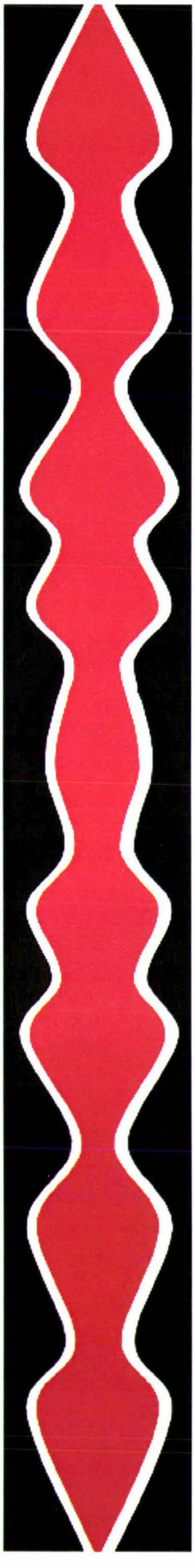

The ecology and conservation of *Latrodectus katipo*, New Zealand's endangered widow spider

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Abstract

New Zealand has two endemic widow spider species; *Latrodectus katipo* Powell, 1871 and *L. atritus* Urquhart 1890. This study focused on the population dynamics and habitat usage of *L. katipo*, which has undergone serious decline in its abundance and range over the last thirty years.

Previous population studies have not included male or juvenile katipo because of their smaller size. A survey of katipo populations was conducted along the Manawatu coastline. There was considerable variation in population density and structure between sites. The highest katipo population density of 21.8 per hectare was recorded at Koitiata. Koitiata, Himatangi, Foxton and Tangimoana populations had a large proportion of juveniles. At Wanganui South and Castlecliff beaches no juveniles could be found, suggesting that reproductive output is very low and that these sites may require conservation attention.

Accurate monitoring is critical to the management of any endangered species, however katipo are not monitored regularly in most areas as current population monitoring methods (transect or quadrat searches) are time and labour-intensive, and require highly-trained observers. I investigated the use of artificial cover objects (ACOs) which have a number of advantages over current monitoring methods; in particular they can be quickly and easily checked by observers. Katipo populations at three sites at Himatangi Beach were monitored between January and July, 2005. More traditional habitat searches were completed concurrently to provide population density estimates. The occupancy rate of the ACOs was strongly correlated with population density, and ACOs are therefore proposed as a reliable alternative monitoring method for katipo. The habitat searches showed that katipo have a longer breeding season at Himatangi than reported in South Island based studies, with males and newly hatched juveniles being found in the field up until about June, as opposed to just during summer months. The katipo population density was relatively constant between January and July, 2005, compared to that of *Steatoda capensis*, an introduced South African spider.

Choice experiments were conducted to investigate whether katipo have preference for certain plant species or driftwood as web sites. Native sand-binding shrubs such as *Coprosma acerosa* are favoured by katipo over other plant species for web construction, and the exotic grass *Ammophila arenaria* is avoided by katipo even when growing at low densities.

L. katipo spiderlings were raised in the laboratory to observe their development. Katipo eggsacs typically produce about 80 spiderlings, however eggsacs I studied contained between 40 and 146 spiderlings. There is substantial variation in the growth rates and abdominal markings of katipo spiderlings during development. Manawatu katipo are unique in that they often retain large areas of white abdominal markings at maturity.

Thesis format and authorship

Each chapter is written as a stand-alone paper. Consequently there is some repetition of material, with references placed at the end of each chapter. I am the principal author of each chapter, with my supervisors Russell Death and Murray Potter providing editing advice.

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Table of Contents

General Introduction

The genus *Latrodectus* has a worldwide distribution with 31 species currently recognised (Platnick 2006). New Zealand has two *Latrodectus* species; *L. katipo* and *L. atritus*. The taxonomic status of these two species is currently under review as genetic analysis suggests they are separate phenotypes of the same species (Griffiths *et al.* 2005). *L. katipo* and *L. atritus* are found solely within coastal sand dunes, with their webs constructed in the bases of vegetation, or under driftwood and other debris. *L. katipo* is found in the South Island and lower North Island, whereas *L. atritus* is limited to the northern half of the North Island (Griffiths 2001).

The New Zealand and Australian *Latrodectus* fauna are closely related (Griffiths *et al.* 2005), and *L. katipo* can hybridise in one direction with the Australian redback, *L. hasselti* (Kavale 1986). However, *L. katipo* and *L. hasselti* are highly distinct in terms of morphology, habitat requirements, reproductive behaviour and development, hence their separate species status. *L. hasselti* is not currently established in New Zealand (J. Derraik, Biosecurity NZ, pers. comm.), though it has been in the past, and presents a threat to *L. katipo* through genetic swamping (Garb *et al.* 2004).

L. katipo is an endangered species, having undergone serious population decline and range reduction over the last thirty years; this decline has been attributed largely to habitat loss and degradation (Patrick 2002). An introduced spider, *Steatoda capensis*, which is established throughout New Zealand and has become very abundant in some coastal dune areas, may also have contributed to the decline of katipo (Hann 1990). Patrick (2002) identified 19 key katipo conservation areas, one of which was Himatangi Beach, Manawatu. He also recommended regular monitoring to track katipo populations nationwide, as this will be critical for the conservation of this species. Few of the key conservation sites identified by Patrick have received additional attention since his report. The current status of many katipo populations is unknown, as regular population monitoring is only occurring at a few sites nationwide, for example at Karitane Spit, Otago. The main reason for the lack of monitoring is that current population monitoring methods include transect and quadrat searches, which are time and labour-intensive, and require experienced observers due to the cryptic nature of katipo webs. There is a need for a monitoring method that can be applied nationwide, that is easily and quickly performed. The use of artificial cover objects (ACOs) is a potential solution. ACOs are already used to monitor weta populations in New Zealand, and amphibian populations overseas. They are standardised and replicable, and can be easily checked.

Much of the original coastal duneland in New Zealand has been replaced by pasture or exotic forest cover (Muckersie & Shepherd 1995), with the remaining dunes being highly modified through the planting of exotic sand-binding plants, grazing by introduced mammals, burning and collection of driftwood, rubbish dumping, and the use of four-wheel drive vehicles (Hilton *et al.* 2000). Understanding how katipo populations are affected by habitat alteration will be crucial to their management so that the restoration of appropriate habitat can occur. Griffiths (2001) studied habitat usage by *L. katipo* and found that they show preferences for warmer sites with non-southerly aspects, low slopes and low to medium vegetation cover. *L. katipo* occupy sand-binding shrubs more than predicted from their abundance, and the introduced grass *Ammophila arenaria* (marram) less than expected (Griffiths 2001). Dense marram is said to exclude katipo as it is unsuitable for web construction (Patrick 2002). It is not known whether katipo prefer certain plant species or driftwood as web sites, when other variables such as microclimate and prey abundance are held constant.

Many population surveys of katipo have not included male or juvenile katipo because of their small size, and less obvious webbing. The structure and seasonal dynamics of katipo populations are thus poorly known, with most observations gleaned from South Island populations. North Island katipo populations may have markedly different population dynamics due to climatic and habitat differences. By investigating population structure we can assess population viability, and therefore identify areas where katipo require more conservation attention.

Previous studies have highlighted the need for an effective monitoring program, a better understanding of how katipo utilise their environment, and an understanding of katipo population dynamics. A thorough understanding of the ecology of katipo spiders will be critical to their conservation. The specific objectives of this study were:

- To investigate whether ACOs are suitable as a reliable alternative monitoring method for katipo, that can be applied in areas where time and labour-constraints are preventing monitoring.
- To compare the population structure and dynamics of Manawatu katipo populations to the existing katipo literature, which is largely based on South Island populations.
- To investigate whether katipo prefer certain plant species or driftwood as web sites when factors such as plant density, microclimatic conditions and prey abundance, are held constant.
- To become familiar with katipo at various developmental stages by rearing them in the laboratory, to assist field-based investigations of population structure.

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Chapter One:

The ecology of New Zealand's katipo spiders; *Latrodectus katipo* and *L. atritus*

Plate 1. A newly moulted sub-mature female katipo. The shed exoskeleton can be seen to the right of the spider. Photograph taken at Himatangi Beach, 2005.

The ecology of New Zealand's katipo spiders; *Latrodectus katipo* and *L. atritus*.

Introduction

The genus *Latrodectus* (family Theridiidae) has a worldwide distribution (Garb *et al.* 2004), with 31 species currently recognised (Platnick 2006). Some members of this genus have been studied extensively, most notably the black widow spiders, *L. mactans* and *L. hesperus,* and the redback spider, *L. hasselti*. This review concerns two comparatively under-studied *Latrodectus* species, *L. katipo* Powell, 1871 and *L. atritus* Urquhart, 1890, both endemic to New Zealand, and the southern-most representatives of this genus (Griffiths 2001). Katipo means 'night stinger' in Maori[1] (Buller 1871); interestingly katipo were the only spiders given their own individual identifier by Maori, with all other spiders being referred to collectively as 'punga-were-were' (Forster & Forster 1999). This was most likely because katipo have special significance as New Zealand's only native venomous animal that poses a danger to humans.

Katipo received their first mention in the scientific literature in 1857, with an account by T. S. Ralph; he gave an interesting description of an experiment in which a mouse and a female katipo were placed together in a bottle and, with much

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[1] Maori = the earliest human inhabitants of New Zealand.

encouragement "by dint of shaking the bottle", proceeded to kill each other! Thus, the venomous status of *L. katipo* was established.

Like all members of the genus, *L. katipo* contain the vertebrate-specific neurotoxin α-latrotoxin in their venom (Garb *et al.* 2004), which triggers massive neurotransmitter release (Beleboni *et al.* 2004). Only mature females are capable of biting humans (Forster & Forster 1999). Bites are rare now, due to these spiders themselves being rare, and non-aggressive. When disturbed katipo will generally first curl up or flee to their retreat (Ward 1998; pers. obs.) If continually provoked they will sometimes swathe sticky silk over their perceived attacker, which is the method they employ to subdue prey items before biting (pers. obs.). However, unprovoked bites have sometimes occurred (Forster & Forster 1999). Symptoms of *L. katipo* bites are the same as bites from other widow spiders, with redback antivenene an effective treatment (Forster & Forster 1999). No deaths have occurred since antivenene has become available (Forster & Forster 1999). Interestingly, there are no records of bites from *L. atritus*, so the venomous status of this species is unclear (Powell 1871; Forster & Forster 1999).

The New Zealand *Latrodectus* fauna has also included the redback spider, *L hasselti*, a native to Australia, which arrived via imported goods and subsequently established here (Garb *et al.* 2004), sometime prior to the early 1980s. However, the population of redback spiders that was established in Central Otago in the 1980's has since died out, and despite occasional incursions, redbacks do not appear to be currently established elsewhere in New Zealand (J. Derraik, Biosecurity New Zealand, pers. comm.).

Both species of katipo spider are endangered, with *L. katipo* in particular having undergone a dramatic decline in abundance and range (Patrick 2002). Research on katipo spiders has been limited, and a large proportion of modern katipo research remains in relatively inaccessible forms, for example as internal Department of Conservation reports, and unpublished theses. *L. atritus* has received less research attention than *L. katipo*, and is therefore less understood.

Species Status and Hybridisation

Katipo spiders, like all members of the *Latrodectus* genus, have had a checkered taxonomic history (see Forster & Kingsford 1983). *L. katipo* and *L. atritus* were once considered to be subspecies of *L. hasselti* (Levi 1958). The status of *L. atritus* and *L. katipo* as two separate species remains unresolved (Griffiths *et al.* 2005; A. Evans, pers. comm.)

Griffiths *et al.* (2005) assessed the fast-evolving ND1 mitochondrial gene region and found very low intraspecific pairwise differences between *L. atritus* and *L. katipo*, suggesting a lack of genetic isolation. The two species were paraphyletic with regards to this gene region (Griffiths *et al.* 2005). However Griffiths *et al.* (2005) recommended that they continue to be regarded as two separate species, recognising the need for further studies, particularly assessing further gene regions, and conducting cross-mating trails to see if *L. atritus* and *L. katipo* can produce fertile offspring. This review considers *L. katipo* and *L. atritus* separately, but it appears likely that further studies will reveal them to be separate phenotypes of the same species. Current levels of gene flow between *L. katipo* and *L. atritus* are unknown (Griffiths 2001). According to Forster & Forster (1999) *L. atritus* and *L. katipo* will mate in laboratory conditions but produce sterile eggsacs, however, no data was provided to support this assertion. A physiological or biochemical block to fertilisation may exist (Kavale 1986).

No such block exists between *L. katipo* and *L. hasselti*, which have readily hybridised in a laboratory setting (Kavale 1986). However, mating occurs in one direction only, as female redbacks do not recognise male katipo as potential mates, and react aggressively to any courtship attempts (Kavale 1986). Male katipo are much larger than redback males, and are not as cautious as redback males during courtship (Kavale 1986).

Redbacks are notorious for a genetically-programmed self-sacrificial behaviour in which the male somersaults during copulation, placing his abdomen against the female's mouthparts, whom then proceeds to slowly devour him (Andrade & Banta 2002). When a male redback was introduced to a female katipo, courtship and copulation proceeded normally, but although the male still performed the somersault manoeuver the female never attacked the male (Kavale 1986). Eggsacs were produced from these matings, and although F1 fertility was very low, eggsacs of F2 crosses returned to normal fertility levels (Kavale 1986).

Hybrids are closer to katipo than redback in appearance (although finer morphological characteristics can be variable), which will prevent accurate identification of hybrids if they do occur in wild populations (Kavale 1986). The establishment of redbacks in New Zealand thus poses a serious threat to katipo populations via genetic swamping (Garb *et al.* 2004), especially as hybrid populations could theoretically have wider ecological tolerances than katipo (Kavale 1986).

Griffiths (2001) found only 2.2% pairwise difference in the mitochondrial ND1 gene region between the two New Zealand species and the Australian redback, *L. hasselti*, whereas Garb *et al.* (2004) found 4.9% genetic divergence in the mitochondrial COI region between *L. katipo* and *L. hasselti*. These results show that the New Zealand and Australian *Latrodectus* fauna are closely related. Despite their close genetic affiliation and ability to hybridise, katipo and redback are very distinct in terms of morphology, behaviour, habitat requirements and development, justifying their separate species status. However, it seems that katipo have speciated within New Zealand much more recently than previously thought (Griffiths 2001). This is in contrast to the earlier view that redback and katipo have been genetically isolated since New Zealand split from Gondwana (Forster 1995).

Development and Morphology

Katipo are typical of most spiders (Foelix 1996, Prenter *et al.* 1998) in having marked sexual dimorphism, the males being much smaller than the females. Likewise, male katipo develop more quickly and live for a shorter period than females (Griffiths 2001, pers. obs.). Female *L. katipo* may live for more than two years (Forster & Kingsford 1983), whereas male katipo raised in the laboratory lived for an average of 77 days past reaching maturity (Chapter 5), and in the wild do not live beyond one breeding season (Griffiths 2001).

Species of *Latrodectus* can be difficult to distinguish in terms of morphology alone (Court 1971). The two species of katipo are equivalent in size, with males and juveniles of the two species being difficult to distinguish from one another (Forster & Kingsford 1983; Griffiths 2001). The females of the two species, however, can be readily separated as female *L. katipo* have a red dorsal stripe running down the middle of the abdomen, whereas *L. atritus* females lack this red stripe, and also tend to be lighter in overall colouration (Forster & Kingsford 1983; Griffiths 2001).

Katipo hatch out from the eggsac at the second instar (Kavale 1986), measuring about 1 mm in length, legs excluded (Chapter 5; pers. obs). A newly hatched spiderling has a dark brown cephalothorax and legs, which are banded, being darker around the joints (see Figure 2 in Chapter 5). Their abdomens are white with the exception of two rows of black diamonds that run down either side of the dorsal midline. When *L. katipo* first hatch they lack the red dorsal stripe; this develops once the third instar is reached (pers. obs.). The red dorsal stripe first appears as a chain of red diamonds, which later join to become a continuous stripe, often retaining the zig-zagged edge.

The ventral 'hourglass' marking, typical of *Latrodectus*, is well-defined in newly-hatched katipo spiderlings, however it is cream in colour. As the spiderling grows and goes through successive moults the white on the dorsal surface of the abdomen is progressively replaced by black pigment, and the ventral hourglass becomes red in colour, though with a less-defined shape. Both *L. katipo* and *L. atritus* have only partial hourglass markings at maturity (Forster & Forster 1999). In comparison the redback, *L. hasselti*, has a well-defined hourglass at maturity (Forster & Forster 1999).

Male *L. katipo* usually reach maturity at the fifth or sixth instar (Kavale 1986), but may take longer (Chapter 5). Mature male katipo resemble immature females in their markings, but tend to have more elongate abdomens (Sutton *et. al.* 2006), and can be readily identified by their large club-shaped pedipalps. The enlarged pedipalps typically develop one or two moults before maturity; they are first pale brown in colour, darkening to dark brown or black upon the final moult (pers. obs.). Male *L. hasselti* tend to reach maturity one moult earlier than *L. katipo* (Kavale 1986), and live for shorter periods (Andrade & Banta 2002). Male katipo are larger, but have shorter legs than redback males, with a mean body weight of 12.14 mg, compared to only 6.83 mg in redbacks (Kavale 1986).

The amount of white colouring on the abdomen of juvenile female katipo continues to decrease, and upon maturity the female katipo will often have no white pigment present at all (Griffiths 2001), although many retain a white border on either side of the dorsal stripe, or even white patches near the anterior end of the abdomen. There appears to be regional variation in markings, with mature female katipo collected from Manawatu beaches often having large areas of white colouration at the anterior ends of their abdomen (Kavale 1986; pers. obs.).

Female *L. katipo* and *L. hasselti* mature at the seventh, eighth or ninth instar (Kavale 1986; Chapter 5). The mean weight of female katipo is 89.8 mg, just over half of the mean weight of redback females; thus redbacks have markedly greater sexual dimorphism than katipo (Kavale 1986). Katipo females also have shorter legs than redback females (Kavale 1986). The two species can be readily differentiated by the abdominal bristles, which on katipo are short and uniform in length, yet are variable in length on redbacks (Kavale 1986). While the dorsal stripe in katipo is typically quite orange whereas the redback's stripe is red, this character is variable and is not the best identifier (Kavale 1986).

There is a large amount of variation in growth rates and patterning in katipo spiders, even between individuals from the same eggsac (Forster & Kingsford 1983; pers. obs.). The colour patterns of katipo are more variable than those of the redback (Kavale 1986). Considerable variation in abdominal markings is also seen in other *Latrodectus* species (Kaston 1968), for example *L. mactans*, the black widow (Reese 1940). However, females from the same eggsac can have almost identical abdominal markings at maturity, despite substantial variation during development (Chapter 5).

The basic black colour of the abdomen can vary in katipo, often being dark brown (Sutton *et al.* 2006; pers. obs.). At Himatangi Beach I found one mature female katipo with a very dark olive green abdomen. This variation in abdomen colour is also seen in black widow spiders (Kaston 1968).

Distribution and Habitat

The current distribution of *L. katipo* extends south of New Plymouth on the west coast of the North Island, and East Cape on the East Coast, spanning as far south as Karamea on the west coast and Dunedin on the east coast of the South Island (Griffiths 2001). *L. atritus* distribution includes the coastline north of New Plymouth and East Cape, extending up to Cape Reinga (Griffiths 2001). The distribution of both species is not continuous within these limits, as dune systems are interspersed with geographical barriers such as rivers and rocky coastline, as well as being highly fragmented due to human modification. There is apparent distribution overlap between *L. katipo* and *L. atritus* on both the east and west coasts (Griffiths 2001). Competition with *L. atritus* could be preventing *L. katipo* from extending northwards, or alternatively, inbreeding between the two may be occurring, blurring the extent to which overlap occurs (Griffiths 2001). Museum records show that *L. katipo* was once found in the Northland and Auckland regions, so *L. katipo* and *L. atritus* were once sympatric over a much greater area (Patrick 2002).

Katipo spiders have very strict habitat requirements, and are only found within coastal sand dune systems. Many other *Latrodectus* species are also restricted to arid environments (Whitehouse *et al.* 2002). However, katipo differ from many of their overseas relatives, including the redback, in that they have never been found in association with human habitation (Kavale 1986; Patrick 2002; Garb *et al.* 2004).

Within the dune system, katipo appear to be most abundant within the foremost dunes (the foredunes and incipient foredunes), becoming less abundant further inland (Griffiths 2001; Patrick 2002). They are also comparatively abundant in the large depressions or blowouts that form in some dune systems (Patrick 2002; pers. obs.).

Katipo may use light and temperature cues to select web sites, showing a strong preference for warm sites (Griffiths 2001). *L. hasselti* also shows a preference for sunny sites in suburban gardens of Australia (Griffiths 2001). It seems that *L. atritus* and *L. katipo* have very similar microhabitat requirements, with both species showing a preference for locations with 34-66% ground cover, sloping ground, and non-southerly aspect (Smith 1971; Griffiths 2001).

Katipo are known to predominantly build webs in the bases of vegetation and on the concave underside of driftwood (Ward 1998, Griffiths 2001), but will also occasionally utilise other debris and refuse such as animal bones, vehicle tyres, metal tins, drink cans, corrugated iron, food wrappers, black polythene sheeting, and have even been found living inside a discarded television set, and under a car bonnet (Forster & Forster 1999; pers. obs.). Many of these objects may have been selected due to the warmer microclimate they create. Katipo are almost never found on damp pieces of wood in the field (Hann 1990; pers. obs.).

