Examining Diversity of Ground Dwelling Terrestrial Invertebrates on Sable Island

By

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Abstract

Islands are often in remote locations, yet these areas can gain species and increase their overall diversity due to the dispersal of organisms. Sable Island is unique not only for its biodiversity but also because it is the only part of a sand bar not submerged by the North Atlantic Ocean. Knowledge surrounding invertebrates on Sable Island is limited, with the last known inventory occurring in 2016. I investigated invertebrate abundance and composition on Sable Island to determine the effects that two different vegetation communities (marram grass and heath) had on these species. Five sites with nine pitfall traps at each site were set up in each of the vegetation types located across Sable Island. Trapped invertebrates were collected every two days for a total of six days, although this thesis focuses only on the first collection. Invertebrates were first identified to family level, and then to species level when possible. Overall, invertebrates were significantly more abundant and species rich in heath vegetation than marram grass. Additional findings showed variability among the types of species identified at each vegetation, most often only occurring on one or the other. Out of the 38 invertebrates successfully identified to species level, four were reconfirmed after going undetected for over forty years and two were new records on Sable Island: the ant *Myrmica americana* Weber and the lady beetle *Nephus ornatus ornatus* Leconte. The information gained has provided a quantitative, up to date list of the invertebrate species currently inhabiting heath and marram grass vegetation on Sable Island. Overall, this study has provided more insight into the types of ground dwelling invertebrates that live on the island and I conclude that with the large difference between the two vegetation types that invertebrates are more abundant and diverse in heath than marram grass vegetation.

April 29, 2020

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1. Introduction

1.1 Biodiversity of Islands

Biodiversity is the examination of the diversity and differences among biological organisms (National Research Council US 1992). Oceanic islands make for fascinating locations to examine for biodiversity due to their remote locations (Paulay 1994). Overall, the contribution of islands to the biodiversity found on Earth is quite uneven (Whittaker et al. 2017). Islands only cover 3.5% of the total land area on Earth, yet account for 15 – 20% of all terrestrial species found (Whittaker et al. 2017). Therefore, how do these islands gain species and increase their rates of biodiversity? Most commonly, biodiversity on islands results from dispersal of organisms, either due to humans transporting species or species travelling to the island on their own (Paulay 1994).

For years, species have been inadvertently introduced to new locations by humans (Gaston et al. 2003). Species introduction to new locations can cause considerable economic, management and conservation costs, although the severity of each cost is still under debate (Gaston et al. 2003; Russell et al. 2017). Additionally, the introduced species can cause harm to island ecosystems and how they function (Russell et al. 2017). Based on their study of introduced species to remote islands, Gaston et al. (2003) found that regardless of how isolated the location and how low the frequency of human activity was, there was still a high rate of biotic invasion of non-native species.

Additionally, species can gain access to remote islands through their own means of dispersal. Previous studies on how dispersal plays a large role in the biodiversity of island have shown that oceanic dispersal is a common contributor to the biodiversity found on islands (Cowie and Holland 2006). Oceanic dispersal is thought to be the result of many factors such as wind, water currents and animals able to swim long distances (Queiroz 2005). Island biodiversity can also be a result of intra-island speciation caused by specific selective forces (Cowie and Holland 2006). Reproductive isolation, such as differences in water levels over a period of time, also occur frequently on islands (Cowie and Holland 2006). Thus, island biodiversity is a direct result of different dispersal factors, that can either add to or limit the overall diversity found on an island.

Oceanic islands are classified as land masses that have never had any connection to continental land masses (Paulay 1994). Some islands are a result of a piece of land breaking off from a large land mass due to sea level rise (Cowie and Holland 2006). However, other islands are formed as products from volcanoes or tectonic plate movement, and in some cases organic reef growth will occur on top of one of the two products (Paulay 1994). Interestingly though, there are some islands that are formed without any of these events, such as Sable Island.

1.2 Sable Island

Sable Island is a sand bar located in the North Atlantic Ocean and is the only part of the outer continental shelf not submerged by water (Stalter and Lamont 2006). The island is formed from what is known as the Sable Island Bank, composed of sand ridges from glacial sediment that washed together (Li and King 2007). The complete bank spans approximately 255 km in length and 115 km in width (Li and King 2007). However, the only visible part of Sable Island spans approximately 49.5 km in length and 1.3 km in width based on the most recent measurements (Freedman and Byrne 2016). As its location was not easily detected, it became an area prone to shipwrecks (Stalter and Lamont 2006) as the sea slowly became a common route for commercial goods (Cameron 1965). Due to the high occurrence of shipwrecks around the island, the area became known as the "Graveyard of the Atlantic" (Stalter and Lamont 2006). As the island is also home to heavy fog banks, varying current strengths and high numbers of shipwrecks, two lighthouses were installed at each end of the island in 1873 (Cameron 1965). Since their installment, both lighthouses have continued to be maintained on the island amid concerns around their placement and the amount of sandbar visible from the cast of the light, as well as needing to move the lighthouse located on the west end of the island further east (Cameron 1965).

Sable Island's climate on an average day is comparable to the climate of coastal Nova Scotia (Freedman et al. 2016). The main difference between the island's climate and coastal Nova Scotia is the higher wind speeds that occur on the island (Freedman et al. 2016). Sable Island's climate can also be described as temperate oceanic, and the overall climate is often more mild than on Nova Scotia's mainland (Stalter and Lamont 2006).

As a result of weather events on the island, the most common conditions observed within the terrestrial habitats are high winds, droughts, and unstable substrates (Freedman et al. 2016). Sable Island is also positioned within the ocean such that it is along the storm track for both summer and winter low pressure systems, resulting in extreme weather events occurring throughout the year (Stalter and Lamont 2006). Extreme weather events can be triggered by tropical storms, hurricanes, and non-tropical storms caused by cold season systems (Freedman et al. 2016). In addition to the extreme weather, Sable Island's climate is very foggy. As a result of the fog, the island has the least amount of sunshine out of any location in Nova Scotia (Stalter and Lamont 2006).

1.3 History of Human Settlement on Sable Island

Some of the first known documentation of Sable Island is from the sixteenth century (Cameron 1965; Wright 1989). It is thought that in 1518, the Baron de Lery left half of his cattle on Sable Island and the other half on Nova Scotia resulting in the first documentation of any domestic animal being housed on the island (Cameron 1965; Stalter and Lamont 2006). Following the discovery of the island came the first map noting the location produced by Jacopo Gastaldi around 1550 listed as Isola della rena or Island of Sand (Cameron 1965). From then on, many Europeans tried to settle on the island, but the majority were unsuccessful. One better known documented attempt at settling on the island is from 1598, when fifty French convicts were placed on the island and only twelve survivors were rescued five years later (Cameron 1965; Stalter and Lamont 2006; Wright 1989).

Throughout the 1700s, some attempts were made to settle on the island, but the next well-known documented attempt occurred in 1738 by Father Andrew LeMercier who introduced several forms of livestock to the island (Stalter and Lamont 2006). LeMercier attempted to reintroduce cattle, horses, pigs and sheep after previous unsuccessful attempts. Although the settlement attempt by LeMercier on the island was quickly deserted, it is believed that some of his horses may have been the sole survivors of the settlement and are the ancestors to the horses that inhabit Sable Island today. It is also argued that the horses found on the island today are from descendants introduced by Thomas Hancock in 1760, however there have been no definitive confirmations on which group of horses are the true ancestors (Stalter and Lamont 2006). Over time, as fewer attempts were made for human settlers to settle on the island, the feral horse population began to flourish and is still found on the island today (Stalter and Lamont 2006).

