

RESULTS AND DISCUSSION

We collected a total of 60,146 individual arthropods in the course of this inventory. Of these, 11,086 (18.4%) were mites (Acari), mealybugs (Hemiptera: Pseudococcidae), or parasitic wasps (Hymenoptera), and were not further identified. The remaining arthropods represented a total of 257 taxa in 17 orders (Table 1, Appendix). For most of these taxa (203) it was possible to make species-level determinations; nearly all of the remainder were identified to the level of genus, but for a few taxa the genus and species remain undetermined. All taxa that were not identified to species (exclusive of the groups listed above) were separated into morphospecies. A database of all arthropods collected is retained by the Pacific Island Network of the National Park Service Inventory and Monitoring Program.

We believe that 81 of our taxa (31.5%) are new records for HALE, the majority representing introduced species (Table 1). Many of these are new records for Maui, and some are new state records (to be reported elsewhere). A minority of the new records are native species. Most new native species records represent range extensions, some represent new species that have arisen through taxonomic revision (or upcoming revision; these are all in the Hemiptera), and two are new species discovered during this inventory. The newly discovered native species are *Orthocladius* n. sp. (order Diptera, family Chironomidae) and *Campsicnemus* n. sp. (order Diptera, family Dolichopodidae). The endemic status of two additional new species discovered during this inventory, *Corynoptera* n. sp. (order Diptera, family Sciaridae) and *Liposcelis* n. sp. “kipukae” (order Psocoptera, family Liposcelidae), currently remains unclear.

The inventory benefitted substantially from sampling in the two different elevational zones. While the lower zone clearly supported more species, and samples collected in the lower zone yielded 80% of the total number of species captured, the remaining 20% of species were unique to the upper zone (Table 2). Sampling in the upper zone was more important for capturing additional endemic species as compared to introduced species: 27% of all endemic species captured occurred exclusively in the upper zone, while only 16% of all introduced species captured occurred exclusively in the upper zone (Table 2).

Species accumulation curves produced from the 2003 dataset indicate that this inventory was not complete – observed richness did not reach an asymptote for native species, introduced species, or species of unknown native status (Fig 2a). Nor did species accumulation plateau with any of the three sampling techniques employed (Fig. 2b). All of the richness estimators that were calculated showed sensitivity to sample size in at least half of all data subsets, and usually in all subsets. This characteristic makes it difficult to evaluate the accuracy of the different richness estimators (Fisher 1999, O’Hara 2005, Walther and Moore 2005). However, several of the non-parametric estimators have been found to most consistently produce the least biased estimates in other inventories (Brose et al. 2003, Walther and Moore 2005, but see O’Hara 2005), and are almost certainly more accurate than the observed richness totals. We therefore followed the guidelines of Brose et al. (2003), and used the second-order jackknife estimator of species richness (Table 3). These estimates suggest that the 2003 standardized sampling only captured about 62-66% of the species that are present in the study area and that are likely to be trapped with our chosen sampling methods.

Pitfall trapping was the most effective technique used (Fig. 2b). Baited pitfall traps accumulated species more quickly than unbaited traps (not shown), and each type of pitfall trap captured a number of species that were not caught with the other type. But because species accumulation had not yet begun to plateau, it is not clear how many of these unique captures were due to the presence or absence of bait, as opposed to simply resulting from the increase in trapping effort when both types of pitfall traps were considered. After pitfall trapping, vegetation beating was the second most effective collecting technique (Fig 2b). Importantly, these two techniques captured largely non-overlapping sets of species: 60.4% of species captured by pitfall traps were unique to this sampling technique, while 54.2% of species captured through vegetation beating were caught exclusively with this technique. In comparison, litter extraction was least effective at capturing many different species (Fig. 2b), and only 19.1% of leaf litter species were caught exclusively with this technique.

