OPTIMISING SPIDER SURVEY TECHNIQUES

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Abstract

Spiders have important ecological roles as generalist predators and bioindicators of environmental health but are poorly studied. To determine spider diversity and abundance, the most commonly used techniques for surveying spiders are pitfall trapping and hand collection, however, each technique has sampling bias as they target different vegetative strata and therefore different spider species. Furthermore, these survey techniques are often time consuming or are primarily used for capturing other arthropods with spiders as secondary capture. A new survey technique based on vibration to attract a wide diversity of spiders was tested. The hypothesis tested was that the vibration-based technique would produce a greater diversity of spider species and a greater species richness quicker than pitfall trapping and hand collection, and thus improve survey techniques for spiders to improve conservation management strategies.

This research (1) compared the two mostly commonly used survey techniques with a new vibration-based survey technique to compare the diversity of spider species captured and time required to undertake each technique; (2) explored the relationship between spider species captured over time in pitfall traps, night collection and from use of the vibration-based technique; (3) provided a species list of spiders in open dry sclerophyll woodland in south-east Queensland; and (4) provided information to expand the limited literature on survey techniques for spiders.

In four locations eight similar 900 m^2 sites in open dry sclerophyll woodland were used; four sites (A) incorporated use of pitfall traps, hand collection and the vibration-based technique, and in four adjacent sites (B) only the vibration-based technique was used to collect spiders. These sites were 30 x 30 m and situated on the property

Stewartdale, in south-east Queensland. The 900 m^2 area was used to conduct nocturnal hand collection for an hour once a fortnight, for three consecutive fortnights. Six pitfall traps were placed at each of four sites, outside of the 900 m^2 area, 5 m apart in two rows, starting at the back corner of the site. These pitfall traps were emptied every fortnight on the day of the night spider collections. The spider survey using vibration involved placing an idling John Deere tractor, for one hour, in a clearing at the front of each of the eight sites and collecting spiders attracted to the tractor.

The pitfall traps were left open during this hour and spiders collected. There were 34 families, 138 genera and 226 species identified. Night collections caught a greater species diversity and richness than pitfall traps and vibration. The vibration-based technique in sites A and B had no significant difference in species diversity and species richness. The pitfall traps left open for six weeks had a greater species diversity than the pitfall traps left open for one hour with the vibration-based technique. Collection of spiders using the night collection and vibration-based techniques were very similar in efficiency and overall material cost. Of all the spider species, 80% were captured during night collection and would be the best technique to use to define the species diversity of an area. As night collection and vibration-based technique are similar in efficiency and overall material cost, it would be recommended to use this technique in conjunction with vibration-based technique as there were species captured during the vibration-based technique that were not captured in night collection. Further research is needed into refining the vibration-based technique in terms of frequency output and portability.

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List of Abbreviations

DR1 – David’s Ridge 1 (study location)

DR2 – David’s Ridge 2 (study location)

RH – Rachael’s Hill (study location)

RL – Robert’s Lane (study location)

Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature: _[redacted]

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Chapter 1: Introduction

1.1 Background

Spiders are important and abundant generalist predators in most ecosystems and have been shown to be good bioindicators of environmental health (Burwell et al. 2010; Pompozzi et al. 2019). Spiders are classified under the class Arachnida and more specifically under the order Araneae (Brunetta 2010).

Spiders have two main body parts, eight legs, typically eight simple eyes (some may have six, four, two or none), “jaws” adapted for prey capture, pedipalps, abdominal spinnerets, and an anterior abdominal genital opening (Figure 1.1) (Murray 2018). The two main body parts of a spider are the cephalothorax (combined head and thorax) and an abdomen that are joined by a thin pedicel (Figure 1.1) (Murray 2018). The cephalothorax has a hard outer cuticular plate (carapace), mouth parts (chelicerae), the simple eyes, pedipalps (which in males serve as intromittent sperm transfer organs) and four pairs of legs (Foelix 1982; Murray 2018). The abdomen contains the heart, book lungs, gut, spinnerets and many spiders also have one or two tracheal spiracles (secondary breathing organ), and females have a genital opening (Figure 1.1) (Murray 2018). Different anatomical features of spiders (e.g., the number of eyes, number of spinnerets, and relative lengths of different legs) are used to identify their species (Foelix 2011).

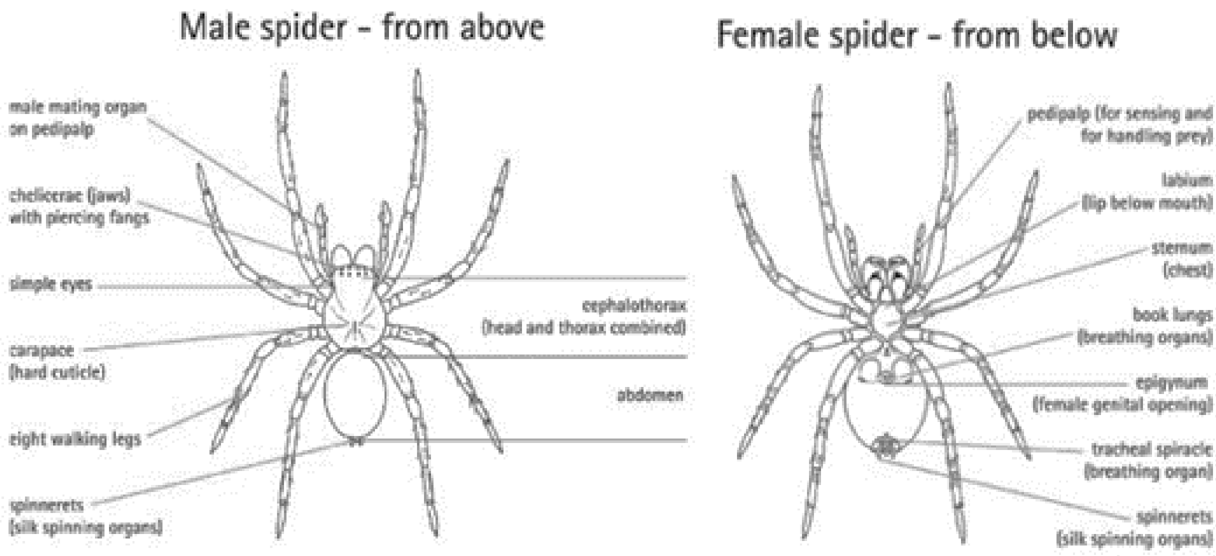

Figure 1.1 - Standard diagram of a spider's external anatomy showing dorsal view of a typical male spider and ventral view of a typical female spider. Taken from Murray (2018).

Spiders are highly diverse in Australia with approximately 86 families with 3,917 species in 679 genera classified; however, it was estimated that there are actually about 8,500 species in 850 genera in Australia (Framenau et al. 2014). This vast diversity has allowed spiders to evolve specific niches to their environment and can be a used as a bioindicator of the health status of their ecosystem (Pearce & Venier 2006).

1.2 Purpose of research

Techniques currently used to survey spiders include pitfall traps, Berlese funnel sampling, hand collection (during the day and at night), malaise traps and sweeping (Churchill & Arthur 1999). Pitfall traps and hand collection are the most commonly used and reliable survey techniques when surveying solely for spiders as they are more likely to yield more spiders than other techniques (Churchill & Arthur 1999; Kapoor 2006; Cardoso et al. 2008; Cardoso et al. 2011; Thomas et al. 2011; Hancock

& Legg 2012; Bali et al. 2019). Berlese funnel sampling, malaise traps and sweeping are commonly used in conjunction with surveying other arthropods as they are more likely to capture other arthropods than spiders (Churchill & Arthur 1999). A new survey technique involving vibration is emerging that could potentially reduce the time required and increase efficiency in sampling spiders to determine their diversity and species richness, and to evaluate the environmental health of the area surveyed.

1.3 Thesis outline

Chapter 2 is a review of the literature that discusses why spiders are important and the different survey techniques currently used for spiders, including their strengths and limitations. Vibration is also discussed as a possible new survey technique. Chapter 3 is a description of the materials and techniques used in this research. The results from the research are given in Chapter 4, and Chapter 5 is a discussion of these results in relation to previous knowledge of spider survey techniques, the role vibration-based surveys have and further research required. Appendices 1 is a species list of all spiders found from this research and their presence across the different sites and from the different survey techniques.

Chapter 2: Literature Review

2.1 Ecological importance of spiders

Spiders are very ecologically important as generalist predators (New 2005; Milano et al. 2021). Their diversity, abundance, biomass, evolutionary history, and functional roles make spiders one of the most important terrestrial invertebrate orders (Milano et al. 2021). Spiders are predators of both an array of invertebrates and on occasion small mammals and reptiles; and prey for amphibians, birds, mammals, and reptiles (Pearce & Venier 2006; Nyffeler & Birkhofer 2017). Spiders are estimated to regulate insect populations by consuming 400 to 800 million metric tonnes of fresh live weight each year (Nyffeler & Birkhofer 2017). In most locations where spiders are present, they are high in diversity and abundance and thus are able to fulfill various ecological niches and exhibit high microhabitat endemicity (New 2005; Pearce & Venier 2006; Milano et al. 2021). In these locations there is an estimated abundance of 50 to 150 individual spiders per square meter, and they can periodically reach more than 1,000 individuals per square meter in northern Europe (Nyffeler 1982; Marc et al. 1999; Nyffeler & Birkhofer 2017).

Spiders have been found to be an excellent bioindicator when measuring the sustainability of an environment for conservation management (Pearce & Venier 2006; Nogueira & Pinto-da-Rocha 2016). Bioindicators reflect the health of an ecosystem when monitored, by acting as early indicators of stress or taxonomic diversity (Schwerdt et al. 2018). Bioindicators are extremely beneficial for monitoring the recovery of an environment in response to conservation management decisions and can be used to prioritise conservation efforts by means of spatial comparisons of site values (Schwerdt et al. 2018). High sensitivity to environmental changes such as vegetation complexity, litter depth and microclimate characteristics means that spiders are valuable animals to provide information on the quality and health of the environment (Schwerdt et al. 2018; Kim et al. 2020). Their high sensitivity as bioindicators is due to a high diversity of spiders that fill a range of environmental niches dependent on vegetation structure (Pearce & Venier 2006; Nogueira & Pinto-da-Rocha 2016).

Three broad classes of bioindicators include environmental, ecological and biodiversity (Pearce & Venier 2006). Species that predict the presence or absence of other species are recognised as biodiversity indicators (Pearce & Venier 2006). Changes in the environment which can be measured directly are reflected by the species as an environmental indicator (Pearce & Venier 2006). Ecological indicators represent a functional change or effect of an environmental change which can include keystone species, dominant species, sensitive species, or those that reflect disturbance (Pearce & Venier 2006). Ecological indicators are important for interpreting the impact a change of the environment has and can help identify factors that place pressure on an ecosystem (Pearce & Venier 2006). Spiders are classified as an ecological indicator due to their high habitat specificity and community composition. Spider diversity is directly influenced by habitat structure and prey abundance and thus are sensitive to changes in either factor (Uetz 1991; Willett 2001; Nogueira & Pinto-da-Rocha 2016).

Currently, there is little data on Australian spider species as a bioindicator. However, studies conducted elsewhere in the world highlight just how spiders can be a useful bioindicator. For example a survey in Uruguay found that the spider *Allocosa brasiliensis* was an indicative species for healthy environments that included dunes with psammophilic vegetation along the coastline (Ghione et al. 2013). Spider presence was positively correlated with vegetation such as *Panicum racemosum*, *Senecio crassiflorus* and *Hydrocotyle bonariensis* which are considered dune-forming species as well as absent in areas that were affected by urbanisation or a reduction of sand dunes (Ghione et al. 2013). Spiders have also been used as a bioindicator of heavy metal concentrations within the environment (Otter et al. 2013). One study focused on sampling spiders from within a site that had the largest coal ash spill in US history and a reference site without any spills (Otter et al. 2013). They found that selenium concentrations in spiders were significantly higher in ash-affected sites than those from reference sites (Otter et al. 2013). Ascertaining information on which spider species to have as a bioindicator for different environmental conditions in Australia will first need an improvement in spider survey techniques.

Spider surveys can be easier and more cost effective when sampled by pitfall trapping, the primary survey technique for terrestrial arthropods (Schwerdt et al. 2018). However, pitfall trapping targets only a few species of spiders and is not indicative of true spider abundance and diversity of an area (Churchill & Arthur 1999; Kapoor 2006; Thomas et al. 2011; Hancock & Legg 2012; Bali et al. 2019). Hand collection, Berlese funnel sampling, malaise traps and sweeping are other survey techniques for spiders to estimate species richness and abundance (Churchill & Arthur 1999; Scott 2001; Jud & Schmidt-Entling 2008; Oxbrough et al. 2010; Seldon & Beggs 2010; Cardoso et al. 2011; Thomas et al. 2011; Spafford & Lortie 2013; Brown & Matthews 2016). These collection techniques have more disadvantages and biases than advantages when sampling. I posit that, as it is important to survey spiders, vibration as a new spider survey technique has the potential to best reflect the diversity of an area or environment in a quick and easy manner. The strengths and limitations of the current spider survey techniques will be discussed in the following sections and an explanation of why a vibration-based survey technique for spiders may be an improvement is given in section 2.2.6.

2.2 Different survey techniques

The diversity and abundance of organisms in an area is usually determined from sampling that area through the use of different survey techniques, or a combination of them. Currently, a range of survey techniques are used when sampling spider fauna to obtain useful data both ecologically and statistically (Churchill & Arthur 1999). Different sampling techniques for spiders can result in a sampling bias across taxa via targeting specific behaviours of spiders or vegetative structure (Churchill & Arthur 1999; Norris 1999; Kapoor 2006) (Table 2.1). A summary of these properties that can lead to biases with each technique is given in Table 2.1. A number of traditional survey techniques - pitfall traps, hand collection both diurnally and nocturnally, Berlese funnel sampling, malaise traps and sweeping - are utilised for surveying invertebrates including arachnids (Churchill & Arthur 1999; Burwell et al. 2010; Oxbrough et al. 2010). These techniques will be described in the following sections. A new technique to target a wider range of spider fauna in a more time efficient manner, than traditional techniques, by sending vibration through the ground to attract spiders to a central location where they can be collected will be described in section 2.2.6.

Table 2.1 - Summary of the traditional techniques used to collect spiders and their properties, such as targeted spider fauna, cost, labour and time.

Survey Technique	OH&S	Labour	Cost	Time Frame	Spider Diversity	Expertise	References
Pitfall traps	Minimal	Intensive intervals	~$5 per trap	Months	Terrestrial	Minimal	Merrett & Snazell (1983); Brown & Matthews (2016).
Hand/ Night Collection	Has risk	Intensive	Head torch	Hours across many nights	Most species	Location and capturing	Cardoso et al. (2011); Bali et al. (2019).
Malaise Traps	Minimal	Initial setup	Expensive	Weeks	Restricted	Specialised	Oxbrough et al. (2010)
Berlese Funnel	Minimal	Minimal	Expensive	Days	Terrestrial	Minimal	Thomas et al. (2011)
Sweeping	Has risk	Intensive	Nets	Hours across days	Arboreal	Requires skill	Churchill & Arthur (1999)

2.2.1 Pitfall traps

Pitfall traps are the most commonly used sampling technique for small ground-active fauna and more specifically, arthropods (Hore & Uniyal 2008; Brown & Matthews 2016). A pitfall trap is a trapping pit that is usually composed of a container sunk into the ground with the top of the container flush with the soil level (Figure 2.1) (Churchill & Arthur 1999; Seldon & Beggs 2010). Small animals travelling across the ground fall into the trap and are unable to escape (Schirmel et al. 2010). This sampling technique can provide an 'activity-density' estimation whereby the activity of species and density of the population sampled is reflected through the abundance found in each pitfall trap (Brown & Matthews 2016). Pitfall traps are useful for determining species richness and distribution to ascertain biodiversity information as spiders caught in pitfall traps are found to have strong spatial and temporal patterns (Churchill & Arthur 1999; Hore &

Uniyal 2008; Brown & Matthews 2016). However, pitfall traps are not reliable in determining species density (Brown & Matthews 2016).