Today, government employees maintain a strong human presence on the island helping to care for the lighthouses, radio beacons and weather station (Cameron 1965; Stalter and Lamont 2006). Radio beacons were installed in the 1930s in a successful attempt to reduce the number of shipwrecks that occurred on the island (Wright 1989). A coordinate referencing system was installed on Sable Island in the early 1980s, and in June of 2014, Global Positioning System (GPS) stations were installed at the Main Station on Sable Island (Bond 2016). A review done in 2016 examined how the current technologies were being used to accurately monitor Sable Island and its need to continue, as well as the added benefits that could be observed (Bond 2016).These systems have allowed scientists to gather much more extensive knowledge of the island, as well as providing them with more accurate analyses of the islands natural features and any trends observed in changes of those features on the island over long periods of time (Bond 2016).

1.4 Invertebrate Communities on Sable Island

Little research has been done to investigate the invertebrate fauna from Sable Island. The most recent species list provided was compiled by Majka (2016), but the research was not quantitative. Additionally, there is no data on the abundance or specific locations of invertebrate species found on the island. Sable Island is a remote place, but with more knowledge available on the invertebrate species present on the island, scientists will be able to provide more in depth information about the invertebrate populations and how they could impact the island's overall ecosystem.

One benefit to knowing what types of invertebrates are living on Sable Island is that they may differ from the invertebrate species usually found on beaches. As Sable Island is a sand bar (Stalter and Lamont 2006), it would be expected that common beach invertebrates would be found on the island. Therefore, it is anticipated that common beach invertebrates are accustomed to frequent human disturbances such as trampling (Schlacher and Thompson 2012). Schlacher and Thompson (2012) did a study that found that invertebrate fauna along upper beaches were dominated by benthic invertebrates such as amphipods, likely due to its ability to burrow deep within the sand to avoid being trampled. Conversely, since there are so many invertebrate species found on Sable Island and the human presence on the island is limited, it is possible that the invertebrates will not all be accustomed to human disruption as they do not face as high a threat on a daily basis.

As a result of the numerous attempts to colonize Sable Island, it is likely that through the many trials, species were introduced to the island. Some of the most well-known colonization attempts that are likely to have introduced invertebrates to the island were when settlers attempted to keep domestic animals on the island. The first documented release of animals on the island occurred in 1518, when the Baron de Lery released horses, cattle, and rabbits onto the island (Stalter and Lamont 2006). Although these animals produced some descendants that provided food for settlers in 1598, all domestic animals were removed from the island by 1668 (Stalter and Lamont 2006). The next known introduction of domestic animals occurred in 1738 when Father Andrew LeMercier brought cattle, horses, pigs and sheep to Sable Island (Stalter and Lamont 2006). It is likely that during each of these colonization attempts, the animals introduced onto the island brought some invertebrates with them adding to the overall invertebrate community known today. Additionally, with the Government of Canada's constant care for the island, it is likely that further introduction occurred as supplies were brought to the island to help build the main station still operating today (Cameron 1965).

Invertebrate species, as well as many others have developed some levels of tolerance to abiotic factors as a result of climate unpredictability (Schilthuizen and Kellermann 2013). The tolerance developed may be acquired via natural selection, which is when genetic traits increase a species fitness in response to a climate, or tolerance may involve phenotypical plasticity where the invertebrates change their phenotype but have no genetic change (Schilthuizen and Kellermann 2013). In general, the invertebrate species on Sable Island normally favour forests and freshwater habitats, which is contrastingly different from the habitats available on the island (Majka 2016).

1.5 Invertebrates in Marram Grass versus Heath Habitats

For invertebrates as well as other species found living on Sable Island, survival can be challenging. The climate on Sable Island results in limited habitat options, as the island does not have any forests and freshwater habitats are scarce (Majka 2016). Therefore, invertebrate species that thrive on Sable Island must be able to survive with limited availability of freshwater and no forest cover, in addition to the high winds that occur and the oceanic environment that engulfs the island (Majka 2016). Sable Island is home to three main vegetative communities, with two of them further broken into sub-categories (Freedman et al. 2016). The main communities are sandwort, marram grass, and heath vegetation, with the sub-categories coming from marram grass (made up of marram-forb, sparse marram grassland, and marram-fescue grassland), and from heath (made up of mesic shrub-heath and cranberry heath) (Freedman et al. 2016).

Marram grass covers approximately 37% of Sable Island whereas heath only covers approximately 12% (Freedman et al. 2016). Additionally, marram grass has a soil base of raw sand compared to heath which has acidic, sandy soil that also contains high concentrations of organic material (Freedman et al. 2016). Through general observations of the island in its entirety, the majority of the vegetated areas begin by being dominated by sandwort communities before transitioning to the marram grass and heath communities respectively (Freedman et al. 2016). The majority of the heath communities are found near the inner areas of the island, whereas some of the marram grass areas can be found near the inner areas as well as along the oceanic edges (Catling et al. 1984).

Within the marram grass areas, the marram-forb grassland has the richest communities of plant species consisting of marram, *Lathyrus japonicus* var. *maritimus* (beach pea), *Achillea millefolium* (yarrow), *Solidago sempervirens* (beach goldenrod), and *Poa pratensis* (bluegrass) (Freedman et. at 2016). This community is comparable to the mesic shrub-heath sub-category from the heath areas. The mesic shrub-heath location is known to be the most species-rich of the plant communities on Sable Island, making it one of the more favourable areas (Freedman et al. 2016). This community consists of a number of different species, but the most common are *Empetrum nigrum* (crowberry), *Juniperus communis* var. *megistocarpa* (juniper), *Juniperus horizontalis* (creeping juniper), *Morella pensylvanica* (bayberry), *Rosa virginiana* (Virginia rose), and *Vaccinium angustifolium* (lowbush blueberry) (Freedman et al. 2016). Although there is potential for some slight variation among marram grass and heath locations within their plant species, recent inventories of the island's overall plant communities have shown that the flora native to Sable Island has remained stable over the past century and non-native flora has not increased in population size (Catling et al. 2009).

1.6 Objectives

My main objective was to examine how invertebrate communities differ between marram grass and heath locations on Sable Island. Recent research has shown a positive relationship between high plant species richness and species richness of other groups, where high plant species richness has increased the species richness of other groups (Li et al. 2018). Additionally, plant communities with greater productivity have been shown to result in higher productivity (specifically richness) from the overall community (plant and invertebrate species combined) (Li et al. 2018). Based on this information as well as the available knowledge about the two vegetation types, I predict that invertebrates occurring in the heath locations will be more abundant than invertebrates occurring in the marram grass. I also predict that there will be a large difference between the composition of invertebrate communities found in each of those locations. Also, using the previous research done as a comparison, I predict that invertebrates native to Nova Scotia will be the most abundant due to the island's proximity to Nova Scotia. Parks Canada controls and limits the number of visitors to the island each year (Cameron 1965), with the departure location being from the Halifax Stanfield International Airport in Nova Scotia (Parks Canada Agency G of C 2020). By examining diversity among invertebrates from two different vegetation, this research will provide further insight into what types of invertebrate species are living on Sable Island, as well as a more accurate understanding of how invertebrate species are distributed across the island. This information will provide awareness about each of the species and allow for further insight into any species that may raise concerns regarding the conservation of the island's ecosystems.

