2011, August 2011, April 2012 and August 2012 within each site.

Effect of management options on feral pig damage

A one-way between groups analysis of variance (ANOVA) (Pallant 2005) was undertaken to determine whether feral pig damage was significantly different between treatment areas before the project commenced (April 2011). The data used were the area (m^2) of ground rooting per 500m line intercept transect within each treatment/non-treatment area before management. Similar analysis were undertaken to determine whether feral pig damage was significantly different between treatment areas when the project finished (August 2012). A series of one-way between groups ANOVA (Pallant 2005) were also undertaken to identify whether feral pig damage (ground rooting) within each treatment/non-treatment area altered significantly throughout the project. The data used these analyses were the area of ground rooting per 500m line intercept transect, during April 2011, August 2011, April 2012 and August 2012 within each site. All damage monitoring one-way ANOVA were repeated using log10 transformation data. As some data were zero, a one was added to all data prior to all undertaking log10 transformations. Log10 transformations were used in order to normalise the data, as an uneven number of transects created per site and some transects were flooded affected.

6.3 Results

A total of 34 feral pig hotspots were used during the project, which included 12 in treatment 1, six in treatment 2, eight in treatment 3 and eight in the non-treatment site. This equated to an average of one HogHopper™, line intercept transect and independent monitoring location per 343 ± 13 (SE) hectares. Hotspots were rarely evenly distributed throughout the landscape, and were more commonly situated near areas of dense habitat or permanent water.

IOA and damage relationships

An initial scatterplot comparing feral pig IOA to feral pig damage revealed three considerable outliers. This included one point with high IOA and uniquely low damage, which is likely to have occurred because many transects were completely flooded at the time, and two points with low IOA and high damage, which may have occurred because line intercept transects may have passed through large areas of ground rooting that was caused by only a few animals. The flood affected outlier was removed from further analysis, although the two points of low IOA and high damage were included. The results showed a significant positive correlation between feral pig IOA and damage (r=0.46, n=15, p=0.04), and thus the higher the mean number of feral pig passes per camera, per night, per site the higher the level of ground rooting (m^2) per kilometre, per site (Fig. 6.2) The coefficient of determination (R^2) was 21.2%. Therefore, feral pig IOA in the Macquarie Marshes explains 21.2% of variation in ground rooting caused by feral pigs. The mean IOA was 0.44 ± 0.09 (SE) feral pig passes per camera, per night and mean damage was 9.20 ± 4.81 (SE) m^2 of ground rooting per kilometre. Data from the x and y axis were accumulated over different amounts of time, with damage being accumulated over months and IOA being recorded over a 10 day period (Fig. 6.2).

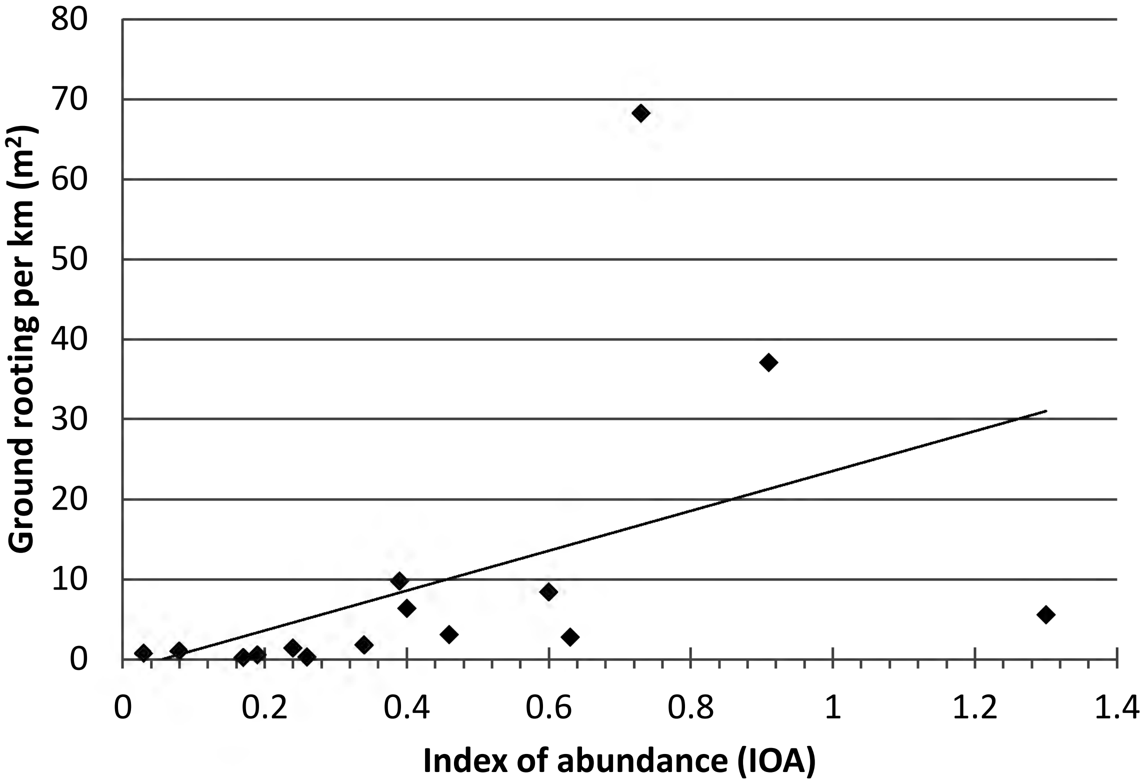

Figure 6.2 – Scatterplot displaying mean ground rooting (m^2) per km compared to feral pig IOA (mean number of feral pig passes, per camera, per night per site). The regression line ($R^2 = 0.21$) is shown. Comparable data were from each property are plotted against each other (1 flooded outlier removed).

Effects of management options on feral pig IOA

IOA between sites before and after management

A one way between groups ANOVA showed a significant difference ($F_{3,36}$= 33.10, p<0.0001) in feral pig IOA between treatment/non-treatment sites prior to the commencement of the project. Post-hoc comparisons using the Tukey HSD indicated that the mean IOA at treatment 2 site (7.5 ± 1.21 SE) was significantly higher than treatment 1 site (0.17 ± 0.07 SE), treatment 3 site (0.26 ± 0.18 SE) and the non-treatment site (0.92 ± 0.20 SE) (Fig. 6.3). Treatment 1 site, treatment 3 site and the non-treatment site were not significantly different. The same analysis was undertaken upon the completion of the project, which demonstrated there was no significant difference ($F_{3,36}$= 2.50, p= 0.07) in feral pig IOA between the four treatment/non-treatment sites (Fig. 6.3).

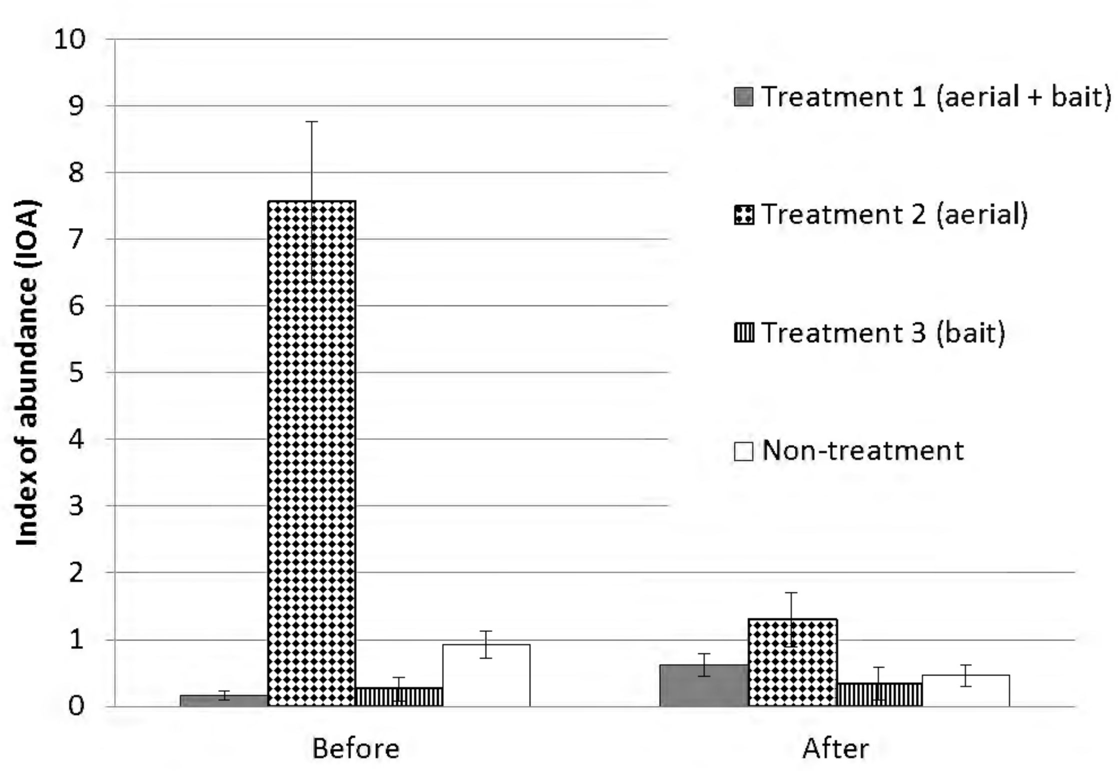

Figure 6.3 – Mean (± SE) number of feral pig passes per camera, per night, per treatment/non-treatment site before (April 2011) and after (August 2012) the project.

