

ASSESSMENT OF EFFECTS OF RODENT REMOVAL ON ARTHROPODS, AND
DEVELOPMENT OF ARTHROPOD MONITORING PROTOCOLS, ON CONSERVATION
LANDS UNDER US ARMY MANAGEMENT

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INTRODUCTION

Arthropods constitute a majority of the biodiversity in most terrestrial ecosystems. In addition, these animals typically play important roles in ecosystem processes such as decomposition, soil turnover and pollination, and form critical links in food webs. In short, native insects and their allies are not only important entities to conserve in their own right, but they are also important for the functioning of native ecosystems. Conversely, invasive arthropod species not only threaten native arthropods, but can also disrupt and alter entire biological communities. Obtaining basic measures of the status and trends of arthropod diversity should therefore be a fundamental component of any natural area management program. Moreover, understanding how arthropods are affected by other invasive species is central to their management and conservation. Because of their many roles throughout the larger biological community, this understanding is likely to have implications for the conservation of other endemic taxa, from plants that rely on arthropods for pollination to birds that use arthropods as prey.

Invasive black rats are believed to exert severe predatory pressure on native arthropod species, but the effects of this pressure on arthropod populations has not been quantified in the field. Because rats are now nearly ubiquitous in natural areas of Hawaii, the most effective way to assess their impacts on arthropod species and communities is to monitor the response of arthropods to rat removal. The Oahu Army Natural Resource Program is implementing or planning rat removal operations in three areas in the Waianae Mountains: Kahanahaiki, Palikea and Ekahanui. In conjunction with these efforts, I am conducting standardized, quantitative arthropod sampling before and after rat removal in two of these areas (Kahanahaiki and Palikea), as well as in adjacent control sites where rats will not be immediately removed, to measure arthropod responses and estimate the impacts of rats on native and introduced arthropod populations. This sampling will also serve as an arthropod inventory, providing important information on the biodiversity of these management areas. Thirdly, the sampling conducted in

this project will be used to help develop broader arthropod monitoring protocols for the OANRP management units, as desired under the Makua and Oahu Implementation Plans.

METHODS

Kahanahaiki site: Arthropod sampling at this site is more limited than at the Palikea site because of very short lead time prior to initiation of rodent trapping. Pre-removal sampling was conducted in Kahanahaiki in May 2009, and post-removal sampling has been conducted in December 2009, May 2010, December 2010 and May 2011. Pahole NAR was selected for the untrapped control site, but because obtaining sampling permits took a little bit of time, the first sampling event did not occur until late June 2009, and subsequent summer sampling events were also offset from the Kahanahaiki sampling by about six weeks. Sampling at Pahole occurred in June 2009, December 2009, June 2010, December 2010 and June 2011. At both sites, sampling included pitfall trapping and vegetation beating on four shrub/tree species (*Charpentiera tomentosa*, *Pisonia umbellifera*, *Pipturus albidus*, *Psidium cattleianum*). At each site, 16 pitfall traps were established, one every 25 m, along the central gulch. Eight individuals of each of the four tree species were randomly chosen in the same general area as the pitfall traps. During each sampling event, each tree received five beats with a stick over a 1x1m beating sheet, and all arthropods dislodged were collected.

Palikea site: Arthropod sampling at Palikea has been conducted seasonally, occurring every four months. Three sampling events were completed, in November 2009, March 2010 and July 2010, before intensive rat trapping began in October 2010. Two post-trapping sampling events have been conducted so far, in March 2011 and July 2011. Sampling at Palikea occurs within a randomly chosen subset of the 5 by 10 m WCA vegetation plots, and includes pitfall trapping, leaf litter extraction, and timed vegetation sweeping at both day and night. Eighteen plots were chosen for arthropod sampling: 3-70, 3-90, 3-100, 3-110, 3-160, 3-170, 3-180, 3-190, 3-200; 4-100, 4-110, 4-140, 4-190, 4-200, 4-210, 4-240, 4-250, 4-260. An additional 18 plots were established at a nearby control site that is not undergoing intensive rodent management. Sampling at removal and control sites are conducted simultaneously. A sampling protocol was also established at each site to monitor *Rhyncogonus* beetles. *Rhyncogonus* is a genus of native weevils that are relatively large, rare and nocturnally active, and could therefore be predicted to be strongly impacted by invasive rodents. It also therefore serves as a good taxon with which to track potential recovery after rodent suppression. These beetles are not easily captured with standardized sampling methods, so potential host plants at each site were selected for targeted monitoring. At both sites, 12 trees or shrubs of two species (*Antidesma platyphyllum* and *Kadua terminalis*) were initially selected during the daytime (when adults are not active) and tagged for monitoring; each selected tree had at least some feeding damage on the leaves that was consistent with the damage caused by *Rhyncogonus* beetles. Numbers of monitored trees/shrubs were gradually increased with each monitoring event, until a total of 25 trees/shrubs were designated at each site by July 2011, including five *Psychotria* sp. individuals at each site. During each sampling event, each tagged plant was visited on one night, and lightly beat over a 1x1m beating sheet to dislodge any adult beetles.

RESULTS TO DATE

I. Potential effects of rodent trapping: Kahanahaiki and Pahole

A. Arboreal communities: vegetation beating sample trends

Changes in abundances of various taxa over time at Kahanahaiki, relative to Pahole, were calculated for each of two time periods: summer of 2009 to summer of 2010 (one year), and summer of 2009 to summer of 2011 (two years). Changes in abundances over time at the matched sites were compared with one another to derive a measure of the magnitude of relative abundance increases or decreases. Positive values indicate that the taxon increased more (or decreased less) over the specified time period at Kahanahaiki relative to Pahole, while negative values indicate the opposite: the taxon increased more (or decreased less) at Pahole relative to Kahanahaiki. A value of 0 indicates that the taxon fluctuated over the time period equally at both sites. The 32 sampling trees at each site were used as replicates, and mean relative changes for each taxon were compared to 0 with a one-sample t-test for taxa whose data were normally distributed, while medians were compared to 0 with a Wilcoxon Signed Rank Test for data that were not normally distributed.

Among spiders, all comparisons had mean positive values, suggesting increases at Kahanahaiki relative to Pahole, however only one comparison was close to being significantly different from zero (Figure 1). This was the comparison of changes in all Araneae from 2009 to 2011 ($t=1.96$, $p=0.059$). (For all Araneae from 2009-2010, $t=1.30$, $p=0.204$; native Araneae 2009-2010, $t=0.37$, $p=0.713$; native Araneae 2009-2011, $t=0.24$, $p=0.812$).

