

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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Dr. Paul Krushelnycky  
Dept. of Plant and Environmental Protection Sciences  
University of Hawaii  
3050 Maile Way, Gilmore 310  
Honolulu, HI 96822  
Phone: 808-956-8261  
Fax: 808-956-2428  
Email: [pauldk@hawaii.edu](mailto:pauldk@hawaii.edu)

## 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. 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 has implemented 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, May 2011 and May 2012. 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, June 2011 and June 2012. 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. Six post-trapping sampling events have now been completed (March 2011, July 2011, November 2011, March 2012, July 2012, November 2012), representing two full years of post-trapping sampling. 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 have not been 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 at Palikea

Sorting, identification and database entry is complete for all samples collected up through May/June 2011 at Kahanahaiki/Pahole and November 2011 at Palikea. Samples collected in 2012 continue to be processed. Because the November 2011 annual report described changes in arthropod abundances one and two years after trapping at the Kahanahaiki site, results reported here will focus on new findings for the Palikea site: arthropod abundance trends at the rodent removal site and control site from one year prior to trapping initiation to one year post-trapping.

#### A. Seasonal patterns in arthropod abundances

Abundances of arthropods as a whole, as well as for most ordinal groups, showed relatively pronounced seasonal fluctuations. This was true for both vegetation-associated communities (as estimated by day and night sweeping samples, combined) and ground-associated communities (pitfall and leaf litter samples, combined). Some representative trends are shown in figures 1-8. Abundances for most groups were highest in July or November of each year. Although seasonal abundance peaks did not always occur in the same month for each particular taxonomic group, November appeared to have slightly more peaks across groups as compared to July. Future sampling plans include reducing collection events to one per year to make longer-term monitoring more efficient. Choosing July versus November for the timing of this sampling will likely be decided by examination of trends during the full year of seasonal sampling in 2012 (already collected), as well trends in patterns of seasonal diversity.

Overall abundances, as well as seasonal fluctuations in abundances, tended to be quite similar between the removal and control site plots. For some taxa, differences between sites were more substantial, such as Hemiptera on vegetation (Fig. 5) and ground-active Araneae (Fig. 7). In general, however, the control site plots appear to be well suited for the purpose of applying seasonal and/or annual adjustments to measured changes in arthropod communities following rodent trapping at the removal site.

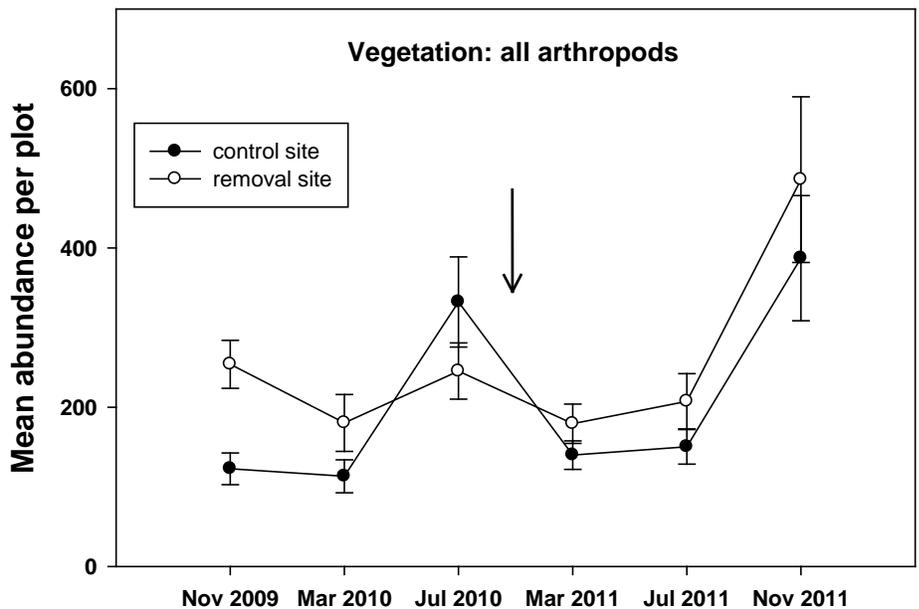


Figure 1. Seasonal trends in mean abundances ( $\pm$  SE) of all arthropods captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

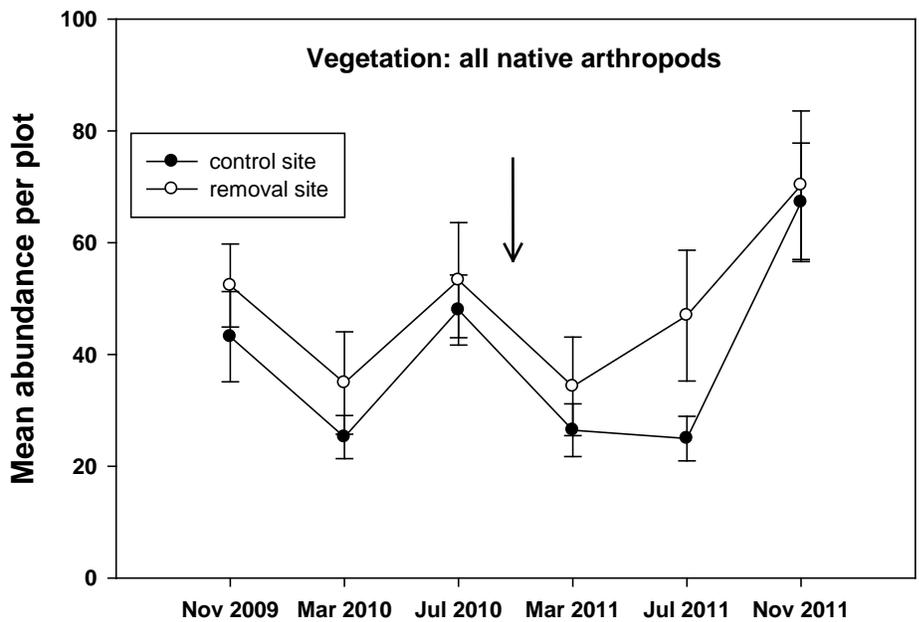


Figure 2. Seasonal trends in mean abundances ( $\pm$  SE) of all native arthropods captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

