Spot the difference: Using camera-traps to analyse the Spotted-tailed Quoll population in the Illawarra Highlands, NSW Australia

J Nicholson

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Abstract
The deleterious effects of habitat loss, modification, and fragmentation continue to drive mammal extinctions worldwide. Understanding population-specific responses to changing landscapes are essential for effective conservation management. In southeast Australia, the spotted-tailed quoll is a threatened marsupial carnivore that occupies large home ranges in low-density populations, therefore increasing the possibility of encountering a multitude of threatening processes. Despite their known vulnerability to these threats, the knowledge of size, distribution, and ecology for stronghold populations are often inadequate to apply effective conservation efforts. This study aimed to investigate the population dynamics of spotted-tailed quolls located in Budderoo National Park, Barren Grounds Nature Reserve, and Morton National Park; an area recognised as a stronghold population of the species. To investigate this, a long-term camera trap survey was undertaken continuously over a 24-month period. In addition, two annual periods of live-trapping were also conducted to determine the distribution, abundance, and spatial organisation of the spotted-tailed quoll across the study sites. Camera-trap surveys were conducted from 2016 to 2018 using 29 infrared cameras. This resulted in an overall sampling effort of 18,898 trap nights, during which 699 independent quoll captures were found. Through the use of the individual profiling to distinguish between individuals, 64 quolls were individually identified. Individual identification was used to determine the movements and behaviours of each quoll by analysing their captures.

This study found that the population was primarily located within the Barren Grounds Nature Reserve and the central portion of Budderoo National Park. Across the two year study period there was an observable increase in quoll captures between the two years, ultimately finding a minimum count of 58 quolls in the population. The highest number of captures occurred during the winter months, coinciding with to the breeding season, and summer (introduction of the current year’s sub-adult population). For a subset of the population, eight males and six females were analysed for their spatial organisation. Findings showed that the home range and movement of males were significantly larger than that of the females. Generally, females only appeared on two or three cameras occupying an average home range of 132ha, while males appeared on an average of six cameras with a larger average home range of 2350ha. Using the known biology, spatial organisation and movement patterns of these quolls, we attempted to determine the sex of another four individuals. Through the comparison of these individuals to the behaviour of the known population, we estimated the sex of the four individuals to be two males and two females. By following the dispersal pattern of the individuals captured as juveniles, we found that males moved far from their natal site to establish new adult home ranges. In contrast, females typically occupied areas near their natal home range. Daily activity pattern differences between males and females were not significantly different. Nonetheless, it was found that individuals were not entirely nocturnal, and had observable diurnal and crepuscular periods of activity. The seasonal analysis of activity patterns found a significant difference with a substantial nocturnal activity increase during the winter months.

Our study provides ecological insights into the life history and biology of spotted-tailed quolls and reveals the current distribution and abundance of a recognised stronghold population. By understanding the distribution and behaviour of the Illawarra highlands, the local factors that constrain population growth can be identified and assessed. This knowledge is vital in the application of effective conservation management strategies needed to prevent further species decline and ensure the persistence of the spotted-tailed quoll on the Australian mainland.

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Spot the difference: Using camera-traps to analyse the Spotted-tailed Quoll population in the Illawarra Highlands, NSW Australia

Joel Nicholson

A thesis submitted in partial fulfilment of the requirements for the award of the Degree of Bachelor of Environmental Science (Honours) in the School of Earth and Environmental Sciences, Faculty of Science, Medicine and Health, University of Wollongong

23rd October 2018
The information in this thesis is entirely the result of investigations conducted by the author unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

Joel Nicholson

23rd October 2018
Abstract

The deleterious effects of habitat loss, modification, and fragmentation continue to drive mammal extinctions worldwide. Understanding population-specific responses to changing landscapes are essential for effective conservation management. In southeast Australia, the spotted-tailed quoll is a threatened marsupial carnivore that occupies large home ranges in low-density populations, therefore increasing the possibility of encountering a multitude of threatening processes. Despite their known vulnerability to these threats, the knowledge of size, distribution, and ecology for stronghold populations are often inadequate to apply effective conservation efforts. This study aimed to investigate the population dynamics of spotted-tailed quolls located in Budderoo National Park, Barren Grounds Nature Reserve, and Morton National Park; an area recognised as a stronghold population of the species. To investigate this, a long-term camera trap survey was undertaken continuously over a 24-month period. In addition, two annual periods of live-trapping were also conducted to determine the distribution, abundance, and spatial organisation of the spotted-tailed quoll across the study sites. Camera-trap surveys were conducted from 2016 to 2018 using 29 infrared cameras. This resulted in an overall sampling effort of 18,898 trap nights, during which 699 independent quoll captures were found. Through the use of the individual profiling to distinguish between individuals, 64 quolls were individually identified. Individual identification was used to determine the movements and behaviours of each quoll by analysing their captures.

This study found that the population was primarily located within the Barren Grounds Nature Reserve and the central portion of Budderoo National Park. Across the two year study period there was an observable increase in quoll captures between the two years, ultimately finding a minimum count of 58 quolls in the population. The highest number of captures occurred during the winter months, coinciding with the breeding season, and summer (introduction of the current year’s sub-adult population). For a subset of the population, eight males and six females were analysed for their spatial organisation. Findings showed that the home range and movement of males were significantly larger than that of the females. Generally, females only appeared on two or three cameras occupying an average home range of 132ha, while males appeared on an average of six cameras with a larger average home range of 2350ha. Using the known biology, spatial organisation and
movement patterns of these quolls, we attempted to determine the sex of another four individuals. Through the comparison of these individuals to the behaviour of the known population, we estimated the sex of the four individuals to be two males and two females. By following the dispersal pattern of the individuals captured as juveniles, we found that males moved far from their natal site to establish new adult home ranges. In contrast, females typically occupied areas near their natal home range. Daily activity pattern differences between males and females were not significantly different. Nonetheless, it was found that individuals were not entirely nocturnal, and had observable diurnal and crepuscular periods of activity. The seasonal analysis of activity patterns found a significant difference with a substantial nocturnal activity increase during the winter months.

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1. Introduction

1.1 Endangered species and Conservation: An Australian mammal perspective

Approximately 50% of global mammal extinctions in the past 200 years have occurred on the Australian continent, assigning Australia with the worst mammalian conservation rates globally (Short and Smith 1994). Close to half of Australia’s marsupial species have experienced dramatic reductions in their geographic range, with nearly one-quarter of marsupials now threatened with extinction (Maxwell et al. 1996). Since European settlement, the Australian landscape has dramatically changed through deforestation resulting in the fragmentation and habitat loss of native species (Jones et al. 2003). Deforestation combined with the introduction of exotic species and diseases has resulted in the extinction of 30 endemic species, and a further 109 mammal species are currently listed as threatened under the Environmental Protection and Biodiversity Conservation Act 1999 (Woinarski et al. 2015). Threats to these species are complex and generally have multiple factors influencing the decline of a population. In addition to habitat loss, many mammals have been identified as affected by the threats of predation or competition from introduced species such foxes (Vulpes vulpes) and the feral cat (Felis catus) (Short and Smith 1994; Woinarski et al. 2015). The decline affects medium-sized ground-dwelling species, particularly mammals (Jones et al. 2003). This pattern has been linked to the threat of predation, as the diet of foxes and feral cats include high proportions of mammal species (Davis et al. 2015).

Despite the knowledge of the mammalian decline rate and the factors influencing these events, less than 15% of carnivores have been the subject of conservation-based scientific research (Ginsberg 2001). This is likely a consequence of the difficulty with studying carnivores, due to their habit of occupying large home ranges in relatively low-density populations and that they require unique efforts for undertaking conservation projects. Nearly all major threats to species in Australia are not easily moderated through the designation of protected areas without additional management (Evans et al. 2011). Evans et al. (2011) suggests that distribution data alone is not enough to effectively manage a threatened species and that an assessment of the processes that threaten biodiversity and
the socioeconomic constraints associated with implementing specific conservation actions must be conducted to ensure the most effective management strategies are implemented.

1.2 Focal species: The Spotted-tailed Quoll

Of Australia’s large marsupial carnivores (> 500g), the Tasmanian devil (Sarcophilus harrisii) and four species of quolls are all either threatened or endangered at a National level (Jones et al. 2003). The spotted-tailed quoll (Dasyurus maculatus maculatus) is a carnivorous, typically nocturnal mammal that is adapted to a semi-arboreal lifestyle. One of the most disadvantageous aspects of their biology is that they tend to occupy large home ranges in very low densities. This significantly increases their chance of encountering a threatening process such as land clearing and consequently lowers their chance of surviving the threats. The south-east mainland population of spotted-tailed quoll is the current focus of conservation efforts, especially since the extinction of the eastern quoll (Dasyurus viverrinus) on the Australian mainland as recently as 1990 (Frankham et al. 2017). With the declining population of Australia’s carnivores and relatively recent extinction of the eastern quoll on the mainland, the focus on effective conservation practices at a species-specific level has never been more important. Such practices require a review of current strategies used to manage endangered carnivores and an assessment of the effectiveness of management plans at a landscape scale. The lack of site-specific data on the ecology and population dynamics of the spotted-tailed quoll impedes the development of appropriate conservation management and recovery plans. Data collected through intensive field studies over several years should provide more reliable information on the structure and dynamics of quoll populations from a specific site or location (Belcher 2003). Through the collection of site-specific ecological data, information on the impact of both current and future quoll management practices can be analysed, and the most effective actions for each region can be tailored and implemented.
1.3 Spotted-tailed Quoll (Dasyurus maculatus) Biology and Ecology

The spotted-tailed quoll is one of Australia’s largest extant marsupial carnivores and the largest of all six quoll species (Edgar and Belcher 1995). Their pelage is sandy-brown to dark reddish-brown, with an undersurface of white fur and irregular white spots covering their back, flanks and tail (Belcher 2000). The key features distinguishing the spotted-tail quoll from other quoll species is the large spotted tail and the presence of five, not four, toes on their hind feet (Figure 1) (Edgar and Belcher 1995). This is a sexually dimorphic species with males growing up to 1.3m in length from head to tip of tail and weighing up to 5kg (2.6 - 4.6kg average), while females typically grow to 85cm in length and weigh up to 3kg (1.5 - 2.2kg average) (Burnett 2001, Körtner et al. 2004, Belcher et al. 2008). The average lifespan is relatively short at 3-5 years; sexual maturity occurs around 11-12 months of age (Edgar & Belcher, 1995, Belcher 2003). The annual breeding season occurs during the winter months (April to July), producing an average litter of five young, often born between late July and mid-August after three weeks of gestation (Settle 1987; Belcher 2003). At seven weeks of age, the young can be left in the maternal den, exclusively raised by the mother who weans her young. After four and a half months of age the young are independent, and the males develop rapidly into larger animals, displaying obvious signs of sexual dimorphism (Settle 1978, Edgar & Belcher 1995). The period from birth to weaning has high mortality (17-50% from observed litters) (Belcher 2003, Glen 2008); however, there is also evidence of high annual recruitment of young into the population (Burnett 2001). Glen (2008) found that the timing of breeding was generally consistent, with little or no latitudinal trend. Winter breeding means that young reach independence in late spring or early summer when easily caught prey are generally most abundant (Belcher 2003).

The breeding season often correlates with peak activity in males who move outside their established home range to maximise the number of potential mate encounters (Belcher 2003, Glen 2008). This can be seen with increased activity at latrine sites during May and June before the breeding season, which are used to communicate reproductive status in the population (Dawson 2005, Ruibal et al. 2010). Independent young are found to still be close to their mother at 5-6 months of age (Andrew 2005).
Figure 1: Image of a spotted-tailed quoll from the Illawarra Highlands population captured by one of the infrared camera traps used in this study. The image of the quoll’s left flank shows the irregularly white-spotted pelage and tail.

1.4 Distribution and Habitat
The Spotted-tailed quoll has a broad but fragmented distribution along eastern Australia, extending from north-eastern Queensland to Tasmania (Figure 2). There are two subspecies of the Spotted-tailed quoll currently recognised: Dasyurus maculatus gracilis from north Queensland; and Dasyurus maculatus maculatus from south-eastern Australia and Tasmania (Long and Nelson 2016). Genetically, the south-east mainland population is sufficiently distinct from the Tasmanian (Tas) population to justify subspecies classification (Firestone et al. 1999); however it has not received formal recognition and remains apart of the mainland classification. The mainland population of D. m. maculatus is distributed from South-eastern Queensland (Qld), through New South Wales (NSW) down to western Victoria (Vic), but is now assumed to be extinct in South Australia (SA) (Edgar and Belcher 1995).

