# The influence of lunar phase on indirect indices of activity for the Common Brushtail Possum (*Trichosurus vulpecula*) on Banks Peninsula, New Zealand

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# Abstract

The brushtail possum, *Trichosurus vulpecula* is an introduced nocturnal marsupial no larger than a house cat. First arriving in 1848, it was intended to bring a profitable fur industry to New Zealand. This proved unsuccessful and many trappers, not understanding the consequences of their actions, released them into surrounding forests. Possum were highly successful in the New Zealand landscape and have become a major vertebrate pest species. Possum not only threaten the native plants and animals (through direct predation) of New Zealand, but also the agricultural industry, as they are vectors of bovine tuberculosis (Tb).

The Department of Conservation (DOC), Animal Health Board (AHB) and various regional and district councils spend an estimated $72 million annually on possum control. This clearly highlights the significant threat they pose and the need for an effective and well thought-out control program.

Being mindful of periods during the month when possum activity is highest can aid in the assurance of successful trapping and poisoning efforts. There are limited studies on possum ecology and even fewer on how they respond to lunar illumination and seasonal changes. Prior to the current study, no published information existed that studied the effects of lunar phase on the activity patterns of the possum during winter months.

Monitoring new-and-full moon phases over a four-month period included the use of WaxTags® and camera traps, which measured activity at three different habitat types including 1) exotic-and-native scrub, 2) pine plantation and 3) mixed-hardwood-and-broadleaf forest.

It was predicted that possum foraging behaviour would vary during the moon phases. According to previous research on small nocturnal mammals, they substantially reduce their activity under moonlit nights, exhibiting a behaviour known as lunar phobia. This includes reducing use of open space, spending less time foraging and reducing vocalizations and movement. This anti-predator tactic is a common behaviour amongst small mammals.

The results of the current study show that possum foraging behaviour does in fact vary during the moon phases however, they are more active during the full moon, exhibiting lunar philia, an uncommon behaviour among potential prey species. This could be due to lack of the possum's natural predators in New Zealand. Another interesting result from the current study is that possum activity significantly decreased during the new moon (less illuminated) phase in forested sites (with canopy) compared to scrubland habitats. Less exposure from daily ambient light coupled with canopy cover provided unfavourable conditions for possum during this study. My results indicate that the behaviour of common brushtail possum in New Zealand is influenced by changing lunar phases and as such, timing must be considered when carrying out future possum control operations.

**Keywords:** common brushtail possum, predator avoidance, philia, phobia, moonlight, phase, *Trichosurus vulpecula*, vertebrate pest control, introduced species

# Zusammenfassung

Der gemeine Fuchskusu, *Trichosurus vulpecula* ein eingeführtes nachtaktives Beuteltier, hat die Größe einer Hauskatze. Mit ihrer Einführung im Jahr 1848 sollte eine lukrative Pelzindustrie in Neuseeland begründet werden. Dies erwies sich als erfolglos und viele Trapper, ohne sich der Konsequenzen ihrer Tat bewusst zu sein, entließen sie in die umgebenen Wälder. Folglich entwickelten sie sich zu dem größten Schädling des Landes. Kusus bedrohen nicht nur einheimische Pflanzen und Tiere Neuseelands, sondern auch die Agrarindustrie, da sie Überträger der Rindertuberkulose sind.

Das Department of Conservation (DOC), Animal Health Board (AHB) und diverse Regional- und Bezirksräte geben schätzungsweise jährlich $72 Millionen für die Kontrolle der Fuchskusus aus. Dies zeigt deutlich die erhebliche Bedrohung, die sie darstellen, und damit den Bedarf für effektive und gut durchdachte Kontrollprogramme.

Verständnis des Zeitraumes, in dessen der Kusu am aktivsten ist, kann sehr zum Erfolg der Fang- und Vergiftungsbemühungen beitragen. Es bestehen nur begrenzte Studien über die Ökologie der Kusus und noch weniger darüber, wie sie auf Mondlicht und jahreszeitliche Änderungen reagieren. Vorhergehende Studien enthielten keine Informationen über den Einfluss der Mondphasen zum Aktivitätsmuster des Kusus während der Wintermonate auf der Banks Peninsula, Neuseeland.

Die Aktivität während Neu- und Vollmondphasen wurde über einen Zeitraum von 4 Monaten mit WaxTags® und Überwachungskameras in 3 verschiedenen Lebensräumen beobachtet: 1) exotisches und einheimisches Gebüsch, 2) Nadelwald und 3) Misch- und Laubwald.

Wie erwartet änderte sich die Aktivität während der Mondphasen. Vorherigen Aufzeichnungen von kleinen nachtaktiven Säugern zufolge reduzieren sie ihre Aktivität wesentlich unter Vollmondnächten. Dieses Verhalten ist als Mondphobie bekannt und ist gekennzeichnet durch einen kürzeren Aufenthalt im Freien, begrenzte Futtersuche, und eine Minderung in Vokalisierung und Bewegung. Diese Schutztaktik Raubtieren gegenüber ist unter kleinen Säugetieren sehr verbreitet.

Die Ergebnisse der aktuellen Studie weisen darauf hin, dass sich das Nahrungssuchverhalten des Kusus während der Mondphasen tatsächlich ändert, allerdings sind sie *mehr* aktiv während des Vollmondes, weisen also eine *Vorliebe* für den Mond auf, was ein sehr seltenes Verhalten unter potenziellen Beutetieren ist. Dies könnte durch den Mangel an deren natürlichen Feinden in Neuseeland liegen.

Ein zusätzliches und interessantes Resultat der aktuellen Studie zeigt ein signifikantes Nachlassen der Aktivität während der Neumondphase (weniger Mondlicht) in bewaldeten Flächen, im Vergleich zum Buschlebensraum. Geringes Tageslicht verbunden mit hohem Überschirmungsgrad bieten ungünstige Bedingungen für den Kusu während dieser Studie.

Meine Resultate deuten an, dass das Verhalten des gemeinen Fuchskusus in Neuseeland von Mondphasenänderungen beeinflusst wird. Aus diesem Grund muss der richtige Zeitpunkt für die Ausübung zukünftiger Kusu-Kontrollmaßnahmen berücksichtigt werden.

# List of acronyms and abbreviations

| | |
|---|---|
| AHB | Animal Health Board |
| ANOVA | Analysis of Variance |
| a.s.l | Above sea level |
| BMI | Bite Mark Index |
| °C | Degrees Celsius |
| CCC | Christchurch City Council |
| CE | Common Era |
| CI | Confidence Interval |
| DOC | Department of Conservation |
| EC | Environment Canterbury |
| GPS | Global Positioning System |
| Ha | Hectares |
| IPCC | Intergovernmental Panel on Climate Change |
| Kg | Kilograms |
| Km | Kilometres |
| $LD_{15}$ | Lethal dose 15 (causing 15% of death) |
| $LD_{40}$ | Lethal dose 40 (causing 40% of death) |
| LU | Lincoln University |
| Lux | Illumination levels |
| M | Metre |
| Mya | Million years ago |
| NASA | National Aeronautics & Space Program |
| NPCA | National Possum Control Agency |
| Pers. comm./obs. | Personal communication/observation |
| PIR | Passive Infrared |
| REML | Restricted Maximum Likelihood model |
| rH | Relative humidity |
| SED | Standard Error of the Difference |
| Tb | Tuberculosis |
| VAR | Variance |
| WBM | Wax Block Method |
| WTM | WaxTag® Method |

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# Chapter 1: General Introduction

## 1.1 Introduced pests

*"Invasive pests and weeds have become the greatest single threat to biodiversity on land, surpassing even habitat loss." – New Zealand Conservation Board (2008)*

Eighty-five million years ago, New Zealand broke apart from the ancient super continent Gondwanaland, a process that lasted about 20 million years. Until the arrival of Maori people from Polynesia, around 1300 CE, New Zealand was geographically and ecologically separate from the rest of the world. As a result, an astonishing and unique native flora and fauna emerged (Hackwell and Bertram, 1999). A mosaic of plant and animal diversity, with many examples of endemism, including 80 percent of all vascular plants, 70 percent of all native terrestrial and freshwater birds, all bats, all native amphibians and reptiles and 90 percent of freshwater fish (http://www.doc.govt.nz/conservation) New Zealand is now under attack by introduced pest species.

While mammalian fossils from 16-18 mya have been discovered on the NZ mainland, during the initial settlement by Maori there were no mammalian ground predators present. As a result the native species had evolved to be quite naïve of predation. The only two native terrestrial mammal species present at the time of colonization (c. 800 BP) were two species of short- and long-tailed bats. These quintessential ecosystems were not prepared for the extent of competition, predation and browsing they faced as a result of human-introduced mammals to New Zealand (Relph, 1998).

When Maori people came to New Zealand, they did not come alone; with them came dogs (*Canis familiaris*) and the Polynesian rat (*Rattus exulans*). The Polynesian rat alone is responsible for the elimination of several species of small birds, flightless insects and reptiles (Clout, 2002). During the initial colonisation period, Clout (2002) states that at least 35 endemic bird species were lost, including the large flightless moa (*Dinornithidae*), which was most likely hunted to extinction within 100 years.

With the later arrival of European settlers, about 200 years ago, the problem greatly intensified (Clout, 2002), as they successfully introduced over 90 species of vertebrates including 32 mammals, 36 birds and 19 fish. The mammal group can be further broken down into three species of rodents, three mustelids, six marsupials and seven deer species with the remainder being for agriculture (Clout, 2002). To understand and implement conservation management in New Zealand one must consider how this problem of introduced species came to be.

Biological invasions are not a recent phenomenon. Shifting landmasses, volcanic activity and environmental changes have caused species to move naturally (Vermeij, 1991). Natural colonisations can occur and some species are known to travel great distances via ocean currents and prevailing winds to relocate. Introduced, invasive species are known most commonly for deteriorating human health and wealth, transforming landscapes, altering the structure and functioning of ecosystems and threatening native biological diversity (Vitousek *et al*., 1997).

While invasive species can deteriorate human health by acting as vectors of various diseases (see Vitousek, 1997 for examples) it is most often humans that create these invasions. As humans have, over the past 50,000 years, colonized much of the world, they have substantially increased the rate and pattern of species distribution through invasions (Gaston *et al*., 2003). This is especially true of the exotic pet trade which Kraus (2003) reports has contributed to the introduction of many aquarium fish species and could be the cause of many introduced non-native birds, reptiles and amphibians. Some introductions of invasive species occurred thousands of years ago as is true with the arrival of the dingo (*Canis lupus dingo*) in Australia however, other ecosystems such as New Zealand have just recently felt the impact of biological invaders (Savolainen *et al*., 2004).

Some biological invasions can become so significant and widespread that they create global environmental change, such as extinction. In the U.S.A, out of a total 40 species of fish to have gone extinct since the late 1800's, 27 were negatively affected by introduced fish (Wilcove and Bean, 1994).

The Intergovernmental Panel on Climate Change, (IPCC, 2007) reports that the overall impact of humans on the biophysical environment is very significant and thus changes in climate are occurring at a much faster rate of time than ever before. Changes in climate can also make for unfavorable conditions as native species become more susceptible to other stressors, such as invasive species and/or infectious diseases. Take for example, the American lobster (*Homanus americanus*) that, in 2002, suffered a massive die-off in Long Island Sound, NY, USA. Lobsters were found by fisherman to be morbid, discolored and lethargic. The overall findings suggest that higher than average sea bottom temperatures that summer created an ideal habitat for a parasitic paramoeba to persist and cause damage to the lobsters' optic nerve fibers and photoreceptors (Dove *et al*., 2004).

There have also been ill-advised attempts at eradicating invasive species with biological control agents. Often, when an unwanted species is introduced into a country attempts to eradicate that species includes introducing another. This usually proves to be unsuccessful and having serious impacts on the native ecosystem. The cane toad (*Bufo marinus*) in Australia is a good example; first introduced to control agricultural insect pests, it itself is now one of the most serious vertebrate pests in the country.

Each year the list of introduced species grows, as does the significant economic and ecological effects on the environment. For instance, the introduced Eurasian zebra mussel (*Dreissena polymorpha*) of North America that entered the U.S.A via the ballast water of ships and rapidly dispersed covering river and lake bottoms as well as industrial inlets (Vitousek *et al*., 1997). Aside from costing approximately US$2 billion to clear blocked pipes (unless otherwise noted, all dollar values hereafter referred to in this thesis are New Zealand dollars) (OTA, 1993) zebra mussels alter populations of algae concentrations of nutrients in entire ecosystems (Caraco *et al*., 1997).

Vitousek *et al*. (1997) and White *et al*. (2008) state that islands, which are frequently visited by humans are more susceptible to alien invasions and to a greater extent than continents or less trafficked islands.

Whether intentional or not, humans are the main culprit when it comes to invasive species colonizing New Zealand. The New Zealand DOC reports that after Europeans arrived with what would later be identified as pests, many native animals were quickly driven to extinction, including 42 percent of all bird species, three species of frogs, a bat species, at least three species of lizards and an unknown number of insect species (http://www.doc.govt.nz/conservation).

While there is currently a lengthy list of introduced predators, the Christchurch City Council (CCC) lists the following as having the greatest threat to NZ ecosystems: feral goats (*Capra aegagrus hireus*), pigs (*Sus scrofa*), deer (*Cenus elaphus*), possum, mustelids, ship rats (*Rattus rattus*), feral cats (*Felis catus*), hares (*Lepus capensis*) and domestic stock (Parks, 2009). For the purpose of this thesis, I will specifically be addressing the problems caused by the common brushtail possum. Interestingly enough in Australia where they originated, the possum is now listed as an endangered species.

## 1.2 The history of the common brushtail possum in NZ

The focal species in this study is the common brushtail possum, a complex species by reason of considerable variation in size and colour that may include eight sub-species (Pracy and Kean, 1949).

Originally from Australia, the common brushtail possum is presumably the most un-welcomed guest in New Zealand. No larger than a house cat and weighing approximately 2-4 kg, it is a solitary, nocturnal, arboreal marsupial that has an extensive distribution both here in New Zealand as well as Tasmania and eastern Australia. McDowall (1994) reports that during the latter half of the nineteenth century, European settlers introduced the common brushtail possum in the Southland, New Zealand. Initially, the first several introductions were unsuccessful in establishment. The very first successful importation of the common brushtail possum was made in Riverton in 1858. The logic behind this introduction was to restore the depleted native flora and fauna following the extinctions of such species as the colossal-sized moa and Haast eagle (*Harpagornis moorei*). Settlers believed that there was very little in the way of interesting fauna remaining in New Zealand. Earliest known deliberate introductions started with Captain Cook in the 1770's with domestic livestock such as pigs and cattle (Clout and Ericksen, 2000). To further complicate the matter, settlers developed and institutionalized 'acclimatisation societies', and according to McDowall (1994) they were dedicated to introducing new and exciting species to New Zealand. These introductions included deer, game birds, trout for sport, European songbirds, among others to serve both economically and as novelty items.