2. Methods

2.1 Location

Invertebrate samples were collected between May 13, 2019 to May 21, 2019 by Dr. Erin Cameron and Parks Canada representatives on Sable Island (43°56'N, 60°01'W). Sable Island is a small island (49.5 km long and 1.3 km wide) located in the northeast Atlantic continental shelf (Byrne and McCann 1995). It most often faces air currents from the North American continent; however, its location in the ocean results in some synoptic weather events due to mixing air masses (Worthy et al. 2003). Sable Island has varying temperatures depending on the season (Parks Canada Agency G of C. Weather 2019). In the winter, island temperatures rarely exceed -13°C with the average winter temperatures ranging from -5°C to 5°C (Parks Canada Agency G of C. Weather 2019; Stalter and Lamont 2006). In the summer, specifically August, temperatures rarely exceed 25°C (Parks Canada Agency G of C. Weather 2019; Stalter and Lamont 2006). Approximately

37% of Sable Island is covered by marram grass and approximately 12% of the island is covered by heath vegetation (Freedman et al. 2016).

Every two days, the field crew (Dr. Erin Cameron and Parks Canada workers) collected samples from pitfall traps located in marram grass and heath habitats (Figure 1). Each trap was left out for 6 days and therefore had three samples collected from it; however, this thesis examines only the samples collected during the first time period. To construct the pitfall traps, 10.16 cm (4 inch) nails, red solo cups (12 cm in height, 9 cm across the top, and 6.5 cm across the bottom), duct tape, and 9 cm x 9 cm white plastic square coverings were used (Figure 2). Nails were pushed through the plastic square coverings and attached approximately 5 cm above the top of the cup with duct tape. A bulb corer, which had an approximate diameter of 8 cm, was used to create a hole in the ground to place the traps into. Soapy water was placed inside the cup to help trap the insects. As only soapy water was used to trap the invertebrates, the pitfall traps could not stay out for six days straight. Upon collection, organisms were preserved in a solution of 70% ethanol.

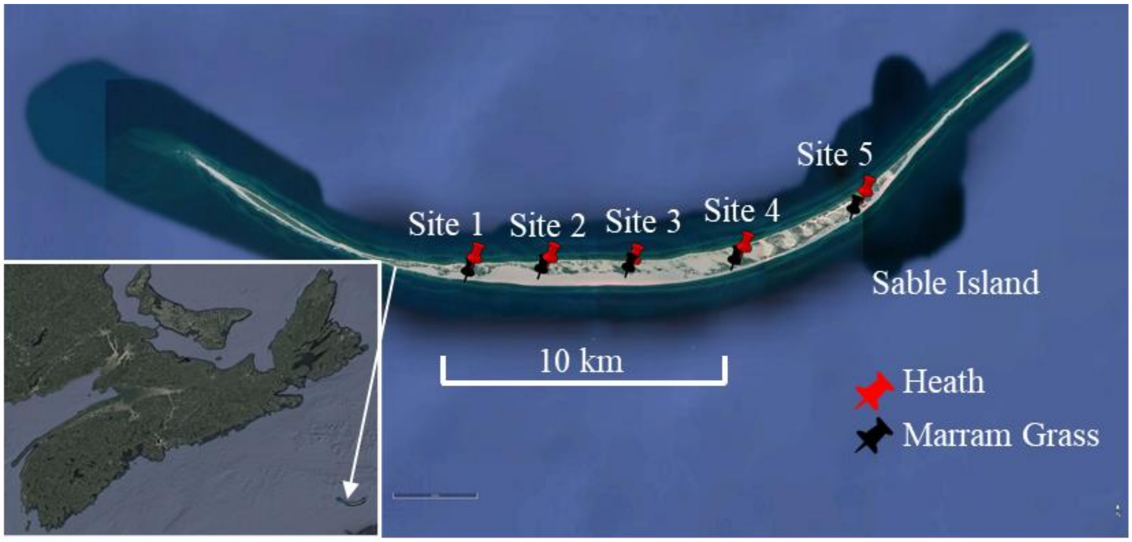


Figure 1: Location of sampling sites on Sable Island. Map was made using Google Earth Pro. Black pins indicate marram grass habitats (n=5) and red pins indicate heath habitats (n=5).

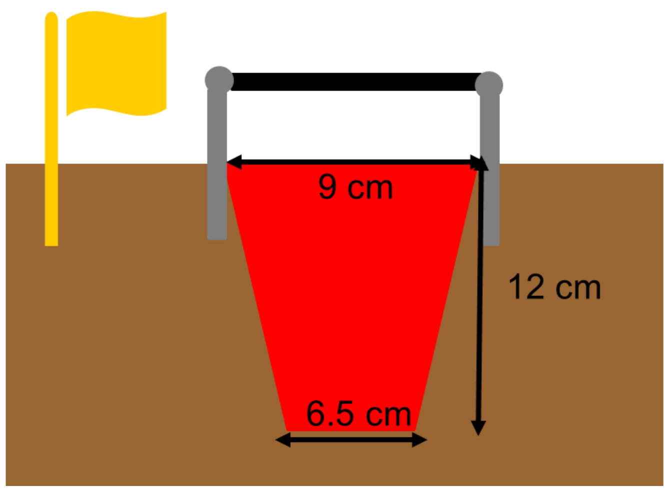


Figure 2: A depiction of the side view of a pitfall trap. The design was adapted from Brown and Matthews (2016) and Ellison et al. (2007).

Pitfall traps were placed at sites in a grid format, with 20 m between each trap, forming a 60 m x 60 m grid (Figure 3). Each site therefore contained 9 pitfall traps where samples were collected. A total of 5 sites were set up in both the grass and heath habitats, for a total of 10 sites overall. Thus, 90 pitfall traps were installed across all sites.

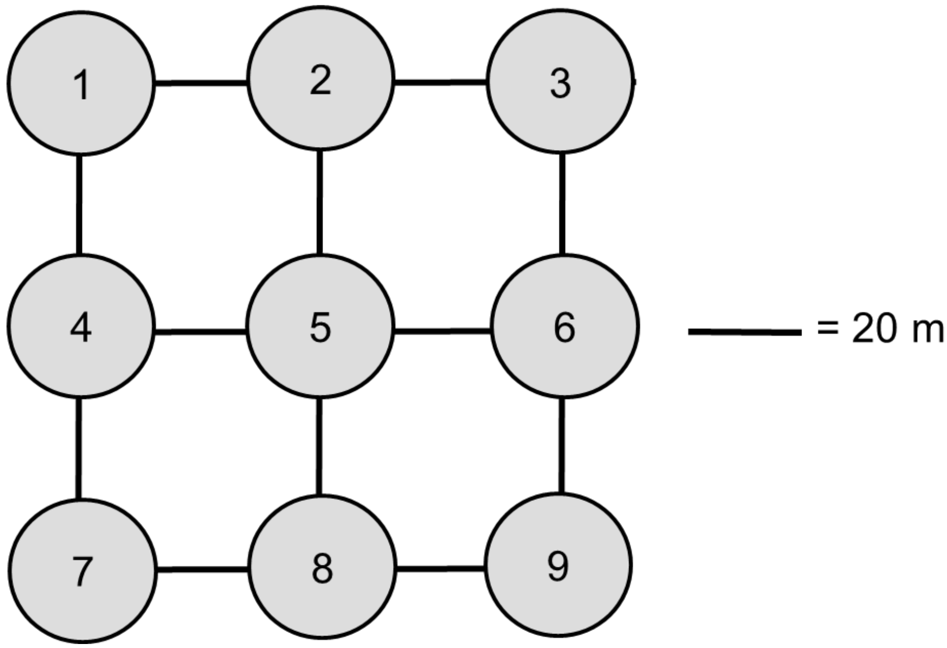


Figure 3: Pitfall trap design adapted from Brown and Matthews (2016) and Ellison et al. (2007). The numbers on each circle represent the label that was used to differentiate between each trap and the black lines represent the 20 m distance between each trap.