The species list for the upper west slope and summit areas of HALE would be substantially expanded by employing other sampling techniques, such as Malaise trapping and light trapping that target strong flying groups like Lepidoptera, and by employing vegetation sampling techniques on additional host plants, including additional shrub and tree species and herbaceous vegetation. A relatively low level of hand collecting during the study period, for example, added 15 species. Naturally, identification of the remaining groups that we were not able to address, particularly the mites, would also dramatically expand the species list. By way of comparison, an inventory of HALE's crater district conducted in the 1970's (Beardsley 1980) reported a total of 389 species. This earlier survey, while excluding non-insect arthropods, sampled at many sites throughout the crater and Kaupo Gap that represent habitat types different from the west slope and summit areas, used different sampling techniques (including light traps and malaise traps), sampled on different host plants, and included some historical records for the crater district that were not collected in the course of the survey.

It is clear that introduced species continue to arrive and establish in the west slope shrubland and alpine zone of HALE, but the rate at which this is occurring is currently difficult to estimate. For well studied groups such as the beetles (Coleoptera), bugs (Hemiptera) and flies (Diptera), our new species records probably mostly represent relatively recent arrivals to the park. In contrast, other groups that had many new introduced species records in our inventory, such as spiders (Araneae), springtails (Collembola), barklice (Psocoptera) and thrips (Thysanoptera), have previously been treated much less thoroughly. New records in these groups probably include many species that had been present at the time of earlier surveys but were simply not targeted or identified.

Taken at face value, the chosen richness estimates for the 2003 dataset imply that the west slope shrubland and aeolian zone arthropod community is composed of about 53% introduced species and 40% native species (plus about 6% species of unknown status). In the 1970's, Beardsley (1980) found an insect fauna represented by only 40% introduced species and 60% native species. A comparison of these two statistics could provide a rough quantification of the changes in the park's arthropod fauna during the intervening years, but this is likely to be fairly inaccurate for several reasons. First, because there were many more individuals of introduced species captured than individuals of native species in the present inventory, the native species

sampling curve rose much more steeply than the introduced species curve when plotted as a function of individuals captured instead of samples collected (not shown). It is therefore possible that additional sampling would have resulted in a higher native to introduced species ratio. Second, the large differences between our inventory and that of Beardsley's make quantitative comparisons regarding species composition and change inappropriate. If we had sampled on more kinds of native plants, for instance, we would likely have increased the number of host-specific native species to a much greater degree than introduced species, which tend to be generalists. Similarly, if we had sampled in wetter and more remote habitats, as Beardsley did, we may have obtained a higher native to introduced species ratio. Also, the use of different sampling techniques, as well as differences in the availability of taxonomists and systematists, means that the two surveys were able to focus to some degree on different arthropod groups. Discrepancies in the proportion of native to introduced species in these different groups would also affect the overall makeup of the surveyed fauna. A final difference between the two inventories was the relative influence of the Argentine ant. By excluding many endemic species and benefiting a number of introduced species, Argentine ant invasion results in a higher proportion of introduced species in the overall arthropod community (Krushelnycky 2007). Because our inventory had many sampling points located within Argentine ant invaded habitat, while Beardsley only had a few collections within habitat invaded by Argentine ants (which were much more localized at the time), our inventory inevitably produced a community composition more biased towards introduced species. As the Argentine ant continues to spread in the west slope shrubland, towards the summit and into the crater (Krushelnycky et al. 2005b), native richness will likely decline and community dominance by introduced species will likely increase in these areas of the park.

A strength of our inventory lies in its inclusion of a standardized and quantitative component (i.e. all of the non-hand collected samples). While species lists can often be efficiently lengthened with haphazard or general collecting techniques, and these techniques should therefore also be included, it is difficult to construct robust species accumulation curves from haphazard methods alone. Without species accumulation curves, or the underlying standardized sampling data, it is difficult to estimate true species richness, estimate inventory completeness, or make comparisons between inventories (Gotelli and Colwell 2001). In addition, our analysis of the standardized sampling techniques used in the present inventory should provide useful information for managers wishing to develop monitoring protocols for arthropod communities in Hawaiian shrubland and alpine habitats.

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