It is currently unclear whether katipo prefer driftwood and debris over vegetation when selecting web sites. Driftwood is apparently favoured by katipo in dune blowouts where vegetation is scarce (Patrick 2002, pers. obs). However, Griffiths (2001) found that katipo were under-utilising driftwood compared to plants, with native sand-binding shrubs being preferred habitat. Web-site selection experiments have indicated that katipo prefer shrubs such as *Coprosma acerosa* over other plant species, and that they avoid the introduced marram, *Ammophila arenaria*, even at low densities (Chapter 4). It was unclear from the experiments whether driftwood was preferred over plants, because although many of the katipo initially went to the driftwood, they often relocated and constructed webs elsewhere (Chapter 4).

There is no evidence that katipo assess prey abundance when selecting web sites, but it appears that structural requirements (in terms of adequate attachment points, and open space between) and microclimate are important determinants of web site selection (Griffiths 2001).

Web construction and prey capture

Theridiid webs are typically constructed at night, and remain in place for long periods, being gradually extended and repaired over time, with *Latrodectus*-type webs considered to be primitive within the family (Benjamin & Zschokke 2003). Most *Latrodectus* species construct their webs just above the ground, with an exception being *L. revivensis* which builds webs at the tops of desert shrubs (Anava & Lubin 1993).

The web of a katipo spider is typical of *Latrodectus*, and consists of a 'messy' platform of threads positioned approximately 50 mm above the ground (Griffiths 2001), with a peripheral retreat. Numerous sticky threads span the distance between the platform and the substrate (Court 1971). These sticky catching threads are under tension, with the result that when a prey item walks into one of the strands the thread is dislodged, often pulling the prey up into mid-air if it is not too large (Court 1971).

The web is not renewed daily but is gradually increased in size and density as the spider grows (Court 1971). Katipo catching webs are usually positioned over open sand, in the spaces between plants or driftwood (Plate 2), therefore dense vegetation excludes katipo by not providing space to build their platform webs (Griffiths 2001).

The retreat is constructed from densely woven silk, with the opening at the lower end, which provides additional protection from the elements (Griffiths 2000). Court (1971) noted that katipo sometimes incorporated prey exoskeletons into the walls of their retreat; katipo may also use dead plant material and shell fragments (pers. obs; see Plate 3). *L. revivensis* will also incorporate debris such as stones, shells, prey remains and plant material into the walls of the retreat (Lubin *et al.* 1993).

Plate 2. Katipo web constructed within *Spinifex sericeus*. Photograph taken at Himatangi Beach, 2005. The arrow is pointing to the opening of the retreat. Sparse catching threads can be seen extending from the retreat over the open sand between tillers.

Plate 3. Mature female *L. katipo* inside retreat. Photograph taken at Himatangi Beach, Manawatu. This spider has incorporated pieces of shell and dead vegetation into the walls of her retreat, presumably to provide additional protection for herself and the two eggsacs she was guarding.

Katipo, like all *Latrodectus* (Garb *et al.* 2004) are generalist feeders, but their diet seems to be biased towards beetles and amphipods (Smith 1971; Forster & Forster 1973; Griffiths 2001). This is probably because these animals are active ground dwellers and are thus more likely to be snared, and does not necessarily reflect a particular prey preference by katipo (Griffiths 2001). *L. hasselti* also have a diet biased towards beetles (Forster 1995). Although the invertebrate communities of coastal sand dune systems in New Zealand are not well-known, pitfall-trapping at Himatangi Beach has revealed Isopoda to be the most abundant taxa present (pers. obs., data not presented), but Isopoda are seldom present in katipo webs (pers.

obs.). Other prey items recorded from katipo webs include other Araneae (Ward 1998) and Dermaptera (Court 1971; Smith 1971).

Some *Latrodectus* species feed on small rodents and lizards in addition to arthropods, which could explain the presence of the vertebrate-specific neurotoxin, α-latrotoxin, in their venom (Garb *et al.* 2004). Although katipo share their habitat with native skinks and introduced rodents, they are not known to prey on these animals. In fact, mice may be significant predators of katipo (Miller & Webb 2001). Redback webs are typically larger and stronger than those built by katipo, and redback females are much heavier than katipo (Forster & Forster 1999), which might explain why redback can tackle much heavier prey. Griffiths (2001) found a strong relationship between web size and number of prey caught by katipo. If this relationship holds true across the genus, then redbacks could be expected to be superior to katipo in the size and abundance of prey caught.

Female katipo can survive up to eight weeks in laboratory conditions without being fed (Griffiths 2001). Long periods of survival without feeding also occur in the much smaller males, who abandon their catching webs upon maturity and wander in search of females (Griffiths 2001). Although they are not believed to feed once reaching maturity (Kavale 1986), I have observed laboratory-reared mature male *L. katipo* catching and feeding on prey. In addition, Anava & Lubin (1993) found that wild male *L. revivensis* would sometimes feed on discarded prey items in female webs.

Life cycle

Juvenile and mature female katipo overwinter and thus can be found in the field year round. Females can live for at least two years, whereas male katipo do not live beyond one breeding season (Forster & Kingsford 1983). Male katipo typically reach maturity in spring and early summer, upon which they abandon their webs to go wandering in search of mates (Griffiths 2001). This is observed in other *Latrodectus* species, for example *L. revivensis* (Anava & Lubin 1993). Male *Latrodectus* apparently locate females by detecting the pheromones in their silk (Anava & Lubin 1993). Despite the female-biased sex ratio of wild katipo populations (Parrott 1948; Smith 1971; Chapter 2), sometimes more than one male can be found on, or near a female's web (pers. obs.). I have observed two male katipo chasing each other on a piece of driftwood occupied by a mature female. Sometimes male katipo can be found in the web of an immature female (pers. obs.), which suggests that male katipo may occasionally guard potential mates. The guarding of immature females, and competition for mates has also been observed in *L. revivensis* (Anava & Lubin 1993).

Latrodectus reproductive behaviour is essentially the same for all species (Kavale 1986), with the obvious exception of *L. hasselti* (Andrade & Banta 2002). Mating may take place over half an hour (Forster & Forster 1973). Katipo lack the genetically-programmed sexual cannibalism behaviour seen in *L. hasselti*, whereby the male redback somersaults into the female's mouthparts during copulation and is subsequently slowly devoured (Andrade & Banta 2002). In addition, the male katipo is seldom killed by the female following mating (Forster & Forster 1973). Both male and female katipo are capable of mating more than once (Kavale 1986), whereas male redbacks are functionally sterile after both palps have been depleted of sperm once (Andrade & Banta 2002).

The interval between copulation and eggsac production is variable but usually around 2-4 weeks (Kavale 1986). According to Forster & Forster (1999) and Griffiths (2001), katipo produce eggsacs during the summer, in November and December, with Forster & Forster (1973) stating that katipo spiderlings emerge at the end of January. However, at Himatangi Beach, Manawatu, mature males and unhatched eggsacs can be found from September up until June, while second instar juveniles can be found between October and July (Chapter 3). This suggests that katipo may have a much longer breeding season than previously thought, at least in Manawatu.

The number of eggsacs produced by female katipo is also variable; female *L. katipo* produced between 1-10 eggsacs in laboratory experiments run by Kavale (1986), whereas Forster & Forster (1999) reported 5-6 eggsacs produced per female. In my field observations along the Wanganui-Manawatu coastline, female katipo were never found with more than three eggsacs. The eggsacs are stored in the upper portion of the spider's retreat, where they receive the best protection from the elements (Griffiths 2001). The eggsacs are produced at 1-4 week intervals (Kavale 1986; Forster & Forster 1999), with subsequent eggsacs tending to decline in both fecundity and fertility (Kavale 1986; Chapter 5). This trend is typical for spiders in general, with fecundity also often influenced by the size of the female or her nutritive state (Foelix 1996).

Interestingly, although *L. katipo* eggsacs are larger than *L. hasselti* eggsacs, they contain fewer eggs, with katipo having lower total reproductive output than redbacks (Kavale 1986). Kavale (1986) found the mean number of eggs inside a *L. katipo* eggsac to be 66 (std. dev. = 19), but katipo eggsacs have produced up to 146 live spiderlings (Chapter 5). Kavale's lower estimate could be due to the females in his experiment being laboratory-reared, as laboratory-reared spiders do not always attain the size of wild-caught females (Forster & Kingsford 1983), and thus might have lower reproductive output. There are few records of *L. atritus* eggsacs but it appears that they have much lower reproductive output than *L. katipo*, for example Forster & Kingsford (1983) record an *L. atritus* eggsac with 20 emergent spiderlings.

Spiderlings hatch from eggs after 20-25 days, and continue development within the eggsac, sustained by internal yolk reserves (Griffiths 2001). Spiderlings begin to ingest the eggsac walls once they reach second instar, and emerge after 4-6 weeks of development through a small hole made in the eggsac wall (Griffiths 2001). This hole is not enlarged by subsequent spiderlings, and they all exit the eggsac one by one, within a few hours (pers. obs.).

The sex ratio of katipo spiderlings appears to be 1:1, although this assumes that early mortality is not sex-biased (Kavale 1986; Chapter 5). Communally-reared katipo spiderlings exhibit high rates of cannibalism and thus low survival rates, however surviving cannibalistic spiderlings grow larger and more quickly than individually-reared spiderlings (Forster & Kingsford 1983). Juvenile katipo raised in controlled conditions in the laboratory mature at a much faster rate than field observations suggest occurs in the wild.

Overall, katipo have a life cycle that is similar to other *Latrodectus* species. *L. revivensis* juveniles also mature over winter and breed in summer, but in this species adults of both sexes are only present during summer (Anava & Lubin 1993).

Intra -specific interactions

Like most spider species (Arnedo *et al.* 2004), katipo are believed to be largely solitary, non-social animals, with low levels of tolerance for conspecifics. Indeed, when raised communally, the rates of cannibalism amongst katipo spiderlings are high (Forster & Kingsford 1983; pers. obs.). Female katipo will also devour their own offspring if they are held together (Ward 1998). Cannibalism between siblings appears to occur as an accidental consequence of prey capture attempts in katipo (Forster & Kingsford 1983), and also in redback spiders (Forster 1995). Cannibalism is prevalent in other *Latrodectus* species (Downes 1981; Foelix 1996).

During my field observations there were many occasions when katipo were found to have built their webs in very close proximity in vegetation or under driftwood. Ward (1998) also noted the clumped distribution of katipo, although it was thought to be uncharacteristic of the species. All possible age and sex combinations were seen living within the same space. The very low density of katipo in these habitats (the highest recorded katipo density at Himatangi Beach was <0.15 spiders per m^2, see Chapter 3), and the abundance of apparently suitable web sites meant that crowding was not a contributing factor. In addition to being apparently tolerant of conspecifics, katipo were often found living within close proximity of other spiders, particularly *Steatoda capensis*, an introduced species that is thought to be a competitor of katipo (Hann 1990, 1994).

On four occasions katipo were found living in retreats that backed onto the retreats of other katipo, with continuous catching webs surrounding the retreats. It was not clear how these catching webs were shared or partitioned. The genetic relatedness of the individuals living in these communal retreats was also unknown. Usually mature females would be found in these communal retreats, but mixed-age female combinations were also seen, suggesting that it was not always siblings in these arrangements. Communal katipo retreats have also been seen at Karitane Spit, South Island (C. Troup, pers. comm.). This high level of tolerance of conspecifics is not isolated to katipo. Kaston (1968) gives an account of two mature *L. hesperus* females that were found sharing a web and were subsequently kept together in laboratory conditions for 40 subsequent days before one killed the other. Before that, the two females were not aggressive towards one another, even when catching and feeding on prey, and Kaston (1968) proposed that they were most likely siblings that had developed together and maintained a high degree of peer tolerance.

Many usually solitary spiders will build webs together because of favorable concentrations of web attachment points, or concentrations of prey (Uetz & Hieber 1997). This did not appear to be the case with the katipo in these cases. An alternative explanation for katipo is that by living in tight clumps female katipo may increase the strength of their pheromone signal, and thus be more likely to attract mates. This would be of advantage for a species existing at such low densities, and would explain why the sex ratio of spider colonies is often strongly female-biased (Avilés 1997).

Whatever the explanation for this behaviour, it is perplexing for a spider species with apparently low levels of tolerance for conspecifics (judging by the degree of cannibalism) to on occasion demonstrate a high degree of conspecific tolerance. This communal living of katipo cannot be considered as true sociality, as the main criterion for sociality in spiders is *cooperation in prey capture*, and although there are many spiders that can live communally, few meet this criterion of cooperating (Foelix 1996).

Dispersal and relocation of web sites

The New Zealand *Latrodectus* fauna is clearly closely linked with that of Australia. Garb *et al.* (2004) postulated that the genus *Latrodectus* originated in Africa, and probably attained its wide geographical distribution through the occasional colonisation of distant landmasses via ballooning. Although its closest relative *L. hasselti* disperses via ballooning, katipo spiders were previously thought not to balloon (Forster 1984). Indeed, ballooning dispersal was considered to be ineffective for all spiders in New Zealand, due to the country being an ocean-bound, narrow landmass (Forster & Forster 1973). However, Griffiths (2001) established that both species of katipo can disperse via ballooning soon after hatching. Ballooning behaviour explains not only the distribution of katipo which spans large natural barriers, for example the Cook Strait, but also the close genetic relationship between katipo and redback (Griffiths 2001). Many other invertebrate taxa, particularly Lepidoptera, regularly arrive in New Zealand from across the Tasman Sea, facilitated by the strong westerly air-flow (Crowe 2002).

However, Foelix (1996) considered successful dispersal across large trans-oceanic distances via ballooning to be unlikely, and proposed that driftwood provided the likely route of dispersal for spiders in the Pacific Islands. Griffiths (2001) ran experiments to examine the survival rates of katipo dispersing via driftwood, and found that no eggsacs remained viable after two weeks of a simulated ocean crossing, and only one mature female *L. katipo* survived. Thus, successful dispersal via driftwood seems less likely than successful ballooning.

Ballooning is a high-risk activity, with spiders having no control over flight direction (Morse 1993, Bonte *et al.* 2003). Bonte *et al.* (2003) predicted that natural selection should reduce the frequency of ballooning behaviour in spider species that are specialised to one, fragmented habitat type. However, the risks of cannibalism or competition for a katipo spiderling that remains at the natal site could also be prohibitively high. Only a small proportion of katipo spiderlings do not initiate ballooning behaviour (Griffiths 2001), which suggests that selection pressures favour spiderlings that do disperse. Ballooning may be used for short distance dispersal to adjacent tillers or plant tips (Griffiths 2001). In addition, spiderlings may also disperse short distances by walking across the sand (Griffiths 2001). Night-time walking dispersal has also been recorded in the redback *L. hasselti*, and the black widow *L. mactans* (Forster 1995).

Despite observations of adult katipo walking across the sand at night (Griffiths 2001), katipo spiders, particularly mature females, are believed to rarely relocate web sites (Forster & Forster 1999; Griffiths 2001). However, in my field studies artificial cover objects placed out in katipo habitat were quickly colonised by both immature and mature female katipo (Chapter 3). Most of the katipo occupied the cover objects for one or two months out of a maximum of six, and were assumed to have relocated to new habitat. *L. katipo* also regularly colonise pitfall-trap lids (M. Lienke pers. comm.; pers. obs). In contrast, female katipo at Karitane Spit, South Island were found living in retreats that contained old eggsacs from previous seasons (C. Troup, pers. comm.). It does appear that katipo spiders are more mobile than previously thought, perhaps in response to changing food supply (Forster & Forster 1999).

L. revivensis also occasionally relocates web sites, but mainly as juveniles, with females not relocating once they have produced eggsacs (Lubin *et al.* 1993). Juvenile *L. revivensis* would often relocate to larger shrubs as they themselves grew in size, and a similar scenario could be expected for katipo where some juveniles are found occupying extremely small pieces of driftwood or debris, or unsuitably dense vegetation (pers. obs.).

Threats and Conservation status

Coastal dune systems in New Zealand have been neglected in terms of scientific research and conservation attention (Griffiths 2001). Museum records and anecdotal evidence indicate that *L. katipo* populations have clearly declined over the last thirty years, and have disappeared from some areas where they were once numerous (Griffiths 2001). Patrick's (2002) nationwide survey of katipo habitat found *L. katipo* present in only 46% of sites where they had been previously recorded. It is less clear whether *L. atritus* has also declined or faced range contraction, although it seems likely (Griffiths 2001).

In many areas where katipo have persisted they have declined in abundance, for example Smith (1971) recorded a katipo density of 1.1 per m^2 at South Brighton Beach, Christchurch. In 1999 the area was resurveyed by Griffiths who recorded a density of 0.004 katipo per m^2 (Griffiths 2001). Recorded densities of katipo at Himatangi Beach in 2005 never exceeded 0.15 per m^2. In some areas katipo populations have fluctuated wildly between years, but the reasons for this are unclear (Patrick 2002).

Patrick (2002) considered habitat loss and degradation to be the largest contributing factor to the decline of katipo. Indeed, the area of active duneland habitat in New Zealand has declined by 70% since the early 1900s (Hilton *et al.* 2000). The main causes of this decline have been the stabilisation and subsequent afforestation of coastal dunes (Hilton *et al.* 2000). Much of the remaining dune land is now dominated by the introduced sand-binding plant marram, *Ammophila arenaria* (Hilton *et al.* 2000).

Marram is thought to be a major agent in the decline of katipo, as once it becomes established its dense growth is unsuitable for katipo web construction (Griffiths 2000, Patrick 2002). Marram also displaces the native sand-binding plants (Partridge 1995; Hilton *et al.* 2000) that appear to be favoured by katipo for web construction (Patrick 2002). Patrick (2002) found no katipo in areas where marram cover exceeded 66%. During my field observations I found juvenile katipo in some areas of dense marram, but mature females were absent. This suggests that juveniles either relocate to more suitable web sites, or that survival rates in dense marram are very low. Web-site selection experiments suggest that katipo avoid marram even when it occurs at low densities (Chapter 4).

Other factors that have undoubtedly contributed to the decline of katipo populations include the burning or collection of driftwood (Griffiths 2001; Patrick 2002), browsing by introduced mammals such as hares and rabbits, and the use of four-wheel drive vehicles in sand dunes (Griffiths 2001).

The only known parasite of katipo is an undescribed species of Ichneumonidae wasp, which feeds on the eggs of katipo and other spiders (Patrick 2002). Introduced rodents are quite numerous in many dune systems, and may be preying upon katipo (Miller & Webb 2001), and competing with katipo for invertebrate prey.

The establishment of an introduced spider species, *Steatoda capensis*, has been associated with the decline of katipo populations in the Wellington area (Hann 1990, 1994). *Steatoda* and *Latrodectus* are sister genera (Arnedo *et al.* 2004; Garb *et al.* 2004). *S. capensis* was first recorded in New Zealand in the 1940s, and is now abundant under logs and in amongst marram in many dune areas, and in areas of human habitation (Hann 1994). *S. capensis* has superior reproductive output to katipo, producing eggsacs year round (Hann 1994). *S. capensis* has wider ecological tolerances, and thus has large reservoir populations inland, allowing it to recolonise dune areas following disturbance (Griffiths 2001). There is also substantial overlap between *L. katipo* and *S. capensis* in the types of prey caught (Hann 1994), and the size of driftwood they inhabit (Hann 1990; Chapter 2). Competitive pressure from *S. capensis* may also be contributing to the decline of katipo.

However, as *L. katipo* has declined in many areas where *S. capensis* is not present (Griffiths 2001), and the two species co-exist in many areas, often found living together on the same piece of driftwood (Patrick 2002; pers. obs), *S. capensis* is not believed to be the main driver of *L. katipo* decline. It is, however, a concern that in many areas, *S. capensis* exists at densities much higher than katipo, or any other spider species (Chapter 3).

The redback spider, *L. hasselti,* poses a risk to katipo populations through hybridisation and subsequent genetic swamping (Garb *et al.* 2004). Although redbacks are not currently established in New Zealand, incursions still occur, and *L. hasselti* could readily disperse through New Zealand via ballooning (Forster 1984). The redback has much wider ecological tolerances than katipo (Forster 1995).

Patrick (2002) proposed 19 key sites for *L. katipo* conservation, although it does not appear that these sites have received much additional attention since the publication of his report. The decline of katipo is mirrored by other coastal specialist species (Patrick 2002). As coastal dune systems are seriously understudied in New Zealand this problem is probably more widespread and severe than currently realised.

Conclusions

It is clear that for both species of katipo, but particularly *L. atritus*, there is still a lot we do not know. Despite their close genetic affiliation with the Australian redback spider, *L. hasselti*, the two species of katipo are highly unique in several aspects. Although both species are endangered, they have received little conservation attention and will remain at risk of extinction if this situation continues. This review reinforces the view of Griffiths (2001) and Patrick (2002), that research into these spiders is needed to halt their decline.

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Chapter Two:

Katipo population structure along the Manawatu-Wanganui coastline

Plate 1. A mature female katipo with two eggsacs. The eggsac on the left has hatched. Photograph taken at Himatangi Beach, 2005.

Katipo population structure along the Manawatu-Wanganui coastline.