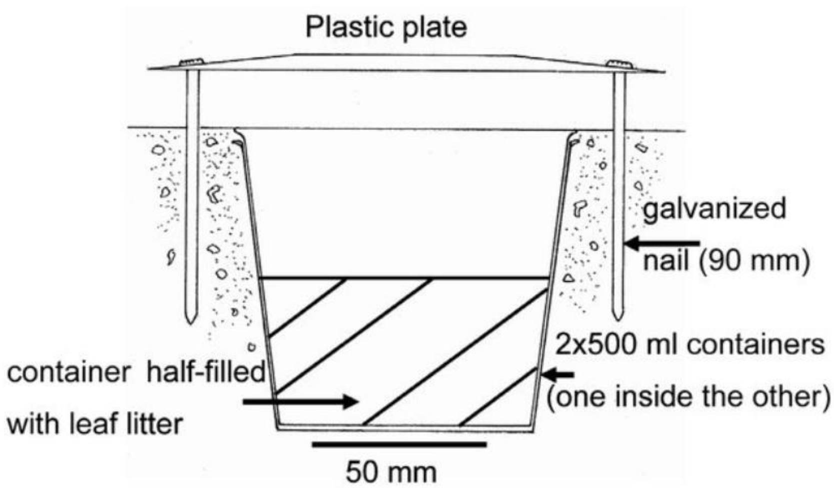

Figure 2.1 - An example of a pitfall trap flush with the ground surface. Either leaf litter is placed inside the container for shelter of trapped invertebrates, or a small amount of preservative can be placed inside the container. Taken from Seldon & Beggs (2010).

Pitfall traps are built using materials such as plastic, metal, and glass; each affecting the rate of capture and retention of captured specimens if preservatives inside the trap aren't used (Brown & Matthews 2016). Out of these materials, plastic containers are favoured because of their ease of accessibility, and they are light weight, cost-effective, and are less fragile than glass (Brown & Matthews 2016). Unlike glass, plastic containers also allow the use of more complex designed pitfall traps, for example, with funnels or lids (Brown & Matthews 2016). A rain guard is placed over a pitfall trap to limit debris from wind entering the pitfall traps, as well as reducing flooding of the trap during rainfall (Buchholz & Hannig 2009; Brown & Matthews 2016). Rain guards or covers over pitfall traps do not have a significant effect on the rate of capture or trapping efficiency (Buchholz & Hannig 2009). For 'killing pitfall traps', different types of fluid are used including formalin, 70% ethanol, ethylene glycol and propylene glycol (Jud & Schmidt-Entling 2008). While formalin is useful for preserving spiders epigynes and pedipalps for identification process, the evaporation rate of formalin is 2% per day (similar to water) so under field conditions, it evaporates leaving specimens to dry (Jud & Schmidt-Entling 2008). Similar results were seen with 70% ethanol (Jud & Schmidt-Entling 2008). Propylene glycol and ethylene glycol had very similar performance in preservation of specimens and capture rates but take much longer to evaporate. However, ethylene glycol is harmful to non-targeted wildlife and is classified as a hazard whilst propylene glycol is not harmful to non-targeted wildlife (Jud & Schmidt-Entling 2008).

Pitfall traps are highly affected by the sampling interval at which trapped arthropods are collected and traps replaced (Schirmel et al. 2010). For example in a German grassland pitfall traps left open and arthropods collected weekly (over two months) had a higher capture frequency of spiders than pitfalls collected fortnightly or monthly (over two months) although this varied depending on which taxonomic group of arthropods was studied (Schirmel et al. 2010). This effect is thought to be a result of an increase in CO^2 levels that are released when digging up the soil for the pitfall trap (Joosse & Kapteijn 1968; Schirmel et al. 2010). An increase in CO^2 was found to increase locomotion in ground-dwelling arthropods for the first two days after installation of the pitfall traps, thus, an increased likelihood of pitfall trap capture (Joosse & Kapteijn 1968; Schirmel et al. 2010). When surveying spiders, pitfall traps are often left open for months at a time which can allow other environmental factors to affect capture rates (Churchill & Arthur 1999; Kapoor 2006; Schirmel et al. 2010; Seldon & Beggs 2010; Thomas et al. 2011). These factors include flooding of the pitfall trap (after rainfall), disturbance of the pitfall trap by other fauna, or disturbance from debris left in or on the pitfall trap from wind (Schirmel et al. 2010; Hancock & Legg 2012).

Pitfall traps are not time efficient (i.e., typically left for months in the environment to capture animals) and primarily only target ground-dwelling spiders, however, they are a cost effective and passive trap that is preferentially used to survey spiders (Norris 1999; Hore & Uniyal 2008). Another technique that is preferentially used to capture spiders is hand collection.

2.2.2 Hand collection

Hand collection using the visual search technique for arthropods can be undertaken at day or night. This technique involves the use of collection jars and an aspirator/pooter (Hore & Uniyal 2008; Cardoso et al. 2011). Specifically, for spiders, hand collection is primarily conducted after sunset as most spider species are nocturnal (Cardoso et al. 2011). Hand collection is normally separated into two sections; ground (below knee height) and arboreal (above knee height) (Hore & Uniyal 2008; Cardoso et al. 2011). As it is a visual search, results from this technique can be biased to species easily seen through eye shine or obvious webs (Scott 2001; Kapoor 2006). Other factors such as time taken to collect spiders, and experience and knowledge of microhabitats favoured by specific spider species can also bias results (Scott 2001; Kapoor 2006; Hore & Uniyal 2008). As this technique involves capturing species from both ground and arboreal settings, a wider range of species can be captured including those that may be important indicator species when compared to other techniques such as pitfall traps that typically only capture ground-dwelling spiders (Scott 2001; Kapoor 2006). The use of an aspirator/pooter allows the surveyor to examine smaller spiders without damaging the specimen, and the spiders can be collected alive in a collection vial, if needed (Scott 2001). Hand collection is also species specific and it avoids unnecessary capture of other invertebrates which cannot be excluded by other surveying techniques (Scott 2001). Hand collection and pitfall traps are the most commonly used surveying techniques as they have more advantages than other survey techniques, such as Berlese funnels, malaise traps, and sweeping, discussed in the following sections.

2.2.3 Berlese funnels

Berlese funnels are a sampling technique most commonly used for surveying invertebrates in leaf litter (Sapkota et al. 2012; Yekwayo et al. 2016). This sampling technique targets very specific spider species that are found only in leaf litter; however, it may be unsuccessful in capturing many active species (Thomas et al. 2011; Yekwayo et al. 2016). Portions of leaf litter are collected from the field and transported back to a laboratory where they are placed into a funnel with a heat lamp over the top, and a collection jar below the funnel (Yekwayo et al. 2016). As the leaf litter heats up, invertebrates begin to move away from the heat and into the collection jar below (Figure 2.2) (Yekwayo et al. 2016). The funnel with a heat lamp runs for a number of days (Thomas et al. 2011).

A comparison of Berlese funnels, pitfall traps and the Winkler extraction technique for arthropods indicated that Berlese funnels were the least effective sampling technique for any arthropod taxa, whilst pitfall traps were the most effective (Thomas et al. 2011). They also reported that there was a low occurrence of spiders collected from Berlese funnel sampling that could be due to the heat source used to drive them into the collection jars likely to cause desiccation and death before reaching the collection jar. Spider specimens that are desiccated, are not ideal for identification.

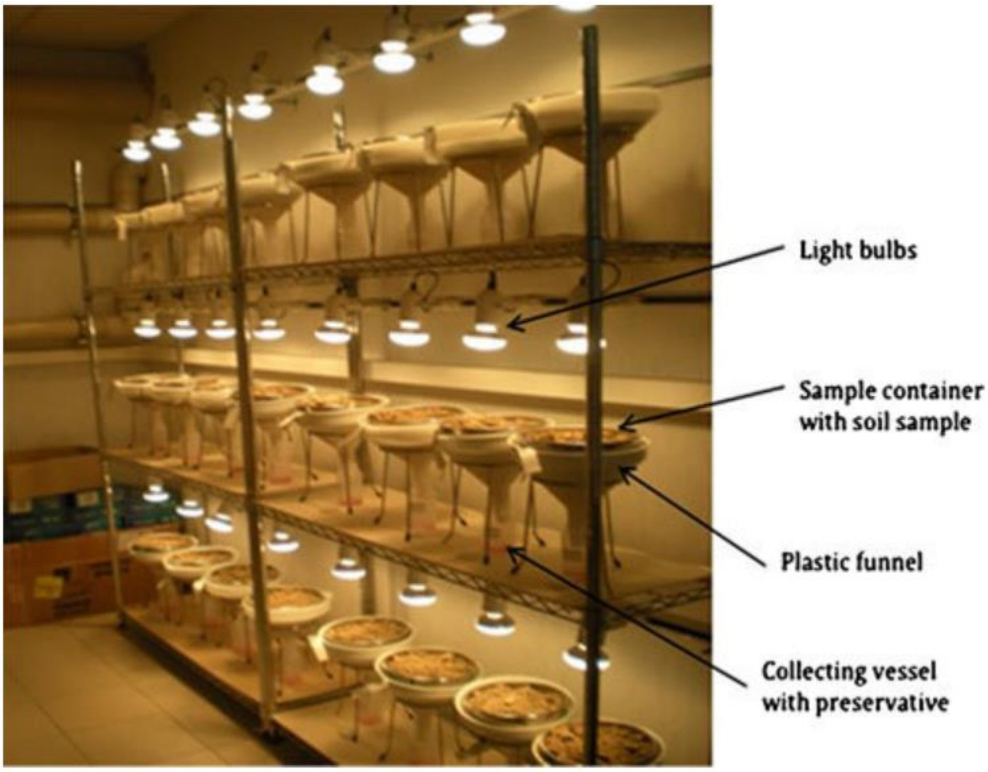

Figure 2.2 - An example of a Berlese funnel setup. It contains the light bulb as the heat source, a sample container with soil sample which is placed over a plastic funnel, and a collection container with preservative. Taken from Sapkot et al. (2012).

2.2.4 Malaise traps

Malaise traps are very efficient traps designed to capture flying insects but can by-capture other invertebrates such as spiders (Figure 2.3) (Oxbrough et al. 2010; Votypka et al. 2019). Insects fly into the black mesh panels and are guided up towards the white coloured roofing where they are then directed into a bottle of 70% ethanol (Ulyshen et al. 2005). Malaise traps were found to have no significant difference in the number of species collected when compared to pitfall traps, but there was a difference in the type of species caught (Oxbrough et al. 2010). Oxbrough et al. (2010) suggested use of this technique for invertebrate biodiversity studies as you were likely to get a different range of species than you would by using pitfall traps. Malaise traps are not cost effective and Oxbrough et al. (2010) suggested that this technique should not be used to solely capture spiders as there are other more cost-effective techniques. Sorting time alone, of the massive insect by-catch, can be counter-productive.

Figure 2.3 - A photograph of a malaise trap. Taken from Votypka et al. (2019).

2.2.5 Sweeping

Sweeping involves the use of a net to capture arthropods in long grass and other vegetation. This technique is preferred for insect surveys as there are higher rates of capture of insects than spiders (Spafford & Lortie 2013). Sweeping in heathland resulted in far less taxa collected when compared to pitfall traps and hand collection in the same landscape (Churchill & Arthur,1999). Complications, such as tearing of the netting on thorns or sharp branches, arose when conducting the survey, leading to problems with the collection of samples (Churchill & Arthur 1999). However, Spafford & Lortie (2013) found this technique to be adequate for collection of spiders in grasslands.

2.2.6 Vibration

Vibration both in air and through substrate plays an important role in a spider's communication with other animals and from their environment (Seo et al. 2020). Vibrations can be used by spiders to identify predators and for prey detection, sexual partners/courtship behaviours, and other behaviours (McConney et al. 2007; Erko et al. 2015). Vibrations are felt through lyriform slit sense organs located on the leg appendages of spiders (Figure 2.4) (Patil et al. 2006; Erko et al. 2015). These organs appear as a cuticle groove that is connected to the spider's nerve ending (Seo et al. 2020). In spiders mechanosensory input, such as vibration, travels through nerve endings at lyriform slits, through interganglionic relays and motor neurons and interpreted by a part of the brain that elicits predatory behaviour (Herberstein et al. 2014). Lyriform organs consist of approximately 144 parallel slit sensilla of which there are around 3,300 different types (Young et al. 2016). Many different morphological arrangements of the lyriform slits occur that allow the spider to respond to differing frequency ranges or respond in a particular direction (Young et al. 2016). A change in any factors including angle between each slit, gradient length, arrangements of the organ on the leg or the connection to the nerve dendrite, and the sensitivity to a particular frequency can alter perception of frequency (Young et al. 2016). Substrate vibrations deflect the tarsus up toward the metatarsus and compress lyriform organs allowing the spider to sense vibrations (Young et al. 2014). Lyriform receptors on the metatarsi and adjacent pads are highly sensitive to vibrations (Foelix 2011).

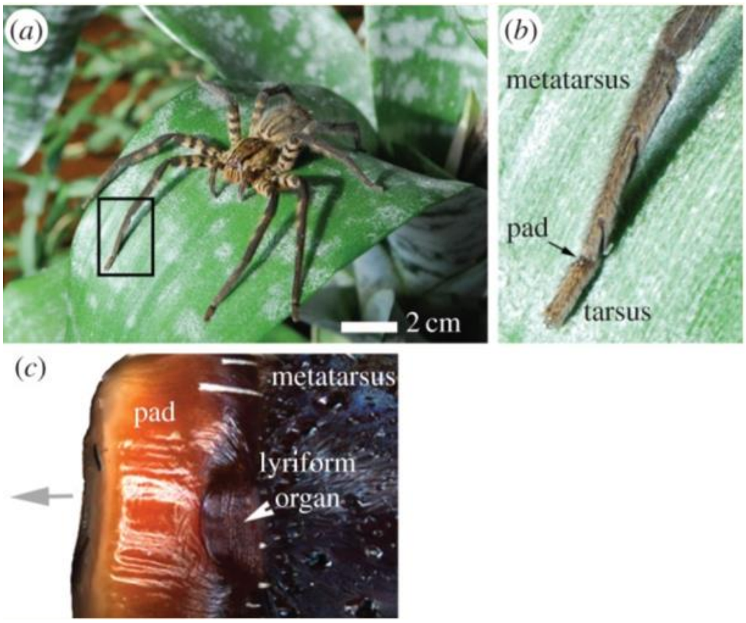

Figure 2.4 - (a) Location of lyriform organs on an adult female spider *Cupiennius salei*. (b) Magnification of last two leg segments; metatarsus and tarsus with a pad located in the joint between the two. (c) Further magnification of the pad with an arrow locating the lyriform organs. Taken from Erko et al. (2015).

A cuticular pad, 100 µm thick, adjacent to the lyriform organs filters background environmental noise vibrations through frequency-dependent damping from viscoelastic properties (Figure 2.4) (McConney et al. 2007). Viscoelasticity is a property of materials that exhibit both viscous and elastic characteristics when stress is applied (McConney et al. 2007). Through the use of surface force spectroscopy (SFS), a mechanical response of the pad's surface was measured against a temperature and frequency gradient (Young et al. 2014). In an adult female *Cupiennius salei*, the surface of the pad had peak viscosity at 20˚C (study temperature range between 15˚C and 40˚C) suggesting high sensitivity to substrate vibrations (Young et al. 2014). This temperature matches that of the natural environment of the arboreal *Cupiennius salei* where the average night-time temperature is 19˚C when they are most active (Young et al. 2014). The viscoelastic properties of the pad decrease the mechanical contact between the pad and tarsus at low frequencies meaning the vibrations are transmitted more efficiently to the lyriform organs at high frequencies (Young et al. 2014). This is because low frequency vibrations are typical of environmental background noise and require a bigger tarsal deflection in order to elicit a neural response (Young et al. 2014). Deflections of the tarsus to elicit this neural response are around 10^{-5} m to 10^{-4} m for vibrational frequencies between 0.1 and 40 Hz. Action potentials are also possible for frequencies above 40 Hz with deflections as small as 10^{-9} m to 10^{-8} m (Young et al. 2014). For a spider to receive the vibratory cues, vibration will travel from the source through the substrate and the environment around them.

