Charlesworth Reserve Invertebrate Survey, Christchurch, Summer 2021 - 2022

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Contents

Abstract ... 3
Introduction ... 3
Methods ... 3
Results ... 7
Discussion ... 9
Conclusion ... 11
Recommendations ... 11
Appendix 1 ... 12
Appendix 2 ... 21
Appendix 3 ... 22
Appendix 4 ... 23
Acknowledgements ... 24
References ... 24

Abstract
This study surveyed a range of invertebrate fauna in Charlesworth Reserve, a coastal wetland located on the western edge of the Avon-Heathcote Estuary/Ihutai, Christchurch, New Zealand. Five different survey methods were used, recording 175 different invertebrate taxa. Using two survey methods from previous studies, I found persistence in pre-recorded invertebrate populations; the introduction of three new survey methods not used in previous studies of Charlesworth Reserve found additional taxa as well as pre-recorded invertebrate populations. Investigation into traits of endemic wētā, beetle and spider species are theorised as potential indicators of habitat quality. Vegetation in Charlesworth Reserve ranges from established native flora to exotic grasslands and such vegetation – including exotic grass – helps to provide diverse habitat for invertebrates to populate. Most ecosystems are reliant on invertebrate diversity for roles such as decomposition, pollination, dispersal, and predation. Invertebrates recorded within this study fill many of these roles and contribute to a sustainable ecosystem in Charlesworth Reserve.

Introduction
The objective of this study is to survey invertebrates present in Charlesworth Reserve. Multiple methods were used to survey flying, ground dwelling, and arboreal invertebrate species. Species richness, diversity and distribution were analysed and compared to different sites within the study and information from previous studies. We can expect to find few common species with many rare species being more habitat specific. Endemic species recorded throughout the study may hold potential traits for wetland indicator organisms. The primary aim of the study is to create an inventory of invertebrate fauna which can be used for future research and demonstrate a working ecosystem.

New Zealand (NZ) is the home to various endemic flora and fauna species making it a biological hotspot (Towns, 2002). Since human settlement, there has been the destruction of native habitats as well as the introduction of predatory mammals resulting in the loss of many of our endemic species. Wetlands have been a main area of degradation due to human intervention (Myers et al., 2013; Peters & Clarkson, 2012). By draining and development of these areas for cities and agriculture, important ecosystem services in these areas have been lost (Myers et al., 2013). Through restoration efforts, such as native plantings and predator control, environments have begun to rebuild (Ausseil et al., 2011; Walker et al., 2007). When restoring habitat, flora components are important for building habitat, but lower trophic levels such as invertebrates can restore structure and function to ecosystems (Bowie et al., 2019).

Using a range of survey techniques can help remove sampling bias of a particular invertebrate taxon (Montgomery et al., 2021). A study by Martin et al. (2005) shows how using species richness and diversity can be a measure of restoration success. Restoring community structure increases productivity encouraging further growth of plants and animal populations. Organisms that show endemism, vulnerability, and rarity can be a measure of ecosystem health. Also known as indicator organisms this method is used in many freshwater studies where organisms present or absent may suggest an excess nutrient or pollution level in a waterbody (Abellán et al., 2005). Currently, there is limited research on invertebrate wetland indicator species for assessing restoration success or habitat quality (Clarkson et al., 2004).

Methods
The study was conducted in Charlesworth Reserve. Further background information can be found in Appendix 2. Six independent sampling sites were set up throughout the reserve. Each site was selected to be a representative of a different habitat within the reserve, as described in Table 1 with Figure 1A and 1B showing the location of each site. Multiple methods including pitfall traps, beating sheets, malaise nets, scrape, and search, and active surveys were carried out at each site to create an inventory of invertebrate. Photographs of each organism were taken and uploaded to iNaturalist – Charlesworth Reserve Invertebrate Monitoring Project for further identification. A final taxon list was compiled of all the species found throughout the survey, located in Appendix 1. All statistical graphs were made within Excel or RStudio.

Table 1. Description of the local environment of each of the six sites surveyed in Charlesworth Reserve.

Site	Description
A	Sheltered location adjacent to Humphreys Drive. Dense vegetation in some areas with canopy ranging from 1 – > 3m. Sufficient leaf litter and moisture.
B	Located on the island of the mudflats. Mostly lowland shrubs < 2 m. Arid environment with low canopy cover. Site adjacent to dense shrub.
C	Located on the peninsula. Exposed location with arid climate. Vegetation consists of trees > 3 m and some shrubs. Thin canopy and low moisture.
D	Sheltered location next to the historical remnant. Vegetation consists of trees > 3 m and shrubs creating a dense canopy. Moderate moisture with sufficient leaf litter.
E	Opposite Charlesworth Street. Vegetation ranging from 1 - > 2m both trees and shrubs present. High moisture area with areas of dense grass cover.
F	Located in the Bund. Varying areas of shrubs > 2 m and patches of trees < 3m creating dense canopy. Area has high moisture and dense grass cover in some areas.

Figure 1A. A Google Earth image of Christchurch, New Zealand. The yellow box indicates the location of Charlesworth Reserve in the suburb Ferrymead, to the east of the Avon-Heathcote Estuary Ihutai. North Arrow in the top right, with scale in the bottom left.

Figure 1B. A Google Earth image of all six sites that were set up in Charlesworth Reserve with the red line indicating the Wetland boundary. North Arrow in the top right, with scale in the bottom left.

A total of 36 pitfall traps were set up throughout the reserve. Six pitfall traps per site were set up in random locations greater than 5 m apart and GPS coordinates were recorded. Clear plastic cups with a diameter of 85 mm and 125 mm long were used. A hole was dug and cups were placed in the hole and made flush with the ground, as seen in Figure 2A, focusing on trapping ground-dwelling insects (Sherley & Stringer, 2016). From November 2021 through to January 2022 pitfall traps were checked four times a week. Invertebrate presence and abundance was recorded, and species were later released back into Charlesworth. Water and debris were cleared from pitfall traps each visit.

Figure 2. Different survey methods used. (A) Pitfall trap placed in a dug hole and made level with the surface of the ground. (B) Beating sheet equipment creating a large white surface to catch invertebrates. (C) Malaise net set up at Site E.

Beating sheets method was carried out using a white cloth attached to the corner of two bamboo sticks that were crossed forming an X, as shown in Figure 2B. This created a large white surface 800 mm x 800 mm which was placed under vegetation of interest (Montgomery et al., 2021). At each site a 10 m x 10 m quadrat was measured and all vegetation within the quadrat was surveyed. A sturdy stick was used to dislodge invertebrates from the vegetation where they fell onto the white cloth. After surveying the invertebrates, they were returned to their host vegetation.

A malaise net is a passive method for surveying flying insects as seen in Figure 2C. The malaise net is a large 'tent-like' structure 2 m long by 1.2 m which is positioned to the North on a reasonably flat surface and pegged to the ground; concrete blocks were used to weigh down the pegs to limit net movement (Evans, 2016). Insects hit the net and fly upwards which funnels them into a collection container at the top of the net (Montgomery et al., 2021). A malaise net was set up at each site for a 24-hour period, and basic weather measurements were taken including temperature (°C), relative humidity (%) and wind speed (km/h). At the end of the 24-hour period, invertebrates were recorded, photographed, and released.