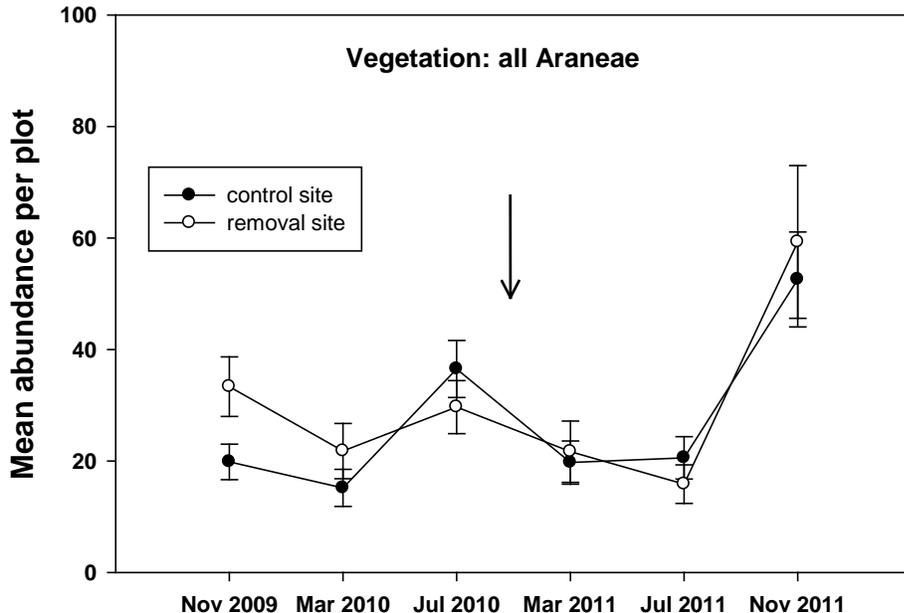


Figure 3. Seasonal trends in mean abundances ( $\pm$  SE) of all Araneae (spiders) captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

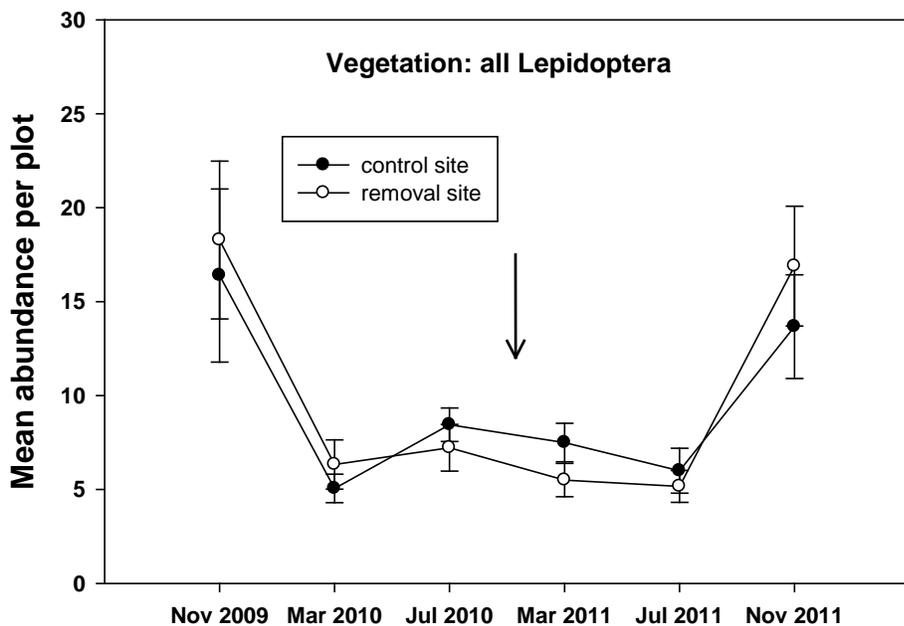


Figure 4. Seasonal trends in mean abundances ( $\pm$  SE) of all Lepidoptera (moths and butterflies) captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

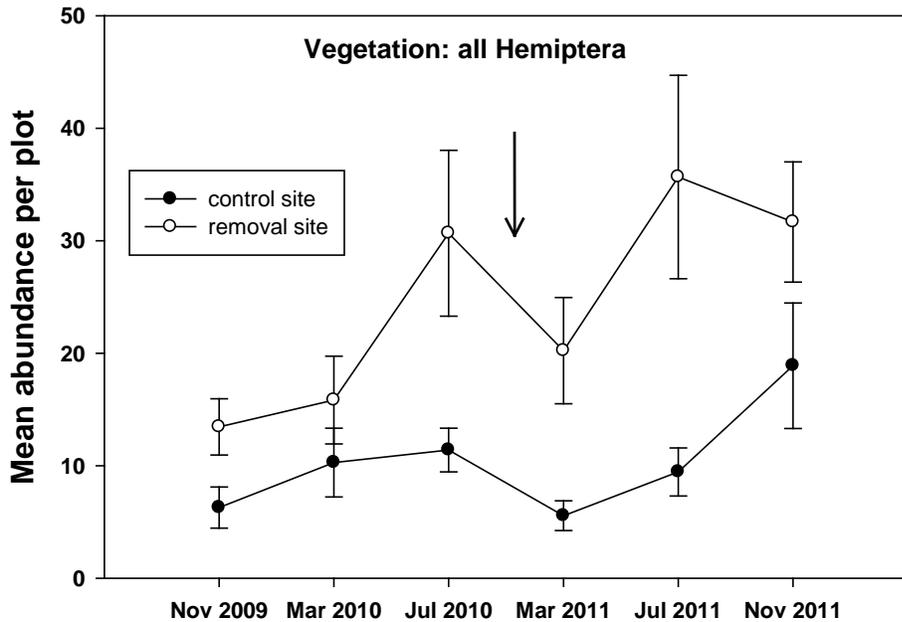


Figure 5. Seasonal trends in mean abundances ( $\pm$  SE) of all Hemiptera (true bugs) captured in vegetation (day and night sweeping) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

