Spring 2019

A survey of beetle diversity (order Coleoptera) on Lizard Island

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SIT Study Abroad

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Manuscript for submission to the *Bishop Museum Occasional Papers*

Submitted in partial fulfillment of the requirements for Australia: Rainforest, Reef, and Cultural Ecology, SIT Study Abroad, Spring 2019

A Survey of Beetle Diversity (order Coleoptera) on Lizard Island

Abstract. The beetles (order Coleoptera) of Lizard Island, a small granitic island on the mid shelf of the Great Barrier Reef, have never been assessed in the scientific literature. Prior to our work, only a single beetle genus had been documented on the island (*Caryotrypes* Decelle, 1968), based on a single specimen collected in 1993 (Reid & Beatson 2013). We conducted a survey of Lizard Island in April 2019 to determine which beetle families are present on the island and which families are the most diverse. The survey also assessed the beetle diversity in different habitats on the island and two smaller islands nearby. Our sampling yielded 111 beetle morphospecies representing at least 23 families, and showed evidence of differential taxonomic composition across the island. The most diverse families were Curculionidae, Carabidae, Scarabaeidae, Tenebrionidae, and Cerambycidae, in general accordance with global patterns in Coleoptera diversity. Greater habitat complexity and vegetation diversity appeared to correspond with greater beetle diversity at certain collection sites. The most densely forested area of Lizard Island yielded the greatest number of morphospecies, while a patch of mangrove forest yielded the least. Several morphospecies were found to be restricted in distribution, including two found only among beachfront *Spartina* grasses (families Anthicidae and Phycosecidae).

INTRODUCTION

The order Coleoptera is the most diverse group of organisms on Earth, constituting about 25% of all described animal species (Zhang *et al* 2018). Beetles play important roles in nearly all terrestrial and freshwater ecosystems (Zhang *et al* 2018), and are found in a remarkable diversity of habitats. In Australia, beetles are found from the continent's highest peak, Mount Kosciuszko, to isolated aquifers with no access to air (Hangay & Zborowski 2010; Jones *et al* 2019).

Beetle communities vary significantly in different habitats. As is the case with most vertebrates, greater habitat complexity is generally correlated with greater beetle species richness (Lassau *et al* 2005). The families Staphylinidae and Carabidae, among others, have been noted to prefer high complexity habitats (Lassau *et al* 2005). Carabid beetle distribution and abundance has also been correlated with habitat characteristics such as soil water holding capacity and soil acidity (Baguette 1993). On islands, total island area is generally the best predictor of beetle species richness, though habitat variation plays a role on a local scale. A study on lake islands in Sweden noted a correlation between forest type (wet vs deciduous) and carabid beetle richness (Nilsson 1988). While many beetles thrive in a range of habitats, others are habitat specialists. In Queensland, Australia, the establishment of certain dung beetle species introduced from Africa has been correlated with the habitat specificity of the different species (Doube & Macqueen 1991).

A gap in the knowledge exists for the beetle diversity of Lizard Island, as this study is the first ever survey of Lizard Island Coleoptera. Lizard Island is a 7 km^2 granitic island located 33 km off the coast of Cape Flattery on the mid shelf of the Great Barrier Reef (Queensland Government 2017a). Lizard Island and the adjacent South and Palfrey islands are continental islands, and were connected to mainland Australia until sea levels rose only 9,000 years ago (Queensland Government 2017a). Despite its recent isolation, Lizard Island is interesting in that a diverse range of habitats are present in a small area. These include grasslands, dune shrublands, eucalypt and acacia woodlands, mangroves, and paperbark (*Melaleuca* sp.) and pandanus swamps (Queensland Government 2017b).

The different habitats vary across the island with topography and the presence of freshwater. Well-drained hillsides and valleys are dominated by grasses (Queensland Government 2017b), while woodlands grow in more sheltered areas. Seasonal streams are present in a few gulches around the island, serving as refugia areas for denser vegetation including palms, pandanus, and paperbarks. Certain species vary in growth form in different areas of the island, highlighting the significant variation in environmental conditions. While *Thryptomene oliganda* grows as a branching tree at lower elevations, it grows only as a low shrub at the highest point on the island (Cook's Look, 359 m). Fire also plays a role in maintaining the interface between grassland and woodland on Lizard, South, and Palfrey islands. The Queensland government has preformed controlled burns on the islands in the past, and a burn is scheduled for July 2019 on Lizard Island (Queensland Government 2019).

In addition to the promising habitat diversity on Lizard Island, the presence of the Lizard Island Research Station makes the island an attractive research site. The research station has been operated by the Australian Museum since 1973, but most research at the station has been marine-oriented. Our work for this study was based out of the research station.

The main objective of our study was to survey the diversity of Coleoptera on Lizard Island and the nearby South and Palfrey islands. Specifically, we aimed to determine which beetle families are the most diverse and which areas of the islands support the greatest beetle diversity. We conducted a baseline survey of the beetle diversity in various habitats on Lizard, South, and Palfrey islands in April 2019, and developed a list of beetle families now known to occur on the island complex.

METHODS

Collection Areas and Sites. We sampled a total of 7 "collection areas" on Lizard, South, and Palfrey islands. Pitfall traps were placed at 5 to 7 "collection sites" for each collection area except the mangroves, yielding a total of 36 collection sites. Pitfall traps were placed at only one site in the mangrove collection area. Active collection (beating sheet and sifting leaf litter) and night collection were conducted at select collection sites. The Appendix provides collection area place names, collection site locations with their associated coordinates, collection dates per site, a description of the methods applied per collection site, and the general habitat type at each collection site. A brief description of each collection area is given below.

Collection Areas:

Researcher's Path: Researcher's path is a sand path through a relatively dense woodland. The researcher's path woodland was the largest tract of forest and most complex overall habitat sampled in this study. Key components of the vegetation include eucalyptus trees, acacia trees, fig (*Ficus* sp.) trees, and *Thryptomene oliganda* in the tree growth form. 7 collection sites were sampled along researcher's path.

Blue Lagoon: The blue lagoon collection area consists of a sand path leading from the dune shrubland down to the beachfront on the southeast side of Lizard Island. The blue lagoon 5 collection site was located furthest from the beach in a homogeneous dune shrubland dominated by *Suriana maritima*. Blue lagoon 1 was located above the tideline on the beach, in an area with sparse *Spartina* grasses and sea purslane (*Sesuvium portulacastrum*). The other blue lagoon collection sites were located in patches of relatively low-growing woodland. A total of 5 collection sites were sampled in the blue lagoon collection area.