Abstract

A survey of the endemic katipo spider, *Latrodectus katipo*, was carried out at seven coastal sites in the Manawatu-Wanganui region. A total of 151 juvenile, 74 female and 14 male katipo were found, with considerable differences in population structure between sites. Most of the spiders were found on driftwood, although some were found in several plant species and other debris. There is substantial overlap between *Steatoda capensis* and katipo in the size of driftwood occupied. Juvenile katipo occupied smaller pieces of driftwood than mature katipo. Juvenile katipo sometimes occupied plants that were too small or too dense for mature katipo, such as hawkbit and marram. The lack of juveniles at some sites suggests there is low reproductive output, but more continuous monitoring will be needed to confirm this. Katipo populations along the Manawatu-Wanganui coastline are threatened by a range of human-induced impacts, which will need to be minimised to prevent further degradation of the dune systems.

Introduction

Latrodectus katipo Powell, 1871 (Theridiidae) is an endangered species of widow spider endemic to New Zealand coastal sand dunes. Populations of katipo have declined over the last 30 years; predominantly as a result of habitat loss and degradation (Patrick 2002). An introduced South African spider species, *Steatoda* *capensis* Hann, is well-established nationwide and may be a competitor with katipo as the two species have similar ecological niches (Hann 1990, but see Griffiths 2001, Patrick 2002). *S. capensis* occupies a wide range of habitats, but in sand dunes is found predominantly living on driftwood (Hann 1990), habitat that is also used by *L. katipo*. *S. capensis* is highly abundant along the Manawatu-Wanganui coastline (Ward 1998; pers. obs.; see Chapter 3).

The Manawatu dunes form the largest transgressive dune field in New Zealand, although much of the original 90 000 ha now has pasture or exotic forest cover (Muckersie & Shepherd 1995), with 80 percent of the original active[1] area lost since the 1950's (Hilton *et al.* 2000). The main cause of this reduction was the stabilisation, and subsequent afforestation of the dunes (Hilton *et al.* 2000). The remaining dune lands have been degraded through vehicle use, rubbish dumping, grazing by introduced mammals, and the introduction of exotic plants (Hilton *et al.* 2000; Griffiths 2001). *Ammophila arenaria* (marram), deliberately planted in dune systems nationwide in an attempt to stabilise dunes, has had a large impact on dune systems as it displaces native sand-binding plants (Partridge 1995), alters the shape and mobility of dunes (Hesp 2002), and its dense growth may exclude katipo (Patrick 2002). However, the sand dunes along the Manawatu-Wanganui coastline still retain comparatively high natural values (Hilton *et al.* 2000), supporting populations of some native sand-binding plants.

Katipo populations along the Manawatu-Wanganui coastline were last surveyed by Ward (1998) and Patrick (2002), in addition to annual checks by Department of Conservation staff. Ward (1998) found a total of 47 katipo across 21 sites along the Manawatu coastline (including the 7 sites of this study), comprising 21 females, 16 males, and 10 juveniles. However, she found no

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[1] 'Active' dunes refers to dunes that have active sand movement, i.e. those that have not become stabilised through vegetational succession or afforestation (Hilton *et al.* 2000).

katipo at Foxton, Himatangi, Tangimoana, Castlecliff or Wanganui South. Patrick (2002) completed a nationwide survey of *L. katipo* populations, finding a total of three female katipo at each of Moana Roa, Himatangi and Foxton, with no katipo found at Tangimoana or Koitiata within a standardised searching time of thirty minutes. Patrick's survey did not include male or juvenile katipo as they "being so small, are difficult to locate".

The purpose of this survey was to update existing distribution information for *L. katipo* along the Manawatu-Wanganui coastline. In contrast to Patrick's study (2002), this survey included female, male and juvenile katipo, in order to compare population structure at each site. Habitat utilisation by katipo was also examined, and driftwood usage by *L. katipo* and *S. capensis* was compared.

Methods

Study sites

Seven beaches along the Manawatu-Wanganui coastline were selected as study sites; Himatangi, Foxton, Tangimoana, Moana Roa, Koitiata, Wanganui South, and Castlecliff (see Fig. 1). These sites had previously been surveyed for katipo by Ward (1998) and/or Patrick (2002).

Of the seven sites, Himatangi, Tangimoana, Foxton and Castlecliff appeared to have the highest levels of human visitation, and thus had the most visible signs of degradation, however, all of the sites had been affected by exotic plant invasion, vehicle use, rubbish dumping, and grazing by introduced mammals. Himatangi Beach was identified as a key site for katipo conservation by Patrick (2002).

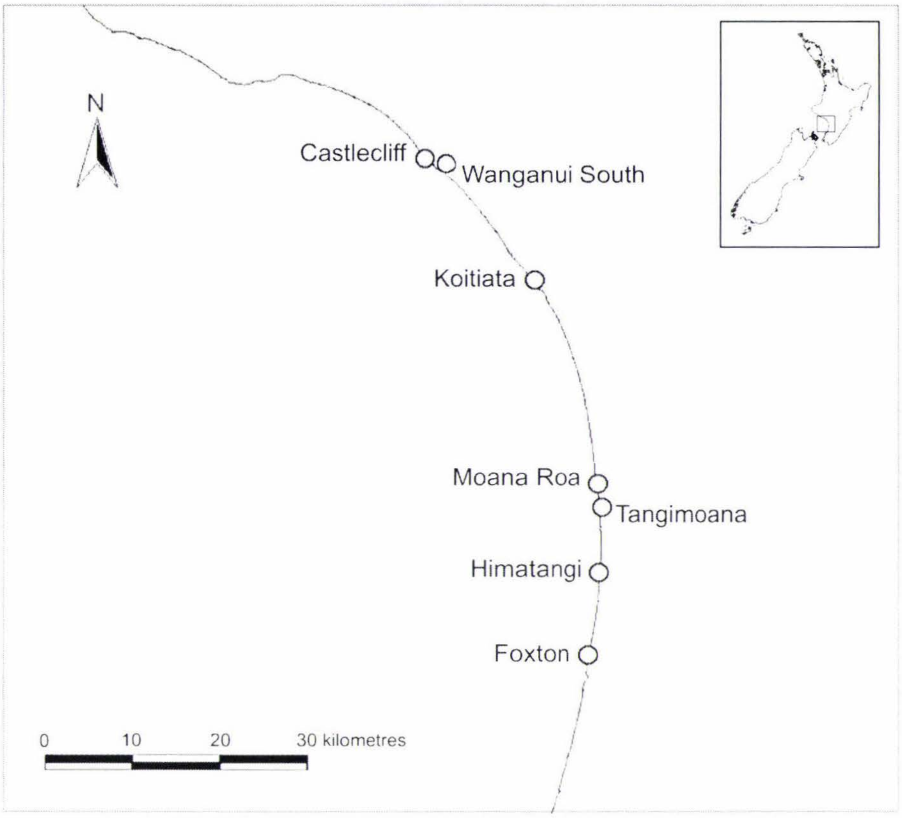

Figure 1. Map of study sites along the Manawatu-Wanganui coastline.

Field methods

The sites were all surveyed between January and April 2005. Foxton, Tangimoana, and Himatangi Beach were visited on more than one occasion, to assess their potential as focus study sites. At each site searches were completed within the established foredunes[2], excluding the seaward side of the foremost dune. Surveys were conducted by two or three searchers. The GPS coordinates of the start and finish points along the beach were taken, to calculate the area of sand dune searched. The area searched varied between sites, due to some sites being visited more than once, and differences in terrain and vegetation.

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[2] Established foredunes are shore-parallel dune ridges formed by aeolian sand deposition within vegetation, occupying a foremost seaward position in the dune system (Hesp 2002). Foredune vegetation is characterised by comparatively sparse grass and shrub cover.

Vegetation was searched by parting plant bases by hand, and looking for webbing between plant gaps. If webbing was found, it was followed until the spider's retreat was found. Driftwood and other pieces of debris such as bones and rubbish were searched by carefully turning them over and inspecting the surface for retreats. An attempt was made to coax out spiders that were concealed within crevices and holes in the driftwood, in order for them to be identified. This was achieved by gently prodding the webbing with a small paintbrush, as the spiders would eventually respond to this by leaving their retreat.

The sex of all mature spiders was recorded, but juveniles could not be sexed until at least the third instar (Griffiths 2001). Additional information was recorded such as whether the spider was occupying driftwood or vegetation, the surface area of the occupied driftwood or the density of vegetation, the slope at the immediate vicinity of the spider's retreat, the GPS position of the spider, and whether the individual was living closely with conspecifics or *Steatoda capensis*. The surface area of driftwood and slope were estimated by eye. If the individuals had webbing that extended through more than one plant species, or incorporated more than one piece of driftwood, this was recorded, however only the individual plant or piece of driftwood that contained the spider's retreat was used for subsequent analysis. If a spider was found living on driftwood, the distance to the nearest vegetation, and the plant species, was recorded. The surface area of driftwood occupied by *Steatoda capensis* was also recorded for individuals found at Himatangi and Foxton beaches, in order to compare driftwood usage by juveniles and mature individuals of the two species.

Analysis

GPS coordinates were used to calculate the distances between individual *L. katipo*, and then averaged for each site to give the mean nearest neighbour distance.

One-way ANOVA analysis was performed in SPSS v.12.0.1© to compare the surface area of driftwood occupied by mature and juvenile *L. katipo* and *S. capensis*. T-tests were performed to compare driftwood usage by spiders of different species and/or age groups. The occupied driftwood was divided into size classes of 250 cm² intervals, with all driftwood over 5000 cm² lumped into one class. The degree of niche overlap in driftwood usage was then calculated using Ecosim v.7© (Gotelli & Entsminger 2001), assuming that driftwood in different size classes were equi-probable, as this data was not collected. However, this is unlikely, and the test will thus tend to over-estimate the degree of overlap (Gotelli & Entsminger 2001).

A Kruskal-Wallis non-parametric test was performed in SPSS v.12.0.1© to compare nearest neighbour distances between sites, as the data were not normally distributed, and did not have equal variances. The nearest neighbour index (Rn) was calculated using the following formula:

$$Rn = \frac{\bar{D}}{0.5\sqrt{\frac{a}{n}}}$$

Where $\bar{D}$ = the mean nearest neighbour distance, a = the area searched, and n = the number of individuals found (Clark & Evans 1954). Populations that have a clumped distribution have Rn values close to 0, whereas an Rn value of 1 suggests a random distribution pattern, and values close to the maximum of 2.15 mean that individuals are regularly spaced (Clark & Evans 1954).

Results

A total of 4.71 kilometres of coastline were surveyed, almost half of this at Himatangi Beach (Table 1). Two hundred and thirty nine katipo were found; comprising 151 juveniles, 74 females and 14 males, however the age:sex ratio varied significantly between locations ($\chi^2 = 45.80$, df = 12, $p \leq 0.001$; see Table 1 and Fig. 2). Some sites, such as Himatangi and Foxton, had proportionally more juveniles, whereas no juveniles were found at Wanganui South or Castlecliff.

Site	Grid Reference (entry point)	Dates surveyed	Length of coastline surveyed (km)	Area surveyed (km^2)	Number of katipo found				Estimated density (number per hectare)
					Females	Males	Juveniles	**Total**	
Himatangi	40° 22' 12" S 175° 13' 46" E	10/1/2005, 21/1/2005, 27/1/2005, 20/2/2005, 24/3/2005	2.05	0.225	39	9	81	**129**	5.73
Tangimoana	40° 18' 49" S 175° 13' 51" E	16/1/2005, 5/2/2005	0.49	0.039	5	1	13	**19**	4.87
Foxton	40° 27' 56" S 175° 12' 93" E	14/1/2005, 18/1/2005, 7/2/2005, 8/2/2005	0.81	0.162	3	1	42	**46**	2.84
Moana Roa	40° 16' 71" S 175° 13' 34" E	5/04/2005	0.36	0.040	8	2	3	**13**	3.25
Koitiata	40° 04' 57" S 175° 08' 16" E	8/04/2005	0.21	0.011	11	1	12	**24**	21.82
Wanganui South	39° 57' 77" S 175° 00' 77" E	5/03/2005	0.5	0.025	3	0	0	**3**	1.20
Castlecliff	39° 56' 58" S 174° 58' 63" E	25/02/2005	0.29	0.015	5	0	0	**5**	3.33
		Total	**4.71**	**0.497**	**74**	**14**	**151**	**239**	

Table 1. List of study sites and their locations, total area searched and number of spiders found at each location. Population densities were estimated by dividing the number of spiders found by the area searched at each location.

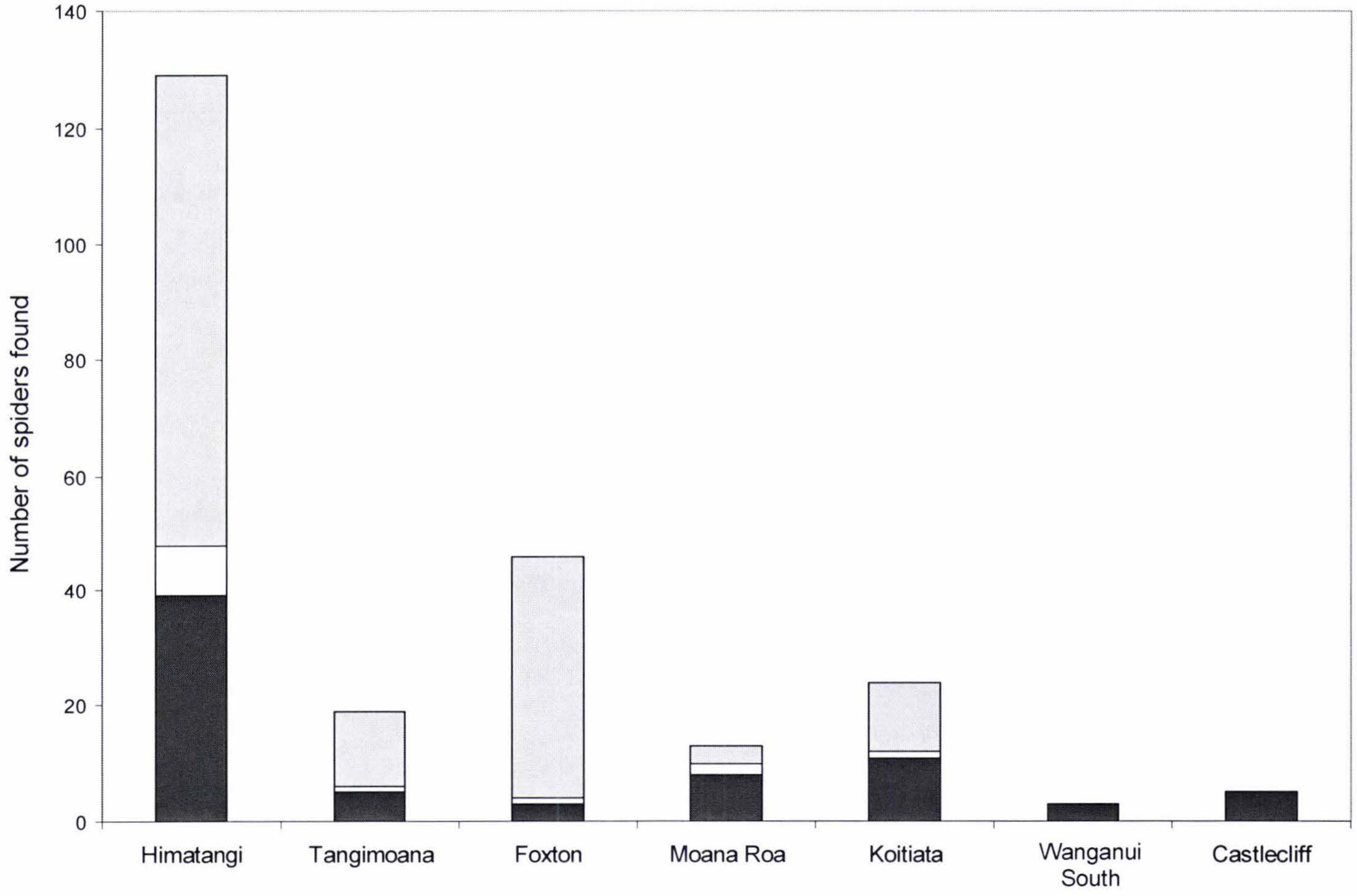

Figure 2. The number of female (■), male (□), and juvenile (□) katipo found at study sites along Manawatu - Wanganui coastline, January-April 2005.

The mean nearest neighbour distances between individual katipo varied between locations ($\chi^2 = 26.51$, $p \leq 0.001$), with *L. katipo* being highly clumped at Koitiata, Himatangi, Tangimoana and Foxton and more randomly spaced at Moana Roa (Table 2).

	Nearest neighbour distance (m)		
Site	Mean	SD	Nearest neighbour index (Rn)
Himatangi	3.5	7.1	0.17
Tangimoana	3.4	6.0	0.15
Foxton	7.6	12.1	0.25
Moana Roa	17.4	29.9	0.63
Koitiata	1.3	2.9	0.12
Wanganui South	18.0	27.4	*
Castlecliff	20.1	43.9	*

Table 2. Nearest neighbour distances, calculated from GPS coordinates for each spider found, and averaged for each site. The nearest neighbour index (Clark & Evans 1954) indicates the basic spatial distribution of individuals, with values of Rn ≈ 0 representing highly clumped distributions, ≈ 1 representing random spacing, and Rn values approaching the maximum value of 2.15 representing regular spacing of individuals. Note that * denotes sites with insufficient sample size.

Most of the searched area consisted of vegetation-sparse blowouts[3], with 74.9% (179/239) of the spiders found on driftwood or other debris, while the remainder were found occupying vegetation. Although proportionally fewer male katipo were found in vegetation compared to that found on driftwood (Fig. 3), this was not statistically significant ($\chi^2 = 2.93$, $p \leq 0.10$).

Katipo webbing was found in a total of eight plant species; the native *Spinifex sericeus* R.Br. (silvery sand grass), *Desmoschoenus spiralis* (A. Rich.)

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[3] 'Blowouts' are depressions or hollows formed by wind erosion on a pre-existing sand deposit, and can be initiated through human activities, wave action, vegetational changes, etc. (Hesp 2002).

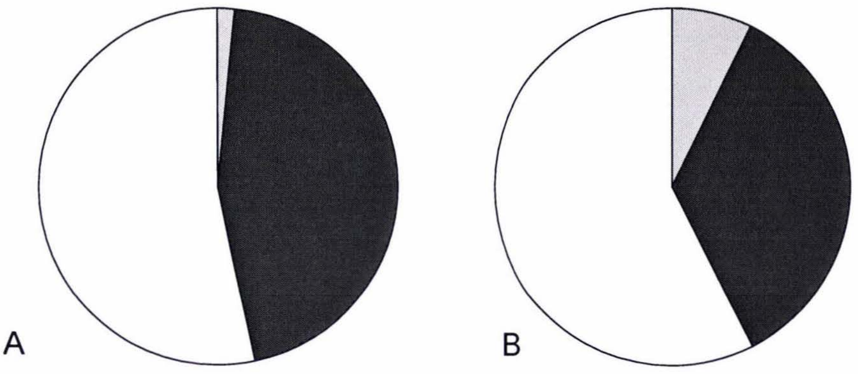

Figure 3. The proportion of female (■), male (□), and juvenile (□) katipo found on plants (A) and driftwood (B).

Hook. f. (pingao), *Calystegia soldanella* (L.) R.Br. (shore bindweed), and the grass *Lachnagrostis billardierei* (R.Br.) Trin.; and the exotic plant species *Ammophila arenaria* (L.) Link (marram), *Senecio elegans* L. (purple groundsel), *Carpobrotus edulis* L. (iceplant), and *Leontodon taraxacoides* (Villars) (hawkbit). Although *C. soldanella* plants sometimes contained katipo webbing, the spider's retreat and the bulk of the catching web were always constructed in an adjacent, larger plant species, therefore this plant species was not included in any analysis. Juvenile katipo were much more likely to be found living in marram than female katipo ($\chi^2 = 22.77$, $p \leq 0.001$); 73% of juvenile katipo found in vegetation were living within marram, 16% were found in spinifex, the remainder were living in other plant species. In contrast, only 28% of mature female katipo were found in marram, with 56% in spinifex (Fig. 4). Two juvenile katipo were also found occupying hawkbit, a dandelion-like plant which would be too small for mature female katipo to construct webs in.

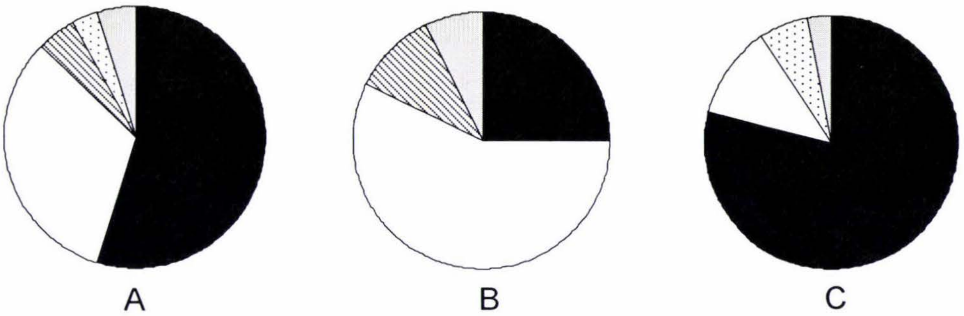

Figure 4. Plant species occupied by katipo. A: all katipo, B: female katipo, C: juvenile katipo.