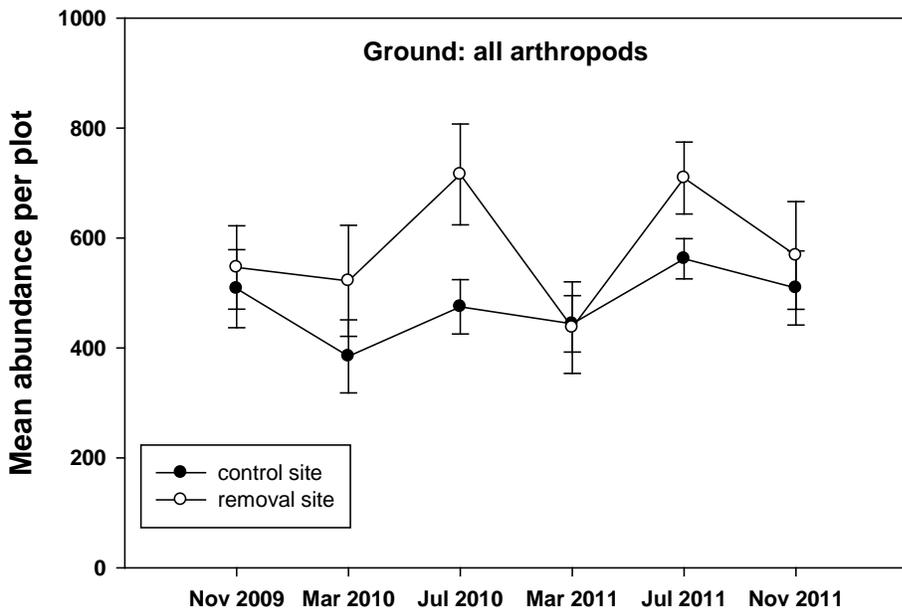


Figure 6. Seasonal trends in mean abundances ( $\pm$  SE) of all arthropods captured in ground (pitfall and leaf litter extraction) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

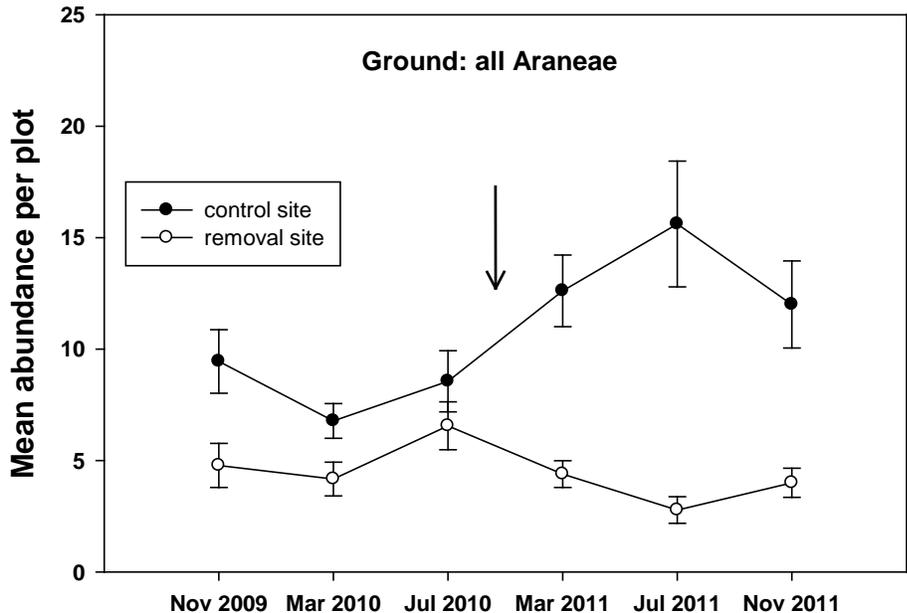


Figure 7. Seasonal trends in mean abundances ( $\pm$  SE) of all Araneae (spiders) captured in ground (pitfall and leaf litter extraction) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

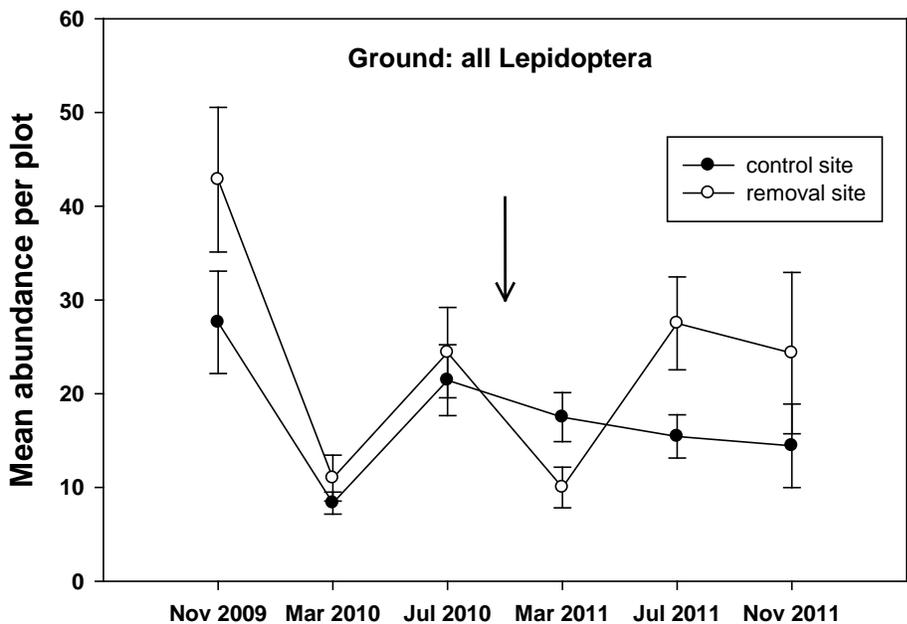


Figure 8. Seasonal trends in mean abundances ( $\pm$  SE) of all Lepidoptera (moths and butterflies) captured in ground (pitfall and leaf litter extraction) samples at Palikea over the first two years of the study. Data shown separately for rodent removal and control sites. Arrow indicates approximate timing of trapping initiation.

## B. Relative changes in abundance following trapping

Changes in arthropod communities after rodent trapping began in October of 2010 would become apparent as divergences between trends at the removal and control sites for sampling events in 2011 (i.e., to the right of the arrow in Figures 1-8). This type of pattern is most easily seen for ground-based spiders (Fig. 7). In this case, spider abundances were lower at the removal site prior to trapping, and this difference became larger during the year after trapping began, indicating a relative decrease in spider abundances at the removal site after trapping.

I conducted a more direct assessment of relative changes in abundances over time for a range of taxonomic groups. Samples were pooled into two temporal periods for each site: the year pre-trapping and the first year post-trapping. Changes in abundances from before to after trapping were calculated for the matched sites, and then these changes were compared between sites to derive measures of the magnitude of relative abundance increases or decreases. Positive values indicate that the taxon increased more (or decreased less) at the removal site relative to the control site, while negative values indicate the opposite: the taxon decreased more (or increased less) at the removal site relative to the control site. A value of 0 indicates that the taxon fluctuated over the time period equally at both sites. The 18 sampling plots at each site were used as replicates, and mean relative changes for each taxon were compared to 0 with a one-sample t-test.