As spiders are such a diverse taxa, there are a range of substrates spiders would encounter when receiving vibrations through different media (Barth 1998). An understanding of how various substrates distort, dampen and filter vibrational transmission to the receiving spider is essential (Barth 1998). This transmission through the substrate is represented as particle motion in an elastic body or fluid (Hill 2009). Vibrational transmission through ground substrates such as soil, sand and leaf litter is commonly referred to as Rayleigh waves or bending waves (through green plant matter) (Michelsen et al. 1982; Barth 1998; Elias et al. 2004; Čokl & Millar 2009; Hill 2009). Bending waves are primarily observed in green plant matter and are characterised with longitudinal and transverse components (Michelsen et al. 1982; Čokl & Millar 2009). These components promote higher amplitudes that increase with frequency without depending on the properties of the substrate through which they were transmitted (Čokl & Millar 2009). Rayleigh waves combine the longitudinal and transverse aspects resulting in a marginally lower velocity than that of longitudinal or transverse waves alone but higher velocity than bending waves (Čokl & Millar 2009). Green plant matter act as low pass filters meaning it effectively transmits vibrations below 500 Hz while attenuating vibrations above 500 Hz (Michelsen et al. 1982; Čokl & Millar 2009; Hill 2009). Other substrates in the environment such as leaf litter, sand and rocks can filter and attenuate vibrational frequencies differently (Hebets 2008; Hill 2009). Shape and mass of solids can affect the vibrational properties for example, rock was found to have a high damping coefficient and passed low frequencies due to very low elasticity (Elias et al. 2004). Sand was found to be complex in attenuation due to band-pass properties (attenuating certain frequencies) and vibration transmission is significantly distorted due to particle size and sand composition (Elias et al. 2004). Leaf litter was found to best conduct vibrations as it has the most consistent transmission of frequency (Elias et al. 2004; Hill 2009). Leaf litter was found to have an all-pass filtering characteristic which is favourable for vibration transmission over long distances effectively (Michelsen et al. 1982; Barth 2002; Elias et al. 2004).

The use of ground-based vibration to attract spiders (and other invertebrates) is in preliminary stages as a survey technique. This technique originated from finding many spiders on idling tractors parked in the field for a period of time and over time any idling 'transportable' diesel engine either in a vehicle or transportable was found to attract spiders. This technique has never been scientifically studied and the results published and, more specifically, compared rigorously to other survey techniques. Vibration from a parked idling tractor coupled with other survey techniques such as pitfall traps is also a new technique. However, pitfall trap capture rate has been found to be influenced by disturbance or other ground-based vibration (Joosse & Kapteijn 1968). Ground based vibration has been used to increase capture efficiency with pitfall traps in other invertebrates such as crickets (Orthoptera: Grylloidea) (Joosse & Kapteijn 1968; Sperber et al. 2007). These vibrations were created from walking through leaf litter around the pitfall traps which were thought to trigger a startled jumping response from the crickets (Friedel 1999; Sperber et al. 2007). While it may be a startle response from crickets, spiders may behave differently to exposure to vibration.

Even though the neurobiology of how spiders interpret the vibratory cues is not currently understood, it is thought that the behavioural reaction from a vibration source is elicited from the same part of the brain that controls the predatory response (Foelix 2011). The reaction spiders elicit to the vibration from an idling engine frequency is also currently not understood; however, the use of vibration as a viable survey technique when compared to other techniques such as pitfall traps and nocturnal hand collection is likely to be more time efficient and as it is targeted to spiders and should reduce any by-catch.

2.3 Conclusions

Araneae are a highly diverse order that have specialised anatomical adaptations to fulfill differing environmental niches with an estimate of over 8,500 species in Australia (Framenau et al. 2014). Spiders are an integral part of an ecosystem as predators and prey and can be excellent bioindicators of the health of the ecosystem due to the vast diversity of environmental niches that they inhabit (Uetz 1991; Willett 2001; Pearce & Venier 2006). Survey techniques should give an optimal reflection of the species richness of an ecosystem. Survey techniques for spiders such as pitfall trapping, hand collection, Berlese funnel sampling, Malaise traps, and sweeping are accepted techniques (Churchill & Arthur 1999; Oxbrough et al. 2010; Seldon & Beggs 2010; Cardoso et al. 2011; Brown & Matthews 2016; Yekwayo et al. 2016). Pitfall trapping is the most commonly used and reliable technique but is not quick (requiring weeks) and can by-capture insects (Brown & Matthews 2016). Hand collection is the next most commonly used survey technique for spiders as a range of spiders can usually be captured by looking in different areas (Cardoso et al. 2011). However, hand collection can be biased to height and sight restrictions, as well as the time taken (Cardoso et al. 2011). A new survey technique that involves vibration should be time efficient and does not involve any by-catch of insects. Research into how this technique compares with other more traditionally used techniques is needed.

Chapter 3: Materials and methods

3.1 Study area

The research was undertaken on Stewartdale a 1,200 ha property located 46 km south-west of Brisbane (Figure 3.1). This property is an extension of the Karrawatha Flinders Corridor and has high conservation value for other native Australian species e.g. koalas (*Phascolarctos cinereus*) and quolls (*Dasyurus maculatus*) (Ipswich City Council 2018). Karrawatha Flinders Corridor is a 60 km stretch of open eucalypt forest (ironbark (*Eucalyptus sideroxylon*), grey gum (*Eucalyptus punctata*), and blackbutt (*Eucalyptus pilularis*) being the most dominant species) however more specifically, Stewartdale contains regrowth and remnant dry sclerophyll forest (Ford 2016). In open areas, the property is dominated by grass species such as *Setaria sphacelate* and *Chloris gayana* (Ford 2016).

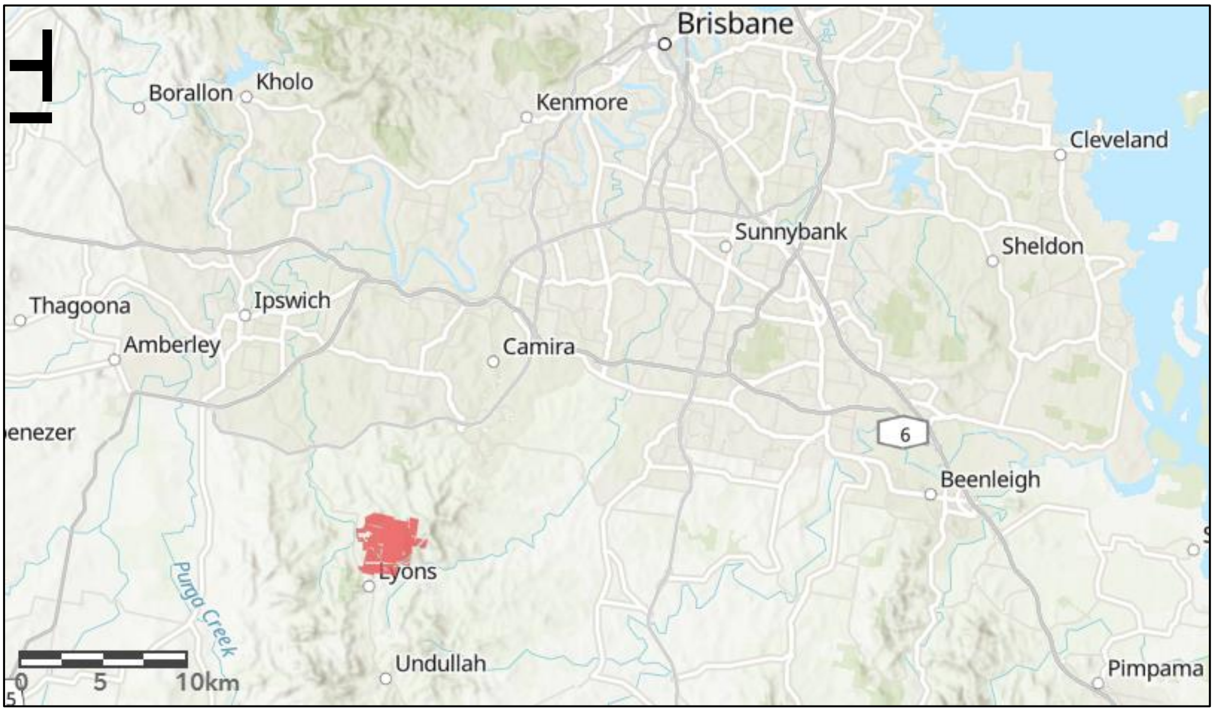

Figure 3.1 - The location of Stewartdale highlighted in red in relation to Brisbane, Queensland, Australia.

3.2 Spider surveys

Surveying for spiders using the different techniques was conducted from 2nd of September to 21st of October 2020. Four pairs of sloping study sites with similar vegetation consisting of regrowth and remnant dry sclerophyll forest with patches of open grassland (Figure 3.2) were used. All eight sites were approximately 30 x 30 m and four of these sites (one from each pair, A) were used for night collections and also had six pitfall traps located at the rear of the site. The pitfall traps were placed outside of the 900 m^2 area, 5 m apart in two rows, starting at the back corner of the site. At the front of all eight sites vibration from an idling tractor was used to attract spiders (Figure 3.3).

Figure 3.2 - The location of four pairs of study sites in Stewartdale consisting of David's Ridge 1, David's Ridge 2, Rachael's Hill, and Robert's Lane.

The use of vibration to attract spiders was the only survey technique used on the other four sites (the other site in each pair, B) on the last day of the six week experiment. The vibration-based technique was conducted after the third fortnightly pitfall and night collections had been completed (Table 3.1). Pairs of sites were studied to determine how many species were missed using traditional techniques (pitfall traps and hand collection) and if the same species (with similar abundance) of spiders were captured just using vibration.

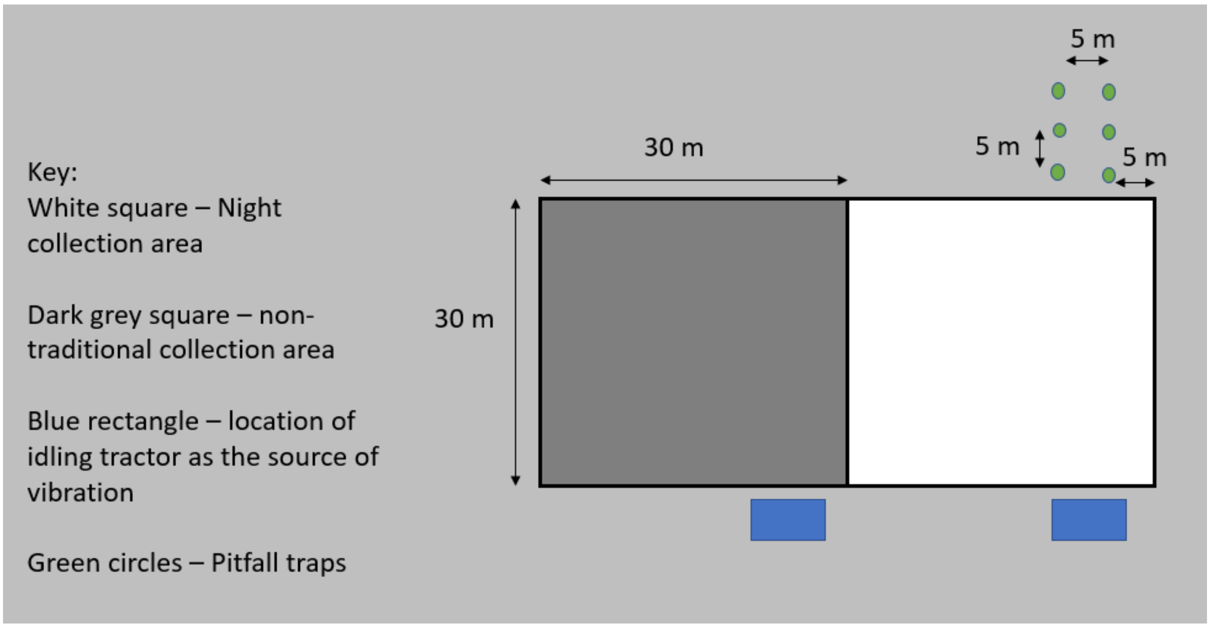

Figure 3.3 - The layout of each site showing the location of the pitfall traps, the area where night collections were undertaken and the location of the idling tractor as the source of vibration. Site A white, site B grey.

3.2.1 Timeline

Pitfall traps were set at the start of the experiment and spiders captured in the pitfall traps collected fortnightly for six weeks (Table 3.1). Night collections of spiders occurred across two nights once a fortnight at about the time the pitfall traps were emptied. Testing of vibration to attract spiders occurred in all sites the day after the last night collection (Table 3.1).

Table 3.1 - The dates of the capture of spiders from pitfall traps, night collections, and attracted to vibration from an idling tractor during 2020.

Date in 2020	Activity
1st September	Four pairs of study sites (each pair had an A and B study site) identified and marked with flagging tape.
2nd September	Pitfall traps were set in the back of the four A sites.
16th September	All pitfall traps were emptied and reset. One hour of night collection of spiders from site A at both David's Ridge 1 and 2.
17th September	One hour of night collection of spiders at both Rachael's Hill and Robert's Lane.
30th September	All pitfall traps were emptied and reset. One hour of night collection of spiders from site A at both David's Ridge 1 and 2.
1st October	One hour of night collection of spiders from site A at both Rachael's Hill and Robert's Lane.
14th October	All pitfall traps were emptied and reset. One hour of night collection of spiders at site A at both David's Ridge 1 and 2.
15th October	One hour during the day of collection of spiders attracted to the vibration from the idling tractor at David's Ridge 1 and 2, sites A and B. One hour of night collection of spiders from site A at Rachael's Hill and Robert's Lane.
16th October	One hour during the day of collection of spiders attracted to the vibration from the idling tractor at Rachael's Hill and Robert's Lane, sites A and B.

3.2.2 Pitfall traps

At each of the four locations, site A in the four pairs of sites, six pitfall traps were set in two lines of three traps, perpendicular to where the vibration technique was tested. Each pitfall trap was 5 m apart (Figure 3.3) and their GPS coordinates recorded. Pitfall traps were set for six weeks and trapped animals removed every fortnight, i.e., a total of 1,008 trap-nights. Each pitfall trap consisted of two cylindrical 600 ml plastic containers with a lid with a 6 cm diameter hole in the centre. 100 ml of propylene glycol was added to each inner plastic container to create a removeable pitfall trap. The tops of the pitfall traps were flush with the surrounding ground. To prevent rain, reptiles, amphibians, or larger mammals from disrupting or entering the pitfall trap, a shelter was made and placed on top of each pitfall trap. This shelter consisted of a face-down plastic plate and three skewers where the skewers were set an equal distance apart in the plate and staked into the ground over the top of the pitfall.

Each time the pitfall traps were emptied, the inner container was removed and the material and propylene glycol poured into a new 600 ml cylindrical container through a sieve to capture any material and the new container, containing the recycled propylene glycol, placed back into the outer pitfall container in the ground. Material captured in the sieve was then rinsed into a 200 ml round container with 70% ethanol. Both the container of captured spiders and the new pitfall container were given a unique paper label, and the pitfall was reset with the lid and shelter put back in place. Material from the 200 ml containers was individually poured into a petri dish and placed under a Nikon dissection microscope and thoroughly inspected for spiders under 20-80x magnification. Any spiders found were removed using forceps and placed into a 50 ml yellow screw cap specimen container with 70% ethanol and a unique paper label, for storage until the spiders were placed onto a petri dish and identified to species level (where possible) under the same Nikon dissection microscope.

3.2.4 Night collections

Night hand collections of spiders were conducted in an area of 30 x 30 m adjacent to the pitfall traps in site A, in each of one of the paired sites. Before and after collections, notes about the weather were recorded and anything unusual that occurred (e.g. an abundance of ants, presence of large spiders identified but not collected). Collections were undertaken for one hour at each site by three people. Collections of spiders seen above knee height was undertaken by two people for the first 30 minutes while the other person collected spiders in vegetation below knee height and on the ground in the leaf litter. After 30 minutes this process was swapped and spiders collected for another 30 minutes. Spiders less than about 5 mm in length were collected using a pooter to prevent damage to the specimen. Spiders were collected into 50 ml yellow screw cap specimen containers with a label for each type of spider at each site i.e., ‘tangle web’, ‘single strand’, ‘orb web’ and ‘other’. Containers were half filled with 70% ethanol.

Any spiders too big to capture using a pooter were captured in an empty 50 ml yellow screw cap specimen container to test for claw tufts at the end of collection. If the container was flipped upside down and the spider stayed in place, the spider was placed into another container with 70% ethanol, labelled with ‘claw tufts’. If the spider did not stay when flipped, it was placed into a separate container with 70% ethanol, labelled ‘other’. Any spiders too big to collect in yellow screw cap specimen containers were photographed, the spider left where it was, and notes made for the site about the number and types of spiders that were seen but not collected.