Scrape and search method was conducted following a similar surface scrape method carried out by Miller (2021). An area of 400 mm x 400 mm was scraped to remove surface debris which was then placed into a large container with a bright blue surface 300 mm x 400 mm. Invertebrates on the surface of the area were closely observed and litter in the container was carefully sorted through to record any invertebrates present. Three replicates of each surface scrape were carried out at each site; all species observed were recorded and photos were taken for further identification.

Active surveys were conducted by observing insects within the vicinity of the sampling site, and species were then identified and recorded separately from other methods taking place. Species were photographed as well as possible and recorded as part of the location they were observed.

Results

As seen in Table 2, over the observation period the most individuals were recorded at Site E counting a total of 1235 individuals. Site B counted the lowest number with 358 individuals. The greatest species richness of 86 species was found at Site F and the lowest was at Site B with 63 species. Using the Shannon Diversity Index (H) accounts for both richness and evenness, Site A had the greatest diversity (H = 3.8), whereas Site E had the lowest diversity (H = 2.8). Overall, the total number of individuals recorded was 3492 and 175 different taxa were identified. Of the 175 species found, we can classify them into two groups – rare and common. Using a baseline of 20, taxa found greater than 20 times were classified as common, and taxa found less than 20 times were classified as rare. From this study of the 175 taxa, 40 taxa were common, and 135 taxa were rare.

Table 2. Summary table of the total individuals, species richness and Shannon diversity at each site. The mean and standard error (SE) was calculated to summarise all sites.

	Site A	Site B	Site C	Site D	Site E	Site F	Total	Mean	SE
Total individuals	456	358	414	458	1235	570	3492	581.8	125.3
Species Richness	85	63	66	73	72	86	175	74.2	4.3
Shannon Diversity	3.8	3.5	2.9	3.5	2.8	3.6	-	3.4	0.18

Using different methods within each site helped remove the bias of surveying a particular invertebrate order. Figure 3 compares the number of taxa found in each order using each method relative to the total number of taxa found in each order. Pitfall traps surveyed a range of taxon from all orders but few from Lepidoptera. Malaise trapping was successful for flying species (Hymenoptera, Diptera and Coleoptera). Beating sheets surveyed many arboreal species, finding the largest number of Araneae species and many Hemiptera and Lepidoptera species. Scrape and search method surveyed many orders that deviated from the main eight orders found. These included orders such as Isopoda (pill bugs), Diplopoda (millipedes) and Lithobiomorph (centipedes) which are ground-dwelling species. Active surveys took place during all field methods recording mostly Lepidoptera, Diptera and Hymenoptera species. Ultimately, each method contributed to surveying of different taxa within Charlesworth Reserve.

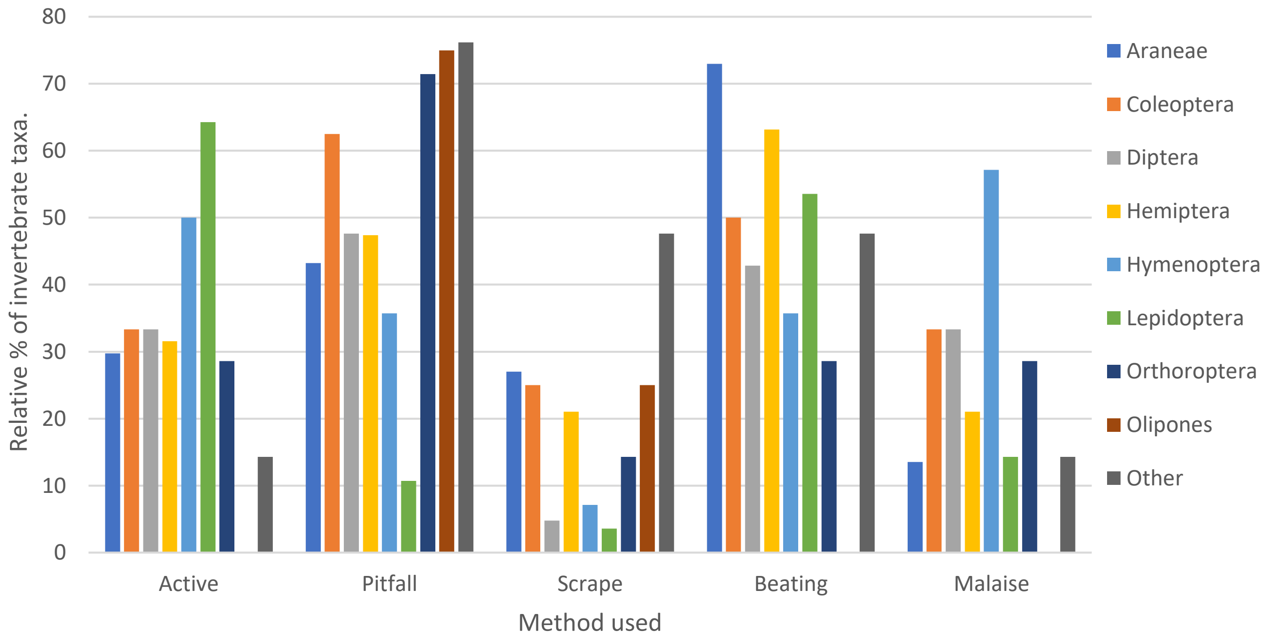

Figure 3. The relative percent of invertebrate taxa per order found with each method compared to the total number of taxa found throughout the whole study. Legend to the left of the graph shows orders of invertebrates.

As seen in Figure 3 pitfall traps were effective for surveying a range of invertebrate orders. Pitfall traps allowed the surveying of many endemic species, shown in Figure 4. *Hemiandrus celaeno* a species of Ground Wētā (Figure 4A) was found once at Site D. *Megadromus antarcticus* also known as the Alexandra Beetle endemic to Canterbury, was recorded twice in pitfall traps and once in scrape and search, all found at Site D (Figure 4B). *Allotrochosina schauinslandi* is an endemic Brown Wolf Spider that was recorded twice in Site A (Figure 4C). Overall, ground-dwelling species are most frequently recorded from pitfall traps.

Figure 4. Photographs of endemic species caught using pitfall traps. A) Hemiandrus celaeno, Ground Wētā. B) Megadromus antarticus, Alexander Beetle. C) Allotrochsina schauinslandi, Brown Wolf Spider.

Using beating sheets, tree species within each site varied in size and height, while density also affected access to some areas. From the data collected the most common vegetation at each site were *Cordyline australis* (Cabbage Tree), *Pittosporum tenuifolium* (Pittosporum), *Plagianthus divaricatus* (Saltmarsh Ribbonwood), *Veronica sp* (Hebe), *Myoporum laetum* (Ngaio), *Ehrharta erecta* (Grass) and other less encountered vegetative species. Figure 3 shows the beating sheet was most effective at surveying Araneae, Hemiptera and Lepidoptera species. Cabbage Trees were present in all sites but varied in the number of invertebrate species found in trees between sites, as shown in Figure 5. Site F was found to have 92 different species and Site B only 25 different species, but it should be noted there was limited access for sampling of some tree species.