Palfrey Island: Palfrey Island is located less than half a km southwest of Lizard Island and was accessed by boat. Aside from Aboriginal rock formations, the only structure on the island is an automated lighthouse. Much of the island consists of grassland interspersed with patches of low-growing woodland. The collection site Palfrey 2 was a grassland located near a patch of woodland, and was the only true grassland sampled in this study. Palfrey 6 was located above the tideline on the beach in an area with sparse *Spartina* grasses. The other collection sites were patches of woodland varying in vegetation density and composition. The Palfrey lighthouse was the most densely vegetated collection site on Palfrey Island, with vine thickets growing atop trees and shrubs. Palfrey 4 appeared to be the wettest collection site, and showed evidence of seasonal water flow. A total of 7 collection sites were sampled on Palfrey Island.

South Island: South Island is located less than half a km south of Lizard Island, adjacent to the slightly larger Palfrey Island. South Island was also accessed by boat, and contains no structures aside from Aboriginal rock formations. Like Palfrey Island, much of South Island consists of grassland interspersed with patches of low-growing woodland. South 1 was located at the base of the southern side of the island in a homogenous acacia woodland. South 2 and 3 were located in areas of dense vegetation overgrown with vine thickets. South 4 was located at the peak of the island in a rocky, grassy area near a patch of low growing woodland. South 5 was located above the tideline on the beach, in an area with sparse *Spartina* grasses. A total of 6 collection sites were sampled on South Island.

Gulches: The three gulches are located on the southeast side of the island, and are surrounded by grassland. Each gulch contains a small freshwater stream descending in elevation towards the beach. All three gulches serve as refugia areas for moisture-dependent species including palm, paperbark, and pandanus trees. A total of 5 collection sites were sampled at the gulches; two sites at each of the first two gulches, and one site at the third gulch. The gulch 1 collection site was located furthest from the running water in a thicket of shrubs and small trees. Gulch 2 was located closest to the beach near a woodland area, and appeared to be occasionally flooded by saltwater. Gulch 4 was located directly above the flowing stream, on a rocky patch covered in ground-hugging vines.

Cook's Trail: Cook's trail begins on the Watson's Bay beach and leads to the highest point on Lizard Island (Cook's Look, 359 m). The habitat transitions from relatively tall eucalypt and acacia woodland at lower elevations to grassland with sparse acacia woodland at higher elevations. Cook 1 was located at the peak of the trail (Cook's Look) in a patch of woodland surrounded by grassland. Cook 2 was located in a rocky, grassy area with patches of acacia woodland. The other Cook collection sites were located in relatively continuous eucalypt and acacia woodland. A total of 5 collection sites were sampled along Cook's trail.

Watson's Bay Mangroves: The mangrove collection site was located in a low-lying area of homogeneous mangrove shrubs. The area appeared to be occasionally flooded by saltwater. One collection site was sampled at the mangroves.

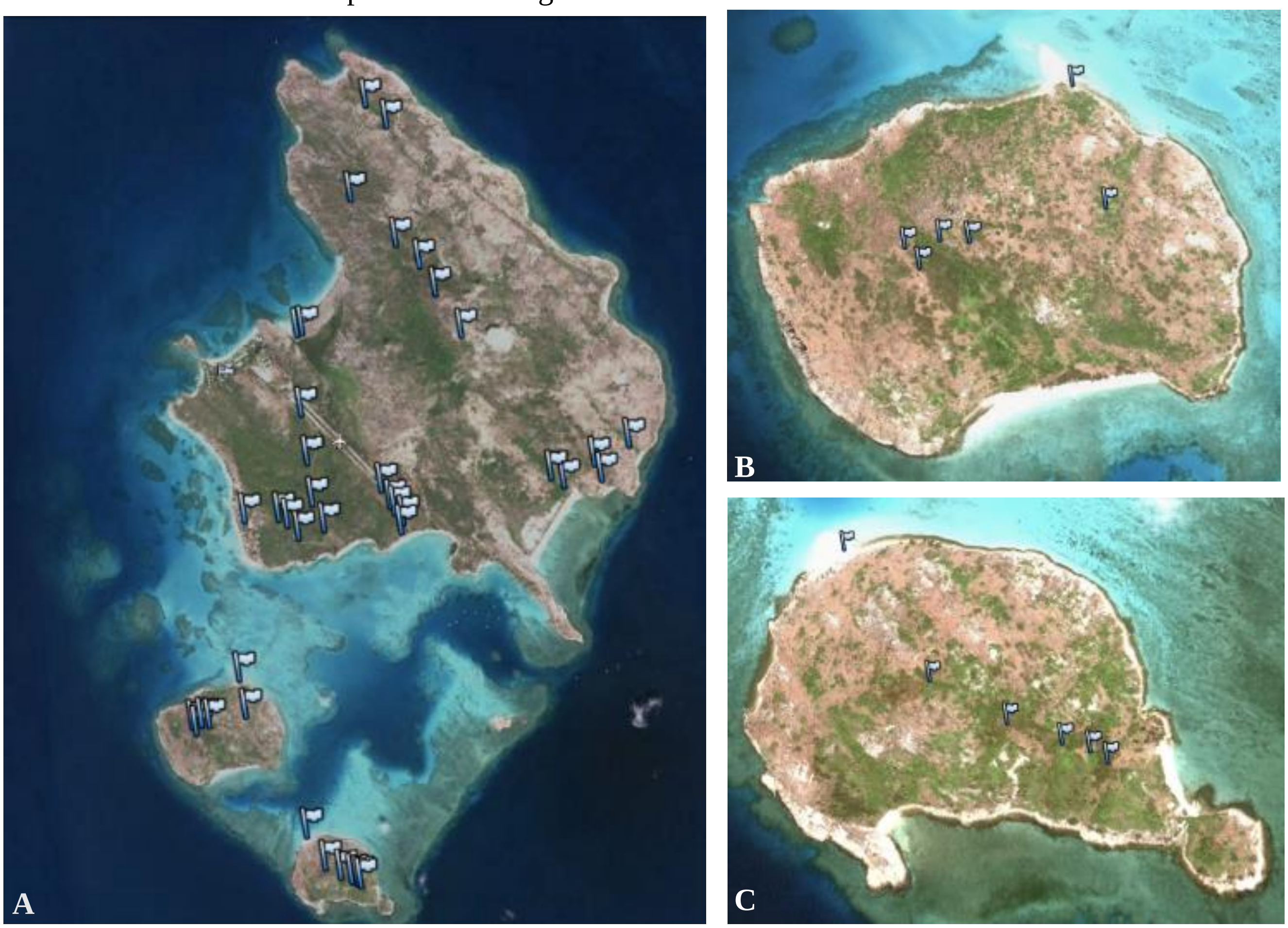

Figure 1. 36 collection sites sampled across Lizard Island (A), Palfrey Island (B), and South Island (C) during April 2019.