For beetles, patterns are difficult to discern. Most comparisons suggested increases in beetle numbers at Pahole relative to Kahanahaiki (Figure 2), although none of these were statistically significant (all Coleoptera 2009-2010, $t=-1.26$, $p=0.217$; native Coleoptera 2009-2010, $t=-0.84$, $p=0.409$; native Coleoptera 2009-2011, $t=-1.81$, $p=0.080$). The only comparison that was significantly different from zero suggests that all beetles increased at Kahanahaiki relative to Pahole over the two year period of 2009 to 2011 ($t=3.01$, $p=0.005$). The same trend did not occur among native beetles, indicating that the large increase at Kahanahaiki was comprised of adventive beetles.

Lepidoptera show the most consistent pattern of increasing abundances at Kahanahaiki relative to Pahole (Figure 3). Both all Lepidoptera and native Lepidoptera (exclusively caterpillars) had statistically significant relative increases at Kahanahaiki over both time periods (all Lepidoptera 2009-2010, $t=2.33$, $p=0.027$; all Lepidoptera 2009-2011, $t=3.09$, $p=0.004$; native Lepidoptera 2009-2010, $t=2.90$, $p=0.007$; native Lepidoptera 2009-2011, $t=3.18$, $p=0.003$). Native Lepidoptera caterpillars were represented by two groups, predatory *Eupithecia* and herbivorous *Hyposmocoma*, and both groups also showed significant relative increases at Kahanahaiki for most comparisons (*Eupithecia* 2009-2010, $W=71.0$, $p=0.013$; *Eupithecia* 2009-2011, $W=70.0$, $p=0.017$; *Hyposmocoma* 2009-2010, $W=123.5$, $p=0.102$; *Hyposmocoma* 2009-2011, $W=74.5$, $p=0.046$).

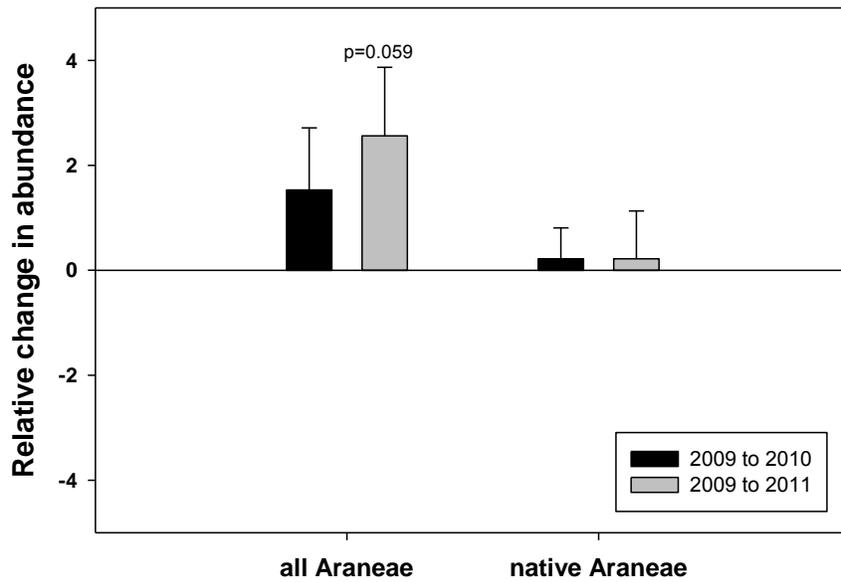


Figure 1. Mean changes in abundances of spiders at Kahanahaiki relative to Pahole, per vegetation beating sample, over one and two year periods. Positive values indicate increases at Kahanahaiki relative to Pahole, while negative values indicate increases at Pahole relative to Kahanahaiki. Only one comparison is marginally statistically significant, indicated with the associated p value.

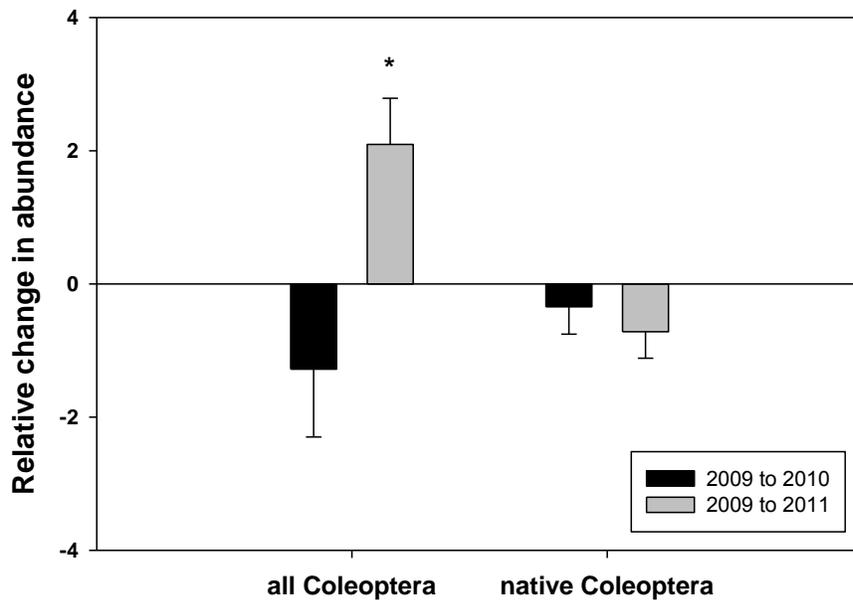


Figure 2. Mean changes in abundances of beetles at Kahanahaiki relative to Pahole, per vegetation beating sample, over one and two year periods. Positive values indicate increases at Kahanahaiki relative to Pahole, while negative values indicate increases at Pahole relative to Kahanahaiki. Comparisons that are significantly different from zero (at $p < 0.05$) are indicated with an asterisk.