Relative changes in abundances of the major arthropod orders are presented in Figures 9 and 10 for communities on vegetation. Statistically significant mean relative increases in abundance at the removal site were found only for Orthoptera and Hemiptera, whereas significant relative decreases were found only for Psocoptera. For both Orthoptera and Hemiptera, relative increases were significant for all individuals as well as for native individuals only (Fig. 9). Other groups sometimes had large mean relative changes, but also had very high variances among replicate plots, and thus were not significantly different from 0.

Orthoptera at Palikea were comprised mainly of native (*Banza* spp.) and introduced katydids (family Tettigoniidae) and native crickets (?*Laupala* spp., family Gryllidae). Lower-level analysis indicated that all three groups showed trends of relative increases in abundances at the removal site after trapping, but that this change was significant only for the crickets, which dominated the overall pattern for Orthoptera (Fig. 11).

Hemiptera (true bugs) at Palikea are very diverse, represented by many species in 24 families. The significant relative increase in abundance of Hemiptera as a group on vegetation at the removal site, post-trapping, resulted predominantly from abundance increases in five families (Fig. 12): Delphacidae (plant hoppers), Lygaeidae (seed bugs), Nabidae (damselfly bugs), Psyllidae (plant lice), and Derbidae (one introduced plant hopper species, *Cedusa* sp.).

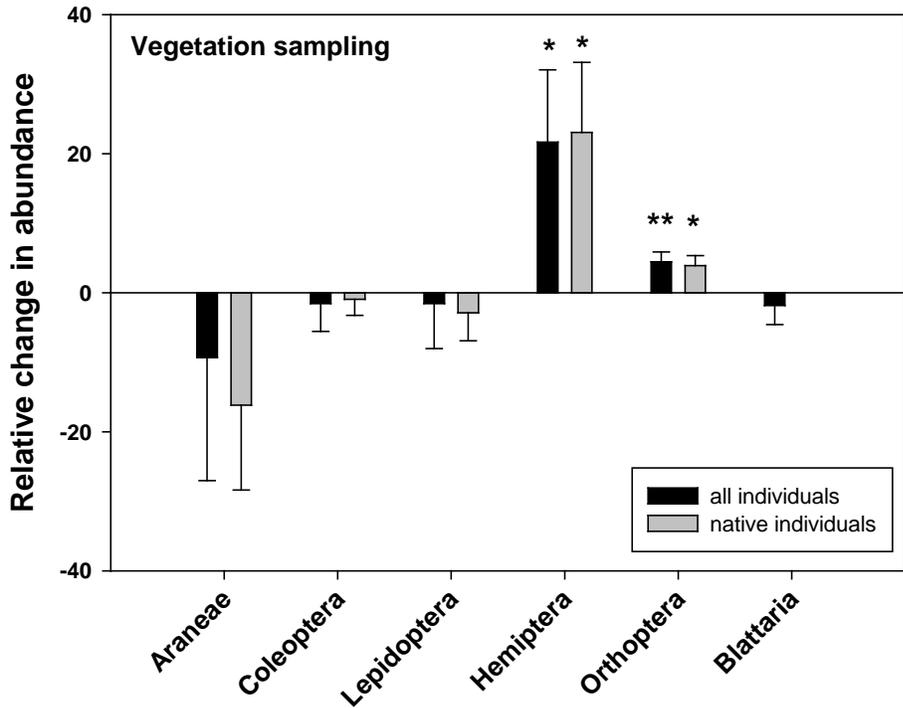


Figure 9. Mean changes in abundances ( $\pm$  SE), per sampling plot, of various taxonomic groups on vegetation (day and night sweeping) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Changes are shown for all individuals as well as for native individuals only for most groups. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with \* for  $p < 0.05$  and \*\* for  $p < 0.01$ .

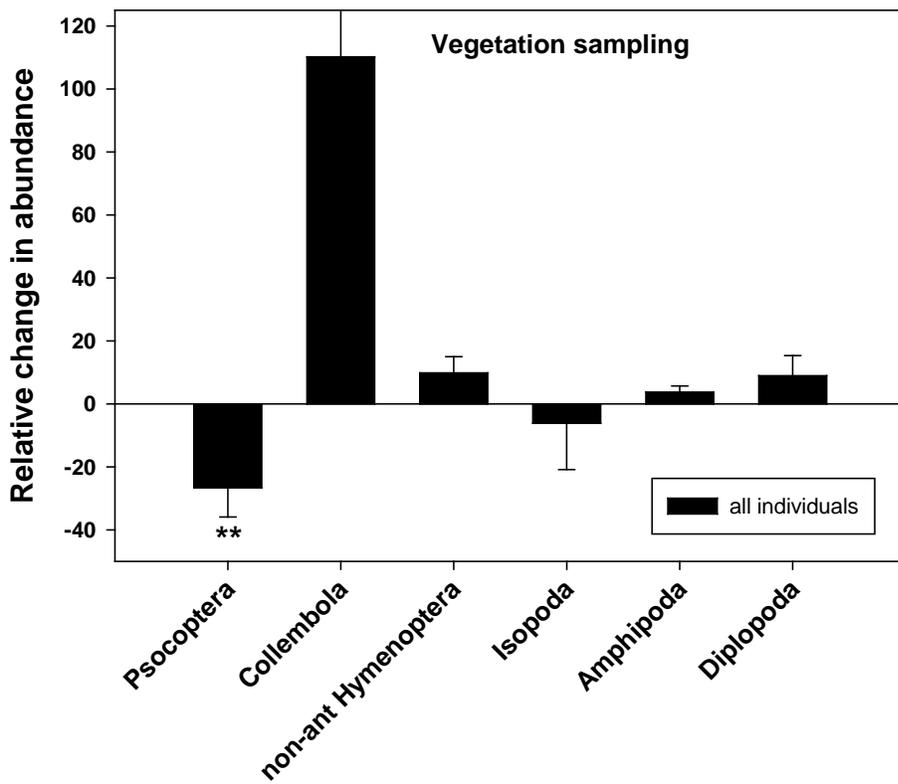


Figure 10. Mean changes in abundances ( $\pm$  SE), per sampling plot, of various taxonomic groups on vegetation (day and night sweeping) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with \* for  $p < 0.05$  and \*\* for  $p < 0.01$ . The standard error bar for Collembola extends far beyond the scale shown on figure; the large mean change in Collembola abundances was not significantly different from 0 because of this high variance.