Sampling

Pitfall Traps: Three pitfall traps were placed at each collection site (see Appendix for exceptions). To create the pitfall traps, 18 oz party cups were buried and filled with approximately 20 mL of water. The water added to the traps contained a small amount of dish soap to reduce its surface tension and thus increase its ability to trap small beetles. Small sticks were placed over the top of the traps to make them less conspicuous, and a dry leaf was added to the water as a "flotation device" for bycatch. The three traps at each site were spaced about one meter apart to account for local variation in microhabitat, and their contents were consolidated to make up a single sample per site. The duration of trap deployment was not standardized, but traps were only left deployed for a single night. Pitfall trapping took place for one night at all sites except researcher's path. Pitfall traps were set for two nights at researcher's path while timing and logistics were under consideration, but were collected and re-set following the first night. The contents of the pitfall traps were sorted using a stereoscopic microscope and tweezers.

Active Collection. Active collection was conducted by the two authors at each collection area. Collection techniques included beating sheet, sifting leaf litter, and opportunistic hand collection. A 71 cm^2 canvas beating sheet (Bioquip Catalog #2840C) was held below selected trees and shrubs while the plants were hit with a PVC pipe. The beetles were collected as they fell off the foliage and onto the beating sheet. Leaf litter was collected beneath selected trees and shrubs, and was sifted over the canvas beating sheet. Opportunistic hand collection involved collecting beetles as encountered – while deploying and removing pitfall traps, and before and after timed searches. Beating sheet and leaf litter sifting were conducted for 15 to 20 minutes at each active collection site (see Appendix for active collection sites).

Night Collection: Night collection was conducted by the two authors at select collection sites for 15 to 30 minutes. Headlamps were used while scanning the litter and vegetation for beetles. In areas with freshwater, the water's surface was scanned for water beetles.

Collection, Curation, and Taxonomy
At each collection site, all new morphospecies were collected. Previously collected morphospecies were also collected if they had not yet been recorded for that site. Variation in beetle abundance was not considered in this study, as only one or two specimens of each morphospecies were collected at each site.* Beetles of the same morphospecies collected from the same sampling site were combined under the same collection number (see data in supplement 1). All beetles collected were preserved in 100% ethanol. The specimens were identified to the lowest taxonomic level possible using Hangay & Zborowski (2010) and Slipinksi & Lawrence (2013). Voucher specimens will be deposited at the Australian Museum in Sydney, Australia.

RESULTS

We detected 111 morphospecies (representing 23 families; Table 1) in our survey, at least 110 of which represent new records for Lizard Island. Because most specimens were identified to the family level, it is not known whether *Caryotrypes* Decelle, the only other beetle documented from Lizard Island, was collected. The best represented families were Curculionidae, Carabidae, Scarabaeidae, Tenebrionidae, and Cerambycidae, which together made up over 57% of all morphospecies. The complete list of morphospecies and their respective photos are attached in supplementary files 1 and 2.

As was expected, the different collection techniques yielded different beetle families. Rove beetles (Staphylinidae) were only detected via leaf litter sifting and pitfall traps. Scarabs (Scarabaeidae) and most ground beetles (Carabidae) were generally found on the ground, while most weevils (Curculionidae), leaf beetles (Chrysomelidae), and longhorns (Cerambycidae) were collected from the foliage.

*Because pitfall traps are non-discriminate, several specimens of the same morphospecies were sometimes collected at one site.

Table 1. List of beetle morphospecies known from Lizard Island.

Family, Subfamily Genus species	Number of Morphospecies Total Per subfamily
Anthicidae	**1**
Notoxinae	1
Bolboceratidae	**2**
Brachypsectridae?*	**1 (larva)**
Buprestidae	**1**
Carabidae	**14**
Cicindelinae	1
Megacephala sp.	
Subfamily uncertain	13
Cerambycidae	**9**
Cerambycinae	1
Strongylurus thoracicus?	
Subfamily uncertain	8
Chrysomelidae	**6**
Cassidinae	1
Chrysomelinae	2
Paropsis sp.?	
Galerucinae	2
Subfamily uncertain	1
Coccinellidae?	**1**
Curculionidae	**24**
Scolytinae	1
Xyleborus perforans?	
Molytinae	1
Orthorhinus sp.	
Subfamily uncertain	22
Dermestidae?	**1**
Elateridae	**2**
Eucnemidae	**1**
Hybosoridae?	**1**
Lucanidae	**1**
Lucaninae	1
Figulus sp.	
Oedemeridae	**1**
Passandridae	**1**
Phycosecidae	**1**
No subfamily	1
Phycosecis hilli	
Ptiliidae	**1**
Scarabaeidae	**10**
Dynastinae?	1
Melolonthinae	4
Sericesthis geminata?	
Scarabaeinae	5
Scirtidae?	**1**
Silvanidae?	**1**
Staphylinidae	**5**
Pselaphinae?	2
Tenebrionidae	**9**
Alleculinae?	2
Stenochiinae?	4
Tenebrioninae?	3
Unidentified	**16**
Total Morphospecies	**111**
Total Number of Families	**23**

*Question mark denotes uncertain identification. Unidentified larvae were not included as morphospecies.