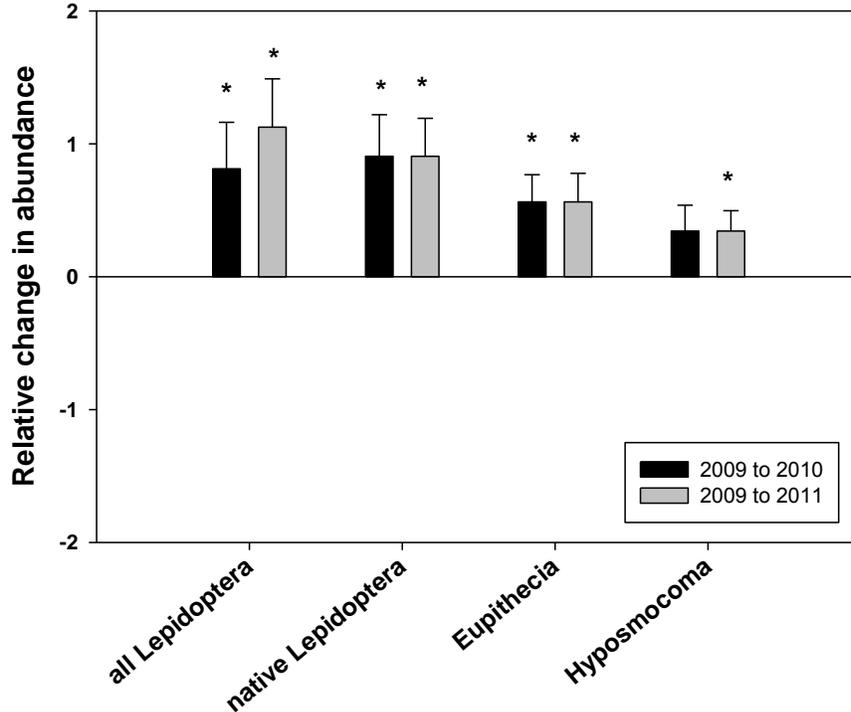


Figure 3. Mean changes in abundances of Lepidoptera at Kahanahaiki relative to Pahole, per vegetation beating sample, over one and two year periods. Positive values indicate increases at Kahanahaiki relative to Pahole, while negative values indicate increases at Pahole relative to Kahanahaiki. Comparisons that are significantly different from zero (at $p < 0.05$) are indicated with an asterisk.

Other groups examined but found not to have significant patterns of relative increases or decreases among sites include Hemiptera (2009-2010, $t = -0.76$, $p = 0.450$; 2009-2010 results for native Hemiptera were very similar, as most Hemiptera individuals were endemic; Hemiptera specimens not yet identified from 2011 samples) and crickets and katydids (all Orthoptera 2009-2010, $W = 50.0$, $p = 0.410$; all Orthoptera 2009-2011, $W = 9.0$, $p = 0.787$; native Orthoptera 2009-2010, $W = 10.5$, $p = 0.612$; native Orthoptera 2009-2011, $W = 4.0$, $p = 0.855$).

Other major groups remaining to be examined include Psocoptera (barklice), Blattodea (cockroaches), Collembola (springtails) and Thysanoptera (thrips).

B. Terrestrial communities: pitfall trap trends

The same procedure described above for vegetation beating samples was used to assess relative changes in abundances of arthropods captured in pitfall traps. The 16 traps at each site were used as replicates, and mean relative changes for each taxon were compared to 0 with a one-sample t -test for taxa whose data were normally distributed, while medians were compared to 0 with a Wilcoxon Signed Rank Test for data that were not normally distributed.

When grouping all Araneae, spiders were found to increase significantly more at Kahanahaiki relative to Pahole both from 2009 to 2010 ($t=3.01$, $p = 0.009$) and from 2009 to 2011 ($t=3.91$, $p=0.001$) (Figure 4). The trends were the same among native spiders, however relative changes were significantly different from zero over only the two year period (for 2009-2010, $W=9.0$, $p=0.787$; for 2009-2011, $W=21.0$, $p=0.036$).

All beetles, as a group, showed trends of increasing abundances at Kahanahaiki relative to Pahole over both time periods (Figure 5), but because of high variances among samples, these trends were not statistically significant (for 2009-2010, $t=0.78$, $p=0.447$; for 2009-2011, $t=1.70$, $p=0.110$). Conversely, trends for native beetles were in the opposite direction, but were much smaller and also not statistically significant (for 2009-2010, $t=-0.86$, $p=0.403$; for 2009-2011, $t=-0.52$, $p=0.609$).

Lepidoptera, as a group, tended to increase more at Pahole relative to Kahanahaiki (Figure 6), however this pattern was significant for only the first year (2009-2010, $t=-2.82$, $p=0.013$; 2009-2011, $t=-0.19$, $p=0.855$). The trends for *Hyposmocoma* were small (Figure 6) and not significantly different from zero (2009-2010, $t=-1.23$, $p=0.236$; 2009-2011, $t=-0.55$, $p=0.590$).

Native crickets in the *Laupala/Trigonidium* group were the only Orthoptera captured in pitfall traps. Species in this group are very difficult to differentiate morphologically, however as the specimens collected at Kahanahaiki and Pahole tend to resemble the genus *Laupala* more than *Trigonidium* according to Otte (1994), I refer to them as ?*Laupala* spp. These crickets tended to increase more at Kahanahaiki relative to Pahole (Figure 7), with this trend being significant over the two year period (2009-2010, $W=9.0$, $p=0.201$; 2009-2011, $W=73.0$, $p=0.009$). Furthermore, ?*Laupala* crickets were almost completely absent from pitfall samples at Pahole during all sampling events.

Earwig (Dermaptera) specimens have yet to be identified for the summer 2011 samples. From 2009 to 2010, neither all earwigs nor native earwigs only (represented by one species, *Euborellia eteronoma*) increased significantly more at one site relative to the other (all Dermaptera, $t=1.06$, $p=0.308$; native Dermaptera, $W=19.0$, $p=0.415$).

Hemiptera specimens have also not yet been identified for the summer 2011 samples. From 2009 to 2010, there was no significant difference in the relative change in Hemiptera abundances between sites ($t=0.81$, $p=0.428$). Hemiptera captured in pitfalls were represented mainly by the adventive burrowing bug (*Rhytidoporus indentatus*), plus nymphs of various other groups such as delphacid planthoppers.

Amphipods are abundant detritivores inhabiting the leaf litter at Kahanahaiki and Pahole. All specimens captured appear to belong to the adventive species *Talitroides topitotum*. These amphipods did not show significant relative changes in abundance between the sites over either time period (2009-2010, $t=-1.08$, $p=0.296$; 2009-2011, $t=-0.07$, $p=0.948$).

Other major groups remaining to be examined include Diplopoda (millipedes), Chilopoda (centipedes), Blattodea (cockroaches) and Isopoda (sowbugs).

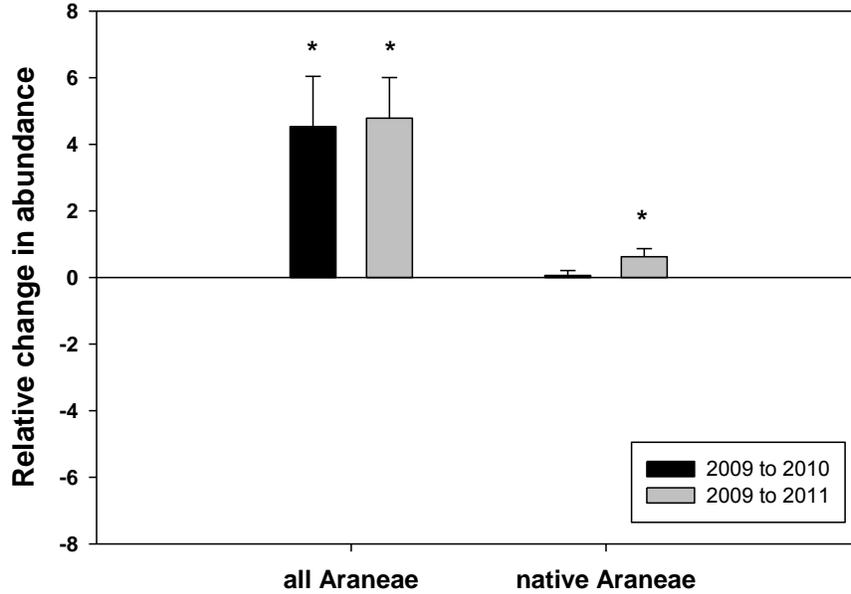


Figure 4. Mean changes in abundances of spiders at Kahanahaiki relative to Pahole, per pitfall trap, over one and two year periods. Positive values indicate increases at Kahanahaiki relative to Pahole, while negative values indicate increases at Pahole relative to Kahanahaiki. Comparisons that are significantly different from zero (at $p < 0.05$) are indicated with an asterisk.