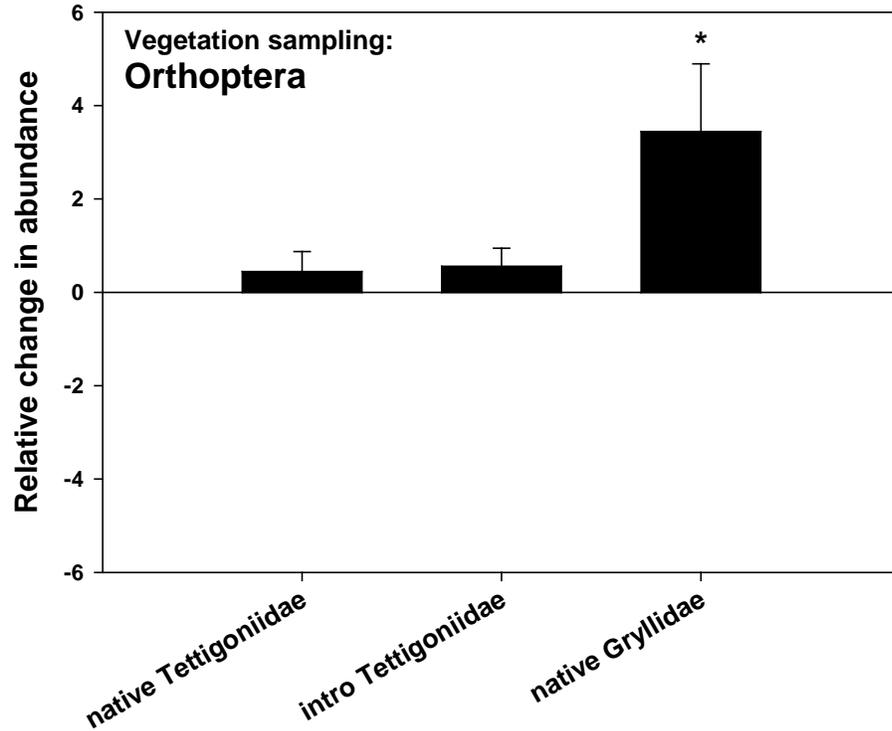


Figure 11. Mean changes in abundances ( $\pm$  SE), per sampling plot, of groups of Orthoptera on vegetation (day and night sweeping) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with \* for  $p < 0.05$  and \*\* for  $p < 0.01$ . Native Tettigoniidae (katydids) were comprised of *Banza* spp., introduced Tettigoniidae were comprised of *Conocephalus saltator* and *Elimaea punctifera*, and native Gryllidae (crickets) were comprised of ?*Laupala* spp.

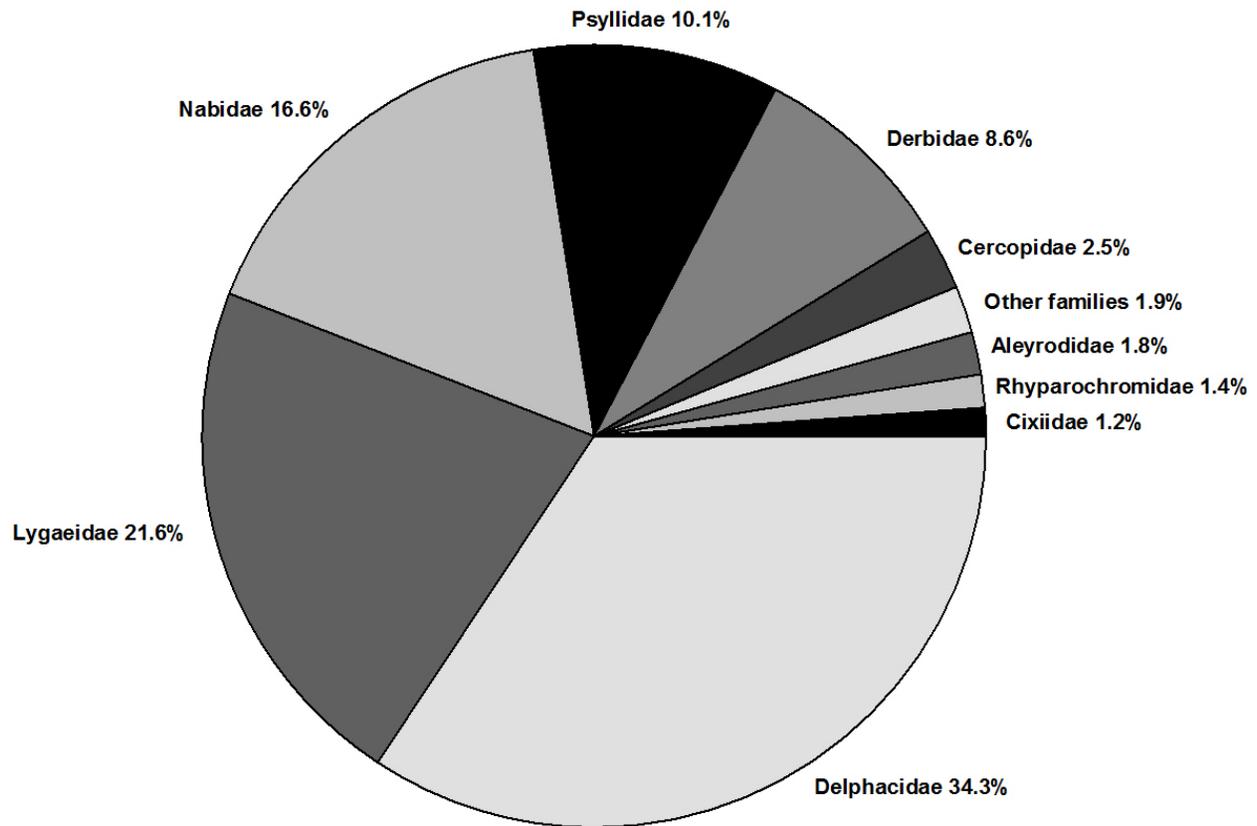


Figure 12. Proportional representation, by family, of the overall relative increase in Hemiptera abundances at the Palikea removal site after rodent trapping. Other families, each contributing to less than 1% of total relative increase at the removal site, include Coccidae, Cydnidae, Flatidae, Membracidae, Pentatomidae, and Saldidae. Families that declined in abundance at the removal site relative to the control site include Aphididae, Cicadellidae, Miridae, Pseudococcidae, Reduviidae, Rhopalidae, and Tingidae.

