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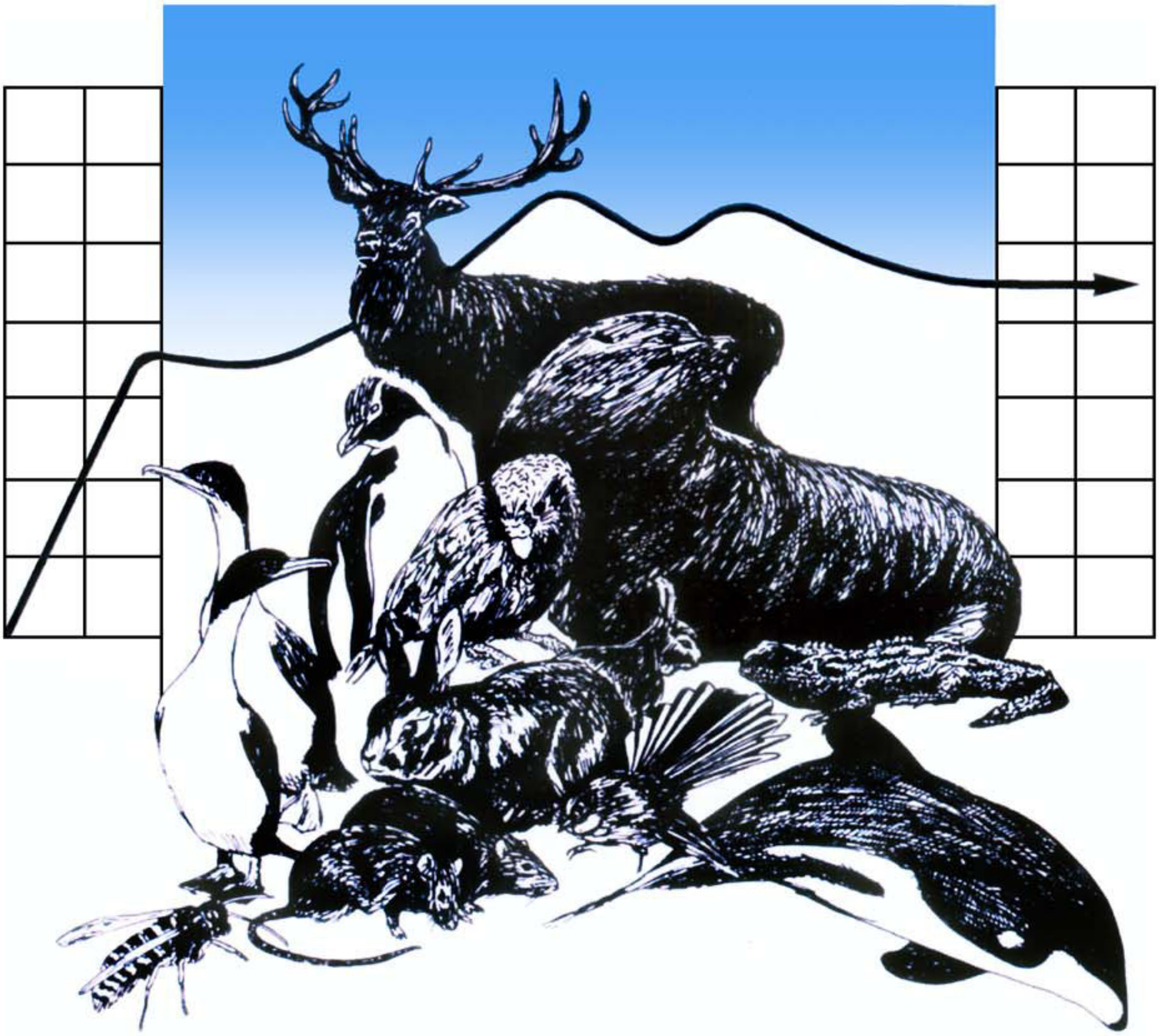

WILDLIFE MANAGEMENT

An investigation into the abundance and ecological impact of Australian redback spiders (Latrodectus hasseltii) within and around the Cromwell Chafer Beetle Nature Reserve, Central Otago.

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Executive Summary

Australian redback spiders (*Latrodectus hasseltii*) are an internationally invasive, opportunistic predator that threatens the survival of native species in New Zealand as well as human health and safety. They were initially recorded in Central Otago in 1981 and were observed to be predating the endemic, nationally endangered Cromwell chafer beetle (*Prodontria lewisii*) in the Cromwell Chafer Beetle Nature Reserve (CCBNR) in 2012. Due to the latter observation this study was designed to sample the redback spider population within the reserve and its immediate surrounds, to evaluate the effect the spiders were having on both the Cromwell chafer beetle and the reserve community in general.

Back-to-back strip transects were performed in late October, 2013, in order to obtain an initial population estimate of redback spiders. This was followed by five weeks of monitoring web occupants, condition and prey caught. Strip transects were repeated in mid December, 2013, to evaluate any changes in the distribution and size of the redback spider population. Artificial cover objects were placed around the perimeter of the reserve to obtain presence/absence data outside the reserve fence line.

The redback spider population within the CCNBR appeared to migrate in a north easterly direction between October and December, the reason for this is unknown and further study is recommended. Investigation of prey size selectivity of redback webs is also recommended in order to assess the relative effect redback spider predation is having on different species within the community. It is suggested that the initial oviposition period for redback spiders in the CCBNR occurs in early spring, though the majority of egg sacs are laid in December. The initial mating period was estimated to be between November 12 and 26. A positive correlation was found between the number of egg sacs and number of prey items in webs. Along with other evidence, this indicates prey storing behaviour among redback spiders. It is strongly recommended further investigation be carried out into this, as it may mean predation rates increase as soon as oviposition begins in the Spring.

It is roughly estimated that redback spiders are removing less than 4 % of the Cromwell chafer beetle population per annum. However, without further population statistics the true effect this has, and will have on the species in the future is unable to be calculated. The reproductive stage at which the female beetles are being killed is also vital for estimating the influence redback spider predation has on Cromwell chafer beetle natality. Research is required into the effect redback spider predation has upon eggs within the beetle's body, in order to elucidate the effect redback spiders have on Cromwell chafer beetle natality.

Excluding the Cromwell chafer beetle, nine of the 26 prey species recorded in redback spider webs were confirmed New Zealand natives. One of which was the McCann's skink (*Oligosoma maccanni*), which is the first record of skink predation by redback spiders in New Zealand. Corrugated iron was shown to be appropriate material for artificial cover objects for redback spiders, and it is recommended these are used to survey redback numbers between in October and November and left in place for more than two weeks in Central Otago.

1 Introduction and background information

1.1 Australian redback spiders, *Latrodectus hasseltii* Thorell 1870 (Araneae: Theridiidae)

The Australian redback spider (henceforth referred to as redback spider) has successfully established populations in many countries across the globe including Japan, New Guinea and Belgium. It was initially recorded beyond border security in New Zealand in 1981 - 1982 in Central Otago, South Island, and has subsequently established populations there and in New Plymouth in the North Island (Vink et al. 2011).