2.2 Identification Process

We sorted samples into preliminary categories using common characteristics to separate individual ground-dwelling invertebrates into six broad groups, including Coleoptera (beetles), Hymenoptera (ants), Diptera (flies), Isopoda (specifically *Oniscus* species (sow bugs)), Arachnida (spiders) and a combination of Myriapoda (millipedes) and Annelida (earthworms). General morphological and visual characteristics such as colour and the presence of wings were also considered simultaneously with the main groups to further separate specimens. Each initial vial was sorted independently to ensure that collection locations did not get mixed up, and the total number of additional vials used during the sorting of the initial vials were recorded. All sorted samples were kept in a solution of 70% ethanol. In each new vial that was used, a piece of paper with the location code written in pencil was placed inside the vial (eg. H 1.1 or G 1.1), and the location code was also written in permanent ink on the lid of each vial. The total number of invertebrates sorted into each group was recorded for each pitfall trap.

I identified each invertebrate separately and kept a record of my steps to more quickly process subsequent invertebrates that appeared to be the same. First, I used various identification keys to determine the family of the species, and then the genus where possible. Once the family (or genus) were determined, I referred to a Sable Island species list of all known invertebrates presently on the island to narrow down the species to its scientific name (Majka 2016). Then I used pictures to help confirm the exact names to ensure I had correctly identified the family or genus. If the species was not found on the Sable Island list, I used additional keys to determine the exact species name as well as had help from experts.

Beetles were first identified to family level using the key by Bland and Jaques (1978), and then Chris Majka completed the identification by determining the exact species of each beetle. Spiders were sorted into morphospecies and then Chris helped to identify them to species level where possible. All remaining unknown spiders were grouped together and labelled as "unidentified spider species." Similar processes were followed for all other insects collected from the island, with the person aiding in the final identification process changing depending on what group of invertebrates was being examined. Aaron Fairweather (University of Guelph) helped to confirm the ant species that had been previously identified using the key by Skinner and Allen 1996. Chris Majka confirmed the ant species that was not already listed on the 2016 list (Majka 2016), as well as the exact species names for the myriapods, isopods, amphipods, and hemipterans. The earthworms were identified by Dr. Erin Cameron.

Once identified, invertebrates were further separated into vials that were labelled with the species name except for some insects that were pinned to ensure they were successfully identified. A list of present invertebrate species found on Sable Island was compiled in 2016 (Majka 2016). I used this list as a guide and along with the help of Chris Majka, I was able to classify each successfully identified invertebrate as native or non-native. Chris also advised on which of our findings were rare, and with the list we were able to determine which species were a new record for the island.

2.3 Statistical Analysis

Once samples were successfully identified to family level or further, the data were compiled into a database for statistical analyses. Analyses tested how habitat type (marram grass versus heath vegetation) affected: 1) overall invertebrate abundance from the collected pitfall trap samples; 2) invertebrate diversity (specifically examining taxon richness and species richness if possible); and 3) invertebrate community composition. The data used to test abundance was not normally distributed therefore a Poisson regression was used. To analyze the species richness data a linear mixed effects regression was used as the data was normally distributed. Spiders were not considered in the species richness analysis due to our lack of confidence in the exact species identification for that group. We used a random effect for site in both the abundance and species richness analyses to account for the lack of independence among the multiple pitfall traps nested within each site. These two tests were both performed in Stata (StataCorp 2011). Figures and tables were compiled in Microsoft Excel and community composition was tested using the Shannon diversity index, calculated in Microsoft Excel. Individual species were also classified into four categories: native, non-native, new record (on Sable Island), and reconfirmed. Reconfirmed was used to describe any species that had an extended period of time between its last known detection on Sable Island and our re-detection of it in this survey.

3. Results

3.1 Overview

Invertebrate species were collected in pitfall traps from five different sites across Sable Island at two different vegetation types (marram grass and heath). Species were then sorted into groups and identified. Identifications allowed us to address overall community abundance at each vegetation type overall and per site, as well as species richness and the quantity of each identified invertebrate found in each vegetation type. Lastly, species not previously recorded to be on the island and species deemed noteworthy (reconfirmed) were recorded.

3.2 Comparison of Invertebrate Communities for Abundance

Overall, significantly more invertebrates were collected from the heath vegetation sites than the marram grass vegetation sites (Poisson regression; coefficient = 11.37931; p-value<0.001) (Figure 4; Figure 5; Table 1). A total of 212 invertebrates were collected from marram grass vegetation and 1978 invertebrates were collected from heath vegetation (Figure 4).

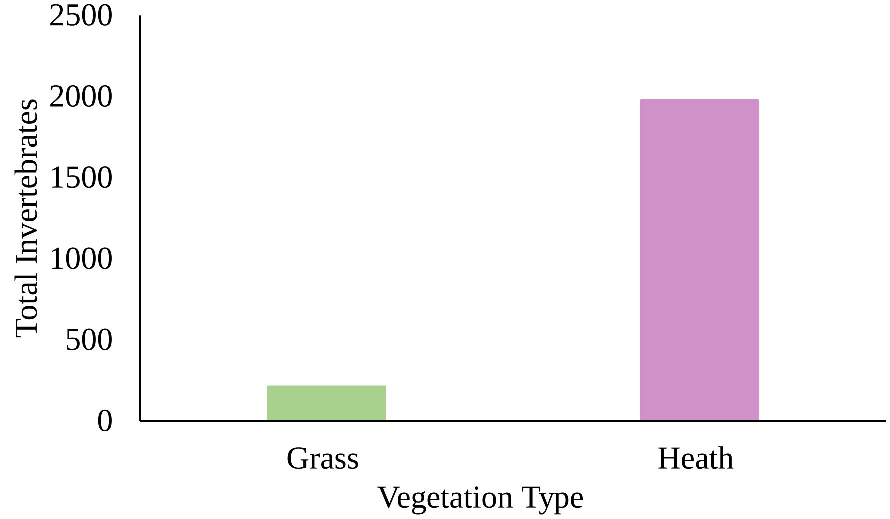


Figure 4: **The total number of invertebrates collected from all five sites for both marram grass and heath vegetation on Sable Island.** Each site contained nine pitfall traps that were combined for the total number of invertebrates collected from each vegetation type.