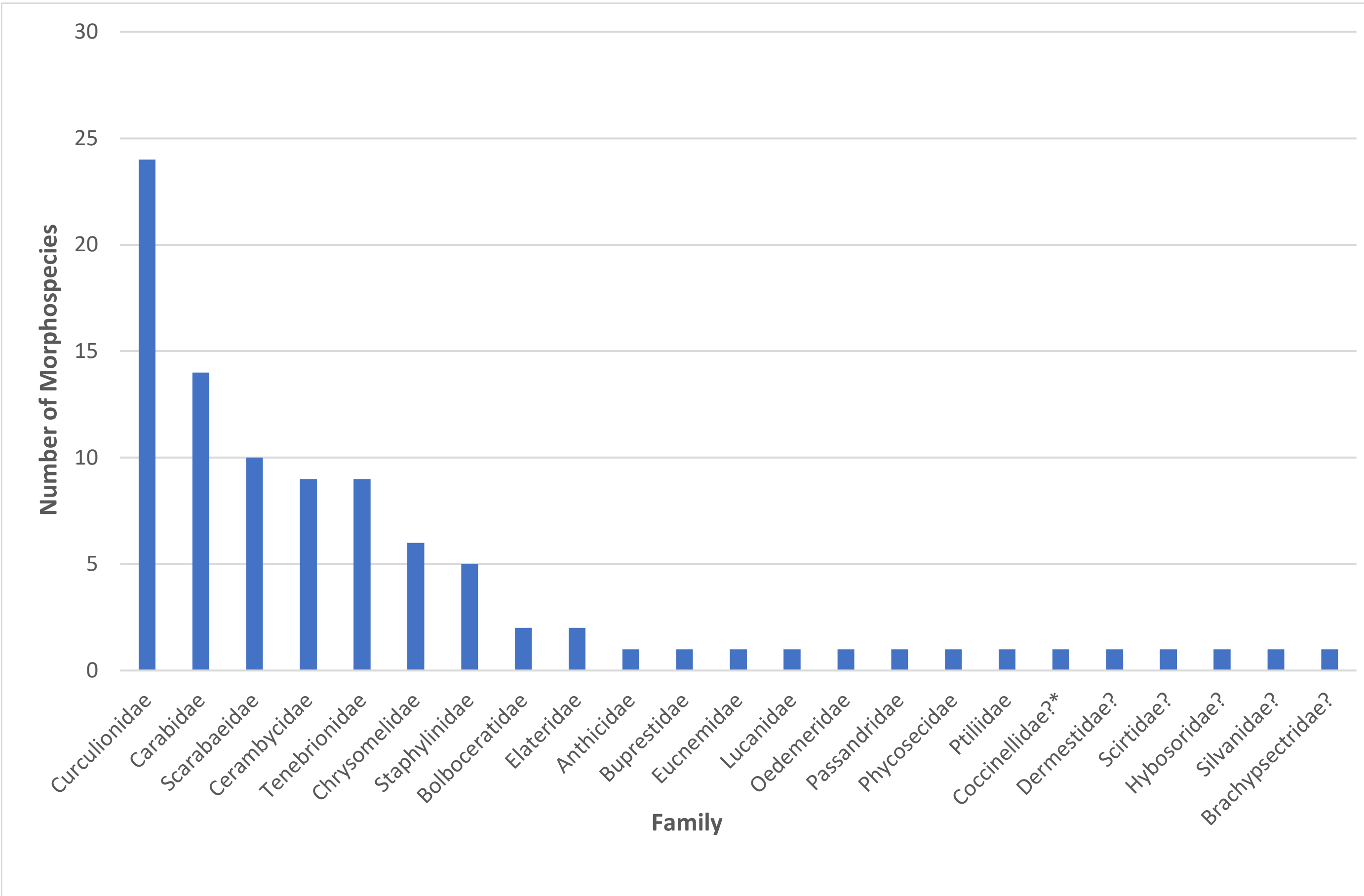

Figure 2. Number of morphospecies by family. *Question mark denotes uncertain identification.

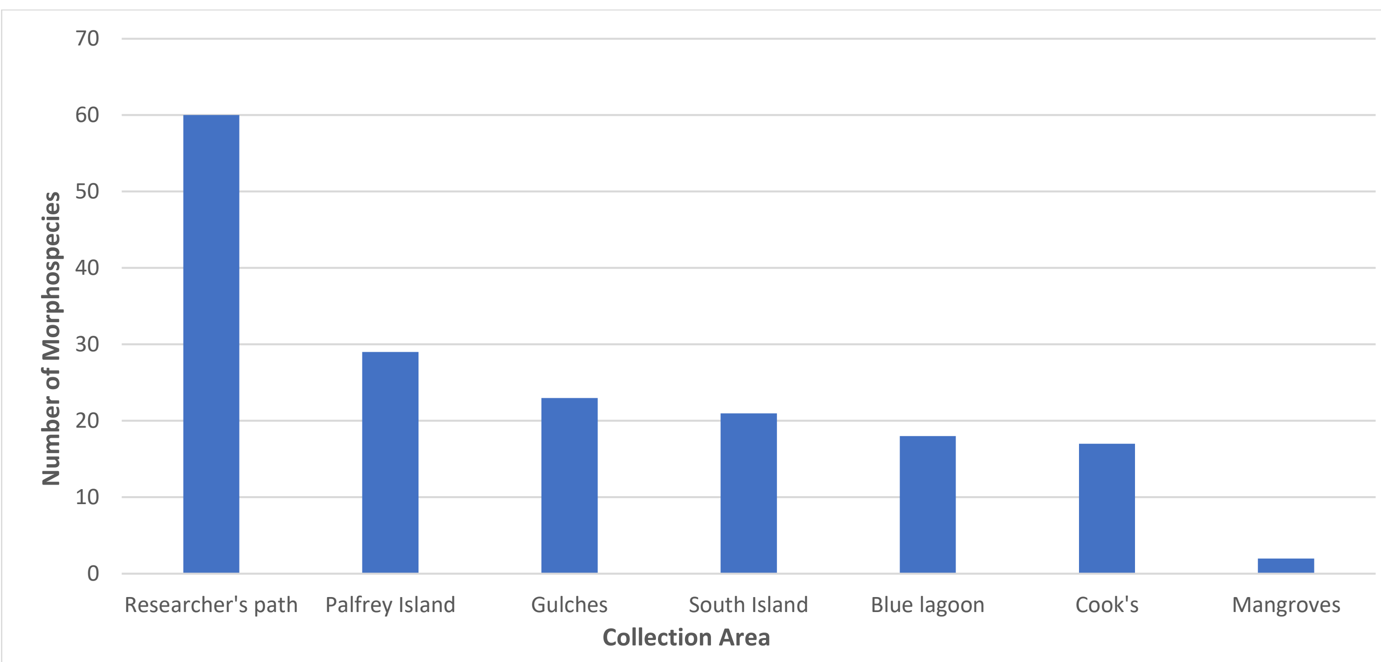

Figure 3. Number of morphospecies by collection area. Researcher’s path represented the most diverse collection area with 60 morphospecies detected, more than double that of the next most

diverse area (Palfrey Island). The mangroves represented the least diverse collection area, with only two morphospecies detected.

