Spring 2016

Epigeal fauna of Bosque Protector Cerro Candelaria

Justine Albers
SIT Graduate Institute - Study Abroad

Follow this and additional works at: https://digitalcollections.sit.edu/isp_collection

Part of the Biology Commons, Environmental Studies Commons, and the Terrestrial and Aquatic Ecology Commons

Recommended Citation

This Unpublished Paper is brought to you for free and open access by the SIT Study Abroad at SIT Digital Collections. It has been accepted for inclusion in Independent Study Project (ISP) Collection by an authorized administrator of SIT Digital Collections. For more information, please contact digitalcollections@sit.edu.
Epigeal fauna of Bosque Protector Cerro Candelaria: Evaluation of pitfall trap efficacy and analysis of Coleoptera community diversity

Albers, Justine
Academic Director: Silva, Xavier, PhD.
Project Advisor: Reyes-Puig, Carolina
Swarthmore College
Biology
South America, Ecuador, Tungurahua
Submitted in partial fulfillment of the requirements for Ecuador Comparative Ecology and Conservation, SIT Study Abroad, Spring 2016

*Psalidognathus sp.*
ABSTRACT

Pitfall traps are commonly used to sample epigeal fauna, and are especially utilized for the collection of ground-dwelling arthropods; however, this sampling method has yet to be employed in Cerro Candelaria, a protected cloud forest reserve in Tungurahua, Ecuador. Pitfall trap systems were established at two different sites in the reserve that differed in elevation and forest type. Although individuals from 4 different phyla, 11 classes and 17 orders were encountered over the duration of the study, pitfalls were most effective at sampling Coleoptera, which comprised 40% of the total catch across both sites. The two communities of beetle surveyed had similar alpha diversities and shared 6 out of 9 total families. However, over half of the morphospecies described at each site were found only at that particular site, indicating some degree of dissimilarity in diversity between the two locations. Overall, pitfall traps are a promising method for the long-term monitoring of beetle communities in Candelaria, and have the potential to provide information about other epigeal fauna inhabiting the reserve as well.

Keywords: Pitfall trapping, epigeal fauna, Coleoptera
Topic Codes: 609, 614, 615

RESUMEN

Trampas de pitfall están usadas para estudiar fauna epigeal, y están utilizados especialmente para colectar artrópodos que viven en el superficie del suelo; sin embargo, este método no ha sido empleado en Cerro Candelaria, un bosque protector en Tungurahua, Ecuador. Sistemas de trampas fueron establecidos en dos sitios diferentes en la reserva que diferenciaron en elevación y tipo de bosque. Aunque individuales de 4 phyla, 11 clases y 17 ordenes fueron encontrados durante el estudio, las trampas eran más eficaces para la colección de Coleoptera, que representaron 40% de la captura total. Las dos comunidades de escarabajos tuvieron diversidades alfas similares, y compartieron 6 de 9 familias en total. Sin embargo, más de la mitad de los morfoespecies encontrados en cada sitio sólo estaban presentes en ese sitio, lo cual indica un cierto grado de disimilitud entre los dos lugares. En total, trampas de pitfall son un método prometedor para monitorizar las comunidades de escarabajos en Candelaria a largo plazo, y tienen la potencial para proveer información sobre otra fauna epigeal que habita la reserva también.