During this time, America and Russia already had an established fur trade and Australia soon recognised the profitability of the possum pelt. It only seemed right then that New Zealand became involved in the trade and as a result, from 1860 onwards, there were an estimated 35 separate 'shipments' of possum made by acclimatisation societies from Tasmania and Victoria, Australia. A total of 127-recorded liberations were made by acclimatisation societies (108) and government agencies (19) between 1865 and 1926 mainly because at that time, the belief was that having possum in New Zealand forests was economically beneficial (Clout and Ericksen, 2000). As one might expect, the possum became accustomed to their new surroundings and settled in quite nicely. Possum were hunted for their fur so much during the early 1900's that the organisations that liberated them were concerned about over-harvesting. However, there were a growing number of complaints from farmers about the damage possum were doing to crops and in 1920, the government commissioned biologist Harold Kirk to assess the situation. He reported back that while there was indeed damage done by possum, it was negligible. His recommendations were that possum be released into the forests, away from orchards and gardens and a levy be placed on their skins. This formed the basis of government policy on possum for the next 25 years (Clout and Ericksen, 2000).

It wasn't until 1947, after scientific evidence pointed to the effect of possum on native forests, that a radical change took place. The government cancelled all restrictions earlier placed on the taking of possum, placed penalties for liberating them and legalised poison to kill them (Kean and Pracy, 1953). From then on they would be viewed as an official pest in New Zealand.

## 1.3 General ecology

At first glance, the common brushtail possum looks to be the most cuddlesome creature with its soft fur, thick woolly tail and pointed snout. Its fur ranges in colour from black to a light brown in wet southern regions and from grey to dark brown in drier, warmer regions (Saxton, 2005). In spite of the fact that possum have a low reproductive rate of one offspring per year (Fletcher and Selwood, 2000), they have become an ominous pest while colonizing over 95% of New Zealand habitat (Cowan, 1990).

The number of possum was once estimated at 70 million, more than the current number of people and sheep combined in New Zealand. This clearly is an over-estimation as possum are controlled annually over approximately 8 million hectares (Cowan, 2008). Prior to 2009, when Landcare Research conducted a study determining the actual number of possum living in New Zealand, one had not been done since the mid-1980's. Their findings were very interesting in that there are not nearly as many possum as once thought which indicates that control methods are indeed working; not in eradicating possum entirely, but at controlling their numbers. The results indicate that without any control methods and allowing possum to reach full carrying capacity their numbers would reach 47.6 million. In contrast, with control efforts and as of 2008/2009, there are an estimated 30 million possum, approximately a 36% reduction from carrying capacity. Control efforts were most effective, according to Landcare Research along scrub and native forest habitats (Warburton *et al*., 2009).

In their native land of Australia, possum are quite fond of eucalypt woodlands (see Figure 1) however, they are not too fastidious and are found in New Zealand feeding in a wide range of habitats consisting of, but not limited to beech forest (*Nothofagus spp*), open pasture, stream-side willows, swamps, farmland and orchards (Brockic *et al*., 1997).

**Figure 1**. Common brushtail possum in Eucalyptus tree
(Photo courtesy of Pavel German©)

While it was once believed that possum maintained a strictly folivorous diet, various research findings, including Cork and Foley (1991) and Nugent *et al*. (2000) indicate that they face numerous challenges meeting all their energy requirements from woody plant foliage alone. This is due to the fact that leaf-based diets are often low in protein, high in fibre and contain anti-herbivore chemicals such as phenols, terpenes and tannins. Nugent *et al*. (2000) suggest that true folivores need to have a body mass of tens of kilograms. Possum usually weigh under 5 kg and they need to compensate by having a higher than average ratio of maximum food intake to energy requirement. The digestive structures of possum are tailored to utilise low-quality foliage since it makes up a large percentage of their diet. However, they are less efficient than other folivorous species at doing this and as such supplement their diet with food higher in nutrients such as meat and invertebrates (Nugent *et al*., 2000).

There are many factors that allow for the proliferation of possum throughout New Zealand including their opportunistic feeding behaviours, the abundance of palatable vegetation and most importantly, a lack of predators. Unlike in their native homeland of Australia, there are, with the exception of the occasional feral cat, no natural predators of the possum in NZ. Of course human assistance in initially establishing a sustainable population has also been a major factor (Clout and Ericksen, 2000).

To implement conservation management effectively it is important to understand the dynamics of social interactions between animals of the same species. Hinde (1976) states that repeated social interactions lead to relationships and eventually social organisations. Of course circumstances and different populations that create these organisations may vary greatly within a species.

The adaptability of a species is thought to be an evolutionary strategy, which allows for the maximum benefits to be gained from a certain situation with minimal cost (Eisenberg, 1966).

Brushtail possum are recognized as being the most adaptable and widely distributed marsupials from the vast territory of Australia (Green, 1984; Kerle, 1984; Pracy and Kean, 1949; Thomas *et al*., 2003).

## 1.4 Activity patterns and home range

Possum activity along with other nocturnal species is restricted to periods of darkness. To effectively control them in New Zealand, it is important not only to understand when they are active during the night but also for how long. Strictly nocturnal, possum spend a majority of their time in dens which are generally sheltered sites, above ground in tree hollows, perching epiphytes, under logs, under tree roots and in the dens of other animals. After sunset, they remain awake in their den for a short period of 30 minutes. When they emerge from their dens they will spend another 1-2 hours grooming, sitting or moving around the den tree (Thomas *et al*., 2003). Rain is a factor, which can inhibit the emergence of possum and according to Ward (1978) sometimes for up to 5 hours. During the fieldwork of my study, I did notice that possum activity was reduced during periods of heavy rain and wind. However, Lennon (1998) and MacLennan (1984) did not find any obvious impacts of rain on activity. Sick animals that may be suffering from diseases are the exception as they are found to be active during the afternoon, especially during winter. In spite of all the damage they do, possum only spend about 1-2 hours each night foraging in a few separate sessions on the ground and in the trees. Little time is spent on social interactions except during breeding season (Paterson *et al*., 1995; Ward, 1978). The peak-time period of possum activity is, according to Paterson *et al*. (1995) during the hours of 2300 and 0230.

Home ranges vary amongst possum, but are generally 1-4 ha in forested areas and are mostly larger for males. They can be as wide ranging as 60 ha for possum living in pastoral regions or for those emerging from the forest to feed on agricultural pasture. Home ranges of possum are largely stable both temporally and spatially. Females will usually inherit their mother's home range while males on the other hand, will over time, distance themselves from their mother. Possum are capable of covering distances of 3 km or more in a night however, this is usually done by dispersing males about the time of sexual maturity. An example of this is given by How (1972) who translocated both common brushtail possum and mountain brushtail possum (*T. caninus*) vast distances from their home range in a pine plantation. The results were intriguing and included one such individual who returned from 3.8 km away in 2 days and another from 7 km in 19 days. Cowan (2001b) found similar results with translocations of four possum, all from the same area who returned 4 km to their home sites on a Manawatu farmland. A number of studies demonstrate that possum display anti-predator tactics and at times adjust their foraging behaviour (Lennon, 1998; McDonald-Madden *et al*., 2000; Pickett *et al*., 2005). This is because unlike Australia, where dingoes, pythons (*Pythonidae spp*), foxes (*Vulpes vulpes*), and feral cats predate on possum, in New Zealand the feral cat is its sole predator. In a study measuring the home ranges of feral cats, Fitzgerald and Karl (1986) found that adult possum are eaten as carrion and the young are probably killed by cats at the age when they first leave their mother. In Australia, Pickett *et al*. (2005) found that ground cover and higher scrub had little impact on reducing predation risk to possum since their larger body size does not allow for hiding under substrate. Because its main predator, the feral cat, is an ambush predator, higher scrub may actually increase predation risk as it could work to conceal a feral cat hiding in scrub or prevent prey from escaping. Accordingly, it may be more beneficial to forage in open areas as it would increase visibility and reduce the numbers of hiding places for a predator. Early detection is undoubtedly helpful in the avoidance of predators. The results of Pickett *et al*. (2005) found however that possum travel closer to escape trees while on the ground and spend less time at feeders in the open than in bush habitats. This is in contrast to McDonald-Madden *et al*. (2000) who conducted field experiments to test whether an urban population of possum adjusted their foraging behaviour. Their findings showed that possum foraged for a longer period of time at feeder stations located the furthest from trees. This decision seemed to be based solely upon travelling costs between the feeder and tree, not by the quantity of food or risk of predation. Clearly the behaviour of possum varies greatly and can sometimes be very difficult to predict.

# Chapter 2: Ecological and economical impact

## 2.1 Introduction

The encumbrance of alien species is felt both, ecologically and economically. There are many complexities associated with the invasive species problem and many difficulties in quantifying non-economic, ecological impacts of pests. This then creates issues of priority for policy makers, government and biosecurity agencies (Kriticos *et al*., 2005). It may also be a challenge to decide where monies should be spent; in eradicating new pests or managing the well-established ones?

Each year the number of invasive species that colonize New Zealand steadily increases, costing the economy a staggering $921 million. According to Kriticos *et al*. (2005) it is estimated that Biosecurity New Zealand will have to deal with more than 542 potential pest incursions and 512 phytophagous species becoming permanently established from 2005 to 2017. Increase in trade and travel, improved surveillance and diagnostic methods could be the reason an increase in species is now detected (Kriticos *et al*., 2005).

The damage that the brushtail possum pose to the native flora and fauna of New Zealand are extensive in many facets and in this chapter I will address both the ecological and economical threats they pose.

## 2.2 Economical impacts

The two largest agencies in New Zealand putting forth the most effort in eradicating possum are DOC and the AHB. Regional and local councils are also greatly involved in pest control efforts although they are mainly involved in high-value conservation areas. To gain insight into how much money is spent on possum control in New Zealand, one must take into account that most reports on control efforts include all pest species in their total figures. Some of the figures provided below are representative of all pest management efforts, but wherever possible specific possum control data have been included. Naturally, it is difficult to obtain total figures from private landowners working to eradicate possum as they may not keep track of how much they spend and/or they are not reporting to a higher entity.

Between the government agencies annual figures of possum control in New Zealand are currently estimated at $72 million per annum. According to Mike Hansen, Communications Advisor of the AHB, this agency spent $53.3 million alone on possum control for the 2008/2009 financial years. During 2009/2010, DOC spent $15.7 million on possum control and according to Parks (2009), manages 41 reserves on Banks Peninsula. Environment Canterbury (EC) reports that $1million is spent annually on their site-led plant and pest control program in the Canterbury region. According to a personal conversation with Graham Sullivan, the biosecurity manager for the Environment Canterbury $ 150,000 is spent annually on possum control in the Banks Peninsula region. The Christchurch City Council (CCC) spends c. $150,000 per annum controlling pest weeds and animals in the Port Hills reserves in Canterbury (Parks, 2009). This is not to mention all the monies that are spent by local councils and private landowners whose efforts go unknown.

## 2.3 Threats to natural ecosystems from the possum

Even in 1949, the negative effects of possum on both native birdlife and vegetation were foreseen as an interview with Dr. R.A. Falla, director of Dominion Museum, demonstrates. When asked about the likely effects on native birds due to possum browsing (i.e. destroying), he replied that, “it represents a serious dislocation of bird economy and must impose critical restrictions on their normal food and cover requirements.” According to Dr. Falla, the following birds are certain to be affected: (i) **pigeon** (*Hemiphaga novaeseelandiae*): would be deprived of seasonal fruits such as konini and poroporo in January; tawa, titoki and maire in March & April; miro and hinau in May & June: (ii) **tui** (*Prosthemadera novaeseelandiae*): adversely affected by shortages of nectar in konini in Oct. & Nov. and rata in January & April, of leaf-eating aphides, in particular of wineberry in February and of a wide range of berries from mid-summer on: (iii) **bellbird** (*Anthornis melanura*): may be affected in the same way as tuis, however they are lucky in that they have a wider range of alternative food selection, especially in beech forest: (vi) **kākā** (*Nestor meridionalis*): noted as the least adaptable among native birds, would suffer from any serious reduction of rata flowers (Pracy and Kean, 1949).

Until 1993, it was thought by many that possum were solely a threat to the indigenous flora and the agricultural industry, as a vector of bovine Tb. However, that all changed when a time-lapse video staged in the field by Landcare Research (Innes, n.d.) took images of possum predating on kōkako eggs and killing chicks. Out of a total of 19 nests monitored over a four-year period, possum were recorded eating chicks and eggs in four. Unless a possum swallows feathers and/or eggshells, it is difficult to find traces of birds in their faeces or intestines and as such, they have in the past been considered herbivorous (Innes, n.d.). Recently, as of November 2010, nest cameras set up in the South Westland prove possum are predating on New Zealand’s only alpine parrot, the kea (*Nestor notabilis*). Video images show the disturbing evidence of a possum eating a nearly fledged kea. Brent Barrett from the DOC stated that they are, "midway through the breeding season and of the 11 nests that have been under surveillance, three have been attacked by possum and stoats" (http://www.doc.govt.nz/about-doc/news/media-releases/possum-eat-kea).

We now know that they are very adaptable opportunistic feeders of any food that is high in energy and protein, including but not limited to flowers, leaf buds, fruit, eggs, birds, insects and snails (Hutching, 2009). In addition, possum are generalists consuming a wide range of food, which has helped them immensely in establishing themselves in New Zealand.

The Department of Conservation (DOC, 2010) states that nine out of ten North Island brown kiwi (*Apteryx australis*) chicks born in the wild will die before they reach their first year as a direct result of predation attacks. Hutching (2009) reports that possum have been caught on film eating the eggs, chicks and adults of a number of other native bird species, such as kererū (*Hemiphaga novaeseelandiae*), kiwi, harrier hawk (*Circus approximans*), fantail (*Rhipidura fuliginosa*), muttonbird (*Puffinsus griseus*) and tui (*Prosthemadera novaeseelandiae*). Naturally, this has caused significant population declines for many native bird species.

Competition of the same resources also occurs between possum and native birds. By consuming fruits and flowers, possum deprive nectar-feeding birds such as tui, kākā and bellbirds the much needed, highly energetic food they demand during breeding season. They are also known for taking over den sites which kiwi use (http://www.doc.govt.nz/conservation/threats-and-impacts).

Unfortunately, the only two native mammals to New Zealand, the long and short-tailed bat are in peril as well. Attacks on both species by possum have been recorded in South Canterbury where the long-tailed population is declining 5-9% annually. Threatened wood rose, a nectar source for short-tailed bats, is also a favourite to possum (Hutching, 2009).