Relative changes in abundances of the major arthropod orders represented in ground-active communities are shown in Figures 13 and 14. Statistically significant mean relative increases in abundance at the removal site were found only for non-ant Hymenoptera (almost exclusively parasitic micro-Hymenoptera) and Diplopoda (millipedes), whereas significant relative decreases were found only for Araneae (spiders). Native Araneae showed a small but statistically non-significant trend of relative increases in abundances at the removal site. However, these make up a small fraction of the overall ground-active spider community, which is dominated by individuals of unidentified linyphiid species of unknown provenance. Other groups sometimes had large mean relative changes, but also had very high variances among replicate plots, and thus were not significantly different from 0.

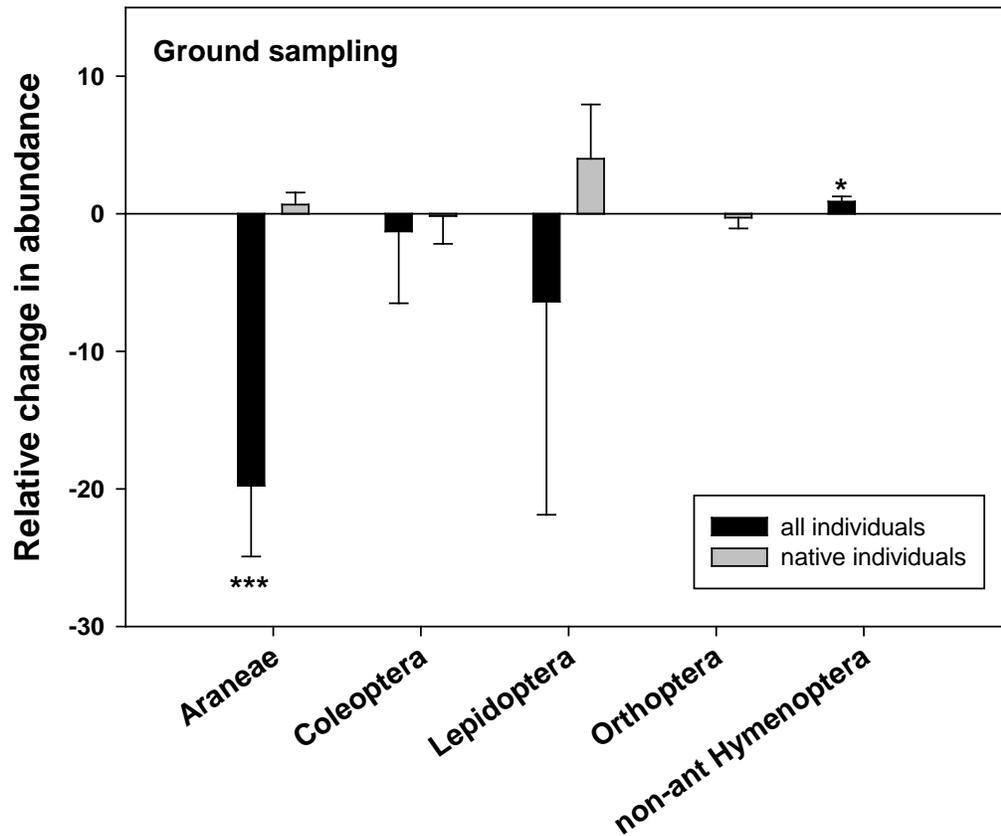


Figure 13. Mean changes in abundances ( $\pm$  SE), per sampling plot, of various taxonomic groups active on the ground (pitfall and litter extraction samples) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Changes are shown for all individuals as well as for native individuals only for most groups. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with \* for  $p < 0.05$ , \*\* for  $p < 0.01$  and \*\*\* for  $p < 0.001$ .

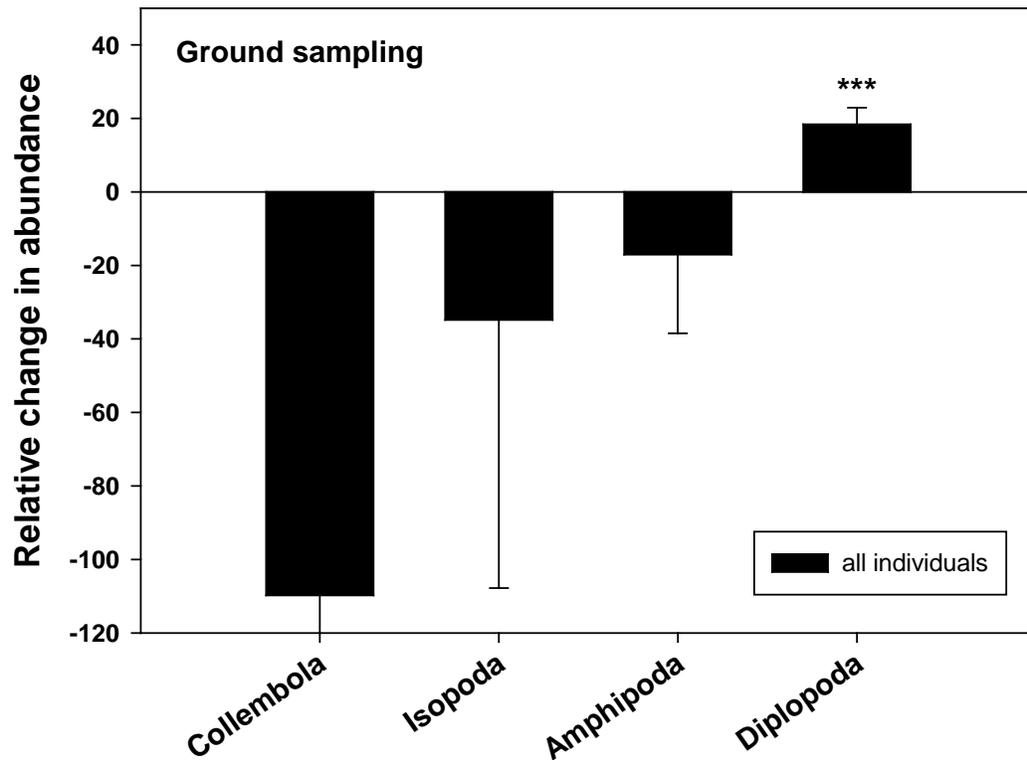


Figure 14. Mean changes in abundances ( $\pm$  SE), per sampling plot, of various taxonomic groups active on the ground (pitfall and litter extraction samples) at the Palikea removal site relative to the control site, from the pre-trapping period to the first year post-trapping. Positive values indicate increases at the removal site relative to the control site, while negative values indicate decreases at the removal site relative to the control site. Comparisons that are significantly different from zero are indicated with \* for  $p < 0.05$ , \*\* for  $p < 0.01$  and \*\*\* for  $p < 0.001$ . The standard error bar for Collembola extends far beyond the scale shown on figure; the large mean change in Collembola abundances was not significantly different from 0 because of this high variance.