The Spotted-tailed quoll is known to inhabit a wide range of forest types including rainforests, woodlands, heathlands, and both wet and dry sclerophyll forests (Maxwell et al. 1996). They show a preference for extensively forested areas with a high annual mean rainfall and low temperatures (Catling et al. 2002, Wintle et al. 2005). Within these habitats, they use multiple dens as shelters and move between them every 1 to 4 days (Belcher 2000; Körtner et al. 2004, Belcher and Darrant 2006b). They have been recorded occupying rock
crevices, hollow trees and logs, caves and the burrows of rabbits and wombats; females are also known to dig their burrows if a suitable substrate is available (Belcher 2000, Andrew 2005). Although they are considered to be habitat generalists, Spotted-tailed quolls show preference to structurally complex habitats that provide suitable den sites and prey abundance (Belcher 2000, Belcher and Darrant 2006b). Preferred shelter includes dense over-story and under-story vegetation, abundant large hollow-bearing trees, large logs and rock outcrops (Belcher and Darrant 2006a, Nelson 2011). They appear to use drainage lines and gullies for movement, as prey density is the highest in these areas (Claridge et al. 2005, Belcher and Darrant 2006a, Nelson 2007). The Spotted-tailed Quoll requires large patches of forest with both high abundances of mammalian prey and suitable denning resources (Belcher & Darrant 2006a). The occupation of habitats and viability of populations are likely to be driven by these factors, and changes in landscape or habitat components can result in a change in site selection behaviour and distribution (Belcher 2000; Belcher & Darrant 2006a, Nelson 2007).

Figure 2: Distribution of the two Spotted-tailed quoll subspecies along the east coast of Australia and Tasmania. The distribution is defined by the records Pre and Post 1980 (image from Long and Nelson 2016)
1.5 Home range & spatial organisation

The Spotted-tailed Quoll displays solitary behaviour as adults, with populations occurring in low densities due to large home ranges. Females typically occupy a home range between 250 and 500 ha, while males have a much larger home range ranging from 875 to 6500 ha (Watt 1993, Burnett 2001, Belcher and Darrant 2004, Claridge et al. 2005). Females display intrasexual territoriality with minimal overlap between their home ranges. However, there has been an observed tolerance for juveniles and related females (usually daughters) within the natal range (Burnett 2001, Claridge et al. 2005). This territorial behaviour observed to secure food resources for breeding results in a limit on the abundance of females that occur over a suitable habitat area (Belcher 2003). Males display less territoriality that often results in overlapping home ranges encompassing many different females (Belcher and Darrant 2004, Claridge et al. 2005). Andrew (2005) found that there was a 48-64% overlap in male home ranges that typically encompassed the home ranges of 2-4 females.

A sex ratio of 5:1 (males to females) is suggested to occur in any female territory; however this ratio could be lower due to the increased capture of males from overlapping home ranges (Belcher 2003). The occupation of large home ranges correlates with this species’ ability to travel large distances in a short period. During the breeding season, males move among a number of female’s territories to monitor the fertility of the females within their territory (Belcher 2003). Typical movements are recorded to be up to 6 kilometres (km) in a day, with the breeding season increasing male movement (Andrew 2005; Claridge et al. 2005). The distribution of prey and partners may influence the spatial organisation, with the availability of prey influencing the distribution of breeding females (Belcher and Darrant 2004).

Spotted-tailed quolls are considered to be predominantly nocturnal; however more studies are finding that they are not restricted to complete nocturnal activity. Nearly 50% of females were monitored during daylight hours, with the most common diurnal activity occurring before 10:00 am and after 2:00 pm (Andrew 2005). Females are most likely to increase diurnal activity during spring when they have young left in the maternal den, while males are less likely to be active during the day with a significantly lower number of daylight observations (12%) (Belcher 2000, Andrew 2005). Andrew (2005) suggests that during the winter there could be a shift towards day-time activity due to the increased
thermoregulatory costs that occur at low temperatures. The occurrence of daytime activity could also be correlated with alterations in prey availability (Körtner et al. 2015).

1.6 Diet
This semi-arboreal species is a carnivorous, opportunistic predator with the bulk of its diet consisting of vertebrate prey (Belcher 1995, Jones 1997, Glen and Dickman 2006a, Dawson et al. 2007). They are active, solitary hunters that kill by leaping onto the prey and delivering powerful bites to the neck area (Jones 1997). From the analysis of scats, Glen and Dickman (2006a) found that medium-sized mammals such as greater gliders, rabbits, bandicoots and possums dominated their diet at 87.9%. The remainder of their diet consisted of insects (8.3%) such as beetles and cicadas, birds (1.5%) and reptiles (0.9%). Although very small amounts of vegetation were frequently found in scats, there was no evidence supporting deliberate consumption and is possibly ingested incidentally with the prey (Glen and Dickman 2006a). The results of a scat survey in the Illawarra highlands found that the most common arboreal prey were three possum species: the Greater Glider (Petaurides volans), Common Ringtail Possum (Pseudocheirus peregrinus) and the Common Brushtail Possum (Trichosurus vulpecula) (Andrew 2005). Spotted-tailed Quolls are also known to consume larger-sized mammals such as the Swamp Wallaby (Wallabia bicolor) and the Common Wombat (Vombatus ursinus) though most likely as carrion from road kill or remains left by foxes and dogs (Andrew 2005). The long, ridged footpads of the Spotted-tailed Quoll assist with climbing and preying on arboreal species such as greater gliders, the staple prey species known from southern NSW studies (Belcher 2000). They have been observed entering hollow-bearing trees during daylight hours to prey upon resting gliders (Belcher 2000).

Diets vary with access to different food resources depending on an individual’s sex, size and the season (Dawson et al. 2007). Although most studies are limited to small sample sizes, there appears to be an observable trend that the influence sex and body size have on diet. Typically, males consumed mainly medium-sized mammals, whereas the smaller females consumed a higher proportion of small mammals and insects (Jones 1997). Similarly, the effect of seasonal variations on diet is limited by a lack of long-term studies to account for any fluctuations in prey abundance or variations in seasonal activity (Glen and Dickman
The most evident seasonal behaviour occurs during the winter months, with increased reliance on mammalian prey due to low availability of other food sources (insects and reptiles) and the increased energetic requirement of the breeding season (Belcher 1995). Andrew (2005) observed more frequent consumption of large mammals in winter, while summer was found to have more insect remains present in scats.

1.7 Threats and Conservation
Since European settlement, the Spotted-tailed Quoll has suffered a substantial decline in both range and abundance. Through fragmentation and isolation, the Australian mainland population has experienced a reduction in its range by 50% (Jones et al. 2001), resulting in the Spotted-tailed Quoll to be listed as threatened in every state and territory it occurs in (Table. 1). Both subspecies, *D. m. gracilis* and *D. m. maculatus* (south-east mainland population), are listed nationally as endangered while the Tasmanian population (*D. m. maculatus*) is listed as vulnerable under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*. In NSW the Spotted-tailed Quoll, *D. m. maculatus*, is listed as vulnerable under the *Biodiversity Conservation Act 2016*.

By occupying large home ranges with a generally low population density, quolls have a higher chance of encountering threats and a consequentially lower chance of survival (Andrew 2005). Similarly, their short lifespan, low reproductive output, and male-biased dispersal, decreases their ability to repopulate areas that have become fragmented (Belcher 2003; Andrew 2005). The habitat and diet of the Spotted-tailed Quoll restricts their range to areas of large, intact forests that contain suitable prey abundance for the breeding females of the population (Belcher and Darrant 2006a). The threats of fragmentation, urbanisation and general removal of these areas can isolate habitats and result in habitat loss.

Long and Nelson (2016) lists some of the major threatening processes as habitat loss and modification, fragmentation, poison baiting and competition, and predation from introduced predators. The reduction of native habitats often results in the fragmentation of quoll populations. Small and isolated quoll populations have an increased vulnerability to local extinction from fire, fluctuating prey abundance, disease and inbreeding depression.
The reduction of habitat mainly occurs through the privatisation of land and urbanisation (Andrew 2005). An example of habitat reduction has been observed in south-east Qld where a decline in population has been attributed to clearing over 70% of the native habitat that once encompassed the local populations’ range (Maxwell et al. 1996).

Similarly, Andrew (2005) has suggested that urbanisation of the coastal regions in NSW pose a significant threat to important quoll populations. Long and Nelson (2016) lists poison baiting as another potential threatening process, as the 1080 poison baits are commonly used throughout the spotted-tailed quolls range and correlate with their dietary behaviours. Used to control Red fox and wild dog (Canis lupus familiaris) populations, the 1080 poison baits are highly toxic to these species but found to be somewhat less toxic to Spotted-tailed Quolls (Mcllroy 1981). Backhouse (2003) also investigated this issue and concluded that 1080 baiting is an indispensable tool for conservation through the control of fox populations. This is due to the competitive and predatory interactions occurring between the Spotted-tailed Quoll and multiple introduced species. Overall, extensive field studies found that Quolls are not as susceptible to fatal poisoning in the field as was initially thought during laboratory testing, possibly due to deterioration of dosage since deployment or other behavioural factors (Claridge and Mills 2007, Kortner 2007).

Due to overlap between habitat and diet, introduced species such as the Feral Cat, foxes and wild dogs are thought to suppress Quoll populations (Glen and Dickman 2005). Suppression occurs through resource overlap and has the potential for exploitation competition, not only between Quolls and predators, but also the predators themselves (Glen 2008). Foxes were found to be absent from areas containing relatively high populations of Quolls in northern NSW; however, there was no correlation found between the interactions of the two species (Catling and Burt 1995; Burnett 2001). Glen and Dickman (2008) observed extensive overlap between introduced species (foxes and cats) and quolls, indicating that the predators were coexisting with little exclusion. This is thought to occur due to the Quoll’s semi-arboreal hunting adaptions and niche partitioning of resources (Glen 2008). However, red foxes have been observed climbing trees in a camera-trapping study in NSW; potentially impacting the spotted-tailed quolls arboreal prey resource (Mella et al. 2007).
There is little direct data available on the impacts that introduced predators have on quoll populations, and any evidence of declining populations due to these species are likely to be magnified by another threatening processes; such as a fragmented population (Catling and Burt 1995, Long and Nelson 2016).

The Australian Government has produced a national recovery plan for the spotted-tailed quoll, providing information on actions necessary for conservation partners to successfully sustain threatened populations. The overall objective of the recovery plan is to reduce the rate of decline of spotted-tailed quolls and ensure viable populations remain throughout its current range in eastern Australia (Long and Nelson 2016). One of the key objectives of the Recovery plan is to determine the distribution and status of the spotted-tailed quoll populations, and to investigate the key biological and ecological characteristics of the populations to acquire targeted recovery information (Long and Nelson 2016). This requires the development of targeted survey techniques and monitoring protocols to assist with the surveillance and mapping of poorly studied populations. Through regular monitoring, the health, density and distribution of spotted-tailed quoll populations can inform the conservation partners (Office of environment and Heritage (SoS) and the National Parks and Wildlife Service) on the management parameters required to effectively prevent the decline of the species (Andrew 2005).

Table 1: The population status of the Spotted-tailed Quoll (D. m. maculatus) across all states and territories where they are still found.