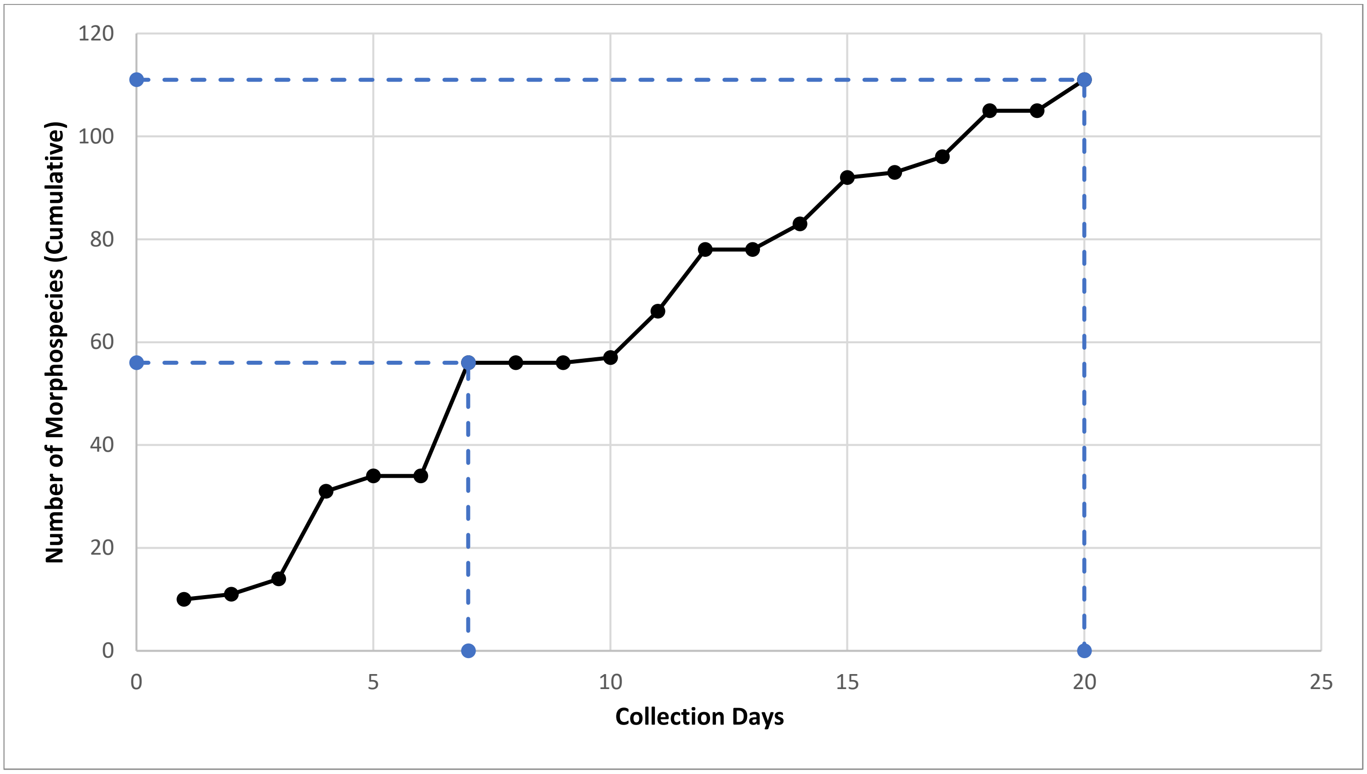

Figure 4. Rarefaction curve reflective of sampling effort. As expected, our sampling efforts yielded fewer new morphospecies with time. Approximately half of the 111 morphospecies were collected during the first seven days, while the remainder were collected over thirteen days. Nonetheless, the rarefaction curve shows no sign of a plateau.

Beetle families and morphospecies were differentially distributed across the collection areas. Curculionidae was the only family detected at all collection areas. Carabidae and Tenebrionidae morphospecies were detected at all collection areas except the mangroves. Cerambycidae was detected at all collection areas except South Island, the blue lagoon, and the mangroves, while Scarabaeidae was detected at all collection areas except South Island, the gulches, and the mangroves. Chrysomelidae was detected at all collection areas except researcher's path, the blue lagoon, and the mangroves.

Researcher's path, the most diverse collection area overall (see figure 3), was particularly diverse in Scarabaeidae morphospecies. 10 scarab morphospecies were detected at researcher's path, while 0 to 3 scarab morphospecies were detected at all other collection areas. The gulches were particularly diverse in chrysomelid morphospecies. 5 of the 6 chrysomelid morphospecies recorded in this study were detected at the gulches. No more than two chrysomelid morphospecies were detected at any other collection area.

A few collection sites were notably poor in diversity. South 1 was the only collection site where both pitfall traps and active collection were conducted yet not a single beetle was found. No specimens were collected in the pitfall traps at the following sites: South 1, South 2, blue lagoon 5, Palfrey 4, gulches 2, 3, and 4, and Cook 3 and 5 (see Appendix for site details). No specimens were collected with the beating sheet at the following sites: gulch 1, the mangroves, research 2 and 3, and South 1. Weevils (family Curculionidae) were found at every active collection site except Cook 2 and South 1.

A few beetle families and subfamilies were found to be restricted in distribution. Dung beetles (family Scarabaeidae, subfamily Scarabaeinae) were found only at the blue lagoon and researcher's path. Morphospecies in the family Hybosoridae were also only detected at researcher's path. The two morphospecies tentatively identified as flea beetles (family Chrysomelidae, subfamily Galerucinae) were detected only at the gulch 3 collection site, a vegetated refugia area next to a freshwater stream. The single morphospecies in the family Ptiliidae was found only at the mangroves, while the single morphospecies in the family Buprestidae was found only on South Island.