■ = marram (*A. arenaria*), □ = spinifex (*S. sericeus*),

░ = hawkbit (*L. taraxacoides*), ▨ = pingao (*D. spiralis*),

□ = all other plant species combined (*L. billardierei*, *S. elegans*, *C. edulis*).

Driftwood tends to be concentrated within the flat basins of blowouts, thus most katipo found on driftwood were found on flat or near-flat ground, whereas the katipo found in vegetation occurred at sites with a range of slopes (Fig. 5). Despite there being many isolated pieces of driftwood present, no driftwood-occupying katipo were found living more than ten metres away from vegetation, with most within one metre (Fig. 6). There was no correlation between the size of occupied driftwood, and the distance to the nearest vegetation (Fig. 6).

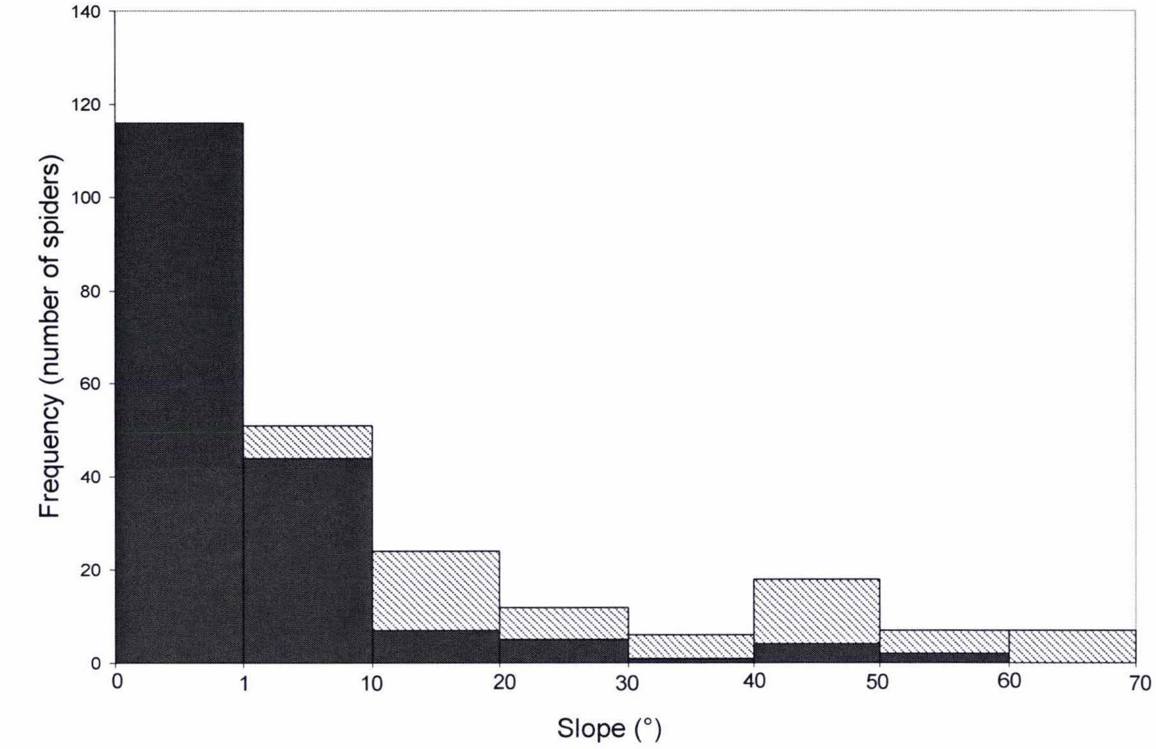

Figure 5. Number of spiders found at sites of differing slopes. Solid portions of the bars represent individuals found on driftwood, whereas hatched bars represent spiders found in vegetation.

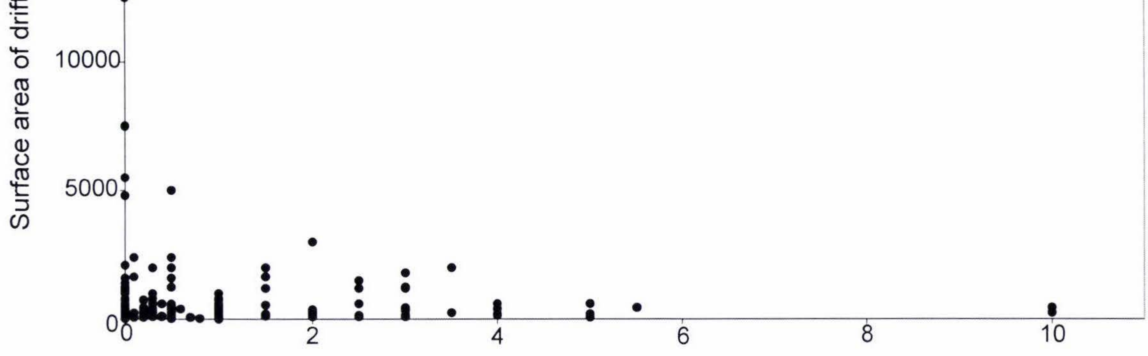

Figure 6. Surface area of occupied pieces of driftwood, plotted against the distance in metres to the nearest vegetation, $r = -0.043$, $p = 0.57$.

It was common to find several *L. katipo* individuals occupying the same piece of driftwood, or living in very close proximity in vegetation with conspecifics or the introduced *S. capensis* (Table 3). Although male *S. capensis* were seen during the survey, they were never found together with *L. katipo* individuals. The most common type of 'sharing', with 16 recorded occurrences, was one juvenile *L. katipo* living closely with one juvenile *S. capensis*. The second most common types of sharing (each with 9 occurrences) was one female and one male *L. katipo* found together, and one female and one juvenile *L. katipo* together. The highest number of individuals found sharing was eight, at Moana Roa Beach, where three female, two male, and one juvenile *L. katipo* were found with one female and one juvenile *S. capensis*, on a piece of driftwood with a surface area of 1250 cm^2. Shared pieces of driftwood were not necessarily larger than driftwood occupied by individual katipo.

L. katipo			*S. capensis*		
Female	Male	Juvenile	Female	Juvenile	Frequency
		1		1	16
1	1				9
1		1			9
1				1	7
		2			4
1				2	3
2					3
1		1		1	3
1	1	1			2
1	1			1	2
1			2	1	2
2				1	2
1			2	1	1
1			1		1
2	1				1
1		1		2	1
2	2				1
2	1	1			1
	1			1	1
	1		1		1
	1	1			1
		1	1	25+*	1
		1		10+*	1
3	2	1	1	1	1

Table 3. Combinations of *L. katipo* and *S. capensis* occupying the same piece of driftwood, and the frequency at which they occurred. Each row represents one type of combination. Note that in the two instances where numerous *S. capensis* juveniles were recorded (marked with *), the individuals were from newly hatched eggsacs.

On four occasions, multiple *L. katipo* were found not only sharing driftwood or vegetation, but living in retreats that were joined together, with separate openings, and surrounded by continuous catching webs. It was not clear how the catching webs were partitioned, or if any cooperation in prey capture was occurring.

Figure 7 compares the surface areas of driftwood or other debris occupied by mature female and juvenile *L. katipo* and *S. capensis*. The largest objects occupied by katipo were; a large log ($12500cm^2$), a discarded car bonnet ($22500cm^2$), and a piece of corrugated iron sheeting ($17500cm^2$).

There were significant differences between spiders of different species and/or age in the sizes of occupied driftwood (F = 6.168, p = <0.05). There was no overall difference in the size of driftwood occupied by *L. katipo* and *S. capensis* (t = 0.202, p= 0.840), however, this was due to a strong age effect. Juvenile *L. katipo* occupy smaller wood than mature female *L. katipo* (t = 2.49, p = 0.015) and likewise, juvenile *S. capensis* occupy smaller wood than mature *S. capensis* (t = 2.84, p = 0.006). Thus, juveniles of both species combined occupy smaller wood than mature individuals (t = 3.47, p = 0.001). While juvenile *L. katipo* occupy smaller wood than juvenile *S. capensis* (t = 2.16, p = 0.033) there was no significant difference in the size of driftwood occupied by mature female *L. katipo* compared to mature female *S. capensis* (t = 0.43, p = 0.669).

Despite significant differences in driftwood use, Pianka's index of niche overlap, calculated in EcoSim©, was 0.86 between *S. capensis* and *L. katipo* overall, with 100% of the simulations having lower overlap than the observed value. When the age and sex of the individuals spiders was taken into account, it showed that overlap in driftwood use was greatest between juvenile and mature female katipo, and lowest between mature male katipo and mature female *S. capensis*, though still substantial (Table 4).

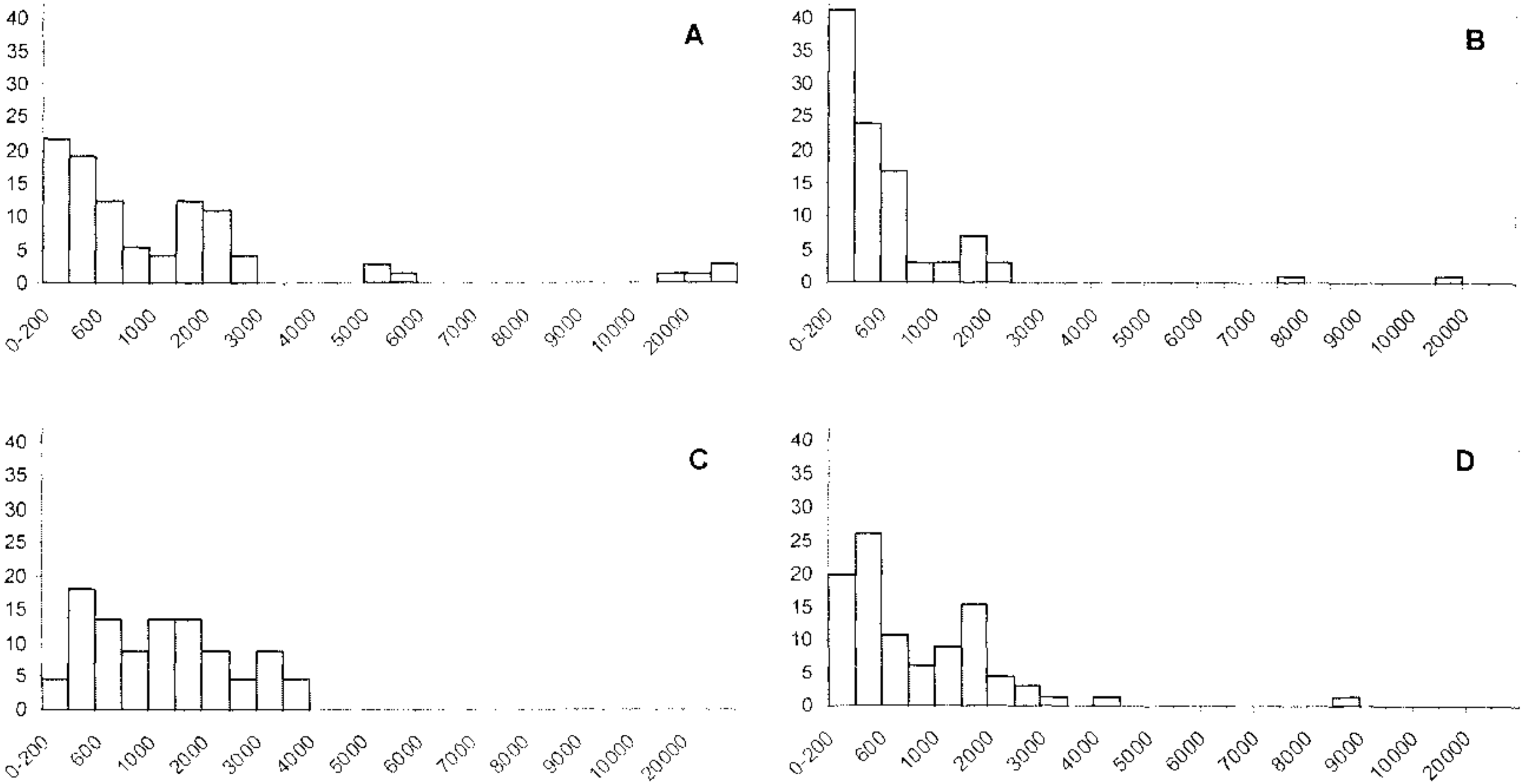

Figure 7. Comparison of the surface area of driftwood or other debris occupied by mature and juvenile *S. capensis* and *L. katipo*. A = mature female *L. katipo* (*N* = 73, mean = 1922.47 cm², SD = 4328.95), B = juvenile *L. katipo* (*N* = 100, mean = 610.21 cm², SD = 1453.27), C = mature female *S. capensis* (*N* = 22, mean = 1682.40 cm², SD = 1649.54), and D = juvenile *S. capensis* (*N* = 65, mean = 968.40, SD = 1006.38).

	Katipo juveniles	Katipo males	Steatoda females	Steatoda juveniles
Katipo females	0.952	0.841	0.799	0.909
Katipo juveniles		0.785	0.629	0.840
Katipo males			0.601	0.777
Steatoda females				0.832

Table 4. Pianka's (1973) index of niche overlap, calculated for driftwood sizes. Index values range between 0 and 1, with a value of 1 representing complete overlap.

Discussion

More katipo were found during this survey than in previous studies (Ward 1998, Patrick 2002). Previous surveys may have underestimated the abundance of juvenile and male katipo, due to their small size. However the variation in the population structure by site was considerable, and is important to consider when assessing the viability of populations.

The population density estimates produced will be lower than actual population densities, as detection probability would have been less than 100%. However it is fair to assume that detection probability was constant across sites, and therefore the population density estimates will be useful in comparing the status of katipo at different sites.

The population density estimates suggest that Koitiata has the highest *L. katipo* density, however only a comparatively small area was surveyed at this site, and the area of foredune is much smaller compared to other areas such as the continuous dune system that incorporates Tangimoana, Himatangi and Foxton Beaches.

It is more difficult to locate katipo within vegetation compared to individuals living on driftwood. Thus the survey results may have been biased towards driftwood-occupying spiders. Much of the area searched consisted of large vegetation-sparse blowouts that are characterised by having large amounts of driftwood present, thus it is not surprising that the majority of katipo were found on driftwood. In other areas of the country, such as along the Canterbury coastline, driftwood tends to be scarce within the dunes, thus katipo are more likely to be found in vegetation (Griffiths 2001). Experiments will be required to test whether katipo have preferences for driftwood over vegetation as web sites, or vice versa (Chapter 4).

Vegetation is still an important determinant of web site, as all of the spiders found on driftwood were within 10 m of vegetation, with most within 1 metre. A possible explanation for this is that katipo are selecting web sites based on prey availability, as pitfall-trapping indicates that sand dune invertebrates tend to be more abundant in areas with high plant cover (data not presented).

There are differences in habitat usage between katipo of different ages, for example, proportionally more juvenile katipo occupy marram than mature female *L. katipo*. In addition, some juvenile katipo were found occupying very small pieces of driftwood, or living in small hawkbit plants. Juvenile katipo probably require a smaller area over which to construct their platform-like catching web, which might explain why they can be found in habitat that is apparently unsuitable for mature katipo (Griffiths 2001, Patrick 2002). It is unclear whether juvenile katipo living in such locations later relocate their web site, or if survival rates for these individuals is low.

At some sites katipo had a strongly clumped distribution, an observation also made by Ward (1998). It was common to find katipo living very closely with conspecifics or with *S. capensis*, despite being considered uncharacteristic behaviour for katipo (Lyn Forster pers. comm. in Ward 1998). Patrick (2002) also noted *S. capensis* and *L. katipo* sharing driftwood during his nationwide survey. This indicates that katipo have a higher degree of tolerance for conspecifics than previously thought (Forster & Kingsford 1983). It also indicates that katipo can successfully coexist with *S. capensis*, although *S. capensis* densities at Himatangi sometimes exceed twice that of *L. katipo* (Chapter 3). There is substantial overlap in the size of driftwood used by *L. katipo* and *S. capensis*, which could result in competition for web sites if they became limiting, perhaps if *S. capensis* population densities increase further.

Griffiths (2001) found that katipo showed a preference for slopes of 1-30° degrees. This survey revealed that katipo living in vegetation were living at a range of slopes below 70°, with no apparent preference for any slope within that range. The large proportion of driftwood-dwelling katipo found at slopes <10° is a reflection of the driftwood distribution within the dunes, with driftwood concentrated within the flat-bottomed blowouts.

Katipo were found living in both exotic and native plant species. Although native plant species such as *Coprosma acerosa* A. Cunn. and *Pimelea arenaria* A. Cunn. were not found to contain katipo webbing, this is a reflection of the comparative scarcity of these plant species, and the patchy distribution of katipo, as later searches at Himatangi did find katipo living within these species (pers. obs.).

The results of this survey have shown that katipo populations are persisting at a number of sites along the Manawatu-Wanganui coastline. However, the differences in population structure and overall abundance of katipo at each of the locations suggests that there is substantial variation in the viability of these populations. For example, the large proportion of juvenile *L. katipo* at sites like Himatangi and Foxton shows that reproductive output is comparatively high at these sites. The lack of juveniles, and the overall low number of individuals found at Castlecliff and Wanganui South beaches, is a cause for concern. The low reproductive output at these two sites could be due to Allee effects, whereby the very low population density makes it hard for male katipo to locate mates.

These results suggest that katipo populations at some sites like Wanganui South and Castlecliff have been more severely impacted than other sites. The reasons for this are unclear, although displacement by *S. capensis* is unlikely to be the cause, as densities of this spider species appeared to be comparatively lower at these two sites, compared to Himatangi and Foxton.

The katipo populations at all of the sites covered by this survey remain under threat through further degradation of the dune system, a problem faced by katipo populations nationwide (Patrick 2002). There is a clear need for further katipo monitoring along the Manawatu-Wanganui coastline. Populations at all sites will need to be monitored in order to assess if current levels of reproduction are sufficient to maintain, or increase current population levels. Translocations of katipo into dune systems at sites such as Wanganui South and Castlecliff may be necessary to prevent local extinctions. More important, however, will be the reduction and reversal of damage that is currently being inflicted upon the dune systems, from vehicle damage, rubbish dumping, grazing by hares and the spread of exotic plants that exhibit dense growth.

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Chapter Three:

Population monitoring of the endangered New Zealand spider, *Latrodectus katipo*, using artificial cover objects

Plate 1. An immature male katipo on an artificial cover object. Photograph taken at Himatangi Beach, 2005.

Population monitoring of the endangered New Zealand spider, *Latrodectus katipo*; using artificial cover objects.

Abstract

The endangered widow spider, *Latrodectus katipo* has undergone marked population decline over the last thirty years. The current status of many populations is unknown because of a lack of monitoring. Current monitoring methods are time and labour-intensive, and require observers with high levels of searching experience. An alternative monitoring method using artificial cover objects (ACOs), has many advantages over other monitoring methods, as they are replicable and standardised, and can be checked more quickly and easily than habitat searches can be performed. The use of ACOs as monitoring tools for katipo spiders was investigated at three sites at Himatangi Beach, Manawatu in 2005. Occupancy rates of the ACOs were compared to population densities obtained from habitat searches, to assess their efficacy as a monitoring tool. Numbers of the introduced spider, *Steatoda capensis*, which may be a competitor of katipo, were also recorded during habitat searches. ACOs were reliable monitoring tools, with occupancy rates higher at the site with the highest katipo population density. ACO monitoring is a reliable alternative to transect or quadrat searches, and should be implemented in areas of katipo habitat where in-depth monitoring is not occurring. *L. katipo* populations were found to have highly female biased sex-ratios, with a longer breeding season at Himatangi than reported elsewhere. *S. capensis* exists at much higher population densities than

L. katipo at Himatangi, however fluctuations in the populations of the two species appear to be independent.

Introduction

The katipo spider, *Latrodectus katipo* Powell, 1871, is an endangered species (Patrick 2002) that is endemic to New Zealand. It is specialised to coastal sand dune ecosystems, with webs constructed in the bases of vegetation, or under driftwood and other debris. A marked decline in the abundance and range of this species has occurred over the last thirty years (Patrick 2002). New Zealand's other endemic widow spider, *L. atritus*, is also believed to have undergone range contraction and population reduction (Griffiths 2001). This decline in katipo populations has been attributed to habitat loss and degradation (Patrick 2002), and competitive pressure from an introduced species; *Steatoda capensis* (Hann 1990, 1994; but see Griffiths 2001; Patrick 2002). *S. capensis* is abundant in many sand dune areas (Hann 1990; pers. obs.), but it is not clear if *S. capensis* affects katipo populations.

It is also unclear whether katipo populations are still in decline. Patrick (2002) completed a nationwide survey of katipo populations, and recommended subsequent monitoring, however this has only occurred at a few locations, for example Karitane Spit, Otago where monitoring is undertaken every six months (A. Evans & C. Troup pers. comm.). This lack of monitoring can in part be attributed to the time and labour-intensive nature of current monitoring methods, principally transect and quadrat searches.

Due to the cryptic nature of katipo webs, detection probability will be low unless searchers receive adequate training and practice. This is a problem common to invertebrate monitoring (Wakelin *et al.* 2003). In addition, many katipo surveys have not recorded the presence of male or juvenile katipo, probably because of their small size, different morphology, and less obvious webbing. Male katipo abandon their webs upon maturity and search for mates, but can often be found in the webs of females (Patrick 2002, pers. obs.)