Palabras claves: trampas de pitfall, fauna epigeal, Coleoptera

INTRODUCTION

Arthropoda is a phylum of invertebrates, which includes arachnids, insects, crustaceans and myriapods. Arthropods have existed on Earth for at least 400 million years, first emerging on land in the Paleozoic Era (Evans, 1984). Organisms in this phylum comprise more than 80% of global species richness. Furthermore, Coleoptera alone represent approximately 25% of all currently described species, and 40% of currently described species of arthropods, with new species still being discovered (Kim, 1993; Work, 2002; Stork, 2015). They are a vital component of any healthy ecosystem, acting as pollinators, predators, prey, parasites, scavengers, and play important roles in nutrient cycling (Work, 2002; Klein, 1989). Their high level of biodiversity, responsiveness to changes in the environment, and fast reproductive cycle, make arthropods- and beetles in particular- robust bioindicators (Work, 2002). In addition, Coleoptera are informative study organisms because population data on certain families, such as carabids, can be used to estimate general arthropod population composition (Butterfield, 1995; Maveety, 2011).
Pitfall traps are a commonly used method for sampling epigeal arthropod populations (Knapp, 2012). Traps typically consist of wide-mouth containers placed in the ground so that their rims are flush with the soil surface, which maximizes capture of both large and small arthropods (Knapp, 2012). The use of a drift fence in conjunction with traps can also allow for collection of small terrestrial vertebrates, including mammals and herpetofauna (Mengak, 1987). Pitfalls can be filled with a preservative, such as formaldehyde or propylene glycol, or with water to a certain level to reduce the likelihood that fauna is able to escape the trap (Knapp, 2012; Mengak, 1987).

This technique is extremely popular, particularly for the study of arthropods, since it is both cost-effective and efficient, permitting the collection of large samples; however, pitfall trapping has also been widely criticized because data obtained using this methodology can be biased in several ways (Knapp, 2012). Factors such as trap design and preservative used can affect total catch size, species composition and abundance of catches (Knapp, 2012). Catch size and composition also depend on factors such as population size, the manner in which locomotor activity is impeded by vegetation, and species behavior (Greenslade, 1964).

Although it is difficult to make conclusions about species density from pitfall trap catches as the data collected reflects activity level rather than abundance, traps can still provide useful information about the arthropods and other fauna that inhabit a particular area (Greenslade, 1964). This is especially true in the case of Cerro Candelaria, where little to no formal work on arthropod populations in the area has been published in recent years. Candelaria is a protected cloud forest reserve along the Rio Pastaza watershed in the Province of Tungurahua, Ecuador (Reyes-Puig, 2013). The reserve is managed by Ecominga, a foundation dedicated to the protection and conservation of threatened areas that boast high levels of alpha- diversity and endemism (Jost, 2010; Reyes-Puig, 2012). The Pastaza watershed is an area of elevated biodiversity is primarily due to the large amount of rainfall and humidity that it receives annually (Reyes-Puig, 2013). Conservation of Candelaria and other nearby reserves in the Pastaza basin is important because this region creates an ecological corridor that connects the northern and southern parts of the Andes mountain range (Reyes-Puig, 2012; Freile & Santander, 2005).

The establishment of pitfall traps in Cerro Candelaria has the potential to provide a large amount of data on the small vertebrates and invertebrates that populate the reserve, since this technique has not previously been implemented in the area. This study surveyed the populations of epigeal fauna in Candelaria by implementing pitfall trap systems in two different microhabitats, with the specific goals of determining species richness and diversity of Coleoptera, as well as more generally evaluating the efficacy of pitfall traps for catching different types of fauna.

**MATERIALS AND METHODS**

**Site Locations**

Pitfall traps were constructed on previously established trails at 2 different sites. One set of traps was placed at coordinates 01°26.174’S, 078°18.633’W. This site, referred to as La Soledad, lies within the reserve and is composed of primary forest at an elevation of 2267m. The area experienced a mean daytime temperature of 19.0°C. Average humidity was 85.2% upon arrival at the site throughout the study. A second set of traps was placed at coordinates 01°24.440’S, 078°16.446 W (Figure 1). These traps were within a private property in the buffer zone of the reserve, next to the town of Machay (Jesus Recalde, Juan Pablo Reyes-Puig, personal communication, May, 2016). The area is composed of mature secondary growth forest at an
elevation of 1537m, approximately 100m above the Rio Pastaza. Average humidity at the site was 87.7%, and average daytime temperature was 20.3°C.

Figure 1. Locations of each set of pitfall traps. Traps at La Soledad were at an elevation of 2267m in primary forest. Traps at Machay were established at an elevation of 1537m in secondary forest (Google, DigitalGlobe).