Redback spiders are notoriously known as part of the venomous black widow (*Latrodectus*) genus (Garb et al. 2004). While death from envenomation is extremely uncommon, symptoms may still be severe in some patients with effects including hypertension, tachycardia, nausea and vomiting (Graudins et al. 2001). Redback spiders therefore pose a threat to human health and safety wherever they colonise, particularly as they are often associated with anthropogenic environments (Matsuse et al. 1997, Nihei et al. 2004).

Such close association with human activity is widely believed to be part of the reason redback spiders and other *Latrodectus* species are such effective colonisers (Jennings & McDaniel 1988; Forster & Kavale 1989; Matsuse et al. 1997; Garb et al. 2004; Nihei et al. 2004; Vink et al. 2011). Although capable of 'ballooning' (where juvenile spiders drift in air currents using a short piece of silk), redback spiders are dependent on anthropogenic assistance for rapid, long - distance dispersal (Nihei et al. 2004). This is apparent in New Zealand as between 1981 and 2009, 54 incidences of post-border redback spider detections were reported (Vink et al. 2011). As the species prefers to inhabit arid climates, it is also suggested they utilise human structures in order to construct webs in sheltered spaces, away from extreme weather (Matsuse et al. 1999; Nihei et al. 2004), especially rain (Vink et al. 2011).

Despite being closely related, the redback spider presents a conservation threat to the New Zealand endemic, *Latrodectus katipo* (Garb et al. 2004). The katipo spider is currently considered in "serious decline" under the New Zealand Threat Classification System (Hitchmough et al. 2005), largely due to anthropogenic development and degradation of its restricted coastal sand dune habitat (Patrick 2002). In addition to this, female katipo spiders have been shown to breed with male redback spiders in the laboratory. Any colonisation of redbacks in katipo territory could therefore result in interbreeding and introgression of the katipo, leading to a loss of the latter species (Garb et al. 2004).

The redback spider is a generalist predator and will eat anything that is small enough to become entangled in its web (Vink et al. 2011). In its native country Australia this has even included prey as large as skinks (Raven 1990; Metcalfe & Ridgeway 2013). In New Zealand, prey recorded caught in redback spider webs includes *Prodontria modesta*, *Mimopeus* sp. and *Odontria* spp. (Vink et al. 2011). While none had been recorded in redback spider webs at the time of publishing, Vink and colleagues (2011) suggested that the nationally endangered Cromwell chafer beetle (*Prodontria lewisii*) was also vulnerable to predation, due to similar habitat and species characteristics to the aforementioned prey.

1.2 The Cromwell chafer beetle, *Prodontria lewisii* Broun 1904 (Coleoptera: Scarabaeidae)

The Cromwell chafer beetle is a nocturnal, flightless scarab beetle that lives in the sands of the Cromwell Chafer Beetle Nature Reserve (CCBNR). Adults emerge to feed, mate and lay eggs during the spring and summer months, with mean activity dates of October 23 (± 26.67 days) for males and November 12 (± 23.30 days) for females (Ferriera & McKinlay 1999). Larvae have been successfully raised through to adults in the lab, though external triggers for development remain unknown (Barratt et al. 2011).

The Cromwell chafer beetle is one of 16 *Prodontria* species and the only one which is formally protected under the Wildlife Act 1953 (Barratt 2007). It is endemic to New Zealand and is classified as nationally endangered by the New Zealand Threat Classification System (Ferriera et al. 1999; Hitchmough et al. 2005). The only available population estimate for the species is 10,000 adult individuals in the central area of the reserve (Figure 1), where the highest population density is believed to be. Although the author of the study admitted this was a tentative estimate at best (Hunt 1998). Barratt (2007) also gives a larval population density for the same central area as being between one and five per square meter.

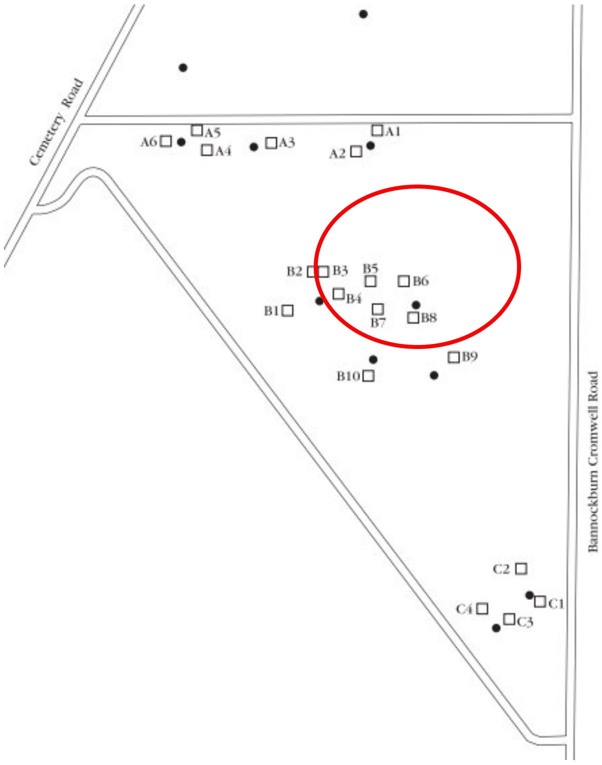

Figure 1: The central sampling area for Cromwell chafer beetles within the Cromwell Chafer Beetle Nature Reserve. Adapted from Ferriera & McKinlay 1999.

Threats to the survival of the Cromwell chafer beetle species are their extremely limited distribution and the degradation of habitat within this by rabbits (*Oryctolagus cuniculus*) and invasive plant species (Barratt 2007). They are also preyed upon at a low rate by little owls (*Athene noctua*), a high rate by hedgehogs (*Erinaceus europaeus*) and may be preyed upon in the future by mice (*Mus musculus*; Brignall-Theyer 1998).

Cromwell chafer beetle larvae are sampled annually in the aforementioned central are of the CCBNR (see Barratt et al. 2013). While the presence of redback spiders within the reserve has been previously acknowledged, during the annual chafer beetle sampling in 2012 a number of redback webs containing numerous chafer beetle cadavers were discovered. This was cause for concern as such predation had not been observed previously, and the extent of the predation effect on the chafer beetle population was unknown (Barratt B., AgResearch, pers. comm.).

This study was designed to investigate the extent of redback spider predation within and in the immediate surrounds of the CCBNR, with a focus on the demographics of chafer beetles being captured, but also a wider interest on any detrimental effects redback spiders may be having on the invertebrate community within the reserve. In addition, the effectiveness of corrugated iron Artificial Cover Objects (ACOs) was investigated both within and outside the reserve.