During the summer of 2004-05 a survey along the Manawatu-Wanganui coastline (Chapter 2) found a total of 239 katipo, 69% of which were males or juveniles, which suggests a large proportion of the population are neglected as many studies ignore males and juveniles. The population structure also varied between locations (Chapter 2), and may reflect differential reproductive output at the different beaches. This survey also revealed that katipo tend to occur in scattered clumps (Chapter 2), so that transect or quadrat searches would have a high probability of missing katipo altogether.

These problems have highlighted a need for a monitoring technique that is quick and easy to perform, incorporates juvenile and mature katipo of both sexes, and can be applied nationwide. There is also a need for the population dynamics of this species to be examined in greater detail than previously as there is little information on katipo population dynamics.

The use of artificial cover objects (ACOs) is a potential solution to the katipo monitoring problem. ACOs are man-made objects that are designed to imitate micro-habitats already utilised by the focus species. They are placed within natural habitat, and are checked on a regular basis for occupancy. ACOs can be considered analogous to roost boxes that are used to monitor bird populations. ACOs are easily replicable, standardised units, provided the ACO design remains unchanged. (Wakelin *et al.* 2003).

The use of ACOs is a relatively new monitoring method, and has been used in only a few studies overseas, particularly for monitoring amphibian populations (e.g. Smith & Petranka 2000; Houze & Chandler 2002). In New Zealand, artificial cover objects have been investigated as monitoring tools for native frogs (Wakelin *et al.* 2003), and are also used to monitor weta (Sherley 1998).

There is no record in the scientific literature of ACOs being used to monitor spider populations, although artificial web sites have been used in various experiments investigating habitat use (Wise 1993). Despite this, katipo have characteristics that make them ideal candidates for this type of monitoring. Katipo readily occupy driftwood and other debris within sand dunes, including car tyres, corrugated iron, and other refuse (Forster & Forster 1999, pers. obs.). Therefore artificial objects placed in their environment are likely to be suitable web sites.

Katipo can be very difficult to locate, except by experienced observers. This is especially true for juvenile and male katipo. ACOs reduce observer bias as they can be easily checked (Houze & Chandler 2002). ACOs can also be checked in a much shorter time period than transect searches, thus a much larger area can potentially be covered by ACO monitoring. Although katipo are not usually aggressive (Ward 1998), the use of ACOs may also reduce the risk of searchers receiving venomous bites as a result of accidental provocation. Checking ACOs also tends to be less disruptive to the study animal than manual habitat searches (Houze & Chandler 2002; Wakelin *et al.* 2003), which will mean that damage to katipo webs is minimised.

Potential drawbacks of ACOs are that, depending upon shelter design, population estimates may be biased if katipo avoid or are overly attracted to the shelters. There is also the concern that ACOs may artificially boost population numbers by increasing available habitat (Wakelin *et al.* 2003). However, as many of the national dune systems have declined in habitat quality due to vegetation changes and driftwood removal (Patrick 2002) this should be seen as a positive potential spin-off, similar to the use of nest boxes that improve nest site availability for birds, but are still valuable monitoring tools.

The aim of this study was to examine the use of ACOs as monitoring tools for katipo, and to use background habitat searches in two ways; firstly as an investigation into the population dynamics of this species, and secondly as a comparison to ACO occupancy rates, as advocated by Wakelin *et al.* (2003). This study tracked katipo populations at three sites at Himatangi Beach, between January and July 2005. Numbers of the introduced species *Steatoda capensis*, and all other spiders were also recorded, to compare with *L. katipo* numbers.

Methods

Study Site

Himatangi Beach is located 30 km west of Palmerston North, on the west coast of the North Island of New Zealand (beach entrance is at 40° 22' 12" S; 175° 13' 46" E). The beach is part of the Manawatu dunefields, the largest transgressive dune fields in New Zealand (Muckersie & Shepherd 1995). Much of the Manawatu dunefields have been stabilised and afforested, and the remaining dune lands modified through the planting of exotic sand-binding plants such as marram, *Ammophila arenaria*, and the use of off-road vehicles. This has occurred in virtually all of New Zealand's coastal dune ecosystems (Hilton *et al.* 2000).

The foredunes at Himatangi consist of large dunes that run parallel to the coastline, punctuated at intervals by large depressions or 'blowouts' which have formed after dune collapse. These blowouts are characterised by having only sparse vegetation, and in many cases large amounts of driftwood. At Himatangi these blowouts contain comparatively high numbers of katipo and *S. capensis* occupying the driftwood. Three of these blowouts were selected as study sites, all south of the main beach entrance. Sites A and B were about 100 m apart, about 5 km south of the main beach entrance, whereas Site C was a further 600 m south, adjacent to a small stream[1]. The three sites were 900, 3390, and 300 m² in size respectively, with the sides of the blowouts designated as the borders of each study area.

ACO design

The ACOs used in this study were designed as analogues to driftwood commonly occupied by katipo spiders, i.e. with a concave undersurface, and linear grooves for the spiders to build retreats, as female katipo in particular are often found within crevices and holes on driftwood (see Fig. 1 for design). The ACOs were designed so that more than one spider could theoretically occupy an ACO, by occupying separate grooves. They were constructed from non-treated timber and galvanised nails.

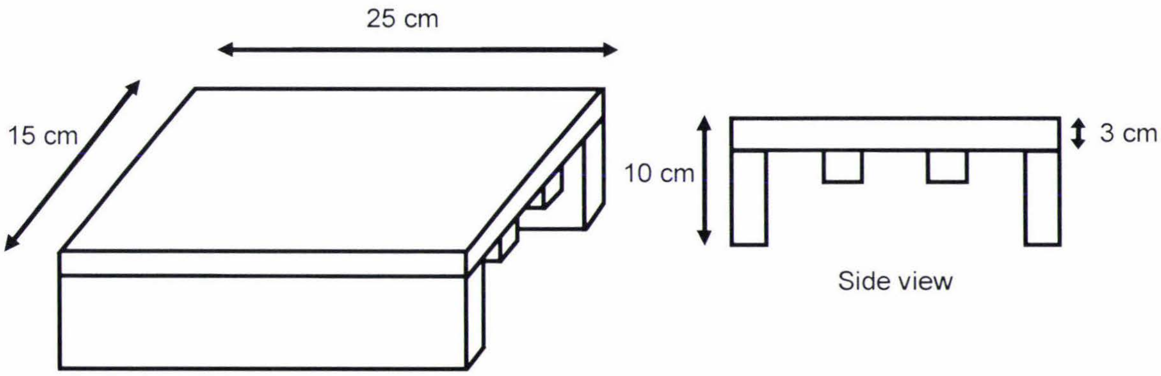

Figure 1. ACO design.

Field methods

The ACOs were first placed at Sites A and B on the 29th of December, 2004, and Site C on the 27th of January, 2005. Initially 5 ACOs were placed in Site A, and 10 shelters each were placed in Site B and C, however the actual

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[1] Grid references for beach-side entrance points to three sites are as follows: Site A 40° 23.386S 175°13.630E; Site B 40°23.303S 175°13.581E; Site C 40°23.890S 175°13.579E.

number of shelters varied slightly over time due to occasional human interference. The ACOs were spread evenly throughout each of the blowouts, and positioned close to existing vegetation and driftwood, as katipo do not occupy isolated pieces of driftwood (Chapter 2). The three sites were surveyed approximately once every four weeks between 27th January and 21st July, 2005. Searches were only completed during reasonably fine weather, because of reduced detection probability during wet and windy conditions. In addition to checking all ACOs a count was made of all katipo, *S. capensis* and other spiders occupying driftwood within the blowouts. All pieces of surface driftwood within the site were checked. These counts were then divided by the area searched, to be used as a measure of actual population density, to be compared with ACO occupancy rates, using Pearson correlations in SAS™. The age and sex (if known) of each individual katipo was recorded. Eggsacs were not counted, as they were often stored deep within a female's retreat, thus it was difficult to distinguish between hatched and unhatched eggsacs without causing substantial damage to the retreat. However, a note was made if any unhatched eggsacs were visible.

Occupancy was calculated as the mean number of katipo per ACO, divided by the area of the blowout. This was done in order to correct for the different densities of ACOs between sites, and the fluctuations in the number of ACOs due to occasional vandalism.

Once monitoring had been completed the ACOs were left out in the dunes, and checked periodically in order to assess their ability to persist in typical sand dune conditions, i.e., prolonged sand-blasting. They were also checked during the following summer (2006) to see if they were used by katipo for reproduction.

Results

Driftwood Counts

The population density estimates based on driftwood counts showed similar patterns at all three sites (Fig. 2a-c). The three katipo populations had strongly biased sex-ratios, with fewer males present than females or juvenile spiders. Females and juveniles were located in the field throughout the study period, but males were only present up until May-June. The number of mature females fluctuated, with increases in the abundance of females often occurring as the number of juveniles decreased. The number of juvenile katipo peaked at different times at each of the three sites; late March at Site A, mid-April at Site B, and during late February at Site C. Site C had a higher *L. katipo* population density than the other two sites. Unhatched eggsacs were found up until June (pers. obs).

Fig. 3a-c compares the population density of *L. katipo* to that of *Steatoda capensis* and other spiders, at each of the three sites. *L. katipo* exists at much lower population densities than the introduced *S. capensis* at site A in particular, whereas at sites B and C *L. katipo* and *S. capensis* had similar densities until May, when numbers of *S. capensis* increased greatly. *S. capensis* populations also fluctuated markedly throughout the sampling period, largely due to large pulses of newly-hatched juveniles. There was no significant relationship between the population density of *L. katipo* and that of *S. capensis* at any of the three sites (Site A: $r = -0.09$, $P = 0.85$; Site B: $r = 0.19$, $P = 0.69$; Site C: $r = -0.14$, $P = 0.79$).

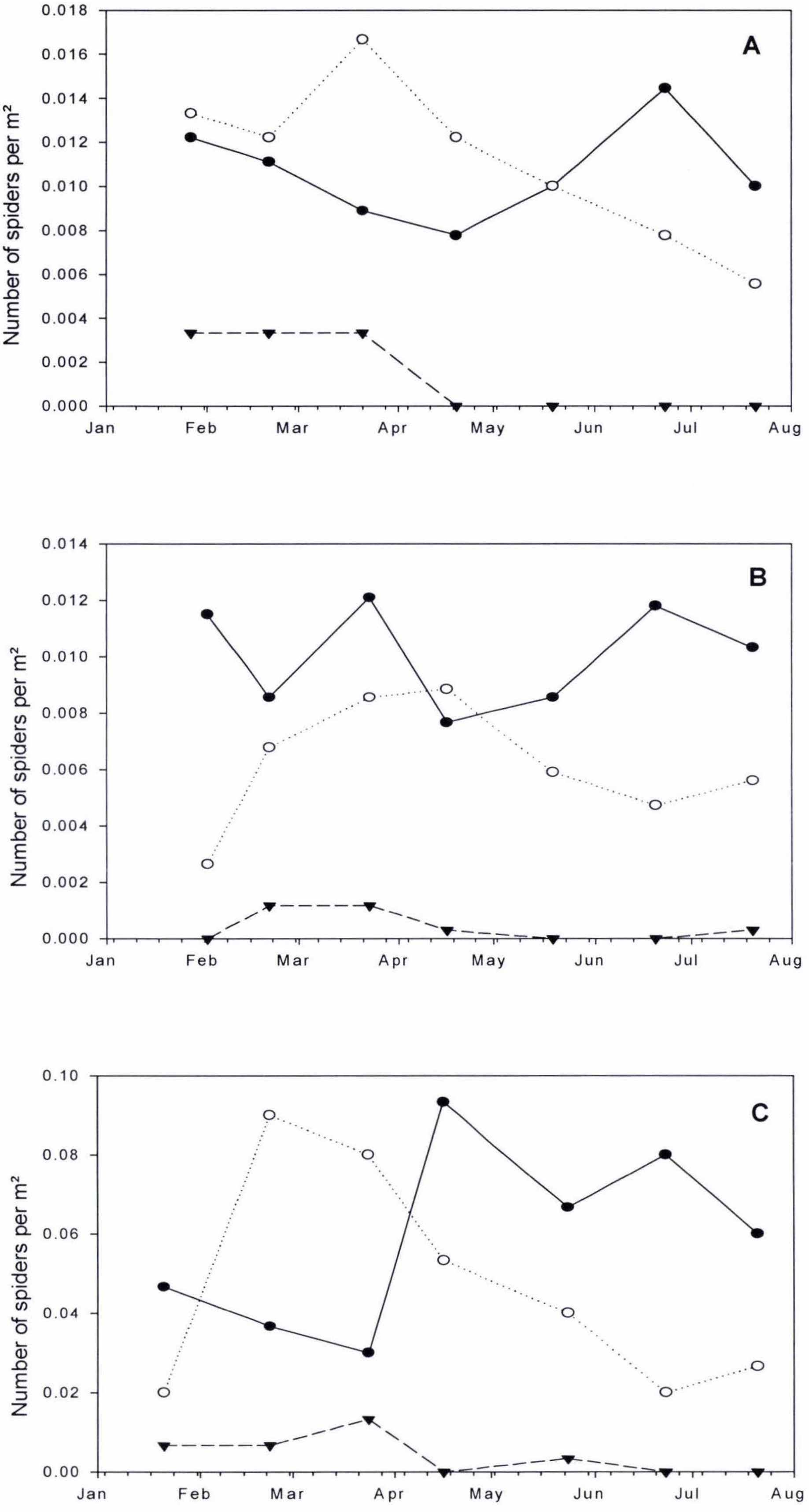

Figure 2. Katipo density estimates based on driftwood counts. Open circles = mature females, closed circles = immature spiders, closed triangles = mature males. A = Site A, B = Site B, C = Site C.

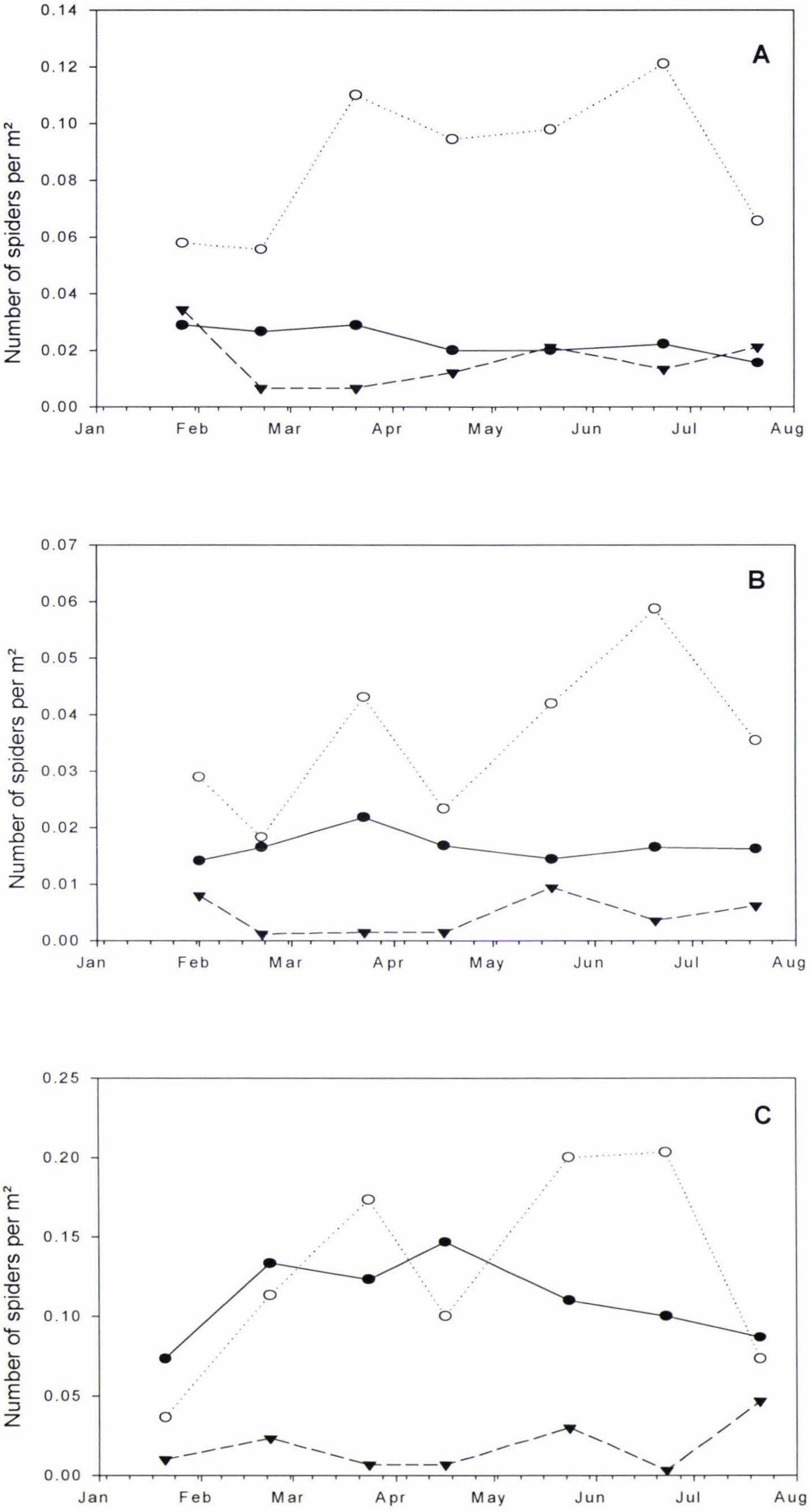

Figure 3. *L. katipo*, *S. capensis* and other spiders density estimates based on driftwood counts. Open circles = *S. capensis*, closed circles = *L. katipo*, closed triangles = all other spiders. A = Site A, B = Site B, C = Site C.

The density of all other driftwood-dwelling spiders remained low throughout the sampling period. These spiders were not identified to species, but were mostly free-living spiders from the families Salticidae and Lycosidae, with a small number of unidentified spiders from other families.

ACOs

The ACOs were quickly colonised, for example at Site C all of the ACOs were occupied within four weeks. At Sites A & B some of the ACOs were not colonised until the 4th sampling period. Over the six month sampling period 76% of the ACOs were occupied by *L. katipo* at least once, whereas 56% of the ACOs were occupied by *S. capensis* at least once. Only 2 of the 25 ACOs were not occupied by either species during the sampling period. The ACOs were also occasionally occupied by other invertebrates, including other spider species (families Salticidae and Lycosidae), beetles (family Oedemeridae), and ants, with cicada nymphs using them as a site for ecdysis.

Male, female and juvenile katipo used the ACOs. Often more than one individual would occupy the same ACO, resulting in occupancy exceeding 100% on occasion at Site C. The ACOs also provided some data on the site tenacity of katipo. Out of a maximum occupancy of six months, female katipo occupied ACOs for an average of 2.17 months (std. dev. = 1.63), whereas juveniles had an average occupancy of 1.68 months (std. dev. = 0.95). Male katipo never occupied an ACO for longer than one sampling occasion.

Figure 4 compares the occupancy rate of the ACO's with the katipo population densities calculated from the driftwood counts. Occupancy was highest at Site C, which also had the highest population density. Occupancy was positively correlated with population density across all sites ($r = 0.91$, $P < 0.0001$; Fig. 5), however this relationship did not hold when sites were considered separately. At sites A and B there was no relationship between population density and ACO occupancy (A: *r* = -0.15, *P* = 0.74; B: *r* = -0.08, *P* = 0.04), whereas at site C occupancy rates were negatively correlated with population density (*r* = -0.83, *P* = 0.04). However it should be noted that this occurred over a small range of population density values.

After one year in the field the ACOs were still intact, although many had been degraded somewhat by sand abrasion. Some of the ACOS at Site C were used by female katipo as sites for eggsac production, during the summer following the monitoring period.

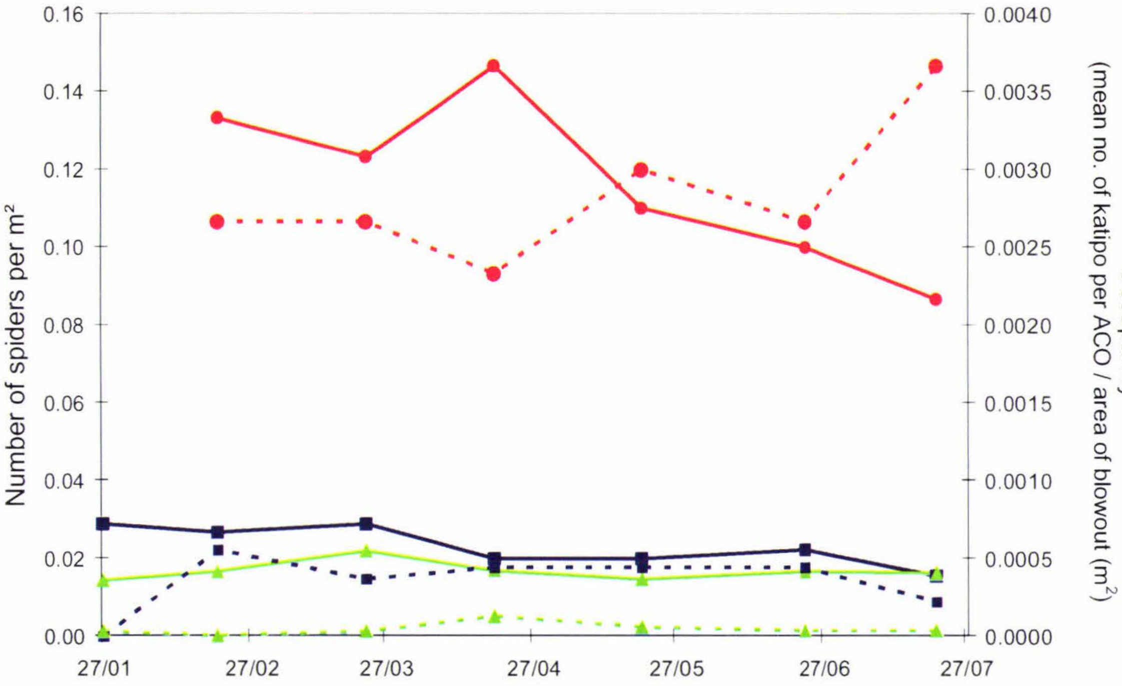

Figure 4. Comparison of occupancy rates of ACOs, with population densities based on driftwood counts. Dashed lines represent occupancy rates (right axis), whereas solid lines represent driftwood count densities (left axis). Blue squares = site A, green triangles = site B and red circles = site C. Occupancy is expressed as the mean number of katipo on an ACO, divided by the area of blowout.