<table>
<thead>
<tr>
<th>Location</th>
<th>Conservation Status</th>
<th>Legislation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queensland</td>
<td>Vulnerable</td>
<td>Nature Conservation Act 1992</td>
</tr>
<tr>
<td>New South Wales</td>
<td>Vulnerable</td>
<td>Biodiversity Conservation Act 2016</td>
</tr>
<tr>
<td>Australian Capital Territory</td>
<td>Vulnerable</td>
<td>Nature Conservation Act 1980</td>
</tr>
<tr>
<td>Victoria</td>
<td>Threatened</td>
<td>Flora and Fauna Guarantee Act 1988</td>
</tr>
<tr>
<td>Tasmanian population</td>
<td>Vulnerable</td>
<td>Environmental Protection and Biodiversity Conservation Act 1999</td>
</tr>
<tr>
<td>Australian South-eastern</td>
<td>Endangered</td>
<td>Environmental Protection and Biodiversity Conservation Act 1999</td>
</tr>
<tr>
<td>mainland population</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.8 Monitoring Techniques

1.8.1 Camera-trapping in conservation management

Camera traps are mounted camera units that are triggered when movement is detected or at prescribed time intervals. They typically record data through the capture of an image, series of images or video of an individual or group of animals (Swann and Perkins 2014). From the 1970s to the mid-1990s, camera traps were mainly composed of flash film cameras and infrared beams, however, current technological advance have resulted in smaller and more efficient digital camera units (Claridge et al. 2004, McCallum 2013, Meek et al. 2015). This has significantly increased the number of studies using camera traps and has been applied to nearly every aspect of vertebrate ecology (Swann and Perkins 2014). They are widely used to detect animals and estimate occupancy, range and habitat selection of species, as well as predator interactions (Swann and Perkins 2014, Austin et al. 2017). Most useful in their study of elusive or threatened species, cameras are often deployed in remote areas which would be otherwise inaccessible to conduct studies safely (McCallum 2013). Cameras can be installed passively or baited with a lure to attract animals, increasing both trap success and chances of capturing key morphological traits that assists in individual identification (Austin et al. 2017).

For individuals that possess unique markings or identifiable physical traits, individual profile population studies can be used to estimate occupancy, distribution and typical behaviour patterns (e.g. Trolle and Kery 2003, Silver et al. 2004, Soisalo and Cavalcanti 2006). This allows researchers to make rapid assessments of wildlife distribution, abundance, behaviour and community structure for conservation strategies and can quickly build a species database by deploying multiple cameras at once (McCallum 2013). Swann and Perkins (2014) identify the advantages of using a camera trap for monitoring as providing basic knowledge of the focus species, relatively inexpensive and practical to distribute, and relatively non-invasive. By encompassing a wide range of ecological applications, camera trapping is now considered as the cornerstone of biodiversity monitoring initiatives (Burton et al. 2015). This rapid generation of targeted data enables wildlife managers to determine the effectiveness of their conservation efforts faster and more reliably (Swann and Perkins 2014). This can be observed in the development of digital storage that enables the data to
be viewed in the field; therefore a real-time understanding of the investigation and possible problematic issues with the set up can be observed and corrected (Claridge et al. 2004).

Camera-trapping data can assist in developing hypotheses on the species and their associated behaviours (Kelly and Holub 2008). The cameras are relatively inexpensive and therefore efficient for wide deployment across large areas (Swann and Perkins 2014). Apart from the initial set-up of cameras in the field, it is significantly easier to sample a population with camera traps rather than live trapping as the camera can operate 24 hours a day in a wide range of habitats and weather conditions. This enables investigators to collect data in remote or dangerous locations much easier than if using another form of data collection (McCallum 2013). By using camera trapping, the effort and time to survey species decreases and this is particularly true for endangered or nocturnal species (Kelly and Holub 2008). The practicality of remote deployment also reduces the adverse effects that can be caused by more invasive methods, such as live-capture (Swann and Perkins 2014). Camera traps are relatively non-invasive and allow the monitoring of wildlife without constant physical capture and handling (Kelly and Holub 2008). This minimises the chances of wounding or stressing the focal species, influencing their behaviour through constant disturbance, and is generally safer for both humans and the animals under investigation (Swann and Perkins 2014, McCallum 2013).

By adopting camera trapping as a new method of surveillance, the rapid generation of targeted data can be collected. However, if data collection outpaces precise sampling designs and statistical analysis, then a false sense of progress can occur (Meek et al. 2014, Burton et al. 2015). Therefore, such surveys must address the variables that influence detection and common sources of sampling error. The most common source of error is imperfect detection, where there are individuals within the sampling area that are not always detected (Burton et al. 2015). Imperfect detection can occur due to individuals never passing the small detection zone and that an individual can be using an area that is assumed to be sampled by a camera (Figure. 3) (Burton et al. 2015). Another factor that causes imperfect detection is variables that can influence the individuals to alter their behaviour. The use (or type) of attractants, weather, trap shyness and ability to detect the individuals when present, are examples of variables that can significantly influence the behaviour and
therefore data of a camera trap survey (Swann and Perkins 2014). If an individual becomes either trap-happy (or shy), they are then considered to be a false representation of common population behaviour and an otherwise untrappable component of the overall population (Claridge et al. 2004). To ensure that the error of imperfect detection is minimised, it is suggested that an effort of approximately 1000 camera-trap nights is required to be confident that an individual is absent from an area (Carbone et al. 2001). This outlines the challenges facing the collection of data for Australian forest-dwelling mammals and investigating their cryptic behaviour accurately (Claridge et al. 2004). By developing straightforward methods that produce shareable data, effective conservation management strategies can be obtained from camera trapping studies (Austin et al. 2017).

Figure 3: The ecological and observational processes occurring at both local and regional scale of the study area that can influence the detection of animals (image from Burton 2015)
1.8.2 Individual identification of quolls

For species that possess unique markings, researchers are able to differentiate among individuals of a population; enabling density estimates and behavioural observations from camera-trap captures (Nelson et al. 2014, Austin et al. 2017). This was first studied by Karanth and Nichols (1998), who estimated the abundance of Tigers (*Panthera tigris*) in India by identifying unique stripe patterns along their pelt, and conducting a capture-recapture investigation. Since then this technique of individual profiling has been used in studies of cheetahs (*Acinonyx jubatus*) (Brassine and Parker 2015), ocelots (*Leopardus pardalis*) (Trolle and Kery 2003), jaguars (*Panthera onca*) (Silver et al. 2004; Soisalo and Cavalcanti 2006), and other species which are individually identifiable from their unique markings or patterns (Royle et al. 2009). This method of data collection, conducted through camera-trapping, has been used to address a wide range of wildlife management issues and assist in collecting specific data that is difficult to achieve with other methods (Swann and Perkins 2014). By using unique markings to monitor individuals, a reliable and effective monitoring method can be implemented in any study area, and can be an essential tool for the conservation and management of threatened species (Nelson et al. 2014). The ability to collect site-specific data is significant as, despite the importance of the spotted-tailed quoll in their ecosystems, their conservation status at a local scale is poorly described due to their cryptic and generally nocturnal behaviour; making them difficult to study (Claridge et al. 2004). The main advantage of using camera traps for monitoring and individual identification of spotted-tailed quolls, is that they can be deployed over large areas for long periods and require relatively low maintenance (i.e. infrequent battery changes, removal of obstructive camera site vegetation) (Meek et al. 2014, Nelson et al. 2014).

By identifying individuals through their unique markings, robust estimates of abundance and density can be made and their behaviour over the study period can be observed (Kelly and Holub 2008). However, some data gathered through live-trapping cannot be obtained through camera-trapping alone, and therefore there is a need to combine both techniques to ensure detailed phenotypic profiles for each individual are obtained (Swann and Perkins 2014). Physical capture or “trapping” of animals can be challenging and time-consuming, particularly in the landscapes that spotted-tailed quolls generally occur (Claridge et al. 2004).
2004). By using live-trapping as a secondary source of data, the effort of conducting a detailed investigation into this species is much easier.

1.9 Aims and Objectives

This research aims to assess the population demographics and spatial organisation of the spotted-tailed quoll population present in Budderoo National Park, Barren Grounds Nature Reserve, and Morton National Park; according to the species’ recovery plan, the population is the south coast stronghold population (see table 1.1, Long and Nelson 2016). This research is essential as any observable spatial and temporal trends in the quoll population at this site, including population numbers, current distribution, distribution of breeding females, males and juveniles, as well as site-specific threats, will inform management of the population. The specific objectives are to:

1. investigate the distribution and abundance of the Illawarra Highlands spotted-tailed quoll population through analysis of imagery collected during a 24-month camera trapping period and an annual cage trapping period;
2. identify the common activity patterns (across a 24 hr period) of the population;
3. analyse the demographic attributes of the same population (objective 1) that may assist in the implementation and monitoring of current and future management procedures;
4. assess the viability of using camera-trap surveillance as a monitoring tool for low-density endangered species in conservation.
2. Methods

2.1 Study Period
Sampling was performed from early September 2016 through to August 2018, for a total of 18,898 trap nights. Each camera was operational for approximately 703 days, with the 24 months of sampling including two breeding seasons and the appearance of two separate sub-adult cohorts. During this time two cage trapping periods were conducted in June 2017 and June 2018, for 9-10 nights during each month.

2.2 Study Area
Led by the NSW Office of Environment and Heritage (OEH) under the ‘Saving our Species’ (SoS) program, this study was conducted on a single population of quolls that spanned two National Parks and a single Nature Reserve within the Illawarra Highlands, NSW. This study investigated the population of Spotted-tailed Quolls in the whole of Barren Grounds Nature Reserve, Budderoo National Park and the northern section of Morton National Park (34°40’18.9"S 150°42’01.0”E); located approximately 30km south-west of Wollongong and 100km south of Sydney (Figure. 4). According to the recovery plan, this area is recognised as the ‘south coast stronghold population’ (see table 1.1, Long and Nelson 2016). The size of the study area is approximately 20,000 hectares (ha), located 13km inland from the coast at an elevation averaging around 600m. The mean daily temperature for summer is a high of 26.3°C and a low of 14°C, while the average daily temperature for winter is a high of 11.8°C and a low of 2.4°C (Bureau of Meteorology 2018). The average annual rainfall measured at the Wattamolla station (Griffiths, 34°43’15"S 150°38’57”E) is 1480mm with the wettest month of February (209mm) and driest month of September (91.7mm) (Bureau of Meteorology 2018). These three parks are part of a large group of sandstone national parks and reserves in the Sydney Basin. The topography of the Budderoo Plateau is flat to undulating, dropping off sharply at the escarpment edge that outlines the majority of the region. The heathland of Budderoo and Barren Grounds is one of four large areas of heathland on the south coast, combined with the woodland vegetation; it creates a diverse area that is home to a variety of plants and animals, including a number of threatened species (NPWS, 1998). Budderoo and Barren Grounds mainly consist of health swamps and woodlands with tall open forest patches on enriched soils. In the centre of Budderoo is a
cleared area of private land and both Budderoo and Barren Grounds connect with the Jamberoo Mountain Road. A more detailed description of this region can be found in Andrew (2005) and NPWS (1998).

2.3 Camera trapping

Quoll camera trapping data was obtained through the deployment of 29 RECONYX PC800 Hyperfire Professional Infrared cameras for a continuous 24-month capture. The cameras were distributed by NSW OEH throughout the study area at 29 predetermined locations by using a systematic grid method. The actual placement of the camera inside each grid was non-randomly chosen to increase capture success (i.e. drainage lines) and the ease of access for researchers to service the camera stations (Figure 5) (Belcher and Darrant 2004, Dawson 2005). Based on the home range and average daily movements of quolls, the cameras locations were determined by using 2km² spaced grids over the study area using

Figure 4: The study area of the Illawarra Highlands across Barren grounds Nature Reserve, Morton National Park and Budderoo National Park. Located on the south-eastern coast of NSW.
ArcGIS v10.4.1 (ESRI). The cameras were generally installed within 100 metres of a track inside each grid, aiming to place the camera near the grids centre when possible. To ensure independent observations, cameras were placed at a minimum of 1km between each other; however there were two exceptions (Nelson et al. 2014). To increase the likelihood of capturing photos of both flanks, sites within each grid that contained logs were chosen to entice quolls to walk along, drop down and come back to investigate. Similarly, to increase capture success cameras were deployed closer to drainage lines where possible to increase the possibility of detection (Belcher and Darrant 2004, Dawson 2005). The cameras were only installed on National Park land, where only a small portion of National Park tenure in a grid dictated camera placement. Inaccessible areas due to terrain or vegetation were unavailable for camera deployment. Once all cameras were deployed, the exact coordinates for each site were recorded.