Several beetle morphospecies representative of widespread families were similarly restricted in distribution. For example, the "micro elephant seal," tentatively placed in the family Staphylinidae, was found only at the peak of Cook's trail (Cook's Look). Researcher's path yielded the greatest number of restricted distribution morphospecies (ie those restricted to only one collection area), followed by Palfrey Island and the gulches (n = 21, 12, and 11 respectively). Cook's trail and the mangroves yielded the fewest number of restricted distribution morphospecies (n = 2 and n = 1 respectively).

DISCUSSION

The most diverse families recorded in this study generally correlate with the most diverse families on mainland Australia (Britton 2019). However, Scarabaeidae, Chrysomelidae, and Buprestidae were found to be proportionally less diverse on Lizard Island than on the mainland.* While chrysomelids constitute about 15% of the 20,000 beetle species found on the mainland, they made up only 5% of the morphospecies detected on Lizard Island. The family Scarabaeidae also makes up about 15% of all mainland beetle species, yet scarabs made up only 9% of the morphospecies found on Lizard Island. The family Buprestidae constitutes about 6% of the beetle morphospecies found on the mainland, yet made up less than 1% of the morphospecies on Lizard Island (only a single buprestid specimen was collected) (Britton 2019).

A survey of Coleoptera on the Capricornia Cay islands in the south of the Great Barrier Reef yielded similar results. Only a single buprestid morphospecies was detected in the 15 islands surveyed, and chrysomelids made up less than 3% of all morphospecies recorded. The authors noted that the family Scarabaeidae was also particularly poorly represented in their survey, with only four morphospecies recorded (Burwell *et al* 2010).

Several factors might contribute to the proportionally low diversity detected in chrysomelids, scarabs, and buprestids on Lizard Island. Chrysomelids are herbivorous beetles, and their diversity has been shown to increase in areas of greater tree and herbaceous vegetation cover (Gok & Sen 2014). As noted in the results, the densely vegetated refugia areas of the gulches yielded the greatest number of chrysomelid morphospecies in our study. Lizard Island consists of about 60% grassland (Queensland Government 2017b) - insufficient habitat for most chrysomelids. The low buprestid diversity detected in this study may be the result of the

*Further mention of Lizard Island refers to Lizard, South, and Palfrey islands collectively.

relatively small number of robust, dead trees on Lizard Island. Buprestids are wood-boring beetles, and generally deposit their eggs in dead or dying trees (Evans *et al* 2007). It is also possible that sampling limitations played a role in the low diversity of both buprestids and scarabs detected in our survey. No dead wood was examined for adult buprestids and their larvae. Many species of scarabs vary in abundance throughout the year, yet this survey was limited to the month of April. Christmas beetles (family Scarabaeidae, genus *Anoplognathus*) have been observed by the directors of the research station in the past, but adults only emerge in November and December and were thus not detected (Ennion 2016).

As previously noted, researcher's path was the collection area with the highest beetle diversity (n = 60 morphospecies). This may be the result of the high habitat complexity and plant species diversity in the woodland surrounding the path. The researcher's path woodland consisted of an assortment of fig, eucalypt, and acacia trees, and contained the tallest trees of all sites sampled. Like most vertebrates, beetles tend to increase in diversity in more complex habitats (Lassau *et al* 2005). Researcher's path also yielded the most carabid and scarab morphospecies of any collection area (n = 6 and n = 10 respectively). This may be attributed to the substantial quantity and diverse composition of leaf litter in the area. The diversity and abundance of carabid beetles in particular has been shown to depend on leaf litter cover, in addition to other soil parameters (Magura et al 2000).

It is important to note that researcher's path was subject to greater sampling intensity than the other collection areas. Pitfall traps were set for two nights at researcher's path collection sites, as opposed to one night at all other collection sites. In addition, a number of specimens were opportunistically collected on the path itself while returning back to the station from other collection areas. Specimens collected around the research station were also included as part of the researcher's path collection area. This sampling bias may have contributed in part to the high diversity recorded at researcher's path.

The mangroves were the collection area with the lowest beetle diversity, with only two morphospecies detected. A study of mangrove herbivory in Townsville, north Queensland, found a similarly low diversity of beetles in the mangroves (six species) (Wayne 2003). This low diversity may be attributed to the homogeneous vegetation composition – the mangroves were dominated by a few species of mangrove shrubs. Research has shown beetle diversity is often lower in areas of homogeneous vegetation, such as plantations (Magura 2003). The mangrove pitfall trap site may have also experienced occasional saltwater flooding, decreasing the habitat viability for most beetle species. Finally, little to no leaf litter was present in the mangroves, making it inhospitable for ground-dwelling beetles (families Carabidae, Tenebrionidae, Staphylinidae). It is important to note that the mangrove branches were not searched for wood-boring beetles (family Cerambycidae) known to occur in mangrove trees.

A few collection sites were also notably poor in beetle diversity. As noted in the results, South 1 was the only collection site where both pitfall traps and active collection were conducted yet not a single beetle was found. The South 1 collection site was a homogeneous acacia woodland that contained little to no understory growth. Such low habitat complexity and vegetation diversity most likely has a negative effect on beetle diversity in the area. It is interesting to note that weevils (family Curculionidae) were detected at every active collection site except South 1 and Cook 2. As in South 1, acacia trees were dominant in the sparse woodland around Cook 2. Research has shown that beetle species richness declines in acacia plantations, though this may be related to a decrease in habitat complexity as opposed to the acacia trees themselves (Chung *et al* 2007).

Other pitfall sites at which no specimens were collected include blue lagoon 5, gulch 2 and 3, Palfrey 4, and Cook 3 and 5. Blue lagoon 5 was a sandy dune covered in a homogeneous layer of low-lying shrubs, and was thus expected to be a species poor site. Gulch 2 and 3 were also expected to be species poor sites, as gulch 2 appeared to be occasionally flooded by saltwater, and gulch 3 consisted of a mat of vines growing atop a stream boulder.

On the other hand, the lack of pitfall success at Palfrey 4, Cook 3, and Cook 5, in addition to South 1, suggests soil and leaf litter properties besides quantity influence ground-dwelling beetle diversity. Each of these pitfall sites contained substantial quantities of leaf litter, yet yielded no beetle specimens. Palfrey 4 and South 1 were sites of particularly thick leaf litter, and appeared to contain rich, sandy loam soil. Aside from the quantity of leaf litter present, other factors known to influence carabid (ground beetle) diversity include soil and litter nitrogen content and soil conductivity (Vician *et al* 2018). These properties are driven by the dominant tree species in an area (Vician *et al* 2018). Thus the variation in tree species at the collection sites, and subsequent variation in soil and litter properties, may influence the local ground-dwelling beetle diversity.