When broken down by site, a greater number of invertebrates were present in heath vegetation than marram grass vegetation both in total number of invertebrates collected at each site for each vegetation type and the mean average of all invertebrates collected at each site (Figure 5; Figure 7). The largest difference between vegetation types occurred at site five (Figure 5; approximately 28 invertebrates from marram grass and 683 invertebrates from heath) and the smallest difference occurred at site three (Figure 5; approximately 72 invertebrates from marram grass and 128 invertebrates from heath). Sites 2 and 5 had the highest means among the heath sites and appear similar in value whereas site 2 had the highest mean among the grass sites (Figure 7). Thus, site 2 had one of the highest means for both vegetation types (Figure 7).

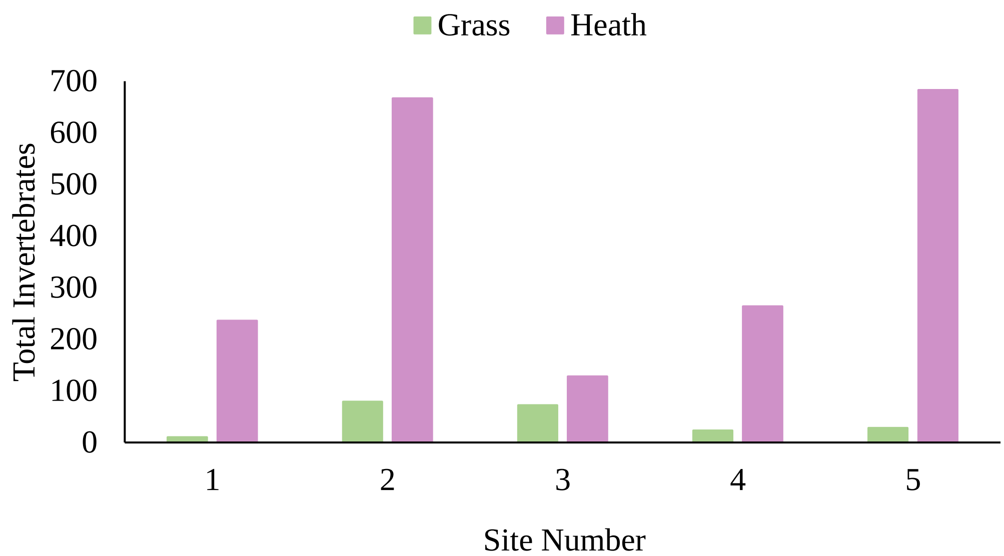
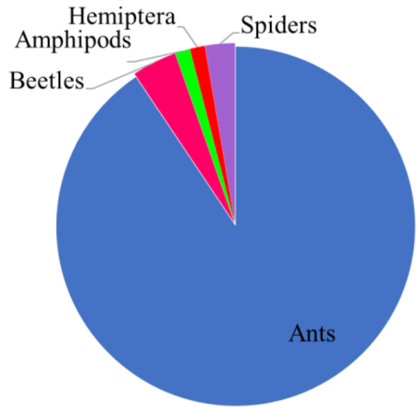


Figure 5: **The total number of invertebrates collected at each site for both marram grass and heath vegetation on Sable Island.** Each site had nine pitfall traps where the invertebrate totals were combined for an overall total from each site at the two vegetation types.

More myriapods (millipedes) were collected in heath vegetation than in marram grass (Figure 6). Hymenopterans (ants) were the most abundant in marram grass vegetation (135 in total) and myriapods (millipedes) were the most abundant on heath vegetation (1038 in total), each making up the majority of the total number of invertebrates collected on their respective vegetation (Figure 6; Table 1). Coleopterans (beetles) followed by arachnids (spiders) were the second most common invertebrate species collected on marram grass, whereas hemipterans (specifically planthoppers) and amphipods (specifically the common Atlantic sandhoppers) appeared in similar quantities (Figure 6A). Hymenopterans (ants) and then arachnids (spiders) were the second most abundant invertebrates collected on heath vegetation with isopods (specifically sow bugs) and coleopterans (beetles) appearing in similar quantities (Figure 6B). No isopods (sow bugs), annelids (earthworms) or myriapods (millipedes) were collected on marram grass vegetation and no amphipods (common Atlantic sandhoppers) or hemipterans (planthoppers) were collected on heath vegetation (Table 1).



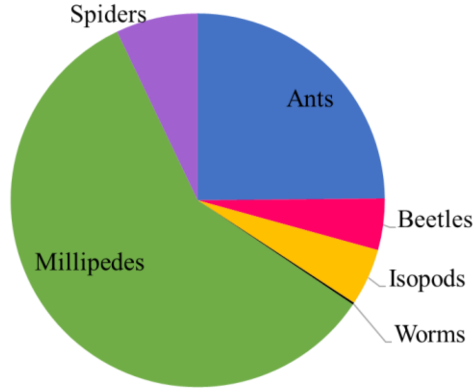


Figure 6: **A comparison between the total number of invertebrate types collected on marram grass vegetation (A) and heath (B) on Sable Island.** Invertebrates that were not collected on the vegetation type were omitted from the figure. Invertebrates were collected from each of the nine pitfall traps at each of the five site locations and then combined for an overall total.

Table 1: **The total number of invertebrate types collected from each vegetation type (marram grass and heath) on Sable Island.** Each total is a combination from the nine pitfall traps at each of the five sites on their respective vegetation types.

	Vegetation	
Invertebrate	Grass	Heath
Ants	135	441
Beetles	6	79
Amphipods	2	0
Isopods	0	88
Worms	0	3
Millipedes	0	1038
Hemiptera	2	0
Spiders	4	126

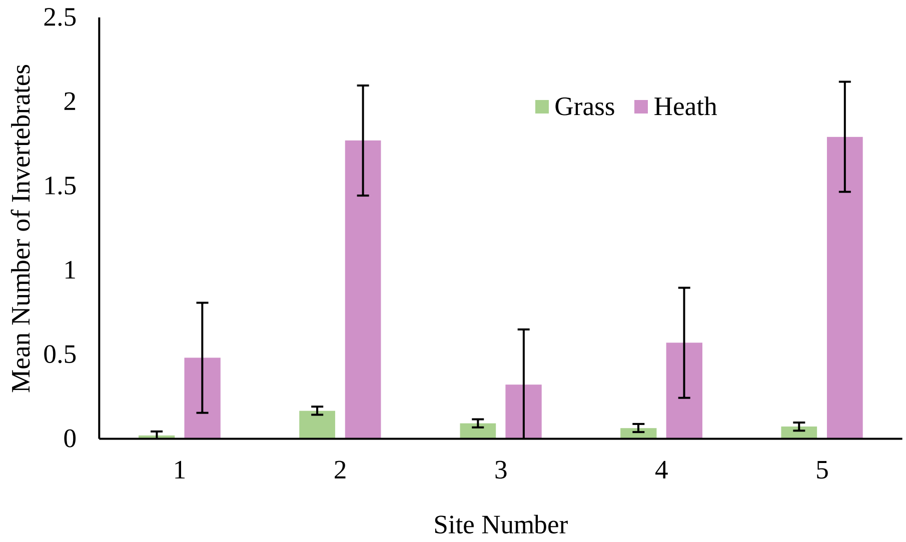


Figure 7: **The mean number of invertebrate species collected at each site on Sable Island.** There were nine pitfall traps at each site and the collection from each trap was combined for the average at the overall site. The error bars represent the standard error.