The cameras were set for 24-hour operation, powered by 12 AA lithium batteries and using a passive infrared sensor to detect heat. Upon the detection of an individual, the cameras were set up to capture ten images on the rapid-fire setting (2 images per second) with no interval between each independent capture event to maximise the number of images captured in a single event. The camera trap recorded the time, date, and temperature of each capture onto the image, which was digitally stored onto a 8GB SD card. The infrared cameras were secured to a metal stake, generally 0.7 to 1 metre above the ground (Figure 6a). Each camera faced a bait station, where a 20 centimetre (90mm) PVC pipe was baited with chicken necks. The pipe was enclosed by a cap on one end, while the other used a metal mesh filter to allow the scent of the bait to escape (Figure 6b). Each baiting station was installed approximately 2-4 metres away from the camera (Figure 6c). The cameras were serviced, on average, every month to replace the bait, batteries and to change the SD card. Before leaving, any vegetation or debris that could obstruct the captures was removed to reduce the number of false triggers or unidentifiable captures (Meek et al. 2014, Claridge et al. 2004). Once the monthly service was completed, the camera was triggered to ensure operation.
Figure 5: The 29 camera trap locations (shown as the blue dots) for the study. The deployment location of each camera was determined using the 2km$^2$ systemic grid method (shown in red). The north-western corner of the study area containing cameras 1 to 3 is Morton National Park. The area starting from camera 24 is Barren grounds nature reserve. The remaining area between these two is Budderoo national park.
Figure 6: The Recoynx hyperfire 8000 camera (a) mounted to a metal post and the baiting station (b) which uses a 90mm PVC capped tube held in place by a large peg through the centre. The baiting station and camera set up (c) varied at each site depending on local topography, but was set generally 2-4 metres away facing the baiting station.

2.4 Cage Trapping

Spotted-tailed quolls were live-captured in wire mesh platform traps (30x30x60cm) baited with fresh chicken pieces (Figure 7a). A total of two trapping periods were conducted by NSW OEH in May to June 2017 and June 2018. This period was chosen as there was a greater chance of capturing males and females, given the likely increase in movement for the breeding season. By using the camera trapping data to inform areas of quoll occupation, the traps were set in these areas for a period of 9-10 nights. The cage traps were placed within 50 metres of a track, with two cages at each site. In the 2017 trapping period, 42 cage traps were installed and operated over ten nights. While in the 2018 period 57 cage traps were installed and operated over nine nights. They were checked daily within 3 hours of sunrise, cleaned, re-baited and reset for the next night. If a quoll was captured, the animal was handled within a soft, thick cotton bag. A scanner was used to check for previous microchips, and if it was a recapture from the current trapping period, it was weighed and...
released. If a new individual was trapped, before release, each quoll was marked by implanting a microchip, sexed, weighed and photos of each flank taken to assist in individual identification (Figure 7b). A tissue sample was taken for genetic analysis and the area surrounding the cage was scanned for any quoll scats that could be used for dietary analysis.

![Image](image.png)

**Figure 7**: A typical cage trap assembly (a) with the pad trigger located inside the cage, baited with chicken and black plastic used to protect the animal from exposure. Once captured, the sex of the quoll was determined, it was then weighed, a genetic sample taken and (b) a photo of each flank captured

### 2.5 Data Analysis

#### 2.5.1 Image processing and identifying individual quolls

Once the SD cards were retrieved from the field, all raw data was transferred to a desktop hard drive and filed according to the camera-trapping session and date of collection. Using the image tagging program ExifPro Image Viewer (http://www.exifpro.com/), the photographs were manually tagged by species name, unique events (e.g. two animals) or ‘false trigger’ in the event of non-wildlife captures. All capture images of Spotted-tailed Quolls were analysed by visual inspection to distinguish different individuals, and each was given a unique identity number (Hohnen et al. 2013). This technique uses the advantage of the quoll’s distinct individual markings to apply individual identification to the images captured at each camera trap (Royle et al. 2009). Individuals were identified based on spot patterns or distinct features on the body, tail and legs. To distinguish between individuals, a minimum of two (preferably three) uniquely spotted patterns or features were required to justify separate identification (Brassine and Parker 2015). If a pattern was deemed to be
sufficiently distinct from any other previous captures, then that was considered to be the first capture of a new individual. Any captures that had obstructed or obscured patterns were tagged as unidentifiable and only used for general, not individually specific, population analyses (Meek et al. 2016). A Quoll Identity kit was developed to assist with identification; this included up to five images of both flanks and other uniquely spotted features such as the tail, rear and top of the back (Figure 8). The identity kit also featured: the individual identification number, most frequently visited cameras and the individual’s sex (if available from cage-trapping). The individual Quoll identity of each capture were categorised and tagged in EXIFPRO, along with additional tags such as observable age (juvenile or adult).

The age estimation to determine if the individual is either a juvenile or adult in that specific capture is based on the Spotted-tailed Quolls biology and behaviour. With the breeding season in the winter months, the entry of the juvenile captures should coincide with the November to January period of young leaving the den for the first time and hunting around their mother’s home range (Andrew 2005, Belcher and Darrant 2004). They are also quite small, enough to be able to visually tell the difference from a juvenile male and an adult female (Figure 9). This was determined by using the size of the bait pipe to see the size of the individual, as different angles and layouts of the capture area can influence the appearance of an individuals capture. These captures were exported to a spreadsheet, and the capture records for each Quoll and camera site subsequently analysed (see section 2.5.2).
Figure 8: Quoll identity kit used to distinguish individuals for the tagging process. Example of individual profile for #14 (“double-dot”), including the tail, and any obscure or infrared images that could assist with identifying sub-optimal capture events. The red circles outline the distinguishable markings that were used to identify both flanks of this individual across all the captures of this study.

Figure 9: Images captured of quoll #24 as (a) a juvenile in December 2017 and (b) an adult in June 2018. This illustrates the clear differences between the two age categories as the juveniles are much smaller, fluffier and have slender limbs and head shape.
2.5.2 Data Analysis

Individual identification
To determine the population dynamics of the Illawarra Highlands quoll population, the camera-trap dataset was analysed using both profile-dependent analysis and live-captured population. To assign an individual identification number to a capture, the spot pattern in the images had to match one of the existing profiles that had both flanks of an individual recorded. However, not all camera sites and resulting captures produced images of both flanks, with some profiles created that have only ever captured a single side of the individual. These images were analysed against all existing profiles, and if proven without doubt to be a separate individual (by identifying a minimum of two uniquely spotted patterns), their profile is created containing only the single featured side (Brassine and Parker 2015). The identification profiles were used to calculate the minimum number of observed quolls. However, the one-sided profiles become a source of error with the chance that two single-sided profiles individuals could be the same quoll. To reduce error in the analysis, between the right-side only and left-side only flanked profiles, only the quolls with the right-side profiles were used as the primary profiles while the left-side profiles were treated as a source of error and excluded in the profile dependent analysis (minimum number of observed quolls, distribution of profiled individuals).

Capture duration
The duration of each camera-trap capture and its importance in this study was dependent on the definition of a single capture event. During any camera trap study, a single individual can trigger the camera multiple times in quick succession due to the continuous capture camera setting. A common source of error is to take each trigger as an independent capture that can over-represent the behaviour or activities of the general population. To reduce this source of error, the dataset was filtered by the rule that if the period between the last capture and the first trigger of the next capture was more than five minutes, then that is considered to be a separate capture event (Meek et al. 2016). If the individual is positively identified in consecutive captures less than five minutes apart, that event is considered to be a single capture. The total capture duration was defined as the time between the first capture and the last image where the individual was visible. The number of trap nights was
calculated for each camera site. A trap night required the camera to operate for that single 24-hour period successfully. Battery exhaustion and camera malfunction resulted in unsurveyed periods between visitations. A camera fail log was used to track these events, recording the start and end date of the malfunction.

2.5.3 Distribution and Abundance

Determining the demographics of an open population is difficult due to constant immigration, emigration, death and births that influence the number of individuals present at one time (Kelly and Holub 2008). Camera-trap studies often have the pitfall of taking their data as a snapshot representation of time (Meek et al. 2014). However, the individual profiling method can observe the introduction of new individuals and identify common residents in the area. To investigate the abundance of the spotted-tailed quoll in the Illawarra Highlands, we used the minimum number of observed individuals as an estimate. Abundance was calculated using the total number of profiled individuals and removing the profiles with the lowest captured single flank (i.e. seven only captured right-side and two on the left; we use the seven right-side profiles for analysis, and the other two are assumed as error). The remaining profiled individuals were used to produce a minimum number of quolls known to be alive. The dataset was then split into a two year period with the first year running from September 2016 to August 2017 and the second year running from September 2017 to August 2018. This shows the differences between the two years, the number of quolls still captured in the past 12 months and the annual introduction of sub-adults into the population.

To gain insight into the distribution and movement of the study population, ArcGIS was used to collate the total captures for each camera site. Spatial distribution was analysed by using the total number of captures (irrespective of profile or the unidentifiable proportion) to identify areas of highest quoll activity. A profile-dependent analysis was used to determine the sites that have the highest number of different individuals captured at each site (Silver et al. 2004, Royal et al. 2009). These two analyses determined the relative density of animals within the study area, including those with the greatest number of quolls and
highest activity over time. Lastly, the distributional data was used to determine movement patterns. The movement analysis was applied to the quolls that had been captured during the live-trapping periods to determine the difference between sexes. The greatest linear distance between captures, number of sites captured and the movement behaviour for both male and female quolls were mapped (Belcher and Darrant 2004, Körtner et al. 2004, Glen and Dickman 2006b).

To designate sex for individuals not captured during the two live-trapping periods, the distribution behaviour and appearance of the un-captured individuals was contrasted against the live-trapped population (shown in section 3.2.2). For this analysis, the selection of individuals was not restricted to any number of cameras or minimum length of time observed, as the classification was often determined by the low availability movement (ie. low dispersal behaviour for females). To justify the classification, the individuals had to meet two criteria of distinct morphological requirements and movement patterns that are common to their sex. Males were defined by their large home range and movement patterns, larger size and brutish, bulky heads (Figure. 10a). Females were identified by their smaller home range and movement patterns, smaller size, and their slender heads (Figure. 10b) (Burnett 2001, Körtner et al. 2004, Belcher et al. 2008). The distribution behaviour was calculated through the occupation of an area, as the difference between male and female quolls in regards to site occupation, and movement behaviour was large enough to appear distinctly on various individual camera trap datasets. Males can move large distances (greater than 2km) in short periods of time, often resulting in their presence at many camera-trap sites. Females rarely move great distances and are often found occupying a small home range (Belcher and Darrant 2004, Claridge et al. 2005, Glen and Dickman 2006b); therefore the females would have a low spread of captures across camera sites during the duration of the 24-month study period.
2.5.4 Spatial organisation

Camera-trap and live-trapping GPS coordinates were used to determine the minimum home range of individual quolls. By using a minimum convex polygon (MCP) on ArcGIS, the home range was defined as the area bounded by the smallest convex polygon containing all locations of each individual. A MCP produces larger estimates for more complex shapes, and has been used in a number of different radio-tracking and camera-trapping studies to estimate the home ranges for highly mobile species (Trolle and Kery 2003, Claridge et al. 2005, Glen and Dickman 2006b, Belcher and Darrant 2006a, Kortner et al. 2015, Meek et al. 2014). However, MCPs are often limited by including a significant portion of the area that cannot be used by the target species in the home range estimation (Meek et al. 2014).

The MCP estimate was used to compare home range sizes between male and female spotted-tailed quolls (Glen and Dickman 2006b, Belcher and Darrant 2006a, Kortner et al. 2015). Males are found to occupy larger home range areas and move greater distances over short periods of time; while females occupy smaller exclusive home ranges and move smaller distances (Burnett 2001, Belcher and Darrant 2004, Claridge et al. 2005, Glen and Dickman 2006b). All home range calculations were applied to the individuals that met the sufficient capture standards of at least three separate capture points over a monitoring period of a month. Once the MCP was applied to the individual, the ArcMap area measurement tool was used to calculate the total area of the estimated home range (Claridge et al. 2005, Belcher and Darrant 2006a, Kortner et al. 2015).

The greatest linear distance between each capture was calculated for live-trapped individuals to determine the difference between sexes (Belcher and Darrant 2004, Körtner et al. 2004, Claridge et al. 2005, Glen and Dickman 2006b). Using ArcGIS, the overall captures of each individual were mapped, and using the measurement tool; the linear distance between the furthest two points was calculated. A t-test was used to determine if the difference in movement distances between males and females was significant.