2 Methods

2.1 Study site

The Cromwell Chafer Beetle Nature Reserve was gazetted in 1983 for the primary purpose of protecting the Cromwell chafer beetle (Barratt 2007). It is located between the townships of Cromwell and Bannockburn in Central Otago, South Island of New Zealand (42°02'S, 169°12'E, 81 ha, 216 m a.s.l.) and consists of sand dunes comprised of Molyneaux very shallow loamy sand and Cromwell sand (McKinlay 1997). The vegetation in the reserve has been described as five main communities, which consist of 37 species, *Anthoxanthum odoratum* (sweet vernal grass), *Rumex acetosella* (sheep's sorrel) and *Trifolium arvense* (haresfoot or rabbitfoot clover) being the most common at the most recent survey in 1997 (Ferriera & McKinlay 2000). The reserve is currently protected from introduced pests such as possums and stoats by traps around the perimeter, though a breeding rabbit population remains within the reserve boundary (pers. obs.).

2.2 Survey and monitoring

2.2.1 Within the reserve

From October 21 to October 30, 2013, strip transects with a width of 20 m, zero metres apart, were run the length of the reserve to establish an initial population estimate of redback spiders and clear all webs of prey cadavers (this process will be henceforth referred to as the "initial clearance"). The distance between transects was chosen to enable the surveyor to clearly see (and thus thoroughly search) the entire area between transect lines. The only times transect intervals were altered was when an increase in 'tall' vegetation (above approximately 10 cm) decreased visibility of rabbit holes (where the majority of redback spider webs were constructed). In such situations the distance between transects was decreased as required. Surveys were performed between 0700 and 1700 hours in fine weather (sun or cloudy). While there was no rain during this period, transects were cancelled twice due to strong winds.

Half of the total population was subsequently chosen by random number generation to be monitored for five weeks. Each week the prey that was caught in the web or discarded nearby (at the base of, or below the web) was collected and recorded, in addition to recording any changes in the inhabitants or condition of the web. Occupants of the web were either noted as unchanged, translocated, abandoned, or additional (such as if a male was found on a female's web). Translocated individuals were recorded when a new web with a spider matching the original spider's description (unique markings, sex and age given time elapsed between monitoring periods) was found within a 15 m radius of the original web. This distance was deemed to be an appropriate size to record any short - range relocations while remaining temporally feasible. Webs were classified as abandoned when the original web was fully intact but lacking occupants and the aforementioned new web could not be located. Webs were considered destroyed if damage had been caused to the internal structure. Care was taken to not disturb the internal structure of the web (where the spider was usually hiding) during the initial clearance and monitoring so as to disrupt the behaviour of the spider as little as possible.

After five weeks of monitoring the initial clearance process was repeated from December 9 - 18, 2013, in order to evaluate how the distribution and the population of redback spiders had changed (this will henceforth be referred to as the "final clearance"). As many prey cadavers were interwoven into the web itself, webs were often completely destroyed during the final clearance in order to uncover the maximum number of individual prey items.

2.2.2 Outside the reserve

ACOs were constructed from forty pieces of corrugated iron, measuring approximately 40 x 40 cm. These were placed outside of the CCBNR: 27 were placed 25 m from the fence line and 13 were placed between 9 m and 20 m from the fence line due to property or terrain restrictions. Two ACOs (#10 and #11) had to be placed on the fence line due to the area outside of the reserve being continually disrupted by construction vehicles. While these two ACOs could not provide information about the redback population beyond the reserve, the area in which they were placed did not have any recorded webs nearby. Therefore the occupancy rates of such ACOs could still provide information regarding suitable habitat within the reserve. It was intended to place all ACOs 110 m apart in order to equally space them around the reserve. However in practice this varied by ± 5 m, and two gaps between four ACOs varied by ± 20 m due to property constraints.

2.3 Data analysis

Welch two-sample t tests in R software were used to calculate all statistically significant differences. In the same software the Pearson correlation coefficient was used to determine the relationship between the number of prey items and number of egg sacs in a web. Welch two-sample t tests were also used to determine significant differences between the number of prey items in webs with different numbers of egg sacs.

Interpretation and mapping of GPS data was completed on QGIS Desktop 2.0.1 software.

Detection rate was calculated by the equation M/((W*P)/100). Where M was the number of webs that were being monitored (which were certainly intact prior to the final clearance), which were also recorded in the final clearance, W was the total number of webs known to be intact at the conclusion of monitoring, P was the average percentage of web persistence each week (the number of spiders which neither abandoned nor moved their web). The number of remaining webs was multiplied by the average web persistence to obtain an estimate of how many webs should have been recorded during the final clearance if detection rate was 100 %. This number was divided by 100 to obtain 1 %, which the actual recorded number was then divided by.

3 Results

3.1 Initial clearance of webs

A total of 218 webs were found, 209 of which were occupied. In these, 218 spiders were recorded, giving an average of 1.04 spiders per web. With the calculated detection rate of 61.0 % from the equation 43/((76*0.9282)/100), the estimated redback spider population during the initial clearance period was 357 spiders, or 4.41 spiders per hectare. The population consisted of 60.1 % juveniles and while only one adult male was identified it is expected some of the juveniles were male and not identified as such. A total of 15 egg sacs was found in eight different webs spread throughout the reserve. The most egg sacs were found in web S3, located 300 m from Bannockburn road along the northern fence line (Fig. 1).

The inhabited webs showed a clumped distribution in the northeast and centre of the reserve, with webs also spread throughout the southern corner (Figure 2). The northern corner of the reserve was relatively devoid of webs, with only one abandoned web found above S 45.057881.