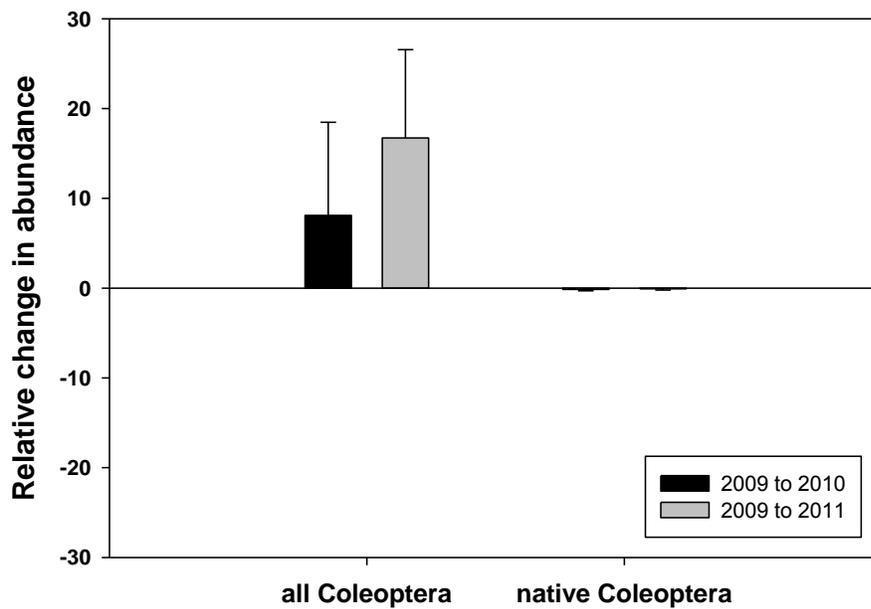


Figure 5. Mean changes in abundances of beetles at Kahanahaiki relative to Pahole, per pitfall trap, over one and two year periods. Positive values indicate increases at Kahanahaiki relative to Pahole, while negative values indicate increases at Pahole relative to Kahanahaiki. None of the comparisons were significantly different from zero (at $p < 0.05$).

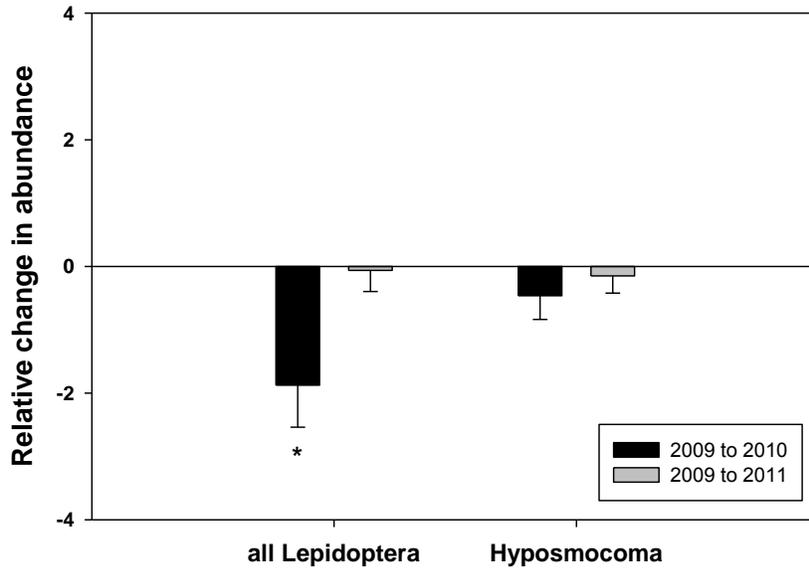


Figure 6. Mean changes in abundances of Lepidoptera at Kahanahaiki relative to Pahole, per pitfall trap, over one and two year periods. Positive values indicate increases at Kahanahaiki relative to Pahole, while negative values indicate increases at Pahole relative to Kahanahaiki. Comparisons that are significantly different from zero (at $p < 0.05$) are indicated with an asterisk.

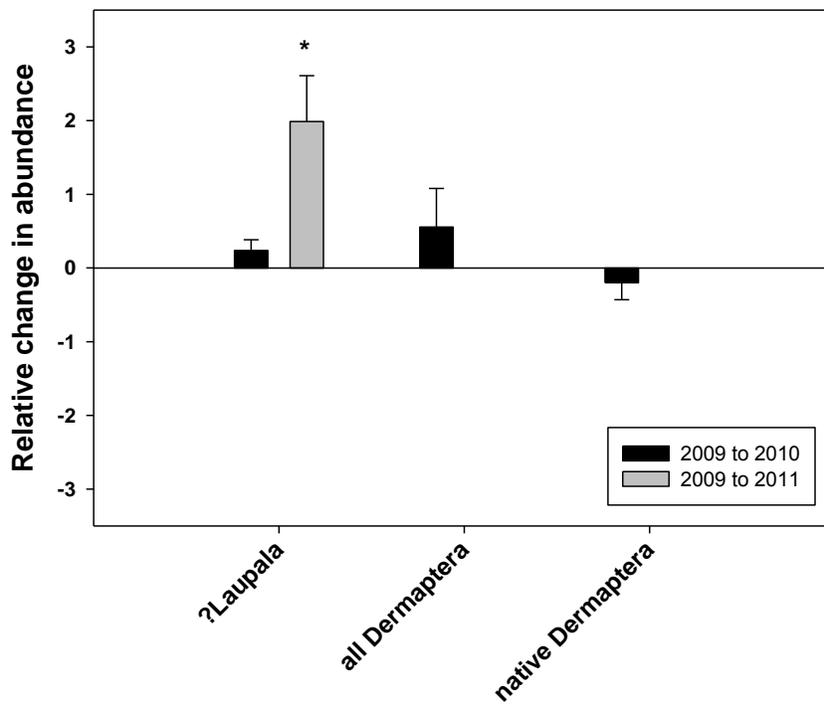


Figure 7. Mean changes in abundances of native ?Laupala crickets and earwigs (Dermaptera) at Kahanahaiki relative to Pahole, per pitfall trap. Data available for one year only for Dermaptera. Positive values indicate increases at Kahanahaiki relative to Pahole, while negative values indicate increases at Pahole relative to Kahanahaiki. Comparisons that are significantly different from zero (at $p < 0.05$) are indicated with an asterisk.