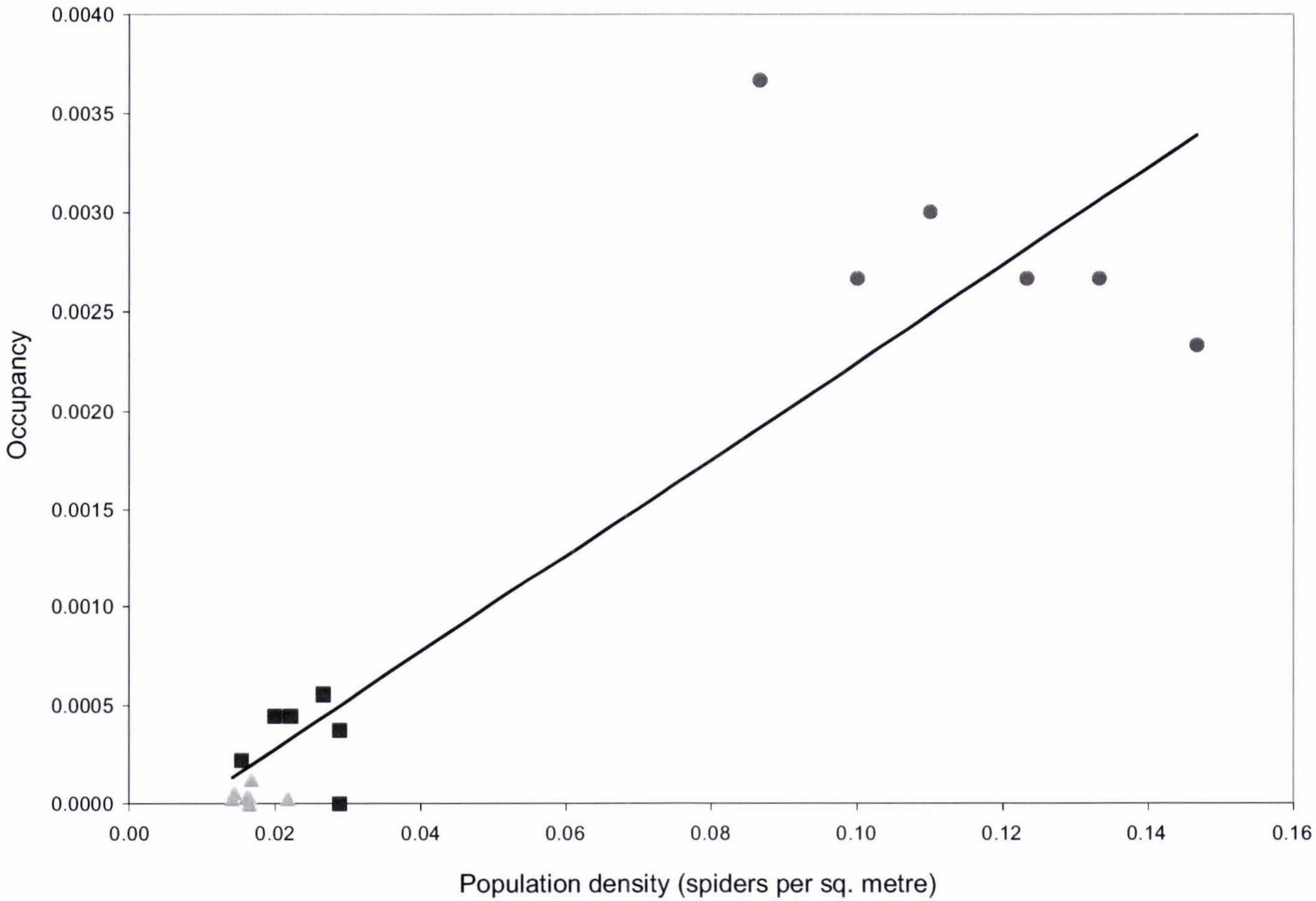

Figure 5. Occupancy (expressed as the mean number of katipo per ACO, divided by area of blowout) plotted against population density estimates, fitted with a linear regression line. Points are coded by site; squares = Site A, triangles = Site B, circles = Site C. $R^2 = 0.83$, $F = 85.61$, *p* <0.0001.

Discussion

The strongly biased sex-ratio of katipo populations is also recorded by Parrott (1948) and Smith (1971), and can be explained by the differing life expectancies of the two sexes, as the sex ratio of katipo eggsacs appears to be 1:1 (Kavale 1986). Male katipo do not live beyond one breeding season, whereas females can live for over two years (Forster & Kingsford 1983). As male katipo are similar in size or larger than juveniles, the low number of males found does not reflect a lower probability of detection. If that was the case similarly low numbers of juveniles would have been found, unless there were sex-based behavioural differences, such as increased mobility of males, which influenced detection probability. However, as katipo are nocturnal (Ward 1998), it seems likely they would be stationary during the day when searches occurred.

According to Griffiths (2001), male katipo typically reach maturity in spring and early summer, and die within a few weeks. A similar short life span is also reported by Kavale (1986), who raised katipo spiders at elevated temperatures in laboratory conditions. However, male katipo I raised in ambient laboratory conditions lived for an average of 77 days past their final moult (Chapter 5), suggesting that male katipo may have a longer life expectancy than previously thought.

Forster & Forster (1999) and Griffiths (2001) state that katipo produce eggsacs during November and December. At Himatangi, male katipo can be found in the field from September onwards (pers. obs.), and the driftwood counts show that males can be found in the field up until May-June. As both male and female katipo can mate more than once (Kavale 1986), eggsacs can theoretically be produced until much later than stated by Forster & Forster (1999) and Griffiths (2001), and indeed unhatched eggsacs and newly hatched (2nd instar) juveniles were found at Himatangi up until June. The number of juvenile katipo peaked in late summer through to spring, presumably once the majority of the season's eggsacs had hatched. The longer male life expectancy, coupled with the length of time that males, unhatched eggsacs and 2nd instar juveniles can be found in the field, suggests a longer breeding season at Himatangi than reported elsewhere. This may be because other studies have been carried out in the South Island (for example Griffiths 2001), where colder temperatures may limit the length of the breeding season.

The density of katipo was much higher at Site C than at Sites A and B. This could be attributed to a number of factors. Site C was adjacent to a stream, and had higher plant cover and diversity, and thus may have had a higher prey abundance. It also faces lower levels of human interference, being further down the beach from the main vehicle access (Himatangi Beach is a public road). The ACO occupancy rates were also highest at Site C, despite the ACOs being installed one month later than at Sites A and B. Many katipo were also found in the dunes adjacent to Site C, on the other side of the stream, during the initial population survey (Chapter 2).

There was no evidence of a negative relationship between katipo and *S. capensis* living on driftwood. According to Patrick (2002) katipo populations are known to fluctuate dramatically in relatively short periods of time, yet in this study katipo populations were remarkably constant, especially compared to *S. capensis*. The marked fluctuations in the abundance of *S. capensis* were due to large influxes of juveniles. Unlike katipo, *S. capensis* reproduces year round (Hann 1990). Despite *S. capensis* being largely discounted as a competitor with katipo (Griffiths 2001; Patrick 2002), it is concerning that an introduced species has reached such comparatively high densities. It may be advisable to monitor *S. capensis* populations in addition to those of katipo. If *S. capensis* populations increase further katipo may be displaced from the dunes at Himatangi, as has occurred at Motueka Beach, Nelson (Hann 1990).

Although the recorded density of other spider species remained low throughout the sampling period these counts may not reflect their true abundance as the majority of these spiders were free-living hunting spiders from the families Salticidae and Lycosidae. These spiders do not construct webs, and thus would only be temporarily present on driftwood.

A high proportion of the ACOs were occupied by katipo during the sampling period. The location of each ACO may have influenced the probability of occupancy, as katipo can show preferences for certain web sites, such as warmer temperatures and adequate ground cover (Griffiths 2001). ACOs that were placed in areas with higher vegetation and driftwood cover seemed to have higher occupancy rates.

The ACOs were often occupied by mature female katipo, indicating that they are more mobile than suggested by Griffiths (2001) and Forster & Forster (1999), who state that female katipo rarely relocate their webs upon maturity. In addition, the short average length of occupation also suggests that female katipo are more mobile than previously thought, although still less mobile than juveniles. This result was not limited to the ACOs, as females occasionally abandoned webs constructed on driftwood, although specific occupancy lengths were not recorded.

It was quite common for more than one katipo to occupy the same ACO simultaneously, often sharing the same groove. On two occasions female katipo had constructed adjoining retreats on an ACO, with one continuous catching web. This was unexpected, as katipo have very high rates of cannibalism when held in captivity (Forster & Kingsford 1983; Ward 1998), although other examples of extended peer tolerance do exist for both katipo (C. Troup, pers. comm.) and for other *Latrodectus* species (Kaston 1968).

The overall correlation between occupancy rates and population density was high, although this relationship did not hold at individual sites. The population densities at each site did not vary considerably over the sampling period, however, it is likely that ACOs would be able to detect large fluctuations in population density if they occurred. Alternative monitoring methods such as transect or quadrat searches can be heavily biased by poor detection probability, and are highly time-consuming. There is no evidence to suggest that they are more accurate at tracking katipo population changes.

After one year out in the field the ACOs were still intact, however due to the gradual effects of sandblasting they would require occasional repair and maintenance if used on a long-term basis. No eggsacs were constructed on the ACOs during the monitoring period, but this was probably because they were placed out in the dunes late in the breeding season. Many of the ACOs were used by female katipo as a site for constructing eggsacs in the following summer. ACOs allow for easier inspection of eggsacs, compared to driftwood or vegetation. I would recommend that ACOs are placed out in late winter or early spring, so that eggsacs can also be monitored.

The occasional vandalism of the ACOs could potentially be avoided through increased public awareness and education. Himatangi Beach is a very popular location during summer, with high levels of vehicle and foot traffic, it is thus inevitable that some interference would occur. However, the levels of interference were low overall, thus the monitoring programme was not badly affected. Most of the vandalism occurred in the first few months of monitoring when the beach was busier, and the ACOs were still new and conspicuous. The ACO design could be altered so that they are better camouflaged, or alternatively ACOs could be pre-weathered before use.

The use of ACOs would be largely preferable to the status quo at many sites around New Zealand where no monitoring occurs. ACOs would be easy to implement in areas that are not currently monitored due to time and labour constraints. Therefore, I would recommend investigating the use of ACOs as monitoring tools for katipo in other areas. Further investigations could include using different ACO designs, varying the density of ACOs in habitat, and comparing the utilisation of ACOs placed in different microconditions.

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Chapter Four:

Web site selection by the katipo spider, *Latrodectus katipo* (Theridiidae)

Plate 1. A mature female katipo on driftwood. Photograph taken at Himatangi Beach, 2005.

Web site selection by the katipo spider, *Latrodectus katipo* (Theridiidae).

Abstract

An understanding of how the endangered katipo spider utilises its environment will be critical to its successful conservation. Field studies have indicated that katipo may have preferences for certain native plant species over the introduced grass, *Ammophila arenaria* (marram). It is also clear that dense patches of marram tend to exclude katipo in the wild. Laboratory experiments were conducted to investigate if katipo preferred to build webs in any of the plant species *Coprosma acerosa, Spinifex sericeus, Desmoshoenus spiralis, A. arenaria,* or on driftwood. The native shrub *C. acerosa* was preferred by katipo, and marram was avoided. As native shrubs like *C. acerosa* are comparatively rare in remaining dunelands, with some species endangered, the conservation of katipo and these native shrubs could be improved through habitat restoration.

Introduction

The red katipo spider, *Latrodectus katipo* Powell 1871, has undergone serious population decline (Patrick 2002). The primary cause of this decline is believed to be habitat loss and degradation (Griffiths 2001; Patrick 2002), thus an understanding of how katipo spiders utilise their environment will be critical to their conservation.

Katipo construct their webs at night (Ward 1998; Benjamin & Zschokke 2003). Their webs are typical of the *Latrodectus* genus, consisting of a 'messy' platform of threads positioned just above the ground (Griffiths 2001). Numerous sticky threads span the distance between the platform and the substrate (Court 1971). The spider also constructs a peripheral retreat out of densely woven silk (Griffiths 2001). The web is not renewed daily as in orb web spiders (Foelix 1996), but is gradually increased in size and density as the spider grows (Court 1971). As theridiid spiders do not recycle their web silk by ingesting it (Benjamin & Zschokke 2003), choosing an appropriate web site is important as there are high energetic costs associated with relocating (Griffiths 2001).

The catching webs of katipo are usually positioned over areas of open sand, either between clumps of grasses or sedges or in the spaces beneath prostrate shrubs, and dense plant growth may exclude katipo (Griffiths 2001). In the wild katipo spider webs have been found constructed within a variety of plant species, under driftwood and in other debris such as metal tins, bones, vehicle tyres, corrugated iron, plastic sheeting, etc. (Forster & Forster 1999, pers. obs.)

Griffiths (2001) found that female katipo webs are more numerous in the native sedge *Desmoschoenus spiralis* (pingao) and in the native scrambling prostrate shrub *Muehlenbeckia complexa* than expected from the plant's abundance, with webs less abundant than expected in the exotic grass *Ammophila arenaria* (marram). Smith (1971) found katipo most abundant in pingao and sparse-medium density marram in a survey at South Brighton Beach.

A survey of katipo along the Manawatu-Wanganui coastline indicated that juvenile and mature katipo may have different web site preferences, with juvenile katipo occupying significantly smaller pieces of driftwood than mature katipo (Chapter 2). Of those spiders found in vegetation, there were age differences in what species was occupied, with 73% of juvenile katipo found in vegetation living in marram, 16% in *Spinifex sericeus* (spinifex), and 11% in other plant species. In comparison, 28% of mature female katipo living in vegetation were occupying marram, 56% spinifex and 16% other plant species (Chapter 2). The desert widow spider, *L. revivensis* also exhibits age-based differences in web-site selection, with spiders occupying larger shrubs as they grow (Lubin *et al.* 1993).

Griffiths (2001), in his field studies along the Canterbury coastline, found that katipo were utilising driftwood less than predicted by its availability. However, driftwood is apparently favoured by katipo in dune blowouts where vegetation is scarce (Patrick 2002, pers. obs). Dunes along the Manawatu-Wanganui coastline are characterised by having large amounts of driftwood within the dune system (pers. obs.).

Relocation of web sites by spiders is interpreted as a foraging decision, and may be influenced by the nutritive state of the spider (Bilde *et al.* 2002) with site tenacity greater when prey capture is successful (Wise 1993). Web site selection will be based not only on structural characteristics such as plant type and density, or driftwood size and shape, but also on microclimate; light, temperature, and humidity conditions. The presence of conspecifics and/or competitors may also influence web site selection, as katipo are often found living in clumps (Ward 1998; Griffiths 2001; pers. obs.). In the species *Nephilengys cruentata* (Tetragnathidae), spiders are attracted to the webbing of conspecifics, which acts as an indirect indicator of habitat quality (Schuck-Paim & Alonso 2001).

It is unclear whether katipo will still hold a preference for any particular plant species and/or driftwood as a web site, when other variables such as temperature and light differences, slope, prey abundance, and the presence of conspecifics and potential competitors are held constant. In this study I examined preference by katipo for four plant species; the native pingao, spinifex and *Coprosma acerosa*, and the exotic marram. I also investigated whether there was any preference for native sand-binding plants or driftwood.

Methods

Plant species preference

As male katipo leave their webs upon maturity and wander in search of females (Griffiths 2001), only juvenile and mature female katipo were used for this experiment. Ten mature and 5 juvenile female katipo were collected from Himatangi Beach, Manawatu, New Zealand, and housed in individual plastic 500 ml containers, fitted with a mesh lid. In addition, 20 laboratory-raised (Chapter 5) mature female katipo were also trialed.

The *C. acerosa*, *S. sericeus* and *D. spiralis* plants were sourced from the Taupo Native Plant nursery, and the *A. arenaria* plants were collected from Himatangi Beach. Four square arenas were set up, with a base consisting of a 4 mm thick plywood frame, with sides 80 cm wide and 40 cm high. The wooden frame was lined with black polythene plastic sheeting, and then filled with sand collected from Himatangi Beach. Potted sand-binding plants were planted into the sand, with four (two in the case of *C. acerosa* due to its larger size) individual plants of each species placed in each corner. The plants were selected so that the density of vegetation in each corner was as similar as possible. The pot rims were covered by sand so that the plants appeared to be growing naturally. Each of the four arenas had the four plant species in a different arrangement, in order to control for any potential directional preference by katipo. A transparent Perspex frame, with sides measuring 65 cm wide and 60 cm high, was buried into the sand around the plants, and fitted with a mesh lid, in order to contain the spiders during the trial.

No prey items were provided in the enclosures to avoid biasing web site selection. The short-term nature of each trial meant that the spiders would not have been adversely affected by a lack of prey. All spiders were prey-satiated when the trials began, and katipo can live for several weeks without food (Griffiths 2001).

The trials took place in a temperature-controlled room with fluorescent "grow lights" fitted in order to keep the experimental plants alive. Temperature was kept constant at 25°C, with a light/dark regime of 10 hours light, 14 hours dark. A fan was used to direct an air current across the tops of the enclosures, in an attempt to deter spiders from the mesh ceiling of the enclosures.

An individual katipo was transferred carefully from its 500 ml container into the centre of the arena, using a small paintbrush. The plant species, and direction that the spider initially moved was recorded. If a spider had not moved onto vegetation within twenty minutes the trial was halted.

The spiders were then left undisturbed for 72 hours. The location of their web after this time was recorded, and the spiders were removed from the arenas. If spiders incorporated both the wall and vegetation in their web-building, only the plant species was recorded, as the retreat was always constructed within the vegetation.

After each trial, the plants and walls of the arenas were wiped down to remove webbing, and rested for one day between trials, to minimise pheromonal cues. The plants within the arenas were watered during this rest period.

Driftwood vs. plant preference

A second series of trials were run, to investigate whether katipo prefer driftwood or vegetation for web construction. The arenas from the first experiment were used, however the layout was changed so that one side of the arena contained pieces of driftwood with concave undersides suitable for web construction, while the other side contained vegetation comprising a mixture of *S. sericeus*, *D. spiralis* and *C. acerosa*. The driftwood used was collected from just above the high tide mark at Himatangi Beach (where no katipo were present), and was washed before being used in the trial.

The trials were conducted using the same protocols as for the plant species trials. A total of 16 wild-caught and 8 laboratory-reared spiders were used. No spider was trialed more than once. All of the spiders used in these experiments were released within the dunes at Himatangi Beach upon completion.

Results

Plant preference experiment

All of the spiders in the trials produced webs during the 72 hr period. The amount of webbing produced varied considerably between individuals, with some building a retreat with only a few sparse catching threads, and others building large areas of catching web. Some individuals began constructing webbing immediately upon first climbing onto vegetation, however most of these individuals relocated during the trial period. The amount of webbing did not appear to be related to the plant species it was constructed in.

The spiders showed no preference for any given corner within the arenas in their initial ($\chi^2 = 5.55$, $p > 0.05$) or final ($\chi^2 = 4.93$, $p > 0.05$) choices.

Most of the spiders went to either *C. acerosa* or *S. sericeus* initially, with significantly fewer katipo climbing onto marram or pingao than would be expected if katipo had no plant species preference ($\chi^2 = 7.86$, $p < 0.05$). There was no significant difference between laboratory-reared and wild spiders in their initial plant choice ($\chi^2 = 0.62$, $p > 0.05$).

Eighty percent of the spiders relocated from their initial location during the trial, and thus constructed their webs elsewhere within the arena. However, if the spider initially occupied *C. acerosa* it was less likely to relocate than if it initially occupied another plant species (Table 1). Seventy one percent of the spiders that relocated moved to either the walls or ceiling of the arenas, and constructed webs there. There seemed to be no differences between juvenile and mature female katipo, nor between lab-reared and wild-caught spiders, in their choices (Fig. 1).

Of the wild-caught spiders, none of those that were collected from vegetation (*N* = 7) went to the same plant species within the arena as they had been collected from in the field, although two of those spiders were collected from plant species not tested in this experiment (*Ozothamnus leptophyllus* and *Pimelea arenaria)*. One of these spiders did subsequently relocate and built its web on the same plant species that it was found on (pingao).