3.3 Species Diversity and Composition

A significant difference was observed between species richness in heath and marram grass vegetation (Linear mixed effect regression: coefficient = 3.622, p-value<0.001). The Shannon diversity index for marram grass vegetation was highest at site 3 (0.627) and lowest at site 4 (0.178844913) (Table 3). The Shannon diversity index for heath vegetation was highest at site 1 (2.05469) and lowest at site 2 (0.85035) (Table 3). A higher index can be observed from heath vegetation at all sites, thus species diversity of invertebrate species was higher in heath vegetation overall (Table 3).

Three ant species were found in both heath and marram grass vegetation (Table 2). *Lasius pallitarsis* Provancher was the most common ant collected at marram grass sites and *Myrmica americana* Weber was the most common ant collected at heath sites

(Table 2). The fourth ant species collected, *Gelis* Thunberg, was rare with only one individual recorded across all five sites from the heath vegetation (Table 2). Coleoptera (beetle) species were most abundant in heath vegetation and the species collected in the marram grass vegetation differed from those collected in heath vegetation (Table 2). Only six individual coleopterans (beetles) were collected from marram grass sites while multiples of many species were collected in heath sites (Table 2). The most abundant beetle species collected was the ground beetle, *Pterostichus mutus* Say, closely followed by the rove beetle, *Paederus littorarius* Gravenhorst, both of which were found on heath vegetation (Table 2). Similar to the Coleoptera (beetle) species, Arachnida (spider) species were most frequent within collections from the heath vegetation sites (Table 2). Only three of the spider species were found in both marram grass and heath vegetation, yet their abundance was higher in heath vegetation (Table 2). The most abundant species was the wolf spider, *Paradosa fuscula* Thorell, found only in heath vegetation sites (Table 2). Quantities of the other spider species were more even in abundance from heath vegetation, and their appearance on marram grass vegetation was minimal (Table 2). Five species were represented by only one individual, and when comparing all five together each species was only collected on either marram grass or heath vegetation (Table 2). The millipede, *Cylindoiulus latestriatus* Curtis and the woodlouse *Porcellio scaber* Latreille were the most abundant out of all five of the species found only on one vegetation (Table 2). Notably, *C. latestriatus, P. scaber* and the earthworm *Dendrobaena octaedra* Savigny favoured heath vegetation whereas the amphipod *Americorchestia longicornis* Say and planthopper *Muirodelphax arvensis* Fitch favoured marram grass vegetation (Table 2).

Table 2: **Totals of each species collected across the five sites for both marram grass and heath vegetation from Sable Island and their classification and zoogeographic status.** Each site contained nine pitfall traps where all same collected species were combined for totals across all sites. Single asterisks represent noteworthy species (reconfirmed) and double asterisks represent new records on Sable Island.

		Vegetation Totals			
Order	Species Name	Grass	Heath	Classification	Zoogeographic Status
Hymenoptera (Ants)	*Formica glacialis*	1	108	Native	Nearctic
	Myrmica americana	1	248	Native**	Nearctic
	Gelis Species	0	1	Native	Nearctic
	Lasius pallitarsis	133	84	Native	Nearctic
Coleoptera (Beetles)	*Mocyta breviuscula*	1	0	Native	Nearctic
	Amara quenseli	1	0	Native	Holarctic
	Agonum placidum	1	0	Native	Nearctic
	Falagria dissecta	1	0	Native	Nearctic
	Philonthus rufulus	1	0	Native	Nearctic
	Amara torrida	1	0	Native	Holarctic
	Calosoma calidum	0	2	Native	Nearctic
	Pterostichus mutus	0	17	Native	Nearctic
	Anthonomus signatus	0	1	Native	Nearctic
	Paederus littorarius	0	16	Native	Nearctic
	Amara otiosa	0	2	Native*	Nearctic
	Hypera nigrirostris	0	1	Non-Native*	Palaearctic
	Ischnosoma pictum	0	8	Native*	Nearctic
	Blapstinus metallicus	0	10	Native	Nearctic
	Gyrohypnus fracticornis	0	7	Non-Native	Palaearctic
	Dalopius pallidus	0	2	Native	Nearctic
	Tachyporus mexicanus	0	2	Native	Nearctic
	Rhinoncus castor	0	2	Non-Native	Palaearctic
	Philonthus cognatus	0	1	Non-Native	Palaearctic
	Nephus ornatus ornatus	0	1	Native**	Nearctic
	Syntomus americanus	0	2	Native*	Nearctic
	Amara familiaris	0	1	Non-Native	Palaearctic
	Amara aenea	0	3	Non-Native	Palaearctic
	Corticarina cavicollis	0	1	Native	Nearctic
Arachnida (Spiders)	*Clubonia abboti abboti*	2	7	Native	Nearctic
	Leiobunum calcar	0	19	Native	Nearctic
	Paradosa fuscula	0	55	Native	Nearctic
	Pirata piraticus	0	4	Native	Holarctic

	Xysticus ferox	0	6	Native	Nearctic
	Agroeca pratensis	1	22	Native	Nearctic
	Unidentified Spider species	1	13	Unknown	Unknown
Amphipoda	*Americorchestia longicornis*	2	0	Native	Nearctic
Annelida (worms)	*Dendrobaena octaedra*	0	3	Non-Native	Palaearctic
Hemiptera	*Muirodelphax arvensis*	2	0	Native	Nearctic
Isopoda (Sow bugs)	*Porcellio scaber*	0	88	Non-Native	Palaearctic
Myriapoda (Millipedes)	*Cylindoiulus latestriatus*	0	1038	Non-Native	Palaearctic

Table 3: **Shannon diversity index for both marram grass and heath vegetation comparing all different invertebrate species identified (n = 40).** There were nine pitfall traps located at each vegetation site which were combined for overall totals of each individual species per vegetation.

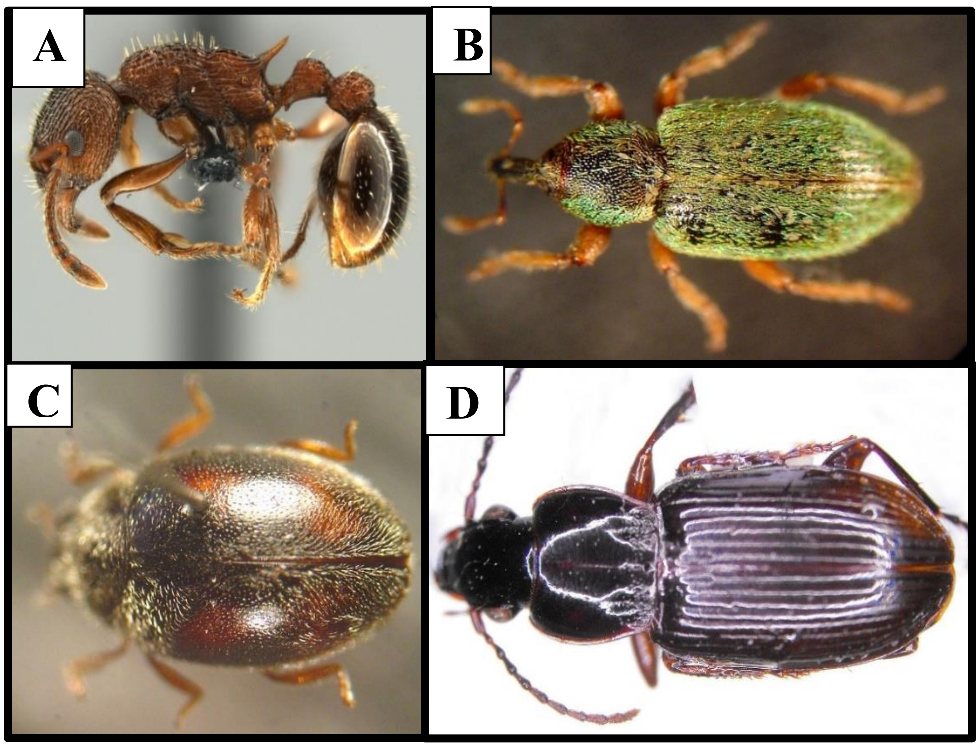
	Shannon Diversity Index for each Vegetation Type	
Site Number	Grass	Heath
1	0.410	2.054
2	0.504	0.850
3	0.627	2.257
4	0.178	1.812
5	0.484	1.021