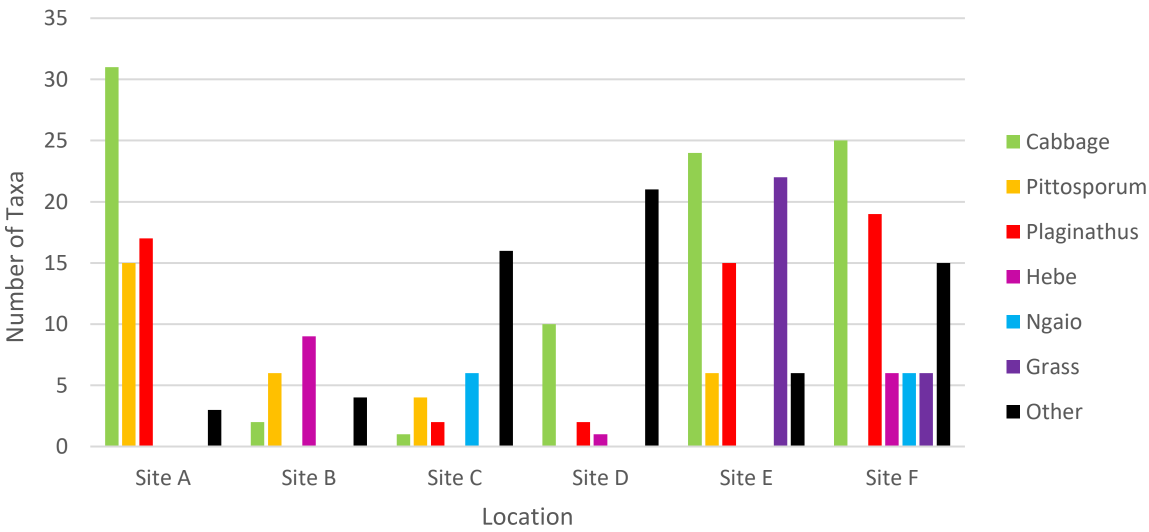

Figure 5. The number of different invertebrate taxa found from each vegetation type at the six different sites throughout Charlesworth Reserve. Note: not all sites had the same vegetation type. Legend to the left of the graph shows different vegetative species.

Malaise nets surveyed many Hymenoptera species, as seen in Figure 3. A regression analysis was conducted on the weather measurements collected, as seen in Figure 6. Figure 6A visually represents a positive relationship, a higher number of species in higher temperatures and windier conditions. The R^2 value demonstrates a weak relationship between these predictor variables. With an alpha of 0.05 the relationship for wind speed and temperature to predict number of taxa is insignificant (°C, P = 0.23, $F_{1,4}$ = 1.96, km/h, P = 0.12, $F_{1,4}$ = 3.86). Figure 6B displays a weak negative relationship demonstrated by the R^2 value between relative humidity and the number of species found. A downward trend can be seen visually, however, the regression is insignificant (%, P = 0.23, $F_{1,4}$ = 1.90). Overall, a greater number of samples may produce a significant result.

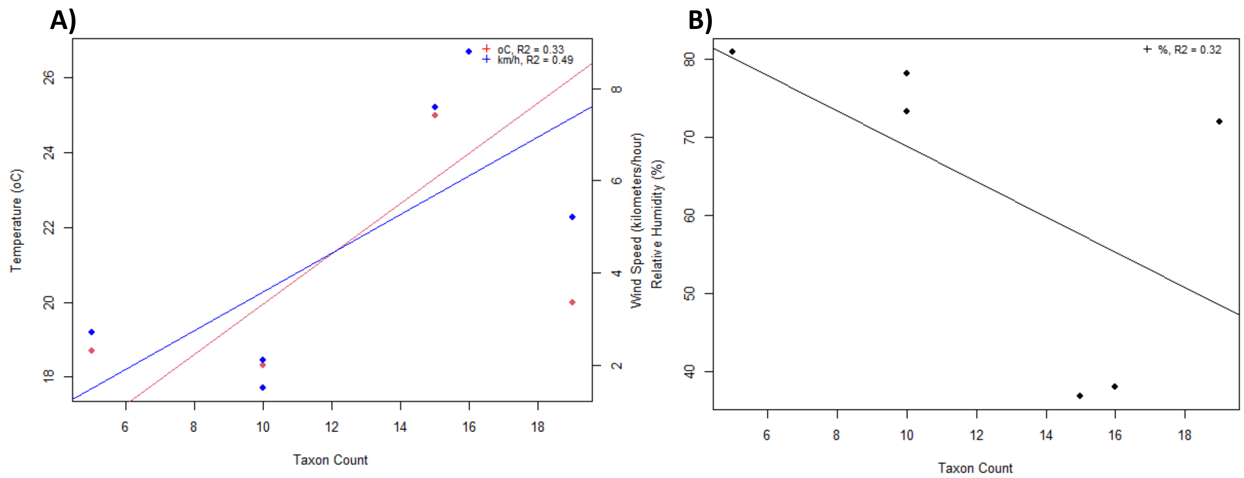

Figure 6. Scatterplot of Temperature (°C) on the y axis and Wind Speed (kilometres/hour) on the z axis versus the number of different taxa found on x axis. b) Scatterplot of Relative Humidity (%) verses the number of different taxa found.

The scrape and search method recorded a total of 35 taxa. A variety of detritivore species were identified, as seen in Figure 3 (other) with the most common species being *Armadillidium species* (pill bugs), *Amphipoda species* (Amphipods), *Oxychilus species* (glass snails) and *Lithobiomorpha species* (centipedes). Few of the species were flying or arboreal.

Active surveys were effective at surveying Lepidoptera and Hymenoptera species, shown by Figure 3. Common species observed from active surveys was the Bumblebee (*Megabombus species*) and Western Honeybee (*Apis mellifera*) both occurring greater than 50 times. Lepidoptera species observed most frequently were Winter Copper (*Lycaena species*), Dark-banded Carpet Moth (*Hydriomena deltoidata*) and Tortricid Leafroller Moth (*Epichorista siriana*) all occurring greater than 30 times. Odonata species including Red Damselfly (*Xanthocnemis zealamdica*) appeared 49 times in the survey and Blue Damselfly (*Austrolestes colensonis*) appeared twice.

Discussion

The primary aim of this study was to record invertebrate species present in Charlesworth Reserve by performing multiple invertebrate sampling methods. The information gathered allows a comparison with previous studies to examine persistence in invertebrate populations and to speculate what species could be used for assessing wetland condition. For example, dense native bush within the reserve was found to house many rare endemic species including wētā, spiders and beetles compared to exposed areas and exotic grasslands were found to house more exotic species, slugs, ants, and katydids. Thus, through future restoration, an increase in endemism would be expected as native plantings mature. The study also points to the value of exotic grasslands for encouraging biodiversity.

Comparing this to an early study by Ford (2017) shows the Alexander Beetle (*Megadromus antarcticus*) and Brown Wolf Spider (*Allotrochosina schauinsland*) have been found at Charlesworth Reserve previously but Ground Wētā (*Hemiandrus celaeno*) is a new record to the area. The presence of these endemic species since the last study suggests there is sufficient habitat and food source to sustain their populations. Pitfall traps surveyed species from multiple orders contributing to counts of both common and rare species. However, some species were unable to be collected in large numbers by any of the survey methods.