		Final location									
		Pingao	Spinifex	Marram	Coprosma	Wall	Ceiling	**Total**	% did not relocate	% relocated to other plant	% relocated to wall or ceiling
Initial location	Pingao	0	1	0	3	3	0	**7**	0.00	57.14	42.86
	Spinifex	1	0	0	0	7	3	**11**	0.00	9.09	90.91
	Marram	0	0	1	0	1	1	**3**	33.33	0.00	66.67
	Coprosma	2	0	1	6	3	2	**14**	42.86	21.43	35.71
	Total	**3**	**1**	**2**	**9**	**14**	**6**	**35**			

Table 1. Plant species occupied by katipo, initially and after 72 hours, in experimental enclosures.

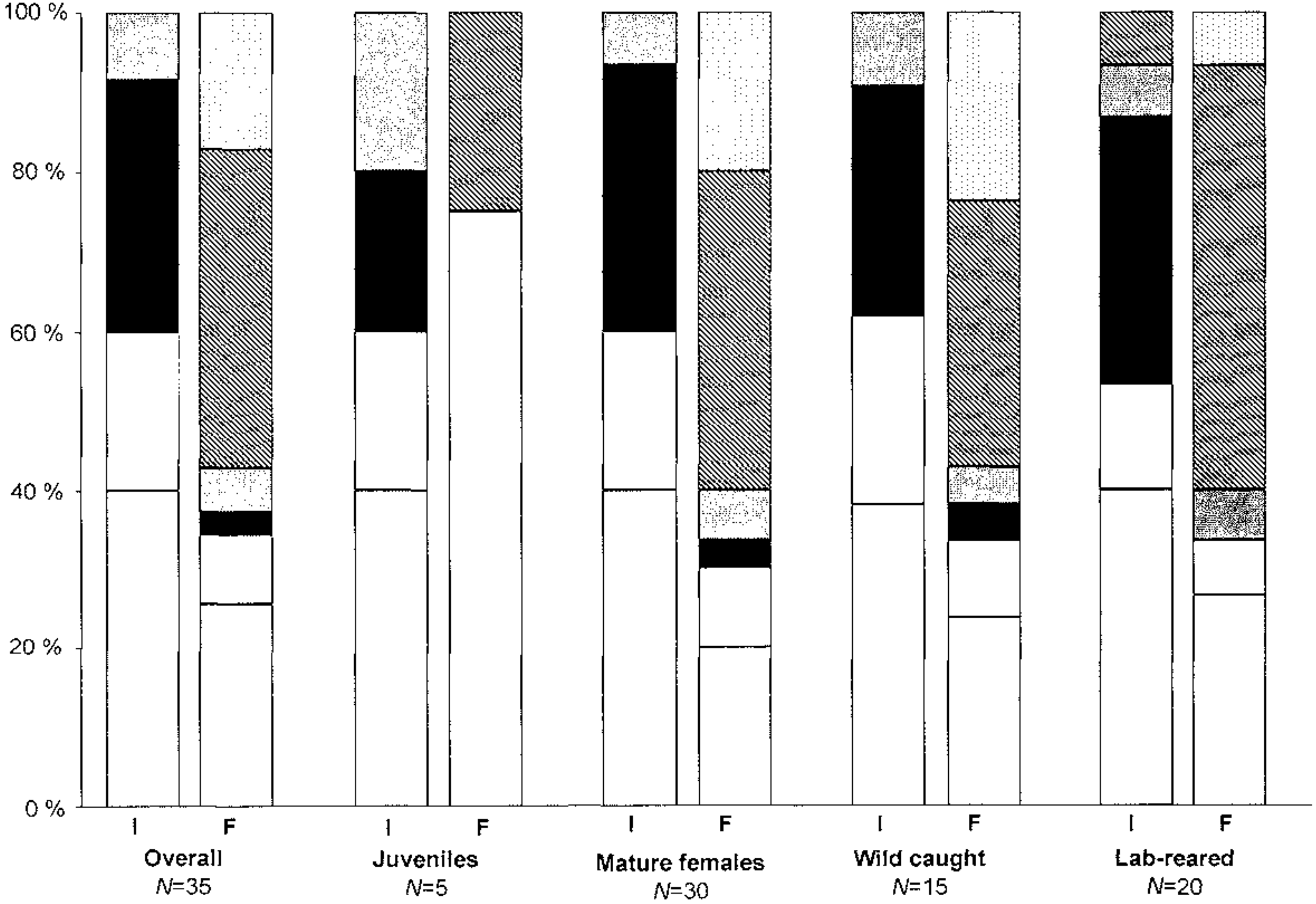

Figure 1. Initial (I) and final (F) choice in plant species experiment. ☐ = coprosma, ☐ = spinifex, ■ = pingao, ▩ = marram, ▧ = wall, ⬚ = ceiling.

Plant vs. driftwood preference experiment

Katipo showed no preference for any particular area in their initial choice (χ^2 = 2.00, $p > 0.05$), however more individuals were found in the back left corner of the arenas at the end of the trials than would be expected by chance (χ^2 = 8.77, $p = 0.05$).

Fifty percent of the spiders went to the driftwood initially, with most of the remainder going to pingao (Fig. 2). However, during the trials 79% relocated from their initial location, mostly to *C. acerosa*, although many still went to the walls or ceiling of the arenas (Fig. 2, Table 2). Again, *C. acerosa* retained a higher proportion of the spiders than the other plants or driftwood, and almost half of the spiders that initially went to the driftwood relocated to *C. acerosa*.

Chi-square tests could not be used to statistically compare different groups of spiders because of the small sample size.

		Final location									
		Driftwood	Spinifex	Pingao	Coprosma	Wall	Ceiling	**Total**	% did not relocate	% relocated to plant	% relocated to wall or ceiling
Initial location	Driftwood	2	1	0	5	1	3	**12**	16.67	50.00	33.33
	Spinifex	0	0	0	1	0	0	**1**	0.00	100.00	0.00
	Pingao	0	1	0	2	2	2	**7**	0.00	42.86	57.14
	Coprosma	0	0	0	3	0	1	**4**	75.00	0.00	25.00
	Total	**2**	**2**	**0**	**11**	**3**	**6**	**24**			

Table 2. Plant species or driftwood occupied by katipo, initially and after 72 hours, in experimental enclosures.

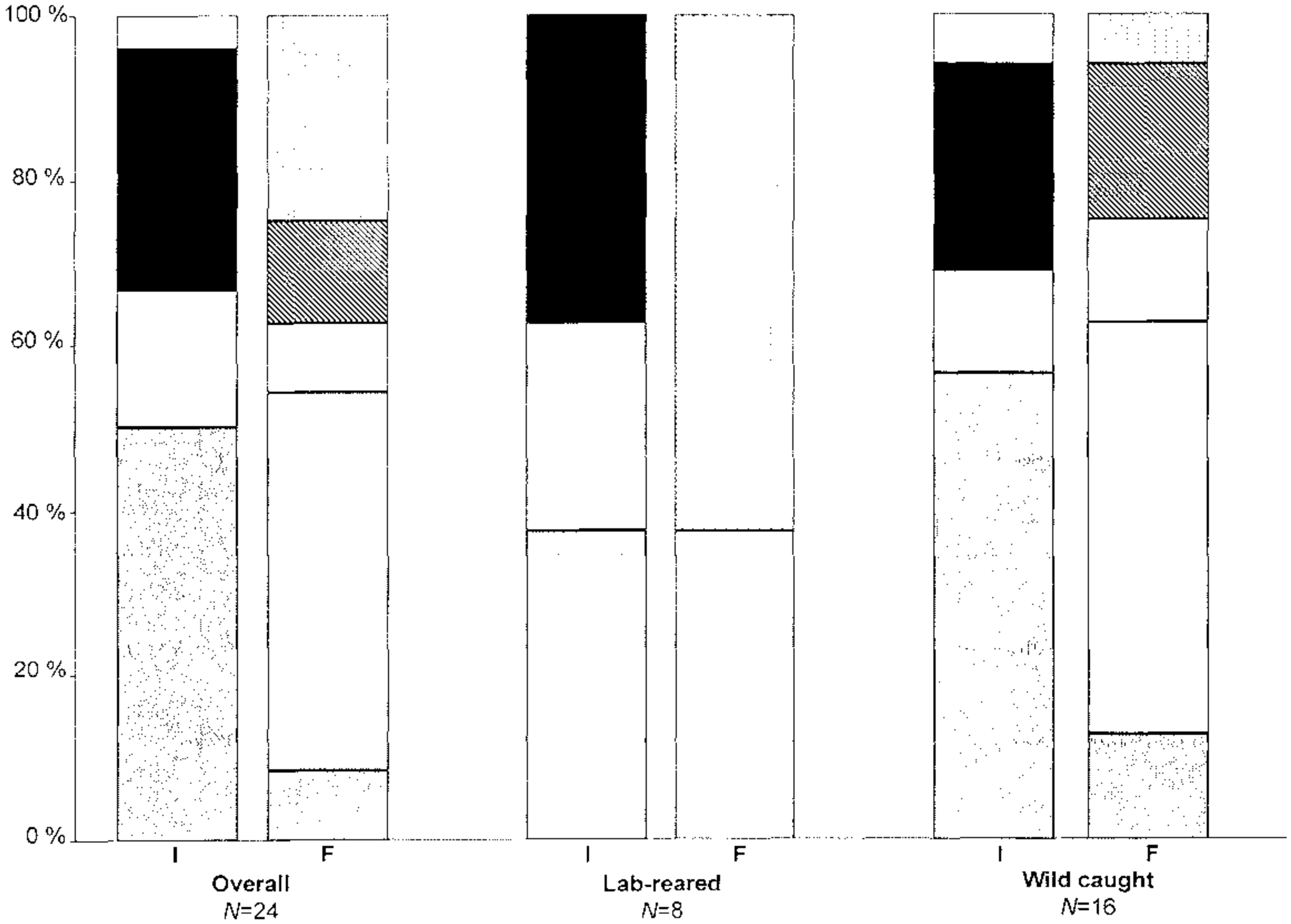

Figure 2. Initial (I) and final (F) choice in plant and driftwood experiment. ☐ = coprosma, ☐ = spinifex, ■ = pingao, ⬚ = driftwood, ▨ = wall, ⬚ = ceiling.

Discussion

The results of this study need to be interpreted with caution because of the small sample sizes involved. As katipo are an endangered species, I was unable to collect too many individuals from the wild.

The initial plant choice made by the spiders could be interpreted as a choice of refuge, rather than web site, although some of the spiders did start web construction immediately. In the second set of trials half of the spiders went to driftwood initially and the other half went to vegetation, which is the expected result if the spiders initially moved in a random direction.

The large proportion of spiders that constructed webs on the walls or ceilings of the enclosures was unexpected, particularly the ceiling webs, as katipo webs in the wild are always constructed just above the ground, with their primary prey items ground-dwelling invertebrates. The individuals that constructed these ceiling webs would not have been able to capture prey if it had been available, as no sticky capture threads could span the distance between web platform and substrate, and still effectively snare prey.

It was interesting that most spiders relocated during the trial, as this suggests they were assessing their available habitat, rather than just settling in their first location. *C. acerosa* not only attracted a high proportion of spiders initially, but also retained a higher proportion of spiders than the other plant species. These results, combined with the field surveys (Smith 1971, Ward 1998, Griffiths 2001, Patrick 2002), suggest that sand-binding shrubs such as *C. acerosa*, and the native sedge pingao, are preferred by katipo over other plant species, and that marram is avoided. It is likely that other sand-binding shrubs such as *M. complexa*, *O. leptophyllus*, and *P. arenaria* may also be favoured by katipo.

Many spider species show preference for certain plant species in which to build their webs, and these preferences are usually related to a spider's structural and microclimatic requirements for web construction (Lubin *et al.* 1993). Shrubs may afford katipo webs more protection than grasses or sedges, while still providing the critical requirement of open sand over which the catching platform web may be constructed, at any density. Shrubs also have a more complex structure, and may provide more suitable web attachment points. The spider species *Argiope trifasciata* (Tetragnathidae) also shows a preference for sites with higher vegetational complexity (McNett & Rypstra 2000). Certain plant species may also be preferred if they support higher numbers of prey, however this was not investigated.

Field studies may actually under-report the incidence of katipo living in sand-binding shrubs as many of these species are now also rare, or endangered, e.g. *Pimelea arenaria* (Dawson *et al.* 2005). In addition, it can be more difficult to locate katipo webs within these shrubs compared to sedges and grasses. My survey of katipo populations along the Manawatu-Wanganui coastline (Chapter 2) found few katipo living in these shrubs, but this is a reflection of their low abundance along this stretch of coastline.

It has already been established that dense marram is largely unsuitable as habitat for mature female katipo as its dense growth excludes web construction (Griffiths 2001; Patrick 2002). However, it was interesting that in this experiment, where comparatively sparse marram was used, the plant was still avoided by most of the spiders. Although marram has a superficially similar growth form to *S. sericeus*, and *D. spiralis*, it does have highly linear vertical growth, compared to the more drooping forms of spinifex and pingao. This might make it less suitable as a refuge or web site. Marram may be occupied by katipo in the wild only when other options are not readily available.

Many dune revegetation projects are underway nationwide (Patrick 2002), with natives such as spinifex and pingao commonly planted. In light of this study, I would recommend increased planting of shrubs such as *C. acerosa* in addition to that of pingao and spinifex. Some of these native sand-binding shrubs are rare or endangered themselves, e.g. *Pimelea arenaria* (Dawson *et al.* 2005), therefore planting of these species could benefit both spider and plant. As *A. arenaria* has the potential to outcompete and exclude native sand-binding plants (Partridge 1995; Hilton *et al.* 2000), weeding of marram may be necessary in some areas in order to ensure that suitable katipo habitat remains in place (Partridge 1995).

As habitat loss and degradation has apparently been the main cause of katipo decline (Patrick 2002), populations of this spider will only ever be able to recover if sufficient areas of adequate habitat are provided. The first step towards achieving this appears to be returning *A. arenaria* dominated dune lands to native sand-binding plant cover, a move that will undoubtedly improve the natural value of sand dune systems as a whole.

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Chapter Five:

Laboratory rearing of *Latrodectus katipo* spiderlings, with notes on fertility and development

Plate 1. A juvenile female laboratory-raised katipo. Photograph taken in the Entomology Laboratory, Ecology Building, Massey University, 2005.

Laboratory rearing of *Latrodectus katipo* spiderlings, with notes on fertility and development.

Abstract

Spiderlings from two *L. katipo* eggsacs were hatched and raised in laboratory conditions in order to become familiar with their development. Eggsacs from wild-caught females were also kept and the number of emergent spiderlings was recorded. The number of spiderlings per eggsac was variable (mean = 80.15, SD = 27.66), with one eggsac containing 146 spiderlings, higher than any other previously recorded katipo eggsac. There was considerable variation in the growth rates of the spiderlings, but this was not related to sex. Although spiderlings were highly variable in the development of abdominal markings, at maturity female spiders had almost identical markings as their siblings. Manawatu katipo are unique in that mature females often retain large areas of white markings on their abdomen at maturity.

Introduction

The reproduction and development of many other *Latrodectus* species is well-known, but information regarding *Latrodectus katipo* reproduction and development is largely limited to two studies completed by Forster & Kingsford (1983), and Kavale (1986).

The reproduction and development of the other New Zealand widow spider species, *L. atritus*, has only been studied once (Forster & Kingsford 1983).

The first developmental study of *L. katipo* was by Forster & Kingsford (1983), in which *L. katipo* and *L. atritus* spiderlings were raised to maturity, with some individuals raised individually, and others communally in jars containing individuals from two eggsacs. Kavale (1986) also reared *L. katipo* spiderlings in his hybridisation studies between *L. katipo* and the Australian redback, *L. hasselti.* Both Forster & Kingsford (1983) and Kavale (1986) used similar methods to raise the spiderlings. However temperature conditions differed between the two studies; Forster & Kingsford (1983) kept temperatures above 15° C, whereas Kavale (1986) kept temperatures constant at 23° C. Spiderlings were initially fed *Drosophila melanogaster* flies, and were switched to larger prey such as houseflies as the spiders grew (Forster & Kingsford 1983; Kavale 1986). The two studies used female katipo that were collected in the Otago region; Forster & Kingsford (1983) used *L. katipo* collected from Karitane Beach, whereas Kavale (1986) obtained females from Waikouaiti Beach.

Most *L. katipo* spiderlings emerge from eggsacs as 2nd instar individuals, although some may emerge as later instars (Kavale 1986); this also occurs in other *Latrodectus* species (Kaston 1968). The *L. katipo* spiderlings in the two studies reached maturity quickly; for example Forster & Kingsford (1983) report that females took 17-18 weeks to reach maturity, and males only 7.5 weeks. However, these development times may have been a function of temperature (Kavale 1986), and thus not reflect actual development times in the wild, where katipo spiderlings develop during winter (Griffiths 2001).

Katipo have lower reproductive output than their closest relative, the Australian redback *L. hasselti,* with redbacks producing twice as many eggs in their first eggsac compared to katipo (Kavale 1986). Kavale recorded the number of eggsacs produced by 19 female katipo, and the number of spiderlings that emerged from each eggsac; 1-10 eggsacs (median = 5) were produced by each female, with a mean of 66 spiderlings (SD = 19) per eggsac, compared to a mean of 130 spiderlings per redback eggsac. Forster & Kingsford (1983) used four wild-caught female *L. katipo* in their study, with twelve eggsacs produced in total; one of the eggsacs produced 80 spiderlings, but the fertility of the other eggsacs was not specified.

Other authors have provided observational notes on the fertility of *L. katipo*, and the morphology of *L. katipo* spiderlings at various developmental stages. Robson (1879) reported 60 live spiderlings from one eggsac, whereas Parrott (1948) noted that the first of two eggsacs produced by a female *L. katipo* contained 98 live spiderlings and 9 dead; whereas 66 live spiderlings emerged from the second eggsac, with an unspecified number dead. Ward (1998) collected a single *L. katipo* eggsac from an unspecified location along the Manawatu-Wanganui coastline, from which an estimated 58-62 spiderlings emerged.

In this study, two *L. katipo* eggsacs were collected from different locations within the foredunes at Himatangi Beach, Manawatu, New Zealand. The purpose of collection was to raise the spiderlings in order to become familiar with the species at each developmental stage, and also to produce mature individuals for the web site selection experiments (Chapter 4). The spiderlings were raised in a laboratory, however temperature conditions were not controlled. Therefore the spiderlings would have experienced diurnal temperature fluctuations during development, albeit less extreme than conditions in their natural environment.

Methods

The first eggsac was collected on December 4, 2004, just as the spiderlings had begun to chew a hole in the silk eggsac wall. The eggsac was transferred to a 500ml plastic container, fitted with a mesh-insert lid, and taken back to the laboratory in Palmerston North.

Upon hatching, all spiderlings from the first eggsac were transferred into 70 ml specimen jars, which contained a small twig to be used as a base for web construction. The lids were screwed on loosely to allow air flow. The spiderlings were all fed one lab-reared *Drosophila melanogaster* (Diptera) fly per week, until they were 40 days old, when feeding was increased to one item twice weekly. The variety of prey also increased at this time to include *Tribolium castaneum* (Coleoptera: Tenebrionidae), and *Acyrthosiphon pisum* (Hemiptera: Aphididae).

The spiderlings were transferred into larger 500 ml containers at 2 months of age. These containers had a mesh-insert in the lid for ventilation and a small hole which was plugged with a rubber bung. The rubber bung could be removed for food delivery, which minimised damage to webbing, as webbing was often destroyed when the lids of the small containers were opened. A small length of dowelling was placed inside the container for web construction. The second eggsac was collected on February 1, 2005, and treated as above except that spiderlings were transferred straight into individual 500ml containers, as the smaller containers made feeding difficult.

After the 5th instar spiderlings from both eggsacs were mostly fed mature and larval *Tenebrio molitor* (Coleoptera: Tenebrionidae), supplemented with wild-caught slaters (Isopoda), sandhoppers (Amphipoda), crane flies (Diptera: Tipulidae) and house flies (Diptera: Muscidae). Spiderlings were raised to maturity, and the dates of each moult were recorded. The life span of males that reached maturity was recorded, but this could not be done for females as they typically live for more than two years (Forster & Kingsford 1983).

Six wild-caught female katipo that were being kept temporarily for experiments on web site selection (Chapter 4) produced eggsacs. These eggsacs were transferred to individual 500ml containers and kept until they hatched. The emergent spiderlings were counted, and subsequently released at Himatangi Beach, where the females had initially been collected from. All of the eggsacs in this study were inspected after hatching, for any spiderlings that had died prior to emergence.

One-way ANOVA analysis was used to compare the length of each instar, and compare the growth rates of males, females, and spiderlings of unknown sex.

Results

Spiderlings started emerging from the first eggsac within a few hours. The eggsac contained 146 live spiderlings, and no dead pre-emergent spiderlings. The initial exit hole was not enlarged by subsequent spiderlings, thus all spiderlings exited the eggsac one-by-one, a process that took approximately 4 hours.

Mortality was very high for the first eggsac spiderlings after the 3rd instar. Some of the spiders apparently died of starvation after failing to catch any prey items. Other causes of mortality included injuries sustained during attempted prey capture of *T. castaneum*, or failure to moult; however the reason for most mortality was unknown, and was not limited to the smaller spiderlings. After 74 days only 28 of the original spiderlings were still alive.

The second eggsac hatched on February 24, 2005, with 92 live spiderlings in total. No dead pre-emergent spiderlings were found within the eggsac. Again all of the spiderlings exited the eggsac one-by-one. Eight spiderlings were killed by their siblings in the two days before they were transferred to individual containers. The mortality of spiderlings from the second eggsac was much lower than that from the first eggsac, and the sex ratio of spiderlings that lived past the 4th instar was 1:1.