Cowan and Moeed (1987) concluded after a 5-year study in the Orongorongo Valley that possum are also a threat to invertebrates. In their study, over half of the fecal analysis measured contained invertebrates of giant wētā, stag beetles and weevils. Snails are not safe either. Hutching (2009) reports that one possum can eat sixty giant amber snails (*Powelliphanta*) in a single night. Invertebrates most at risk are large-bodied, sluggish and nocturnal.

The threats that possum present to New Zealand's native forests is staggering. They attack on three levels, including catastrophic dieback of forest, gradual depletion and inhibition of regeneration (Nugent, n.d.). Aside from completely defoliating flowering trees such as pohutukawa (*Metrosideros excelsa*) and northern and southern rata (*Metrosideros robusta* and *umbellata*), they change the structure and formation of forests. Some of the possums' favourite tree species include tawa (*Beilchmiedia tawa*), northern and southern rata, kohekohe (*Dysoxylum spectabile*), kāmahi (*Weinmannia racemosa*) and Hall's totara (*Podocarpus totara*) (Hutching, 2009), fuchsia (*Fuchsia excorticata*), wineberry (*Aristotelia serrat*), mahoe (*Melicytus ramiflorus*) pate (*Schefflera digitata*), *Pseudopanax spp*., *Raukaua spp*., *Coprosma spp*., pohuehue (*Muehlenbeckia complex*), bush lawyer (*Rubus spp.*) and forest herbs (Nugent *et al*., 2000). One should keep in mind, according to Pracy (1949), that defoliation of trees could be caused by a number of factors other than possum, such as rats, birds, caterpillars, insects, disease, root damage or wind. The greatest damage appears to occur on high steep faces as they are unable to endure attacks from possum for as long as normal stands of bush (Pracy and Kean, 1949). A nationwide survey from 1961 to 1963 indicated that there were over 200 indigenous trees and/or plants browsed by possum (Pracy and Kean, 1969).

Within a forest, canopy dieback can occur, a process in which the peripheral part of woody plants and/or trees are killed. This process, according to Mueller-Dombois (1983) takes two forms, tree-to-tree dieback, (i.e. where many adjacent trees are affected); or salt-and-pepper dieback, (i.e. where dying trees occur repeatedly in a matrix of healthy trees). These processes can occur over small patches of < a hectare to large tracts of land anywhere between 10-100 ha (Mueller-Dombois, 1983). In the Westland of New Zealand for example, many valleys have lost more than 50% of canopy trees within 15-20 years of possum first arriving. Unpalatable shrubs then replace the trees and the entire area changes from tall forest to open forest and shrubland (Hutching, 2009). Susceptibility to catastrophic dieback varies between areas, depending on factors such as stand history, age, diversity, substrate type and landform.

Mamaku, the black tree fern can be mercilessly damaged by possum browsing during the spring (see Figure 2) when the fronds (i.e. leaf-like parts) begin to open. Just after the winter months these young fronds are rich in protein and are a much awaited food source to many native birds (Hutching, 2009).

**Figure 2**. Mamaku tree. Left photo: possum damage. Right photo: after 2 yrs of possum control
(Photo courtesy of DOC)

Nugent (n.d.) also states there are eight threatened species of mistletoe (*Santalales spp*.) eagerly eaten by possum. The National Possum Control Agency (NPCA, 2009) reports that damage to young exotic pine forests can be fatal, as possum are known to browse the shoots and strip the bark.

Gradual, intermittent depletion of forests is another effect of possum browsing. Possum, unfortunately, do not use all available forage homogeneously; rather they systematically break down the forest by selectively targeting one species and leaving its neighbour untouched until a later time. This process affects New Zealand's mixed broadleaf forests where there are many possum preferred species (e.g. northern rata, pohutakawa, tawa and fuschia, to name a few, (Nugent, n.d.).

At the moment, the question that remains unanswered is whether the most severely affected forests will be able to recover successfully (i.e. would the forests return to their natural state if possum were fully eradicated?) The species most affected by possum browsing, are grouped into two categories: (i) common species, which if lost, would affect the forest community as a whole (kamahi, rata, pohutukawa, tree fuschia, totara and kaikawaka (*Libocedrus bidwillii*)): and (ii) rare species that could possibly be driven to local extinction (e.g. mistletoe and wood rose (Nugent, n.d.).

It appears that certain species of trees vary in their environmental response to possum foraging. For example, Southern Island tree fuschia for reasons unclear, seem to be far less palatable to possum than fuschia elsewhere (Nugent, n.d.).

## 2.4 Threats to livestock and agriculture from the possum

Possum are especially harmful to New Zealand's agricultural sector on an economic level because they are the main wildlife transmitter of bovine tuberculosis (Tb). This bacterial disease can attack humans (*Homo sapiens*), cattle (*Bos primigeni*), deer, pigs, ferrets (*Mustela putorius furo*) and cats. If left uncontrolled, New Zealand could be prohibited from exporting beef, venison and dairy products to markets overseas (NPCA, 2009) and could potentially cost the country $1.3 billion in lost export earnings (AHB (Inc), 2000). Beginning in 1979, and lasting for a decade, New Zealand witnessed a continuous increase in cattle and deer herds infected with Tb. During this time, there was a lack of funding for possum control, which did not get resolved until 1990 (Cowan, 2001a). When possum are sick they can develop lesions and becoming lethargic they can come in close contact with farm animals who, curious by nature, are known to lick and/or sniff the sores. Knowles *et al*. (2005) states that ferrets and deer are termed 'secondary' Tb vectors and are a result of contact with infected possum. They also conclude that feral pigs and cats contract Tb from scavenging dead carcasses but do not pass on the disease (i.e. dead-end hosts). Accordingly, understanding the dispersal of possum will improve management in dealing with the spread of bovine tuberculosis and recolonization rates following eradication efforts.

Gardens and pastures are an all time favourite to possum and they have been known to travel vast distances of 1.5 km to feed on some of their favourite crops (NPCA, 2009). According to Pracy and Kean (1949), some of the most desired food source is as follows:

**Fruit:** apples (*Malus domestica*), citrus (*Citrus spp.*), peaches (*Prunus persica*), plums (*Prunus spp.*), pears (*Pyrus spp.*) and passionfruit (*Passiflora edulis*)

**Vegetables:** carrots (*Daucus carota*), parsnips (*Pastinaca sativa*), cabbage (*Brassica oleracea*), beans (*Fabaceae spp.*), parsley (*Petroselinum crispum*), turnips (*Brassica rapa*), corn (*Zea mays*), lettuce (*Lactuca sativa*), potatoes (*Solanum tuberosum*), peas (*Pisum sativum*) and silver beet (*Beta vulgaris*)

**Flowers:** roses (*Rosa spp.*), carnations (*Dianthus caryophyllus*), polyanthus, godetia, cyclamen and gladiolus

**Exotic trees:** willows (*Salix spp.*), poplars (*Populus spp.*), eucalyptus, oaks (*Quercus spp.*), pines (*Pinus spp.*), Douglas fir (*Pseudotsuga*) and walnuts (*Juglans spp.*)

## 2.5 Current and previous pest control efforts

Currently there are various control methods underway to reduce possum in New Zealand including trapping, poisoning and shooting. Long-term biological controls are currently being sought after by Landcare Research (Duckworth and Cowan, 2004). There are a number of government and individual parties involved in the control of possum such as the AHB, DOC, regional councils, property owners, private individuals and forestry companies. DOC and the regional councils generally control public conservation lands. Often the AHB will fund the regional councils and private contractors to carryout control of possum for Tb elimination. Lastly there are individual landowners and companies controlling possum with varying interests to protect biodiversity, farmland and forestry (DOC, 2004).

Thomas *et al*. (2003) state that leg-hold trapping is the most commonly used method carried out by Regional Councils, DOC and New Zealand research organizations to measure possum abundance.

The NPCA reports that in 1996, leg-hold trapping became a standardized method so that estimates could easily be compared nationwide. However, it is not a very practical control solution for a number of reasons, which include, cost, weight and bulkiness of traps as well as animal welfare concerns. Another limitation, recognized by Dutton (2008), is in accordance to a clause of the Animal Welfare Act that states all live-capture traps must be checked daily. Naturally, this substantially increases labour costs (please refer to NPCA (2008) for a more comprehensive guide to the various leg-hold traps used in New Zealand).

Shooting possum is another method but is generally practiced in and around pastures and small orchards. Being more labour-intensive and expensive, it is also not an attractive option.

Of all the potential methods to control possum in New Zealand probably the most cost-effective and practical method is by using poison (either ground-based or aerially delivered). This is the preferred method for *sustained* control of possum in large remote areas, which is necessary since completely eradicating possum from New Zealand is currently not an achievable goal. Of course this raises much public concern as poisons can not only be harmful to humans and non-targeted species but they also have the potential to bioaccumulate in the environment (NPCA, 2009). Ground poison employs the use of 1080 (sodium monofluoroacetate) and cyanide, both particularly harmful poisons. Only those holding a license may, by adhering to strict protocols, lay these poisons. Large inaccessible areas are often controlled with aerial drops of 1080 in the form of poisoned carrots or other forms of cereal bait (DOC, 2004).

There are ample variations of poisons currently on the market for use in possum control. Five poison baits are currently available for public use including brodifacoum and pindone (anticoagulant (blood clotting) poisons), Feracol®, No Possum Gel Bait and Decal pellets (poisons containing Cholecalciferol) (NPCA, 2009). In 2009, the NPCA put together a detailed guide for landowners who want to control possum on their private land. It includes a summary of each poison, animal welfare concerns and safety issues so that people can make informed decisions.

Control areas are designated based upon priority (i.e. areas that have animals affected by Tb or having threatened plant or animal species). Keeping that in mind, certainly there are some areas that do not get controlled at all. Therefore, it is important for the abovementioned agencies and organizations to allocate efforts and funds to those sites that need it the most. Banks Peninsula, the location of all fieldwork sites in this thesis, has a myriad of organizations working to control both pests and weed species (see Table 1).

**Table 1**. Sites currently controlled on Banks Peninsula, New Zealand

| Pest/weed controlled | Where | What is done |
|---|---|---|
| Darwin's barberry | 15 sites | Survey and control |
| Chilean flame creeper | Wainui Reserve | Control |
| 19 weed species | Hay Scenic Reserve | Control |
| Multiple weed species | Lyttelton Reserve | Control |
| Multiple weed species | Kaitorete Spit | Control |
| RPMS weeds | 26 sites | Comply with RPMS on DOC land |
| Feral goats | Whole peninsula | Contribute to goat eradication project |
| Possums | 20 reserves | Annual control |
| Mustelids | Flea & Stony Bays, Purau, Godley Head , Otanerito/Long Bay, Akaroa Harbour near Nikau Palm Gully | Protect white-flippered penguins |
| Predators | e.g. Stony and Tumbledown bays, Kaituna River (for Grebes) | Support for Ngai Tahu kereru, titi, pingao projects |
| Multi-species | Quail Island | Control of hedgehogs, mustelids, rodents |
| Rabbits | Control as needed on DOC land | Comply with RPMS on DOC estate |
| Domestic stock | All reserves | Fence reserves |

(Table courtesy of Banks Peninsula Conservation Trust and Environment Canterbury)
Note. Figures do not include DOC control efforts

## 2.6 Ineffective control operations

In spite of the millions of dollars spent annually on possum control, it seems New Zealand will only ever be able to reduce possum numbers, with total eradication appearing very unlikely. One common question that needs addressing is why do some possum continue to survive control operations? Since poisoning possum is the most sought after, cost effective, large-scale method of control in New Zealand, it should be relatively flawless however, it is not. Morgan *et al*. (1987) was interested specifically in aerial poisoning operations and attributed their failure at killing possum to sub-lethal toxic loading, undersized sub-lethal baits, non-learned behavioural aversion to 1080 and failure to encounter bait. They devised a problem analysis of factors likely to influence the effectiveness of control operations. This analysis consisted of eight stages and/or questions and are as follows: stage (1)- the preparation of palatable bait (2)- is the non-toxic bait taken by an adequate % of population? (3)- does the toxic bait kill an adequate % of population? (4)- are the toxicity levels for the chosen bait correct? (5)- is the final bait toxicity consistent? (6)- are possum averse to 1080? (7)- eliminate any aversion by masking 1080 (8)- change method of bait distribution to ensure that all possum encounter bait. Morgan *et al*. (1987) also found that the widely held notion that possum have an unlearned strong aversion to 1080 was proved unlikely. They asserted that the improvement of the quality of baits, modification of the required toxicity and preventing taste and/or smell aversion by masking bait would guarantee death; that is of course provided the possum finds the bait. A later study by Morgan *et al*. (1996) indicated that one of the greatest challenges in controlling possum was the problem of learned bait shyness, which occurs when possum learn to avoid poison after ingesting sub-lethal levels of toxin in an operation. In their study, they captured possum from North Canterbury and offered them sub-lethal (1 or 2.5 g) bait of 1080, followed by lethal (6 g) bait two days later. They found that most possum displayed a learned shyness towards the lethal baits and this was related to the size of the initial dose. They retested the possum three months later with lethal bait and found most of the survivors were still bait-shy. In this study, shyness was not overcome solely by switching to a different flavoured bait (e.g. orange to cinnamon flavour), but also by changing the base of the bait as well (e.g. from cereal to carrot baits). Possum have learned to associate toxic symptoms with the bait and avoid it at all cost for at least, according to Morgan *et al*. (1996), two years following initial consumption. One could argue that perhaps a reason as to why possum rejected the lethal bait is because it was given only 2 days after the sub-lethal bait. Maybe this did not give the possum enough time to make a clear distinction between the two baits.

This does not seem to have a significant effect according to Morgan and Milne (2002), who found that when lethal cholecalciferol (vitamin $D_3$) bait was presented to possum 21-30 days after the initial sub-lethal bait (being either $LD_{15}$ or $LD_{40}$), 40 and 88 % of possum respectively survived, compared with only a 21 % survival rate among naïve possum. Changing the bait type (to a gel) and the toxicant (to 1080) seemed to make a significant difference, with 63 % of the previous bait-shy animals killed. Ross (1997) researched the best approach for dealing with bait shyness in possum and was interested in finding a bait that bait-shy possum would accept. Pen trials showed that both cholecalciferol and brodifacoum are effective at alleviating shyness and using a sub-acute/chronic toxin in a cereal bait was most likely the best method to overcome 1080 bait-shyness in possum.