Comparisons of feral pig IOA within sites over time

A series of one way between groups ANOVA were undertaken to determine whether feral pig IOA within each treatment/non-treatment site altered significantly over time (April 2011, August 2011, April 2012 and August 2012). Results showed there was a significant difference ($F_{3,36}$= 6.31, p= 0.001) in feral pig IOA at the treatment 1 site (the aerial shooting and toxic baiting site), with mean IOA being significantly higher during August 2012 (0.63 ± 0.17 SE) compared to April 2011 (0.17 ± 07 SE), August 2011 (0.03 ± 0.02 SE) and April 2012 (0.24 ± 0.08 SE). Mean IOA during April 2011, August 2011 and April 2012 were not significantly different (Fig. 6.4). The results also showed a significant difference ($F_{3,36}$= 26.77, p<0.0001) in feral pig IOA at the treatment 2 site (aerial shooting only) where mean IOA was significantly higher in April 2011 (7.5 ± 1.2 SE) than it was in August 2011 (0.73 ± 0.23 SE), April 2012 (0.40 ± 0.23 SE) and August 2012 (1.3 ± 0.41 SE). No significant differences in feral pig IOA were identified at treatment 3 site ($F_{3,36}$= 0.463, p=0.71) and the non-treatment site ($F_{3,36}$= 2.19, p= 0.11) throughout the project. Feral pig IOA increased at treatment 1 site by 287.5%, decreased at treatment 2 site by 82.8.

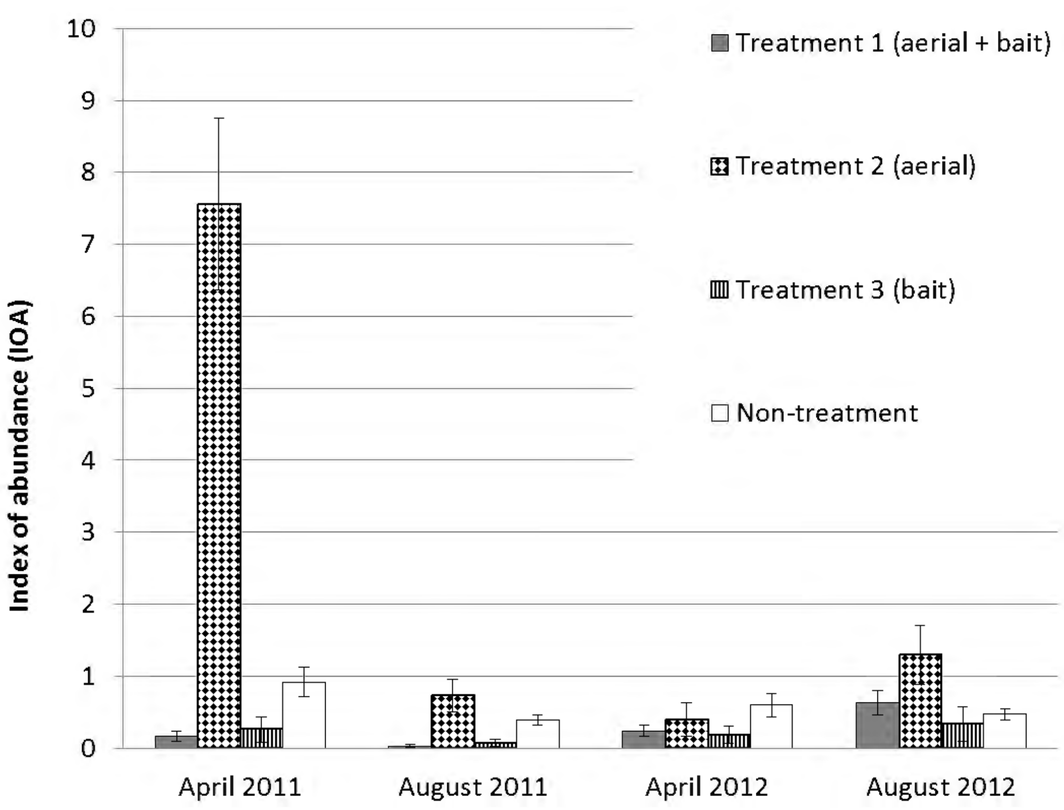

Figure 6.4 – Mean (± SE) number of feral pig passes per camera, per night during each collection period throughout the project. April 2011 is the first round of monitoring which was undertaken before management and August 2012 is the final round of monitoring undertaken after management.

Effect of management options on feral pig damage

Comparison of damage between sites before and after management

A one way between groups ANOVA showed there was no significant difference ($F_{3,30}$= 1.59, p= 0.21) in the mean level of ground rooting (m^2) per 500m line intercept transect between treatment/non-treatment sites prior to the commencement of the project (Fig. 6.5). The same analysis was undertaken upon the completion of the project, which also demonstrated there was no significant difference ($F_{3,30}$= 0.46 , p= 0.71) in the mean level of ground rooting between the four treatment/non-treatment sites (Fig. 6.5). Two additional one-way ANOVA were performed using log10 transformation data, which also demonstrated there was no significant difference in the mean level of ground rooting between sites before ($F_{3,30}$= 2.80, p= 0.057) or after ($F_{3,30}$= 0.76, p= 0.53) the project.

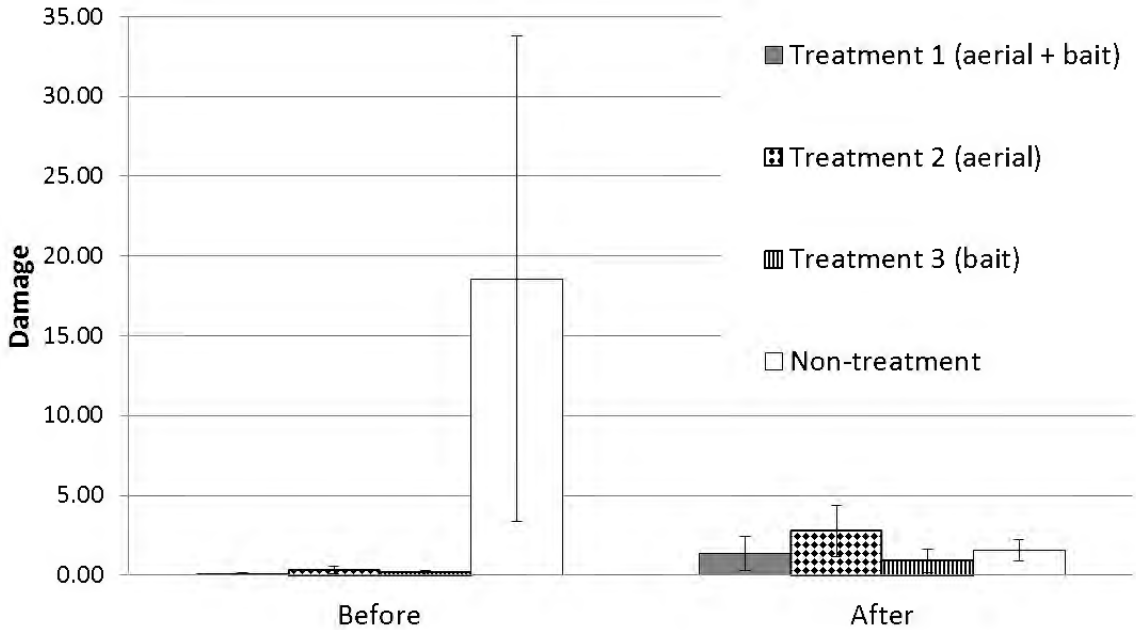

Figure 6.5 - Mean (± SE) area feral pig damage (ground rooting m^2) per transect per treatment/non-treatment area before (April 2011) and after (August 2012) the project.