By tracking the individuals marked from birth, we can understand the movements of a juvenile and the difference of dispersal habits between males and females. By removing the sites initially captured as a juvenile, and creating an MCP around the adult captures, I
calculated the difference in juvenile dispersal between male and female quolls. ArcGIS was used to create the new MCP and measure the area of the adult home range. To measure the approximate distance of dispersal, the ArcMap measurement tool was used to find the distance between the juvenile capture and the centroid of each adult home range MCP.

2.5.5 Activity

Activity analysis was conducted at both the daily and seasonal level, to determine the temporal activity patterns of quolls within the study site. Daily activity was classified as diurnal if recorded between 1 hour after sunrise and 1 hour before sunset; nocturnal if recorded between 1 hour after sunset and 1 hour before sunrise; and crepuscular if recorded up to 1 hour before and after sunrise and sunset (Porfirio et al. 2016). The average sunrise and sunset times were obtained for each month in 2017 from the Geosciences climatic database and used to define all captures (GeoScience Australia 2018) (Appendix 1).

The seasonal activity was defined by four, 3-month seasonal periods that incorporate the lifecycle of a quoll, including the breeding cycle, sub-adult population entry and territorial behaviour. The summer season (December-January-February months) is typically when young are becoming independent and more activity around their natal site. Autumn (March-April-May) is the pre-breeding season and has the potential establishment of territories (Andrew 2005). The winter months (June-July-August) includes the breeding season and the females carrying small pouch young. Spring (September-October-November months) includes when young are deposited in dens through to when the young make short independent forages, as that is a time of heavy lactation demand on the mother (Andrew 2005).

Activity was assessed for the profiled individuals that met sufficient capture requirements; a minimum of ten separate captures over the span of minimum six months. This ensures the activity monitored is common behaviour for that individual. Activity was defined by using descriptive statistics of both sex and season categories. A chi-square test was applied to both categories and was used to determine if the captured activity was statistically significant.
3. Results

3.1 Basic Population demographics

3.1.1 Camera-trap captures

During the 24-month study, a total of 283,671 images were captured across the 29 camera sites. During this time, 55% of cameras (15/29) experienced periods of failure, ranging from 9 to 117 days of consecutive malfunction. The most common cause was battery exhaustion, with the more substantial periods resulting from camera malfunction (operational but not triggering). The collective number of trap night failures was 1,489 resulting in an overall effort of 18,898 trap nights.

Spotted-tailed quolls were recorded on 7% of the camera-trap images, representing 19,577 images or 1,939 captures across the study area. Over 50% of images came from the two most dominant captures: Swamp wallabies (*Wallabia bicolour*) and false triggers. Of the total number of images captured, approximately 27% were tagged as false triggers. These events were often caused by sunlit vegetation moving in windy conditions, resulting in consecutive triggers. Another 28% of all images were tagged with Swamp wallabies identified in the frame, often grazing in front of the camera for five to ten minutes. The remaining 38% of captures belonged to a variety of birds and mammals (Table 2).

Table 2: Species detected by camera-traps over a 24-month monitoring period in Budderoo National Park, Barren Grounds Nature Reserve, and Morton National Park.

<table>
<thead>
<tr>
<th>Species</th>
<th>% of total camera images (n=283,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swamp wallaby <em>Wallabia bicolour</em></td>
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<tr>
<td>False triggers</td>
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<tr>
<td><em>Rattus</em> sp.</td>
<td>11</td>
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<tr>
<td>Red fox <em>Vulpes vulpes</em></td>
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<td>Spotted-tailed quoll <em>Dasyurus m. maculatus</em></td>
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<tr>
<td>Common wombat <em>Vombatus ursinus</em></td>
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</tr>
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<td>Short-beaked echidna <em>Tachyglossus aculeatus</em></td>
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<tr>
<td>Birds</td>
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<td>Long-nosed potoroo <em>Potorous tridactylus</em></td>
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<td>Feral cat <em>Felis cattus</em></td>
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<td>Common ringtail Possum <em>Pseudocheirus peregrinus</em></td>
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<td>Other species</td>
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3.1.2 Live-trapping of quolls

The two NSW OEH live-trapping events, spanning 933 trap nights, resulted in 33 captures of 22 individual quolls (13 females; 9 males). The first trapping period in 2017 caught seven individuals (4 females; 3 males) over 420 trap nights. The second trapping period in 2018 caught 16 individuals (10 females: 6 males) over 513 trap nights. Only one quoll (#16, female) was captured during both trapping events. The number of live-captures increased between the two years, with 12 quolls captured in 2017 and 21 captured in 2018 (Figure 10). All individuals captured during the two live-trapping events were previously identified on camera and matched to their existing profiles.

![Figure 10: Total number of quolls captured in the Illawarra Highlands study area during 2017-2018. The values in brackets represent the number of trap nights conducted that year. The black colour represents males and the grey females.](image-url)
3.2 Abundance

3.2.1 Observable Population

The sampling effort of 18,898 camera-trap nights over 24 months resulted in a total of 699 independent captures of Spotted-tailed Quolls (19577 images, 1939 triggers). Twenty-four of the 29 infrared cameras captured quolls; the highest number of captures was in Barren Grounds. At Barren Grounds Nature Reserve there were 411 quoll captures (on 8/8 cameras), compared to 288 quoll captures (on 16/18 cameras) from Budderoo National Park and zero quoll captures (on 0/3 cameras) from Morton National Park. Cameras 24 and 27 recorded the highest number of quoll visits at 106 and 107 captures respectively. The next highest number of captures is from camera 17 that had a total of 82 captures (Figure 11). The high capture yield cameras were located closer to the east side of the study site in the Barren Grounds Nature Reserve and overlap of park boundaries between Budderoo and Barren Grounds. To the west of the study site, five cameras only recorded nine captures which were all located at camera 4. Cameras 1, 2, 3, 5 and 18 were the only five cameras that did not capture a single image of a quoll over the entire study.

There was an overall increase in the number of camera-trap captures across the 24-month camera-trapping period. The lowest occurred in October 2016 at a total of five captures and the highest occurring during the June and July months of 2018 with both totalling at 85 captures each (Figure 12). This can be attributed to the latency of detection that occurred on most cameras, with only nine cameras capturing quolls within the first seven months of the study. From September 2016 to April 2017 there is only an average of 3.8 cameras capturing quolls each month. After May 2017 there is a significant increase of activity on the cameras that remains fluctuating around an average of 10.6 cameras capturing images each month (Figure 13) (t=5.2, d.f.=22, p<0.001). The highest number of captures generally occurred during the May to August months and the November to January period, with the lowest number of captures, generally occurred from February to April (Figure 12).
Figure 11: The distribution of all spotted-tailed quoll captures (n=699) at the twenty-nine camera trap locations throughout Budderoo National Park, Barren Grounds Nature Reserve and Morton National Park. The coloured circles represent the number of quolls appearing at each camera over the entire 24-month study period.
**Figure 12:** Monthly total number of spotted-tailed quoll captures from September 2016 to August 2018 across Budderoo National Park, Barren Grounds Nature Reserve, and Morton National Park. The spotted-tailed quoll captures were collected through a 24-month camera-trapping period.

**Figure 13:** The total number of cameras that captured a spotted-tailed quoll each month, across the entire 24-month study.
3.2.2 Profile-dependent demographics

Of the 699 captures, 93.7% were individually identified. A total of 64 identification profiles were created with 51 quolls identified using both the left and right flanks of the body (Table 3). The number of individuals recorded at each camera varied from 0 to 14. Cameras 24 (n=14) and 25 (n=12) recorded the highest number of individuals (Figure 14). The cameras with the lowest number of captures occurred in the northern section of Budderoo with only cameras 7 and 12 yielding more than three individuals from each site. Camera 25 had the highest ratio of total captures to the number of individuals seen at 4:1 (Figure 14).

The number of individuals captured on camera notably increased between the two 12-month camera-trapping periods. A total of 24 individual quolls were observed in the first 12 months, followed by 48 quolls in the second 12-month period (Table 3). Of the 24 first year individuals, only 62.5% (n=15) were observed in both the first and second year, with a total of 33 new individuals identified from September 2017 to August 2018 (ie. second year of study). Of the 48 quolls captured in the last second 12-month period, a total of 30 were captured during the most recent breeding season (June to August 2018). The first 12-month period saw an average of two new individuals each month; while during the second year, this increased to four (Figure 15). Irrespective of year, November to January and June to August had the highest number of captures (Figure 16). The November to January period typically yielded more juveniles.

Across the 24 months, a total of 22 quolls were observed as juveniles with 12 caught during live-trapping periods. Spatially this is attributed to two subsequent breeding events. Initially, during the 2016 sub-adult introduction period we captured nine juvenile quolls across the camera-traps, while in the 2017 period we captured 13. In contrast to the introduction of quolls into the Illawarra Highlands population, there have been two recorded instances of quoll mortality during this study. The first was #31, a juvenile that was found dead on a walking trail, and the second was #8, one of the most prominent males in this study, who died from old age. He was first captured in October 2016 and was found dead in February 2018 by wildlife officers. The last captures of #8 saw patches of lost fur and sores developing on the body (physiological signs of aging).
Figure 14: The distribution density of the profiled spotted-tailed quolls. The coloured circles represent the number of profiled individuals appearing at each camera over the entire 24-month study period.
Figure 15: The number of spotted-tailed quoll profiles created each month during the study period. The number of profiles across the study period is accumulative, with each monthly value representing the number of quoll profiles created in total during each month.

Figure 16: The raw number of profiled individuals that were captured each month, across the 24-month study period.
Table 3: Summary of the 64 individually profiled quolls captured on camera-traps across Barren Grounds Nature Reserve and Budderoo National Park. The sex of each quoll (if determined) is listed, next to the criteria of which it was determined. Similarly, this table presents if the individual was captured as a juvenile. The total number of camera-trap captures, the length of each observation, and the presence of the individual in each of the two 12-month periods of this study. Unavailable results are represented by a dash (-).

<table>
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<th>Juvenile Capture</th>
<th>No. of Captures</th>
<th>Observation Length (months)</th>
<th>Yearly Presence</th>
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<td>25</td>
<td>699</td>
<td>24</td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

* These individuals were profiled using only their left-flank. As the number of right-flank profiles is higher than the number of left-flank profiles; the left-flank profiled quolls were excluded from profile dependent analyses as they are a possible source of error (double-profiling) (see section 2.2.5).
3.2.3 Assumed sex

Through the analysis of the Illawarra highlands spotted-tailed quoll population, we have identified the differences of behaviour and organisation between males and females. By using these findings, we can make an assumption as to the sex of non-trapped individuals that met both set criteria (morphological requirements and movement patterns). Of the 42 non-trapped individuals, a total of 14 quolls met the criteria to justify an estimation of sex (Table. 4). All of these individuals met the morphological requirements of the first criteria, with the males identified by their large body and brutish head, contrasting to the smaller, slender headed females.

Four individuals met both justification criteria, a total of two males and two females. In addition to their morphological and distribution differences, these individuals met the requirements to estimate home range size (Figure. 17). We found that the home range of the two males (1632ha, and 1832ha) was similar to the live-captured male’s home range mean of 2350ha (Table. 6). In addition to the captured mean, the two males are also similar to the established adult home ranges found from the juvenile dispersal analysis (Table. 7). The two females have smaller home ranges at 264 and 207ha, similar to the live-captured female mean of 132ha (Table. 6). These four quolls also have similar distributional differences observed between the males and females of the captured quolls. The two males have a larger distance between two captures at 10 and 13km, in contrast to the two females that only travelled 3.6 and 3.9km. This is similar to the mean distances of males and females at 8.49km and 2.14km respectively (Table. 5).

The remaining ten quolls (five males and five females) met both criteria. However, as their camera-capture distribution did not meet the requirements, their home range could not be estimated. In addition to their morphological justification, the distributional behaviour of these quolls meets the requirements of the second criteria. The males were found to move vast distances in relatively short periods of time, ranging from 8 to 13km in as little as a month. Three of the males were captured on camera as juveniles; however, they were only recorded at one camera after the initial capture. We captured the juveniles between November and January and six months after their natal capture, and they moved an average of 8.95km (SE=0.42) from their natal camera. The five females were only captured on one to
two cameras for extended periods of time (3-17 months). This is similar to the average number of cameras for females and matches their low dispersal behaviour (Table 6).