3.2.5 Vibration-based technique

A week prior to the final spider collections, an area 1 m wider than the total area of the tractor, to be used to attract the spiders, was cleared in the front of each study site (Figure 3.3). This meant there was no vegetation around the tractor; increasing visibility to ensure capture of spiders attracted to the vibration. The tractor engine was left idling for an hour. The vibration technique was conducted at all eight sites (sites A and B) after the final fortnightly pitfall trap and night collections had been undertaken. Just prior to the vibration technique beginning, all six pitfall traps that had been closed, were re-opened at the site of the vibration testing to collect spiders during the hour while vibration was occurring. This technique was conducted during the middle of the day as earlier unpublished research indicated that spiders were only attracted to the vibration when the soil was not moist, it was sunny and the vibration was used in the middle of the day. The vibration came from a John Deere 6520SE tractor that was idling at 750-800 rpm, for an hour at the site being tested. Sites A and B from each location were conducted sequentially with four sites conducted each day. Three people collected spiders in the cleared area, as the spider emerged from the study site. Any small spiders that came from the study site towards the tractor were captured using a pooter and put into a labelled 50 ml yellow screw cap specimen containers containing 70% ethanol. Larger spiders were caught by hand and placed in appropriately labelled 50 ml yellow screw cap specimen containers. Collection times were separated into 10-minute intervals with a new 50 ml yellow screw cap specimen container being used for every 10 minutes to obtain data on the spider species collected over time. Each 10-minute interval collection of yellow screw cap specimen containers were placed in a zip lock bag and labelled with the site, date, and time interval. Once the vibration-based technique had finished, the contents of the pitfall traps were collected in the same manner as described in 3.2.2.

3.2.6 Identification and counting of captured spiders

For identification, spiders were carefully removed from the 50 ml yellow screw cap specimen containers and placed into a petri dish with 70% ethanol. This petri dish was then placed on a black background under a Nikon dissection microscope. Key factors for identification such as the position and number of eyes, the relative lengths of the different legs, presence or absence of claw tufts and the patterns of the abdomen on both dorsal and ventral sides were considered, and the spider identified. Once identified, a photograph was taken of the dorsal and ventral sides of the spider and of any other unusual characteristic such as claw tufts or spinnerets. The photographs were then recorded against that spider for later reference.

For the pitfall trap collection technique, specimens were kept in a 50 ml yellow screw cap specimen container for each pitfall at each site and labelled as such. These directions were repeated for each pitfall trap at each site. For the night collection technique, specimens were kept in 50 ml yellow screw cap specimen containers for each spider type (i.e., tangle web, single strand, orb web, other and claw tufts) at each site and labelled as such. For the vibration technique, specimens were kept in 50 ml yellow screw cap specimen containers for each 10-minute interval at each of the eight sites and labelled as such. These processors were repeated for each site for both night collections and spiders captured during the vibration-based technique.

3.3 Statistical analyses

Species richness and diversity indices were calculated using a two-way ANOVA with model terms for site and trapping technique using R (version 4.0.5). One set of analyses compared the results collected from pitfall traps, night collection, during the vibration-based technique, and also from the pitfall traps that were open during the vibration-based technique. A second set of analyses compared the two sets of vibration-based collection data at each site. When a significant effect of technique was found, means were compared using pair wise t-tests. A probability of less than 0.005 was considered significant and a probability of more than 0.005 was considered not significant. Significance was expressed in different superscript groupings (a or b) with a pooled SEM under each table.

The counts of each spider species recorded at each site with each technique were used to generate an ordination plot. Ecological distances between each of the 20 (4 sites by 5 techniques) units was calculated using a Bray-Curtis dissimilarity metric and then analysed using multidimensional scaling (MDS). Analysis was carried out using the vegan library in R (version 4.0.5).

Chapter 4: Results

4.1 Species richness and diversity

Spiders collected at Stewartdale from the four study locations were identified into 34 families, 138 genera and 226 species (Appendix I). Overall, the most diverse families in terms of the number of species were Araneidae (41 species), followed by Salticidae (37 species), Theridiidae (30 species), Gnaphosidae (19 species) and Corinnidae (15 species). While 22% of taxa were found at all four locations 41% were only found at one location (12% at DR1, 8% at DR2, 14% at RH and 7% at RL).

Approximately 9% of species were captured using all three techniques with 67% being captured using only one technique (night collection 50%, pitfall traps 10%, and vibration 7%). Subsequently, 24% of spider species were found using two of the three survey techniques (Figure 4.1).

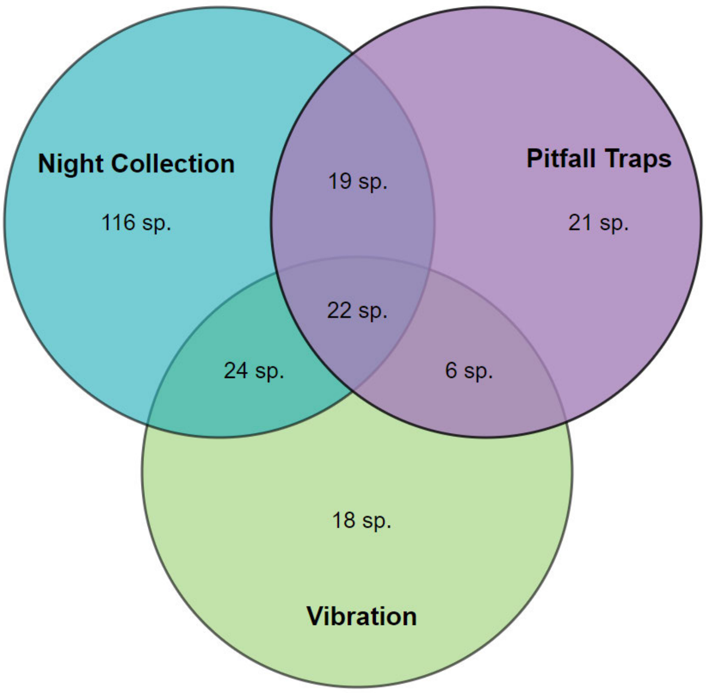

Figure 4.1 - Venn diagram of the number of species caught with each survey technique showing the overlap with other techniques.

(a) All three techniques

The data was analysed to determine the species richness and diversity of spiders captured in all techniques (Table 4.1). There were significant differences between techniques for diversity ($F_{2,6}$ = 20.449, P<0.001) and species richness ($F_{2,6}$ = 44.175, P<0.001), however, there was no significant effect of locations (DR1, DR2, RH, RL) for diversity ($F_{3,6}$ = 0.158, P=0.92) or species richness ($F_{3,6}$ = 0.516, P=0.686) (Table 4.1).

Table 4.1 - Mean values of species richness and diversity of spiders captured from night collection, vibration and pitfall traps in four locations combined (David's Ridge 1 and 2 (DR1 and DR2), Rachael's Hill (RH), and Robert's Lane (RL)).

Technique	**Shannon Index Diversity**	**Species Richness**
Night collection	5.87[a]	95.2[a]
Pitfall traps	4.39[b]	30.8[b]
Vibration-based	3.88[b]	29.2[b]
Pooled SEM	*0.229*	*5.67*

** Means followed by same superscript letter are not significantly different*

(b) Pitfall traps

Spiders captured in the pitfall traps left open for six weeks were compared to those from pitfall traps left open for the hour of vibration treatment to produce means of diversity and species richness (Table 4.2). There was a significant difference in diversity between pitfall traps left open over six weeks and the pitfall traps open during the vibration-based technique ($F_{3,9}$ = 4.017, P=0.0455). Spider species richness was the same in all site A locations ($F_{3,9}$ = 0.584, P=0.64), techniques ($F_{3,9}$ = 0.669, P=0.592), and sites ($F_{3,9}$ = 1.097, P=0.406) for spiders caught in pitfall traps.

Table 4.2 - Shannon diversity indices and species richness means for spiders caught in the pitfall traps left open over six weeks and for an hour during the vibration-based technique.

Technique	Shannon diversity index	Species richness
Pitfall trap week 2	3.33^{a}	11.8^{a}
Pitfall trap week 4	3.72^{a}	16.5^{a}
Pitfall trap week 6	3.22^{a}	13.8^{a}
Pitfall trap vibration-based	1.41^{b}	9.5^{a}
Pooled SEM	*0.515*	*3.64*

* *Means followed by same superscript letter are not significantly different*

(c) Vibration-based

Species captured at site A and B for vibration were used to estimate the values of species richness and diversity to compare trapped and un-trapped locations (Table 4.3). Spider species diversity was the same at all locations ($F_{1,3}$ = 0.086, P=0.788) and at sites A and B ($F_{3,3}$ = 2.219, P=0.265). Likewise, species richness was the same (location, $F_{1,3}$ = 2.298, P=0.227; site $F_{3,3}$ = 2.442, P=0.241).

Table 4.3 - Shannon diversity indices and species richness means (with standard errors) for vibration-based collections of spiders at sites A and B.

Technique	Shannon diversity index	Species richness
Vibration technique at A sites	3.88	29.2
Vibration technique at B sites	3.81	20.0
Pooled SEM	*0.167*	*4.31*

(d) Ordination

There was an observable difference between the composition of spider species collected by night collections, pitfall traps, and vibration in sites A and B as shown by an MDS ordination from the spider data showing dissimilarity for each location and technique (Figure 4.2). The spider species collected from vibration-based collections in sites A and B were separated along the first ordination axis but not separated along the second ordination axis for all locations. Spiders collected in the pitfall traps and the night collections were strongly separated from each other along the first ordination axis (Figure 4.2). The spider species collected from vibration-based collections in sites A and B were separated from the pitfall traps and the night collection (Figure 4.2).

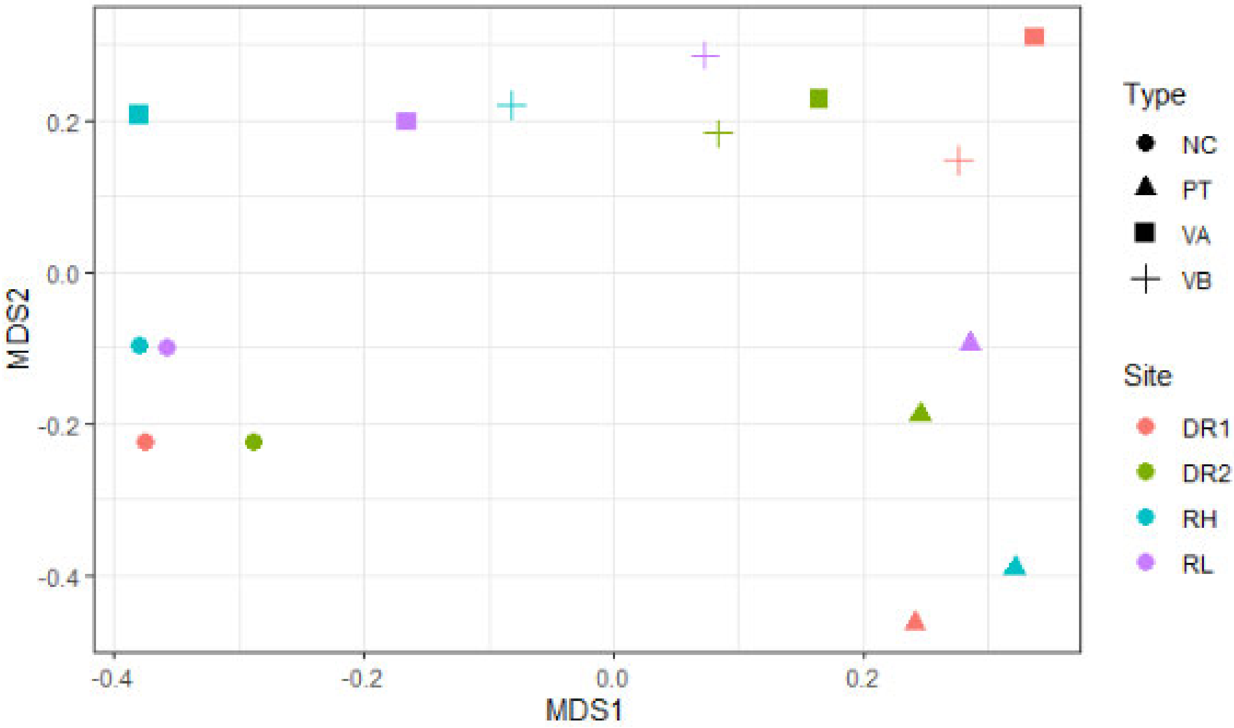

Figure 4.2 - MDS ordination of spider data using Bray-Curtis dissimilarity, showing dissimilarity between techniques: night collection (NC), pitfall traps (PT), vibration-based at site A (VA), and vibration-based collections at site B (VB). VA and VB are intermingled while NC and PT are in distinct groupings.

4.2 Technique efficiency and spider community composition

The efficiency and cost of each survey technique are outlined in Table 4.4. Factors include the preparation time for the survey technique, the time it took for the collection to occur, time in between each repetition, the average cost, the labour involved and any potential OH&S risks (Table 4.4). Finer detail is described below in each section. The night and vibration-based collections are similar in efficiency of time for preparation, for collection and to reset. All three survey techniques each cost between $60-$70 (Table 4.4). The labour differs with each survey technique with night collection having the highest amount whilst pitfall traps and vibration-based collections were equivalent for labour. Night collection had the highest potential OH&S risk whilst both pitfall traps and the vibration-based collection had relatively low OH&S risks (Table 4.4).

Table 4.4 - Efficency and cost of each survey technique per one collection location.

Parameter	**Night collection**	**Pitfall traps**	**Vibration-based**
Preparation time	**1 hour**	**4 hours**	**2 hours**
	Ethanol in specimen containers. Labels in specimen containers. Specimen containers in labelled bags.	Buying and constructing pitfall traps and lids. Digging the pitfall hole and setting the pitfall trap. Moving between each pitfall trap.	Ethanol in specimen containers. Labels in specimen containers. Specimen containers in labelled bags. Clearing of ground for tractor.

Collection time	**1 hour**	**6 weeks**	**1 hour**
Reset time	**15 minutes**	**1 hour**	**20 minutes**
	Moving between sites.	Filter out the pitfall contents into separate container. Refill pitfall trap. Moving between sites.	Transit time between locations with tractor.
Total cost of materials	**$47-$127**	**$70**	**$57**
	$20 specimen containers. $2 labels. $10 pooter. $80 head torch (one off cost). $15 ethanol.	$30 propylene glycol. $10 containers. $30 accessories.	$20 specimen containers. $2 labels. $10 pooter. $10 tractor fuel. $15 ethanol.
Labour	**Intensive**	**Short intensive**	**Short intensive**
OH&S risk associated with technique	**High**	**Low**	**Low**
	Walking through the bush at night.		

**This table does not include the time or cost for identification of spider species.*

Night collections of spiders had the highest percentage of taxa in both the number of species and families of spiders. The pitfall trap and vibration-based technique resulted in the same number of species of spiders; however, pitfall traps captured a greater number of families than collected from the vibration-based technique (Figure 4.3).

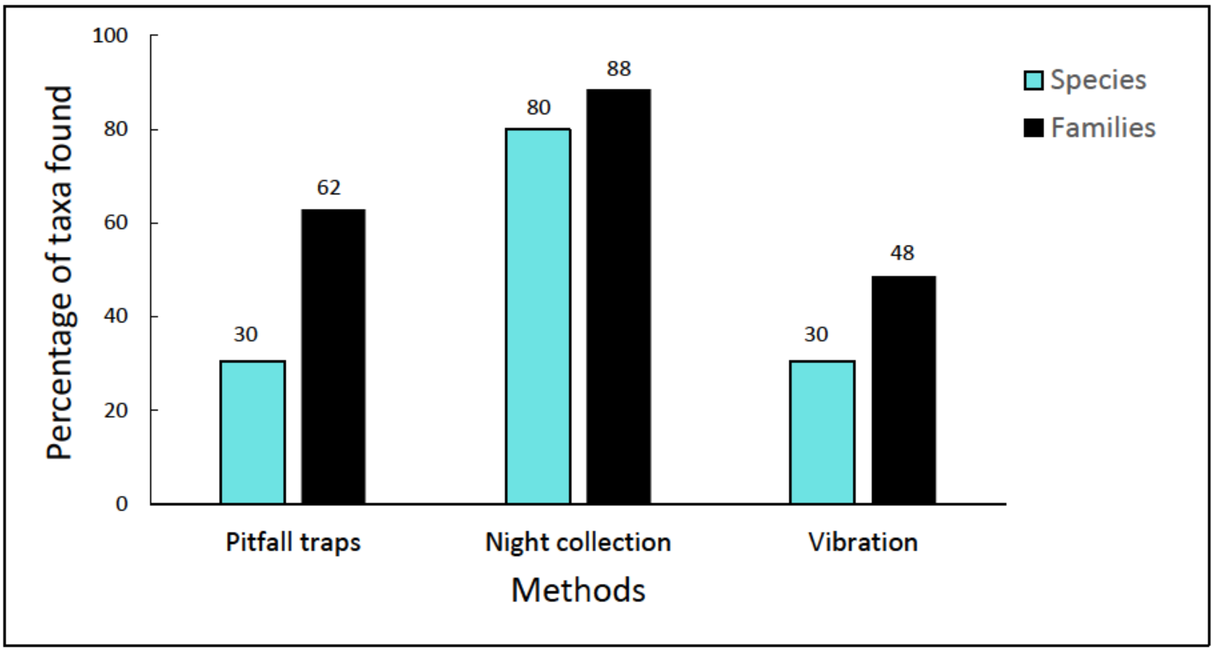

Figure 4.3 - The number of species (and families) captured by the different techniques as a percentage of the total species (and families) recorded in the four A study sites.