<u>Comparison of feral pig damage within sites over time</u>

A series of one way between groups ANOVA were undertaken to determine whether the average area (m^2) of feral pig damage (ground rooting) per transect altered significantly within treatment/non-treatment sites throughout the project (April 2011, August 2011, April 2012 and August 2012). Varying degrees of freedom in the subsequent analysis occurred because the number of transects per site varied due to different number of feral pig hotspots per property and property size. The results showed there was no significant difference in the average area of ground rooting (m^2) per transect within each treatment/non-treatment site over the duration of the project; treatment 1 site ($F_{3,44}$= 0.82, *p*= 0.49), treatment 2 site ($F_{3,20}$=1.96, *p*= 0.15), treatment 3 site ($F_{3,28}$=0.48, *p*= 0.70) and the non-treatment site ($F_{3,28}$=1.00, *p*=0.42) (Fig. 6.6). A series of one-way ANOVA using log10 transformation data also showed no significant difference; treatment 1 site ($F_{3,44}$= 0.95, *p*= 0.42), treatment 2 site ($F_{3,20}$=0.21, *p*= 0.45), treatment 3 site ($F_{3,28}$=0.33, *p*= 0.80) and the non-treatment site ($F_{3,28}$=0.31, *p*=0.82). Figure 6.6 indicates ground rooting at treatment 2 site and the non-treatment site was variable with ground rooting being high at treatment 2 site during August 2011 compared to other months and other treatment sites within the same month. Ground rooting at the non-treatment site was relatively high in April 2011 compared to other months and other treatment sites within the same month. The mean level of ground rooting per 500m line intercept transect for the duration of the project was 0.82 ± 0.62 m^2 (SE) for treatment 1 site, 10.09 ± 6.07 m^2 (SE) for treatment 2 site, 0.44 ± 0.22 m^2 (SE) treatment 3 site and 7.31 ± 3.88 m^2 (SE) for the non-treatment site.

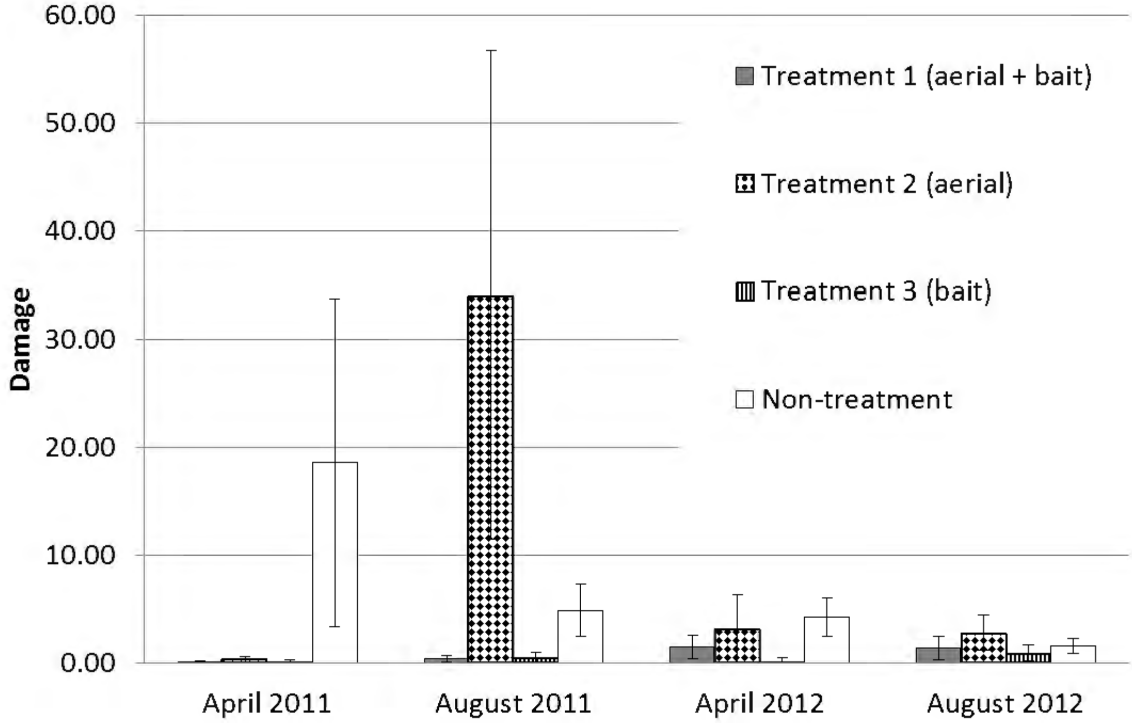

Figure 6.6 – Mean (± SE) area of feral pig damage (ground rooting m^2) per transect (500m) per treatment/non-treatment area during each collection period throughout the project.

Cost effectiveness

During the project, four poison baiting programs were undertaken (Table 6.3). Each program generally occurred for 12 days, which included ~7-8 days of free-feeding and ~4-5 days toxic baiting. Toxic bait was only deployed at treatment 1 site and treatment 3 site HogHopper™s during the project. The results for each baiting program and their associated costs are listed in Table 6.3. They show that the average cost per kill varied considerably; from as high as $922.94 per pig to as low as $39.72 (Table 6.3). The average feral pig removal rate at the poison sites was 45 ±14 % (SE). The lowest cost per kill ($39.72) and the greatest feral pig removal rate (75 ± 15% SE) were achieved during the summer (January) poison baiting campaign.

Table 6.3 – Expenses incurred during each poison baiting program. Number of pigs present refers to the total number of individual feral pigs at bait stations. Number of pigs removed is the assumed number of individuals removed based on camera observations and poison bait-uptake.

Date and treatment	*Expenses#*	*No. pigs present*	*No. removed*	*Cost per kill*
June 2011				
Aerial + bait site	$1,408.46	13	4	$352.12
Bait only site	$728.79	0	^	^
August 2011				
Aerial + bait site	$988.30	5	2	$494.15
Bait only site	$593.14	2	^	^
Jan 2012				
Aerial + bait site	$879.80	5	3	$293.27
Bait only site	$476.65	13	12	$39.72
June 2012				
Aerial + bait site	$922.94	30	1	$922.94
Bait only site	$473.25	1	^	^

#Based on figures from Table 6.1
^no toxic bait deployed due to lack of regular activity.

Routine aerial shooting was undertaken in the Macquarie Marshes Ramsar Wetlands, and on all immediately adjoining properties (willing to participate), during May 2011, September 2011 and March 2012. This area encompassed treatment 1 site and treatment 2 site. Treatment 3 site and the non-treatment site were situated outside the aerial shooting zone. All properties within the aerial shooting zone were generally shot within a 10 day period and treatment 1 site and treatment 2 site were generally shot within 5 days of each other. The results for each aerial shoot are displayed in Table 6.4. The results show that the average cost per kill during aerial shooting varied considerably from as low as $13.91 to as high as $137.33 (Table 6.4). During the May 2011 aerial shoot, feral pig IOA increased at the aerial shooting and poison baiting site, and at the aerial shooting only site immediately after aerial shooting. IOA was also recorded at the poison baiting only site (treatment 3 site) and at the no management site (non-treatment site) during each aerial shooting program. Feral pig IOA at these sites increased by mean of 185 ± 147.5% immediately after aerial shooting. Conversely, during the May 2011 shoot mean IOA at the non-treatment site decreased by 6.5%. The results showed that cost per kill remained below $25 when mean feral pig IOA was ≥ 1, although there was one anomaly which occurred at treatment 1 during May 2011, where the mean IOA was 0.07 ± 0.03 and the cost per kill was $20.82.

Table 6.4 - The expenses incurred during each aerial shooting program as well as index of abundance (IOA) (average passes, per camera, per sight ± SE) before and after aerial shooting. The data have been used to determine cost per kill, per site, per aerial shooting program.

Date and treatment	*Expenses#*	*IOA Before*	*IOA After*	*No. removed*	*Cost per kill*
May 2011					
Aerial + bait site	$5,204.00	0.07 ± 0.03	0.09 ± 0.09	250	$20.82
Aerial only site	$1,536.00	2.30 ± 0.68	3.00 ± 0.79	68	$22.59
Sept 2011					
Aerial + bait site	$3,296.00	0.02 ± 0.02	0.13 ± 0.11	24	$137.33
Aerial only site	$1,308.00	1.00 ± 0.57	0.90 ± 0.37	94	$13.91
March 2012					
Aerial + bait site	$1,936.00	^	^	16	$121.00
Aerial only site	$1,308.00	^	^	57	$22.95

Based on data from Table 6.1
^no index of abundance as cameras were not in position due to flooding.