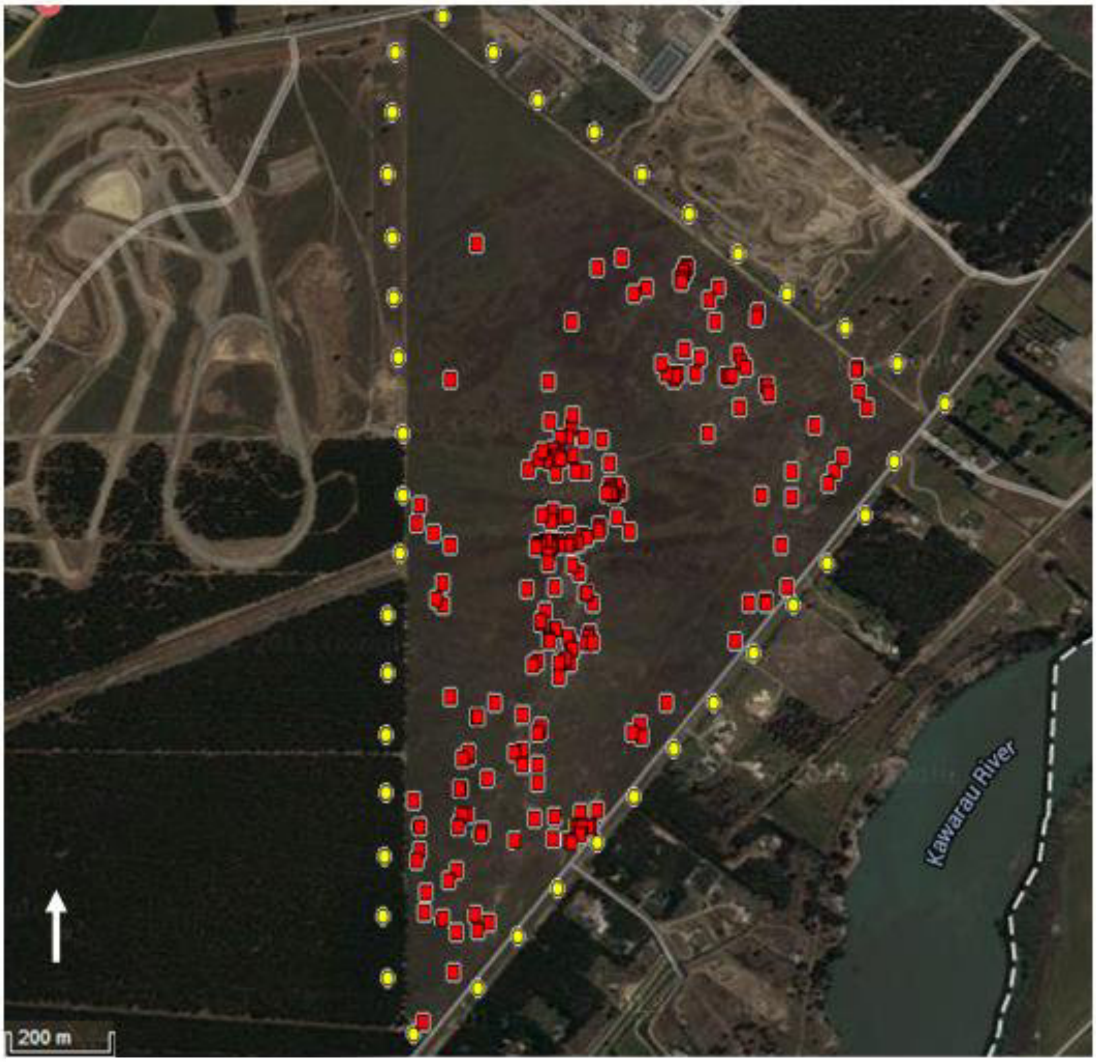

Figure 2: Distribution of redback spider webs (red squares) and ACOs (yellow dots) within and surrounding the CCBNR from October 21 - 31, 2013.

A total of thirteen species were found in the redback spider webs, the most common of which was darkling beetles (*Mimopeous* sp. cf. *otagoensis*), followed by Cromwell chafer beetles (Figure 3). The chafer beetles found consisted of 16 males, 13 females and 24 carcasses where the gender was indistinguishable. These were recorded from webs spread throughout the reserve, though the majority were contained in webs S71 (occupied) and A7 (abandoned), in the centre and southern corner of the reserve respectively.

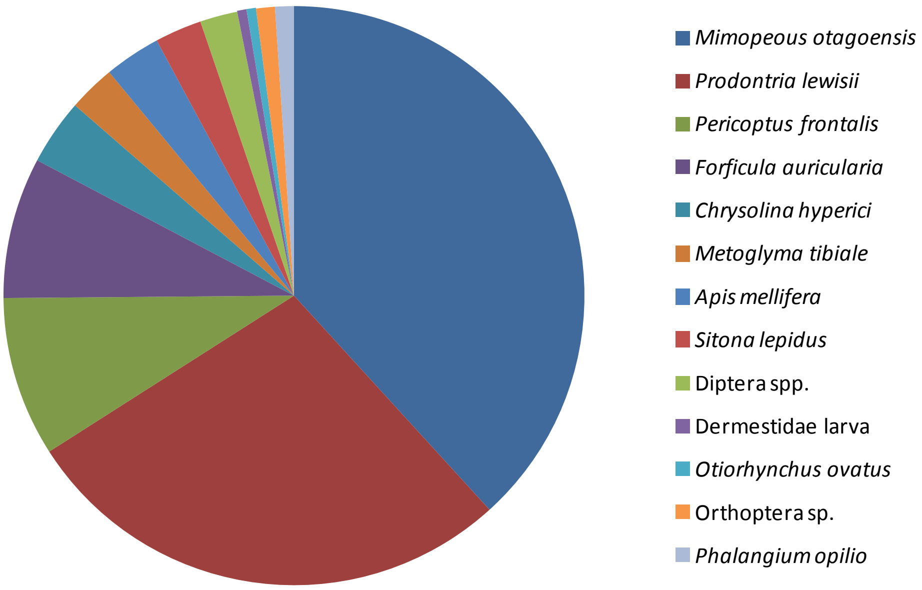

Figure 3: Composition of prey species collected from occupied redback spider webs during initial clearance (October 21 - 30, 2013).

3.2 Monitoring within the reserve

After five weeks monitoring, 19 webs had been abandoned and 14 had translocated, giving an average of 3.8 webs abandoned and 2.7 translocated per week. Only one web was recorded as destroyed, the spider of which was not found to be relocated and thus presumed deceased. One juvenile female spider in its last instar was found deceased in a web, though the reason for this was not apparent. The majority of damage sustained to webs in the reserve was caused by severe wind and rain, and rabbit activity. The majority of redback spider webs were found in disused rabbit burrows. Three webs were observed constructed around the base of vegetation after approximately two weeks of dry weather.

Seven female Cromwell chafer beetles were found with mature eggs in their ovaries when they were collected. Two were found in webs S81 and S90, week one of monitoring, both of which are within the central sampling area for Cromwell chafer beetles. The remaining five were found during the final clearance (December 12 and 13) in webs 69, 72, 78 and 83 which are also located in the central area of the reserve. All six webs were occupied with redback spiders at the time of collection.

A male bias was recorded in chafer beetle cadavers during the five weeks of monitoring, though there was a general increase in both male and female cadavers found over the period, with a distinct decline in male cadavers in the final week of monitoring (Figure 4).