**Construction**

Plastic buckets were positioned 10-12 meters apart in holes dug at the center of the trail at each site. 10 buckets were used per location. Buckets measured 26.5cm across the top, 18.5 cm across the base, and were 23.0 cm deep. Small holes in the bottom of each bucket allowed water to drain. Half of the traps at La Soledad were positioned between 10 and 15cm below the surface in order to increase their depth. The other half remained at surface level. All traps at Machay remained at surface level. 7 out of 10 buckets at La Soledad and 6 out of 10 buckets at Machay were buried on inclined sections of the trails; the other buckets were buried in relatively flat areas.

A drift fence was created to connect the buckets at each location using 100m strips of black heavy-duty plastic sheeting. The strips were pulled taught, tied to poles, and stuck into the ground with stakes. Soil and leaf litter was piled against the edge of each strip to prevent fauna from crossing to the other side of the fence (Figure 2).
Figure 2. Pitfall traps were constructed at both La Soledad (top right and left-hand images) and Machay (bottom right and left-hand images). Trap systems consisted of a plastic bucket buried flush with the soil surface and a drift fence spanning a total of 100m connecting each bucket.
Operation

Pitfall catches were reviewed periodically. Visits were between 40-72 hours apart. Each set of traps was in operation for a total of 370.75 hours. The duration of each visit to a set of pitfalls was not included in the total number of hours that traps were considered to be “open” or in operation. Traps at La Soledad were visited on 7 separate occasions; traps at Machay were visited on 6 separate occasions. At each visit, bucket number, inundation level (cm of water), faunal composition was recorded. Specimens were removed from the traps, identified to the most specific taxonomic level possible, and either released or collected for further study. Once the faunal composition of an individual trap had been noted, the trap was cleared entirely of all fauna, water (if present), soil, and leaf litter, and a fresh layer of leaves was placed in the trap. A bait mixture of tuna, oats and vanilla was placed in traps during the first 2 visits to each set of traps; but use of bait was discontinued for the remaining duration of the study.

Specimen Collection and Preservation

Arthropods collected from pitfalls were documented and preserved in 70% ethanol. Any live specimens were sacrificed before preservation in alcohol using a kill chamber containing a cotton-ball soaked in nail polish remover. Ventral and dorsal photographs were taken of each specimen before preservation.

Long-horned beetles (*Psalidognathus*) were measured and weighed. 1 beetle was collected for preservation purposes; all other individuals were released following processing. Photos were taken and identification markings were painted on the elytra of 2 of the beetles before release.

Squamates were sacrificed in a kill chamber containing the local-anesthetic lidocaine. Dorsal, ventral and lateral photographs were taken of each specimen. Weight, snout-vent length, tail length, head width, head length, body width (at midbody), hindleg length and tarsus length were also measured and recorded. Specimens were preserved with formaldehyde (formol) and placed in 90% alcohol.

All other non-living specimens were placed in 90% alcohol.

Identification

Specimens were identified at least to the level of order, and to the level of family or genus if possible. Xavier Silva, Juan Pablo Reyes-Puig, Carolina Reyes-Puig, and Santiago Villamarin confirmed identifications.

Data Analysis

Diversity analysis was performed using vegan 2.3-5 for R following recommendations for calculating community diversity presented in Jost (2006). True alpha, beta and gamma diversities were determined using Shannon-Weiner entropies (H) calculated in R and eq. 5 from Jost (2006):

\[(\exp(H_\alpha))(\exp(H_\beta)) = \exp(H_\gamma).\]

Exponential values of Shannon entropies were calculated in order to permit straightforward comparisons between sites (Jost, 2006). Species accumulation curves were created for each site using EstimateS. A Wilcoxon ranked-sum test was also performed in R to compare the average total catch of *Coleoptera* per trap between sites.
RESULTS

*Trap Inundation Levels*

Individual buckets at both sites were often full or partially filled with rainwater and soil upon arrival at the sites.