# Chapter 3: Indirect indices of activity

## 3.1 Introduction

In New Zealand, we have a considerable amount of scientific information on possum behaviour around indirect indices of activity (e.g. foraging behaviour and food preferences). There is, however limited information about general possum ecology and even less on the behaviour of possum in response to lunar illumination. Much of the documented research in this area focuses on small terrestrial mammals, such as rats and mice. Research shows from a number of studies that animals react differently to low and high levels of illumination (see section below). These are better referred to as lunar philia, where animals become more active under moonlit nights and lunar phobia, where they actively avoid illumination and decrease activity. As an increase in moonlight naturally leads to an increase in visibility, one would assume many prey species would exhibit phobia, a persistent desire to avoid high levels of illumination. This behaviour is understood to be a form of predator avoidance (Gursky, 2003). Moon phase is also proven to have an effect on the reproductive cycles of marine animals, various terrestrial birds and amphibians (Byrne, 2002; Dixon *et al.*, 2006). The common brushtail possum, on the other hand, according to a study from Dutton (2008) exhibits a philic response to full moon phases, becoming more active in conjunction with Indonesian spectral tarsiers, *Tarsius spectrum* and neo-tropical primate, *Aotus trivirgatus* (Gursky, 2003). This is likely due to the fact it is easier to forage with increased moonlight and thus visibility. It is also reasonable that possum have, over the last 150 years, become aware they have no natural predators in New Zealand and as such, audaciously altered their inherent foraging behaviour.

## 3.2 Moonlight and its effects on small mammals

Biotic factors, including food availability, predation and inter-specific competition for food, water, shelter and mates can influence activity patterns of small mammals. In the same way, abiotic factors such as temperature, moonlight, wind and precipitation are also responsible for changes in activity. Light, whether in the form of moonlight or artificial illumination, has been proven in numerous studies to have the greatest effect on circadian rhythms, the primary zeitgeber (i.e. change in light or temperature (Kramer and Birney, 2001)). The intensity of light, timing of activity and transition from light to dark (White and Geluso, 2007) act indirectly on the nervous system through retinal photoreceptors to alter endogenous rhythms and activity levels. Moonlight alters the activity patterns of small mammals, such as crested porcupines, *Hystrix indica* (Alkon & Saltz, 1988), white-tailed jackrabbits (Rogowitz, 1997), wholly opossum, *Caluromys philander* (Julien-Laferriere, 1997), coppery brushtail possum, *Trichosurus vulpecula johnstoni*, green ringtail possum, *Pseudocheirus archeri* (Laurance, 1990) Ord's kangaroo rat, *Dipodomys ordii* (White and Geluso, 2007) and snowshoe hares, *Lepus americanus* Erxleben (Griffin *et al*., 2005).

How moonlight affects the activity patterns of mammals varies. For example, bushy-tailed wood rats, *Neotoma cinerea* (Topping *et al*., 1999), tropical ringtails, *Pseudocheirus herbertensis*, *Pseudocheirus archeri* and *Hemibelideus lemuroids* (Laurance, 1990), springhares, *Pedetes capensis* (Brown and Peinke, 2007) and Patagonian leaf-eared mice, *Phyllotis xanthopygus* (Kramer and Birney, 2001) all exhibit a decrease in activity during moonlit nights, lunar phobia. The primary hypothesis for this behaviour is attributed to the avoidance of predators, as under an illuminated sky, both prey and predator become more easily visible. Brown & Peinke (2007) found that springhares (*Pedetes capensis*) even shift their activity to dark, moonless periods of the night and reduce their use of open space. According to Gursky (2003), some animals can respond by restricting their foraging activity and movement, reducing their vocalizations and the duration of activity period or by switching their activity to darker periods of the night. This is very common behaviour and expected amongst nocturnal mammals. Di Bitetti *et al*. (2006) found that ocelots in Argentina alter their activity during the moon phases by using trails less frequently a week prior to the full moon and during peak full moon. They concluded that the reason for reducing activity is primarily due to their increasing vulnerability to larger predators such as the jaguar (*Panthera onca*), bobcat (*Lynx rufus*) and cougar (*Puma concolor*) under a moonlit sky.

One particular exception to this hypothesis are two species of primates, a spectral tarsier (*Tarsius spectrum*) native to Sulawesi, Indonesia and a unique neotropical primate living in Brazil, (*Aotus trivirgatus*). Both of these species demonstrated what scientists refer to as lunar philia, becoming more active during full moons. Gursky (2003) offers two potential reasons for this observed behaviour: (i) foraging efficiency increases during full moon and outweighs the risk of predation: and (ii) predation risk is not greater during full moons, instead it is greater during new moons. Gursky (2003) also suggests that the prey of spectral tarsiers increase their activity on moonlit nights and accordingly, the tarsiers seize an opportunity to increase foraging.

Sometimes moonlight alone is not enough to alter activity patterns of species but coupled together with seasonal variations, behavioural changes can be observed. White and Geluso (2007) found that 61 % of kangaroo rats, *Dipodomys* in the summer and 63 % in autumn emerged from their burrow before full darkness. Conversely, in winter only 19 % of kangaroo rats began surface activity before full darkness. They concluded that this could be associated with seasonal tradeoffs between costs of predation and benefits of food abundance and reproduction. Griffen *et al*. (2005) investigated the 'predation-risk hypothesis', which predicts that the activity behaviour of prey should decrease dramatically at times of increased predation risk if there is high temporal variation in predation risk but should remain uniform when temporal variation in predation risk is low. Their results, which looked at predation risk of the snowshoe hare, suggested that the effect of lunar illumination on many predator-prey interactions could vary seasonally. The movement of hares in winter decreased during periods of bright illumination (full moon) and increased during the darkest periods (new moon). In the summer months, snowshoe hare movement supports the second part of the abovementioned hypothesis in that it did not vary when temporal variance in predation risk was low.

Naturally, there are also animals that are not at all affected by the changing phases of the moon. Examples of this are provided by Stokes *et al*. (2001) who analyzed 15 years of trapping data on prairie voles (*Microtus ochrogaster*) and cotton rats (*Sigmodon hispidus*) to determine behavioural responses to weather by season and time of day. Their findings show that nighttime illumination was of little importance and did not significantly alter behaviour patterns of the voles and cotton rats. An explanation given for the lack of response is the presence of heavy ground cover that may in fact, shelter mammals from potential avian predators. Moonlight also had little effect (spatially or temporally) on the microhabitat use of *Antechinus agilis*, a semi-arboreal species of dasyurid marsupial (Sutherland and Predavec, 1999). One of the first studies that examined the influence of moonlight on marsupials was Julien-Laferriere (1997) who concluded that woolly opossum (*Caluromys philander*) in French Guiana maintained their normal activity patterns in spite of variations in moonlight intensity. An interesting observation they made was in regards to the differences in activity between male and female opossum. Males were more active during low-light levels (new moon) and females, on average seemed to have a constant low level of activity. Since the opossum breeding cycle can range from December to October, and the study was from July-February, the females' lack of activity could have been influenced by the mating and/or breeding season.

## 3.3 Habitat preference

One of the tasks associated with controlling and/or eradicating invasive species is to understand how they behave in their natural environment (e.g. do possum have the same foraging behaviour response to moonlight and habitat preference in New Zealand compared to

Australia?). Certainly this is an interesting question because possum do not have the threat of natural predators in New Zealand. Some of their Australian predators include snakes and birds-of-prey such as the wedge-tailed eagle (*Aquila audax*), foxes, dingos, feral cats and dogs. Pickett *et al*. (2005) were interested in the influence of predation risk on the common brushtail possum in their native southeastern Australian woodlands. The habitats they surveyed included eucalypt and cypress-pine dominated regions within three areas of red fox abundance. It was believed that higher scrub or ground cover would not reduce the risk of predation as possum do not normally use habitat to conceal themselves from predators. There is also a possibility that ground cover could increase chances of predation (Pickett *et al*., 2005) as it offers predators a place to hide and hinders prey from escaping. The results of this study indicated that possum displayed anti-predator behaviour by travelling closer to escape trees while on the ground and made fewer visits to feeders placed in the open habitat than in the bush (see below for more information).

These results vary considerably from those of Lennon (1998) who found that activity levels of brushtail possum were higher in open habitats in Banks Peninsula, New Zealand. Lennon (1998) who compared feeding patterns in a forested and farmland habitat concluded that bait consumption was 31% higher at bush-edge when compared to the forested site. This may have been influenced by the fact that the bush-edge feeder station was closer to other preferred food sources such as walnut trees located only 50 m away.

Similarly, McDonald-Madden *et al*. (2000) investigated whether an urban population of brushtail possum living in the Fitzroy Gardens in Victoria, Australia adjusted their foraging behaviour in response to manipulation of food items placed in feeders at different distances from trees. Possum are common in the urban parks of Australia and as such, they are vulnerable to dog attack. It is observed in a study by McDonald-Madden *et al*. (2000) that possum forage on the ground, scanning the environment, keeping a close distance to trees where they can run up at the sight or sound of dogs and/or sudden noises. Their results showed that possum remained longer at feeders placed further from trees and their initial behaviour did not increase with the initial amount of food. This suggests that there is not a simple trade-off between foraging efficiency and the risk of predation.

Perhaps, as noted by Bowater (n.d.) possum living in urban environments are secluded from their main predators and as a result they do not detect certain odours and scents associated with them, thereby having a low perceived predation risk. Another reason could also be that in urban parks dogs are more likely to be walked on a lead.

The only predator of juvenile possum in New Zealand is the feral cat, which is an ambush predator that prefers low light and enclosed spaces for hunting. Accordingly, foraging in open areas even during the full moon phase may reduce predation pressure.

## 3.4 Seasonal effects on activity

The diet of possum is often related to seasonal changes that not only change the availability of certain foods such as fruits and flowers, but also the digestibility of evergreen species. The species that offer foliage year round (e.g. Hall's totara) are noticeably more favourable to possum during late spring and summer when new leaves are present. This most likely indicates a seasonal change in palatability. Seasonal variation has proved to be an important factor, which shapes the behaviour of mammals (Brown and Peinke, 2007; White and Geluso, 2007). Changes over an extended period of time can occur when the relentless browsing of possum brings about changes in the composition of vegetation (Nugent *et al.*, 2000).

There are many other examples of seasonal changes impacting the activity of small mammals such as in the Eastern Cape Province of South Africa, where African springhares increased their aboveground activity during the warmer months (Brown and Peinke, 2007). In a study by Laurance (1990) it was concluded that three species of possum, including *Trichosurus vulpecula*, significantly reduced their activity when temperatures fell below 14-16 °C. Stokes *et al*. (2001) hypothesized that the activity of prairie voles (*Microtus ochrogaster*) and cotton rats (*Sigmodon hispidus*) would be reduced under bright moonlight however, cloudy conditions should show an increase in activity. The reasoning behind this hypothesis is the belief that all animals are most active during periods of low physiological stress and reduced risk of predation. Warm weather therefore should lessen physiological stress and cloudy, rainy weather minimises predation risk (Brown *et al.*, 1988; Daly *et al.*, 1991)

A number of studies also indicate that possum are not fervent about inclement weather. Pracy and Kean (1949) observed that in windy and showery conditions, possum in the Orongorongo Valley, New Zealand reduced travel time, limiting movement to the ground and sheltered positions. Jolly (1976), after collecting radio-tracking data in Prices Valley, New Zealand concluded that rain inhibits possum activity even to the extent that they will return to their den sites at the onset of it. These examples clearly demonstrate that weather and/or seasonal changes can influence the activity patterns of animals.

## 3.5 Aim of research

Bering in mind the large impact of the possum in NZ, the aim of this study is to determine the influence of moonlight on the common brushtail possum foraging behaviour by measuring activity levels during new and full moon phases in varying habitat types (i.e. open versus closed canopy). While there is much research on other animals indicating changes in lunar phase do impact the activity patterns of nocturnal mammals, (see Chapter 3), few specifically contrast new and full moon phases. One exception is Dutton (2008), a summer scholar with Lincoln University (LU) who conducted a five-month study measuring activity during new and full moon phases only. His findings suggested that possum exhibited higher levels of activity over a period of time during the full moon phase when compared to the new moon phase during the summer season.

With this study there are three research questions that need to be addressed:

1. Are indirect indices of activity for possum (e.g. predator avoidance and changes in habitat) influenced by changes in lunar phase?
2. Is there an apparent change in possum behaviour that is directly correlated to seasonal changes (i.e. summer versus winter) or shifts in weather patterns (i.e. rain or no-rain)?
3. Is adhering to the lunar cycle beneficial in terms of vertebrate pest control?

# Chapter 4: Methods

## 4.1 Introduction

According to Lennon (1998), moonlight is merely one of many environmental factors that can shape the activity patterns of animals. Whilst some direct indices of animal activity are related to seasonal changes in food supply and reproductive conditions, numerous research indicate that moonlight, an indirect measure, plays a significant role (for more information, see Chapter 3). Dutton (2008) began an investigation measuring the effects of moonlight intensity (full vs. new moon) on possum activity levels in varying habitat types. His study was carried out for a period of five months mostly during the summer season. The purpose of the current study is to act as a continuation to his summer study however; there are a few notable differences, such as change of season and varying study sites. I am interested to discover whether season and temperature play a significant role in the activity patterns of possum. The current study was conducted and fieldwork took place during the New Zealand autumn and winter months (late April-August 2010). Like Dutton (2008), I also restricted activity observations to full and new moon phases. To ensure that I will have enough information to make a scientific inference, I collected four months of data, totalling three full and new moon phases for every site. Both new and full moon phase dates for April-August of 2010 were collected from the NASA eclipse website (http://eclipse.gsfc.nasa.gov/phase/ phase2001pst.html).

My main research hypotheses are as follows:

***Null hypothesis:***
The mean of the full moon activity levels measured by WaxTags® is equal to the mean of the new moon.

$H_o = M_{full} = M_{new}$

***Alternate hypothesis:***
The mean of the full moon activity levels measured by WaxTags® is not equal to the new moon.

$H_1 = M_{full} \neq M_{new}$

## 4.2 Banks Peninsula

Banks Peninsula is ecologically copious, offering traces of original forest, native scrubland, farmland and tussock grasslands. According to Parks (2009), many native plant species reach their northern or southern limits along this peninsula. Threatened plants and animals make up these habitats, including 41 species of native plants (Wilson, 2002), three species of lizard (Lettink and Whitaker, 2004), six endemic plants and at least 60 endemic invertebrates. Endemism refers to an ecological state of being unique to a defined geographic location and is also sometimes referred to as indigenous (http://en.wikipedia.org/wiki/Endemism). Twelve species of birds have become locally extinct however, under suitable conditions, including predator-free habitats, they (e.g. tui and the eastern buff weka) could have a chance at re-colonisation. The vegetation composition of Banks Peninsula historically included lowland podocarp and broadleaf forest, including rimu (*Dacrydium cupressinum*), matai (*Prumnopitys taxifolia*) and totara (*Podocarpus totara*). Unfortunately, with the arrival of European settlers, much of the native trees were milled to accommodate nearby demands for timber (EC, 2010). Currently, protecting and restoring biodiversity in the area has captured the interest of many organizations, landowners and groups, such as Regional Council, DOC, Banks Peninsula Conservation Trust, Christchurch City Council and Environment Canterbury. These parties collaborate together to promote biodiversity conservation in the area and tackle some of its greatest threats such as the control of introduced weeds and pests (EC, 2010).