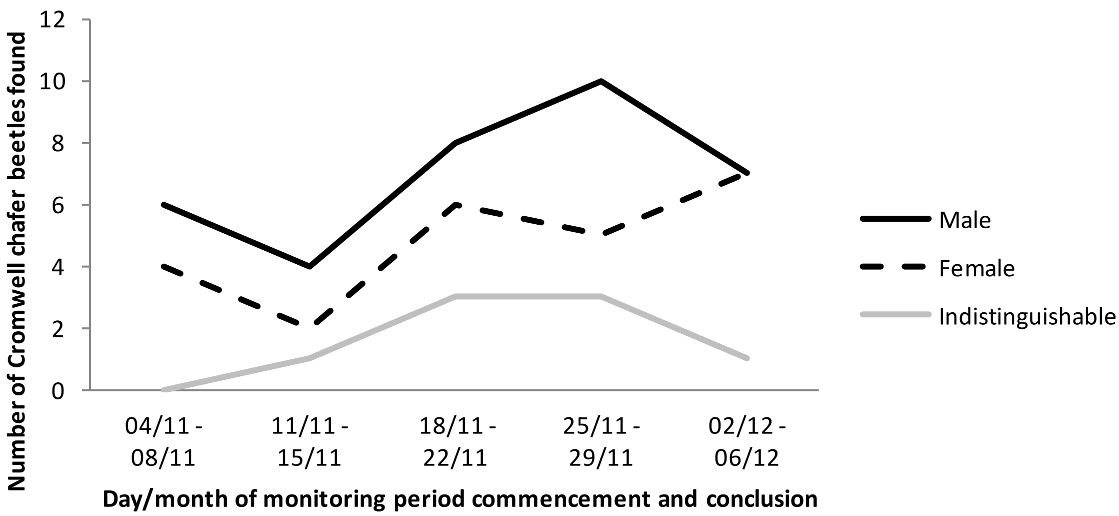

Figure 4: The number of male, female, and adults of undetermined gender Cromwell chafer beetle carcasses found in redback spider webs within the Cromwell Chafer Beetle Reserve from November 4 to December 6, 2013.

There were eight recorded instances of males visiting females on their webs; one in week two (November 12), five in week three (November 18 and 19) and two in week four (November 25 and 26). Two adult females were also recorded sharing their web with other adult females.

3.3 Monitoring outside the reserve

Only two ACOs were found to be inhabited after two weeks. One (#40) had been displaced by the owner of the property it was placed adjacent to, so it was lying flat on the ground, and an adult McCann's skink (*Oligosoma maccanni*) was found sheltering beneath it. An adult female redback spider had made a small web beneath ACO 14, which was located on gravel substrate on an industrial property to the west of the reserve (Figure 5). One ACO was stolen within a few days of being placed.

Figure 5: An adult female redback spider (*Latrodectus hasseltii*) was found beneath ACO 14; located to the West of the Cromwell Chafer Beetle Reserve, 25 metres from the fence line.

3.4 Final clearance of webs

During the second transect survey of the reserve (December 9 - 19) 274 webs were recorded, of which only 115 were occupied with 127 spiders. Given the detection rate, this provides a population estimate of 205 spiders. Juveniles comprised 18.3 % and males 4.72% of the population.

From the inhabited webs, 22 identifiable prey species were recorded in addition to five specimens that were too disfigured to make an identification. Darkling beetles were again the most numerous prey species, followed by Cromwell chafer beetles and *Pyronota* sp. (Figure 6).

Of prey retrieved from unoccupied webs, the most common prey item remained darkling beetles, while the second and third most common species are *Pyronota sp.* and Cromwell chafer beetles respectively. A full list of species and numbers of individuals recorded in unoccupied redback webs during the final clearance can be found in Appendix One.

For all surveys, a total of 212 Cromwell chafer beetles were collected from occupied webs: 116 males, 91 females and 5 indistinguishable cadavers. Both the numbers of males and females were higher than those recorded in the initial clearance (Figure 7). From abandoned webs 26 male, 28 female and 12 indistinguishable Cromwell chafer beetles were collected.

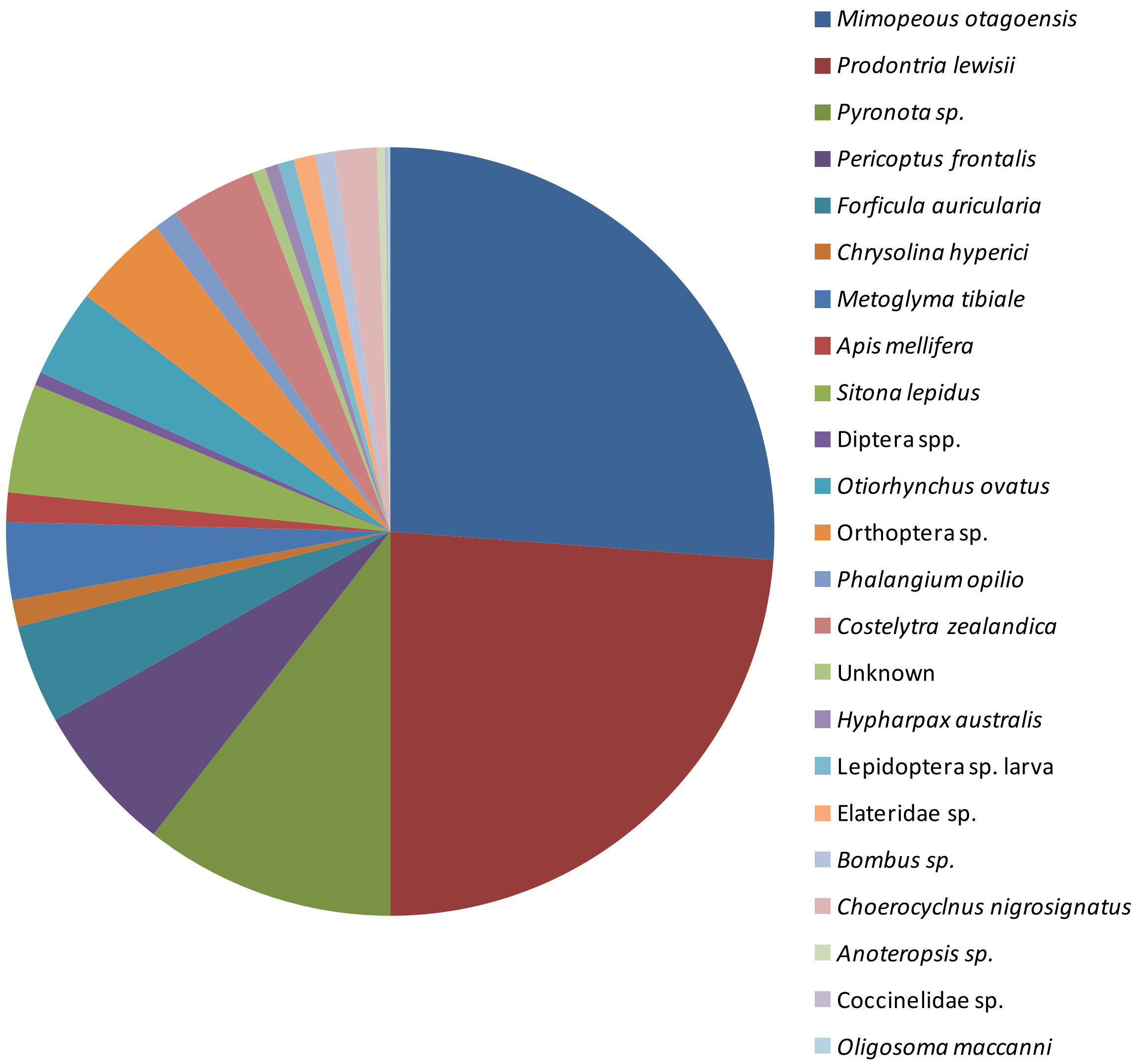

Figure 6: Composition of prey species found in occupied redback spider webs during the final clearance, December 9 - 18, 2013.