Table 4: A total of seven male and seven female spotted-tailed quolls met the two criteria (morphological requirements and movement patterns) to estimate sex. The home range calculation requirement was only met by two males and two females. The number of cameras, length of observation and overall number of captures for each profiled quoll is displayed in this table. For individual that were captured on more than one camera, the greatest distance between cameras was calculated and displayed as max distance. Unavailable results are represented by a dash (-)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Individual ID#</th>
<th>No. of cameras</th>
<th>Observation length (months)</th>
<th>No. of detections</th>
<th>Maximum movement distance (km)</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
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<td>Males</td>
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<td>1</td>
<td>2</td>
<td>12.91</td>
<td>-</td>
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<td>12</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>10.47</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>7</td>
<td>12</td>
<td>52</td>
<td>9.16</td>
<td>1832</td>
</tr>
<tr>
<td></td>
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<td>3</td>
<td>3</td>
<td>8.70</td>
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<td>11</td>
<td>9</td>
<td>1.67</td>
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<td></td>
<td>40</td>
<td>3</td>
<td>4</td>
<td>15</td>
<td>3.65</td>
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<td>4</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 17: The home range of four quolls that were not captured during the two live-trapping periods. This Figure demonstrates the similarities between the four quolls and the captured portion of the Illawarra highland population. The two females are the purple (6) and pink (40) lines. The males are the yellow (14) and orange (34) lines.
3.3 Distribution

3.3.1 Sex-based spatial organisation

Males were widely distributed throughout both Budderoo and Barren Grounds and captured on 72% of the camera traps (Figure. 18). The females were primarily found within Barren Grounds, with only five of the 13 females captured in the centre of Budderoo. The females were captured on 45% of the camera traps, occupying the eastern side of the study area and only captured as west as camera 15 in Budderoo (Figure. 19).

We found there was a significantly higher linear distance between captures for the male quolls ($t=5.5$, d.f= 14, $p<0.001$). The males’ greatest linear distance ranged from 4.78 to 14.25km with a mean of 8.49km (SE=1.11). The distance of the female quolls ranged from 1.43 to 3.65km with a mean of 2.14km (SE=0.254) (Table. 5).

Table 5: Greatest linear distance between two points in an individuals captures gives an indication of the scale of movement undertaken by Spotted-tailed quolls in the Illawarra Highlands. The detections are across the entire study period.

<table>
<thead>
<tr>
<th>Males ID#</th>
<th>Greatest linear distance between locations (km)</th>
<th>Females ID#</th>
<th>Greatest linear distance between locations (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>14.25</td>
<td>3</td>
<td>1.67</td>
</tr>
<tr>
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<td>11</td>
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<td>16</td>
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<td>2.13</td>
</tr>
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<td><strong>Mean</strong></td>
<td><strong>8.49</strong></td>
<td><strong>Mean</strong></td>
<td><strong>2.14</strong></td>
</tr>
</tbody>
</table>
Figure 18: The coloured circles represent the records of each male quoll capture. A total of nine males are represented across Budderoo National Park, Barren Ground Nature Reserve, and Morton National Park.
Figure 19: The coloured circles represent the records of each male quoll capture. A total of thirteen males are represented across Budderoo National Park, Barren Ground Nature Reserve, and Morton National Park.
3.3.2 Home range estimates

Minimum home range estimates were made for eight males and eight female Spotted-tailed quolls that had three or more points of capture (Table 6). The estimates were determined by using a minimum convex polygon (MCP) to measure the minimum captured area. Males had significantly larger home range size compared to females (t = 3.8, df=16, p< 0.0018). The minimum home range for the eight males ranged between 457 - 4928ha with an average of 2350ha (SE = 574.3); the minimum home range for the eight females ranged between 47 – 437ha with a mean of 170ha (SE= 52.9). We found that the male home ranges overlapped each other, often occupying areas with other males and a number of different female home ranges (Figure 20). Similarly, some of the female home ranges were overlapping; however, this could represent different periods of occupation across the 24-month study period (Figure 21). By using an MCP around all capture sites of both sexes, males were found to occupy 45% of the total monitored area, while females occupied a total of 15%.

Table 6: Minimum home range estimates for Spotted-tailed Quoll population in the Illawarra Highlands. A total of eight males and six females sufficiently met the minimum 3-point capture requirements. The Minimum home ranges were obtained using the Minimum Convex Polygon (MCP) method. The locations were obtained from the positive identification on camera-trap captures and trapping. This table shows the number of months a trapped individual was observed, the number of cameras appeared on (the values in brackets represent the number of live-capture coordinates used in the calculation) and the minimum area seen.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Individual ID#</th>
<th>No. months captured</th>
<th>No. of cameras</th>
<th>Area (h)</th>
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<tbody>
<tr>
<td>Males</td>
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<td>20</td>
<td>9</td>
<td>4928</td>
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<td>8</td>
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Females

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<th>No. months captured</th>
<th>No. of cameras</th>
<th>Area (h)</th>
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Figure 20: Eight male spotted-tailed quoll minimum home ranges in the Illawarra Highlands. The greatest home range area was calculated by the minimum convex polygon method on camera and trapping locations for each individual. Not all individuals were contemporary and apparent overlap of home range may have only occurred after the movement or disappearance of individuals.
Figure 21: Six female spotted-tailed quoll minimum home ranges in the Illawarra Highlands. The greatest home range area was calculated by the minimum convex polygon method on camera and trapping locations for each individual. Not all individuals were contemporary and apparent overlap of home range may have only occurred after the movement or disappearance of individuals.
3.3.3 Juvenile Dispersal

A total of four juvenile males and eight females from the camera-trapping data met the requirements to calculate their home range by using the minimum convex polygon method. Males were found to move an average of 6km away from their natal home range and to establish a new adult home range (Table 7). Out of the four males monitored, all but one was observed switching from Budderoo to Barren Grounds (Figure 22). The female quolls were observed only moving short distances to establish their adult home ranges, often located on or close to their natal home range camera. Most of the juvenile captures occurred from November to January, with the establishment of their adult home ranges occurring six months after this time. By removing the initial juvenile captures and the home range of the adult quoll can be observed. The establishment of adult home ranges resulted in a substantial reduction of initial home range estimates (Table 7). By including the captures of a juvenile male in their home range estimates, the established adult home range could be up to 45% smaller than initially calculated.

Males: Individual dispersal profiles

#9 was first located as a juvenile at camera 22, located near the entrance to Barren Grounds. He appeared on this camera for two months and then was seen six months later from the first capture at camera 9. As an adult, #9 moved among five cameras located in the southern area of Budderoo. This initial Barren Grounds birth resulted in a southern Budderoo life approximately 7km away.

Quolls #11 and #4 exhibited the same movement as #9 following a birth at Budderoo that lead to a Barren grounds dominant home range. #4 was captured as a juvenile at camera 16, located in the centre of Budderoo. He then was captured five months later at camera 23, located at the entrance of Barren Grounds. As an adult, #4 rotated around six cameras and was most recently captured at Barren grounds on camera 22. #11 was captured as a juvenile at camera 17, located along the southern ridge of Budderoo. He was observed at this camera for six months before he was captured at camera 28, located along the eastern ridge of Barren Grounds. He rotated among five cameras as an adult and occasionally was detected moving outside Barren Grounds; however, the majority of captures is found within
the Barren grounds reserve. These two quolls are examples of juvenile dispersal occurring from an initial Budderoo birth to an adult home range located in Barren Grounds as both #4 and #11 moved 8 and 5km respectively.

The fourth quoll, #18 was captured as a juvenile at camera 14, located in the centre of Budderoo. Approximately six months later he was captured at camera 15, nearly 4km north-west of his first capture. As an adult, he was captured on three cameras, all located in the north-western area of Budderoo. This male was the only one observed to not switch between Budderoo and Barren Grounds; instead, he moved from the middle of Budderoo to establish an adult home range nearly 6km away from the first capture.

Females: Individual dispersal profiles
There were three females captured during the first juvenile introduction in 2016. Quoll #15 and #20 were both captured on their natal range camera right through to adulthood, while #16 moved south from her natal range at camera 22 to establish her adult range near camera 24. Each of these females was observed for a single capture on a neighbouring camera before resuming their regular captures on the natal camera. We captured five females as juveniles during the second introduction in 2017. Quolls #13, #24, #25 and #41 were all captured on their natal camera right through to adulthood, with #41 being the only female quoll occupying a home range in Budderoo at camera 14. Quoll #3 was first captured on camera 25, six months later she appeared to move north to camera 24.

Table 7: The total home range of four males, including the juvenile captures. The adult established home range is excluding the juvenile capture and results in an overall reduction of estimated home range.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Total home range (ha)</th>
<th>Adult Established Home range (ha)</th>
<th>Home range reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4928</td>
<td>1529</td>
<td>69%</td>
</tr>
<tr>
<td>9</td>
<td>3031</td>
<td>2257</td>
<td>25%</td>
</tr>
<tr>
<td>11</td>
<td>1134</td>
<td>878</td>
<td>23%</td>
</tr>
<tr>
<td>18</td>
<td>1842</td>
<td>613</td>
<td>67%</td>
</tr>
</tbody>
</table>
Figure 22: The movement for juvenile spotted-tailed quoll males from their natal site to the establishment of an adult home range. The coloured dots represent the natal capture of the quoll and the polygon is the observed adult home range. The lines dictate the movement from natal capture to the centroid of each home range polygon.
3.4 Activity

3.4.1 Daily Activity

Monitoring of the Illawarra highlands quoll population found that they are not exclusively nocturnal from this study location. Of the 699 captures, 49% of the activity was nocturnal, with diurnal activity at 29.5% and crepuscular activity at 21.5%. The quolls were very active before dawn rather than after dusk, with the peak of activity found at 0500 (Figure. 23). From 0900 to 1500 quoll activity dropped markedly, and at 1300 activity was lowest. After 1500 activity increased to the high values seen before dawn. The highest daily activity occurred between midnight and sunrise. Nocturnal and crepuscular activities were similar with an average of 34, and 35 quoll captures respectively caught per hour; diurnal activity was lower and during this time 20 quolls per hour were recorded.

There was no significant difference between males and females for daily activity ($\chi^2 = 7.641$, d.f.=5 p<0.1772). Males were observed to be active after midnight with peaks at 0100 and 0300. Male activity dropped fastest from this period to the lowest recording of zero at 1200. Male activity slowly increased to the activity levels noted after midnight (Figure. 24). Females showed greater crepuscular and diurnal activity than males with their activity peak occurring between 0400 and 0800; the highest activity levels were found at 0600. During diurnal hours females were slightly more active than males were.
Figure 23: The total number of captures of in each hour of the day across the 24-month study. The dotted grey lines note the general period where diurnal, crepuscular and nocturnal activity occurred over a 24 hour period.

Figure 24: The total number of captures of males and females in each hour of the day across the 24-month study. The red line represents the female quoll activity and black is male quoll activity.
3.4.2 Seasonal Activity

A significant increase in the level of nocturnal activity was found during the winter months ($\chi^2 = 36.6$, d.f= 11, p<0.0001). The nocturnal activity for the other seasons ranged between 49 to 73 captures; however, the winter nocturnal activity was found to be 166 (Figure. 25). Winter was found to have the highest count of crepuscular activity at 73 captures. The lowest number of captures occurred during autumn at 20 captures. The highest level of diurnal activity days occurred during summer at 69 captures, with the lowest occurring in autumn at 27. It was found that both sexes exhibited the same activity behaviour with the highest level of nocturnal activity occurring during winter. Females generally had higher levels of activity throughout the year while males seemed only active at night. In the winter period, male quolls significantly increased their nocturnal, crepuscular and diurnal activity levels.