C. Tentative conclusions

Because I have assessed numerous population changes involving multiple taxa without applying adjustments for multiple statistical comparisons, caution needs to be used when concluding that population fluctuations are real as opposed to resulting from statistical sampling error (the chances of which increase as number of comparisons increase). Furthermore, because of the nature of the design of this study, in which the treatment (rodent suppression) is only replicated once in each study area, further caution needs to be used when inferring a causal relationship between rodent trapping and population trends among arthropods. For this reason, single statistically significant results that don't appear to fit a larger pattern (at least yet) should be regarded as questionable evidence of a treatment effect. On the other hand, patterns of similar results among related taxa, or results that appear to be consistent over multiple time periods or between sampling methods, are unlikely to be due to haphazard population fluctuations or random sampling error, and can be regarded as tentative evidence of a response to rodent trapping. As patterns remain consistent over longer time periods, this evidence will strengthen.

After the first two years of sustained high intensity rodent trapping at Kahanahaiki Valley, the strongest evidence for a response to this effort has been among Araneae and Lepidoptera. Spiders, as a group, showed trends of increasing more at Kahanahaiki relative to Pahole over both one and two year time periods in the vegetation beating samples, although due to high variances among samples only the two year time period was marginally statistically significant ($p=0.059$). Nevertheless, the effect size appeared to get larger over time, and represents a relatively large proportional increase (44%) in spider abundance at Kahanahaiki. This pattern is supported by even stronger trends for the pitfall samples. Spiders in terrestrial communities increased at Kahanahaiki relative to Pahole over both time periods, and there was even evidence that this relative increase occurred among native spiders, at least after two years. It is not surprising that the apparent changes in native spiders were much weaker than for spiders overall, because most spider individuals captured are immature and are often very young stages, and are therefore difficult to assign to native vs. adventive species. A large proportion of spider individuals are typically categorized as unknown provenance.

Trends for Lepidoptera were also relatively consistent, at least for the vegetation beating samples. All Lepidoptera, as a group, as well as all native Lepidoptera, increased significantly more at Kahanahaiki relative to Pahole over both time periods. While the magnitude of these increases appear relatively small (Figure 3) for mostly herbivorous insects that are typically fairly abundant in the environment, the sampling methods used at these sites did not capture large numbers of adult or larval Lepidoptera. As a result, the changes in abundances measured at Kahanahaiki actually amount to an 80% to 125% increase in relative terms over the two years (at the same time that abundances decreased at Pahole). Native Lepidoptera were represented exclusively by larval forms of *Hyposmocoma* and *Eupithecia* species (the remaining caterpillars were unidentifiable and therefore of unknown provenance), and both of these groups also showed significant relative increases at the Kahanahaiki site. Both of these groups remain active on arboreal vegetation during the daytime when vegetation beating sampling was conducted, so,

perhaps in contrast to many other groups of Lepidoptera, this sampling method can be expected to sample their populations fairly accurately. Moreover, the relatively low numbers of captures of *Eupithecia* caterpillars is in line with expectations for a predatory species (*Hypsmocoma* capture rates were at times fairly high, but tended to be so only in December sampling events). Unfortunately, pitfall trapping results did not corroborate these patterns of increase among Lepidoptera apparent in the vegetation beating samples. However, most trends for the pitfall data were small in size and not statistically significant. These discrepancies between pitfall and vegetation beating data could indicate that apparent trends are unrelated to rodent trapping, but alternatively they could reflect differences in responses between terrestrial and arboreal species. *Hypsmocoma* morphospecies at these sites, for example, show almost completely non-overlapping distributions between ground and arboreal samples.

These tentative conclusions of recovery among spiders and caterpillars following rodent suppression are consistent with the fact that spiders and especially caterpillars were among the most common arthropod prey items in rodent stomachs collected at Kahanahaiki (Shiels unpub. data). Other groups found in rodent stomachs included relatively large-bodied representatives of Coleoptera and Orthoptera. To date, population dynamics in these groups do not provide strong evidence of recovery at Kahanahaiki subsequent to rodent trapping. Beetle numbers (all species combined) typically suggested relative increases at Kahanahaiki relative to Pahole, but only one such comparison was statistically significant (vegetation beating 2009 to 2011), while one comparison suggested a change in the opposite direction (vegetation beating 2009 to 2010). At this point it is difficult to be confident that the significant relative increase in vegetation beating samples over the two year period is not simply a localized short-term population fluctuation unrelated to rodent trapping. In addition, the sampling methods used have to date captured almost entirely small sized beetle species. If rodents tend to directly impact larger species (St Clair 2010), then our sampling efforts may fail to detect their effects on beetles. Alternatively, population recovery among beetles may take longer, and larger species may increase in samples over time. Effects on native beetles appeared to be much smaller than beetles overall (Figures 2, 5). This is likely due to the fact that native beetles represent a fairly small proportion of total beetle numbers at these sites, especially in terrestrial communities.

Orthoptera captured in vegetation beating samples included native *Laupala* crickets, introduced katydids and one individual of the native katydid *Banza*. All Orthoptera captured in pitfall traps appeared to be *Laupala* crickets. Neither all Orthoptera nor native Orthoptera showed trends of relative increase or decrease among sites that were even close to being statistically significant for the vegetation beating samples. Pitfall trapping, however, provided evidence that *Laupala* cricket populations may be increasing at Kahanahaiki relative to Pahole, and this effect may be increasing over time (Figure 7).

Overall, the monitoring at Kahanahaiki and Pahole suggests that Araneae and Lepidoptera tend to be increasing in abundance at Kahanahaiki relative to Pahole, and the consistency of these patterns suggest that these effects may be due to rodent suppression. These results also concord with results from rodent stomach contents at Kahanahaiki. Results for other arthropod groups containing large-bodied species that are known to be common rodent prey items, such as Coleoptera and Orthoptera (St Clair 2010), must be regarded as still inconclusive. Evidence of a

positive response to rodent trapping for these groups may become stronger over time, as populations have more time to recover.