### C. Conclusions to date

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 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 or study areas, 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.

In general, there were relatively few statistically significant changes in abundances among the various arthropod groups at the Palikea removal site, after adjusting for changes at the control site, in the first year after rodent trapping began. In addition, there is relatively little agreement between the taxonomic trends seen in the first two years after trapping at Kahanahaiki Valley and those presented here for the first year post-trapping at Palikea. The estimated relative changes in abundances to date, for both study areas, are summarized in Table 1. Relative increases have been strongest and/or most consistent at Kahanahaiki for Araneae and Lepidoptera, but both of these groups failed to increase and instead showed tendencies to decrease after rodent trapping at Palikea. However, only one of these relative declines, among ground-active spiders, was statistically significant, and the (non-significant) decrease in Lepidoptera in ground samples at Palikea matched the significant decline in the same group at Kahanahaiki. The most consistent response between study areas has been significant declines in Psocoptera abundances on vegetation after trapping began.

The two groups that significantly increased in abundance after trapping at Palikea, Hemiptera and Orthoptera, have shown only inconsistent evidence for increase at Kahanahaiki, namely, crickets increased in abundance on the ground at Kahanahaiki after two years. However, recovery by Orthoptera fits well with predictions, as this group of relatively large-bodied insects represent common prey items in rodent diets (St Clair 2010), and one *Banza* leg was found in a black rat stomach trapped at Kahanahaiki (Shiels et al. in press). Increases in numbers of Hemiptera at Palikea, especially among small-bodied Delphacidae, Psyllidae and Lygaeidae, could represent a trophic cascade mediated by the apparent decline in predatory spiders, as rodents may be unlikely to prey heavily on these groups. Other Hemiptera, such as the Nabidae and larger lygaeid species, may be more common rodent prey items and could experience release from predation by both rodents and spiders. Hemiptera have not increased in abundance at Kahanahaiki, but this matches expectations based on the apparent increase in spider numbers in that area.

Spiders make up a substantial portion of the arthropod communities in both study areas, and given their predatory roles are likely important mediators of arthropod food web dynamics. It is unclear why they have apparently increased after rodent trapping at Kahanahaiki but decreased (or shown trends in this direction) at Palikea. One potential explanation is a differential role of birds in the two study areas. Birds have been shown to strongly control spider populations in Hawaiian forests (Gruner 2004), and their top-down effects appear to be weaker on lower trophic levels, such as herbivorous insects. If predation pressure by birds is stronger at Palikea than at Kahanahaiki, especially after rodents are suppressed, the above pattern in spider abundances could emerge.

Analysis of changes in arthropod abundances after the second year of rodent trapping at Palikea, and the third year at Kahanahaiki, should help clarify potential patterns. In addition, dynamics in arthropod diversity have not yet been examined, and may shed additional light on changes in arthropod communities. I will be focusing on both of these questions in future work.

Appendix ES-12 Assessment of Effects of Rodent Removal on Arthropods

Table 1. Summary of mean (or median) relative changes in abundance estimated in the two study areas to date. Increases at the trapped sites relative to the control sites in each area that differ from 0 at  $p < 0.05$  highlighted in green and at  $0.05 < p < 0.1$  in light green. Decreases that differ from 0 at  $p < 0.05$  highlighted in red and at  $0.05 < p < 0.1$  in pink.

Taxon	Vegetation Sampling			Ground Sampling		
	Kahanahaiki/Pahole		Palikea	Kahanahaiki/Pahole		Palikea
	1 year	2 years	1 year	1 year	2 years	1 year
	mean/med score	mean/med score	mean/med score	mean/med score	mean/med score	mean/med score
Araneae	1.53	2.56	-9.33	4.533	4.783	-19.78
native Araneae	0.218	0.219	-16.17	0.062	0.625	0.67
Coleoptera	-1.28	2.09	-1.56	0.75	7.15	-1.28
native Coleoptera	-0.344	-0.719	-0.94	0	0	-0.17
Lepidoptera	0.812	1.125	-1.56	-1.875	-0.062	-6.39
native Lepidoptera	0.906	0.906	-2.89			4
Eupithecia	0.563	0.563	-0.06			
Hyposmocoma	0.344	0.344	-2.78	-0.462	-0.15	3.5
Orthoptera	0.125	0.094	4.44			
native Orthoptera	-0.062	-0.031	3.89	0	2	-0.28
Blattodea	0.062	0.25	-1.83			
Dermoptera				0.554	-0.258	-1.44
native Dermoptera				-0.2	0.05	
Hemiptera	-3	2.5	21.67	1.821	1.071	-1.39
native Hemiptera	-3.25	2.5	23.06			
Psocoptera	-6	-1.5	-26.67			
Hymenoptera (all non-ant)	0	0	9.83	-0.062	0.062	0.89
Formicidae	0.5	1	2.83	0.5	0.5	-0.11
Diptera				4.25	1	14.78
Collembola	14.344	16.75	110.17	-4.962	8.788	-109.78
Isopoda	0	1	-6.17	3.904	4.217	-34.83
Diplopoda	0.188	0.062	8.94	-2.483	-0.921	18.39
Amphipoda			3.72	-9.5	17	-17.06
All arthropods	7.5	36.25	83.67	-1.562	37.188	-217.67
All native arthropods	-2.5	5.5	8.72			2.67

## II. Inventory and biodiversity patterns

The standardized plus opportunistic sampling for this project has resulted in the collection, sorting, and databasing, to date, of over 220,000 arthropod specimens. All specimens in many taxonomic groups have been identified to species or morphospecies. So far, 300 arthropod species or morphospecies have been identified from Kahanahaiki and Pahole, and 417 species or morphospecies have been identified from Palikea. One interesting recent find was the collection of several individuals of a new, undescribed species of *Nysius* seedbug (family Lygaeidae), provisionally named *N. "kaala"* and previously only known from the Kaala summit area (J. Eiben pers. comm.). The collections at Palikea therefore substantially expand the known habitat area for this apparently rare species.