Thirteen male katipo reached maturity, only one of which was from the first eggsac. On average they took 220 days to reach maturity, and lived for an average of 77 (SD = 28.3) days past their final moult (a total life span of 297 days, SD = 29.6).

The number of emergent spiderlings from eggsacs ranged between 40 and 146 (mean = 80.15, standard deviation = 27.66). When results from Robson (1879), Parrott (1948) Forster & Kingsford (1983) and Ward (1998) are included, the average number of live emergent spiderlings per katipo eggsac is 78.1 (SD = 24.78). Four of the wild-caught spiders produced more than one eggsac during captivity, with two spiders producing three eggsacs (one was defective, and contained no eggs). Subsequently laid eggsacs tended to contain fewer spiderlings than previous eggsacs, but this was not always the case (Table 1). None of the eggsacs examined in this study contained spiderlings that had died prior to emergence.

	Eggsac Number		
Individual	1st	2nd	3rd
1	64	85	52
2	92	69	0*
3	97	40	
4	95	93	
Mean	87.00	71.75	
Standard deviation	15.47	23.40	

Table 1: Numbers of spiderlings per eggsac for captive females that laid multiple eggsacs. Note: * refers to a defective eggsac that did not contain eggs.

Moulting usually occurred at night, but some spiderlings initiated moulting during daylight. The number of days between emergence and the first moult did not vary significantly between males and females nor individuals of unknown sex (those that died before sexual characteristics became apparent) from the second eggsac (F = 2.8, p = 0.07, df = 2,55; Fig. 1). Likewise the length of the 3rd instar did not differ significantly between males, females and spiderlings of unknown sex (F = 0.15, p = 0.86, df = 2,48), and although males did have slightly shorter later instars than females this was not significant (F = 0.00, p =0.98, df = 1,61). The 4th instar was longer than the other instars (F = 24.4, p = 0.00, df = 5,167). Individuals from the second eggsac had longer 2nd and 4th instars than individuals from the first eggsac (F = 100.29, p = 0.00, df = 1,201 for the second instar, F = 159.75, p = 0.00, df = 1,75 for the fourth), though the length of the 3rd instar was not significantly different (F = 0.67, p = 0.41, d.f = 1,158). Females typically took six moults to reach maturity (i.e. at the 8th instar), whereas males typically reached maturity at the 6th or 7th instar. One male did not reach maturity until the 8th instar.

There was substantial variation between spiderlings from the same eggsac in prey capture success, the extent of web construction, the rate of growth and the abdominal markings. Webs were built slowly, becoming more extensive over time. Some individuals incorporated prey remains into their retreats, and many built their retreats on the underside of the container's lid. Despite variation in markings during development, upon maturity females from the same eggsac had very similar markings, so that individuals from the two eggsacs could be readily distinguished (see Plate 2).

Sixty one percent of the spiderlings from the first eggsac successfully caught and fed on their first prey within 24 hours of it being added to the container. 91% of the remaining spiders achieved success within 48 hours, leaving 5 spiders who had not fed on first prey item after 48 hours. The spider's abdomens increased noticeably in size after feeding. Some spiderlings continued to have lower prey capture success than others, and subsequently remained much smaller than the others, and took longer to develop.

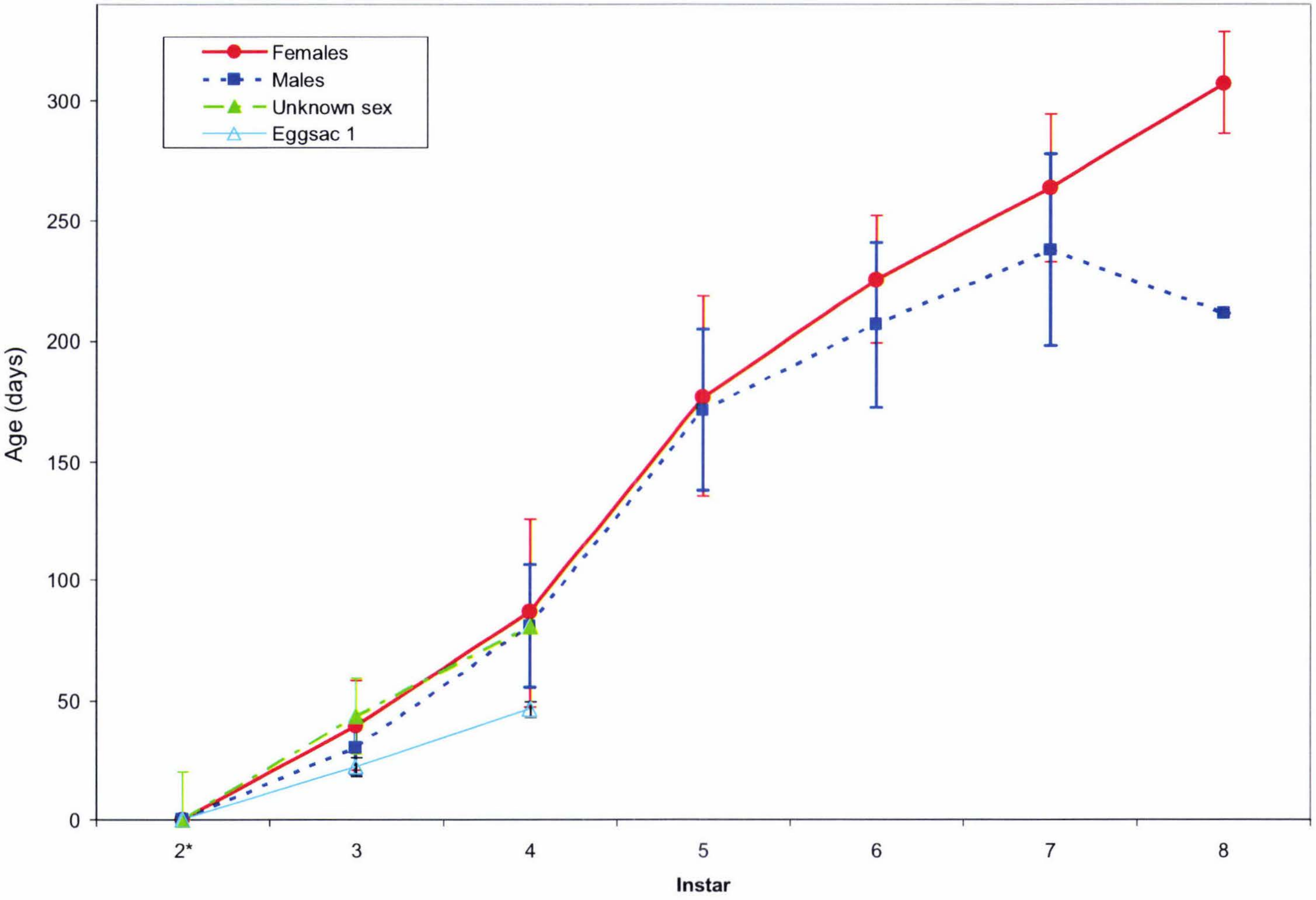

Figure 1. Length of instars (days), comparing males, females, and unknown individuals (died before sex could be determined) from the second eggsac, and the 2-4th instar for individuals from the first eggsac. *Note that the 2nd instar will be longer than indicated by this graph, as the period shown is post-emergence. The period of time between moult and emergence from the eggsac is unknown.

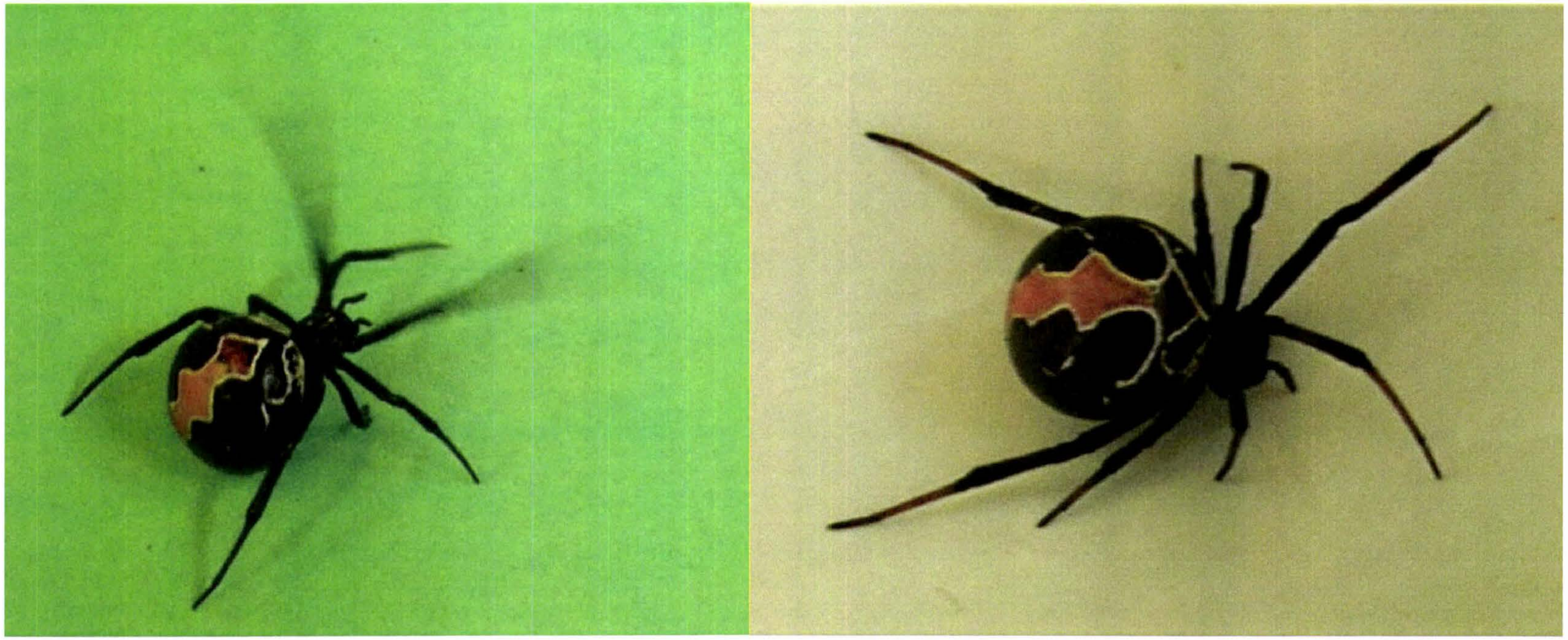

Plate 2. Photographs showing variation in markings at maturity. Left: Mature female from first eggsac, Right: mature female from second eggsac.

Discussion

The numbers of spiderlings from eggsacs were all within the range currently reported by the literature, with the exception of the first eggsac which contained 146 individuals. This is a very high number of individuals, more comparable with the numbers of spiderlings per eggsac recorded for *L. hasselti* (Kavale 1986). One defective eggsac was produced by one of the wild-caught females, and this has also been recorded for black widow spiders, *L. hesperus* and *L. mactans* (Kaston 1968).

The high mortality of the first eggsac was puzzling, as individuals from the second eggsac had much lower mortality despite almost identical treatment. It may have been result of the high number of individuals that emerged from this eggsac (146), as this is much higher than any other recorded katipo eggsac. Perhaps these spiderlings did not receive adequate nutritional reserves during pre-emergent development. However, it is likely that mortality in the wild is also very high, due to factors such as losses from ballooning dispersal, cannibalism, and injuries from prey items.

Cannibalism is commonly recorded for *L. katipo* (Forster & Kingsford 1983, Ward 1998) and other *Latrodectus* species (Forster 1992), especially when spiderlings are communally reared. Forster & Kingsford (1983) found that communally reared *L. katipo* spiderlings that survived were larger and developed more quickly than individually-reared spiderlings. None of the *L. katipo* spiderlings raised by Forster & Kingsford (1983) attained the size of wild females. Although mortality was higher in this study compared to that by Forster & Kingsford (1983), the females that reached maturity in this study were comparable in size to wild females. This suggests that the spiders in this study had their nutritional requirements met.

Males took over 31 weeks to reach maturity, much longer than the 7.5 weeks reported by Forster & Kingsford (1983). However, the lifespan of male katipo past their final moult was similar to that of Forster & Kingsford (1983), who found that male *L. katipo* lived for 72 ± 14 days after reaching maturity. Forster & Kingsford (1983) and Kavale (1986) also state that male katipo did not feed upon maturity, but I observed some males catching and feeding on prey, albeit less often than their female counterparts. In the wild male katipo abandon their webs at maturity, however some may still feed on prey items within female webs. This is observed in *L. revivensis* (Anava & Lubin 1993).

The females in this study typically reached maturity after 8 instars, which is comparable to that reported by Kavale (1986). However, the male katipo in Kavale's study reached maturity at the 5th or 6th instar, whereas in my study males typically took until the 6th or 7th instar, with one male not reaching maturity until the 8th instar. Kavale (1986) and Forster & Kingsford (1983) also recorded much shorter instar lengths, and thus overall time to maturity than I did, with successive instars tending to increase in length (Forster and Kingsford 1983, Kavale 1986). These developmental differences could be due to differences in rearing techniques, for example instar length may be a function of food intake (Forster & Kingsford 1983) but is more likely a reflection of temperature (Kavale 1986). Developmental times in the wild remain unknown, and would be difficult to assess. Moulting almost always occurred at night, as recorded by Forster & Kingsford (1983).

The considerable variation in growth rate, instar length, relative size and markings between individuals was also observed by Forster & Kingsford (1983), but upon maturity mature females from the same eggsac were very similar in markings and size. The sex-ratio of *L. katipo* eggsacs appears to be 1:1, assuming that early mortality is sex-independent; interestingly *L. hasselti* has a sex ratio biased towards males (Kavale 1986). This may reflect differences in their respective mating systems; both sexes of katipo can mate more than once (Kavale 1986), whereas redback males are functionally sterile after two palpal insertions, and sacrifice themselves during copulation (Forster 1992).

The following paragraph gives a brief description of *L. katipo* spiderling development, based on my own observations. A newly hatched spiderling has a dark brown cephalothorax and legs, which are banded, being darker around the joints. Their abdomens are white with the exception of a row of black diamonds running down either side of the dorsal midline, and corresponding black lateral stripes (see Fig. 2). When *L. katipo* first hatch they lack the red dorsal stripe; this develops once the 3rd instar is reached. The ventral 'hourglass' marking, typical of *Latrodectus*, is well-defined upon emergence, however at this stage it is cream in colour. As the spiderling grows and goes through successive moults the white on the dorsal surface of the abdomen is progressively replaced by black pigment, and the ventral hourglass becomes red in colour, though with a less-defined shape. Both *L. katipo* and *L. atritus* have only partial hourglass markings at maturity (Forster & Forster 1999). In many females the hourglass is reduced to a reddish smudge. Female katipo may retain some white pigmentation on their abdomen, usually outlining their red dorsal stripe but sometimes also with large patches near the anterior of the abdomen. Female katipo from the Manawatu region have comparably large amounts of white patterning at maturity compared to individuals from other areas around the country (Kavale 1986; pers. obs).

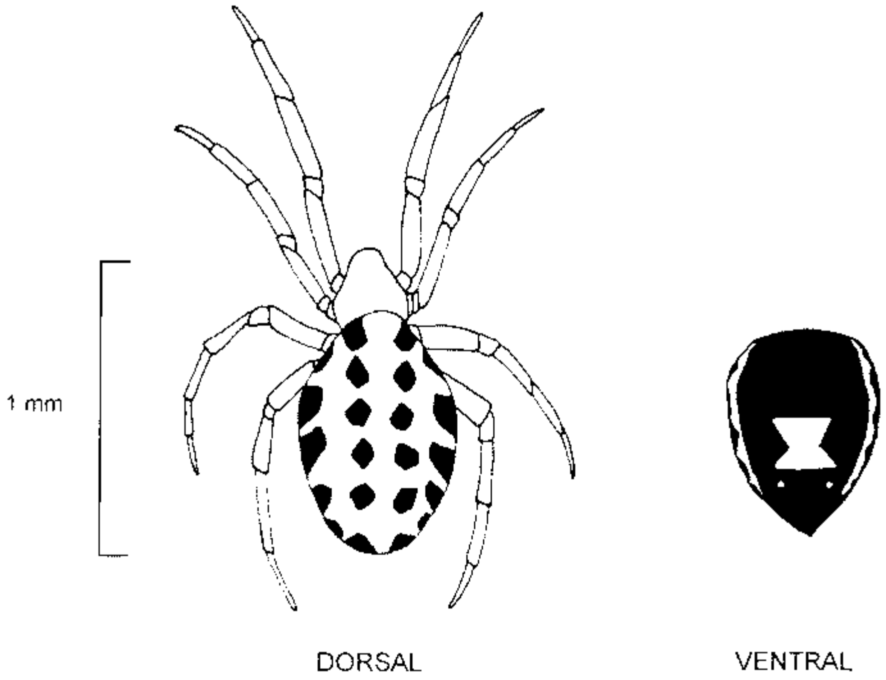

Figure 2. Diagram of a newly hatched *L. katipo* spiderling (2nd instar), showing colouration of abdomen. Legs and cephalothorax have been left unshaded.

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Synthesis

Findings of this study

Latrodectus katipo was present at all surveyed sites along the Manawatu-Wanganui coastline, however there was substantial variation in population density and structure. Population structure can be used as an indicator of population viability. The low population density and lack of juvenile katipo found at Castlecliff and Wanganui South suggests that these areas are in need of urgent conservation attention. Continued population monitoring will be required in order to investigate whether populations at sites such as Himatangi and Foxton are stable, or in decline.

ACOs were quickly occupied by juvenile and mature katipo of both sexes, with occupancy rates highly correlated with population density. Thus ACOs are a reliable monitoring method, and as they can be checked quickly and easily they have advantages over current monitoring methods. Habitat searches revealed katipo populations were comparatively stable over the sampling period, compared to that of *S. capensis*, with fluctuations of the latter attributed to pulses of eggsac hatching. *S. capensis* exists at much higher densities than katipo at Himatangi. Katipo have a longer breeding season at Himatangi than reported elsewhere, with males and 2nd instar juveniles found in the field between early spring and early winter.

The exotic plant marram has already been established as unsuitable for katipo web construction when it exists at high densities, however web site selection experiments show that it is avoided by katipo at low densities also. The highly linear growth form of marram may provide inadequate structure for katipo webs, regardless of density. Sand-binding shrubs like *Coprosma acerosa* are apparently favoured by katipo for web construction over sedges and grasses.

The fertility of katipo eggsacs is variable, but can be as high as 146 spiderlings per eggsac. Katipo spiderlings are highly variable in growth rates and the development of abdominal markings. The markings of mature female katipo vary considerably, particularly in the Manawatu region where many mature females have large amounts of white pigmentation present at maturity. Male katipo live for an average of 77 days upon reaching maturity, and can mate more than once, supporting the view that katipo have a longer breeding season in the North Island.

Recommendations for management

- Future surveys of katipo populations should include male and juvenile katipo, so that variation in population structure can be assessed, and the dynamics of *L. katipo* in different parts of its range compared. Populations with low numbers of juveniles can then be prioritised for conservation measures.

- ACO monitoring should be implemented at sites where no katipo population monitoring is currently occurring. Monitoring will be aided if photographic identification guides are produced, as a lack of identification tools appears to be hindering monitoring efforts. A guide will help observers to distinguish katipo from *S. capensis.*

- Populations of *S. capensis* should be monitored alongside katipo in areas where they are posing concern. Although the two species are currently co-existing along the Manawatu-Wanganui coastline, *S. capensis* is highly successful, and may displace katipo if its population density increases further.

- Dune revegetation projects should include increased planting of native sand-binding shrubs like *Coprosma acerosa* and *Pimelea arenaria*, in addition to spinifex and pingao. This will increase available katipo habitat, and coincidentally improve the conservation of these native shrubs.

- The exotic sand-binding plant marram is unsuitable for katipo webs even at low densities, and as this plant also displaces native sand-binders and alters the shape and mobility of sand-dunes, replacement of marram is desirable, particularly in key katipo conservation areas.

- Further incursions of redbacks, *L. hasselti*, need to be prevented so that it does not re-establish, and threaten katipo populations via genetic swamping. Redbacks do have the potential to disperse here naturally via ballooning, but it seems that these events are rare, and less likely than accidental importation.

- More research on katipo is needed. Suggested avenues for further research include the investigation of alternative ACO designs, the success rates of ballooning dispersal in katipo, and rates and causes of mortality in juvenile katipo. The population dynamics of katipo in other regions should be studied, as climatic and habitat differences may affect the length of the breeding season and mortality rates.

Conclusions

Coastal dune ecosystems as a whole are neglected in New Zealand, in terms of conservation and research attention. Habitat loss and degradation has been identified as a key cause of katipo population decline, thus habitat restoration will be a key step in conserving katipo. As many other coastal specialist species are also endangered or in decline, a whole-system conservation approach appears to be the most suitable way forward. The impacts of introduced plant and animal species need to be addressed in addition to current revegetation projects.

Most invertebrates, particularly spiders, are unappreciated and even reviled by members of the public. Katipo have a worse reputation than most, due to the unsubstantiated belief that they are aggressive killers. Although they deserve to be treated with caution, katipo are far from dangerous. Increasing the level of public education on the shy nature and beauty of this species is needed in order to reverse their negative image.