Endemic rare species could be used as potential indicator organisms (Abellán et al., 2005). Wētā are flagship species of NZ conservation as wells as having long lifecycles for invertebrate species (Leisnham et al., 2003). Because of the prolonged lifecycle of Ground Wētā, for this species to reach adulthood it may suggest sufficient habitat and food sources are available which could be used as a proxy for environment quality. Alexander Beetle is endemic to Canterbury, New Zealand, and the Brown Wolf Spider is endemic to New Zealand. Both these species are generalist predators, meaning they prey upon many species (Fountian, 2013; Sanders et al., 2015). It is suggested by Roth and Weber (2008) through their study of raptors that having predators present can indicate the diversity of several taxa. Although raptors and invertebrates are disparate there may be leading principles that apply to both trophic levels. Further research is needed to suggest how Ground Wētā, Alexander Beetle or Brown wolf spider could be used as indicator organisms.

Araneae was the most common order found using beating sheets, recording 27 different spider species. Spider diversity is important as they are predatory species, thus regulating prey populations (Samu et al., 2014). The diversity of invertebrate species found in trees, shrubs, and grasslands shows there is adequate shelter, food, and breeding grounds available. Future studies should consider accounting for height, leaf density and number of trees at each site to account for underlying variation of the sites. For example, comparing species richness between cabbage trees (*Cordyline australis*) shows huge ranges of high species richness to low species richness from the same tree species.

Hymenoptera include ants, bees, wasps, and sawflies. More Hymenoptera species were caught through malaise trapping than by alternative methods. These species can play an important role in pollination as well as suppressing pest species through parasitism (Lindauer, 2019). Weather measurements obtained throughout this study show insignificant relationships between wind speed, temperature, relative humidity, and taxon count. A study by Vebrová et al. (2018) shows how lower relative humidity can limit invertebrate activity; it also suggests temperature and relative humidity are collinear. Therefore, high temperatures with high humidity result in a greater number of active flying individuals being trapped in the net. High wind speeds may also affect taxon count depending on the wind strength; higher wind speeds can disperse soft-bodied insects, but also restrict flight of some species (Vebrová et al., 2018). It is important for future studies to account for weather variation between sites. Taking more replicates would give a clearer relationship between the number of species caught and weather conditions.

Grassland density was thickest at Sites E and F which both had high species richness. Drier sites, Sites B and C, with lower grass density had a lower species richness. Site A and D vegetation was dense with canopy leaf litter, leaving smaller areas for grass for surveying but key endemic species – Alexander Beetle, Ground Wētā and Brown Wolf Spiders –were, nonetheless, found in these sites. While statistical analysis has yet to be undertaken, it is suggested that sites with grassland and leaf litter have a higher species richness than dry sites. Having the one type of grass present can suppress noxious weeds while native plantings establish (Beyers, 2009). Although grasses can compete with native plantings, coastal wetlands are prone to drought because of high salinity. Grass can cover exposed soil to help retain moisture until the canopy is high enough to create a leaf litter carpet (Wang et al., 2012). As native plantings mature, we will begin to see a reduction in exotic grasses and re-establishment of native and endemic species.

Detritivorous species were commonly found using the scrape and search method, as in previous studies by Ford (2017) and Miller (2021) that frequently found these species. Abundant Detritivore including millipedes, centipedes, pill bugs, and snails were found in their highest densities in August through the scrape and search method (Miller, 2021). Thus, during the November 2021 to January 2022 survey period abundance may not have been at its highest. Ford (2017) reports centipedes, slugs, snails, spiders, and millipedes were the most common invertebrates found in Charlesworth Reserve. This is consistent with results from this project with all the common invertebrates being found greater than 20 times. Ultimately, the presence of these detritivores throughout multiple studies and a large distribution across Charlesworth Reserve indicates the cycling of organic material.

Active observations were a sufficient way to survey flying invertebrate species that could not be obtained by the other trapping methods. Hymenoptera species observed were mostly bees *Megabombus sp* (Bumblebees) and *Apis mellifera* (Western Honeybee). Although most bee species seen were introduced species they are still evidence of pollination. Winter Copper (*Lycaena species*) were commonly seen through active surveys which pollinate *Muehlenbeckia complexa* native to NZ. While not recorded in this survey, sightings throughout Charlesworth Reserve have located the butterfly Rauparaha copper (*Lycaena rauparaha*) which is endemic to

NZ. Damselflies are aquatic species which can often be used as indicator species for water quality. The larval stage of damselflies is aquatic and the adult stage is terrestrial, therefore seeing damselflies present may indicate the water quality is sufficient to support the larval stage (Silva et al., 2010). Further research into aquatic indicators is required before reaching more definitive conclusions.

Conclusion

The aim of this study was to survey invertebrates present in Charlesworth Reserve and to compile an inventory of invertebrate fauna. 175 different taxa were found, of which 40 were common and 135 were rare. The use of multiple surveying methods contributed to the substantial inventory of invertebrate species recorded, including three new survey methods not used in previous studies of the reserve. The use of different methods also helped remove bias in the invertebrate data. Vegetation in Charlesworth Reserve ranges from established native flora to exotic grasslands and so helps provide diverse habitat for invertebrates to populate. Significantly, grassland and leaf litter habitats were found to have greater species richness than sites lacking these habitats. The presence of pollinators, dispersers, detritivores, and predators demonstrates that Charlesworth Reserve is already a working ecosystem and points to the success of restoration efforts. With further establishment of native vegetation, we can expect to see an increase in endemic and native invertebrate species. It is recommended that future studies investigate underlying environmental factors to help explain the diversity and distribution of invertebrates throughout the wetland. Areas of further research could include wetland indicator organisms, post-predator control and different vegetative communities to assess restoration success and habitat quality.

Recommendations

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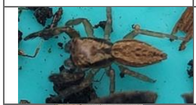
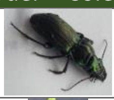
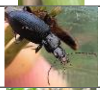
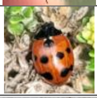
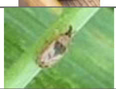
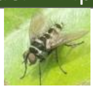
1. That the value of exotic grasslands is better recognised as a habitat for invertebrates, as for other wetland fauna, in Canterbury's severely degraded environment and that Christchurch City Council not routinely mow expanses of exotic grass, to facilitate habitat for endemic and native invertebrate species.
2. That funding is allocated for further research into indicator species of ecosystem health in wetlands, for example on the Ground Wētā, Alexander Beetle and Brown wolf spider as indicator organisms, on the effects of predator control in restoration projects, and on habitats provided by different vegetative communities during wetlands restoration.
3. Building on evidence of restoration success at Charlesworth Reserve, that further support is made available for wetland restoration programmes to increase habitats and improve adaptive capacity in the Te Ihutai/Avon-Heathcote Estuary catchment.