The overall distribution of redback spider webs followed a similar pattern to the initial clearance in the central area of the reserve. However, many more spider webs were found along the northern fence line and less were found in the southern corner.

Figure 7: The numbers of male, female, and cadavers with an indistinguishable sex recorded in occupied redback spider webs during intial web clearance (October 21 to Oct 30, 2013) and final web clearance (December 9 to December 18, 2013).

Some significant differences in number of prey items collected from the webs were found in relation to the numbers of egg sacs found in redback spider webs (Figure 8). Seven out of eight differences which were not significant involved webs with four or seven eggs.

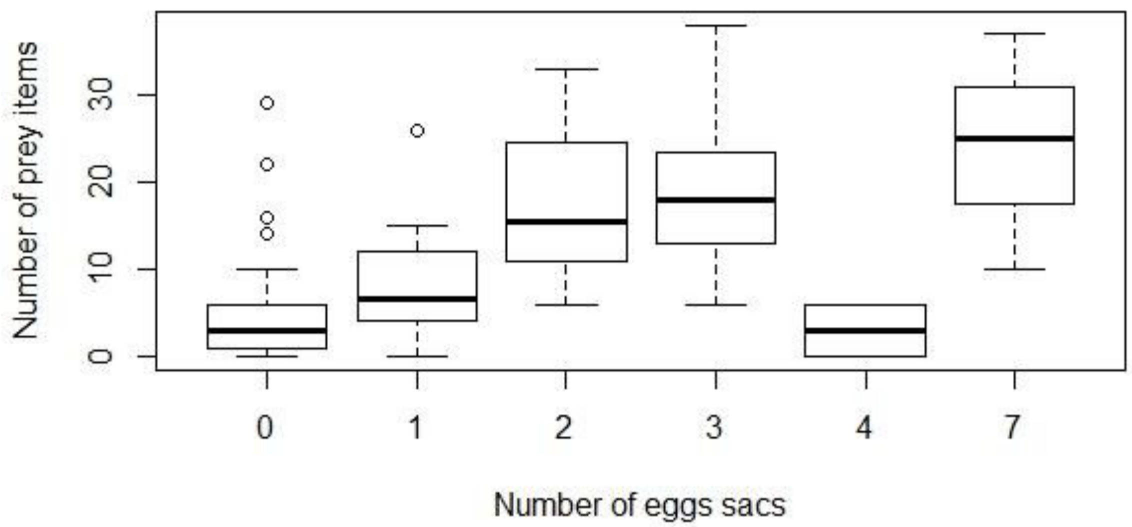

Figure 8: A comparison between number of egg sacs and number of prey items found in redback spider webs within the CCBNR between Dec 9 - 18, 2013.

A significant difference was found between the overall number of prey items in webs with and without egg sacs from the final clearance ($p < 0.05$, $df = 30.8$, CI = -6.02, -0.209). In addition to significantly more egg sacs being recorded in the final clearance than the initial clearance ($p < 0.05$, $df = 202$, CI = -0.545, -0.210). A Pearson's correlation coefficient of 0.567 was calculated for the relationship between egg sac and prey item numbers present in a web.

Significantly more juveniles were found to be present in the redback spider population during the initial clearance than the final clearance ($p < 0.05$, $df = 310$, CI = -0.513, -0.324).

4 Discussion

4.1 Redback spider web distribution

From both the initial and final clearances of redback spider webs it is clear there is an aggregation of redback spiders in the central area of the reserve where it has been shown there is the highest population density of Cromwell chafer beetles (Figure 1). This is obviously a concern for the future survival of the latter species, already at risk from habitat loss. Despite the lack of any strong relationship being found between Cromwell chafer beetle larvae distribution and substrate type (Barratt 2007), there may be other extraneous variables (such as the sand dunes) attracting both species to the central area of the reserve, which requires further investigation. There is also a redback spider population to the northeast of the central population, and scattered webs in the southern corner of the reserve. These webs may be constructed around lower density Cromwell chafer beetle populations, populations of other prey species within the reserve, or other unknown variables.

Between October and December the redback spider population appeared to move in a north easterly direction. This may either be showing the spiders in the reserve moving in this direction for some reason, or it shows spiders immigrating into the CCBNR from the land to the northeast and spiders in the south of the reserve simply dying off. The former scenario is deemed more likely, as if there was a population close to the northeast fence line it would be expected that this would have been shown by spiders colonising the ACOs placed there. Why the population of spiders would move in a north easterly direction is currently unknown and warrants further study. The cause may be related to temporal variation in prey abundance.

While redback spiders are opportunistic predators, Hódar and Sánchez-Piñero (2002) found that prey ranging from 12.5 - 22.5 mm in length were more likely to be captured in webs of *Latrodectus liliane*. It is possible that this is the case also within the CCBNR, as three of the most commonly caught invertebrates (*Mimopeous otagoensis, Prodontria lewisii, Pericoptus frontalis)* were also the three largest species: the majority being between 10 and 20 mm long. Of course this size selectivity would only apply to adult webs as juvenile webs are thinner and thus would not be strong enough to catch prey as large as the adult webs do. The size selectivity of redback spider webs would be a useful investigation to assist in the assessment of the effect the spiders are having on different invertebrate species, and is recommended for future projects.

4.2 Redback spider population demographics

Significantly more juveniles being present in the redback spider population in October than December indicates that the initial oviposition period for redback spiders occurs in early Spring. In Western Australia it has been recorded that spiderlings fail to hatch at 9 °C, but those which hatched at higher temperatures withstood up to 56 days at 7 - 9 C° (Downes 1986). The average temperature for Cromwell in October 2013 was 11.7 °C and the mean high was 17.8 °C (NIWA 2013a). Spiderlings must have hatched during a period of warm days, though it is expected redback spiders may have adapted to the colder climate of Central Otago as temperatures were often below 7 °C at night (average low being 5.6 °C). This is particularly evident given many of the juveniles recorded were at least in their third instar which means they must have hatched around 20 days prior to the commencement of the study (Downes 1986). The adaptation to a colder climate may be physiological or behavioural, the latter having many possibilities such as spinning thicker webs or obtaining protein ice nucleators from prey (such as Tanaka 2001).

While more spiderlings were recorded earlier in the study, significantly more egg sacs recorded later in the study (during the final clearance) indicates the main oviposition period began in December. This is consistent with the average temperature for December being higher at 16.4 °C (NIWA 2013b)

While no copulations were sighted, adult males recorded on adult female webs occurred between November 12 and 26, with the majority in the middle of this period. This may indicate the initial mating period for the summer season. It is expected there would be further mating periods later in the season as male spiderlings mature. If any biological control involving prohibition of mating were to occur, it would be suggested to be implemented prior to this period.