3.4 Native, Non-Native, New Record and Reconfirmed Species

Two new species records were identified: *Myrmica americana* (common grass ant) and *Nephus ornatus ornatus* Leconte (ornate lady beetle) (Figure 8; Table 2). Six species identifications reconfirmed their presence on Sable Island: *Hypera nigrirostris* Fabricius (lesser clover leaf beetle), *Philonthus rufulus* Horn (rove beetle), *Amara otiosa* Casey (ground beetle), *Ischnosoma pictum* Horn (rove beetle), *Syntomus americanus* Dejean (ground beetle), and *Pterostichus patruelis* Dejean (woodland ground beetle) (Figure 8;

Table 2). Non-native species were more abundant than native species in heath vegetation (Table 2). In contrast, native invertebrate species were the most abundant in marram grass vegetation (Table 2). The majority of the new species records came from heath vegetation with a miniscule quantity coming from grass (Table 2).

Figure 8: **Photographs of the two new species records and two of the noteworthy species identified.** *M. americana* (A) taken by Gary D. Alpert, *H. nigrirostris* (B), *N. ornatus ornatus* (C) and *P. patruelis* (D) taken by Chris Majka.



4. Discussion

4.1 Comparing Invertebrate Communities on Heath and Marram Grass Vegetation

Substantial differences between invertebrate totals indicated that invertebrates were more abundant in heath vegetation than marram grass, as predicted. The comparisons between each of the individual invertebrate species identified showed that more often the species found in marram grass were not found on heath vegetation and vice versa. Thus, I can conclude that the invertebrate communities found on both marram grass and heath vegetation are different in both abundance and composition which is consistent with my first and second predictions. These first two findings made sense as higher plant species richness (as found in the heath) frequently correlates with higher invertebrate species richness. However, multiple other factors exist that affect diversity and abundance of species, such as soil types and different plants (Boulton et al. 2005).

One specific study broadly examined how plant characteristics can affect ant diversity within grasslands in California, USA (Boulton et al. 2005). Ants act as structural forces within many terrestrial groups, and their species diversity has been linked to a variety of plant characteristics such as richness (Boulton et al. 2005). It has also been shown that ants tend to favour certain plant species over others based on what their overall survival needs are (Boulton et al. 2005). This is likely the reason the new ant species record, *Myrmica americana*, was more abundant in heath vegetation than the marram grass. Further studies are necessary to determine what is attracting ants to heath over grass vegetation, and the same type of study could be used to determine why the ant *Lasius pallitarsis* was more abundant in marram grass. Additionally, the same questions can be posed to all the different invertebrate species collected. I speculate that because marram grass has a soil consisting mainly of raw sand (Freedman et al. 2016), it was less appealing to majority of the ground dwelling terrestrial invertebrates because it offered less habitat and nutrition options. Furthermore, past research has shown that many families of the invertebrates collected during this study have been found on other heathland sites in north-western Europe (Webb 1989).

4.2 Native, Non-Native, Reconfirmed and New Record Invertebrates

Sable Island is home to 573 terrestrial invertebrate species and out of that number 480 species are deemed native species (Majka 2016). The majority of the native species found on the island are also abundant on the mainland of Nova Scotia, with their preference being coastal habitats similar to those found on Sable Island (Majka 2016). I predicted that the invertebrate species known to be native to Nova Scotia would be the most abundant as a result of the islands proximity to the peninsula. In fact, there was a higher number of individuals (i.e., total abundance) that were non-native species, which thus did not support my prediction. On the other hand, in terms of the number of species recorded, the majority were native and only nine were non-native.

We were able to successfully identify two new records to Sable Island: *Myrmica americana* (common grass ant) *and Nephus ornatus ornatus* (ornate lady beetle). I found one individual species deemed noteworthy by Majka (2016), *Philanthus rufulus* (rove beetle). This particular beetle is known to inhabit only Sable Island within Canada, with its next closest known location in Maine, United States of America (USA) (Majka 2016). Thus, this beetle species is native to Nova Scotia. I listed *Hypera nigrirostris* (lesser clover leaf beetle) in my results as a reconfirmed species to the Sable Island record because the last recorded specimen of this species occurred in 1966-1967 and has not been found since until now (Majka 2016). This was the same case for *Ischnosoma pictum* (rove beetle) and *Syntomus americanus* (ground beetle). *Amara otiosa* (seed eating ground beetle) was a reconfirmed species as only two other individual records are known of this species (Majka personal communication 2020). Based on this analysis, the same argument could be made for the earthworm, *Dendrobaena octaedra*, with the last known reported finding occurring in June of 1966 (Wright 1989).

Nine species in my data were non-native: *Porcellio scaber* (common rough woodlouse), *Cylindroiulus latestriatus* (millipede), *Amara aenea* DeGeer and *Amara familiaris* Duftschmid (ground beetles), *Dendrobaena octaedra* (earthworm), *Philonthus cognatus* Stephens (rove beetle), *Rhinoncus castor* Fabricius (weevil), *Gyrohypnus fracticornis* Müller (rove beetle) and *Hypera nigrirostris* (lesser clover leaf beetle). Furthermore, I found that the woodlouse *P. scaber* and the millipede *C. latestriatus* had the highest individual species totals. Both species are listed as non-native on the list developed by Majka (2016), which is why the non-native species are more abundant than the native in terms of their individual quantities. Further investigation into species spread from mainland Nova Scotia to Sable Island is required to determine if the peninsula's proximity to the island is impacting the number of native species presently found on Sable Island.

4.3 New Records and Their Survival on Sable Island

Overall, this study emphasizes the importance of researching invertebrate communities in various locations. I was able to show that in approximately 3-4 years after completion of a thorough inventory of the invertebrates known to be on Sable Island, six new species appeared to have settled (or had managed to remain undetected in the previous inventory). Interestingly, four of the six new records were found individually over the years, but the ant species *M. americana* and the beetle species *N. ornatus ornatus* were completely new records to the island (Majka email conversations 2020; Majka personal communication 2020). It has been found that different variations among habitats such as the types of floral shelters offered, can influence the rate of successful colonization of invertebrates (Simberloff and Wilson 1969). Therefore, further research into invertebrate presence in different habitats is necessary.