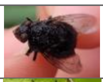
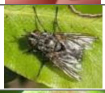
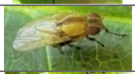
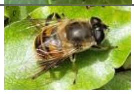
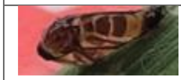
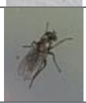
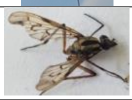
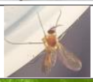
Appendix 1

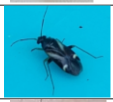
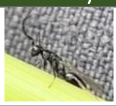
Table 3. Taxon list displaying identification of all the species encountered throughout the survey at Charlesworth Reserve. Within methods column; P = pitfall traps, A = active survey, S = scrape and search and BS = beating sheets. All observations can be found on iNaturalist at - https://www.inaturalist.org/projects/charlesworth-reserve-invertebrate-monitoring

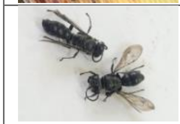
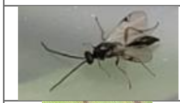
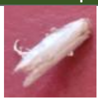
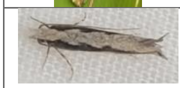
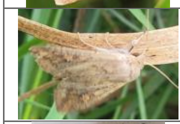
	Family	Genus	Species	Common Name	Method
Order – Araneae: 37 Species					
	Lycosidae	*Anoteropsis*	*Anoteropsis sp.*	Wolf Spider	P
	Theridiidae	*Steatoda*	*Steatoda capensis*	Black Cobweb Spider	S, P, BS.
	Salticidae	*Trite*	*Trite planiceps*	Black-headed Jumping Spider	BS
	Salticidae	*Helpis*	*Helpis minitabunda*	Bronze Hopper	P, BS, A.
	Lycosidae	*Allotrochosina*	*Allotrochosina schauinslandi*	Brown Wolf Spider	P.
	Theridiidae	-	*Theridiidae sp*	Cobweb spiders	BS
	Linyphiidae	*Diplocephalus*	*Diplocephalus sp*	Money Spider	P, S, BS, M
	Thomisidae	*Diaea*	*Diaea ambara*	Crab Spider	BS
	Theridiidae	*Steatoda*	*Steatoda sp*	False Widow Spiders	A, S.
	Thomisidae	*Diaea*	*Diaea sp*	Flower Spiders	P, BS
	Salticidae	*Trite*	*Trite auricoma*	Golden-brown Jumping Spider	BS, S, A.
	Oxypidae	*Oxyopes*	*Oxyopes gracilipes*	Graceful-legs Lynx	A, S, BS
	Gnaphosoidae	-	*Gnaphosoidae sp*	Ground Spiders	BS
	Desidae	*Badumna*	*Badumna sp*	House Spider.	BS
	Salticidae		*Salticidae sp*	Jumping Spider.	P, S, BS
	Araneidae	*Eriophora*	*Eriophora pustulosa*	Knobbled Orbweaver	A, BS
	Clubionidae	*Clubiona*	*Clubiona sp*	Leafcurling Sac Spiders	BS
	*Tetragnathidae*	*Tetragnatha*	*Tetragnatha sp*	Long-Jawed Orbweavers	BS

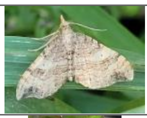
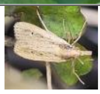
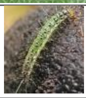
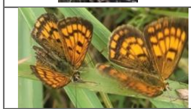
	Dictynoidea	-	*Dictynoidea sp*	Meshweavers and allies	BS
	Araneidae	*Novaranea*	*Novaranea queribunda*	Orbweaver	A
	Plsauridae	*Dolomedes*	*Dolomedes minor*	Nurseryweb spider	A, BS.
	Araneidea	-	*Araneidea sp*	Orbweavers	BS, M.
	Mimetidae	Australomimetus	*Australomimetus sp*	Pirate Spiders	P
	Linyphiidae	-	*Linyphiidae sp*	Sheetweb and Dwarf Weavers	P, BS.
	Desidae	*Cambridgea*	*Cambridgea sp*	Sheetweb spiders	P
	Uloboridae	*Philoponella*	*Philoponella congregabilis*	Social House Spider	BS
	Araneidae	*Cyclosa*	*Cyclosa fuliginata*	Sooty Orbweavers	A, BS.
	Thomisidae	*Sidymella*	*Sidymella angularis*	Square-ended Crab Spider.	A, BS.
	Thomisidae	*Sidymella*	Sidymella sp.	Square-Ended Crab Spiders.	A, P, B, M.
	Corinnidae	*Nyssus*	*Nyssus coloripes*	Spotted Ground Swift Spider	A
	Theridiidae	*Rhomphaea*	*Rhomphaea urquharti*	-	BS.
	Araneomorphae	-	*Araneomorphae sp*	Typical Spiders	P, M, BS.
	Zoropsidae	*Uliodon*	*Uliodon sp*	Vagrant Spiders	P.
	Araneidae	*Zealadranea*	*Zealaranea crassa*	Whitebanded Orbweb Spider	BS.
	Lycosidae	-	*Lycosidae sp*	Wolf Spider	P, S, BS.
	Dysderidae	*Dysdera*	*Dysdera crocata*	Woodlouse Spider	P.
	Desidae	*Poaka*	*Poaka graminicola*	Intertidal spider.	BS.
Order – Coleoptera: 24 Species.					
	Carabidae	*Megadromus*	*Megadromus antarcticus*	Alexander Beetle	P, S
	Entiminae	-	*Entiminae sp*	Broad-nosed Weevils	P

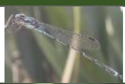
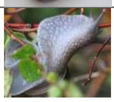
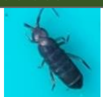
	Entiminae	*Chalepistes*	*Chalepistes spermophilus*	*Chalepistes spermophilus*	A, P, S, BS
	Elateridae	*Conoderus*	*Conoderus exsul*	Pasture Wire Worm	BS
	-	-	*Coleoptera sp*	Beetles	M
	Carabidae	*Laemostenus*	*Laemostenus complanatus*	Cosmopolitan Ground Beetle	A, P, S, BS
	Coccinellidae	*Coccinella*	*Coccinella undecimpunctata*	Eleven-spotted Ladybird Beetle	P, BS, M
	Lamiinae		*Lamiinae sp*	Flat-faced Longhorn Beetle	P, S, BS
	Lamiinae	*Xylotoles*	*Xylotoles sp*	Flat-faced Longhorn Beetle	P
	Lamiinae	*Psilocnaeia*	*Psilocnaeia sp*	Flat-faced Longhorn Beetle	P
	Scarabaeidae	*Costelytra*	*Costelytra zealandica*	Grass Grub Beetle	A, P, S, M
	Anthribidae	*Euciodes*	*Euciodes suturalis*	Grass Stem Anthribid	A, P, BS, M
	Coccinellidae	*Rhyzobius*	*Rhyzobius sp*	Lady Beetles	BS
	Scirtidae	-	*Scirtidae sp*	Marsh Beetle	A, P, BS, M
	Latridiidae	*Cartodere*	*Cartodere bifasciata*	Minute Brown Scavenger Beetle	BS, S
	Melonlonthinae	*Odontria*	*Odontria sp*	June Beetle	P
	Coccinellidae	*Coccinella*	*Coccinella leonina*	Orange-spotted Ladybird beetle	A
	Curculionoidea	*Peristoreus*	*Peristoreus sp*	True Weevils	BS, P
	Curculionidea	*Aneuma*	*Aneuma rubicale*	Pittosporum Flower Weevil	BS
	Anthribidae	*Hoherius*	*Hoherius meinertzhageni*	Ribbonwood fungus Weevil	M
	Staphylinidae	-	*Staphylinidae sp*	Rove Beetle	P
	Curculionoidea	-	*Curculionoidea sp*	Snout and Bark Beetles	M
	Melyridae	-	*Melyridae spp*	Soft-winged Flower Beetle	P, BS, M
	Coccinellidae	Adalia	*Adalia bipunctata*	Two-spotted Ladybeetle	A, P
Order – Diptera: 21 Species					
	Tachinidae	*Trigonospila*	*Trigonospila brevifacies*	Australian Leafroller Tachinid	A, P, BS
	Stratiomyidae	*Benhamyia*	*Benhamyia apicalis*	Benhamyia apicalis	A, P