The mean cost per kill rate for aerial shooting varied between the aerial shooting and poison baiting site ($93.05 ± $36.42) and the aerial shooting only site ($19.81 ± $2.96). The mean cost per kill was lower at the aerial shooting only site (Table 6.5). The mean cost per kill for poison baiting varied between the aerial shooting and poison baiting site ($515.62 ± $142.17) and the poison baiting only site ($39.72). Poison baiting was more cost effective at the poison baiting only site (Table 6.4). However, mean cost per kill at the poison baiting only site did not include rounds of baiting where poison bait was not deployed, as no kills were recorded during these times.

Table 6.5 – Mean cost per kill for aerial shooting and poison baiting at each treatment site during the trial. Means were derived from data in cost per kill (CPK) rates in Table 6.3 and Table 6.4. Data were only included in the mean cost per kill for poison baiting when poison bait was deployed.

Treatment	Mean (±SE) CPK aerial	Mean (±SE) CPK bait	**Total**
Aerial + bait site	$93.05 (± 36.42)	$515.62 (± 142.17)	**$608.67**
Aerial only site	$19.81 (± 2.96)	N/A	**$19.81**
Bait only site	N/A	$39.72	**$39.72**
No-management	N/A	N/A	**N/A**

6.4 Discussion

The project demonstrated that feral pig IOA and damage in the in the Macquarie Marshes have a significant positive relationship. That is, the higher the mean number of feral pig passes per camera, per site, per night, the higher the mean level of ground rooting per kilometre, per site. It was also discovered that the effectiveness of feral pig management for reducing feral pig IOA was variable, and none of the management options significantly altered the mean level of damage per property.

IOA and damage relationships

It was important to determine the relationship between feral pig IOA and damage, as this had not been done in the Macquarie Marshes before, and abundance/damage relationships can be useful for developing measurable management objectives. The damage chosen for monitoring in this study was ground rooting, because ground rooting is well studied, it is relatively simple to identify and measure, it has been used as a damage measure in other areas and it has been linked with abundance/density (Hone 1988, 2002, 2006, 2012). The results showed that feral pig IOA and damage in the Macquarie Marshes had a significant positive correlation ($r=0.46$, $n=15$, $p=0.04$), hence higher feral pig IOA (mean feral pig passes per camera per night per site) equates to high levels of damage (mean level of per km). In Namadgi National Park (ACT), Hone (1988, 2002, 2006) also provided evidence to demonstrate that feral pig abundance and the extent of ground rooting were positively related. Similarly, in the Hawaii Volcanoes National Park Katahira *et al.* (1993) reported feral pig activity and feral pig density had a statistically significant positive linear relationship.

In the Macquarie Marshes, feral pig IOA explained 21.2% of variation in ground rooting. Additional factors that have been reported to influence ground rooting by feral pigs in other areas include seasonal conditions (temporal) and particular site preference (spatial) (Alexiou 1983; Hone 1988, 2002, 2012; Bowman and McDonough 1991; Mitchell and Mayer 1997; Mitchell *et al.* 2007a). Alexiou (1983) reported areas most susceptible to ground rooting by feral pigs in Namadgi National Park were drainage lines, depressions and around the grassy flats. Hone (1988) also reported in Namadgi that ground rooting significantly related to altitude, frequency of rocks, drainage lines and vegetation. Hence, sites at high elevations with few trees and some rocks were more likely to contain ground rooting. Hone (2012) mentions that the frequency of ground rooting in Namadgi National Park was not significantly related to the Southern Oscillation Index (SOI) or rainfall, although the ratio of feral pig ground rooting per unit of abundance was positively correlated with the SOI.

In northern Australia, Mitchell and Mayer (1997) reported that ground rooting was more prevalent in lowland areas and coastal swamps in the wet tropics of north Queensland during the dry season, and that ground rooting was positively associated with roads, tracks and drainage lines. Mitchell *et al.* (2007) also mentioned in north Queensland that feral pig ground rooting occurred in moist micro-habitats (swamps and creeks), where soil moisture remains into the dry season. Similarly in the Northern Territory, Bowman and McDonough (1991) reported ground rooting occurred more often in seasonally flooded swamp communities in the dry season. In contrast, dryland communities were exploited more so during the wet season.

Effects of management options on feral pig IOA

<u>Feral pig IOA between sites before and after management</u>

Feral pig IOA was assessed between the treatment/non-treatment areas prior to the implementation of management because historical feral pig management and habitat quality varied between sites. Hence, it was likely that populations were already different before the project commenced. The results confirmed this, with feral pig IOA being significantly higher at treatment 2 site (7.5 ± 1.21 SE), compared to treatment 1 site (0.17 ± 0.07 SE), treatment 3 site (0.26 ± 0.18 SE) and the non-treatment site (0.92 ± 0.20 SE). This was surprising as treatment 2 site has been subjected to various level of aerial shooting over the years, whereas treatment 3 site and the non-treatment site received very little feral pig management, yet they had lower feral pig IOA. An obvious difference between treatment 1 and 2 sites, and treatment 3 site and the non-treatment site was habitat quality. In that, treatment 1 site and treatment 2 site contained semi-permanent wetland areas, whereas the other two sites did not. Therefore, it is likely that semi-permanent wetlands provided better conditions for feral pig population growth than the surrounding drier ephemeral wetlands. It is also possible that feral pigs from the drier ephemeral wetland areas move towards the wetter semi-permanent wetland areas when the region dries out. Giles (1980) reported feral pig densities in the Macquarie Marshes were highest in semi-permanent wetland areas, particularly the large reed beds. In addition, Choquenot *et al*. (1996) provides a summary of feral pig abundance estimates from various studies around Australia, which also show that wetland habitats in NSW generally contain higher densities of feral pigs than the drier rangeland habitats in NSW. Future studies may therefore wish to investigate seasonal movements of feral pigs in, and around, the Macquarie Marshes using GPS collars to determine whether the feral pigs that reside in the semi-permanent wetlands are sedentary, and to determine whether feral pigs that reside in drier ephemeral wetlands move towards the semi-permanent wetlands during dry seasons. Nevertheless, when the project finished, feral pig IOA between all treatment/non-treatment sites was not significantly different. Therefore, bi-annual aerial shooting was able to reduce the previously significantly different feral pig IOA levels at treatment 2 site (semi-permanent wetland) to a level similar to other sites. In addition, a combination of aerial shooting and poison baiting at treatment 1 site (semi-permanent wetland) was able to keep feral pig IOA to a level similar to the drier ephemeral wetland sites.

<u>Comparisons of feral pig IOA within sites over time</u>

This analysis were undertaken to determine whether feral pig IOA within treatment/non-treatment sites altered significantly throughout the project. The results showed that feral pig IOA at treatment 1 and 2 sites did alter significantly. Feral pig IOA at treatment 1 site (baiting and aerial shooting) was higher during the final monitoring phase. Conversely, feral pig IOA at treatment 2 site (aerial shooting only) was lower during the final monitoring phase. Despite this, feral pig IOA at treatment 1 site remained 51.5% lower than feral pig IOA at treatment 2 site upon completion of the project. Numerous authors have previously reported that shooting from helicopters is effective for rapidly reducing feral pig numbers (Hone 1990b; Saunders 1993; Dexter 1996; Choquenot *et al.* 1999). In addition, numerous studies have reported that poison baiting, using either warfarin or sodium monoflouroacetate can also be effective for achieving relatively large reductions in a relatively short period of time (Hone 1980, 1983, 2002; McIlroy *et al.* 1989; Choquenot *et al.* 1990; Saunders *et al.* 1990; Cowled *et al.* 2006a). However, often it is the rapid rate of recovery of feral pig populations that can quickly undo management efforts (Giles 1980, Hone and Pederson 1980; Izac and O'Brien 1991; Saunders 1993; Twigg *et al.* 2006). Izac and O'Brien (1991) discuss the importance of implementing sustained management feral pig management in a coordinated fashion to limit reinvasion. Reinvasion of feral pigs from neighbouring areas may have occurred during the present study, hence why there may have been little long term effect on IOA between management options.

The Macquarie Marshes received above average rainfall and several inflows from the Macquarie River during the study. In similar conditions, Saunders (1993) reported feral pig populations were able to recover by approximately 77% one year post aerial shooting. Results by Giles (1980) also infer populations must be reduced by at least 45% in a short period of time to remain below pre control levels after one year. The results obtained at treatment 1 (aerial shooting and baiting) and 2 (aerial shooting only) sites are therefore encouraging, as pig numbers remained relatively low despite excellent seasonal conditions for population growth. Conversely, feral pig IOA at treatment 3 site and the non-treatment site (the areas without semi-permanent wetlands) did not alter significantly throughout the project. IOA levels at these particular sites actually remained lower than the two areas that contained semi-permanent wetland (treatment 1 and 2 sites). This is unlikely to be because these management options are more effective for managing feral pigs in the Macquarie Marshes, and more likely that the drier surrounding ephemeral wetlands are less suitable for rapid population growth.