## 4.3 Field sites

Four areas on the peninsula of relatively close proximity to one another were surveyed as part of this study including two at Port Levy, Prices Valley and Okuti Valley. Varying habitats such as pine forests, native bush and forested areas were selected to obtain a general idea of possum habitat preference (see Figure 3). Movements were likely to differ amongst the habitats as food and shelter (Jolly, 1976) become less uniformly distributed. According to a study by Jolly (1976), possum' preferred habitat in Banks Peninsula were exotic trees (gums, macrocarpas and willows), orchard trees (apples, pears, peaches and walnuts) and native forest. Pasture was used very little.

**Site 1: Port Levy**

*Port Levy*, a 319 ha reserve, located at 43˚42´54.85"S and 172˚47´02.27"E is a sheltered bay enclosed by two long, high spurs, cradling two main valleys, Western Valley and Owhetoro Stream. Elevation is approximately 669m a.s.l and the sampling area for this study was 6.3 ha. The vegetation is greatly diverse and relatively balanced, composing modified grassland, native scrublands, regenerating bush including kowhai (*Sophora tetraptera*), kanuka (*Kunzea ericoides*), pepper tree (*Pseudowintera colorata*), tree fuschia (*fuschia excortica*), lemonwood (*Pittosporum eugenioides*) and many hectares of exotic pine forest (Miskell, 2007). Due to large open grassland areas, which offer little protection from the elements and close propinquity to the sea, weather in Port Levy can often times be cold, windy and unpredictable.

**Site 2: Port Levy-Pine plantation**

Adjacent to and within 1km from Port Levy is a *pine plantation* that is approximately 2.5 ha and has an elevation of 688 m a.s.l. Found at 43˚42´39.70"S and 172˚46´48.63"E, it was also a site used for this study. Pine trees are not native to New Zealand and were first introduced in the late 1850's to establish widespread plantings eventually to be used for timber. This site offered no variety of trees, only Monterey Pine (*Pinus radiata*).

**Site 3: Prices Valley**

*Prices Valley*, positioned at 43˚46´22.99"S and 172˚42´22.91"E is located 60 km south of central Christchurch and contains a mixture of pasture, exotic trees and shrubs. Examples of some species found there are ngaio (*Myoporum laetum*), titoki (*Alectryon excelsus*), mahoe (*Melicytus ramiflorus*), manatu (*Plagianthus regius*), kotukutuku (*Fuchsia excorticata*) and horopito (*Pseudowintera colorata*). According to Lennon (1998), the site has in the past served as a study area for numerous possum studies, including Jolly; 1976, Henderson and Hickling; 1997 and Triggs; 1982). The particular study area is roughly 6.5 ha in size, 30 m a.s.l and is mostly dominated by regenerating scrubland.

**Site 4: Okuti Valley**

*Okuti Valley* is a 5.5 ha reserve located at 43˚47´04.83"S and 172˚50´02.49"E just 3 km southeast of Little River in Banks Peninsula. It is a lowland podocarp-broadleaf forest, elevated at 113 m a.s.l comprised of kotukutuku (*Dacrycarpus dacrydioides*), totara (*Podocarpus totara*), mahoe (*Melicytus ramiflorus*), kanuka (*Kunzea ericoides*), horoeka (*Pseudopanax crassifolius*), ponga (*Cyathea dealbata*), mamaku (*Cyathea medullaris*), nikau (*Rhopalostylis sapida*), pate (*Schefflera digitata*) and puahou (*Pseudopanax arboreus*). It has moderately steep lower hillslopes on and above an old river terrace in a broad lowland valley.


**Figure 3**. Fieldwork sites marked with transect points (top photo: Port Levy with 9 transect lines, including 3 lines from Pine plantation, bottom left: Prices Valley with 9 transect lines and Okuti Valley with 4 transect lines). (Note. Map created using Google Earth (Google, 2010)).

## 4.4 Sampling Protocol

Fieldwork took place during the fall/winter season over a period of four months, from May-August 2010. Sampling nights varied at each particular site depending on logistics but in total were as follows: Port Levy- 29 nights, Port Levy pine plantation- 29 nights, Prices Valley- 32 nights and Okuti Valley- 32 nights. In continuance of a study carried out by Dutton (1998), non-toxic fluorescent WaxTags® were used to measure possum activity levels. The WaxTag® method (WTM) is a step up from the previous wax block method (WBM) in that it uses a light-weight possum monitoring device which can be affixed to a tree (Thomas *et al*., 2007). Possum interference can be measured by bite marks on the wax. Note: The WaxTags® used in this study were a bright orange colour different from the white tags that were originally used (see Figure 4).

**Figure 4**. WaxTag® affixed to a tree

One could assume that the orange tags are much easier to detect from further distances. I could detect them in the field 150-200 m away (pers. obs., May 2010); however, it is not known if this increases attractiveness for possum.

While I could have used lures such as icing sugar, flour and fruit oil as an attractant in conjunction with WaxTags®, I did not for fear of ‘saturation’ and 100% detection (i.e. all devices were bitten). According to Morgan *et al*. (1995), hunters assume that using lures increase the kill by attracting possum to the bait. While this has not been proven to always work, I did not want to take any chances. Transect lines were 100 m wide and contained five WaxTags® every 10 m for a total transect length of 50 m. WaxTags® were affixed roughly 30 cm from the base of trees with a staple gun. This sampling protocol was adopted from

NPCA (2008) to ensure independence of individual lines and to prevent contagion between transects. Contagion is defined as 'disease transmission via indirect or direct contact' and can occur when an infected possum bites all of the WaxTags® in a given area. This is very probable and naturally would result in an overestimation of possum density (Thomas *et al*., 2007). In a report made for National Possum Control Agencies (NPCA), Diederik (2005) claims that WaxTag® monitoring has excellent sensitivity at low population densities, so the contagion issue warrants close scrutiny in high possum density areas.

When retrieving the tags, line and tag number were all recorded using a waterproof sharpie® marker. Both Okuti and Prices Valley had a fence which ran perpendicular to the transect lines and as such was used as a marker for the starting point. For the two sites at Port Levy, Prices Valley and Okuti Valley there were 12, 9 and 4 transect lines, respectively for a total of 25 lines in the four habitat types measured. During the first field visit, GPS coordinates were mapped for each starting point of a transect line. In addition, they were marked with pink biodegradable tape. This was done primarily to ensure that if something were to happen to the marker tape or WaxTags®, the GPS coordinates would allow for relocation of the transect lines. Initially there were five transect lines at Okuti Valley, however one line was removed as its' length was too small and within close proximity to the others, therefore determined insignificant.

HOBO® H8 Pro Series light sensors were also used to measure luminous emittance (lux), temperature (°C) and humidity (rH). They have a programmable start date/time, and sampling rate (0.5 second to 9 hours) as well as a 7-9 day non-volatile memory (Equipment, 2009). Because there were only two sensors available, they were put out at Prices Valley and Okuti Valley. At both sites, they were randomly placed on the first transect line. Due to their small size (see Figure 5) and vulnerability to the elements, prior to being left in the field, they were reset and put into plastic containers and then into plastic bags to waterproof them. Once they were collected, the information was then downloaded and saved in a Microsoft Excel 2004 spreadsheet (Microsoft Corporation, USA).

Camera trapping is a non-invasive method of monitoring most often used for surveying elusive, medium-to-large terrestrial mammals. Increasingly, this is becoming the preferred method, as it is more cost-effective and practical than traditional live-trapping techniques (De Bondi *et al*., 2010). Another advantage of using camera traps when practicing wildlife management is the ability to replicate the study and spatial area over time. As such, they were used in this study, not to measure species abundance (because they were not used for the entire duration of study and not at each field site), but to validate findings of bitten

WaxTags®. Camera trap locations were selected based upon the most ‘popular’ sites (i.e. highest possum bite mark index (BMI)) earlier visited by possum. These sites were line seven of Prices Valley and line four at Okuti Valley.


**Figure 5**. Light sensors used in this study (Photo courtesy of Envco: http://www.envcoglobal.com)

Each time the cameras were retrieved, the batteries were fully charged and memory card reformatted. The camera traps used in this study were PixController - DigitalEye 7.2 Digital Trail Cameras. These cameras were ideal for this study and most fieldwork as they are lightweight, small and compact, fitting into the palm of a hand (see Figure 6). Locks were used to fasten the cameras to trees (also see Figure 6) and they were set c. 30 cm off the ground, opposite the trees where the WaxTags® were set.

They use an integrated passive infrared (PIR) motion sensor, which is triggered by ‘body heat and motion’ and have a detection range of 25 m. Equipped for rain they are enclosed in a rugged and waterproof case. Fast trigger time and long battery life made this camera a good choice (DigitalEye, 2009) for this study.

**Figure 6**. DigitalEye camera traps in their waterproof casing and attached to a tree (Photos courtesy of PixController Inc, DigitalEye™ Trail Camera)

sensors, other data collected included date of monitoring and retrieval, block size ocollected included date of monitoring and retrieval, block size of sampling area, habitat, weather, and total number of sampling nights.

## 4.5 Study limitations

There were some limitations of the current study that should be addressed. Access to the field at times was impossible due to unreliable driving conditions (snow, high winds and ice) at Site 1, Port Levy. This resulted in two cancelled trips to do field work, the 27 & 28th of May and the 12th of June.

Light sensors, which were established at the beginning of each new and full moon phase were intended to identify changes in temperature, light (lux) and humidity (rH). Unfortunately, they were not sensitive enough to detect any differences in light for this study. This became apparent as all the results from the three new and full moon phases showed a constant lux level of 2.0 from dusk to dawn. According to Kramer and Birney (2001), a new moon should equate to approximately 1.0 lux with minimal light and full moon and up to 3.0 lux with maximum light. With a constant lux level of 2.0, we can assume there was an average amount of light and the devices were not sensitive enough to detect subtle changes. It is not plausible that the light levels remained the same from dusk to dawn each day for the study period and as a result the light results were not used. Temperature and humidity (rH) levels also did not show any significant differences or obvious trends over the study period, so it was determined these results too, would be dismissed and not used in the final results. This decision was also supported by the fact there were only two light sensors, and with four field sites, they could only be used at two field sites (Prices and Okuti Valley). In the future, I would recommend using different light sensors, ones that are more sensitive to changes in light levels. Since this study took place over two seasons (fall, winter) I would recommend having enough light sensors for each study site if possible to conclude whether changes in temperature and/or humidity also impacts possum foraging behaviour.

## 4.6 Data analysis

Data was analysed using the possum bite mark index (BMI: see NPCA 2008) whereas WaxTags® were left out for a certain number of nights ranging from four to six and upon collection they were inspected for incisor bite marks. Prior to the start of fieldwork I was shown how to positively identify possum bite marks (see Figure 7) and also how to distinguish them from the bite marks of other mammals in the study area, such as rats, rabbits, hares and mice (Ross, J., pers. comm., Lincoln University May 2010).

**Figure 7**. Possum bite mark incisions on WaxTags®
(Photo courtesy of Malcolm Thomas, Pest Control Research, Ltd.)

At the time of retrieval, only the WaxTags® positively identified as having been bitten by possum were recorded. Possum density was then estimated by calculating the percentage of WaxTags® with bite marks per transect line. The data was then put into a Microsoft Excel 2004 spreadsheet and for each night out, at each site, the mean was established to further determine the variance, standard error and 95% confidence intervals of possum activity.

Camera trap data was also entered into an Excel spreadsheet, which identified date, time, moon phase and species detected. Because camera traps were not used at all four sites and for the duration of this study, no inferences could be made about possum activity, hence the photos that captured hares, rabbits, possum and feral cats will be used solely to support WaxTag® data for identification purposes.

## 4.7 Statistical analysis

Genstat Version 12 (VSN, International Ltd) was the statistical software program used and the Restricted Maximum Likelihood (REML) method (Gilmour *et al*., 1995) used to analyze the WaxTag® BMI data. In contrast to maximum likelihood estimates, REML estimates are known to be unbiased (Baker, 2002). As likelihood functions are not linear and quite complicated, maximization of the likelihood function requires numerical methods and extensive computation.

Dr. Searle, a biostatistician and leader in the field of linear and mixed statistical models implies that REML estimates are identical to Analysis of Variance estimates (ANOVA) using mixed repeated measures. The apparent disadvantage of using ANOVA is that often times the designs will lack balance because of missing experimental units, need for the use of a covariate and/or non-homogeneous variances (Baker, 2002). Repeated measures (i.e. same fieldwork sites) have temporal correlation that needs to be addressed and in this study the means had to be adjusted accordingly. Measuring site-by-date interaction includes all variables and alleviates the autocorrelation allowing me to analyze the interactions as if they were independent (i.e. was there a change in moon phase observed over a period of time)?

The REML model looked at both fixed and random effect parameters. Fixed parameters included phase and phase by field site interactions. These were the main variables I was interested in finding a correlation between, in essence, the main effect of my study. Namely, was a significant variance of means detected in the different phases of the moon independent of other variables such as time or site (i.e. was there a difference in possum activity during the different phases of the moon)? Another question is whether there was a significant correlation between phases of the moon and activity at study sites (i.e. were possum more active at certain field sites during different moon phases)? To determine the significance of my fixed effects a Wald Test was used to determine the true value of parameters based on a sample estimate and as such was used for this study (Harrell Jr., 2001).

This technique sequentially added fixed terms (including the higher order interactions) to the model. As with any study, conventional teaching has taught us that the more data we have collected in an experiment, the better predictions we can make and lessen any risk of error. It is keeping this in mind; I have included previous data from Dutton (2008) who was also interested in possum foraging behaviour over the new and full moon phases during the summer months. Assessing both studies, which span a total of nine months (Dutton- 5 months, current study- 4 months) I will be able to make an accurate assessment of the overall effect of moon phase on possum foraging behaviour in Banks Peninsula, New Zealand.

# Chapter 5: Results

## 5.1 Introduction

All collected field data including date, site, habitat, weather, block size, nights out (for WaxTags®), temperature and humidity were recorded over the four-month monitoring period. This data was then used to determine mean possum BMI, standard errors, variance and 95% confidence intervals (CI), (see Table 2, pg. 41). As mentioned in section 4.5, data obtained from light sensors, including lumen levels, temperature and humidity were not sensitive enough to detect any significant changes. That coupled with the fact they were not used for the entire duration of the study made it difficult to determine if any trend was present. Because of these issues the data from the light sensors was not used. While results from Dutton (2008) determined there was an increase in possum activity over time during the full moon events, I was interested in whether other variables, such as weather, season and moon phase with regards to habitat was significant.

Because both the current and previous data were analyzed, for each result listed below, I have noted the data set I am referring to (please see Appendix, Table 3, pg. 56 for results from Dutton (2008)). Results varied significantly between the studies.