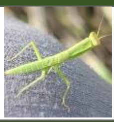
	Oestroidea	-	-	Bot Flies, Blow Flies and Allies	P
	Brachycera	-	*Brachycera sp*	Brachyceran Flies	P
	Calliphoridae	*Calliphora*	*Calliphora sp*	Brown Blow Fly	A, P, BS
	Lauxaniidae	*Sapromyza*	*Sapromyza neozelandica*	Brown-striped Litter Fly	M
	Syrphidae	*Eristalis*	*Eristalis tenax*	Common Drone	A, ACO
	Sciaroidea	-	Sciaroidea	Fungus Gnats/Gall Midges	P, BS
	Muscidae	-	*Muscidae sp*	House Flies and Allies	A, P
	Syrphidae	-	*Syrphidae sp*	Hover Flies	A, BS
	Agromyzidae	*Liriomyza*	*Liriomyza spp*	Leaf-miner Flies	A, BS
	Limoniidae	-	*Limoniidae spp*	Limoniid Crane Flies	BS
	Dolichopodidae		*Dolichopodidae sp*	Long Legged Flies	ACO, M
	Dolichopodidae	*Tetrachaetus*	*Tetrachaetus bipunctatus*	Long-legged Flies	M
	Therevidae	*Ectinorhynchus*	*Ectinorhynchus spp*	Member of Stiletto Flies	P, S
	*Nematocera*	-	*Nematocera spp*	Nematoceran Flies	P, M
	*Chironomoidea*	-	*Chironomoidea sp*	Non-biting Midges	A, P, M, BS
	Dolichopodidae	*Parentia*	*Parentia sp*	Parentia (Fly)	A, BS, M
	Asilidae	*Neoitamus*	*Neoitamus spp*	Robber Flies	A
	Simuliidae	*Austrosimulium*	*Austrosimulium sp*	Sandflies	P, S, BS, M
	Syrphinae	*Eocheilosia*	*Eocheilosia sp*	Typical Hover Flies	BS
Order – Hemiptera: 19 Species					
	Aphididae	-	*Aphididae spp*	Aphids	P, S, BS, M
	Berytidae	*Bezu*	*Bezu wakefieldi*	Bezu wakefieldi	P
	Delphacidae	-	*Delphacidae sp*	Delphacidae	p
	Miridae	*Deraeocoris*	*Deraeocoris maoricus*	*Deraeocoris maoricus*	P, BS
	Aphrophoridae	*Philaenus*	*Philaenus spumarius*	Meadow Spittlebug	P, BS

	Miridae	*Chinamiris*	*Chinamiris aurantiacus*	Ngaio Mirid	BS
	Pentatomidae	*Monteithiella*	*Monteithiella humeralis*	Pittosporum Shield Bug	A, P, BS
	Miridae	-	*Miridae sp*	Plant Bugs	P, S, BS, M
	Miridae	*Romna*	*Romna sp*	Plant Bugs	BS
	Psylloidea	-	*Psylloidea sp*	Psylloid	A
	Lygaeidae	*Arocatus*	*Arocatus rusticus*	Swan plant seed bug	BS
	Emesinae	*Empicoris*	*Empicoris sp*	Thread-legged Bugs	BS
	Fulgoroidea	*Siphanta*	*Siphanta acuta*	Torpedo Bug	BS
	-	-	-	True Bugs, Hoppers, Aphids, and Allies	A
	*Auchenorrhyncha*		*Auchenorrhyncha sp*	True Hoppers	A, P, M
	Aphrophoridae	-	*Aphrophoridae sp*	True Spittlebugs	M
	Miridae	*Stenotus*	*Stenotus binotatus*	Two Spotted Grass Bug	M
	Cicadidae	-	*Cicadidae sp*	Typical Cicadas	A, BS
	Cicadellidae	-	*Cicadellidae sp*	Typical Leafhoppers	P, S
Order – Hymenoptera: 14 Species					
	-	-	-	Ants, Bees, Wasps, and Sawflies.	M
	Vespidae	*Polistes*	*Polistes chinesis*	Asian Paper Wasp	A
	Braconidae	-	*Microgastrinae sp*	Braconid Wasp	BS
	Apidae	*Bombus*	*Megabombus sp*	Bumblebee	A, P, BS, M
	Chalcidoidea		*Chalcidoidea sp*	Chalcidoid Wasps	M
	Formicidae	*Ochetellus*	Ochetellus glaber	Copper-bellied ant	P, S, BS, M
	Vespidae	*Ancistrocerus*	*Ancistrocerus gazella*	European Tube Wasp	M
	Vespidae	*Vespula*	*Vespula vulgaris*	Common Wasp	A

	Ichneumonidae	-	*Ichneumonidae sp*	Ichneumonid Wasp	A, P, BS, M
	Colletidae	Leioproctus	*Leioproctus sp*	Leioproctus	A
	Colletidae	*Hylaeus*	*Hylaeus*	Masked Bees	A
	Crabroninae	*Pison*	*Pison morosum*	Pison morosum square headed wasp	P
	Proctotrupidae		*Proctotrupidae sp*	Proctotrupidae	M
	Apidae	*Apis*	*Apis mellifera*	Western Honeybee.	A, P
Order - Lepidoptera: 28 species					
	-	-	-	Butterflies and Moths	M, S
	Gelechioidea	*Batrachedra*	*Batrachedra sp*	Batrachedra	BS
 (Photo by Noah Fenwick)	Pieridae	*Pieris*	*Pieris rapae*	Cabbage White	A
	Tortricinae	*Capua*	*Capua semiferana*	Capua semiferana	BS
	-	-	*Lepidoptera sp*	Unidentified Catepillar	P, BS
	Oecophoridae	-	*Oecophoridae sp*	Concealer Moths	BS
	Geometridae	*Hydriomena*	*Hydriomena deltoidata*	Dark-banded Carpet Moth	A, BS
	Tineidae	*Erechthias*	*Erechthias fulguritella*	*Erechthias fulguritella*	BS
	Geometridae	-	*Geometridae sp*	Geometer Moths	A, BS
	Stathmopodida e	*Stathmopoda*	*Stathmopoda plumbiflua*	Greylined Featherfoot	BS
	Oecophoridae	*Leptocroca*	*Leptocroca sp*	Leptocroca	P, BS, M
	Torticidae	*Epiphyas*	*Epiphyas postvittana*	Light Brown Apple Moth	A
	Noctuidae	*Mythimna*	*Mythimna separata*	Northern Armyworm	A
	Tineidae	*Opogona*	*Opogona comptella*	Opogona comptella	A