IOA data were gathered using images that were collected from a series of permanent camera locations (n= 6-12) within each property (n=4) over a 10 day period during each monitoring event. It is possible that some camera locations within each site were not independent, although they were spaced at distances ≥ 1km to reduce this risk. In addition, the analysis was undertaken on the mean number of feral pig passes per camera, per night, per site over a 10 day period during each round of monitoring. Therefore, the conclusions for IOA data are tentative due to possible pseudoreplication (Krebs 1999). Pseudoreplication (or sample replicates) is more precise than true replication and may increase the chance of a Type I error (reject H_o when there is no significant difference). However, it was un-avoidable in the present study as feral pigs have relatively large home ranges compared the size each property (more cameras per site would further decrease camera site independence) and their populations are rarely evenly dispersed throughout the landscape (random camera site selection may lead to highly variable results).

Effect of management options on feral pig damage

Most studies that have assessed the impacts of management on feral pigs often focus on abundance/density reductions (Hone and Pederson 1980; Hone 1983; Saunders and Bryant 1988; McIlroy *et al.* 1989; Choquenot *et al.* 1990; Saunders *et al.* 1990; Saunders 1993; Choquenot *et al.* 1999; Twigg *et al.* 2005, 2007; Cowled *et al.* 2006a), and very few have assessed the impacts of management on damage. Hone (2002), who monitored the impacts of annual poison baiting (using warfarin) on feral pig abundance and damage (ground rooting) in Namadgi National Park between 1985 and 2000, reported density may have been reduced by as much as 95.1%, which also equated to a significant decline in the level of ground rooting. Internationally, Engeman *et al.* (2007) reported sport hunting reduced the level of ground rooting by 78% in Florida's seepage slopes one year after allowing hunting in a previously hunting closed area.

During the current study, no significant difference in the mean level of ground rooting between treatment sites was detected before management had commenced (April 2011). Similarly, no significant difference in the mean level of ground rooting between sites was detected upon the completion of the project (August 2012). However, the results should be interpreted with caution as it possible that a type II error may exist, in that, no significant difference in the mean level of ground rooting between treatment areas was detected even though one may be present. This may have occurred due to the relatively low and uneven number of line intercept transects created per site. In addition, some transects were flooded during monitoring events. The number of transects created were associated with the number of hotspots (areas of regular feral pig activity) at each site and the size of each property. Transects were also to be monitored at the same time each year irrespective of rainfall or flooding so that results were comparable. Using statistical power analysis in Krebs (1999), it is recommended that sixteen 500m line intercept transects would be required per site to detect a difference of 0.67 between the poison baiting only site (treatment 3) and the no management site (non-treatment). Hence, future studies in the Macquarie Marshes should create a minimum sixteen 500m line intercept transects per property when monitoring ground rooting by feral pigs.

During the current study, no significant difference in the level of ground rooting within each treatment/non-treatment site was detected over time, despite significant differences being found in feral pig IOA at treatment 1 site and treatment 2 site. This may be because the level of ground rooting is less sensitive to short term changes, in that it may take longer for changes in the level of ground rooting to occur (Hone 2012); unlike changes in IOA which could be detected almost immediately using remote camera technology. Monitoring of ground rooting may therefore be better suited for long term studies similar to Hone (2002). Similar to the between site comparison analysis, non-significant results may have also occurred due to the varying number of line intercept transects and site flooding. Hence, results should be interpreted with caution.

General observations in the current study were that most of the ground rooting that occurred in the semi-permanent wetlands was found in areas immediately surrounding flooded areas, in areas were the soil was exposed within flooded areas or within shallow flooded areas. Engeman *et al.* (2004) also reported most feral pig ground rooting (70%) occurred around the water's edge in the basin marsh system in eastern Florida, USA. Mitchell and Mayer (1997) reported ground rooting was common in areas were soil moisture persists and suggest this may have occurred because of the softer soils, the abundant bulb producing species, and high soil invertebrate populations in these areas. During the current study, feral pigs seemed to target the roots of *Typha sp.*, *Marsilea drummondii*, *Eleocharis plana* and various monocot species in the semi-permanent wetland areas. Giles (1980) also noted that roots of these species were very common in feral pig stomachs in the Macquarie Marshes.

Observations in the drier ephemeral wetlands were that ground rooting seemed more common in wetter months/conditions, which may be because this is when soil is likely to be softer (Bowman and McDonough 1991; Mitchell and Mayer 1997; Hone 2012). Feral pigs seemed to target the roots of *Eleocharis plana* (around dams, deep depressions), chenopod species including *Sclerolaena birchii* and *Atriplex versicaria* and various monocot species in the ephemeral wetland areas. Alexiou (1983) and Hone (2002) reported feral pigs in Namadgi National Park (situated in south eastern Australia) commonly root up plant species including vanilla lily, bulbine lily, black thorn and orchids. In the Northern Territory, Bowman and McDonough (1991) reported that feral pigs seemed to exploit yams and other rootstocks in the forests, whereas sedge rhizomes were favoured in the swamp communities, similar to the current study.

Cost effectiveness

Generally, aerial shooting seemed most cost effective (< \$25.00 per kill) when feral pig IOA was high (≥ 1 pig passes per camera per night per site). Hone (1990b) lists average cost per kill for several studies throughout Australia, which were \$7.31 (Adelaide and Mary Rivers NT), \$38.00 (Willandra NSW), \$3.00 (north-west NSW) and \$12.00 (Macquarie Marshes NSW). Many of these averages were lower than the current study, although annual inflation has not been taken into account. The average cost per kill for the pre-mentioned studies at an inflation (ARI) of 3.7% per annum (P.A.) since 1990 equates to \$12.85, \$66.82, \$5.28, \$21.00, respectively (RBA 2013). Moreover, if the costs for the current project (Table 6.1) are applied to data in Saunders (1988) (also undertaken in the Macquarie Marshes), cost per kill equates to \$30.95, which is similar to this study. Choquenot *et al.* (1999) also assessed the efficiency of three different feral pig aerial shooting programs; one of these areas was in the

Macquarie Marshes. They reported that time per kill increased exponentially below threshold densities of 2, 3 and 6 pigs per km^2 for the Mary River, Macquarie Marshes and Paroo River, respectively. They also reported that the average cost per kill above the density threshold was $11.36 (2012 equivalent at an annual inflation rate of 3.7% = $16.77 @ ARI 3.7% P.A.) whereas below the threshold (5 per km^2 in the Macquarie Marshes) cost per kill increased substantially. Unfortunately, it is not possible to compare the current study to the previous studies as IOA (index of abundance) estimates were used instead of density estimates.

Poison baiting seemed to be affected by season, unlike aerial shooting, with the greatest removal rate and cost per kill ($39.72) for poison baiting occurring in summer (Jan 2012). Choquenot and Lukins (1996) reported bait-take in the semi-arid rangelands can be influenced by seasonal conditions, whereby bait-take is generally greatest when alternate foods are scarce. Various other authors have also mention that bait-take is likely to be affected by the availability of alternate foods (Hone 1983, 2002; O'Brien and Lukins 1988; Saunders and Bryant 1988; Choquenot *et al.* 1993; McIlroy *et al.* 1993; Saunders *et al.* 1993; Caley 1994; Fleming *et al.* 2000; Twigg *et al.* 2005). Poor poison baiting results during the present study may have occurred for several reasons. Firstly, alternate foods were relatively abundant during all baiting periods due to above average rainfall and water in-flows from the Macquarie River system. Secondly, a large mob of feral pigs (n=23) failed to attend a poison bait station on the night bait was deployed at treatment 1 site during June 2012 despite visiting on numerous nights of free-feeding. It is not known why this result occurred, although it may be due to illegal hunting. Finally, feral pig IOA was low at the poison baiting sites (treatment 1 and 3 sites), hence large amounts of effort were expended to attract small numbers of feral pigs. Future studies should simultaneously replicate each treatment/non-treatment, which would help interpret the results. They should also implement at least one round of poison baiting during hot dry conditions and select properties (treatment areas) with similar (high) level of feral pig IOA. Unfortunately, this was not possible during the present study, as site selection was largely dictated by landholder willingness to participate and the implementation of routine aerial shooting in the region. Additionally, it may be beneficial in future studies to compare the cost effectiveness of 1080 poisoned PIGOUT® and 1080 poisoned barley for controlling feral pigs in the region. This is not possible for the current study, as the two bait substrates were not directly compared as they were often used in combination.