The proportion of juvenile and adult, and male and female spiders was not consistent for each survey time over the six weeks the pitfall traps were left open (Figure 4.4). There was an increased number of juvenile female spiders caught each fortnight (from 12 to 35 to 42 in weeks two, four and six respectively). Similarly, there was an increased number of adult male spiders caught in the second fortnight (from 13 to 32 in weeks two, four) (Figure 4.4).

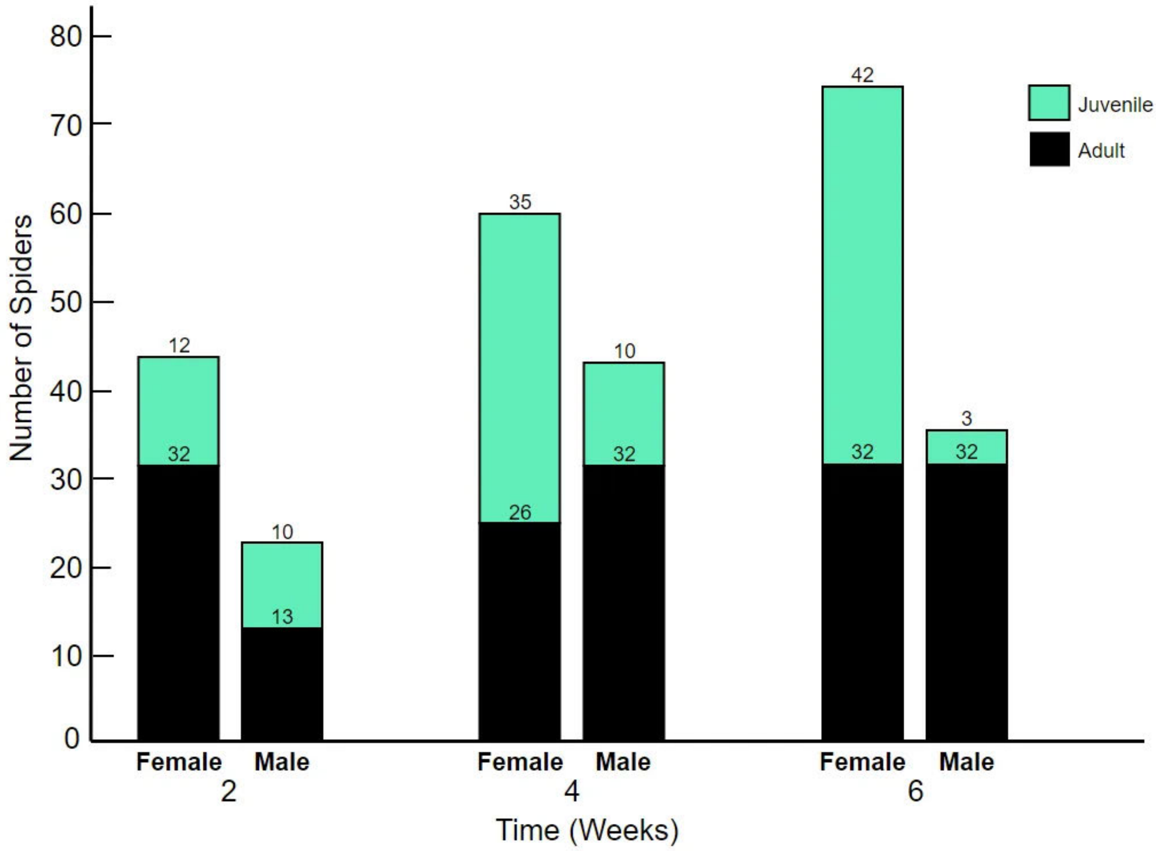

Figure 4.4 - The number of juvenile and adult, and male and female spiders captured in pitfall traps over six weeks. The number of juvenile and adult spiders captured is shown on the graph.

From night collections considerably more juvenile spiders were caught than adult spiders in all three fortnightly collections (Figure 4.5). The number of adult spiders caught each fortnight were within a relatively narrow range (47 to 69 spiders) whilst the number of juvenile spiders caught were within a much wider range (84 to 209 spiders) for both males and females (Figure 4.5). The overall number of females caught each fortnight decreased from 224 to 204 to 135 spiders in weeks two, four and six respectively (Figure 4.5). However, the number of overall males captured, increased each fortnight from 171 to 222 to 257 spiders in weeks two, four and six respectively (Figure 4.5).

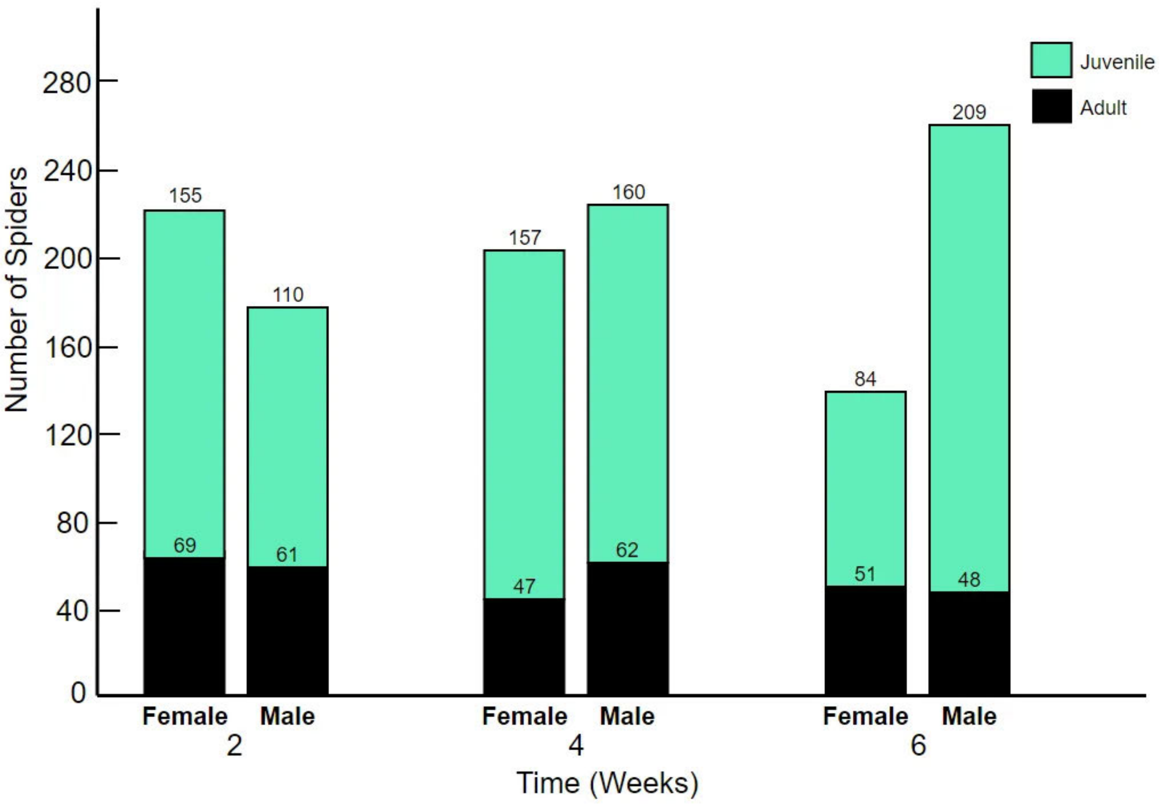

Figure 4.5 - The number of juvenile and adult, and male and female spiders from night collections over three fortnightly collections. The number of juvenile and adult spiders captured is shown on the graph.

There were a greater proportion of female juvenile spiders attracted to the vibration than there were adult female spiders collected during the hour (Figure 4.6). Overall, there were more female than male spiders collected during the hour, for the vibration-based technique. The number of adult spiders collected over the hour remained within a relatively narrow range (14 to 28 spiders) in each 10 minute collection whereas the number of juveniles collected in each 10 minute collection had a much wider range (8 to 101 spiders) (Figure 4.6).

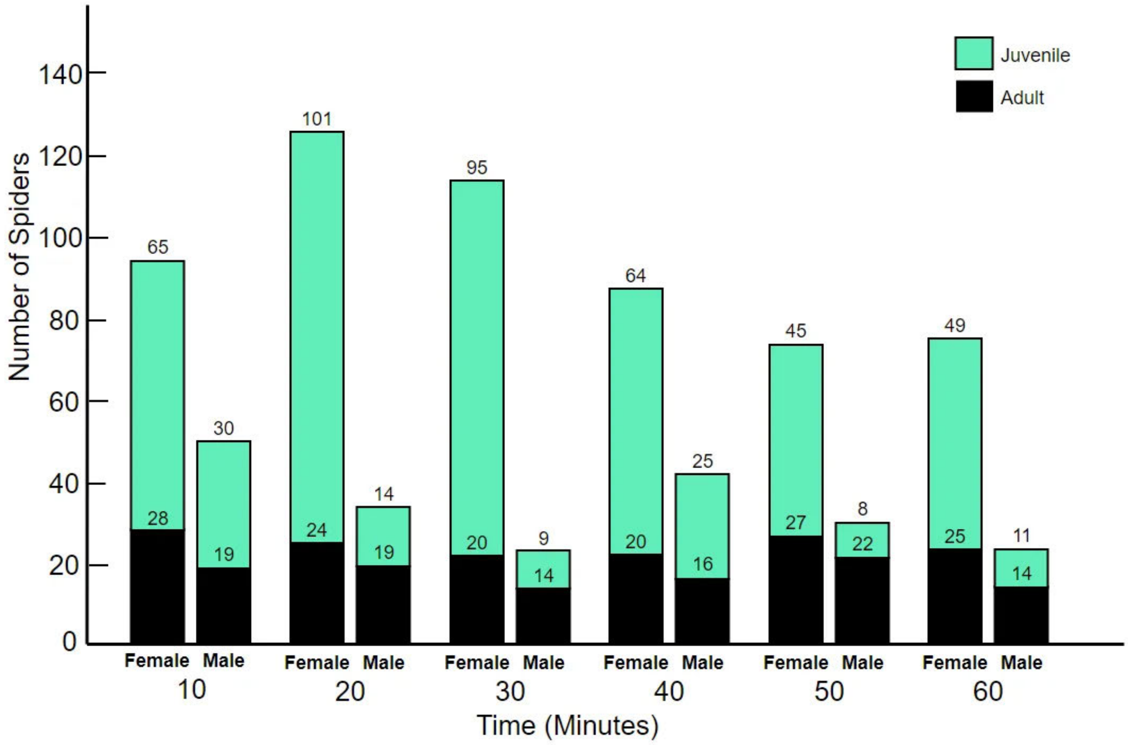

Figure 4.6 - Number of juvenile and adult, and male and female spiders collected each 10 minute, in the hour using the vibration techniquet. The number of juvenile and adult spiders is shown on the graph.

Spider species were categorised into three vegetative strata: low, middle, and high. Low vegetative strata was defined as any spider species caught on the ground up to 0.5 m (on the ground or in leaf litter). Middle vegetative strata was defined as any spider species caught between 0.5 and 2 m on vegetation (such as leaves and tree trunks). High vegetative strata was defined as any spider species that was found on a web (at any height) and above 2 m on vegetation. The vibration-based technique and pitfall traps both primarily targeted spiders from the low vegetative strata with 85% of spider species normally found on the ground or in leaf litter, with the remaining 15% from the middle or high vegetative strata (Figure 4.7). The night collection had the highest percentage of spider species found in high or middle vegetative strata with 63% whilst the remaining 37% found in the low vegetative strata (Figure 4.7).

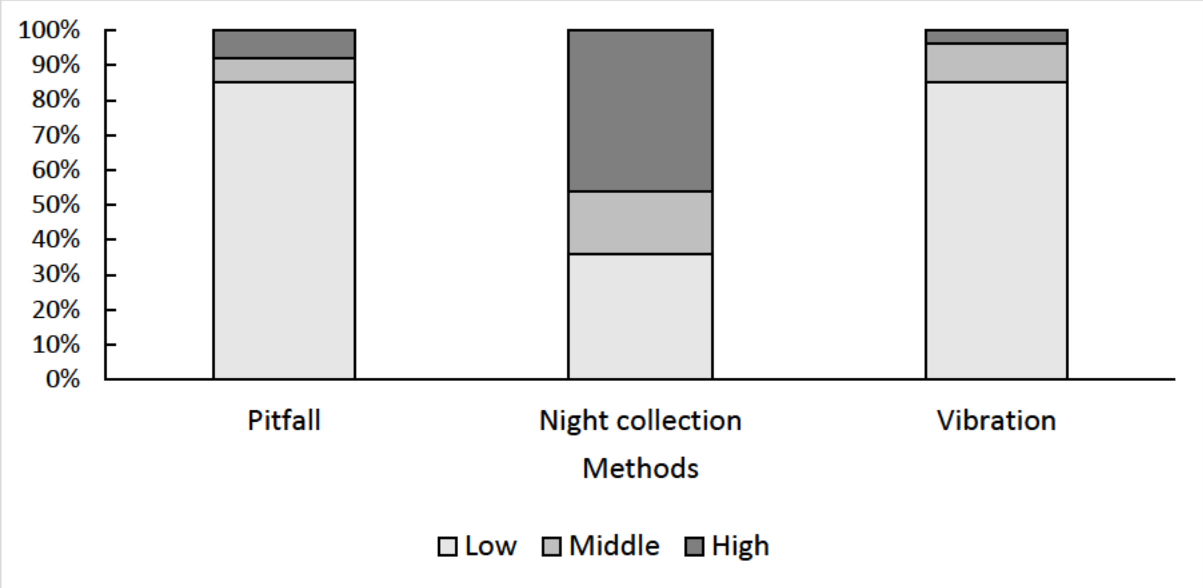

Figure 4.7 - The percentage of spiders caught in the three different vegetative strata (low, medium and high) for the three techniques.

The five most abundant spider species were different for each survey technique. *Habronestes hab4* (Zodariidae) was the only common species caught using all three survey techniques with 55 caught during the three night collections, 14 caught in six weeks of pitfall trapping and 80 captured during the vibration-based technique. *Argiope keyserlingi* (from the family Araneidae; orb-weaving spiders) was the most abundant species caught during night collections (n = 90), whilst *Genus M* sp.1 (from the Lycosidae family) (n = 37) and *Habronestes hab2* (from the Zodariidae family) (n = 98) (both ground-dwelling families) were the most captured in the pitfall traps and from the vibration-based technique (Figure 4.8).

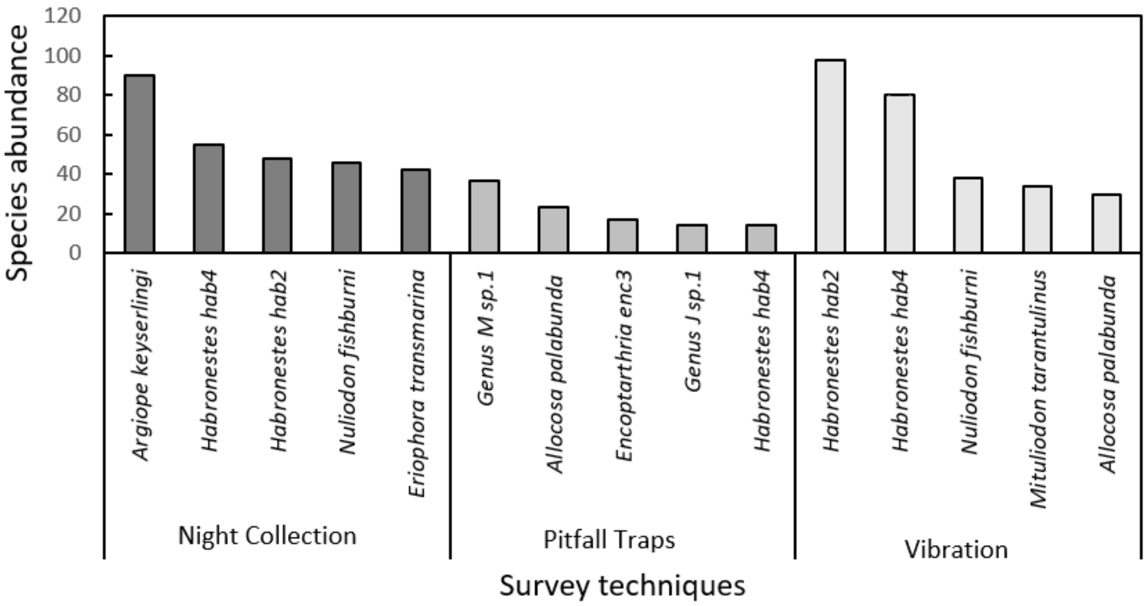

Figure 4.8 - The five most abundant spider species captured from each survey technique: night collection, pitfall traps and the vibration-based technique.