4.3 Prey storing behaviour

During week three (November 18 - 22) of web monitoring two incidences occurred of what appeared to be prey storing. The adult females from webs S143 and S160 abandoned and translocated their webs respectively, both leaving behind one egg sac wrapped in silk, debris and prey cadavers. The bundle from S143 contained three *Pericoptus frontalis* and three darkling beetles, with all of the former and one of the latter intact (had not been eaten by the adult spider). Prey included in the bundle of S160 were two darkling beetles and two grasshoppers. One of the darkling beetles and both grasshoppers had not been entirely consumed but whether they had been partially eaten or had degraded in the sun was unclear.

Previous records for such behaviour in *Latrodectus hasseltii* could not be located, and storing food at all is rare in invertebrates (Champion de Crespigny et al. 2001). However, food storing that does occur is primarily related to providing for future offspring and is more common in spider species that have long-term webs and wrap food in silk for later ingestion (Champion de Crespigny et al. 2001): the current situation fits both criteria.

The Pearson's correlation coefficient for egg sac number and prey item number in webs of 0.567 indicates a positive relationship between the two variables. In addition, the difference between the number of prey items in webs with and without egg sacs was statistically significant. These both indicate food storing behaviour, which could mean increased predation rates in the reserve not just when the juvenile spiders leave their mother's web and start catching prey themselves, but from the moment the egg sac is produced. It is recommended this matter be investigated further with a larger sample size of webs that contain a large number of egg sacs. It is believed the sample sizes were insufficient to produce any statistically significant results with webs with four and seven egg sacs. In addition, data on webs with five and six egg sacs would add valuable information.

4.4 Cromwell chafer beetle population characteristics

It was anticipated that Cromwell chafer beetle cadavers may have a male bias, as males of related species often have a relatively high activity rate due to actively searching for females with which to mate (Barratt B., AgReaserch, pers. comm.). This hypothesis seems to be supported by the data, with more males than females being recorded in abandoned and occupied webs during the initial clearance (though this was not statistically significant), throughout the first four weeks of monitoring and in occupied webs during the final clearance. During the fifth week of monitoring the numbers of each sex were equal, and abandoned webs during the final clearance contained two more females than males. The sudden decline in male cadavers found in week 5 of monitoring (Figure 4) may be explained by males having an earlier mean activity date than females (Ferriera & McKinlay 1999). Thus, while males may move about more than females while they are active, their period of activity might conclude earlier in the season than that of females.

In addition to 53 Cromwell chafer beetles being captured prior to the commencement of the study (recorded in the initial clearance), over the five weeks of monitoring and two weeks of final clearance, 346 Cromwell chafer beetles were captured and killed in redback spider webs within the CCBNR. The latter equates to 49.4 chafer beetles being killed every week. These seven weeks were equivalent to the last of the 11 mean weeks which Cromwell chafer beetles were active in 1999 (Ferriera & McKinlay 1999), and while the cadavers recorded in the initial clearance cannot be dated, it may assumed many of them were captured in the four weeks prior to the commencement of the study. An exact weekly number of chafer beetles caught is not possible from this study as some of the cadavers recorded during the final clearance may have been caught in previous weeks (or even the previous summer season) and simply well hidden, so as not to have been discovered until the web was destroyed and examined in detail.

If the total number of chafer beetles recorded in this study is the majority of annual predation, this would mean less than 4 % of the total population is removed due to redback spiders on an annual basis (using Hunt's population estimate of 10,000 beetles in the central survey area; 1998). Unfortunately a population viability analysis may not be completed without a recovery factor, maximum population growth rate and (ideally) a more recent population estimate of adult beetles. However, it is unlikely a removal rate of less than 4 % per annum will have a large effect on a species with such a short life cycle. This will be additional to other sources of mortality such as predation from hedgehogs and degradation of habitat.

The reproductive stage at which female Cromwell chafer beetles are being captured must also be considered. As chafer beetles only lay one batch of eggs in their lifetime, if all female beetles were captured before they had a chance to lay eggs then the redback spiders would be negatively affecting the natality in addition to the mortality rate. While only seven beetles were actually found carrying eggs, the temporally patchy distribution of these being recorded suggests this is not a true representation of those which were caught in webs while carrying eggs. It is likely that the redback spiders will consume eggs along with other organs of the body when they feed on the chafer beetles. Thus those beetles recorded with eggs may be an underrepresentation of the actual number caught while carrying eggs. It is recommended the effect of spider poison and consumption on eggs being carried within the Cromwell chafer beetle body be investigated in order to accurately estimate the effect of redback spider predation on female beetle fecundity.

4.5 Other prey captured

Only nine of the 26 other species discovered in redback spider webs within the CCBNR were confirmed native to New Zealand. In fact, some species such as *Forficula auricularia* are considered pests within the reserve (Barratt B., AgResearch, pers. comm.). Therefore the redback spiders may actually be helping to control pest species' populations within the reserve. However, three of the most common species found in the webs (*Mimopeous otagoensis, Prodontria lewisii, Pericoptus frontalis*) are endemic, and thus the benefit the redback spiders are having on the CCBNR community is likely outweighed by the detrimental effect they are having on the native invertebrates and vertebrates alike.

Considering redback spiders have been recorded predating on small reptiles in both Australia and Spain (Raven 1990; Hódar & Sánchez-Piñero 2002; Metcalfe & Ridgeway 2013), it was unsurprising to find sub-adult skinks (approximately just over one year old) that had been consumed by redback spiders in the CCBNR. However, the consequences of this for New Zealand's native reptiles could be significant. While the McCann's skink is not a threatened species, it is already affected by predation from other species throughout its range (Lettink et al. 2010). There are also threatened skinks in the same region that redback spiders are colonizing. For example, the grand skink, *Oligosoma grande*, originates from tussock grasslands of Central Otago and is currently considered Nationally Endangered to Nationally Critical by the New Zealand Threat Classification System (Eifler & Eifler 1999; Hitchmough et al. 2005).

It is expected that skinks will have a higher risk of predation than geckos given their preference for living on rocky outcrops (Berry et al. 2005), as redback spiders prefer to build their webs in sheltered environs. This was observed in the CCBNR as all skinks were found in webs that were built in old rabbit holes in a rocky substrate, not sand. However, even though geckos may lead a largely arboreal lifestyle (Jusufi et al. 2008), if the vegetation in which they are living is in a sheltered area redback spiders may build webs within it, or at the base of the plant. Consequently, many of New Zealand's lizards may be at risk of predation from the redback spider if it continues to successfully spread to other parts of the country.

4.6 Redback spiders outside the reserve

Anecdotal evidence from residents suggests redback spiders have a very patchy distribution outside the reserve. This may be because only some properties provide the appropriate structures within which a web could be built (such as old building materials, unused machinery), or only certain residents' activities lead them to come into contact with the webs. On the south eastern side of the reserve only one resident reported having seen redback spiders, though this one resident claimed they were prolific. Workers on the construction property to the west of the reserve claimed they had not seen any redback spiders, though this would be unlikely as their daily activities involved working in large vehicles, not looking under rocks or the like.