	Crambinae	*Orocrambus*	*Orocrambus ramosellus*	Orocrambus	A
	Noctuoidea	-	*Noctuoidea sp*	Owlet Moths and Allies	S, A
	Nymphalidae	*Vanessa*	*Vanessa atalanta*	Red Admiral	A
 (Photo by Noah Fenwick)	Glyphipteriginae	*Glyphipterix*	*Glyphipterix triselena*	Sedge Moths	A
	Geometridae	*Homodotis*	*Homodotis megaspilata*	Small Hooked-Tip Looper Moth	A
	Crambidae	*Eudonia*	*Eudonia sabulosella*	Sod Webworm	A
	Gelechiodea	*Stathmopoda*	*Stathmopoda sp*	Stathmopoda	BS, M
	Oecophoridae	*Tingena*	*Tingena sp*	Tingena	A, BS
	Tortricidae	*Epichorista*	*Epichorista sp*	Tortricid Leafroller Moth	A, BS
	Elachistidae	*Elachista*	*Elachista sp*	Typical Grass Miner Moths	A, M
	Crambidae	*Uresiphita*	*Uresiphita sp*	Uresiphita (Catepillar)	S, A
	Lycaenidae	*Lycaena*	*Lycaena sp*	Winter Copper	A
	Stathmopodida e	*Stathmopoda*	*Stathmopoda skelloni*	Yellow Featherfoot	BS
	Nymphalidae	*Vanessa*	*Vanessa itea*	Yellow Admiral	A
Order – Opiliones: 4 species					
	-	-	*Opiliones sp*	Harvestmen	S
	Sclerosomatida e	*Nelima*	*Nelima doriae*	Sclerosomatid Harvesmen	P
	Phalangioidea	-	*Phalangiodea sp*	Eupnoan Harvestmen	P
	Triaenonychida e	-	*Triaenonychidae sp*	Triaenonychidae Harvestmen	P
Order – Orthoptera: 7 species					
	Tettigoniidae	*Caedicia*	*Caedicia simplex*	Australian Common Garden Katydid	A, BS
	Trigonidiinae	*Metioche*	*Metioche maorica*	Sword-tailed crickets	A, P, M

	Rhaphidophoridae	-	*Rhaphidophoridae*	Camel Crickets, Cave Crickets and Cave Wētā.	P
	Macropathinae	-	Macropathinae sp	Cave Wētā.	P
	Anostostomatidae	*Hemiandrus*	*Hemiandrus celaeno*	Ground Wētā.	P
	Tettigoniidae	*Conocephalus*	*Conocephalus bilineatus*	Common Meadow Katydid	A, BS, M
	Anostostomatidae	-	*Anostostomatidae sp*	Wētā and King Crickets	P
Order – Isopoda: 2 species					
	Armadillidiidae	*Armadillidium*	*Armadillidium sp*	Pillbugs	P, S
	Armadillidiidae	*Armadillidium*	*Armadillidium vulgare*	Common pill woodlouse	P
Order – Neuroptera: 2 species					
	Hemerobiidae	*Drepanacra*	*Drepanacra binocula*	Australian alexanderble lacewing	BS
	Hemerobiidae	*Micromus*	*Micromus tasmaniae*	Tasmanian Brown Lacewing	P, BS
Order – Odonata: 2 species					
	Lestidae	*Austrolestes*	*Austrolestes colensonis*	Blue Damselfly	A
	Coenagrionidae	*Xanthocnemis*	*Xanthocnemis zealandica*	Red Damselfly	A
Order – Stylommatophora: 2 species					
	Oxychilidae	*Oxychilus*	*Oxychilus spp*	Glass Snail	P, S
 (photo by Noah Fenwick)	Helicidae	*Cornu*	*Cornu aspersum*	Garden Snail	A, P
Order – Amphipoda: 1 specie					
	Talitridae	-	*Talitridae sp*	Amphipods	P, S
Order – Blattodea: 1 specie					
	-	-	*Blattodea sp*	Cockroaches	P, S
Subclass – Collembola: 1 specie					
	-	-	*Collembola sp*	Springtails	S, P
Order - Decapoda: 1 specie					
	Varunidae	*Austrohelice*	*Austrohelice crassa*	Tunneling Mud Crab	P

Order – Dermaptera: 1 specie					
	Forficulidae	*Forficula*	*Forficula auricularia*	European Earwig	P, BS, M
Class – Dipolopoda: 1 specie					
	Juliformia		*Juliformia sp*	Millipede	P, S
Order – Haplotaxida: 1 specie					
	Lumbricidae	*Lumbricus*	*Lumbricus sp*	Earthworm	P, S
Order – Lithobiomorpha: 1 specie					
	-	-	*Lithobiomorpha sp*	Stone Centipede	P, S
Order – Mantodea: 1 specie					
	Mantidae	*Orthodera*	*Orthodera novaezealandiae*	New Zealand Mantis	A, BS
Order – Polydesmida: 1 specie					
	-	-	*Polydesmida sp*	Flat-backed millipede	P, S
Order – Psocodea: 1 specie					
	-	-	*Psocodea sp*	Barklice, booklice, and parasitic lice	P, BS
Order – Trombidiformes: 1 specie					
	Anystidae	*Anystis*	*Anystis sp*	Whirligig Mites	P, S, BS, M
Order – Thysanoptera: 1 specie					
	-	-	*Thysanoptera sp*	Thrips	BS

Appendix 2

Background of Study Site

Charlesworth Reserve is a 20-hectare wetland on the western edge of the Avon-Heathcote Estuary Ihutai, Christchurch, New Zealand (-43.55137, 172.70094). The reserve has been undergoing restoration since early 2002 by landscaping, native plantings, and predator control. Historically, the reserve was remnant saltmarsh which was converted to grazing land for farming from 1920 - 1990. Through restoration efforts of the Avon-Heathcote Estuary Ihutai Trust (Estuary Trust) volunteers and Christchurch City Council Park Rangers the reserve now consists of a tidal basin forming mud flats at low tide and islands for nesting birds. The mud flats are surrounded by saltmarsh, coastal shrubland and coastal bush. These habitats provide nesting, roosting, and feeding sites of native and migratory birds, fish, estuarine marine life, lizards, aquatic, and terrestrial invertebrates.

From the beginning of restoration over 130,000 trees, shrubs and marsh vegetation have been planted in the reserve. Volunteers of Charlesworth Reserve play a huge role in actively restoring and maintaining the plantings throughout the wetland. The Estuary Trust organises working bees and community planting days which are supported by Trees for Canterbury.

Previous studies in Charlesworth Reserve have been carried out by Ford (2017) and Miller (2021). Ford's study focused on small mammal and arthropod monitoring from 2015 – 2017. Miller carried out a monitoring project surveying pests, invertebrates, birds, and other observations from 2020 – 2021.