The three most abundant spider families for each survey technique were different (Figure 4.9). Zodariidae was the only family common to all three survey techniques with an abundance of 126 spiders from night collections, 41 spiders in pitfall traps, and 225 spiders collected during use of the vibration-based technique (Figure 4.9). Night collection resulted in the greatest number of Araneidae and Theridiidae spiders whilst pitfall traps resulted in the greatest number of Lycosidae and Gnaphosidae spiders, and the vibration-based technique had the greatest number of Zodariidae and Miturgidae spiders (Figure 4.9).

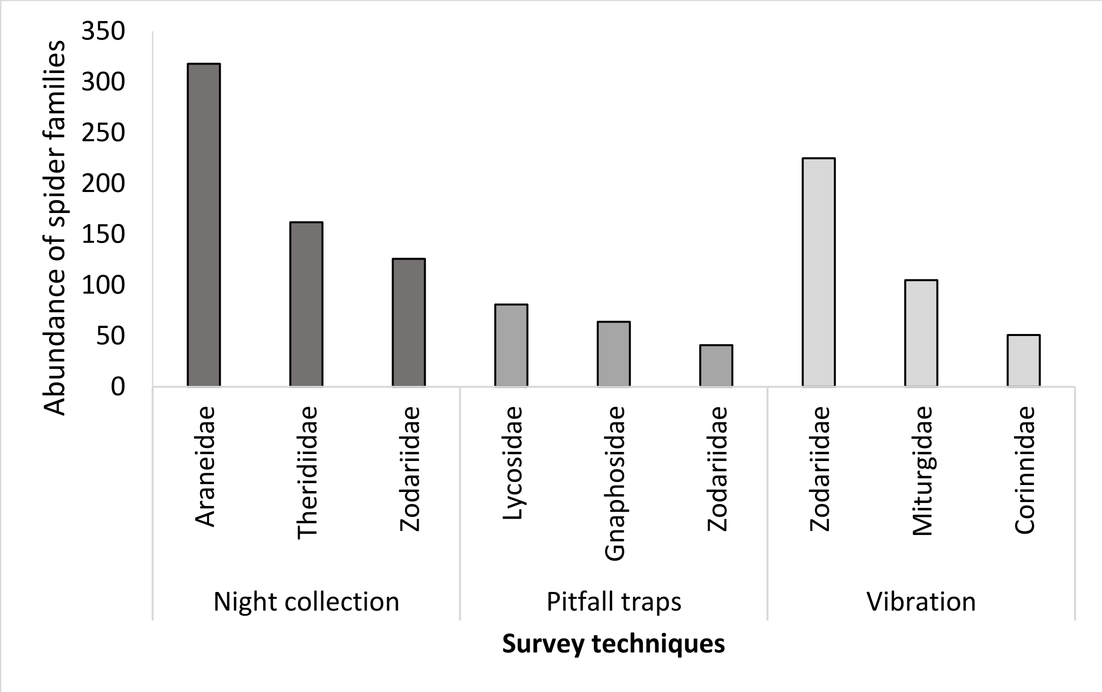

Figure 4.9 - The three most abundant families from the number of spiders recorded for each survey technique: night collection, pitfall traps and the vibration-based technique.

4.3 Accumulation curves

(a) Pitfall traps

The number of new species recorded each fortnight was used to calculate an accumulation curve for pitfall traps over the six weeks of trapping (Figure 4.10). There was a positive trend for the number of additional species found each fortnight with an overall average increase of 67.3% between sites and time (Figure 4.10). There was an average increase across four sites of 99.3% between weeks two and four and 35% between weeks four and six. DR1 had the highest number of additional species found each fortnight with an increase of 66.6% between weeks two and four and a further 60% increase between weeks four and six (Figure 4.10).

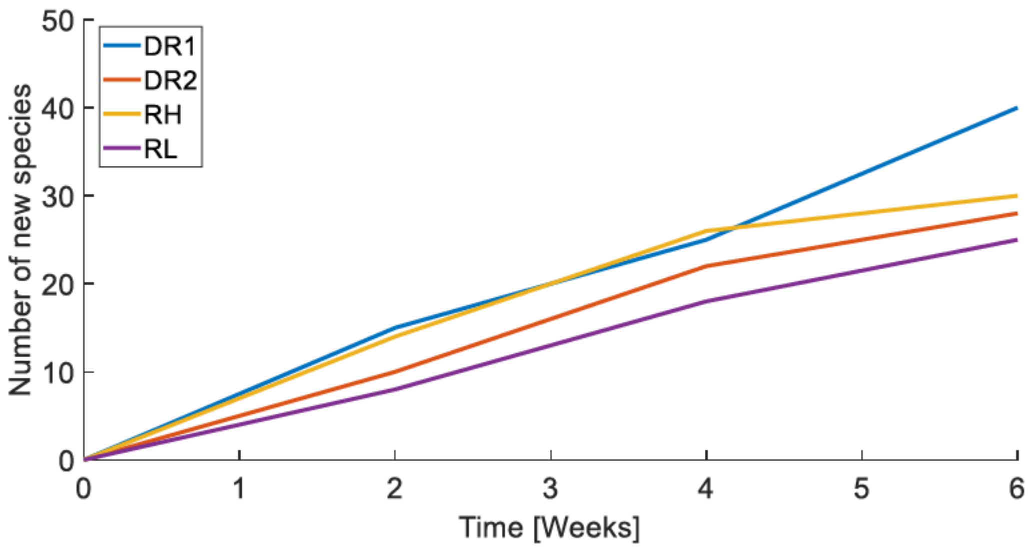

Figure 4.10 - Accumulation curves of spiders captured in pitfall traps in four locations (David's Ridge 1 and 2 (DR1 and DR2), Rachael's Hill (RH), and Robert's Lane (RL)) every fortnight for six weeks in spring 2020, on Stewartdale in south-east Queensland.

(b) Night collection

The number of additional species of spiders collected each fortnight during the night collections was used to calculate an accumulation curve for the night collection over three fortnights (Figure 4.11). There was a positive trend for the number of additional species found each fortnight with an overall average increase of 41.5% between sites and time (Figure 4.11). There was an average increase across four sites of 58.3% between weeks two and four and 25% between weeks four and six. RL had the highest increase of species between weeks two and four at 73.3% while DR1 had the highest increase of additional species between weeks four and six at 43.8% (Figure 4.11).

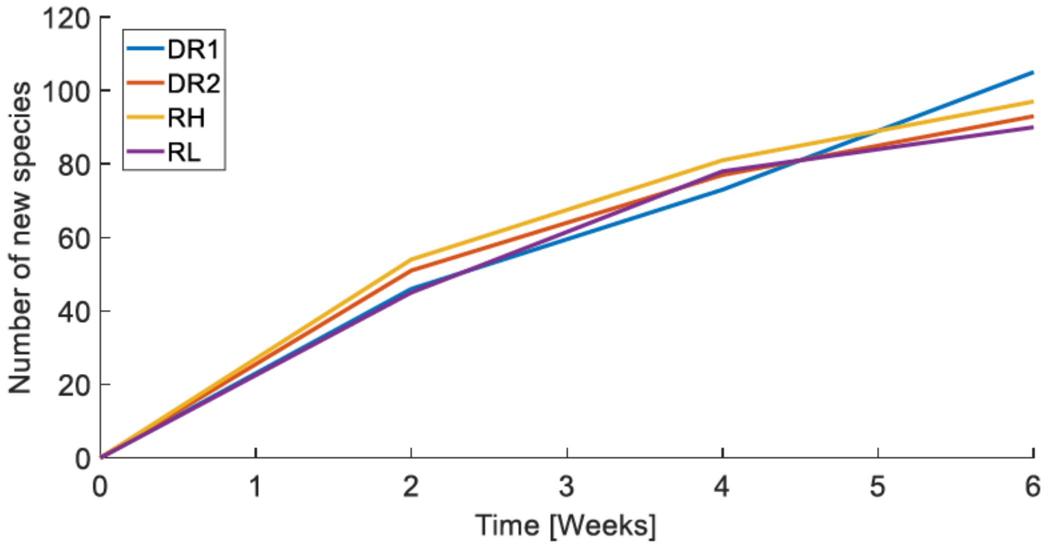

Figure 4.11 - Accumulation curves of spiders captured from night collection in four locations (David's Ridge 1 and 2 (DR1 and DR2), Rachael's Hill (RH), and Robert's Lane (RL)) every fortnight for six weeks in spring 2020, on Stewartdale in south-east Queensland.

(c) Vibration-based

The number of additional spider species collected in each 10 minute interval was used to calculate an accumulation curve for the vibration-based collection over an hour in both sites A and B (Figure 4.12). There is a positive trend for the number of additional species found in each 10 minute interval with an overall average increase of 46% between sites and time (Figure 4.12). There was an average increase across eight sites of 117% between the 10 and 20 minute intervals and a further 8% between the 50 and 60 minute intervals. RHA had the highest increase of species with a total of 41 species over the 60 minutes with an average increase of 109% for the 60 minute collection (Figure 4.12). Seven sites begin to plateau between the 50 and 60 minute intervals with the addition of only one or two new species. RLA was the only site to have an increase of 29% between the 50 and 60 minute intervals with six additional species in this 10 minute interval (Figure 4.12).

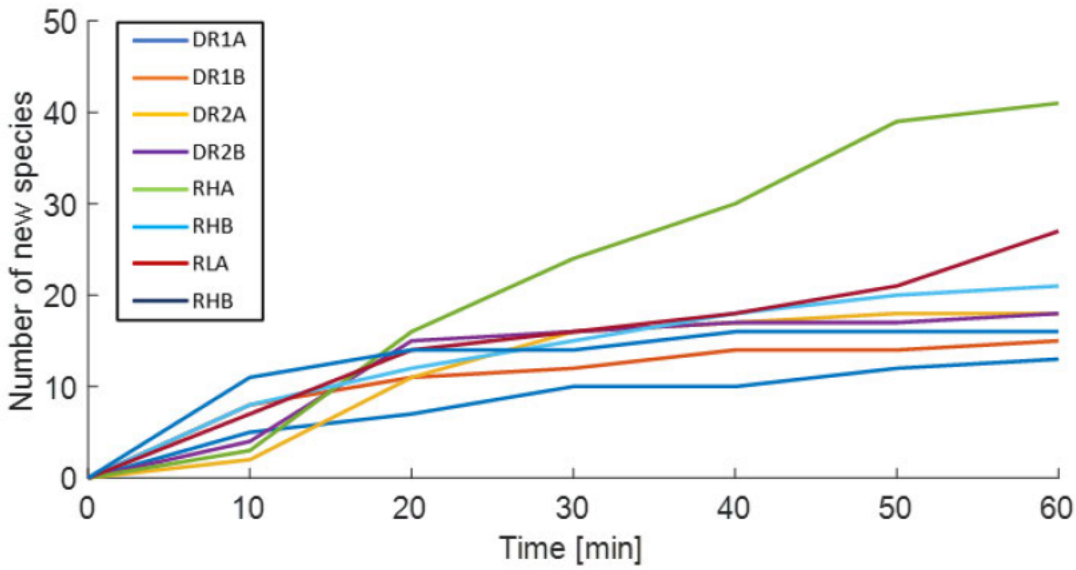

Figure 4.12 - Accumulation curves of spiders captured from vibration-based collections in four locations with paired sites (David's Ridge 1 and 2 (DR1 and DR2), Rachael's Hill (RH), and Robert's Lane (RL)) every fortnight for six weeks in spring 2020, on Stewartdale in south-east Queensland.

(d) Number of pitfall traps and species of spiders collected

The number of additional species found in each additional pair of pitfall trap (across all locations) are shown in Figure 4.13. The pitfall traps were grouped randomly into pairs (pitfall trap 1 and 6) (2 and 3) (4 and 5) to compare the number of additional species caught using four pitfall traps (1, 2, 3 and 6) or all six pitfall traps. Spider species that were not caught in pitfall traps 1 or 6 are represented in pitfall traps 2 or 3. Species that were not caught in pitfall traps 1, 2, 3, or 6 are represented in pitfall traps 4 and 5 (Figure 4.13). Pitfall traps 2 and 3 caught an extra six species in week two, four species in week four, and a further six species in week six that were not caught in pitfall traps 1 and 6. Pitfall traps 4 and 5 caught an extra eight species in week two, two species in week four and one species in week six that were not caught in pitfall traps 1, 2, 3, or 6 (Figure 4.13).

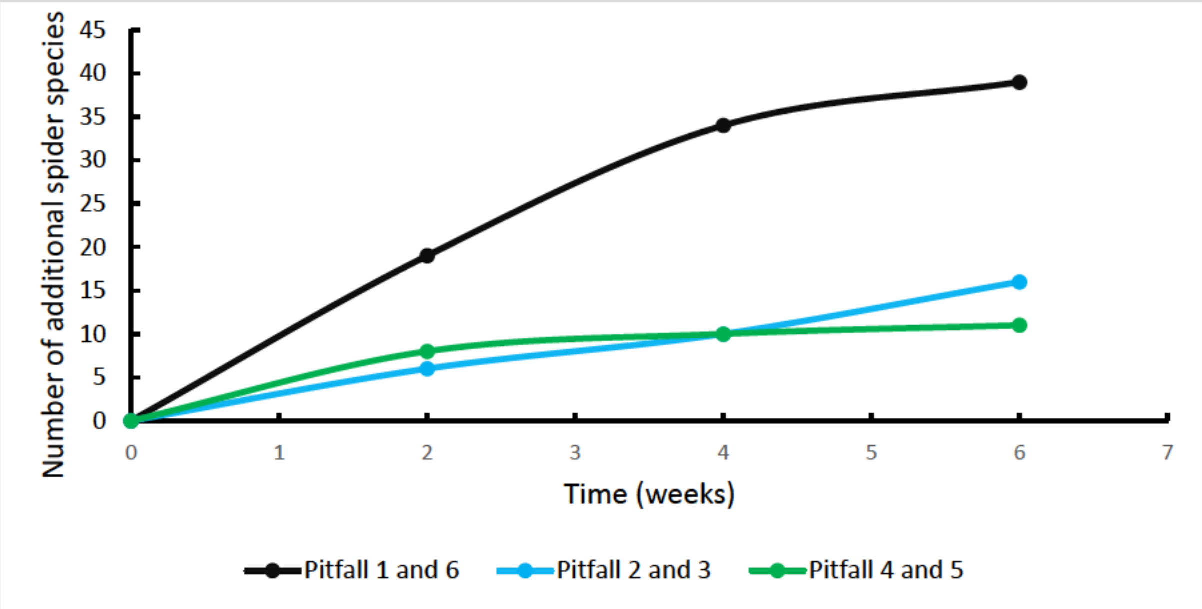

Figure 4.13 - The number of new species with two pitfall traps (pitfall 1 and 6), four pitfall traps (pitfall 2 and 3), or six pitfall traps (pitfall 5 and 6) over six weeks.

Chapter 5: Discussion

5.1 Species richness and diversity

The eight study sites at Stewartdale in South Ripley contained a highly diverse spider fauna including an estimated four previously undescribed species, emphasising the need to optimise efficiency of spider survey techniques (Churchill & Arthur 1999; Hore & Uniyal 2008; Buchholz & Hannig 2009; Seldon & Beggs 2010; Thomas et al. 2011; Brown & Matthews 2016; Kim et al. 2020). Survey techniques used can greatly influence the spider fauna captured through collection biases such as targeted vegetative strata, length or duration of technique or specific spider behaviour (Churchill & Arthur 1999; Norris 1999; Kapoor 2006; Cardoso et al. 2008). Overall, the most diverse families in terms of the number of species were Araneidae (41 species), followed by Salticidae (37 species), Theridiidae (30 species), Gnaphosidae (19 species) and Corinnidae (15 species) which is similar to the overall diversity of these families worldwide (World Spider Catalog 2021).