*Total Catch*

The total catch obtained from traps at La Soledad was 918 individuals, while the total catch obtained from traps at Machay was 704 individuals, resulting in an aggregate of 1622 individuals across both locations. Fauna collected included representatives from 4 phyla, 11 classes, and 17 orders. *Insecta* was the most represented class, with 1089 total individuals collected (Table 1). While more individuals were captured at La Soledad than at Machay, nearly 80% of fauna from Machay was classified as insects, compared to approximately 57% at La Soledad. *Arachnida* and *Malacostraca* were the second and third most represented classes, respectively comprising 24.95% and 10.46% of the total catch from La Soledad, and 11.08% and 3.05% in traps at Machay. Individuals belonging to 8 of the 11 total orders surveyed were collected at both elevations; however, there were no *Aves* or *Gastropoda* present in pitfalls at Machay, and no *Amphibia* were present at La Soledad at any point during the duration of the study (Figures 3&4).

*Arthropoda*

891 arthropods were captured at La Soledad and 697 were captured at Machay, for a total of 1588 individuals across both locations. Observed orders include *Blattodea, Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera and Phasmatodea*. All orders were encountered in traps at both sites with the exception of *Diptera*, of which only one individual was found at La Soledad. *Coleoptera* was the most abundant order of insects captured, making up 41.63% of all arthropods (Table 1).

*Arachnida*

A total of 307 arachnids were recorded across both sets of traps. 229 individuals were reported in higher elevation traps at La Soledad; 78 individuals were present in lower elevation traps at Machay. The arachnid catch was primarily composed of the order *Araneae*, but individuals belonging to *Opiliones* and *Scorpiones* were also captured (Table 1; Supplementary Figures 1&2).

*Malacostraca*

A total of 121 *Malacostraca*, a class of crustaceans, were present across both sites. All crustaceans registered belonged to the order *Isopoda*. Almost 4 times the number of *Isopoda* recorded at Machay were encountered at La Soledad (Table 1).

*Other fauna*

A total of 19 mammals were collected from traps at La Soledad; 3 mammals were collected from traps at Machay. The total mammalian catch was comprised of at least 10 different species, including rodents and one marsupial (Juan Pablo Reyes Puig, personal communication, May, 2016)

One juvenile individual of an unknown species of bird was collected from pitfalls at La Soledad. A total of 3 lizards were caught in pitfalls over the duration of the study.
(Supplementary Figure 3). One anuran (likely *Pristimantis*) was observed in pitfalls at Machay, but was not collected. Worms (*Megadrilacea*), snails (*Gastropoda*), centipedes (*Chilopoda*) and millipedes (*Diplopoda*) were also recorded in pitfalls (Supplementary Figure 4).

Table 1. Taxonomic breakdown of total catch of *Animalia* collected from pitfall traps established in the Cerro Candelaria cloud forest reserve at ~2250m (Soledad) and ~1500m (Machay). Total number of individuals belonging to each phylum, class and order are listed, as well as the total number of individuals collected at each site.

<table>
<thead>
<tr>
<th>Phylum</th>
<th>Class</th>
<th>Order</th>
<th>Soledad</th>
<th>Machay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arthropoda</strong></td>
<td><strong>Insecta</strong></td>
<td><strong>891</strong></td>
<td><strong>697</strong></td>
<td><strong>526</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Blattodea</strong></td>
<td>46</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Coleoptera</strong></td>
<td>219</td>
<td>435</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Dermaptera</strong></td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Diptera</strong></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Hemiptera</strong></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Hymenoptera</strong></td>
<td>10</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Lepidoptera</strong></td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Orthoptera</strong></td>
<td>212</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Phasmatodea</strong></td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td><strong>Arachnida</strong></td>
<td><strong>229</strong></td>
<td></td>
<td><strong>78</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Araneae</strong></td>
<td>217</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Opiliones</strong></td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Scorpiones</strong></td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td><strong>Chilopoda</strong></td>
<td><strong>17</strong></td>
<td></td>
<td><strong>10</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Diplopoda</strong></td>
<td><strong>23</strong></td>
<td></td>
<td><strong>21</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Malacostraca</strong></td>
<td><strong>96</strong></td>
<td></td>
<td><strong>25</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Isopoda</strong></td>
<td></td>
<td></td>
<td>96</td>
<td>25</td>
</tr>
<tr>
<td><strong>Mollusca</strong></td>
<td><strong>4</strong></td>
<td></td>
<td><strong>0</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Gastropoda</strong></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td><strong>Annelida</strong></td>
<td><strong>2</strong></td>
<td></td>
<td><strong>1</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Megadrilacea</strong></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Chordata</strong></td>
<td><strong>21</strong></td>
<td></td>
<td><strong>6</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Aves</strong></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Mammalia</strong></td>
<td><strong>19</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Didelphimorphia</strong></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Rodentia</strong></td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Reptilia</strong></td>
<td>1</td>
<td><strong>2</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Squamata</strong></td>
<td>1</td>
<td><strong>2</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Amphibia</strong></td>
<td>0</td>
<td><strong>1</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Anura</strong></td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**Total Catch** | **918** | **704** |
Figure 3. Composition of epigeal fauna population collected from Cerro Candelaria pitfall traps at ~2250 m in primary forest (Soledad).
Figure 4. Composition of epigeal fauna population collected from Cerro Candelaria pitfall traps at ~1500 m in secondary forest (Machay).