Previous work found a preliminary, but strong relationship between arthropod species richness and the richness of native plant species in the forest understory at Palikea. Recently OANRP staff quantified the plant community richness and cover at the Palikea control plots, which doubles the sample size for this type of analysis. Combined with the increased number of arthropod samples now fully processed at Palikea, this will allow robust examination of patterns between plant community structure, including degree of invasion by adventive plants, and arthropod community characteristics.

Similarly, prior work indicated a preliminary trend of lower overall abundances of arthropods on *Psidium cattleianum* relative to native tree species at Kahanahaiki and Pahole. This finding led to the hypothesis that strawberry guava could provide inferior foraging habitat for the endangered insectivorous elepaio. However, the arthropod data at the time were incomplete, missing several abundant taxonomic groups, and the interpretation regarding habitat quality for elepaio would be contingent on abundance patterns of arthropod groups that serve as the main prey items for elepaio. Over the past year, the question has been investigated further, resulting in two main findings. First, when all arthropod groups are included, *P. cattleianum* trees at Kahanahaiki and Pahole did not have significantly lower numbers of arthropods than three native tree species (Fig. 15). However, many of the arthropods in *P. cattleianum* samples were springtails (Collembola). Unpublished USGS data on the prey composition of 92 elepaio fecal pellets from Hakalau NFR, Hawaii Island, indicate that Collembola were completely absent from elepaio diets.

When the Kahanahaiki and Pahole arthropod samples were re-examined with a consideration of elepaio prey preference, a different picture emerged. Mean total abundances of arthropod prey items were significantly lower on *P. cattleianum* than on two of the three native tree species, regardless of whether prey item abundance was estimated by a) including only arthropod groups that comprised at least 5% of elepaio diet contents, or b) by weighting the abundances of each arthropod group by its proportional representation in the elepaio diet (Fig. 16). This pattern is compelling, and a next step is to examine whether these results are corroborated by patterns of arthropod abundances as they relate to levels of *Psidium* infestation in the Palikea vegetation plots. In addition, elepaio fecal samples from the Waianae mountains are now being collected by OANRP staff, and these samples will be dissected to identify local diet composition. These data, possibly combined with observations on elepaio foraging behavior, may provide an important insight into a possible link between plant community composition and elepaio habitat quality, as mediated by arthropod community composition.

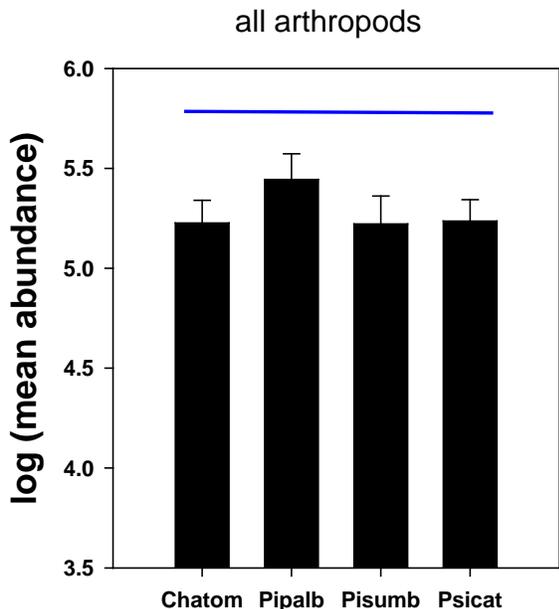


Figure 15. Mean total abundance ( $\pm$ SE) of all arthropods on four species of trees at Kahanahaiki and Pahole. Means are averages of all trees sampled at both sites (n=16 per species). Tree species connected by blue bar are not significantly different ( $p > 0.05$ ).

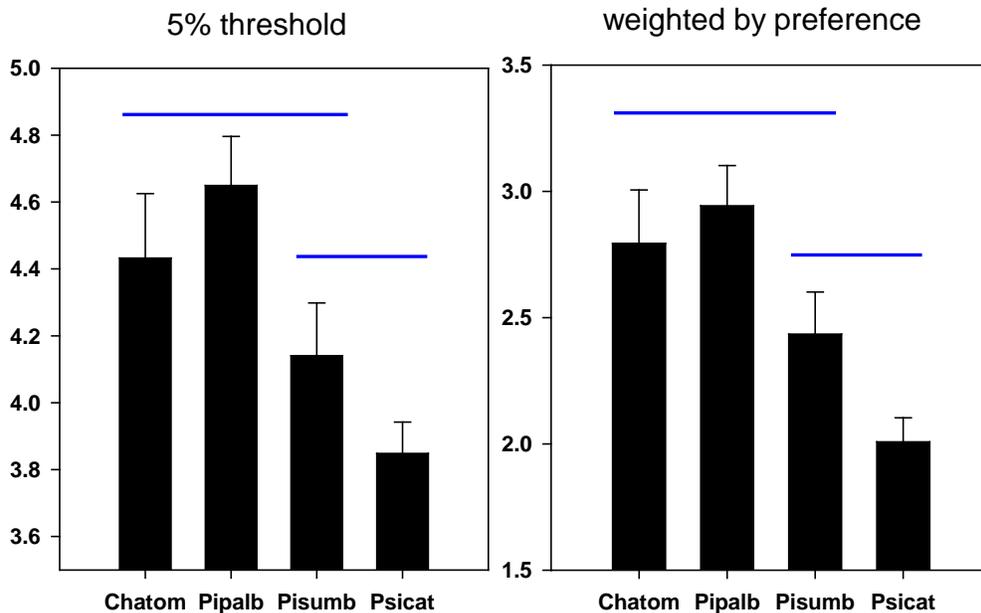


Figure 16. Mean total abundance ( $\pm$ SE) of all arthropods on four species of trees at Kahanahaiki and Pahole, when adjusted for elepaio diet composition (USGS unpub. data). Left panel shows mean total abundances of all arthropod groups that comprised at least 5% of elepaio prey items. Right panel shows mean total abundances of all arthropod groups, but with abundances of each group weighted by proportional composition in elepaio diets. Means are averages of all trees sampled at both sites (n=16 per species). Tree species connected by blue bars are not significantly different ( $p > 0.05$ ).

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