Natural History Notes (see figure 5 below for photos)

A few morphospecies were found to be very restricted in distribution. The single morphospecies in the family Anthicidae, tentatively identified as *Mecynotarsus* sp., was found only on the blue lagoon beach, while the single morphospecies in the family Phycosecidae, tentatively identified as *Phycosecis hilli*, was found only on the South Island beach. Both morphospecies were only a few mm in length, and were characterized by an anterodorsal horn extending over the head. 11 *Mecynotarsus* specimens were collected from the pitfall traps set on the blue lagoon beach, while only two *Phycosecis hilli* specimens were collected from the pitfall traps on the South Island beach. Both the blue lagoon and South Island beach sites were sandy areas with sparse *Spartina* grasses, and were located above the tideline. Anthicids are known to associate with decaying vegetation along beaches, and *Phycosecis* species are known to scavenge on dead birds and fish along the coast (Lawrence & Britton 1991). All four species in the family Phycosecidae are in the genus *Phycosecis*, and are confined to Australia and New Zealand (Lawrence & Britton 1991). The previously mentioned Capricornia Cay beetle survey also found *Phycosecis hilli* to be restricted to beaches (Burwell *et al* 2010).

The carabid *Megacephala* sp. was detected only at the blue lagoon collection area. Though only one specimen was collected, this morphospecies was seen several times while passing through the blue lagoon area at night. Some *Megacephala* species are known to favor salt marsh habitats (Sekeroglu & Aydin 2013), which may explain their presence at the coastal blue lagoon. Although they are known to be predators, the function of the oversized mandibles in *Megacephala* species is not well known.

Dung beetles (family Scarabaeidae, subfamily Scarabaeinae) were found only at the blue lagoon and researcher's path. The two larger dung beetle morphospecies were found only at researcher's path (see supplementary file 1 for morphospecies names). On several nights, dung beetles were observed collecting and burying dung in the sand on researcher's path. The two common morphospecies were always found together – the small "little shovel-heads" and the much larger "little horn rhino." The blue lagoon and researcher's path, the only two collection areas at which dung beetles were detected, were the only sandy paths sampled. Certain dung beetle species are indeed known to prefer sandy areas (Lobo *et al* 2001).

A

Photo: *Phycosecis hilli*. Photo lost due to computer failure. I will attempt to get a new photo; none are available online.

B

C

D

E

F

Figure 5. Examples of beetles from Lizard Island: [A] *Mecynotarsus* sp.; from beach; [B] *Phycosecis hilli*; from beach; [C] "shiny green tiger"; family Carabidae; [D] *Megacephala* sp.; [E] "little horn rhino"; family Scarabaeidae; [F] salt and pepper big-weevil; family Curculionidae. Images courtesy of John McCormack (A, B) and Darko Cotoras (C, D, E, F).

The carabid referred to as the "shiny green tiger" was also found only at the blue lagoon and researcher's path. Although abundance was not considered in this study, the shiny green tiger appeared to be by far the most abundant morphospecies present at researcher's path. This localized abundance suggests the shiny green tiger may prefer the habitat complexity and vegetation diversity characteristic of the researcher's path woodland.

The weevils (family Curculionidae) also appeared to vary in abundance, in addition to diversity, in different collection areas. Most notably, the "bumpy Palfrey weevil" and the "salt and pepper big-weevil" appeared to be the most abundant weevils on Palfrey Island, while the salt and pepper big-weevil alone appeared to be the most abundant weevil on South Island. No specimens of the bumpy Palfrey weevil were collected on South Island. This apparent variation in dominant species most likely involves the particular habitat preferences of the two weevil morphospecies.

Finally, the family Ptiliidae, represented by a single morphospecies in our study, was found to be restricted to the mangroves. The family Ptiliidae contains the smallest of all beetles, and some species are indeed known to occur in saltwater mangroves (Balakrishnan *et al* 2014).

Further Research

Our study offers several pathways for further research on Lizard Island Coleoptera. As shown in the rarefaction curve (figure 4), our sampling effort was far from complete, and subsequent surveys would almost certainly yield new morphospecies. Aside from further sampling, our study could be expanded to consider the abundance of beetle morphospecies in different habitats. As previously noted, certain morphospecies appeared to be remarkably abundant in certain areas yet absent from others. Our study could also be expanded to more closely examine how the Lizard Island beetle community compares with that of mainland Australia. The Lizard Island beetle community may correspond with that of the closest mainland areas, or the areas with the most similar habitats to Lizard Island. Additional research could also consider the effect of climate change on the Lizard Island beetles with restricted distributions. The morphospecies only found near the coastline (families Anthicidae, Ptiliidae, and Phycosecidae) might be especially vulnerable to sea level rise.

Further research could also examine how chemical compounds in leaves influence ground-dwelling beetle communities. As previously noted, soil and leaf litter properties aside from quantity appear to influence beetle species richness. Some species of acacia are known to be allelopathic, producing phytotoxic compounds in their leaves that inhibit the growth of neighboring plants (Chou *et al* 1998). At collection site South 1, the homogeneous acacia woodland, it is possible that phytotoxic compounds in the leaf litter negatively affect the beetle community present.

The function of the horn structure in the anthicid and phycosecid beetles found on the beaches might also be an interesting topic to explore. Both morphospecies were characterized by anterodorsal horns, which were not noted in any other morphospecies collected. Finally, the dung beetles collected could also be the subject of future work. The specimens could be identified to the species level, and compared with the dung beetles known to occur on the mainland. A number of exotic dung beetle species were introduced into Queensland in the late 1900s (Doube

& Macqueen 1991); it would be interesting to ascertain whether these dung beetles have dispersed to Lizard Island.