## 5.2 Effects of site and moon phase

According to the Wald test, there was a significant main effect of possum activity during different phases of the moon ($\chi2$ =7.38, DF=1, P=0.022). These results include only the current study. A model of adjusted means verified that possum bite mark index (BMI) was significantly greater during full moon when compared to new moon (see Figure 8). This is in conjunction with the previous study by Dutton (2008), which also shows that the possum BMI was higher during the full moon period when measured over time.

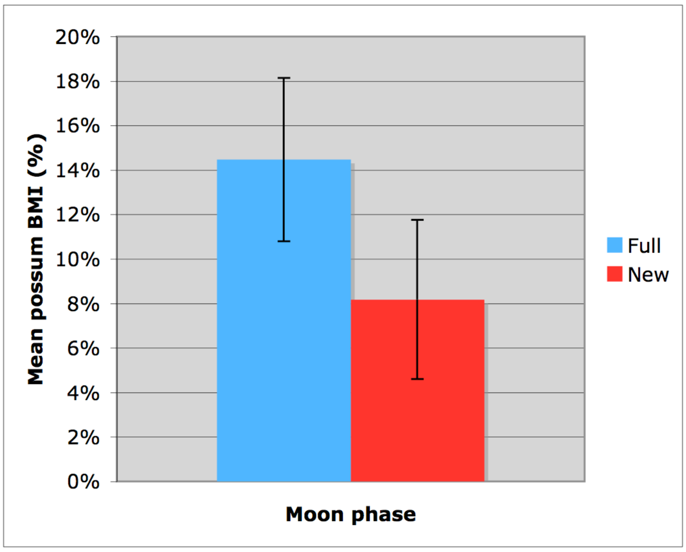


**Figure 8**. Adjusted means for moon phase interaction (±SED)

Note. Means are adjusted to account for autocorrelation

I then analysed whether there was an overall moon phase effect. This combined data included not only the results from the current study but also previous results from Dutton (2008). The result was statistically insignificant ($\chi 2$ =1.84, DF=1, P=0.187); however, activity during the full moon was considerably higher than during new moon phase (see Figure 9).

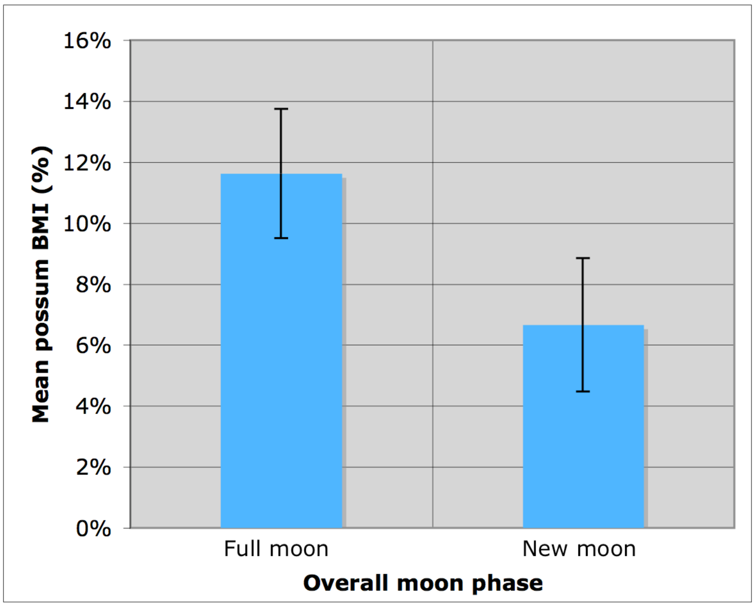


**Figure 9**. Adjusted means for overall moon phase interaction (±SED)

Note. Means are adjusted to account for autocorrelation

Results from the current study show that Prices Valley, compared to all other field sites showed the highest possum activity. Next was Port Levy, then Okuti Valley and finally Port Levy pine plantation (see Figure 10). The mean BMI percentages for each site are as follows from highest to lowest: Prices Valley (18.41%), Port Levy (9.63%), Okuti Valley (7.14%) and lastly Port Levy pine plantation (3.33%); however, the means did have high variability most likely due to differences between the moon phases (see below).

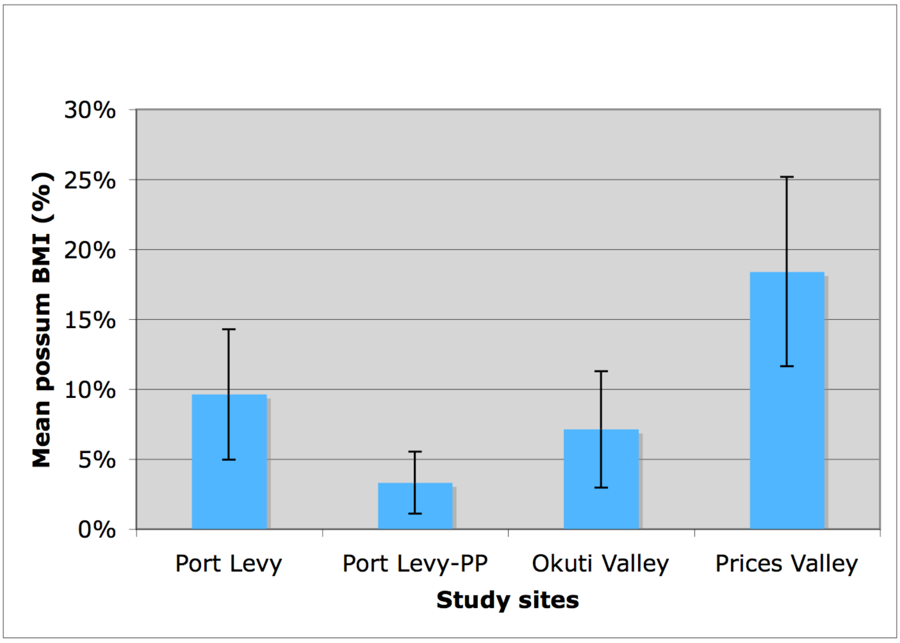


**Figure 10**. Mean possum activity levels (±SED) at all four study sites

Considering only the current study, there was no significant overall interaction between moon phase and site ($\chi 2$ =14.84, DF=6, P=0.699). Inspection of means noted big differences between full and new moon phases at Okuti Valley and Port Levy pine plantation (see Figure 11). There were no notable changes in activity during the moon phases at Port Levy and Prices Valley.

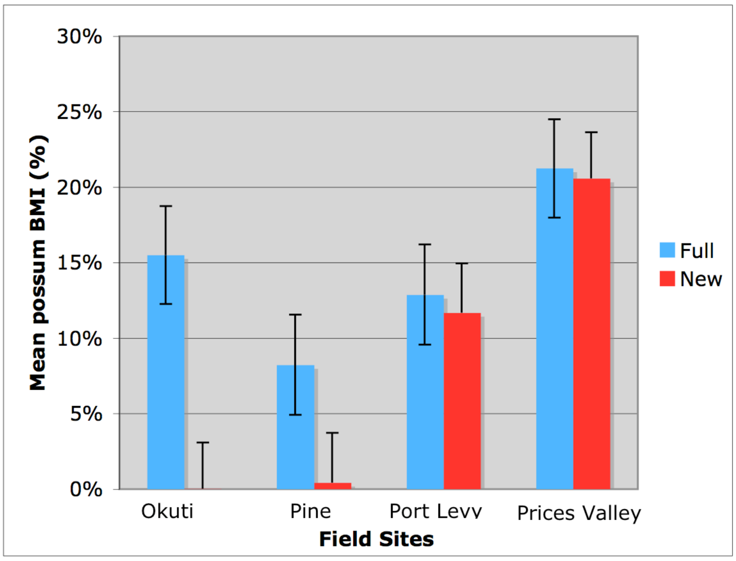


**Figure 11**. Adjusted means for site by moon phase interaction (±SED)

Note. Means are adjusted to account for autocorrelation
*Note. Okuti Valley and Pine plantation are forested sites with canopy cover

Dutton's results indicated temporal changes in possum behaviour. To determine whether there were any temporal trends in moon phase BMI activity, adjusted means were also predicted for the site by date interaction. These means indicated that unlike Dutton (2008) who's findings showed an increase in activity during full moon over time, there was no obvious upward or downward trend in BMI activity over time (see Figure 12).

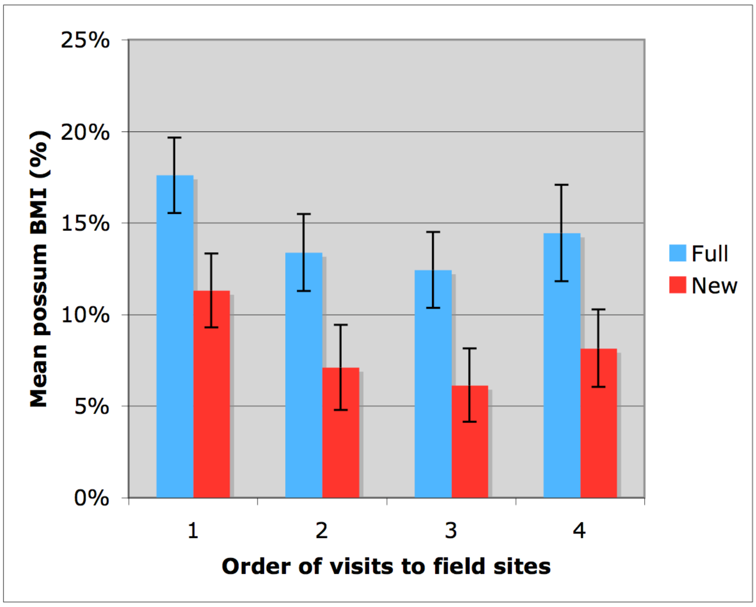


**Figure 12**. Adjusted means for site by date by moon phase interaction (±SED)

Note. Means are adjusted to account for autocorrelation

## 5.3 Effects of habitat variables

Reviewing the results from Dutton (2008) would help me determine if other variables, which were not significant in my study, combined with previous results, would be. Accordingly, the fixed effects used in analysing the combined data set included moon phase, habitat (i.e. forest or scrub), the moon phase by habitat interaction, weather (i.e. rain or no-rain) and season (i.e. summer or winter).

The previous results paired with my study show that there is significant effect of moon phase effect but only with regards to habitat type ($\chi 2$ =10.72, DF=2, P=0.010, see Figure 13).

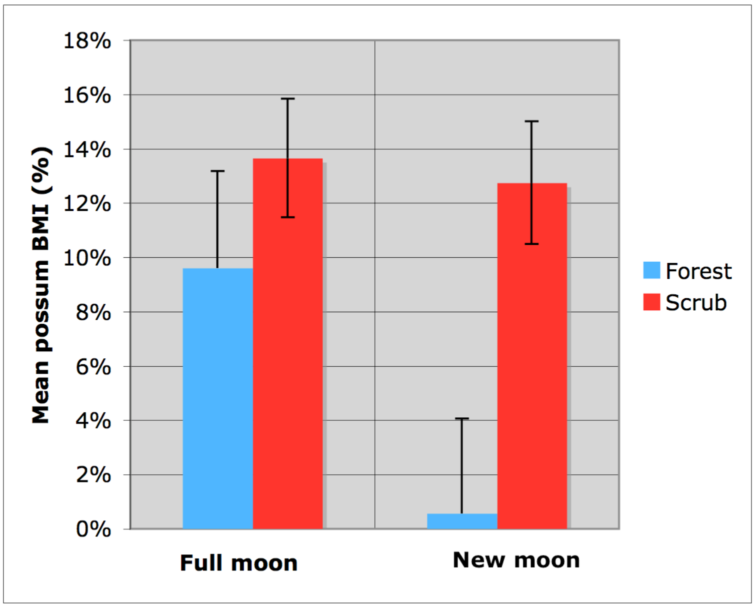


**Figure 13**. Adjusted means for moon phase by habitat interaction (±SED)

Note. Means are adjusted to account for autocorrelation

Whilst the literature suggested differences in activity levels during seasonal changes (e.g. more activity during the summer months), there were no significant differences in overall BMI activity ($\chi 2$ =0.14, DF=1, P=0.713, Figure 14) with both data sets.

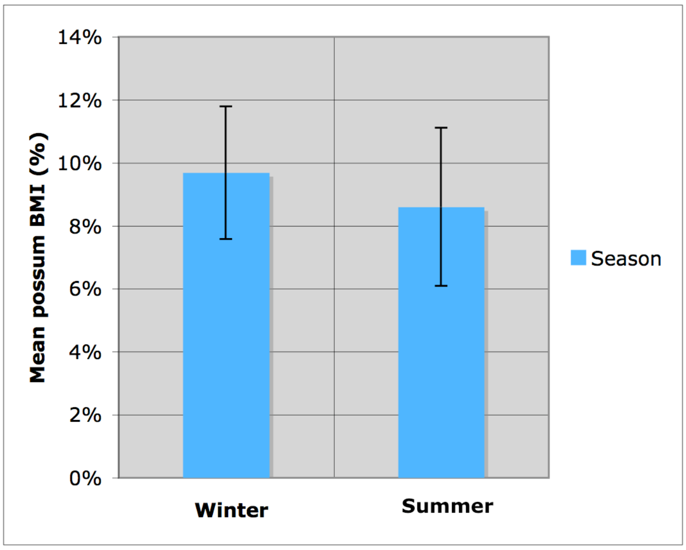


**Figure 14**. Adjusted means for seasonal interaction (±SED)

Note. Means are adjusted to account for autocorrelation

It is unclear if changes in weather had a significant role since my data did not include much heterogeneity of weather patterns (i.e. there were not many rainy days). Possum BMI was reduced under inclement weather patterns (i.e. rain), but not significantly ($\chi 2$ =0.83, DF=1, P=0.368, see Figure 15).