Night collection had the greatest number of spider species captured by a single technique (116 species) (Figure 4.1). Pitfall traps captured 21 spider species that were not found in either night collections or from the vibration-based technique (Figure 4.1). Using the vibration-based technique there were 18 species of spiders that were not caught in pitfall traps or through night collections (Figure 4.1). Thus, all three techniques contributed to the overall spider species richness and diversity. Overall, the three techniques were perceptibly different in the species richness and species diversity in the dissimilarity ordination where each technique were separated from each other (Figure 4.2).

(a) Night Collection

Spider species diversity and richness were significantly different between techniques (pitfall traps and night and vibration-based collections) than they were between locations. Night collection was significantly different to the pitfall traps and the vibration-based techniques as the night collection technique had a diversity index of 5.87 whilst the pitfall traps and vibration-based collections had diversity indices of 4.39 and 3.88, respectively (Table 4.1). Night collection of spiders resulted in a species richness of 95.2 whilst the pitfall trap and the vibration-based collection techniques had a species richness of 30.8 and 29.2, respectively (Table 4.1). This could be due to biases from more familiar or experienced persons collecting the samples, for example, targeting microhabitats more likely to contain spiders or identifying spiders over other similar invertebrates, such as ants (Churchill & Arthur 1999; Norris 1999). Another bias can come from having a higher diversity of species in higher vegetative strata which could have been easier to find and thus producing an under-sampling bias for other techniques such as the vibration-based technique for the one hour time sampling effort (Norris 1999). This would support the results of the most abundant families present in night collection: Araneidae, Theridiidae and Zodariidae (Figure 4.9). Araneidae and Theridiidae are web-building spiders and are some of the most commonly found spiders and largest families, with Araneidae encompassing 2,600 species in 160 genera and Theridiidae with 2,300 species in 79 genera worldwide (Scharff & Coddington 1997; Heiling & Herberstein 1999; Agnarsson 2004). Similarly, the pitfall traps caught the most abundant ground-active families.

(b) Pitfall traps

Pitfall traps have typically been a favoured technique for collecting spiders when compared to sweeping, malaise traps and Berlese funnels as pitfall traps are cheap and are less labour intensive (Churchill & Arthur 1999; Seldon & Beggs 2010; Hancock & Legg 2012; Brown & Matthews 2016).

A key limitation to pitfall traps is the targeted spider fauna: they primarily capture only ground-active spider species (Hancock & Legg 2012). The most abundant families collected in pitfall traps were Lycosidae, Gnaphosidae and Zodariidae (Figure 4.9). These results are supported by other literature that have documented these dominant ground-active spider families captured in pitfall traps (Merrett & Snazell 1983; Hancock & Legg 2012; Bali et al. 2019).

There was an observable difference in the diversity index between spiders collected in pitfall traps left open for six weeks and pitfall traps left open for one hour. During the vibration-based technique collection, however, there was no significant difference for species richness (Table 4.2). This meant both pitfall trap collections caught the same number of species but the pitfall traps left open for six weeks caught a higher abundance of those species. This is to be expected given the duration of each collection. Locations DR1 and DR2 with vibration-based collections from pitfall traps caught 1 spider each from two families. RH and RL locations caught 28 spiders (in 8 families) and 8 spiders (in 4 families) respectively. Differences between DR1 and DR2 locations with RH and RL locations could be attributed to many factors such as the weather (wind, rain and cloud cover) in relation to when spiders were collected as we experienced an overcast day with light rain, with DR1 and DR2 location collections, whilst experiencing a clear and sunny day with RH and RL locations collections (Hore

& Uniyal 2008; Schirmel et al. 2010; Bali et al. 2019). It could also be attributed to the location of pitfall traps with respect to site composition (e.g., presence and location of nearby termite mounds, logs, grass, leaf litter, rocks, trees etc.) (Hore & Uniyal 2008; Schirmel et al. 2010; Bali et al. 2019). Vibration has been found to increase capture rates from pitfall traps for other invertebrates such as crickets (Sperber et al. 2007). The vibration was produced by people walking through leaf litter near pitfall traps triggering a startle response from nearby crickets and increasing the likelihood of crickets entering a pitfall trap (Sperber et al. 2007). This could mean that under certain conditions the pitfall traps coupled with the one-hour vibration-based technique could produce the same species richness as leaving pitfall traps open for six weeks without any vibration, improving time efficiency with pitfall traps. Future work with this coupled technique (vibration and pitfall traps) could involve various distances and/or frequencies to optimise capture for species richness and diversity. Collection of spiders from the vibration-based technique was comparable to the pitfall traps left open for six weeks.

(c) Vibration-based

Collection of spiders using the vibration-based technique had comparable spider species richness and diversity with that for the six week collection using pitfall traps. There was no significant difference for either species richness or diversity between vibration site A and vibration site B. This indicates that the trapping processes of night collection and pitfall traps did not interfere with the collection of spiders in an adjacent location using the vibration-based technique alone (Table 4.3). The vibration-based technique and the pitfall traps left open for six weeks had no significant difference for species richness or species diversity (Table 4.1). Their similarity could be due to both techniques targeting ground-active spider fauna as the most abundant families collected using the vibration-based technique were Zodariidae, Miturgidae, and Corinnidae (Figure 4.9). This indicates the main vegetative strata that the vibration-based technique is reaching, is based on how vibration waves move along the ground. Leaf litter (prevalent across all locations) is a low pass filter meaning the Rayleigh waves can pass through the leaf litter easily (Michelsen et al. 1982; Barth 1998; Elias et al. 2004; Čokl & Millar 2009; Hill 2009). This supports the results as the three main spider families collected using the vibration-based technique are all commonly found in leaf litter (Framenau et al. 2014). The vibration-based technique also attracted Araneidae and Theridiidae spiders i.e., web-building spiders (and thus situated in a higher vegetative strata) across all eight locations (Scharff & Coddington 1997; Heiling & Herberstein 1999; Agnarsson 2004; Framenau et al. 2014). There were 18 species collected exclusively by using the vibration-based technique (Figure 4.1). This indicates that this technique is a valuable addition to survey techniques as it targets species that aren’t normally found even after six weeks of pitfall trapping and three nights of night collection of spiders. Unexpectedly, the vibration-based technique captured nocturnal species such as *Deinopis subrufa* and *Neosparassus diana*. This was surprising as it was conducted during the middle of the day (between 10 am and 4 pm). This suggests that vibration-based technique is not limited to attraction of diurnal species of spiders.

The two locations with the greatest number of spiders, RH and RL (405 spiders (in 39 genera) and 192 spiders (in 33 genera) respectively) were very different to the number of spiders collected at DR1 and DR2 (69 spiders (23 genera) and 98 spiders (in 27 genera) respectively). A potential reason for this difference in abundance between RH and RL locations compared to DR1 and DR2 locations could be related to weather factors. Collections of spiders were undertaken with overcast skies with light rain and light wind for DR1 and DR2 locations. In contrast conditions were clear and sunny for the second day of vibration-based technique collections at RH and RL locations and this may have altered the behaviour of spiders (Dondale & Binns 1977; Lensing et al. 2005). Other factors could include environmental objects within the site that would distort or dampen the vibration, for example, rocks and trees (Michelsen et al. 1982; Hebets 2008; Čokl & Millar 2009; Herberstein et al. 2014). Future research with the vibration-based technique should involve measuring and mapping the vibration frequency throughout the study area to gain insights into how natural objects such as rocks and trees interfere with vibration. More research is also needed on the behavioural reaction of spiders to various frequencies in a more controlled environment. Another area for research would be to replicate the vibration-based technique at night to understand if the results are biased towards nocturnal/diurnal spider species.

5.2 Technique efficiency and spider community composition

(a) Technique efficiency

An efficient and cost-effective survey technique will take the least amount of time to prepare, have the least amount of labour and lower OH&S risks involved, and have the least amount of material costs. An efficient survey technique will also take the least amount of time to conduct whilst producing the most desirable results (e.g., highest species richness or diversity, or highest abundance of a particular spider family) (Privet et al. 2020). Night collection and the vibration-based technique had very similar high efficiency whilst pitfall trapping had the lowest efficiency (Table 4.4). The preparation time for the night collection and vibration-based technique only differed in the need to clear the ground around the tractor for collections. Collection time for the vibration-based technique and night collection were both for one hour, however, the night collections were more intensive and had a higher potential for OH&S issues than the vibration-based technique (Table 4.4). The cost for both of these techniques were very similar with night collection costing $47 per one location collection exclusive of the one-off cost of a head torch (essential). Whilst the vibration-based technique had a total cost of $57 with the only difference in the fuel for the tractor to idle at each site for one hour (Table 4.4). Pitfall trapping is notably lower in efficiency and cost when compared to night collection and the vibration-based technique (Azevedo et al. 2014; Privet et al. 2020). Pitfall traps need four hours to prepare, six weeks minimum to collect spiders, an hour once a fortnight to reset, and cost $70 per one collection location. While there were small differences in the efficiency of night collection and vibration-based technique, there were some notable differences in the species of spiders each survey technique captures.

Night collection had the highest percentage of taxa found from the total number of taxa across all techniques (Figure 4.3). This technique captured 80% of all the species and 85% of all the families. These results correspond to other studies using night collection where this technique produced between 50% to 80% of the total number of species sampled (Cardoso et al. 2008; Azevedo et al. 2014; Tourinho et al. 2018). The methodology of these night collections vary with the number of people searching, the area searched, the vegetative strata targeted (e.g., above ankle height), or vegetation type (rainforest/Mediterranean forest) (Cardoso et al. 2008; Azevedo et al. 2014; Tourinho et al. 2018). Both pitfall traps and the vibration-based technique captured 35% of all species found; however, pitfall traps had 65% of families whilst the vibration-based technique accounted for 55% of families (Figure 4.3). This indicates that the vibration-based technique attracted more species within a smaller number of families than did pitfall traps despite the difference in time (one hour vs six weeks).

This contrasts with other reports which concluded that pitfall traps sampled a higher number of families (31) and species (113) than did the hand collection (23 and 53 respectively) (Churchill & Arthur 1999). Although these techniques were conducted in Tasmanian heathland, they had a lot more pitfall traps (a total of 108) across four locations (Churchill & Arthur 1999). Hand collection was conducted for 30 minutes during the day where the time of day has been suggested to impact the number of species sampled (Churchill & Arthur 1999; Azevedo et al. 2014).

(b) Spider community composition

The sampled spider community varied based on the technique used to sample the spider population. There were more adults (60%) than juveniles (40%) and more females (64%) than males (36%) in the pitfall traps (Figure 4.4). The proportion of adult males increased from 13 spiders in week two to 32 spiders in weeks four and six (Figure 4.4). The increase of both females and males in pitfall traps correlates with other findings and has been suggested to be due to the males behaviour of actively seeking a mate or post-copulatory behaviour of females searching for nesting sites and food sources (Merrett & Snazell 1983; Topping & Sunderland 1992; Foelix 2011; Schneider et al. 2011). This supports results of more adults than juveniles in pitfall traps and is subsequently also supported by a study that found pitfall traps are more likely to capture adults than juveniles even though juvenile spiders were abundant on the ground and in leaf litter (Topping & Sunderland 1992). Sex identification of juvenile spiders can be difficult as they will not have formed the identifying sexual morphologies e.g., epigyne in females and enlarged pedipalps in males. This could lead to a juvenile female identification bias (as only spiders in their last moult were identified as adults) and could potentially explain the increase in female juveniles over the six weeks in pitfall traps and potentially in the vibration-based technique discussed below (Merrett & Snazell 1983; Foelix 2011).

There were more juveniles (72%) than adults (28%) and more males (54%) than females (46%) captured in the night collection (Figure 4.5). Night collections can target spider nesting areas, resulting in a sampling bias towards juveniles for each of the three night collections (Privet et al. 2020). This bias can be avoided in future by selectively avoiding sampling nesting areas and clusters of juvenile spiders (Norris 1999; Privet et al. 2020). The proportion of males increases each fortnight from 171 spiders in week two to 222 spiders in week four to 257 spiders in week six whilst female spiders decreased from 224 to 204 to 135 spiders, respectively (Figure 4.5). Spiders are sexually dimorphic in size where female spiders are larger than male spiders indicating the females may have been easier to catch our attention during the night collections (Foelix 2011). Similarly, as discussed with the pitfall traps, males were more active possibly looking for a potential mate (Foelix 2011). This movement from males may have been just as equally easy to spot when searching for spiders nocturnally (Foelix 2011). This could explain why there was almost as many females sampled as there were males with the night collection. There is very little literature published on differences in male-female and adult-juvenile ratios for different survey techniques when surveying a spider population. This is presumably due to low abundance of each spider species. Often when a sex or age ratio is described, the publication only provides an overall description of the area rather than an age or sex ratio of spiders identified or the survey technique (R Raven 2021, pers. comm., 24 September).

There were more juveniles (68%) than adults (32%) and more females (74%) than males (26%) for the vibration-based technique (Figure 4.6). Over the hour of collections, the proportion of adults stayed within a narrow range whilst the proportion of juveniles collected had a much wider range (Figure 4.6). In contrast to pitfall traps and night collections, the vibration-based technique resulted in more females than males. While sex ratios will vary between species upon emergence from the egg sac, one possible explanation would be that females are more likely to respond to vibratory cues initiated from male counterparts and thus are more likely to respond to the vibration-based technique (Schüch & Barth 1990; Barth 1993; Hill 2001; Foelix 2011). If their reaction is copulatory based, one would then question why there would be more juveniles than adults responding to the vibration-based technique. A possible explanation is the identification bias towards the female juveniles discussed above, or juveniles were more abundant than adults at the time of the survey. The pitfall traps trend show an increase in juveniles each fortnight which might suggest why there were more juveniles than adults found with the vibration-based technique conducted after the pitfall traps as they both target ground-dwelling spider fauna (Figures 4.4 and 4.6).

As only spiders in their last moult were identified as adult (both male and female), this could explain why there were more juveniles than adults for all techniques. Further, many young are predated on or die before reaching adulthood leading to greater number of young than adults in the population (Foelix 2011). There is very little literature on the breeding seasons of spiders as there are thousands of different species and is difficult to assess. However, there has been two suggested breeding periods in November and February (summer) in Tasmania (Churchill 1995). As this survey was conducted just prior to November, many of the identified juveniles could have been one or two moults from maturing for this breeding season. In future, further classification of the maturation stage of a spider may help to clarify if these juvenile spiders were about to mature, or freshly hatched (Churchill 1995). Further research into the behavioural reaction of spiders to the vibration-based technique is required to answer why there were more females than males attracted to the vibration and why there were more juveniles than adults attracted to the vibration-based technique. Understanding their behavioural response to various vibrational frequencies would also further progress research into targeting differing spider species.

There was an observable difference in the targeted vegetative strata from all techniques (Figure 4.7). Pitfall traps and vibration-based technique target very similar vegetative strata (Figure 4.7). Both techniques resulted in 85% of the spider species to have been located in low vegetative strata (on the ground or in leaf litter below 0.5 m), with the remaining 15% found in the middle or high vegetative strata (above 0.5 m) (Figure 4.7). In comparison, however, night collections resulted in 63% of the spider species to have been located in middle or high vegetative strata with the remaining 37% found in low vegetative strata (Figure 4.7). This data supports the significant differences between night collection with pitfall traps and vibration-based techniques (Table 4.1). The sampling bias comes from the technologies used by each technique (Uetz 1991).

Pitfall traps were biased toward ground-active species such as Lycosidae, Gnaphosidae, and Zodariidae (Figure 4.9). These families are consistent with the most abundant species found in pitfall traps: *Genus M* sp.1*, Allocosa palabunda, Encoptarthria enc3, Genus J* sp.1 and *Habronestes* hab4 (Figure 4.8). A high abundance of spiders in these families in pitfall traps could be attributed to their inability to escape from the pitfall traps (Topping & Sunderland 1992). Most spiders caught in pitfall traps do not have claw tufts that allow them to attach themselves to vertical slippery surfaces such as the plastic of the pitfall traps (Uetz 1991; Topping & Sunderland 1992; Foelix 2011).