**Coleoptera**

The 654 Coleoptera collected across both sets of traps belong to a total of 9 families, 4 morphofamilies and 26 morphospecies (Figures 5&6). A total of 213 Coleoptera were caught at La Soledad, for an average of ~21 individuals per bucket. The catch was comprised of 8 different families and 1 morphofamily, with a total of 14 distinct morphospecies of adult beetle, as well as 2 morphospecies of larvae. Traps at Machay yielded 435 individuals, for an average of ~44 individuals per bucket (Table 2). The catch consisted of 6 families, 3 morphofamilies, 15 distinct
morphospecies of adult beetles and 2 morphospecies of larvae. A Wilcoxon signed-rank test demonstrated that the average total catch of beetles per trap differed significantly between the 2 locations (Figure 7; p = 0.0002).

Figure 5.

Figure 5. Representative Coleoptera collected from pitfall traps constructed at ~2250m in primary cloud forest (Soledad site). A1&2) Lampyridae larvae. B) Psalidognathus beetle (Cerambycidae). C) Scarabaeidae sp. D) from left to right: Carabidae sp., Carabidae sp., Silphidae sp. E) Plochionocerus sp. (Staphylinidae).
Figure 6. Representative *Coleoptera* collected from pitfall traps constructed at ~1500m in secondary cloud forest (Machay). A) *Carabidae* sp. B) *Scarabaeidae* sp. C) *Scarabaeidae* sp. D) *Carabidae* sp. E) *Carabidae* sp. F) unidentified *Coleoptera* sp. G) *Scarabaeidae* sp. H) *Carabidae* sp. I) unidentified *Coleoptera* sp. J) unidentified *Coleoptera* sp. K) *Carabidae* sp. L) *Curculionidae* sp. M) *Scarabaeidae* sp.
Table 2. Total number of *Coleoptera* caught in each trap at each cloud forest site. Average total catch per trap at each site is also reported.

<table>
<thead>
<tr>
<th>Trap</th>
<th><em>Coleoptera</em> caught</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soledad (2250m)</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>33</td>
</tr>
<tr>
<td>7</td>
<td>33</td>
</tr>
<tr>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

| avg. caught/bucket | 21 | 44 |

Figure 7. Mean number of *Coleoptera* caught per trap at each site. Machay pitfalls at ~1500m caught a significantly higher average number of *Coleoptera* per trap than the La Soledad pitfalls at ~2250m (p = 0.0002).

Figure 7. Mean number of *Coleoptera* caught per trap at each site. Machay pitfalls at ~1500m caught a significantly higher average number of *Coleoptera* per trap than the La Soledad pitfalls at ~2250m (p = 0.0002).
**Community Diversity**

Families of *Coleoptera* collected included *Carabidae* (ground beetles), *Scarabaeidae* (scarab beetles), *Staphylinidae* (rove beetles), *Coccinellidae* (lady beetles), *Curculionidae* (weevils/snout beetles), *Cerambycidae* (longhorn beetles) *Lampyridae* (fireflies) and *Silphidae* (carrion beetles). Ground beetles, scarabs, rove beetles, weevils, fireflies, and lady beetles were found in both higher and lower elevation traps. At La Soledad, 5 individuals of the longhorn beetle *Psalidognathus* were collected from traps; however, no *Psalidognathus* were found in pitfalls at Machay. In addition, carrion beetles were present in La Soledad traps, but not in those at Machay. The two sites shared 7 morphospecies of beetles. There were 9 species unique to La Soledad and 10 species unique to Machay (Figures 5&6).