Appendix 3

Lizard Monitoring

When pitfall traps were being checked for the invertebrate survey, it was a common occurrence to catch *Oligosoma polychroma,* a New Zealand Grass Skink in the traps. A total of 30 skinks were counted over the survey period. Figure 6 shows the greatest number of individuals were found at Site A and Site E. Site D and Site C were found to record the least number of individuals. Collectively, all sites were found to have skinks present.

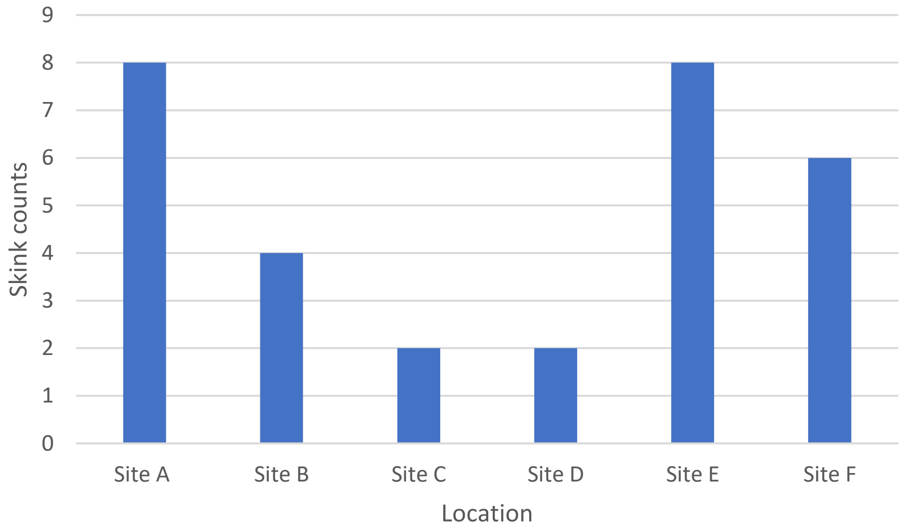


Figure 6. The number of Oligosoma polychroma - New Zealand Grass Skink - individuals found in pitfall traps at each survey site.

Oligosoma polychroma (O. polychroma) was present at all sites in Charlesworth Reserve. *O. polychroma* feeds primarily on invertebrates but also seeds and fruit making them an important agent of dispersal (Freeman, 1997). A total of 30 skinks were caught from all traps over the course of two months. Comparing this number of skinks to a previous study by Ford (2017), who captured a total of 16 skinks suggests sufficient food availability to sustain these skink populations. We can infer that pitfall traps were an effective method for surveying lizard populations in Charlesworth Reserve. Furthermore, it should be noted during the study mark-recapture was not accounted for allowing for multiple surveys of the same lizard. Ultimately, pitfall traps with the mark-recapture technique will be suited for a true count of lizard populations in future studies.

This study was not directly looking at the links of grassland and species present, but we can also make indirect links with lizard populations. Looking at data from pitfall traps, areas dense in grasslands had a higher number of skink encounters. There is little research being done on the effects of exotic grassland on restoration and species composition within these habitats.

Table 4. Lizard specie found in Charlesworth Reserve.

	Family	Genus	Species	Common Name	Method
Order – Squamata: 1 specie					
	Scincidae	*Oligosoma*	*Oligosoma polychroma*	New Zealand Grass Skink	P

Appendix 4

Tracking of Introduced Mammalian Predators

Tracking tunnels composed of 3 mm corflute black plastic measuring 100 mm x 100 mm x 500 mm were randomly allocated to a position in each of the six sites (one tunnel per site). A tracking tunnel card was placed in each tunnel, a sponge with food colouring and peanut butter was placed on the tracking card in the middle of the tunnel. Tunnels were baited the night before and tracking cards were collected the following day. Prints left by the animals moving through the tunnel were identified using a footprint identification guide by Gillies and Williams (NA). Tracking cards were baited at each site on the following dates: 27/11/2021, 08/12/2021, 13/12/2021, 21/12/2021, 01/01/2022 and 04/01/2022.

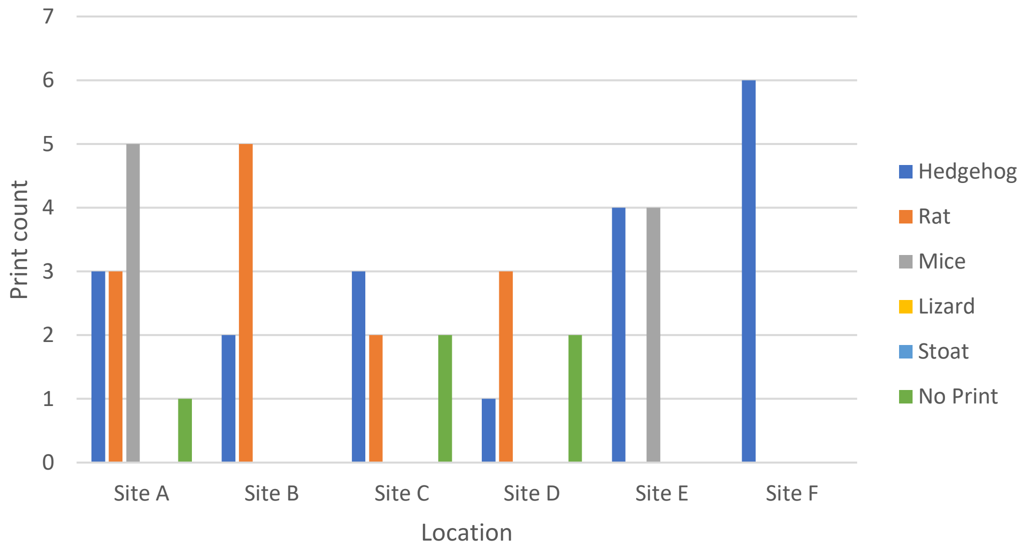


Figure 1. The number of times mammalian predator prints were encountered in tracking tunnels at each site over the six observation dates.

Tracking Tunnels allowed us to see what small mammals or lizards were present at each site. Figure 11 shows that there were rats, mice, and hedgehogs present within sites, but no evidence of lizard or mustelid activity. Hedgehogs were found to be present at each site, with most found at Site F with tracks being present each time the tracking cards were collected. Site A was found to have a larger number of mice tracks recorded and Site B with more rat tracks recorded. Previous studies from Ford (2017) and Miller (2021) found that hedgehogs, rats and mice were also highly present at their tracking sites along the bike trail and peninsula. With further trapping programs being put forward in Charlesworth Reserve, we can expect to see a decrease in the number of pest species.

Introduced mammalian predators were found at all sites across Charlesworth Reserve, having negative impacts on invertebrate and lizard populations. Hedgehogs (*Erinaceus europaeus*) were found at each site and are known to feed primarily on invertebrates but also found to eat lizards (Nottingham et al., 2019). Mice (*Mus musculus) and* rats (*Rattus sp*) are omnivores eating invertebrates and lizards but also seeds and flowers which induces competition with native fauna for food sources. Currently, predator trapping is being carried out in Charlesworth Reserve. The reduction in predation on lizard and invertebrate fauna may result in an increase in populations as well as increased available food sources. Further research is recommended to monitor the effects of reduced mammalian predators in Charlesworth Reserve.

Acknowledgements

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