Night collections involve active searches for spiders in all vegetative strata and thus were more likely to result in a higher abundance of spiders caught in middle and high vegetative strata, than in pitfall traps (Figure 4.7) (Uetz 1991; Churchill & Arthur 1999). The most abundant species collected in night collection were *Argiope keyserlingi*, *Habronestes hab2*, *Habronestes hab4*, *Nuliodon fishburni*, and *Eriophora transmarina* (Figure 4.8). All of these spider species belonged to the most abundant families found in the night collections: Araneidae and Zodariidae. However, *Nuliodon fishburni* belongs to the Gnaphosidae family which is not one of the most abundant families

(Figure 4.9). This indicates Theridiidae (second most abundant family found in night collection) have a higher number of spider species collected in the night collection than Gnaphosidae. Araneidae and Theridiidae are some of the most abundant orb-weaving families and are thus more likely to be spotted and sampled when undertaking night collection (Uetz 1991; Scharff & Coddington 1997; Heiling & Herberstein 1999; Agnarsson 2004). Species such as *Nuliodon fishburni* and *Habronestes hab4* (ground-dwelling species) found in night collection, are abundant in the selected study areas as they are also one of the most abundant species in other survey techniques such as pitfall traps and or vibration-based technique (Figure 4.9).

The most abundant species collected from the vibration-based technique include *Habronestes hab2*, *Habronestes hab4*, *Nuliodon fishburni*, *Mituliodon tarantulinus*, and *Allocosa palabunda* (Figure 4.9). They belong to two of the most abundant families: Zodariidae and Miturgidae (Figure 4.8). *Allocosa palabunda* (Lycosidae family) is an abundant species of the study area, as it was also abundant in pitfall traps. This indicates the Corinnidae family have a greater number of species sampled with the vibration-based technique. Whilst both pitfall traps and vibration-based technique target low vegetative strata (Figure 4.7) and therefore capture more ground-dwelling species, the most abundant species differ between the two techniques (Figure 4.8 and 4.9). The differences in the most abundant families between the pitfall traps and the vibration-based technique could be attributed to the claw tufts that are present in Corinnidae and Miturgidae, as these families are abundant in the vibration-based technique but are not in pitfall traps. These families may not be as abundant in pitfall traps as the claw tufts may have allowed them to escape falling into the pitfall traps (Jocqué & Alderweireldt 2005; Wolff & Gorb 2012).

5.3 Accumulation curves

Completeness of an inventory of species likely to be found in an area can be described using a species accumulation curve (Coddington et al. 1996). As sampling time increases the likelihood of capturing additional species decreases (Coddington et al. 1996). All three survey techniques were still capturing additional species in the final collections indicating the inventory of species was not yet complete. Night collection produced the greatest number of additional species each collection with 105 additional species in the last collection at DR1 (Figure 4.11). Pitfall traps and the vibration-based collection were very similar with 40 and 41 additional species in the last collection at DR1 and RHA respectively (Figures 4.10 and 4.12).

(a) Pitfall traps

The accumulation curves for pitfall traps had DR1 increasing 67% between week two and week four from 15 additional species to 25 and a further 60% between weeks four and six from 25 to 40 additional species for that location (Figure 4.10). DR2 increased 120% between weeks two and four from 10 species to 22 and a further 27% between weeks four and six from 22 to 28 additional species for that location (Figure 4.10). RH increased 86% between week two and week four and a further 15% from 26 to 30 additional species for that site. RL increased 125% between weeks two and four from 8 species to 18 and a further 39% between weeks four and six from 18 to 25 additional species for that location. This indicates that across all locations, pitfall trapping would need to be extended in time to reach a point where there are no additional species.

Projection curves in data analyses were unlikely to predict how long the pitfall traps should be extended as there was not enough data.

Pitfall traps are usually left for months at a time without resetting the trap when surveying for spiders (Topping & Sunderland 1992; Churchill & Arthur 1999; Thomas et al. 2011; Hancock & Legg 2012; Azevedo et al. 2014; Bali et al. 2019). Pitfall traps were observed to be affected by external factors such as weather or other animals rendered the trap ineffective when left for long periods of time. This could lead to the loss of spiders captured in the pitfall trap and therefore a loss of data by the end of the pitfall trap collection. Collection every fortnight served to preserve those spiders already caught in the pitfall traps and by resetting the trap it became effective again if affected by flooding or disturbance.

The number of pitfall traps were found to influence the additional species captured (Figure 4.13). Across all locations, two pitfall traps (1 and 6) acquired 60% of species from the pitfall traps. With four pitfall traps (1, 2, 3, and 6), the total number of additional species increased 40% from 40 species in two pitfall traps to 56 species in four pitfall traps (Figure 4.13). With all six pitfall traps, the total number of additional species increased a further 20% from 56 species in four pitfall traps to 67 species in six pitfall traps (Figure 4.13). This suggests the number of pitfall traps is important in adequately surveying spider species richness. There is very little literature on the comparison of the number of pitfall traps used to survey spiders. However, the number of pitfall traps used to survey spiders varies between surveys but is often kept to a small number at one location to reduce the number of spiders acquired (Topping & Sunderland 1992; Churchill & Arthur 1999; Thomas et al. 2011; Hancock & Legg 2012; Azevedo et al. 2014; Bali et al. 2019; Privet et al. 2020). Pitfall trapping is often used in conjunction with other techniques such as night collection to survey a broader spider community than ground-active spiders (Topping & Sunderland 1992; Churchill & Arthur 1999; Thomas et al. 2011; Hancock & Legg 2012; Azevedo et al. 2014; Bali et al. 2019; Privet et al. 2020).

(b) Night collections

The accumulation curves for night collection indicated that DR1 spider species increased 59% between week two and week four from 46 additional species to 73 and a further 44% between weeks four and six from 73 to 105 additional species for that location (Figure 4.11). DR2 increased 51% between weeks two and four from 51 species to 77 and a further 21% between weeks four and six from 77 to 93 additional species for that location (Figure 4.11). RH increased 50% between week two and week four from 54 species to 81 species and a further 20% from 81 to 97 additional species for that site. RL increased 73% between weeks two and four from 45 species to 78 and a further 15% between weeks four and six from 78 to 90 additional species for that location (Figure 4.11).

This indicates that across all locations, night collection survey technique did not capture all potential species in the survey area. Projection curves in data analyses were unlikely to predict how many sessions night collections should be extended as there was not enough data. In future, however, alteration of the methodology of night collections could be used to acquire the accumulation of these additional species instead of increasing the number of collection sessions (Merrett & Snazell 1983; Churchill & Arthur 1999; Norris 1999; Tourinho et al. 2018; Privet et al. 2020). An increase in the number of searchers and the time spent at each location would increase the likelihood of more species found from each collection sooner (Merrett &

Snazell 1983; Churchill & Arthur 1999; Norris 1999; Tourinho et al. 2018; Privet et al. 2020).

(c) Vibration

The accumulation curves for the vibration-based technique found that between 10 minutes and 20 minutes the greatest number of extra species were captured at all locations with an average of 117% increase (Figure 4.12). However, three out of eight locations had no increase in the number of additional species captured between the 40 minute and 50 minute interval (Figure 4.12). Between the 50 minute and 60 minute interval only an additional average increase of 8% was recorded for all eight sites (Figure 4.12). Even though the 50 minute to 60 minute interval still acquired additional species, if time were restricted it would be recommended to reduce the vibration-based technique to 40 minutes instead of 60. This would still allow 92% of the vibration attracted species to be collected and sampled. A key limitation would be that there is no published literature on vibration as a spider survey technique, limiting the comparison of results from this research to previous literature. In future, further research into vibration as a survey technique could refine and improve the methodology of this survey technique. Further research is required to determine the effect of varying vibrational frequencies on different spider species to increase the survey efficiency. A more compact vibration generator needs to be developed to allow access to more inaccessible survey locations.

Chapter 6: Conclusions

In total, 2,294 spiders were identified into 34 families, 138 genera and 226 species. The hypothesis of this research was that vibration-based survey technique would be more efficient and result in a higher species diversity and richness than traditional survey techniques such as pitfall traps and night collection. To test the hypothesis, spider species richness and diversity, technique efficiency and spider community composition and accumulation curves for the spiders caught, using the different techniques were studied.

Night and vibration-based collections were the most efficient in terms of cost and time when compared to pitfall traps (Table 4.4). Night collections had the highest species richness and species diversity and were significantly different to pitfall traps and the vibration-based technique (Table 4.1). The vibration-based technique would be preferred over pitfall traps if a more comprehensive spider species list is needed as it produced more species with fewer families whilst pitfall traps produced less species with a greater number of families (Figure 4.3). A 10 minute interval of spider collection using vibration-based technique produced fewer adult males (preferred for species identification), than a fortnight of pitfall trapping, however, the total number of adult males collected in the vibration-based technique (in one hour) was greater than the total number of adult males in pitfall traps (in six weeks) (Figures 4.4 and 4.6). Therefore, if needing to acquire a greater number of adult males, the vibration-based technique would be more efficient and thus preferred over pitfall traps. Pitfall traps and the vibration-based technique overlap in the targeted vegetative strata, and if time were limited, the vibration-based technique is preferred. The vibration-based technique would be preferred over pitfall traps to capture families with claw tufts such as Corinnidae and Miturgidae. As indicated by the accumulation curves, pitfall traps need to be left open for a longer period than six weeks to obtain all additional species (Figure 4.10). In contrast, the accumulation curve for the vibration-based technique indicated that 60 minutes was enough time to obtain all spider species available (Figure 4.12). Night collections contributed at least 80% of all species collected, by the different techniques, and would be necessary for a comprehensive survey of spiders in an area. The vibration-based technique is a more time and cost-effective alternative to pitfall traps but should be used in conjunction with night collections to attain a broader spider community.

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Appendix

Appendix 1 - Complete species list of spiders collected

Family	Genus and Species
Amaurobiidae	*Dardurus Dar1*
Ammoxenidae	*Genus A Sp.1*
Araneidae	*Acroaspis acr1* *Anepsion peltoides* *Araneus acuminatus* *Araneus albotriangularis* *Araneus ara1* *Araneus ara1* *Araneus ara11* *Araneus ara12* *Araneus ara2* *Araneus ara3* *Araneus ara4* *Araneus ara5* *Araneus ara6* *Araneus ara7* *Araneus ara8* *Araneus ara9* *Araneus arenaceus* *Araneus cytarachnoides* *Araneus dimidiatus* *Araneus lodiculus* *Araneus lutulentus* *Argiope keyserlingi* *Austracantha minax* *Celaenia cel1* *Cyclosa cyc1* *Cyclosa trilobata* *Cyrtobil darwini* *Cyrtophora hirta* *Dolophones dol1* *Dolophones turrigera* *Eriophora eri1* *Eriophora transmarina* *Larinia montagui* *Neoscona theisii* *Nephila edulis* *Ordgarius monstrosus* *Phonognatha graeffi* *Phonognatha wagneri* *Plebs eburnus* *Poltys pol1*

Arkyidae	*Arkys walckenaeri*
Cheiracanthiidae	*Cheiracanthium che1* *Cheiracanthium che2* *Cheiracanthium che3*
Clubionidae	*Clubiona clu1* *Clubiona clu2* *Clubiona clu3*
Corinnidae	*Battalus bat1* *Iridonyssus formicans* *Iridonyssus iri1* *Iridonyssus kohouti* *Iridonyssus leucostaurus* *Nucastia nuc1* *Nyssus albopunctatus* *Nyssus coloripes* *Nyssus jaredwardeni* *Nyssus luteofinis* *Nyssus paradoxus* *Poecilipta janthina* *Poecilipta kgari* *Poecilipta kohouti* *Poecilipta poe1*
Cycloctenidae	*Cycloctenidae cyc1*
Deinopidae	*Deinopis subrufa*
Desidae	*Badumna bad1* *Badumna bad2* *Badumna bad3* *Barahna bar1* *Corasoides australis*
Family 1	*Genus B sp.1*
Gnaphosidae	*Eilica Eil1* *Eilica Eil2* *Eilica Eil3* *Encoptarthria enc1* *Encoptarthria enc2* *Encoptarthria enc3* *Encoptarthria enc4* *Encoptarthria enc5* *Encoptarthria enc6* *Genus C sp.1* *Genus D sp.1* *Genus E sp.1* *Genus F sp.1* *Genus G sp.1* *Genus H sp.1* *Hemicloea hem1* *Myandra Mya1*

	Zelotes zel1
Hahniidae	*Hahniidae hah1* *Hahniidae hah2*
Hersiliidae	*Tamopsis tam1*
Lamponidae	*Asadipus asa1* *Centrothele cen1* *Genus I sp.1* *Lamponata daviesae* *Pseudolampona brookfield* *Pseudolampona pse1*
Linyphiidae	*Laetesia lat1* *Laperousea lap1* *Laperousea lap2*
Liocranidae	*Orthobula ort1*
Lycosidae	*Allocosa palabunda* *Anomalosa ano1* *Artoria art1* *Genus J sp.1* *Genus L sp.1* *Genus M sp.1* *Genus N sp.1* *Genus O sp.1* *Tasmanicosa godeffroyi* *Tasmanicosa tas1* *Venatrix ven1* *Venonia micarioides*
Malkaridae	*Anarchaea ana1*
Miturgidae	*Argoctenus arg1* *Argoctenus arg2* *Genus P sp.1* *Mituliodon tarantulinus* *Miturga gilva* *Mitzoruga insularis* *Nuliodon fishburni* *Thasyraea tha1* *Tuxoctenus gloverae* *Zora zor1*
Nicodamidae	*Ambicodamus amb1*
Oonopidae	*Opopaea opo1*
Oxyopidae	*Oxyopes elegans* *Oxyopes oxy1* *Oxyopes oxy2* *Oxyopes oxy3*
Philodromidae	*Tibellus tenellus*
Pisauridae	*Ornodolomedes orn1*
Prodidomidae	*Molycria mol1*

Salticidae	*Cytaea cyt1*
	Genus Q sp.1 *Genus R sp.1* *Genus R sp.3* *Genus R sp.4* *Genus S sp.1* *Genus S sp.2* *Genus S sp.3* *Holoplatys hol1* *Holoplatys hol2* *Holoplatys hol3* *Holoplatys hol4* *Holoplatys hol5* *Holoplatys planissima* *Maratus mar1* *Maratus mar2* *Maratus mar3* *Maratus mar4* *Maratus mar5* *Maratus mar6* *Maratus purcellae* *Myrmarachne myr1* *Zenodorus orbiculatus* *Opisthoncus opi1* *Opisthoncus opi2* *Opisthoncus opi3* *Opisthoncus opi4* *Opisthoncus opi5* *Prostheclina pro1* *Sandalodes bipenicillatus* *Sandalodes san1* *Sandalodes san2* *Simaetha sim1* *Zebraplatys zeb1* *Zenodorus orbiculatus*
Sparassidae	*Delena cancerides* *Delena del1* *Isopedella flavida* *Neosparassus diana* *Pediana regina*
Tetragnathidae	*Leucauge decorata* *Tetragnatha tet1*
Theridiidae	*Achaearanea ach1* *Argyrodes antipodiana* *Ariamnes colubrinus* *Cryptachaea veruculata* *Dipoena dip1*

	Dipoena dip2
	Episinus bicornis *Euryopis elegans* *Euryopis eur1* *Euryopis eur2* *Euryopis eur3* *Genus T sp.1* *Genus U sp.1* *Genus V sp.1* *Genus V sp.2* *Genus W sp.1* *Janula bicornis* *Latrodectus hasselti* *Parasteatoda decorata* *Parasteatoda par1* *Parasteatoda par2* *Parasteatoda tepidariorum* *Phoroncidia pho1* *Rhomphaea cometes* *Steatoda ste1* *Theridion albostriata* *Theridion pyramidale* *Thwaitesia argentiopunctata* *Thwaitesia nigropunctata*
Thomisidae	*Cymbacha saucia* *Genus X sp.1* *Runcinia elongata* *Sidymella bicornis* *Sidymella sid1* *Stephanopis scabra* *Tharrhalea multopunctata* *Tmarus tma1* *Zygometis xanthogaster*
Trochanteriidae	*Trachycosmus tra1* *Trochanteriidae tro1*
Uloboridae	*Miagrammopes mia1* *Philoponella congregabilis*
Zodariidae	*Euasteron enterprise* *Habronestes hab1* *Habronestes hab2* *Habronestes hab3* *Habronestes hab4* *Hetaerica scenica* *Neostorena neo1* *Notasteron lawlessi*