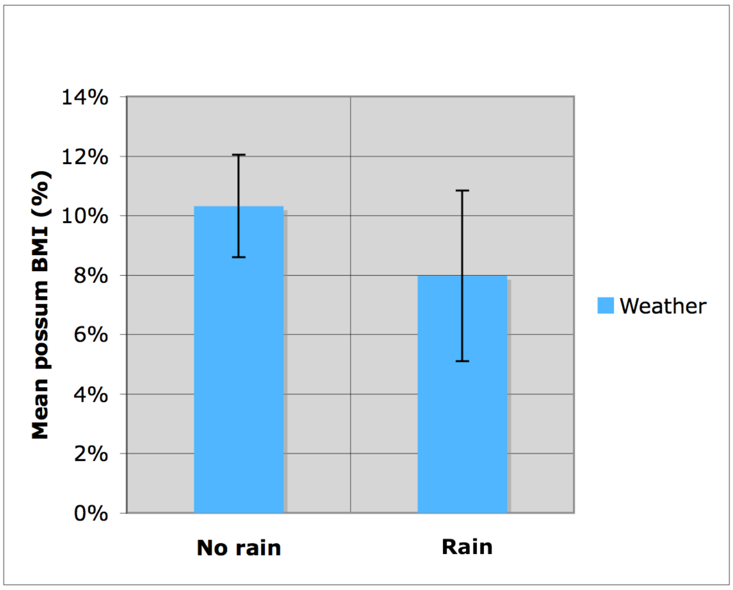


**Figure 15**. Adjusted means for weather main effect (±SED)

Note. Means are adjusted to account for autocorrelation

## 5.4 Camera trap results

The camera traps employed during the last two-field site visits (1 full moon, 1 new moon phase) fully support the notion that possum were certainly present in one of the research areas and happy to interfere with the tags (see Figure 16). While Prices Valley and Okuti Valley were the two sites where cameras were established (see Chapter 4 for more information), activity was only found at Prices Valley over the last two trips to the field (1) July 26-30th and (2) August 11-15th and results are represented in Figure 16. This was not due to malfunctioning of the camera at Okuti Valley as it did take photos during the time it was left in the field; however, it did not capture any images of animals. Upon collection of WaxTags® and the camera trap from Okuti Valley, I retrieved a severely bitten WaxTag® (identified as possum) at transect line number-four directly across from where the camera trap was stationed. It was unfortunate that the camera did not capture any images of possum.

**Figure 16**. Prices Valley camera trap results.

Visit 1 - left side of photo from top to bottom, feral cat, hare and possum.
Visit 2 - right side of photo from top to bottom, possum removing WaxTag® and bottom right picture is of a hare (circled) in motion (WaxTag® (circled) seen on ground near tree).
Note. Photos are all taken at transect line 7 in Prices Valley

**Table 2**. Possum Bite Mark Index (BMI) results over a four-month period during full and new moon phases for four sites at Banks Peninsula

| Site | Date retrieved | Block size (ha) | Moon phase | Habitat * | Weather | Nights out | Mean | Count ** | VAR | SE | 95%CI (low) | 95%CI (high) | Av. Temp | Av. Humidity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Port Levy | 3/5/10 | 6.3 | Full | RENB | fine | 4 | 13.33% | 9 | 17.32% | 5.77% | 2.02% | 24.64% | N/A | N/A |
| Port Levy | 19/5/10 | 6.3 | New | RENB | fine, sunny | 4 | 8.89% | 9 | 14.53% | 4.84% | 0.60% | 18.38% | N/A | N/A |
| Port Levy | 1/7/10 | 6.3 | Full | RENB | cloudy | 5 | 6.67% | 9 | 14.14% | 4.71% | 2.57% | 15.90% | N/A | N/A |
| Port Levy | 16/7/10 | 6.3 | New | RENB | fine, sunny | 5 | 6.67% | 9 | 10.00% | 3.33% | 0.14% | 13.20% | N/A | N/A |
| Port Levy | 30/7/10 | 319 | Full | RENB | fine | 5 | 8.89% | 9 | 10.54% | 3.51% | 2.01% | 15.77% | N/A | N/A |
| Port Levy | 16/8/10 | 319 | New | RENB | fine | 6 | 13.33% | 9 | 17.32% | 5.77% | 2.02% | 24.64% | N/A | N/A |
| Port Levy-Pine Plantation | 3/5/10 | 2.5 | Full | PR | fine | 4 | 13.33% | 3 | 11.55% | 6.67% | 0.26% | 26.40% | N/A | N/A |
| Port Levy-Pine Plantation | 19/5/10 | 2.5 | New | PR | fine, sunny | 4 | 0.00% | 3 | 0.00% | 0.00% | 0.00% | 0.00% | N/A | N/A |
| Port Levy-Pine Plantation | 1/7/10 | 2.5 | Full | PR | cloudy | 5 | 6.67% | 3 | 11.55% | 6.67% | 6.40% | 19.74% | N/A | N/A |
| Port Levy-Pine Plantation | 16/7/10 | 2.5 | New | PR | fine, sunny | 5 | 0.00% | 3 | 0.00% | 0.00% | 0.00% | 0.00% | N/A | N/A |
| Port Levy-Pine Plantation | 30/7/10 | 2.5 | Full | PR | fine | 5 | 0.00% | 3 | 0.00% | 0.00% | 0.00% | 0.00% | N/A | N/A |
| Port Levy-Pine Plantation | 16/8/10 | 2.5 | New | PR | fine | 6 | 0.00% | 3 | 0.00% | 0.00% | 0.00% | 0.00% | N/A | N/A |
| Okuti Valley | 3/5/10 | 5.5 | Full | MPB | fine | 5 | 25.00% | 4 | 25.17% | 12.58% | 0.34% | 49.66% | N/A | N/A |
| Okuti Valley | 19/5/10 | 5.5 | New | MPB | fine | 5 | 0.00% | 4 | 0.00% | 0.00% | 0.00% | 0.00% | N/A | N/A |
| Okuti Valley | 17/6/10 | 5.5 | New | MPB | sunny, windy | 5 | 0.00% | 4 | 0.00% | 0.00% | 0.00% | 0.00% | 6.04 | 25.31 |
| Okuti Valley | 1/7/10 | 5.5 | Full | MPB | heavy rains, cold | 4 | 10.00% | 4 | 11.55% | 5.77% | 1.31% | 21.31% | 6.67 | 26.22 |
| Okuti Valley | 16/7/10 | 5.5 | New | MPB | fine | 4 | 10.00% | 4 | 11.55% | 5.77% | 11.21% | 11.41% | 4.37 | 25.64 |
| Okuti Valley | 30/7/10 | 5.5 | Full | MPB | fine | 4 | 5.00% | 4 | 10.00% | 5.00% | 4.80% | 14.80% | 3.51 | 43.00 |
| Okuti Valley | 16/8/10 | 5.5 | New | MPB | fine | 5 | 0.00% | 4 | 0.00% | 0.00% | 0.00% | 0.00% | 6.44 | 44.53 |
| Prices Valley | 3/5/10 | 6.5 | Full | RENB | fine | 5 | 41.44% | 9 | 30.88% | 10.29% | 21.27% | 61.61% | N/A | N/A |
| Prices Valley | 19/5/10 | 6.5 | New | RENB | fine | 5 | 15.56% | 9 | 27.89% | 9.30% | 2.67% | 33.79% | N/A | N/A |
| Prices Valley | 17/6/10 | 6.5 | New | RENB | sunny, windy | 5 | 15.22% | 9 | 19.38% | 6.46% | 2.56% | 27.88% | 4.75 | 30.67 |
| Prices Valley | 1/7/10 | 6.5 | Full | RENB | heavy rains, cold | 4 | 4.44% | 9 | 8.82% | 2.94% | 1.32% | 10.20% | 6.76 | 49.56 |
| Prices Valley | 16/7/10 | 6.5 | New | RENB | fine | 4 | 20.00% | 9 | 28.28% | 9.43% | 1.52% | 38.48% | 4.81 | 25.54 |
| Prices Valley | 30/7/10 | 6.5 | Full | RENB | fine | 4 | 13.00% | 9 | 14.00% | 4.67% | 3.85% | 22.15% | 4.63 | 43.10 |
| Prices Valley | 16/8/10 | 6.5 | New | RENB | fine | 5 | 19.22% | 9 | 13.06% | 4.35% | 10.69% | 27.75% | 7.82 | 42.00 |

* Habitat abbreviations are RENB= Regenerating Exotic & Native Bush, PR= Pinus radiata, MPB= Mixed Pododarp-Broadleaf, RENB= Regenerating Exotic & Native Bush
** Count refers to number of WaxTag® lines

# Chapter 6: Discussion

## 6.1 Introduction

This chapter looks to quantify findings of the current study and draw inferences regarding whether moonlight is responsible for changes in behaviour of common brushtail possum in Banks Peninsula, New Zealand. One could easily assume that since most small nocturnal mammals are lunar phobic, avoiding activity under intense moonlight, the same would be true for possum. This is because during a full moon and bright illumination, predators of the juvenile possum (e.g. *Felis catus*), can easily detect them. If possum reduce their activity they would follow a common behaviour of small nocturnal mammals known as predator avoidance. Gursky (2003) stated that the probability of a successful hunt decreases substantially if and when the prey becomes aware of a predator before an attack. While there is very limited information about how possum respond to moonlight, we do know that it appears they do not exert this common avoidance behaviour of most nocturnal mammals (see Results).

## 6.2 Main findings

The aim of this thesis was to determine the significance of moonlight on the activity patterns of the common brushtail possum in varying habitat types during the fall/winter months of 2010. There were also some external variables other than moonlight that I was interested in measuring such as weather, season and habitat to determine their significance in this study.

The current data combined with that of Dutton (2008) indicated that overall, possum are more active during the full moon phases; however, the previous study indicated an increase in activity during full moon over time whereas this study did not recognize any trend over time.

Considering all four study sites, Prices Valley showed the highest possum activity irrespective of lunar activity. This could be due to the heterogeneity of vegetation at this site. As mentioned earlier, Prices Valley contains a mixture of pasture, exotic trees and shrubs. Perhaps this is also a reason why this site has served as a study area in the past for possum research. Very little human disturbance at Prices Valley was also observed and is another factor that undoubtedly results in higher possum activity. The transect line that had the highest activity (i.e. most bitten WaxTags®) was line-seven out of a total nine lines. Open scrubland and pasture dominate Prices Valley.

Line-seven consisted of open scrubland, exotic trees, such as kotukutuku and horopito and it was in relatively close proximity (200 m) to a small river.

Port Levy followed with the second highest level of activity. Vegetation at this site is also greatly diverse and balanced made up of modified grassland, native scrublands and regenerating bush. Both of these sites are considered to be open scrubland areas with low canopy. Port Levy, while a DOC reserve, also had very little human disturbance (pers. obs., May-August 2010). This also could have been due to the winter season as it is an unsheltered bay near the sea with unfavourable weather patterns at times.

The current study indicates that possum activity was significantly less during periods of low illumination (i.e. new moon) but only in the forested habitats (e.g. Okuti Valley and the pine plantation). These two sites had the least activity overall. While they are both forested regions with high canopy, Okuti Valley is a lowland podocarp forest rich in diversity and the pine plantation is of low richness and fragmented by an access road. Activity was the highest in scrub habitat (e.g. Prices Valley and Port Levy) with a slightly higher possum BMI during the full moon. This clearly indicates that the most preferred time for possum to forage is during a full moon in scrubland habitat.

Keeping in mind that this study took place during the winter months, the sun usually set around 17:00-17:30 each day (pers. obs., June 2010) with little to no light under the formed canopy. From these results, it appears possum do not prefer dark, covered areas to forage. Another possible reason why activity is lower in these areas could be due to higher levels of disturbance. Okuti Valley is a scenic reserve with high levels of visitor use. A few times while I was conducting fieldwork I noticed people trekking in the area. I also noticed poison stations indicating pest control activity. It was unclear however, if the site was currently being controlled or had in the recent past. I observed tracking tunnels and possum-kill-traps near some of my transect lines and these may deter possum from feeding there. These results differ from those of Lennon (1998) who was interested in whether habitat choice, bait consumption rate and duration of feeding bouts were influenced by changes in moonlight intensity. His results showed that bait consumption increased by 33% during the dark nights (i.e. new moon) at the forest bait station compared to the forest/farmland ‘edge’. However, the site at Prices Valley that Lennon (1998) is referring to is in fact scrubland, not a forested canopy.

Change of seasons can be very important to foraging mammals as it can sometimes mean the difference between having to feverishly search for food (that may or may not be available) or having an ample food supply. According to previous studies, small mammals are expected to be more active during the summer months compared to winter (for more information see section 3.3). The results from this study do not indicate that there is more activity during the summer; instead there was a slightly higher BMI during the winter months. Some of the preferred possum food species at Prices Valley and Port Levy were evergreens such as totara, pohutukawa and rata. Seeing that there are no variations in their food supply throughout the seasons and pasture is available all year round, it is understandable why there are no noted changes in foraging activity.

Weather was crudely noted throughout the study and I did observe a lower possum bite mark index (BMI) during the periods with heavy rain and wind. Unfortunately, there weren't enough total sampling events to make any definitive conclusions between periods of rain or no-rain weather.

Dutton (2008) found that upon analyses of 'order of monitoring operation' there was an increase in activity during full-moon phases over time. Possum activity was lowest during full-moon phases during the initial stages of monitoring suggesting an early sign of aversion to the WaxTags®. Dutton (2008) states that this behaviour can be noted as 'neophobia' (an extreme dislike towards anything new). My study revealed different results including no trend in possum foraging behaviour over time with regards to the order of visits to the field sites. During the first three visits to the field, BMI activity shows a steady decrease but during the fourth visit activity increased. Possum did not in the current study show any initial aversion towards WaxTags® and in fact their BMI activity was highest during their first encounter. This could be due to a few reasons such as initial low detectability of WaxTags® as also mentioned in Dutton (2008). For example, when a possum bites a tag it is impossible to know whether they did so because they detected its bright colour or they found it by chance and their innate curiosity took over.

## 6.3 Future Research

Possum foraging behaviour certainly needs to be further researched as much of the information on how moonlight affects animals is focused on small rodents. While moonlight has proven to be, in this study, very important to the behaviour of the brushtail possum it should not be measured alone, but rather with a wider range of environmental factors, such as temperature, wind, threat from predators, weather and season. All of these variables ought to be taken into consideration.

Since weather in this study was crudely noted, better devices or techniques should be used in the future as it would give a more accurate result. Improved light sensors that are sensitive enough to detect minute changes are one example. Improved sensors will also not only identify the availability of light levels (i.e. lux) but also temperature and humidity. Being able to quantify light levels will give much insight into determining how-much-or-how-little light affects possum behaviour. For example, while this study resulted in possum being more active during full moon periods, with improved light sensors we can determine if perhaps they are more or less active during periods of the full moon (i.e. more active during onset or peak full moon?). We can also ascertain the threshold for which possum feel safe foraging without potential threat from predation during changes in light levels (e.g. how dark is too dark?).

Current research concerning long-term possum control management includes biological control options. A likely vaccine that can be deployed in a genetically-modified bait depends on certain characteristics such as, its expense relative to existing methods, its longevity in the field, its efficacy at reducing female breeding success (Tompkins and Ramsey, 2007) and any potential risk to non-targeted species. It will be important if and when a vaccine such as this is deployed to make sure it is designed to affect only possum in the field. Biological control should be used to maintain possum numbers at low density (Tompkins and Ramsey, 2007) however, trapping and poisoning techniques will still be need to be employed to reduce possum numbers at high densities. It is not feasible that biocontrol methods alone be administered as from numerous trials, they have been found to degrade rapidly in the animal, especially if delivered orally (McDowell *et al*., 2006).