CONCLUSION

Our survey of Lizard Island Coleoptera highlighted several important points. The family Curculionidae was identified as the most diverse beetle family on the island, in accordance with global patterns in beetle diversity. The families Chrysomelidae, Scarabaeidae, and Buprestidae were proportionally less diverse on Lizard Island than on mainland Australia, a trend also noted in a survey of the Concordia Cay islands on the southern Great Barrier Reef. Researcher's path represented the most diverse collection area on Lizard Island, most likely due to the high habitat complexity and vegetation diversity in the surrounding woodland. The mangroves were identified as the least diverse collection area, in accordance with previous surveys from mainland Queensland. Notably poor collection sites tended to exhibit a homogeneous assemblage of vegetation, generally dominated by acacia trees. The fact that certain sites with substantial leaf litter yielded no pitfall specimens suggests leaf litter and soil properties aside from simple quantity may influence ground-dwelling beetle diversity. Several morphospecies were found to be highly restricted in distribution, including the anthicid and phycosecid representatives found only on beaches. Our sampling of Lizard, South, and Palfrey islands was far from exhaustive, and more morphospecies undoubtedly remain to be recorded on the islands. Aside from further sampling, future research on Lizard Island could investigate the variation in beetle abundance in different habitats, providing insight into the ecology of individual beetle species.

ACKNOWLEDGMENTS

We thank Lyle and Anne Hoggett, the directors of Lizard Island Research Station, and John and Maryanne of the Lizard Island Research Station staff for their assistance during our stay at Lizard Island. We also thank Tony Cummings and the School for International Training for helping orchestrate this project and providing necessary materials.

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Supplementary file 1: morphospecies data sheet.
Supplementary file 2: photos of all morphospecies.

APPENDIX. Description of collection areas and sites. BS = beating sheet, SF = sifting litter, PF = pitfall traps, NC = night collection. Opportunistic hand collection was done at all sites.

Collection Area: Researcher's Path (RP)

Collection Site	GPS Coordinates	Collection Dates	Collection Methods	Habitat Type
RP 1	-14.678764 N, 145.450674 E	4/5, 4/8, 4/9	BS, SL, PF	Woodland
RP 2	-14.679181 N, 145.451268 E	4/5, 4/8, 4/9	BS, SL, PF	Woodland
RP 3	-14.680024 N, 145.452066 E	4/5, 4/8, 4/9	BS, SL, PF	Woodland
RP 4	-14.679469 N, 145.453874 E	4/5, 4/8, 4/9	BS, SL	Woodland
RP 5	-14.677770 N, 145.453015 E	4/5, 4/8, 4/9	BS, SL, PF	Woodland
RP 6	-14.674986 N, 145.452659 E	4/5, 4/8, 4/9	BS, SL, PF	Woodland
RP 7	-14.671709 N, 145.452228 E	4/5, 4/8, 4/9	BS, SL, PF	Woodland

Collection Area: Blue Lagoon (BL)

Collection Site	GPS Coordinates	Collection Dates	Collection Methods	Habitat Type

BL 1	-14.679610 N, 145.459237 E	4/11	PF, NC	Beach
BL 2	-14.678984 N, 145.459378 E	4/11	PF, NC	Woodland
BL 3	-14.678353 N, 145.458785 E	4/11	BS, SL, PF, NC	Woodland
BL 4	-14.677911 N, 145.458476	4/11	BS, SL, PF, NC	Woodland
BL 5	-14.676827 N, 145.457857 E	4/11	PF, NC	Dune scrubland

Collection Area: Palfrey Island

Collection Site	**GPS Coordinates**	**Collection Dates**	**Collection Methods**	**Habitat Type**
Palfrey 1	-14.692506 N, 145.444730 E	4/15, 4/16	BS, SL, PF	Woodland
Palfrey 2	-14.692869 N, 145.444992 E	4/15, 4/16	BS, SL, PF	Grassland
Palfrey 3	-14.692367 N, 145.445366 E	4/15, 4/16	BS, SL, PF	Woodland
Palfrey 4	-14.692403 N, 145.445892 E	4/15, 4/16	BS, SL, PF	Woodland
Palfrey 5	-14.691768 N, 145.448407 E	4/15, 4/16	BS, SL, PF	Woodland
Palfrey 6	-14.689352 N, 145.447950 E	4/16	PF	Beach
Palfrey lighthouse	??	4/16	BS, SL	Woodland

Collection Area: South Island (SI)

Collection Site	**GPS Coordinates**	**Collection Dates**	**Collection Methods**	**Habitat Type**
South 1	-14.702735 N, 145.456343 E	4/18, 4/19	BS, SL, PF	Homogeneous woodland
South 1B	-14.702836 N, 145.456119 E	4/18	BS	Woodland
South 2	-14.702478 N, 145.455738 E	4/18, 4/19	BS, SL, PF	Woodland
South 3	-14.702201 N, 145.454988 E	4/18, 4/19	BS, SL, PF	Woodland
South 4	-14.701589 N, 145.453910 E	4/18, 4/19	BS, SL, PF	Rocky, grassy area near woodland
South 5	-14.699525 N, 145.452626 E	4/18, 4/19	PF	Beach

Collection Area: Gulches

Collection Site	GPS Coordinates	Collection Dates	Collection Methods	Habitat Type
Gulch 1	-14.675971 N, 145.469787 E	4/21, 4/22	BS, SL, PF	Woodland*
Gulch 2	-14.676532 N, 145.470674 E	4/21, 4/22	BS, SL, PF	Woodland
Gulch 3	-14.675071 N, 145.472831 E	4/21, 4/22	BS, SL, PF	Ground vines
Gulch 4	-14.676103 N, 145.473317 E	4/21, 4/22	BS, SL, PF	Woodland
Gulch 5	-14.673801 N, 145.475290 E	4/21, 4/22	BS, SL, PF, NC	Woodland

*All gulch sites except gulch 1 were located within a few meters of freshwater streams.

Collection Area: Cook's Trail

Collection Site	GPS Coordinates	Collection Dates	Collection Methods	Habitat Type
Cook 1	-14.666366 N, 145.463554 E	4/25	PF	Sparse woodland*
Cook 2	-14.663516 N, 145.461738 E	4/25	BS, SL, PF	Woodland
Cook 3	-14.661619 N, 145.460617 E	4/25	BS, SL, PF, NC	Woodland
Cook 4	-14.660128 N, 145.458962 E	4/25	PF	Woodland
Cook 5	-14.656982 N, 145.455737 E	4/25	PF	Woodland

*Cook 1 was located in a patch of trees surrounded by grassland.

Collection Area: Watson's Bay Mangroves

Collection Site	GPS Coordinates	Collection Dates	Collection Methods	Habitat Type
Mangroves	-14.666208 N, 145.452299 E	4/14, 4/25	BS, PF	Mangrove swamp