Inference regarding the causal relationship between rodent trapping and arthropod population trends can be strengthened through comparison of patterns obtained at multiple independent sites. The arthropod sampling being conducted at the Palikea study area will serve this purpose. Because sampling efforts at that site are considerably more intensive than those at Kahanahaiki/Pahole, however, processing of the Palikea samples is much more time and labor consuming. To date I have focused on identification of those groups judged to be most likely to respond to rodent trapping (such as Araneae, Coleoptera, Lepidoptera, Orthoptera), and large numbers of specimens in these groups have been identified for many of the sampling events conducted so far, but no full datasets are yet available with which to begin assessing the effects of rodent trapping. However, one exciting and encouraging piece of data from Palikea regards the *Rhyncogonus* beetle sampling at this study area. In the four sampling events from November 2009 through March 2011, not a single *Rhyncogonus* was captured on the tagged *Rhyncogonus* sampling trees (or in any of the standardized vegetation sweeping samples) at either the rodent removal site or control site. During the July 2011 sampling event, approximately nine months after intensive rodent trapping was initiated at the removal site, six *Rhyncogonus* individuals were captured (and released) on five of the tagged sampling trees at the rodent removal site, while none were captured at the control site. All appeared to be individuals of *R. howarthi*, and were found on *Antidesma platyphyllum* (1 beetle on 1 tree/shrub), *Kadua terminalis* (4 beetles on 3 trees/shrubs) and a *Psychotria* sp. (1 beetle on 1 tree/shrub). It is still too early to tell if this represents the beginning of a population recovery due to rodent suppression, but it clearly indicates the importance of continued monitoring to track arthropod species and community changes.

II. Arthropod biodiversity patterns

The standardized plus opportunistic sampling for this project has resulted in the collection and identification, to date, of 274 arthropod species or morphospecies at the Kahanahaiki and Pahole sites and 305 species or morphospecies at the Palikea site. These numbers will increase as additional taxonomic groups are examined for lower-level identification. Most of the high-diversity orders, however, have already been worked on to some degree, so further increases in total species richness will likely be moderate. These inventories provide invaluable information regarding the native biological resources present at these sites, as well as the invasive species that may threaten them. At least one new endemic species has been discovered and is now described: the predatory carabid beetle *Mecyclothorax palikea*, which is apparently restricted to the southern Waianae mountains (Liebherr and Krushelnycky 2011).

The standardized samples enable exploration of various patterns of biodiversity among arthropods and their relationships to plant species and communities. At Kahanahaiki and Pahole, for example, vegetation beating samples collected on single host tree species permit comparison among these plant species. Interestingly, so far the total richness of arthropods on each of the four sampled tree species as well as in pitfall traps is fairly similar, and there is no statistically significant difference in the proportional composition of total richness of native, adventives and

unknown provenance species between the tree species and pitfall traps (Figure 8). Surprisingly, *Psidium cattleianum* hosts a similar number of arthropod species, including native species, as the three other native trees. However, this analysis does not yet include all arthropod groups (such as Collembola and Psocoptera), and should therefore not be considered final and conclusive at this point. When the same data are viewed from the perspective of arthropod abundance rather than species richness, a very different preliminary picture emerges (Figure 9). The native trees host a much higher proportion of individuals of native arthropod species than does *Psidium cattleianum*, and terrestrial arthropod communities (as sampled in pitfall traps) are completely dominated by adventive individuals, with only 5% of all individuals captured in pitfalls belonging to native species. A further interesting preliminary pattern is that while *Psidium cattleianum* hosts a similar number of species as the three native tree species, the total abundance of arthropods on strawberry guava is considerably lower (Figure 10). Again, this analysis does not yet include all arthropod groups, so is subject to change (the main groups missing are Collembola and Psocoptera). However if this pattern holds, it could indicate that strawberry guava provides inferior foraging habitat for the endangered insectivorous elepaio. This conclusion would depend on patterns of abundances for arthropod taxa that serve as the main prey items in the elepaio diet.

Sampling at Palikea is not tied to individual host plant species, but instead occurs within the WCA vegetation plots at the site. Preliminary patterns among spiders and beetles are fairly similar to those at Kahanahaiki and Pahole, in that richness in arboreal communities (vegetation sweeping samples) is divided among native, adventive and unknown provenance species in similar proportions to that in terrestrial communities (pitfall and leaf litter samples) (Figure 11). Total richness for these two taxonomic groups is much higher for arboreal communities, however. Also similar to Kahanahaiki and Pahole, the proportion of native individuals is much higher in arboreal communities compared to terrestrial communities, at least among spiders and beetles (Figure 12).

Taking a broader taxonomic view of just arboreal communities, slightly over half of the species in Araneae, Coleoptera, Hemiptera and Lepidoptera combined are native (Figure 13). However, the richness of native species per plot varies dramatically, from a low of 3 native species per plot to a high of 21 native species per plot. The factors underlying this dramatic variation in native species richness are of great interest, as understanding them may be central to conserving and restoring native arthropod species and communities. Although this dataset represents just a small subset of the sampling conducted to date, preliminary analyses have so far found that the strongest associate of native arthropod richness in the Palikea plots is native richness of the plant community in the understory (Figure 14). Native plant richness in the understory was more strongly correlated with native arthropod richness than was native plant richness in the canopy, or total cover of native plants in either the understory or canopy. If this pattern holds, it would suggest that plant restoration efforts that increased native plant diversity in addition to native plant cover would have the strongest beneficial effects on native arthropods. As more samples are sorted and identified from Palikea, the ability to discern these types of patterns should increase greatly, providing excellent opportunities for developing a better understanding of the relationships between native arthropods, adventive arthropods and plant communities.