To understand why each of the new record species have been able to find a home on Sable Island, it is first necessary to examine each species individually and determine their preferred habitat. As stated already, the ant *M. americana* was a completely new record for Sable Island, yet it was also extremely abundant in its individual totals, specifically on heath vegetation. This raised the question how did this species remain undetected for so long? Most colonies of the ant species *M. americana,* are small and scattered across large areas (Ayre 2009). In more recent studies, it has been found that this species resides most often in light sandy soil that is frequently used for reforestation purposes (Ayre 2009). Additionally, it was determined through a study of the species in Ontario, Canada that their colonies, although appearing spread out, might actually be connected by a central source (Ayre 2009). This speculation was elaborated on when the study highlighted that *M. americana* (ant) workers seem to build small nests near food sources (Ayre 2009). Based on this knowledge, it makes sense that *M. americana* (ant) was more abundant in heath vegetation as it offered higher concentrations of organic material for food sources (Freedman et al. 2016).

Nephus ornatus ornatus (ornate lady beetle) was only found on heath vegetation and only in low numbers. This species is an introduced species, as are many beetles found in North America from the family Coccinellidae (McNamara 1861). Coccinellids are important to plants as they prey on herbivorous pests like aphids (Majka and McCorquodale 2006; McNamara 1861). Generally, coccinellids will feed on their preferred food of herbivorous pests, but when they are not available, they will feed on immature stages of a variety of different insects (McNamara 1861). It is unclear how this species will survive on the island, as this beetle has not been recorded in abundance within Nova Scotia and tends towards coniferous areas (Majka oral conversation 2020).

Ischnosoma pictum (rove beetle), *Syntomus americanus* (ground beetle), *Amara otiosa* (ground beetle), *Hypera nigriostris* (lesser clover leaf beetle) and *Pterostichus patruelis* (ground beetle) are five other species of Coleoptera deemed to be reconfirmed species. *Ischnosoma pictum* belongs to the family Staphylinidae, commonly referred to as rove beetles. These beetles live abundantly on a variety of functional niches and are responsive to any change in their habitat (Pohl et al. 2007). *Syntomus americanus* and *Amara otiosa* belong to the family Carabidae, commonly referred to as ground beetles. These beetles, along with rove beetles tend towards litter habitats belonging to forests (Pohl et al. 2007). This preference helps to explain why all three of these beetles were only found on heath vegetation, as the heath vegetation presented with more favourable habitat conditions than the marram grass.

Hypera nigriostris, commonly known as the lesser clover leaf beetle, is a weevil that has a worldwide distribution (Hansen and Boelt 2008). It finds a home in its primary host, which is any *Trifolium* (clover) species. This species is a known pest of clover on which both its larval and adult stages can cause extensive damage (Hansen and Boelt 2008). Our collection found this species in heath vegetation and based on the list of the common plant species found on heath vegetation compiled by Freedman et al. (2016) the *Trifolium* species is not listed. Therefore, I suggest more research into what species are found in the heath vegetation to determine if there are any *Trifolium* species now present or if this weevil has found a new host plant.

For majority of the analysis, *Pterostichus patruelis* (ground beetle) was removed and its totals added to that of *Pterostichus mutus* (ground beetle) due to the two species being so similar. Upon secondary analysis of the original identification, it was decided that for analytical purposes the two species should be combined as the only difference between the two species was too complex to confidently differentiate (Majka email conversation 2020). We are currently waiting to hear back from another expert on if the two species are the same or different.

4.4 Limitations and Summary

Given my results, there is a lot of scope for future research. This research should focus on attempting to survey the other groups of invertebrates such as freshwater, marine, protozoa and air borne ones (Diptera, Lepidoptera and Odonata) to achieve an optimal survey of all invertebrates known to be living on Sable Island. Further research into the two new record species as well as the reconfirmed species would also be beneficial to determine how each might be surviving and affecting the overall ecosystem function. Specifically, a study into the ant *M. americana* would be beneficial as the numbers of individuals collected was extremely high. These high numbers suggest that this species has likely settled on the island, so it will be important to determine if it might cause any future disruptions. The previous study done on foraging and nesting habits of the ant *M. americana* in Ontario, Canada has shown that a single colony of these ants can exist in a spread-out fashion with multiple spaced out nests interconnected by underground pathways (Ayre 2009).

It would also be worthwhile to delve further into different collection techniques for ground dwelling invertebrates. Previous studies have highlighted how pitfall traps are just one technique used when collecting ground-dwelling invertebrates and if certain designs affect the numbers yielded by the traps (Brown and Matthews 2016; Ellison et al. 2007). Specifically, pitfall traps can be composed of plastic, metal or glass and their design as well as the researcher's interpretation of the results have caused large variations in the pitfall trap method (Brown and Matthews 2016). Furthermore, studies have even begun questioning if the colour of the trap is impacting the types of invertebrates collected (Brown and Matthews 2016). Research is now beginning to investigate how different colours tend to attract certain invertebrate species. Since the pitfall traps used in this study were red, a future study might be to determine if the pitfall trap colour played a role in the types of invertebrates collected.

Ground dwelling terrestrial invertebrates live in abundance on heath vegetation across many different types of species whereas on marram grass the types of species are specific and rarely found on heath. Given this result, the different invertebrate species living on both heath and marram grass differ greatly in both abundance and composition.

Additionally, when observing the abundance between native and non-native invertebrates collected on Sable Island, non-native invertebrates were more abundant. However, in observing the composition between native and non-native invertebrates on Sable Island, native invertebrates were more diverse. Lastly, two new records not previously listed to be on the island were identified; *Myrmica americana* (common grass ant) and *Nephus ornatus ornatus* (ornate lady beetle). Further research needs to be done to determine if each of these species has established a population on Sable Island or not.

For future studies, examination of the two new species records and the four reconfirmed species will be important, as well as examination into how they are settling on the island. Several of these species such as *Ischnosoma pictum* (rove beetle), *Syntomus americanus* and *Amara otiosa* (ground beetles), do not normally settle in unforested areas, so their ability to survive would make an interesting research study. Additionally, how they either are spreading across the island or if they will spread is a key follow-up question to determine their lasting effect on the island's ecosystems. Finally, studies into different trapping methods and their efficacy will be important to determine any biases in previous work. Specifically, research into what colours attract which invertebrates to determine if a trap colour is affecting the yield amount.

Based on the above findings I was able to learn that heath vegetation differed from marram grass in terms of invertebrate species present and their abundance in each vegetation, as well as conclude that the total number of non-native specimens collected was higher than the total number of native specimens collected for both vegetation types.

5. Conclusion

Islands maintain high rates of biotic invasion even when lacking human activity and occurring in isolated locations (Gaston et al. 2003). Sable Island is no exception. Overall, invertebrate abundance was greatest on heath vegetation both in total abundance and types of species collected. In addition, the number of non-native invertebrates collected was overwhelmingly high when compared to those of the native invertebrates. Although the number of successfully identified species were mostly native, their total numbers were much lower than those of the non-native species. This research has identified four reconfirmed and two new records of species on Sable Island. This has allowed the development of a quantitative species list, which will permit future studies to focus on how these species are getting to and surviving on the island.

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