The only case of a redback spider inhabiting an ACO was within the construction property. The ACO was placed approximately 50 m away from a pile of old tires and a rubbish heap, and it is expected there may be more spiders living within this refuse. The presence of this spider confirmed that metal ACOs are an attractive environment for redback spiders and that the spiders may inhabit them within two weeks during warm weather. It is suggested that more spiders may have colonised the ACOs if they were placed earlier in the season (when many of the juvenile spiders were dispersing) and left in place for longer. The lack of ACO colonisation in front of the residential properties may not necessarily indicate that there are no spiders present on these properties, but that the spiders may have been at the rear of the property (too far away to find the ACO in two weeks) or have a well established web and thus did not disperse within the two weeks.

It is suggested that corrugated iron ACOs be used in the future for locating redback spider populations, though they should be left out for more than two weeks, during October or November when used in Central Otago. These months appeared to contain the most juvenile dispersal within the CCBNR.

5 Conclusion

The redback spider population within the CCNBR appeared to migrate in a north easterly direction between October and December, the reason for this is unknown and further study is recommended. As three of the main species caught in redback spider webs were also three of the largest species caught, investigation of prey size selectivity of redback webs is also recommended in order to assess the relative effect redback spider predation is having on different species within the CCBNR community.

As initial oviposition is believed to have occurred in early spring, it is suggested that redback spiders in Central Otago have a lower temperature threshold for hatching than their Australian counterparts. The majority of oviposition is expected to occur in December, two or three weeks after the initial mating period.

A positive correlation was found between the number of egg sacs and number of prey items in webs. Along with other evidence, this may show prey storing behaviour among redback spiders. It is strongly recommended further investigation be carried out into this, as it may mean predation rates increase as soon as oviposition begins in the spring.

A male bias of Cromwell chafer beetles cadavers was found in the majority of data recorded. The remaining data showed a decline in male capture rates towards mid December, which possibly reflects the discrepancy between mean activity dates for male and female beetles.

It is roughly estimated that redback spiders removed less than 4 % of the Cromwell chafer beetle population from October - December 2013 if Hunt's (1998) estimate of the chafer beetle population in the central reserve area is used. However, without further population statistics the true effect this has, and will have on the species in the future is unable to be calculated. The reproductive stage at which the female beetles are being killed is also vital for estimating the influence redback spider predation has on Cromwell chafer beetle natality. Research is required into the effect redback spider predation has on fecundity in female beetles, in order to elucidate the effect spider predation is having upon Cromwell chafer beetle reproduction.

Excluding the Cromwell chafer beetle, nine of the 26 prey species recorded in redback spider webs were confirmed New Zealand natives. One of which was the McCann's skink, which is the first record of skink predation by redback spiders in New Zealand. This may have significant implications for the survival of more endangered species of lizard such as the grand skink.

Corrugated iron was shown to be appropriate material for ACOs for redback spiders, and it is recommended, when used for redback spiders in Central Otago, these are placed between October and November and left in place for more than two weeks.

Redback spiders are obviously common throughout the reserve, which appears to be facilitated by the numerous rabbit holes in which they can construct sheltered webs. Despite their abundance, the impact the spiders are having on the Cromwell chafer beetle may not be too severe at present. Their population does remain a threat to both the Cromwell chafer beetle and other native species in the area, particularly if they continue spreading throughout Central Otago.

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Appendix One

Species of prey recorded in redback spider webs from October 21 - December 18, 2013.

Order	Family	Scientific name	Common name	Number found in abandoned webs from December 9 - 18, 2013 (final clearance).
Coleoptera	Tenebrionidae	*Mimopeous* sp. cf. *otagoensis* Bates	Darkling beetle	403
Coleoptera	Scarabaeidae	*Pyronota* sp.	Manuka beetle	73
Coleoptera	Scarabaeidae	*Prodontria lewisii* Broun	Cromwell Chafer beetle	66
Coleoptera	Scarabaeidae	*Pericoptus* sp.		61
Dermaptera	Forficulidae	*Forficula auricularia* L.	European earwig	53
Coleoptera	Curculionidae	*Otiorhynchus ovatus* L.	Strawberry weevil	49
Coleoptera	Curculionidae	*Sitona lepidus* Gyllenhal	weevil	26
Opiliones	Phalangiidae	*Phalangium opilio*	Harvestmen	24
Hemiptera	Heteroptera	*Choerocydnus nigrosignatus* White		22
Orthoptera	Acrididae	Orthoptera sp.	Grasshopper	19
Hymenoptera	Apidae	*Bombus* sp.	Bumble bee	17
Coleoptera	Chrysomelidae	*Chrysolina hyperici* (Forster)	St Johnswort beetle	16
Coleoptera	Carabidae	*Metoglymma tibiale* Cast.		13
Coleoptera	Scarabaeidae	*Costelytra zealandica* (White)	Grassgrub	13
Hymenoptera	Apidae	*Apis mellifera* L.	Honey bee	11
Isopoda		Oniscidea sp.	Woodlouse	11
		Unknown		7
Coleoptera	Carabidae	*Hypharpax australis* (Dejean)		4
Coleoptera	Elateridae	sp.		4
Lepidoptera		spp.		2
Squamata	Scincidae	*Oligosoma maccanni*	Maccann's skink	3
Araneae	Lycosidae	*Anoteropsis* sp.	Wolf spider	3
Diptera		spp.	Fly	3
Coleoptera	Dermistidae	sp.		
Coleoptera	Coccinelidae	sp.	Ladybird	
Coleoptera	Curculionidae	*Irenimus* sp. Broun		
Hymenoptera		spp.		

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Figure 3: The central sampling area for Cromwell chafer beetles within the Cromwell Chafer Beetle Nature Reserve. Adapted from Ferriera & McKinlay 1999.

Figure 4: Distribution of redback spider webs (red squares) and ACOs (yellow dots) within and surrounding the CCBNR from October 21 - 31, 2013.

Figure 3: Composition of prey species collected from occupied redback spider webs during initial clearance.

Figure 4: The number of male, female, and adults of undetermined gender Cromwell chafer beetle carcasses found in redback spider webs within the Cromwell Chafer Beetle Reserve from November 4 to December 6, 2013.

Figure 5: An adult female redback spider (*Latrodectus hasseltii*) was found beneath ACO 14; located to the West of the Cromwell Chafer Beetle Reserve, 25 metres from the fence line.

Figure 6: Composition of prey species found in occupied redback spider webs during the final clearance, December 9 - 18, 2013.

Figure 7: The numbers of male, female, and cadavers with an indistinguishable sex recorded in occupied redback spider webs during intial web clearance (October 21 to Oct 30, 2013) and final web clearance (December 9 to December 18, 2013).

Figure 8: A comparison between number of egg sacs and number of prey items found in redback spider webs within the CCBNR between Dec 9 - 18, 2013.