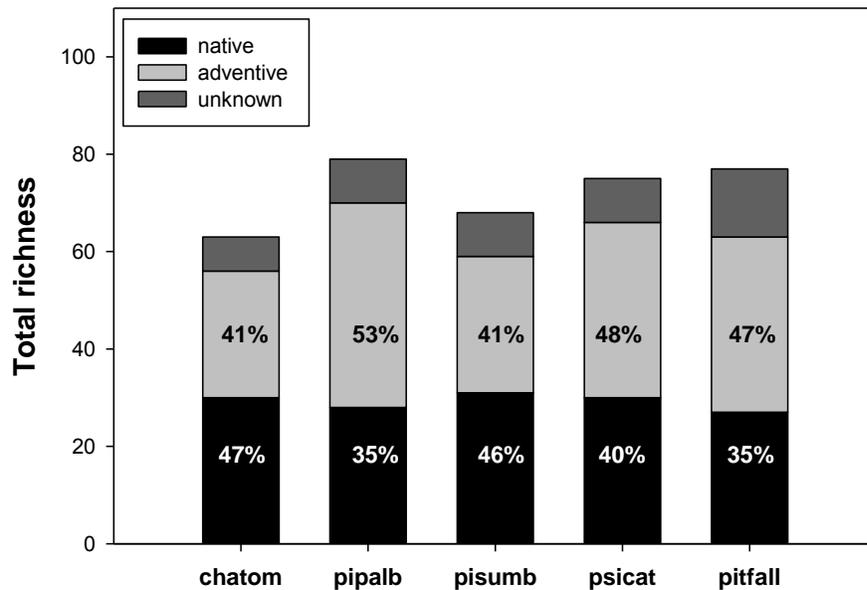


Figure 8. Total richness of arthropod species/morphospecies captured in vegetation beating samples on the four tree species and pitfall samples on the ground at Kahanahaiki and Pahole. Dataset includes all samples collected in summer 2009, winter 2009 and summer 2010, and the following taxonomic groups: Araneae, Coleoptera, Hemiptera, Lepidoptera plus several other families or lower taxonomic groups. Richness totals are subdivided by provenance of species, with percentages indicating contributions from native and adventive species. Abbreviations are: Chatom = *Charpentiera tomentosum*, pipalb = *Pipturus albidus*, pisumb = *Pisonia umbellifera*, psicat = *Psidium cattleianum*, pitfall = pitfall traps. There was no significant difference in proportions of native, adventives and unknown provenance species among the tree species or pitfall traps (chi square = 5.798, $p = 0.67$).

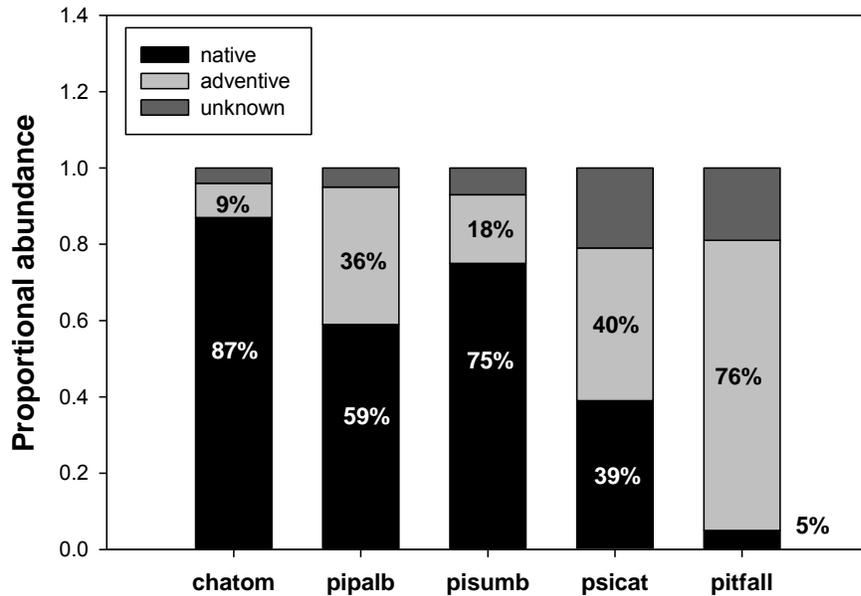


Figure 9. Proportional abundance of native, adventive and unknown provenance individuals in the arthropod communities on the four tree species and in pitfall traps at Kahanahaiki and Pahole. Dataset includes all samples collected in summer 2009, winter 2009 and summer 2010, and the following taxonomic groups: Araneae, Coleoptera, Hemiptera, Lepidoptera plus several other families or lower taxonomic groups. Abbreviations as in Figure 8. There was a significant difference in proportions of native, adventives and unknown provenance individuals among the tree species and pitfall traps (chi square = 207.904, $p < 0.001$).

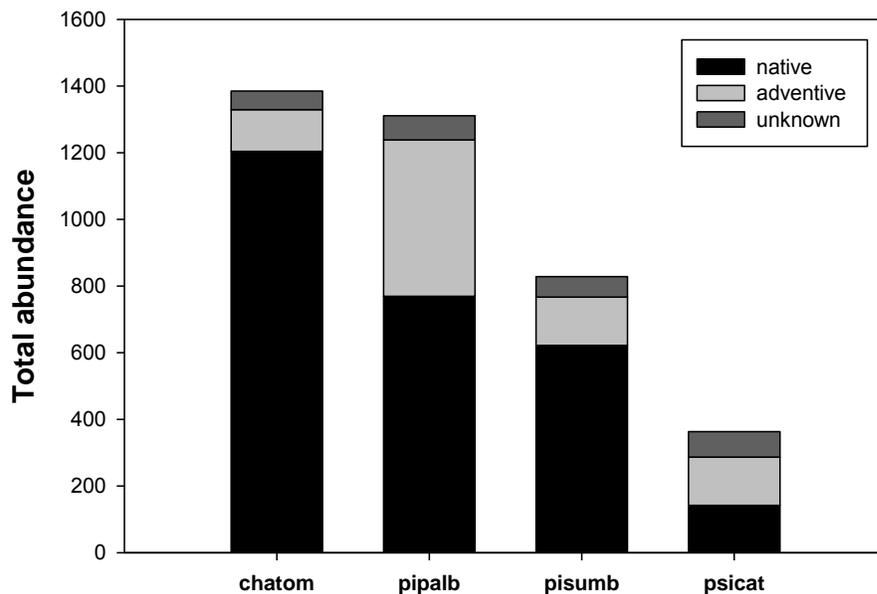


Figure 10. Total abundance of native, adventive and unknown provenance individuals in the arthropod communities on the four tree species at Kahanahaiki and Pahole. Dataset includes all samples collected in summer 2009, winter 2009 and summer 2010, and the following taxonomic groups: Araneae, Coleoptera, Hemiptera, Lepidoptera plus several other families or lower taxonomic groups. Abbreviations as in Figure 8.

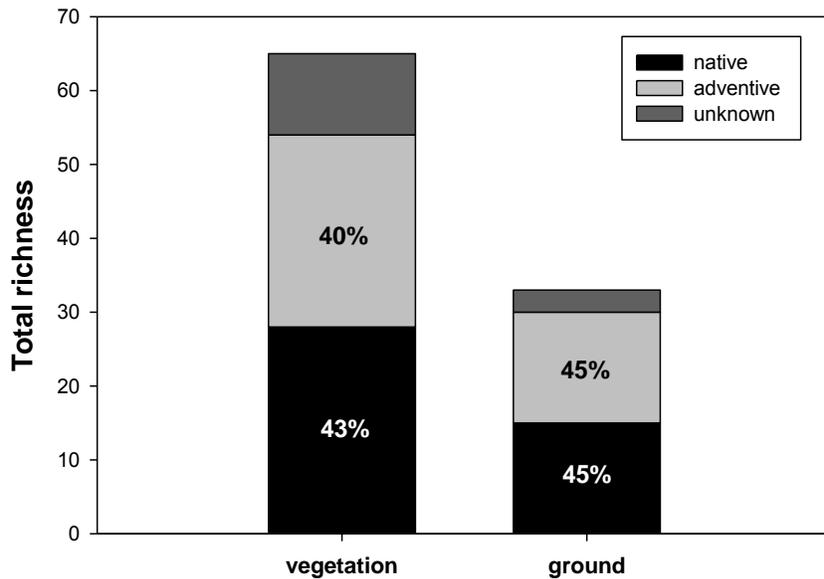


Figure 11. Total richness of spider and beetle species/morphospecies captured in arboreal and terrestrial communities in November 2009 at Palikea. Arboreal communities sampled with timed day and night vegetation sweeping, terrestrial communities sampled with pitfall traps and leaf litter extraction. Richness totals are subdivided by provenance of species, with percentages indicating contributions from native and adventive species. There was no significant difference in proportions of native, adventives and unknown provenance species among the two community types (chi square = 1.124, $p = 0.570$).