Polkinghorne *et al.* (2005) suggest immunocontraception as a humane means to control unwelcome wildlife and propose that marsupial-specific reproductive antigens in edible plant tissue may provide safe, cost-effective options for control of possum in NZ. In the abovementioned study, female possum vaccinated with these antigens showed reduced fertility so this could be a potential option, perhaps for possum at low-densities. Many reproductive, developmental and hormone-based antigens have been successfully tested in various animal species and humans (Ferro, 2002).

This study will help to ensure that possum eat the modified bait and even if a fertility control is developed, trapping and poisoning will still be needed to initially reduce possum numbers. More research still needs to be done to develop ways to maximise possum activity around bait stations.

## 6.4 Contributions of this study

Government agencies in NZ have different agendas or goals concerning pest management. For example, the mission of DOC is to, "conserve New Zealand's natural and historic heritage for all to enjoy now and in the future" whereas the goal of the AHB is to "eradicate bovine tuberculosis from New Zealand".

Since possum are responsible for threatening the native wildlife found in NZ and they are transmitters of bovine Tb, the abovementioned organisations need to understand possum foraging behaviour to maximize control effort. This study provides valuable information pertaining to the most ideal time of the month to carry out possum monitoring and/or control. Considering the millions of dollar spent annually exclusively on possum control, this is vital information for NZ government agencies such as DOC and AHB. If these agencies adhere to current research such as this study that illustrate when possum are most active in the field, they could potentially save time and money executing the most effective management options.

## 6.5 Implications for future management

The desired objective of any pest control management plan is eradication. When that is not a likely option as is the situation with the brushtail possum in New Zealand, controlling their numbers to where they present the least damage to native flora and fauna is the key. There are a number of reasons why total eradication is unlikely on the NZ mainland. They are as follows: (i) adaptability & establishment of possum to varying habitat types in New Zealand; (ii) high density; & (iii) ineffective control operations resulting in bait-shy survivors.

Deciding how to manage introduced mammals has proved to be quite complicated as according to King (2001) because: (i) all natural ecosystems are dynamic (ii) possible long-term implications of invasive species are unknown (iii) human value systems are linked with management decisions.

Controlling pest species involves an amount of risk assessment and Andersen (2007) recommends conducting an ecological risk assessment which firstly identifies the objectives, then estimates the damage or harm (i.e. characterization of exposure) followed by analysing the effects of the stressors (i.e. characterization of ecological effects) and finally calculating the probability of a negative effect happening and addressing any uncertainty and significance of risks identified

(Andersen, 2007). This research will help to reduce the risk of a failed operation and potentially increase the duration between control operations.

Concerning the previous study by Dutton (2008) and this study I would suggest that possum monitoring with the WaxTag® method should continue to be carried out seasonally since there is still not enough research to definitively determine when possum are more active at certain times of the year. I believe this is an effective, cheap and non-lethal way to continue monitoring for possum. In the future the behavioural patterns mentioned in this study as well as previous ones must be taken into account when considering pest control programs. This research demonstrates that animals can and will change their behaviour depending on external environmental variables.

In conclusion, there will be countless benefits to the future wildlife of New Zealand from keeping possum numbers as low as possible. For example, on Rangitoto Island in Hauraki Gulf, New Zealand, populations of native birds such as kereru, kaka, kakariki (*Cyanoramphus auricep*), whitehead (*Mohoua albicilla*), robin (*Petroica australis*) and bellbird have continually increased during a 7-year possum eradication program (Veltman, 2000). Native vegetation like pohutukawa and rewarewa (*Knightia excelsa*) also responded well to the initial reduction of possum and wallabies (*Macropodidae spp*.) with increased growth and flowering. Australian harriers, silvereye, tui and greenfinch increased in numbers one year after the 1080 eradication program (Miller and Anderson, 1992). Studies in the Tongariro forest have shown that kiwi chick survival rate increased from 27-69% percent in the year subsequent aerial operations against predators. Fantail populations also rebounded dramatically with an increase in chick population from 10 percent to 48 percent (DOC, 2010).

There also appears to be hope for the eradication of Tb in the Southland of New Zealand. According to Knowles *et al*. (2005) the National Possum Management Strategy (NPMS) assumes that in the Southland, Tb will die out of possum populations that are sustained at low and even densities.

This will require the correct timing of control operation to ensure populations do not recover to a level where disease transmission begins to occur again. This research suggests that open scrubland and full moon phase is the preferred foraging conditions of the possum and therefore, control efforts carried out during that time will most likely yield higher capture rates.

## 6.6 Conclusions

The focus of this study was to determine the significance of lunar phase on the foraging behaviour of the introduced common brushtail possum. The Results indicate that common brushtail possum, unlike most nocturnal mammals, are actually more active during full moon periods with higher illumination. The possum is a significant threat to the biodiversity of NZ and because currently a long-term eradication program does not exist, there is a great demand for an effective control management plan. Effective management should include understanding the foraging behaviour of possum and thus, when they are most active during periods of the month.

It appears from this study that the preferred foraging conditions of possum include an open scrubland habitat during the full moon period. Hence, I conclude that agencies that are looking to control and/or eradicate possum from NZ for various reasons should adhere to this study and consider the behaviour of animals when deciding on the timing of pest control operations and thus maximising the probability of control success.

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# Appendix

**Table 3**. Possum Bite Mark Index (BMI) results of three monitoring sites over five months during full and new moon phases.

| Site | Date retrieved | Block size (ha) | Moon phase | Habitat | Weather | Nights out | Mean | Count | VAR | SE | 95%CI(low) | 95%CI(high) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Okuti Valley | 28/12/2008 | 5.5 | new | PHB | Fine | 3 | 6.00% | 5 | 0.30% | 2.45% | 1.20% | 10.80% |
| Okuti Valley | 12/01/2009 | 5.5 | full | PHB | Fine | 3 | 2.00% | 5 | 0.20% | 2.00% | 0.00% | 5.92% |
| Okuti Valley | 1/02/2009 | 5.5 | new | PHB | Fine | 3 | 10.00% | 5 | 0.50% | 3.16% | 3.80% | 16.20% |
| Okuti Valley | 9/02/2009 | 5.5 | full | PHB | Fine | 3 | 10.00% | 5 | 0.50% | 3.16% | 3.80% | 16.20% |
| Okuti Valley | 14/03/2009 | 5.5 | full | PHB | Rain | 3 | 14.00% | 5 | 1.30% | 5.10% | 4.01% | 23.99% |
| Okuti Valley | 27/03/2009 | 5.5 | new | PHB | Fine | 3 | 10.00% | 5 | 1.00% | 4.47% | 1.23% | 18.77% |
| Port Levy | 4/12/2008 | 319 | new | PR | Rain | 3 | 12.00% | 10 | 1.73% | 4.16% | 3.84% | 20.16% |
| Port Levy | 16/12/2008 | 319 | full | PR | Rain | 3 | 5.00% | 10 | 0.50% | 2.24% | 0.62% | 9.38% |
| Port Levy | 29/12/2008 | 319 | new | PR | Rain | 3 | 11.00% | 10 | 0.99% | 3.14% | 4.84% | 17.16% |
| Port Levy | 12/01/2009 | 319 | full | PR | Fine | 3 | 11.00% | 10 | 0.77% | 2.77% | 5.57% | 16.43% |
| Port Levy | 26/01/2009 | 319 | new | PR | Fine | 3 | 5.00% | 10 | 0.94% | 3.07% | 0.00% | 11.02% |
| Port Levy | 9/02/2009 | 319 | full | PR | Fine | 3 | 12.00% | 10 | 0.62% | 2.49% | 7.11% | 16.89% |
| Port Levy | 14/03/2009 | 319 | full | PR | Rain | 3 | 8.00% | 10 | 0.84% | 2.91% | 2.30% | 13.70% |
| Port Levy | 27/03/2009 | 319 | new | PR | Fine | 3 | 10.00% | 10 | 1.78% | 4.22% | 1.74% | 18.26% |
| Rockwood Forest | 26/03/2009 | 220 | new | MBT | Fine | 1 | 18.00% | 5 | 0.70% | 3.74% | 10.67% | 25.33% |
| Rockwood Forest | 1/01/2009 | 220 | new | MBT | Fine | 1 | 20.00% | 5 | 2.50% | 7.07% | 6.14% | 33.86% |
| Rockwood Forest | 14/01/2009 | 220 | full | MBT | Fine | 1 | 16.00% | 5 | 0.30% | 2.45% | 11.20% | 20.80% |
| Rockwood Forest | 28/01/2009 | 220 | new | MBT | Rain | 1 | 14.00% | 5 | 0.30% | 2.45% | 9.20% | 18.80% |
| Rockwood Forest | 10/03/2009 | 220 | full | MBT | Fine | 1 | 34.00% | 5 | 4.30% | 9.27% | 15.82% | 52.18% |
| Rockwood Forest | 28/11/2008 | 220 | new | MBT | Fine | 1 | 24.00% | 5 | 1.30% | 5.10% | 14.01% | 33.99% |
| Rockwood Forest | 11/12/2008 | 220 | full | MBT | Rain | 1 | 18.00% | 5 | 1.70% | 5.83% | 6.57% | 29.43% |

(Table is taken from Dutton (2008) and representative of previous study during summer season)

**Table 4.** List of flora (including fruits & vegetables) referred to in text

| Scientific name | English name | Maori name |
|---|---|---|
| Alectryon excelsus | - | tītoki |
| Aristotelia serrat | Wineberry | makomako |
| Beilchmiedia tawa | - | tawa |
| Beta vulgaris | Silver beet | - |
| Brassica oleracea | Cabbage | keha |
| Brassica rapa | Turnip | pōwhata |
| Citrus spp. | Citrus | - |
| Coprosma acerosa | Sand coprosma | tarakupenga |
| Cupressus macrocarpa | Monterey Cypress | kaiperi |
| Cyathea dealbata | Silver tree fern | ponga |
| Cyathea medullaris | Black tree fern | mamaku |
| Cyclamen spp. | Persian violet | - |
| Dacrycarpus dacrydioides | White pine | kahikatea |
| Dacrydium cupressinum | Red pine | rimu |
| Dactylanthus taylorii | Wood rose | pua o Te Reinga |
| Daucus carota | Carrot | kareti |
| Dianthus caryophyllus | Carnation | kanehana |
| Dysoxylum spectabile | - | kohekohe |
| Eucalyptus spp. | Blue gum | purukamu |
| Fabaceae spp. | Bean | kano |
| Fuchsia excorticata | Tree fuchsia | kotukutuku |
| Gladiolus spp. | Sword lily | - |
| Godetia spp. | Satin flower | - |
| Juglans spp. | Walnut | - |
| Knightia excelsa | New Zealand Honeysuckle | rewarewa |
| Kunzea ericoies | White tea-tree | kanuk |
| Lactuca sativa | Lettuce | rētihi |
| Libocedrus bidwillii | Native cedar | kaikawaka |
| Malus domestica | Apple | āporo |
| Melicytus ramiflorus | Whiteywood | māhoe |
| Metrosideros excelsa | Coastal evergreen | pohutakawa |
| Metrosideros robusta | Northern rata | rata |
| Metrosideros umbellata | Southern rata | rata |
| Muehlenbeckia complex | Wire vine | pōhuehue |
| Myoporum laetum | - | ngaio |
| Nothofagus spp. | Southern Beech | tawhairauriki |
| Passiflora edulis | Passionfruit | pōhue |
| Pastinaca sativa | Parsnip | pāhinipi |
| Peraxilla tetrapetala | Red-flowered beech mistletoe | pirirang |
| Petroselinum crispum | Parsley | pāhiri |
| Pinus spp. | Pine | paina |
| Pisum sativum | Pea | pī |
| Plagianthus regius | Lowland ribbonwood | mānatu |
| Podocarpus totara | - | totara |
| Polyanthus | Primrose | - |
| Populus spp. | Poplar | pāpara |

| Scientific name | English name | Maori name |
|---|---|---|
| Prumnopitys taxifolia | Black pine | matai |
| Prunus persica | Peach | pītiti |
| Prunus spp. | Plum | paramu |
| Pseudopanax arboreus | Five-finger | puahou |
| Pseudopanax crassifolius | Lancewood | horoeka |
| Pseudowintera colorata | Pepper tree | horopito |
| Pseudotsuga spp. | Douglas fir | - |
| Pyrus spp. | Pear | pea |
| Quercus spp. | Oak | oke |
| Raukaua spp. | - | raukawa |
| Rhopalostylis sapida | Palm | nīkau |
| Rosa spp. | Rose | rōhi |
| Rubus spp. | Bush lawyer | taramoa |
| Salix spp. | Willow | whiro |
| Schefflera digitata | Seven-finger | pate |
| Solanum tuberosum | Potato | puteito |
| Sophora tetratera | - | kowhai |
| Weinmannia racemosa | - | kāmahi |
| Zea mays | Corn | kānga |

**Table 5**. List of fauna referred to in text

| Scientific name | English name | Maori name |
|---|---|---|
| Antechinus agilis | Brown antechinus | - |
| Anthornis melanura | Bellbird | kōpara |
| Apteryx australis | Kiwi | kiwi |
| Canis familiaris | Dog | kīrehe |
| Capra aegagrus hireus | Feral goat | nanekoti |
| Carduelis chloris | Greenfinch | - |
| Cyanoramphus auriceps | Yellow-crowned parakeet | kakariki |
| Cenus elaphus | Feral deer | tia |
| Chalinolobus tuberculatus | Long-tailed bat | pekapeka |
| Circus approximans | Harrier hawk | kahu |
| Deinacrida spp. | Wētā | wētā punga |
| Dinornithidae | Moa | moa |
| Dreissena Polymorpha | Eurasian zebra mussel | - |
| Felis catus | Feral cat | ngeru |
| Harpagornis moorei | Haast eagle | pouākai |
| Hemiphaga novaeseelandiae | New Zealand pigeon | kereru |
| Lasiorhynchus spp. | Weevil | tūwhaitara |
| Lepus capensis | Hare | hea |
| Lucanus cervus | Stag beetle | tātaka |
| Macropodidae spp. | Wallaby | warapī |
| Mohoua albicilla | Whitehead | tātāeko |
| Mystacina tuberculata | Short-tailed bat | pekapeka |
| Nestor meridionalis | Kaka | kākā |
| Nestor notabilis | Kea | kea |
| Petroica australis | Robin | pītoitoi |
| Powelliphanta | Snail | ngata |
| Prosthemadera novaeseelandiae | Tui | tui |
| Puffinsus griseus | Muttonbird | tītī |
| Pythonidae spp. | Python | - |
| Rattus exulans | Polynesian rat | kiore |
| Rattus rattus | Ship rat | kiore |
| Rhipidura fuliginosa | Fantail | tīwaiwaka |
| Sus scrofa | Feral pig | kunekune |
| Tarsius spectrum | Spectral tarsier | - |
| Trichosurus vulpecula | Common brushtail possum | paihamu |
| Vulpes vulpes | Fox | pōkiha |
| Zosterops lateralis | Silvereye | pihipihi |