Using exponential Shannon entropy, it was determined that the *Coleoptera* population collected from La Soledad had 5.66 effective species. The Machay beetle population had 5.93 effective species. The exponential of Shannon gamma entropy shows that when both communities are combined, the number of effective species of beetle is 9.68 (Table 3). Because the exponential of Shannon beta entropy, $H_\beta$, is less than 2.0, the two communities are not completely distinct from each other (Jost, 2006, 2007).

Table 3. Shannon alpha ($H_\alpha$), beta ($H_\beta$) and gamma entropies ($H_\gamma$), as well as exponential Shannon entropies calculated for total catches of *Coleoptera* collected from pitfall traps in Cerro Candelaria. The exponential of $H_\alpha$ represents the effective number of species at each site, the exponential of $H_\gamma$ represents the species diversity across both sites, and $H_\beta$ is a measure of how similar the two communities are to each other.

<table>
<thead>
<tr>
<th>Site</th>
<th>$H_\alpha$</th>
<th>exp($H_\alpha$)</th>
<th>$H_\beta$</th>
<th>exp($H_\beta$)</th>
<th>$H_\gamma$</th>
<th>exp($H_\gamma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soledad</td>
<td>1.72</td>
<td>5.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machay</td>
<td>1.78</td>
<td>5.93</td>
<td>0.52</td>
<td>1.68</td>
<td>2.27</td>
<td>9.68</td>
</tr>
</tbody>
</table>
Rarefaction curves for each site depict the predicted numbers of species that will be encountered in each location as more individuals are sampled (Gotelli, 2011). When extrapolated by a factor of 3, the accumulation curve for La Soledad predicts that a total of 19.16 beetle species will be encountered. The extrapolated curve for Machay predicts that a total of 20.44 species will be encountered (Figure 8).

**DISCUSSION**

Although insects comprised more than half of the total catch at both sites, the trap systems permitted the collection of a wide variety of taxa. Pitfalls were considered “reasonably effective” for sampling a particular taxa if that taxa had a frequency corresponding to greater than 25% of the overall catch (Sabu, 2011). By applying this criteria across all orders sampled, it was determined that Candelaria pitfalls were only effective for sampling Coleoptera. For this reason, diversity analysis was only be performed on beetles, since abundances of other taxa were not high enough to permit more detailed study.

The diversities of the two beetle communities sampled were compared using several different measures, including species accumulation. An asymptotic species accumulation curve indicates that no new species will be discovered in the community sampled (Gotelli, 2011). The rarefied curves describing Coleoptera communities sampled from pitfalls at both Machay and La Soledad appear to be approaching asymptotes, as the slopes at the rightmost ends of the curves become increasingly flatter (Figure 8). Extrapolation of the original abundance data that was used to create the curves predicts that the total expected species richnesses of the two sites are 19...
(La Soledad) and 20 (Machay) species. According to the rarefied accumulation curves, it appears that both sites have similar expected species richnesses (Figure 8). However, because this study was conducted in the neotropics, an area of high diversity inhabited by many rare species, it is possible that some species may not have been encountered, even though a large number of individuals were sampled (Gotelli, 2011). For this reason, the estimates based off of the rarefaction curves may not fully represent the species richness of each area.