![Figure 25: The total number of captures recorded in the three activity categories (nocturnal, crepuscular and diurnal) the seasons across the 24-month study. The blue is nocturnal activity, red is crepuscular, and green diurnal.](image-url)
4. Discussion

4.1 Summary of results

The central aim of this thesis was to investigate the Illawarra Highlands Spotted-tailed Quoll population in Budderoo National Park, Barren Grounds Nature Reserve and the northern section of Morton National Park; a recognised stronghold location of the species. Specifically investigated, was the distribution, abundance, spatial organisation and temporal behaviour of the quoll population through a 24-month camera-trap monitoring program. This study is the first to investigate the Illawarra Highlands spotted-tailed quoll population. To date, there is no published research on this population or species in the study location and as such very little data available to guide conservation management. The results of this study assist in determining the most effective conservation management practices for the quoll population and assessing the viability of using camera-trapping as a monitoring tool for a low-density endangered species. While the results of this study are at a local scale, the findings also contribute to the wider context of spotted-tailed quoll conservation across Australia.

This study has found that the population occupies both Barren Grounds Nature Reserve and Budderoo National Park. The highest quoll activity occurred in Barren Grounds, with a majority of the profiled females establishing their home range in this area. A significant increase in the number of captures was identified between the two 12-month periods. The highest captures occurring from November to January and June to August. By analysing the spatial organisation of the males and females, we found that the home range and movement of males are significantly larger than the females. Using the biology, spatial organisation and movement patterns of these quolls, we estimated the sex of another 14 profiled individuals to be seven males and seven females; bringing the total to 16 males and 20 females. By following the dispersal pattern of the individuals captured on camera from a juvenile age, it was found that males moved far away from their birthplace to establish a new adult home range. Female quolls typically occupied the area near their natal home range. Through an analysis of quoll activity on both daily and seasonal ranges, there was
observable diurnal and crepuscular activity and significantly more nocturnal activity in the winter season.

4.2 The Illawarra Highlands Population

Based on the 699 camera-trap captures within the study area, it was found that the spotted-tailed quolls were not evenly distributed across the landscape. The highest density of captures occurred in Barren Grounds Nature Reserve and the centre of Budderoo National Park, while in Morton National Park no quolls were captured during the 24-month study. In the northern area of Budderoo, multiple quolls were captured; however, a more detailed investigation of the data revealed no sign of consistent occupation from any of the individually profiled quolls (irrespective of sex). This distribution appears to be dependent on habitat suitability as seen in other studies on spotted-tailed quolls in NSW, including Belcher and Darrant (2004) and Claridge et al. (2005). The Barren Grounds area has large intact areas of dense forest, while the northern area of Budderoo National Park is intersected by a major road and has patchy vegetation. These attributes could determine the distribution of the spotted-tailed quolls throughout the study area as the availability of suitable habitats is markedly higher in Barren Grounds than other areas investigated in the study.

Data generated from the camera-traps suggest that the Illawarra Highlands spotted-tailed quoll population has increased over the 24-month monitoring period. This could have occurred in response to either a change in this studies trapping effort or a change in the population itself. As the effort of the camera-trapping has remained constant from the start of the study in September 2016 through to the last data extraction in August 2018; the observed increase is more likely a representation of a change in population behaviour. The increase in captures could be a result of culling success of red foxes that are sympatric competitors (Long and Nelson 2016).

Identified were two distinct peaks of detection that resulted in an increase of profiled individuals. The first peak from November to January observed an increased number of juveniles and identifies the period of which they begin to leave the den and become independent (Andrew 2005). The second peak occurred from May to August and correlates
with the observed increase in quoll movement during the breeding season. Similarly, Glen and Dickman (2006b) noted that trap success peaked in the mating season, reflecting the greater mobility of males at this time. Belcher (2003) also observed this pattern and suggested that the breeding season is the most ideal time to conduct trapping surveys to capture more individuals.

4.3 Home range and spatial organisation

4.3.1 Home range size

Spotted-tailed quoll populations are widely distributed through a variety of forest habitats, with males and females occupying large home range areas. The size of male home ranges is, on average, significantly larger than the females. However, the range has been observed to vary between different habitats and study sites (Claridge et al. 2005, Belcher and Darrant 2004, Körtner et al. 2015). The adult Spotted-tailed Quolls in the Illawarra highlands were found to range from 457-4928ha (mean 2350ha, n=8) for males and 47-437ha (mean 170ha, n=6) for females (table 3.2).

These results are comparable with the findings of Belcher and Darrant (2004) for radio-tracked spotted-tailed quolls in the high altitude eucalypt forests of south-eastern Australia (Table. 8). In this area the male home range size ranged from 687-4186ha with a mean of 1755ha and the females ranged from 185-1157ha with a mean of 495ha. Similarly, Körtner et al. (2015) found a mean male home range of 1549ha (±808ha) and a mean female home range of 509 (±152ha) in a radio-tracked population located in north-eastern NSW. Both these studies found similar home range sizes to the Illawarra highlands population, however, of the three sites that Belcher and Darrant (2004) surveyed, it was found that the mean female home range rarely differed, opposed to the male home range which varied significantly between sites. The variation of home range size between sites is apparent in Claridge et al. (2005) who radio-tracked a population in a rain shadow woodland in southern NSW. The home range sizes of both sexes were much smaller in comparison to the Illawarra Highlands population, with a 244ha (±72) mean for females and 992ha (±276) for males. Similarly, Glen and Dickman (2006b) found smaller means for both females at 133ha and males 343ha in north-eastern NSW.
Table 8: Comparison of the spotted-tailed quoll MCP home range sizes from multiple studies across New South Wales. Unavailable results are represented by a dash (-)

<table>
<thead>
<tr>
<th>Location</th>
<th>Male home range (ha)</th>
<th>Female home range (ha)</th>
<th>Reference</th>
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<td>Range</td>
<td>Mean</td>
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<td>495</td>
</tr>
<tr>
<td>Byadbo, NSW</td>
<td>992 ±276</td>
<td></td>
<td>244</td>
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<tr>
<td>Marengo State Forest, NSW</td>
<td>343 -</td>
<td>133 -</td>
<td>Glen and Dickman (2006b)</td>
</tr>
<tr>
<td>Tuggolo State Forest, NSW</td>
<td>1549 ±808</td>
<td>504 ±152</td>
<td>Kortner et al. (2015)</td>
</tr>
<tr>
<td>Illawarra Highlands, NSW</td>
<td>2350 457-4928</td>
<td>170 47-437</td>
<td>This study</td>
</tr>
</tbody>
</table>

Our results confirm that spotted-tailed quolls occupy large home ranges, with a significant difference in size between males and females. The Illawarra Highland males are found to have large, overlapping home ranges that are consistent with other populations investigated across NSW (Belcher and Darrant 2004; Körtner et al. 2015; Claridge et al. 2005, Glen and Dickman 2006b). The species is solitary, and the home ranges are likely determined by the distribution of females in the landscape (Körtner et al. 2015, Belcher and Darrant 2004). The organisation of the female quolls is primarily determined by the availability of denning and foraging areas and their interactions with other females (Belcher and Darrant 2004, Glen and Dickman 2006b). The home range of adult females is defined by their intrasexual territorial behaviour with minimal overlap occurring between neighbouring females (Belcher and Darrant 2004, Claridge et al. 2005, Burnett 2001). By using this territorial behaviour to secure resources, the number of females that can occur over a suitable area is limited (Belcher 2003). In the Illawarra highlands area, the majority of the captured female population were located within Barren Grounds. The dense woodlands and rocky outcrops of the surrounding ridges and gullies in this area may provide the female quolls with suitable denning and foraging resources for maternal care (Belcher 2000, Nelson 2011, Belcher and Darrant 2006). What this distribution may account for the females having a smaller home
range size in the Illawarra Highlands as the area of Barren Grounds in comparison to the entirety of the study area is quite small.

The significantly larger home ranges occupied by the male quolls also resulted in having much larger movements. The greatest distance between capture sites of individual quolls in the Illawarra Highlands was consistent with previous studies, finding that the male quolls moved significantly further than females (Belcher and Darrant 2004, Körtner et al. 2004, Clardige et al. 2005, Glen and Dickman 2006b). The greatest linear distance between two captures for the males ranged from 4.78-14.25km (mean 8.49km, n=8), while females ranged from 1.43-3.65km (mean 2.15km, n=8) (table 3.1). The results were similar to those recorded by Glen and Dickman (2006b) of 5.3km for males and 2.9km for females; however, the males in the study appeared to move much greater distances. Other studies recorded the daily movements of males ranging between 2.3-6.6km and the females ranging between 1.28-2.6km (Burnett 2001, Körtner et al. 2015, Glen and Dickman 2006b). Similarly, these daily observations show a significant difference between the movements of male quolls in comparison to females. This behaviour is consistent with the increased movement of males, particularly during breeding season, to maximise the number of females encountered (Belcher 2003, Glen and Dickman 2006b).

4.3.2 Juvenile Dispersal

Understanding the behaviours of juvenile quolls and their introduction to the adult population is of great importance to the conservation of threatened spotted-tailed quoll populations. However, few studies other than captive animals follow juveniles through weaning and beyond (Andrew 2005, Dawson 2005). Previous studies have identified the adult females display natal philopatry for juvenile or sub-adult females, with the daughters possibly inheriting some of the mother’s home range area (Firestone et al. 1999, Belcher and Darrant 2004, Körtner et al. 2004). Andrew (2005) observed sequential occupation of mothers and daughters, as the mother was seen moving away from her daughter, while the daughter moved a little south in the mother’s home range. The juvenile males are known to leave the area, however, due to the difficulty of monitoring them after the weaning period.
and the high infant mortality rate, very little is known after this period (Firestone et al. 1999, Belcher 2003).

This study found that juvenile males move a notable distance away from their natal site, while the juvenile females often occupy an area next to their natal range. The juveniles captured on camera typically weaned off their mother around December to January and appeared as independent generally five to six months after this time. All the females observed in the Illawarra Highlands occupied the same capture site as their mother, even after the weaning period. This is consistent with the findings of Andrew (2005) that shows natal philopatry between mothers and daughters and the sequential occupation of home ranges. In contrast, the juvenile males moved great distances (up to 8km) away from their natal site, with the establishment of their adult home ranges typically six months after weaning.

The dispersal of juvenile males is significant as it implies genetic variation between local quoll populations. The genetic diversity within and between quoll populations are largely unknown; with the isolation of low-density populations possibly resulting in deleterious genetic effects (Watt 1993, Backhouse 2003, Long and Nelson 2016). By observing the movement of juvenile males out of their natal site and not including this area in their breeding season movements, the male quolls of the Illawarra Highlands appear to maintain genetic flow between quoll communities.

4.4 Activity patterns

This study provides detailed information on the activity captures of the Illawarra highland quoll population. Our results on activity time did not support the strict classification of quolls as a nocturnal, diurnal or crepuscular species. As the Spotted-tailed Quoll has been primarily considered as nocturnal (Jones 1997), a number of studies have observed a high number of diurnal and crepuscular activities throughout NSW (Belcher 2003, Belcher & Darrant 2004, Claridge et al. 2005, Andrew 2005, Glen & Dickman 2006b, McLean et al. 2015).
In a forest habitat like the Illawarra Highlands, changes in temporal patterns are usually related to resource availability with activity patterns often changing between seasons. Previous changes in the activity patterns of males and females at different times of the year in respect to the seasonal and daily changes were not available (Andrew 2005). However, in this study, an increase in nocturnal activity was observed in the winter breeding season, with the summer season displaying higher peaks of crepuscular activity. Similarly, Körtner et al. (2015) found the majority of his New England Tableland population were predominantly nocturnal during winter, despite the suggestion of a shift towards daytime activity in the face of increased thermoregulatory costs while foraging in colder temperatures (Andrew 2005). The increase of all three activity classifications during winter suggests that the increased metabolic consumption of breeding results in an increased consumption of prey. (Andrew 2005)

The data suggests that the variation of daily activity between spotted-tailed quoll populations may be dependent on prey availability. This was first noted by Settle (1978) as he observed that the availability of food governed the activity of captive spotted-tailed quolls, and if they are considered to be satisfied with their consumption, they generally rest. The spotted-tailed quoll is a generalist predator that predominantly feeds on small to medium-sized mammals (Dawson et al. 2007, Glen and Dickman 2006). In the Illawarra Highlands, the greater glider, common brushtail possum, and common ringtail possum are the most abundant prey available to the spotted-tailed quoll, typically considered to be nocturnal or crepuscular mammals (Belcher 2000, Andrew 2005). Belcher et al. (2007) have suggested that diurnal hunting of inactive arboreal mammals may be more energetically efficient. This has been observed by Belcher (2000) in south-eastern NSW when spotted-tailed quolls were observed hunting the tree-top hollow dens of Greater Gliders during daylight. Therefore, the diurnal activity observed in the Illawarra highlands could occur from energetically efficient foraging behaviours.