Hone and Pederson (1980) provide basic costs for a meat baiting program on a property in western NSW. Cost per kill is not listed although total cost for the program was $2,378.00 (2012 equivalent = $9,117.17@ ARI 3.7% P.A.) to achieve a 58.1% population reduction. Hone (1983) lists costs for a trial eradication program near Hillston NSW, whereby the poisoning component was able to remove 73% of feral pigs for $1,205.00 (2012 equivalent = $3,443.71 @ ARI 3.7% P.A.). Saunders *et al.* (1990) provides costs for a warfarin baiting program baiting program at Sunny Corner NSW, during which they reduced feral pig numbers by 98.9% for $7220, or $39.00 per pig (2012 equivalent = $12,696.27@ ARI 3.7% P.A.). If the costs for the current study (Table 6.1) are applied to Saunders *et al.* (1990) the total cost for the Sunny corner pig baiting program becomes $21,353.61 (excluding poison cost) or $114.19 per pig. During this study, both management techniques were expensive (aerial shooting $137.33 or toxic baiting $922.94) if they were undertaken in unfavourable conditions. Therefore, feral pig IOA (likely baiting and aerial shooting) and season (primarily baiting) should be considered when planning management actions in the Macquarie Marshes. As previously mentioned, the conditions in the Macquarie Marshes can change considerably between seasons and spatially within seasons (semi-permanent wetlands and drier ephemeral wetlands, and also abundance), and thus management should vary accordingly. For example, aerial shooting may be more useful in the inaccessible semi-permanent wetlands where densities are often higher and access is limited (Giles 1980; Saunders and Bryant 1988). Conversely, baiting may be more suitable near permanent water in the drier ephemeral wetland areas, where food is often scarcer. Both techniques are likely to be most cost effective when densities are highest.

Another interesting result was feral pig IOA sometimes increased at the aerial shooting sites and in the treatment/non-treatment sites situated outside the aerial shooting zone immediately after aerial shoots. It is difficult to explain such results, although it may be possible that pigs became more active due to the disturbance, or that some animals may have moved out of the area and into the non-aerial shoot zones. Saunders and Bryant (1988) reported that feral pigs in the Macquarie Marshes did not move great distances after aerial shooting events. Dexter (1996) suggests that dispersal of feral pigs is unlikely to occur as a consequence of aerial shooting. Therefore, it seems that unsettled behaviour and increased activity by fewer animals may be the cause. Hence, IOA measures for aerial shooting efficacy might be better taken when the feral pigs return to normal behaviour, or by using a different technique. Alternatively, motion sensing camera data may be better suited as an index of activity, rather than an index of abundance as large numbers of feral pigs were removed from the population during aerial shooting yet the IOA often increased for a period of time. However, other methods for gathering IOA estimates may also have limitations. For example, sand plots may experience similar results to the camera trapping, in that a low number of animals may increase activity patterns after management. Conversely, Saunders (1993) mentions aerial survey may be less likely to detected individuals post aerial shooting despite animals being present. Future studies should therefore compare the effectiveness of camera trapping, sand plot monitoring and aerial survey for gathering feral pig IOA estimates before and after aerial shooting to determine which is most appropriate. Another limitation may to this study may be that treatment 3 site (bait only) was too close to treatment 1 site (baiting and aerial shooting), therefore feral pig IOA at this site may have been reduced by the aerial shooting program at treatment 1 site. However, this is unlikely because IOA remained stable or actually increased at treatment 3 site during each aerial shooting program.

Conclusion

In summary, this study demonstrated that feral pig IOA and feral pig damage in the Macquarie Marshes are positively correlated, which may be useful for measuring future management program efficacy. In addition, it was discovered that feral pig management in the Macquarie Marshes is complex due to the diverse habitat conditions and varying feral pig IOA throughout the region. The results largely support the null hypothesis in that there is little difference between management approaches for reducing feral pig damage, although aerial shooting was able to significantly reduce high feral pig IOA.

Chapter 7 - General discussion and conclusions

Feral pigs have existed in the Macquarie Marshes for over 100 years and their densities in the area have been estimated to be among the highest anywhere in Australia (Giles 1980; Saunders and Bryant 1988; Choquenot *et al.* 1996; Hogendyk 2007). Environmental damage caused by feral pigs in the Macquarie Marshes is likely to include competition with native species, destruction of native habitat and predation of eggs and slow moving terrestrial species (Anon 2005). Feral pigs are also expected to be adversely impacting agriculture through infrastructure damage, competition with livestock, predation of new born lambs and crop destruction and consumption (Pullar 1950; Pavlov *et al.* 1981; Choquenot *et al.* 1996, 1997). Importantly, feral pigs in the Macquarie Marshes carry endemic diseases such as leptospirosis (Giles 1980), and they have the potential to harbour and spread exotic diseases such as Foot and Mouth Disease (Pullar 1950; Pavlov and Edwards 1995; Choquenot *et al.* 1996; Anon 2005).

Feral pigs have been subjected to various forms of management in the Macquarie Marshes for many years. Despite this, they remain abundant and widespread (Giles 1980; Saunders and Bryant 1988; Saunders 1993). To be able to enhance feral pig management in the region, it is important to understand their ecology and the causal effects of management on their abundance and damage (Braysher 1993; Choquenot *et al.* 1996; Olsen 1998; Hone 2007, 2012). This study aimed to bridge some of these knowledge gaps to help refine future management of feral pigs and their damage in this complex system.

7.1 Feral pig diet in the Macquarie Marshes

This section of the study was implemented to determine whether collection site, collection date or feral pig demographics influence feral pig diet and related predation of vertebrate wildlife in the Macquarie Marshes, and to identify which species are most at risk so that an appropriate monitoring program may be developed. Feral pigs were largely herbivorous, with vegetable matter occurring in 100% of stomachs and making up 94% of the food that was consumed. Animal matter occurred in 31% of stomachs and made up the remaining 6%. Numerous national and international studies have also reported that feral pigs are largely herbivorous (Everett and Alaniz 1980; Thomson and Challies 1985; Coblentz and Baber 1987; Baber and Coblentz 1987; Chamera 1995; Taylor and Hellgren 1997). However, unlike many other studies (Everett and Alaniz 1980; Thomson and Challies 1985; Baber and Coblentz 1987; Chamera 1995; Pavlov and Edwards 1995; Taylor and Hellgren 1997) vertebrate wildlife prey in larger proportions and more frequently among feral pig stomach than invertebrates and carrion in the Macquarie Marshes. Reptiles and amphibians were the most common vertebrate prey item in the current study. Giles (1980) also reported that frogs were the most common vertebrate prey item found in feral pig stomachs in the Macquarie Marshes. Elsewhere in Australia, Fordham *et al.* (2006) reported that feral pigs were significant predators of northern snake-necked turtles (*Chelodina rugosa*) and internationally, Coblentz and Baber (1987), Taylor and Hellgren (1997) and Jolley *et al.* (2010) discovered reptile and amphibian species in feral pig stomachs.

Of the vertebrate wildlife species that were consumed, none are listed under the NSW Threatened Species Conservation Act 1995, although this does not necessarily indicate that feral pigs do not consume threatened or endangered species in the Macquarie Marshes. It may be that these food items are simply less likely to be encountered. The Sloane's froglet (*Crinia sloanei*) occurs in the Macquarie Marshes and it is listed as vulnerable under the NSW Threatened Species Conservation Act 1995. This species possess life traits similar to those found in the diet of feral pigs in the present study, therefore they may be at risk. No ground nesting waterbirds, or their eggs, were found in feral pig stomachs during the present study. Giles (1980) also reported no evidence of waterbird or waterbird egg predation. Again, this does not necessarily mean that feral pigs do not consume waterbirds, or waterbird eggs in the Macquarie Marshes, as other studies, including Miller and Mullette (1985) and Cuthbert (2002) have shown that feral pigs cause considerable damage to ground nesting bird species such as the Lord Howe Island woodhen (*Tricholimnas sylvestris*) and Hutton’s shearwater (*Puffinus huttoni*), respectively. It is possible however that waterbirds or their eggs were not discovered because of the spatial distribution of waterbird colonies in relation to stomach collection sites or because of collection dates in relation to nesting dates. Aerial shoots are typically undertaken prior to nesting to minimise disturbance from the helicopters and perceived predation rates. Additionally, it is possible that egg-shell may deteriorate more rapidly than other food items in feral pig gastric juices, or that feral pigs may be consuming the yolk, hence they may be underrepresented in the diet (Isle and Hellgren 1995).