Further comparisons can be drawn between the Coleoptera communities encountered in each location by comparing their Shannon diversities. Exponential Shannon entropies represent the “true” alpha, beta and gamma diversities of the beetle communities sampled, thereby permitting a direct comparison of the 2 sites. This transformation removes any favoring of extremely common, or extremely rare species. In this manner, the exponential Shannon entropy of a particular site can be thought of as the quantity of equally common species required to be present in a community in order to obtain a certain value of the unmodified Shannon index. This modification permits the linear comparison of effective numbers of species between sites to be utilized as a method for assessing diversity, as opposed to using the nonlinear, raw index (Jost, 2006). Although Machay had a higher number of effective species of beetles than La Soledad, this difference translates to only a 5% drop in diversity between the sites (Table 3). The exponential Shannon gamma diversity, which represents the effective number of species across both sites, is 9.68, nearly double the alpha diversities of each individual site (Table 3). This jump in diversity is most likely explained by the fact that over half of the morphospecies encountered at each site were unique to only that set of pitfalls, and not recorded at the other site. Hence, the aggregate diversity of both sites is greater than either site on its own. This conclusion is further supported by the true beta diversity, which is 1.68. According to Jost (2007), this value can be interpreted to mean that there are 1.68 distinct communities represented in the complete set of data. A true beta diversity value of 1.0 corresponds to the presence of only one distinct community, while a value of 2.0 corresponds to two, completely separate communities with no overlap whatsoever. Since the true beta lies between 1.0 and 2.0, but is closer to 2.0, the Coleoptera catches from each site have some degree of overlap, but are more dissimilar than they are alike (Jost, 2007).

Moreover, despite finding that more beetles were caught per trap on average at Machay than at La Soledad (Figure 7), it is difficult to determine if there was any one factor that caused this difference, since sites differed in both elevation and forest type. It is not extremely surprising that average total catch per trap differed between the sites, given that analysis of exponential Shannon diversities revealed that although the beetle populations sampled at the 2 sites have some degree of dissimilarity. Traps were constructed in the same manner in both sites on paths with similar incline levels, and both locations experienced similar average temperatures, and average humidities; therefore, it is not likely that a methodological difference between the sites caused the difference in catch size. Consequently, it is possible to infer that Machay traps caught more beetles on average because of a difference in activity level or locomotor capabilities between the populations sampled (Greenslade, 1964). Further study is required to investigate the specifics of this discrepancy between the two communities.

There are several inherent limitations of conducting a study with pitfall traps that may have prevented a more complete sampling of Cerro Candelaria fauna. Pitfalls are primarily geared toward epigeal fauna, simply because they are situated in the ground. Consequently, it is not surprising that there was a distinct lack of fauna with the capability to fly out of traps. For example, only one Diptera and one Ave were captured in total. Although 24 Lepidoptera were
recorded across both sites, only 4 of those individuals were live adults that happened to be inside the traps at the time they were visited, and the remaining 20 were larvae. Therefore, pitfall trapping is a somewhat indirect form of sampling taxa that utilize aerial locomotion through the collection of larvae, but fails to capture most other non-epigeal fauna.

The size of the traps also restricted their capability to sample the full suite of ground-dwelling fauna present in the reserve and at Machay. On April 16th, 2016, a direct observation of a medium-sized mammal leaping across the mouth of one of the buckets at La Soledad to cross the trail confirmed that larger animals were able to avoid being caught in the pitfalls. This limitation could be remedied with the installation of deeper buckets or by burying the already established pitfalls at a greater depth. However, Work (2002) cautions against the use of increasingly larger pitfalls for the study of arthropods, as this increases the quantity of non-target species encountered in the traps.

Since both sets of pitfalls were constructed on previously established trails, a set of traps established off-trail in thicker vegetation would be useful for comparison, and in certain cases might be able to provide additional information about true population sizes. It is known that vegetation density can affect locomotor activity and consequently impact catch size, making it possible to infer activity levels of different species, but not to estimate their true abundances in the community (Greenslade, 1964). However, Greenslade (1964) also suggests that a particular species being more abundant in a densely vegetated area than in an open area could be an indicator that the population of the species is actually greater in the dense area. Moreover, because the reserve contains reforested areas, traps could be monitored at sites with different land-use histories to determine how human activity has impacted the diversity of the beetle communities at these locations (Jesús Recalde, personal communication, April, 2016).