Alternatively, the Illawarra highlands population has been observed interacting with sympatric predators such as the red fox, and the feral cat, the increased levels of crepuscular and diurnal activity may be to minimise potential competition among these meso-predators (Glen and Dickman 2005). This suggests that there may be temporal
partitioning occurring in the Illawarra highlands (Körtner et al. 2015). The variation of activity patterns within the Illawarra Highlands population suggests that activity is specific to each individual and influenced by the variation of resources available throughout their home range.

4.5 Camera trapping effectiveness

One of the critical issues in species conservation is the development of reliable detection and survey methodology (Backhouse 2003). By using camera-trapping as the primary method of data collection, we can reduce the effort and invasiveness of conducting population assessments. Camera-traps can be deployed over large spatial and temporal scales and reduces the need to physically handle the captured animals (Kelly and Holub 2008, Swann and Perkins 2014). Using camera-trapping in the Illawarra Highlands to monitor the spotted-tailed quoll was found to be effective due to the ability to tailor the monitoring design to the studies objectives. The deployment of cameras provided a robust monitoring program in inaccessible, remote and difficult to work in environments. This permitted the monitoring of spotted-tailed quolls to occur continuously for 24 months, with occasional maintenance required (change of batteries and memory cards) (McCallum 2013). The ability to adapt the camera deployment to maximise the success of capture to the focus species lifestyle traits is a valuable tool in ecological management.

Alternatively, in this study, evidence was found that camera-trapping is not entirely non-invasive, as spotted-tailed quolls were recognised as the detecting cameras in some capture events. Meek et al. (2016) found similar responses from four mammalian predators that sensed and responded to camera traps during a trail-based survey. The Illawarra Highland quolls were found only to detect the camera traps at night, as they were observed stopping, looking at the camera, and then quickly leaving the detection zone. This behaviour displays negative behavioural responses and can be considered as intrusive, resulting in the altered behaviour of a captured animal (Meek et al. 2014, Meek et al. 2016). However, this study was not intended to be completely non-invasive, as the use of a baiting station already created site bias. This camera trap set-up was ultimately designed to maximise the capture
probability of the spotted-tailed quolls as a landscape scale species with large home ranges in low densities (Brassine and Parker 2015, Austin et al. 2017).

This study confirms the effectiveness of using profiling of individuals to monitor and estimate elusive terrestrial mammals. By using the spots as markers on each individual spotted-tailed quoll capture, it was possible to profile 93.4% of the camera-trap captures and make ecological assessments on the population. Hohnen et al. (2013) found similar success on the individual identification of northern quolls, suggesting that by maximising the number of images taken, there will be an increased success of individual identification. This is also evident in the estimation of Jaguar populations where repeated camera trap density estimates from long-term studies provided the local conservation programs with a valuable tool (Silver et al. 2004, Soisalo and Cavalcanti 2006). By using the individual profiling method to identify individual quolls and monitor their lifestyle, we have gathered preliminary information that can assist in the implementation of effective conservation management programs.

4.6 Implications for conservation management

The overall objective of this study was to investigate the dynamics of the Illawarra Highland’s spotted-tailed quoll population to assist conservation management. Although numerous spotted-tail quoll populations have been investigated over the last two decades, there are still gaps in understanding the distribution, organisation and structure of different quoll populations. This can be attributed to the varying size and structure of their habitats across the eastern coast of Australia and the impact that local threatening processes have on the quoll’s behaviour. Currently, there is a lack of knowledge regarding the spotted-tailed quoll population throughout the Illawarra Highlands. However, through the analysis of a 24-month camera-trap survey, this thesis provides a basis for conservation management and recovery plans for the Illawarra Highlands quoll population.

This investigation assists conservation management by identifying the spatial organisational and temporal behaviour of the Illawarra Highland quolls that can improve the success of future capture and monitoring efforts. The results from the profile-dependent and spatial
organisation analyses revealed the most active and densely populated areas were Barren Grounds Nature Reserve and the centre of Budderoo National Park, with the identification of Barren Grounds as the area of highest female density. The understanding of population distribution and more importantly, female organisation, assists in determining the regions where conservation management would be most effective. Similarly, we determined the most effective periods for capture success by analysing the highest periods of activity. The profile-dependent analysis found that the highest captures occurred during winter for adults and summer for juveniles, with the highest daily activity occurring between midnight and sunrise. By using this information, future surveys of the Illawarra Highlands can be more efficient, and the trapping effort can be more focused.

As a result of their large home ranges, spotted-tailed quolls occupy a wide range of vegetation communities and land tenures (Körtner et al. 2004, Belcher & Darrant 2006a). The retention of these habitats is considered to be the primary focus of quoll conservation management, and the practices that destroy or alter these areas may have detrimental effects on their conservation (Long and Nelson 2016). As the majority of Illawarra Highland population occurs throughout National Parks and Reserves, the importance of preserving and rehabilitating the native vegetation in these areas is vital to their recovery. The conservation of large native forests areas and linear corridors are essential for genetic diversity and the connection of the spotted-tailed quoll to neighbouring communities. The vegetation of the private land surrounding the National parks and Reserves should be treated with equal importance. By informing the surrounding landholders about the important ecological roles the spotted-tailed quoll has in our forests, the current population decline and the impacts of clearing remnant vegetation, we can prevent further loss of suitable forest habitats.

If the spotted-tailed quoll is to make a substantial recovery in the Illawarra highlands, then the most effective conservation actions must be put into effect. The results of this study highlight the importance of using population-specific ecological information to inform management strategies as each area has different factors influencing animal behaviour. By
using these findings in future management efforts, the conservation of the spotted-tailed quoll can be more effective.

4.7 Limitations
The investigation into the Illawarra highlands spotted-tailed quoll population highlights the use of camera-trapping as an effective monitoring tool in threatened species management. However, the results of this study were constrained by a few factors that limited the depth of the dataset and the ability to analyse the population. Firstly, the placement of camera-traps throughout the study area does not provide blanket coverage. The placement of camera-traps was constrained by the lack of access to deployment sites due to the areas topography, the density of vegetation, and lack of tracks for surveyors. This study chose to focus the number of cameras across a larger area to monitor the majority of the region rather than using the paired deployment. The data collected from each site is not set up to estimate population numbers; instead, we used the profiled information to identify the minimum known to be alive. Secondly, the constraints on the live-trapping periods due to logistical and animal ethical considerations, lead to a restricted deployment of cage-traps. Ideally, a larger number of cage-traps would have provided the more records of profiled individuals. However, we could not deploy the number of traps while also meeting the animal ethics requirements of live-trapping animals; especially an endangered predator like the spotted-tailed quoll.
5. Conclusion and Recommendations

5.1 Conclusions
As one of Australia’s largest extant marsupial carnivores, the conservation of the Spotted-tailed Quoll is vital to the maintenance of forest biodiversity. Increasing threats from habitat loss, modification and fragmentation have resulted in a substantial reduction in their dispersal across the east coast of Australia. The large home ranges and low-density populations of the spotted-tailed quoll increase their susceptibility to these threats. To ensure the persistence of the spotted-tailed quoll, accurate and descriptive localised studies are required to ensure effective conservation management actions are implemented.

This study has provided insight into the dynamics of the Illawarra Highlands spotted-tailed quoll population through the analysis of a 24-month camera-trapping dataset. These findings were applied to create an individual profile analysis of the captured quoll population through individual profiling methodology. The abundance, distribution, spatial organisation and activity patterns of the population was investigated to determine the ecological patterns of the spotted-tailed quolls in this area and assist in their conservation.

Results of this study provide the first empirical evidence of spotted-tailed quoll behaviour in the Illawarra Highlands region, identifying that the Illawarra Highlands population are displaying similar behaviours to other quoll populations across NSW. The distribution and spatial organisation of the population appears to be dependent on the availability of resources for breeding females, while the abundance of the population appears to be rising steadily. The roles of juvenile dispersal in maintaining genetic diversity and the partitioning of resources between quolls observed in this study are considered to be positive ecological behaviours to assist in the recovery of the population. These behaviours are also observed in the daily and seasonal activities of the Illawarra Highlands population, as they are observed with high activity during diurnal and crepuscular hours suggesting temporal partitioning of resources between quolls and also other sympatric competitors.
The influence that the habitats of spotted-tailed quolls have on their behaviour highlights the need for site-specific data of threatened species. This requires an effective and reliable method of gathering population data in an otherwise large and difficult habitat to monitor. For this, we have confirmed the usefulness of camera-trapping in the monitoring of elusive threatened carnivore species, through the ability to provide a robust ecological assessment on the Illawarra Highlands population. This was achieved by using the individual profiling assessment on all captured individuals that ultimately enabled the monitoring of each individual quoll in the Illawarra Highlands.

The establishment of more intensive and coordinated conservation efforts is needed to ensure the recovery of the spotted-tailed quoll throughout Australia. This should focus on protecting and restoring native vegetation while reducing any further degradation through habitat modification. This effort requires the cooperation of all landholders, governments and the public to ensure the survival of the spotted-tailed quoll on mainland Australia.

5.2 Future Research

Through the analysis of the two-year camera-trap dataset, we have identified the ecological behaviours that occur in the Illawarra Highlands spotted-tailed quoll population. This assessment is vital to conservation managers to create effective recovery plans and is defined in Long and Nelson (2016) as the first significant action required in conserving NSW populations. However, the ecological assessment conducted in this study is only a preliminary investigation into the general behaviours and interactions that the spotted-tailed quolls exhibit in this area. Upon the conclusion of this study, we find that there are more areas to research to understand what drives the Illawarra highlands population to behave in this way, ultimately assisting in the long-term conservation and management of this species.

As one of the longest spotted-tailed quoll camera-trapping studies that continuously monitor the movement and activity of the population, the data gathered in this study is important in determining the trends and fluctuations of the population over time. The ecological assessment from the two-year study permits researchers with the ability to
contrast the two years, however, we cannot conduct a comparison to determine if the behaviour observed is influenced by that year. We suggest that the monitoring is continued over another 24-month to provide a more robust assessment of the quoll population and the behaviour of individuals over time. The monitoring of the following breeding season will allow researchers to determine the number of juveniles that survive infant mortality and indicate whether the population is truly increasing.

Most camera-trapping studies focus on a single species, yet often the information obtained on non-target species often far outweighs the target species (Kelly and Holub 2008). In this study, the spotted-tailed quoll only occupied a small proportion of the overall dataset, with sympatric predators such as the red fox and feral cat occupying similar, if not greater number of camera-trap captures. By using this data, an investigation into the interactions between the spotted-tailed quoll and these species could identify the resource overlap that occurs throughout the Illawarra Highlands (Glen and Dickman 2005, Glen and Dickman 2008). The identification of resource overlap could assist with predator control at a landscape level.

Through spatial organisation analysis of the Illawarra highlands population, it was found that the juvenile males move far away from their mothers and often establish their adult home range without returning to their natal site; this behaviour possibly increasing the gene flow at this site. By using the genetic material of the live-trapped quolls in the Illawarra Highlands population, a genetic analysis of the live-captured population can be conducted to ensure that adequate gene flow is occurring within the population. This analysis can also determine how genetically diverse the population in this location is with a possible comparison of this population and those nearby. Potential outcomes from the knowledge of the genetic diversity in these populations are whether there is adequate gene flow between them occurring in order to maintain a genetically diverse population that is able to withstand possible stochastic events.

The distribution of quolls in this study was found to be determined by the availability of prey and den resources. Future research should aim to determine the impact that vegetation density and the proportion of cover has on the distribution of spotted-tailed quolls at
multiple spatial scales. The analysis should determine the factors that limit the dispersal of quolls in an area and assist the conservation of the Illawarra highlands population by protecting and restoring the areas that have the highest habitat preference.
6. Reference List


Appendices

Appendix 1: The average sunrise and sunset times for each month in 2017, these times are not adjusted for daylight savings hours. The camera-traps do not adjust for daylight savings either, therefore the times were used without adjustments (GeoScience Australia 2018)

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