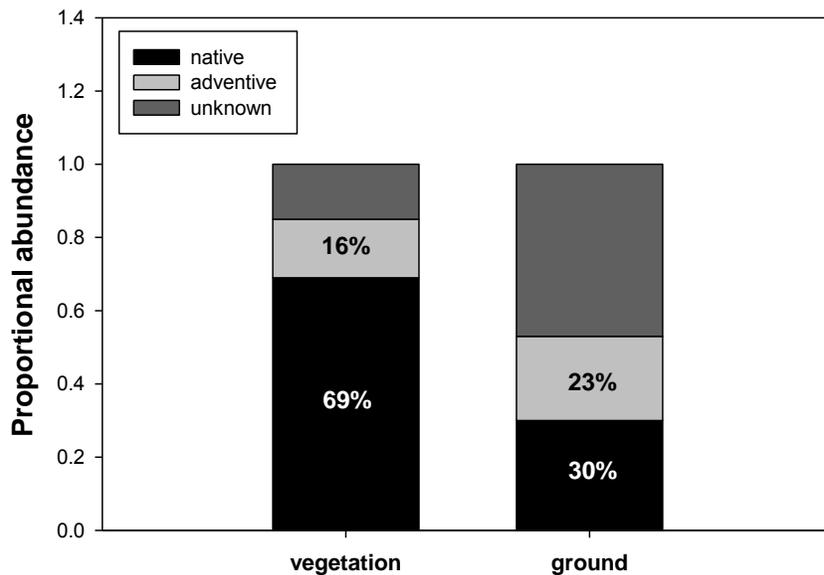


Figure 12. Proportional abundance of native, adventive, and unknown provenance spider and beetle individuals in arboreal and terrestrial arthropod communities at Palikea, November 2009. There was a significant difference in proportions of native, adventives and unknown provenance individuals among the two community types (chi square = 261.008, $p < 0.001$).

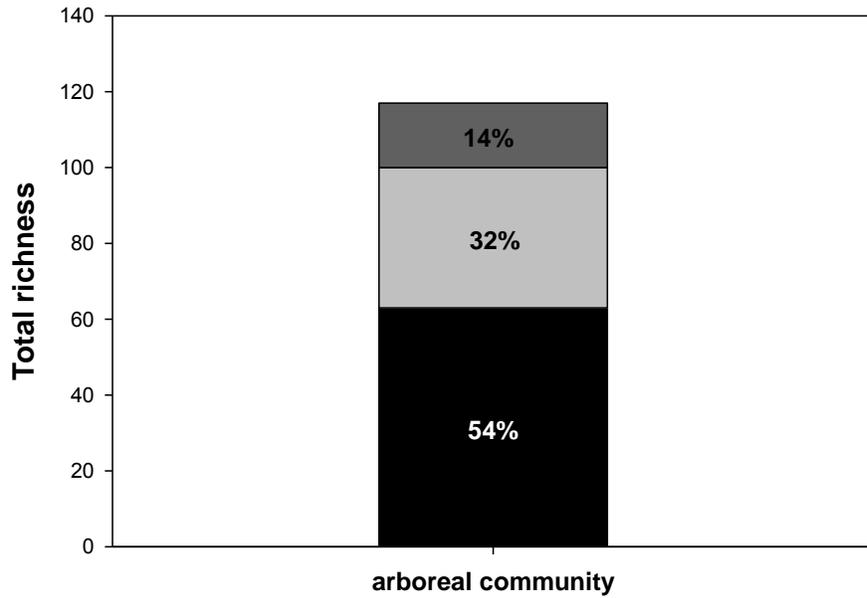


Figure 13. Total richness of Araneae, Coleoptera, Hemiptera and Lepidoptera species/morphospecies captured in arboreal communities in November 2009 at Palikea. Arboreal communities sampled with timed day and night vegetation sweeping. Richness totals are subdivided by provenance of species, with percentages indicating contributions from native and adventive species.

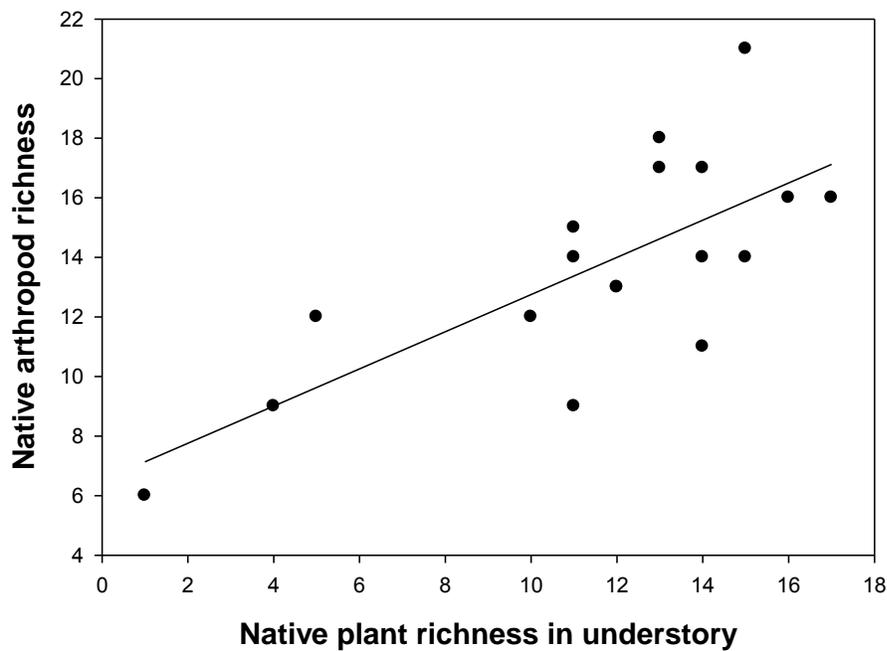


Figure 14. Relationship between richness of native arthropods (including Araneae, Coleoptera, Hemiptera and Lepidoptera) and richness of native understory plants in arboreal communities in November 2009 at Palikea ($r^2=0.54$, $p=0.001$).

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