Additionally, activity levels of different families, or even species, could be monitored to a higher degree of specificity. Mechanized, battery-powered traps can be used to segregate trap catches by time of day (Williams, 1958; Blumberg, 1988). If such a device were installed in Candelaria, the time of day at which certain species are most active could be determined. For instance, because carabids are typically nocturnal, the abundance of carabids in a time-sorting pitfall should be higher during nighttime hours than during daylight hours (Maveety, 2011).

Results demonstrate that these pitfalls are a promising method for the long-term study of epigeal fauna in Candelaria. The reserve is an especially diverse area for herpetofauna: approximately 40% of the Pastaza watershed’s total reported reptile and amphibian population, as well as 45% of the region’s endemic species, are known to inhabit Cerro Candelaria (Reyes-Puig, 2013). Additionally, there are 17 registered species of Squamata in the reserve (8 species of lizards, 9 species of snakes), but by 2013, only 10% of the reserve’s total area had been investigated (Reyes-Puig, 2013). This implies that much of the ecosystem is yet to be characterized, and suggests that there are likely species new to science in these unexplored areas. Therefore, continuing monitoring of the established trap systems has the potential to provide new information about the squamates inhabiting the reserve. In addition, this technique may prove useful for conducting a catch-and-release study of cloud forest fauna. Potential targets for the initiation of such a study include lizards, mammals and the longhorn Psalidognathus beetles recorded at the upper elevation traps within the reserve.

Pitfall trap systems established in Cerro Candelaria successfully sampled a wide range of taxa. The traps were most effective for sampling arthropods, namely Coleoptera. The high abundance of beetles in the aggregate catches at both sites permitted an in depth analysis of the diversities of two communities that were surveyed to be performed. While some morphospecies
were recorded in both higher and lower elevation traps, others were only present at one of the sites and not the other, demonstrating that while the two communities are not completely distinct from each other, they do share a certain degree of dissimilarity. Using pitfalls to monitor Coleoptera and other epigeal fauna in areas of the reserve with varying land-use histories could permit further investigation of how faunal diversity varies across different microhabitats.

ACKNOWLEDGEMENTS

I am extremely grateful to a number of people who assisted me with this study. I would like to extend my thanks to Juan Pablo Reyes-Puig, Luis Recalde, Jesús Recalde, and Hannah Alverson for their help with construction of pitfall traps; to Darwin Recalde for accompanying me in the field and for his help with sample collection; to Xavier Silva, Juan Pablo Reyes-Puig, Carolina Reyes-Puig, and Santiago Villamarín for their expertise in identification of specimens; and to Lou Jost and Jaeyln Bos for their suggestions regarding statistical analysis. Special thanks to Juan Pablo Reyes-Puig and Carolina Reyes-Puig for advising me throughout the duration of my research, and to Xavier Silva, Javier Robayo and Diana Serrano for their continued support as well. Finally, I would like to thank the Recalde family for hosting me while I completed this project.
LITERATURE CITED


Supplementary Figure 1. *Arachnida* collected from pitfall traps in Cerro Candelaria at ~2250 m (Soledad) and ~1500 m (Machay). Represented individuals include members of *Scorpiones* (top left), *Opiliones* (top right), and *Araneae* (middle and bottom rows). Individuals of the family *Theraphosidae* (tarantulas) are pictured on the middle-right and bottom-right.
Supplementary Figure 2. Female specimen of a newly discovered species of tarantula belonging to the genus *Cyclosternon* encountered in pitfalls at ~2250m in Cerro Candelaria.
Supplementary Figure 3. Lacertilia collected from BPCC pitfall traps. A) *Potamites flavogularis* from Machay. B) *Lepidoblepharis festae* from la Soledad. C) *Pholidobolus dicrus* from Machay.
Supplementary Figure 4. Miscellaneous fauna collected from pitfall traps in BPCC at two different elevations. A) *Lepidoptera* larvae caught in traps at ~1500m. B) *Chilopoda* caught in traps at ~2250 m. C) *Diplopoda* caught in traps at ~1500m.
Supplementary Figure 5. Unidentified species of *Insecta* encountered in pitfall traps at ~1500m in the Cerro Candelaria reserve.