The only factor to specifically and significantly influence predation levels was collection date, with vertebrate wildlife occurring more frequently and in larger quantities during warm months; mean maximum temperature was 26ºC (September 2011 and March 2012). This is not surprising as the vertebrate wildlife prey were cold blooded and mostly nocturnal, so this is when predator-prey activity patterns are likely to coincide. Jolley *et al.* (2010) also reported district seasonal peaks in reptiles and amphibian consumption at Fort Benning Military Base during July-August (summer) and December/January (winter). They suggest that the first peak may have occurred in July-August, as it is warm and it coincides with the eastern spadefoot toad *Scaphiopus holbrookii* breeding season. They hypothesise the second peak in predation may have occurred in December/January, because it is cooler and it is when the green anole *Anolis carolinensis* takes refuge in rotten logs or dense debris to escape the cold. Hence, they may be more likely to be discovered by feral pigs whilst they are foraging for roots and invertebrates.

In summary, it was confirmed that feral pigs consume vertebrate wildlife species in the Macquarie Marshes (specifically reptiles and amphibians), and that predation was highest during warmer months. Spatial distribution of collection sites and feral pig demographics, such as gender or age, had no significant influence on predation levels, but they did influence general diet composition. It is also recognised that although wildlife species were found in feral pig stomachs, it does not necessarily mean that the level of predation is detrimental to their long term survival. It is possible that feral pigs predation may be a compensatory source of mortality than an additional one, and thus supporting the doomed surplus theory (Banks 1999). However, it warrants further investigation (see section 7.5 - 1).

7.2 Feral pig activity patterns in the Macquarie Marshes

This part of the study was undertaken to assess feral pig activity patterns in the Macquarie Marshes, using remote camera technology, to determine whether season or management option influence feral pig activity patterns. The study confirmed that feral pigs in the Macquarie Marshes are generally nocturnal. 72.1% feral pig activity occurred at night, whereas only 21.6% and 6.3% occurred during twilight or daylight hours, respectively. Feral pigs became active between 05:00pm and 09:00pm and where most active between 05:00pm and 07:00am. There was also some evidence to suggest that feral pigs in the Macquarie Marshes display bimodal activity patterns, with the initial peak in activity occurring at ~09:00pm and the second, lower, peak in activity occurring at 06:00am, which is similar to what was reported by Caley (1997) in the Northern Territory. Interestingly, very little activity was recorded during daylight hours and no activity was recorded between 12:00 noon and 04:00pm. Giles (1980) also reported that feral pigs were most active on dusk or at night in the Macquarie Marshes.

Numerous other Australian (McIlroy *et al.* 1989; Saunders and Kay 1991; Caley 1997) and international studies (Biotani *et al.* 1994; Russo *et al.* 1997; Nogueira *et al.* 2007; Campbell and Long 2010) have investigated feral pig, wild boar or their hybrids activity patterns using radio telemetry or global-positioning system collars, and most achieved similar results to the present study, in that activity general commences shortly before or after sunset, and finishes before or shortly after sunrise. Therefore, the results from these studies, in combination with the present study, suggest the feral pigs are largely nocturnal in a variety of habitats and locations.

There was little evidence to support that feral pigs became more diurnal in cooler months. Conversely, nocturnal activity was less pronounced in summer than it was in other seasons. This was surprising, as it may be expected that feral pigs become more nocturnal in summer to escape high ambient temperatures. A possible explanation may be that the nights are shorter in summer, and perhaps lesser quality foods are available. Therefore, feral pigs may be forced to feed during daylight hours to satisfy their relatively high daily dietary needs. Keuling *et al.* (2008) also reported that diurnal activity was significantly higher in May and June (summer). Russo *et al.* (1997) also hypothesised that wild boar may have become active during afternoon daylight hours due to lack of food and possible lack of human interference.

Feral pigs may also adapt their behavioural patterns according to human disturbance or lack thereof (Giles 1980; Saunders and Bryant 1988; McIlroy and Saillard 1989; Saunders and Kay 1991; Biotani *et al.* 1994; Choquenot *et al.* 1996; Dexter 1996; Russo *et al.* 1997; Keuling *et al.* 2008). During the current study, nocturnal activity was higher than crepuscular and diurnal activity within all treatment sites, apart from the bait-only site where crepuscular and nocturnal activity was similar. Giles (1980) reported in the Macquarie Marshes that feral pigs were observed foraging during the day on a property where hunting was not permitted. Saunders and Bryant (1988) also reported that feral pigs in the Macquarie Marshes rarely moved outside their home range in response to aerial shooting, although they may have learned to hide to avoid detection. Dexter (1996) reported aerial shooting had little impact on the general movement of feral pigs in the rangelands of western NSW. It is possible however that feral pig activity patterns in the Macquarie Marshes may have already been influenced by previous management, general farm activities or illegal hunting, although this cannot be said for certain.

In summary, the current study demonstrated that feral pigs in the Macquarie Marshes are largely nocturnal irrespective of season or management option, and that remote cameras are a useful, low labour technique for gathering information on daily feral pig activity patterns in relatively remote and inaccessible areas. Based on the results, it may increase the effectiveness of feral pig management to include at least one technique in an integrated program that exploits the nocturnal behaviour of feral pigs. This may include techniques such as poisoning or trapping. In addition, it is likely that most feral pigs in the Macquarie Marshes rest in dense vegetation between 12:00 noon and 04:00pm, as no animals were recorded on camera during this time. Hence, this may provide an additional opportunity to targeting unwary animals with techniques such as ground hunting/shooting.

7.3 The effectiveness of various feral pig bait attractants in the Macquarie Marshes

This part of the study was implemented to assess whether various bait attractants (Carasweet, vanilla, molasses, meat meal, fish meal, fermented barley) and bait substrates (barley and PIGOUT®) could significantly outperform the non-treatment bait (dry barely) in regards to bait station visitation and bait-take by feral pigs. Based on the results of previous studies, it may have been expected that bait station visitation and bait-take by feral pigs would alter significantly between summer and winter trial periods (McIlroy *et al.* 1993; Saunders *et al.* 1993; Caley 1994; Choquenot and Lukins 1996). However, there no significant differences in bait station visitation or bait-take by feral pigs between seasons. This may have occurred because alternate foods were relatively abundant during both study periods, due to above average rainfall in the summer of 2012. If alternate foods were scarce during one of the study periods, the results may have been different, although this cannot be said for certain. Choquenot *et al.* (1990) reported that feral pig baiting program efficacy may have been reduced at their rangeland study site because baiting was undertaken after heavy rain.

As no significant differences in were identified between trials (Jan 2012 and June 2012) the data were pooled. Despite the larger treatment group size, there was still no significant difference in station visitation or bait-take between attractants. Nevertheless, some interesting results were discovered, in that Carasweet®, molasses, vanilla and fermented grain were consumed when they were discovered by feral pigs. In contrast, PIGOUT®, meat meal, fish meal and dry barley (non-treatment) all received at least one situation where feral pigs visited a station but did not eat. Several authors have shown a proportion of the population do not find bait, some pigs will find bait and not eat, and some pigs will eat and not die (Hone 1983, Hone 2002, 2012; Choquenot *et al.* 1990; Choquenot *et al.* 1993; McIlroy 1993; Saunders *et al.* 1993; Choquenot and lukins 1996). In the present study, it is possible that feral pigs existed in the immediate area and did not visit, or that feral pigs did not exist in the immediate area and did not visit. However, each of the bait stations were positioned at areas renowned for regular feral pig activity and each trial was undertaken for 10 days reduce such risks (Saunders *et al.* 1993; McIlroy *et al.* 1993). It was possible however to confirm instances where feral pigs visited stations and did not eat, using remote cameras, and these data may indicate varying palatability or attraction of the attractants. For example, attractants that received equal visitation and bait-take rates such as Carasweet®, molasses, vanilla and fermented barley may have been more palatable to feral pigs than those that received unequal visitation and bait-take rates.

There was no significant difference between attractants in the mean number of nights until first visitation throughout the trial. It was observed that feral pigs often returned to bait stations on a nightly basis once it was discovered, and the number of visiting individuals sometimes increased. McIlroy *et al.* (1993) and Saunders *et al.* (1993) experienced similar results in the hill country of south-eastern Australia, where the number of feral pigs visiting bait stations continued to increase for 10 - 15 days. During this study, a potential total of 121 individual feral pigs bait stations, although there was no significant difference in the mean number of feral pigs per station per attractant. Despite this, Carasweet™, molasses, fermented barley, meat meal and vanilla received an average of ≥ 1 per station created. Non-significant results may have occurred due to low number of replicates per attractant, and because alternate foods were often abundant. Therefore, future studies should use a minimum of 32 replicates per attractant (Krebs 1999) and at least one trial should be undertaken during hot and dry conditions.

Numerous non-target species, particularly birds, consumed bait material during the study. However, most of this bait material was consumed off the ground in front of the

HogHopper™s. This is not likely to occur during toxic baiting, as the HogHopper™ doors are fully closed and all bait material is housed within the device. Nonetheless, the bait substrates and/or attractants that were taken by the least amount of non-target species were PIGOUT® and fish meal barley. Cowled *et al.* (2006b) also mentions PIGOUT® was more target specific than other commonly used substrates, such as grain or meat. Birds were the most common non-target species observed to consume barley, particularly galahs, crested pigeons and apostle birds. However, none of the bait was dyed green apart from PIGOUT®, which is process that may help reduce acceptance of grains by birds (Bryant *et al.* 1984; Cowled *et al.* 2006a). Conversely, Hone *et al.* (1985) reported that galahs and crested pigeons consumed grain irrespective of whether it was dyed or undyed, although intake varied according to year, season, grain and time within season. Each of the bait attractants tested in the present study added between $1.00 and $3.00 dollars to 10kg of barley, apart from PIGOUT® which a commercially available manufactured bait and fermentation which does not add to the cost but does take time.

In conclusion, this study demonstrated that none of the attractants tested could significantly outperform the non-treatment bait (dry barley) in regards to visitation, bait-take, nights until visitation and level of bait consumption in the Macquarie Marshes NSW. Unfortunately, alternate foods were abundant at the time of both trials due to above average seasonal conditions, and thus the results are likely to be worst case scenario (see section 7.7 – 5 for future research recommendations).

7.4 Feral pig damage management

Understanding abundance and damage relationships is important for developing strategic and cost effective management solutions. Therefore, this part of the project was undertaken to identify the relationship between feral pig abundance and damage (ground rooting), and to assess the efficacy of various management options to help refine future management in the Macquarie Marshes region.

It was confirmed that index of feral pig abundance (IOA) and damage were significantly positively correlated ($r=0.46$, $n=15$, $p=0.04$), with greater a greater mean number of feral pig passes, per camera, per night, per site equating to a greater mean level of ground rooting per, kilometre, per site. Hone (1988, 2002, 2012) also reported that feral pig abundance and ground rooting were positively related in Namadgi National Park (NNP). Internationally, Katahira *et al.* (1993) reported feral pig activity and feral pig density had a statistically significant positive relationship in the Hawaii Volcanoes National Park. Other factors that may influence ground rooting may include spatial and temporal variation, as well as rainfall (Alexiou 1983; Hone 1988, 2002, 2012; Bowman and McDonough 1991; Mitchell and Mayer 1997; Mitchell *et al.* 2007a). In NNP, Alexiou (1983) reported ground rooting by feral pigs was particularly common in drainage lines, depressions and around the grassy flats and Hone (1988) reported feral pig rooting was significantly related to altitude, frequency of rocks, drainage lines and vegetation in NNP. Elsewhere in Australia, ground rooting by feral pigs was discovered to be more prevalent near roads, tracks and drainage lines and at certain times of year in particular micro-habitats (Bowman and McDonough 1991; Mitchell and Mayer 1997; Mitchell *et al.* 2007).

Feral pig IOA was significantly higher at the aerial shooting site prior to the commencement of the project. This may have occurred because historical management practices varied at each property, or because it may have contained more suitable habitat for feral pig population growth, or both. Specifically, the aerial shooting only site and the aerial shooting and poison baiting sites contained semi-permanent wetlands and the remaining two sites did not. Giles (1980) and Saunders and Bryant (1988) reported that wetland habitats in the Macquarie Marshes often contained higher feral pig densities than drier surrounding areas. Unfortunately, it was not possible to select four identical properties due to site restrictions, logistics and spatial habitat variation in the region. Nevertheless, there was no significant difference in feral pig IOA between the treatment and non-treatment sites upon the completion of the project. During the project the Macquarie Marshes received above average rainfall and several inflows from the Macquarie River. Therefore, conditions were exceptional for rapid growth in the feral pig population (Giles 1980; Saunders 1993; Hone 2012). Under the circumstances, the results obtained at the aerial shooting only site and the aerial shooting and poison baiting site may be considered relatively successful. Therefore, in the Macquarie Marshes aerial shooting may be useful for rapidly reducing abundant populations and a combination of aerial shooting and poison baiting may be useful for maintaining relatively low populations. Numerous authors have also reported that aerial shooting (Hone 1990b; Saunders 1993; Dexter 1996; Choquenot *et al.* 1999) is suitable fast initial population reductions and that poison baiting (Hone and Pederson 1980, 1983, 2002; McIlroy *et al.* 1989;

Choquenot *et al.* 1990; Saunders *et al.* 1990; Cowled *et al.* 2006a) can produce relatively large population reductions in a short period of time.

As previously stated, very few feral pig management studies have focused on the effects of management on damage, apart from Hone 2002; Engeman *et al.* 2007; who reported that management significantly reduced the level of ground rooting. During the current study, none of the management options significantly altered the level of ground rooting, despite significant differences occurring IOA levels. This may have occurred because ground rooting is less sensitive to short term changes in feral pig abundance/density (Hone 2012) compared to IOA which was measured using remote camera technology. It is also possible that a low number of transects per site, and site flooding may have influenced the results. Hence, the results should be interpreted with caution due to the possibility of a type II error. Future studies should use a minimum of sixteen 500 metre line intercept transects per site (Krebs 1999).

The cost effectiveness of poison baiting and aerial shooting varied considerably throughout the project. Aerial shooting seemed most cost effective (< $25.00 per kill) when feral pig abundance was high (≥ 1 feral pig pass per camera per night) and season seemed to have little influence. Hone (1990b) lists cost per kill for several aerial shooting studies which includes the Macquarie Marshes. The average cost per kill in the Macquarie Marshes at an annual rate of inflation (ARI) of 3.7% per annum (P.A.) $21.00, which is similar to the results obtained in the present study. Poison baiting seemed to be affected by season with the best cost per kill ($39.72) and greatest removal rate (75 ± 15% SE) occurring in summer (January 2012). Saunders *et al.* (1990) provides costs for a warfarin baiting program baiting program at Sunny Corner NSW, during which they achieved a cost per kill rate of $39.00. However, if the costs for the current study are applied to data from Saunders *et al.* (1990) the cost per kill becomes $114.19 per pig, which is relatively high. Poor baiting results in the present study are likely to have occurred because alternate foods were often abundant due to above average rainfall and in-flows from the Macquarie River. In addition, feral pig abundance was relatively low at the poison baiting study sites; hence a large amount of effort was expended to attract a small number of feral pigs. Therefore, it may be important to consider environmental conditions and feral pig abundance levels when planning management actions in the Macquarie Marshes.

This study demonstrated that feral pig management in the Macquarie Marshes is complex because of the diverse habitat conditions and feral pig abundance levels throughout the region. Feral pig IOA and feral pig damage are positively correlated, which may be useful for measuring the efficacy of future management program. It was also evident that aerial shooting and poison baiting can be expensive or cost effective depending feral pig abundance and environmental conditions. Most importantly, none of the experimental treatments were able to completely remove all animals from an area, as feral pigs were recorded on camera in all areas immediately after aerial shooting and/or toxic baiting exercises. Based on the results, it is likely that aerial shooting may be more useful within the in-accessible semi-permanent wetlands where densities are often high, access is limited and alternate food is abundant. Conversely, poison baiting may be more suitable in the drier ephemeral wetland areas, where food is often scarce.

7.5 Future research

Additional areas of future research that will help to enhance management of feral pig damage in the Macquarie Marshes system were identified. Areas of future research are:

1. Determine the relationship between feral pig abundance and the density and diversity of reptiles and amphibians. This will then guide the need for the extent of population reduction in feral pigs required to conserve these species.

2. Compare the effectiveness of aerial survey, remote camera technology and sand plots for monitoring feral pig abundance before and after aerial shooting programs to determine which is more suitable.

3. Assess the various attractants that were used during the present study when alternate foods and water are scarce, using a minimum of 32 replicates per attractant (Krebs 1999).

4. Assess the performance of various management options for reducing feral pig damage (ground rooting) using simultaneous replicates (multiple properties same management option) of each management approach and a minimum of sixteen 500m line intercept transects per property (Krebs 1999).

5. Utilise GPS collars to monitor seasonal movements of feral pigs in and around the semi-permanent wetland areas of the Macquarie Marshes.

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