



RESEARCH NOTE

Native arboreal land snails in the Mt Kaala Natural Area Reserve, Oahu, Hawaii,
have similar plant preferences: implications for conservation

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The native Hawaiian land snail fauna is one of the most species-rich (over 750 species) in proportion to the area of the archipelago (28,311 sq. km; Solem, 1984; Cowie, Evenhuis & Christensen, 1995). This rich Pacific island fauna resulted primarily from *in situ* speciation (Cowie, 1995), since land snail colonization events were extremely rare (e.g. two colonization events resulted in 42 succineid species; Rundell, Holland & Cowie, 2004). As such, the land snail fauna in Hawaii is considered disharmonic, with high species richness but low family richness (10 families), and with an extremely high level of endemism (over 99%; Cowie *et al.*, 1995). Unfortunately, the majority of these native Hawaiian land snail species may now be extinct or highly endangered, with estimates of extinction ranging from 65 to 90% (Solem, 1990; Cowie, 1998, 2001; Lydeard *et al.*, 2004).

In most areas throughout the Hawaiian Islands, even those at higher elevations and away from human disturbance, the fauna and flora are dominated by widespread nonnative species (Cowie, 1998; Meyer & Cowie, 2010; Meyer, 2012). As such, only a few places in the Hawaiian Islands remain relatively intact, primarily supporting native species (both plant and animal), where interactions among native land snails and native Hawaiian plants can be investigated. Studies in these intact places are rare, but are valuable for informing restoration and management efforts. For example, examining which native plant species are preferred by different native arboreal land snail species and how these resources are partitioned to allow species to coexist in sympatry will help conservation practitioners to determine which combination of native plant species can facilitate the preservation of native snail diversity, and provide insights into how loss of specific native plant species may influence extant native snail populations. While studies in other areas with nonnative species (plants and animals) are also informative, the presence of nonnative species may modify the behaviours of the snail species in such a way as to change the utility of the findings. For instance, Meyer (2012) found that native succineids preferred nonnative ginger species to native plants as habitat in areas where ginger was abundant but had yet to form a monotypic understory. While this study is informative for understanding how

native snail species use plant resources in forests invaded by ginger, it provides little information for understanding the ecology of snails in areas without ginger, or on how best to restore areas with native plant species.

The purpose of the present study was to examine the plant preferences (the plants the snails were found on) of the native arboreal land snails in the Mt Kaala Natural Area Reserve (NAR) (21.506441°N, 158.145386°W). The Mt Kaala NAR is one of the few remaining intact, protected areas in the Hawaiian Islands and is home to at least 28 native land snail species (Hayes *et al.*, unpubl.). In the Mt Kaala NAR, all of the arboreal snails, and many of the ground dwelling snails, are native and these arboreal snails are presumed to graze on epiphytic fungi, since little evidence of herbivory has been observed (Hayes *et al.*, unpubl.). In addition, the flora on Mt Kaala is composed primarily of native plants (Table 1). Nonnative ginger species (*Hedychium* spp.) and raspberry (*Rubus* sp.) can be found in this area, but comprise <1% of the available plant surface area. Because effective partitioning of resources could help to limit niche overlap, allowing species to coexist (Jennings & Barkham, 1975; Losos, 1994; Meyer & Yeung, 2011), we hypothesized that sympatric arboreal snails in the Mt Kaala NAR prefer different plant species.

To test this hypothesis, five 5 × 5 m quadrats were surveyed during two sampling trips on 19 June 2013 and 21 June 2013. Quadrats were *c.* 100 m apart and located adjacent to a preexisting boardwalk path built by NAR managers to limit negative impacts of trampling. All plants in each quadrat were identified to lowest taxonomic level and the percent cover of each species was estimated. Snails were identified to the lowest taxonomic level and the number on each plant type was recorded (top and bottom of leaves, stems and trunks were surveyed). Most of the plants were short enough (<2 m in height) to survey the whole plant. In the few cases of tree species that were too tall to survey completely, areas above our reach were not included in our estimate of plant cover. One surveyor collected all the snails on one plant species in a quadrat and recorded the number of individuals for each snail taxon found on that plant before moving on to search for snails on another plant species. Since there were

many surveyors (at least six on each sampling trip), we switched which plant species each surveyor focused on among plots. This was done to limit any potential effect of differences in surveyor ability on patterns recorded. Most snails were released upon completion of each survey, but two to three individuals of each snail morphotype were collected from each site for genetic analyses in the laboratory to (1) identify cryptic diversity and (2) assign morphotypes to the appropriate taxonomic group. This study is part of a larger study to assess the current conservation status of Hawaiian land snails. All specimens will be vouchered at the Bishop Museum, Honolulu.

To estimate the plant preferences of each species, Jacobs' (1974) selectivity indices were calculated using the following formula:

$$D_{ia} = (r_i - p_a) / (r_i + p_a - 2r_i p_a),$$

Table 1. Average percent cover of all plant taxa in the five plots in the Mt Kaala NAR.

Plant species	Average % cover
<i>Metrosideros polymorpha</i>	34
<i>Cibotium</i> spp.	14
<i>Broussaisia arguta</i>	12
<i>Melicope</i> sp.	11
<i>Ilex anomala</i>	9
<i>Styphelia tameiameia</i>	8
<i>Dianella sandwicensis</i>	5
<i>Cheirodendron trigynum</i>	5
<i>Vaccinium reticulatum</i>	3
<i>Coprosma</i> sp.	2
<i>Peperomia</i> sp.	2
<i>Dicranopteris linearis</i>	1
<i>Rubus</i> sp.*	<1
<i>Hedychium</i> spp.*	<1
<i>Smilax melastomifolia</i>	<1

*Nonnative species.

Table 2. Plant selection by snails in the Mt Kaala NAR.

Plants species	Snail species					
	<i>Catinella rotundata</i>	<i>Elasmias</i> spp.	<i>Tornatellides</i> sp.	<i>Philonesia hartmanni</i>	<i>Philonesia oahuensis</i>	<i>Auriculella</i> spp.
<i>Metrosideros polymorpha</i>	-0.32	-0.35	-0.89	-0.25	-0.73	-0.27
<i>Cibotium</i> spp.	-0.20	-0.17	-0.72	-0.55	-0.64	-0.41
<i>Broussaisia arguta</i>	0.43	0.66	0.42	0.43	0.53	0.42
<i>Melicope</i> sp.	0.15	-0.04	0.03	-0.21	0.14	-0.21
<i>Ilex anomala</i>	0.61	0.47	0.20	0.67	0.38	0.42
<i>Styphelia tameiameia</i>	-1.00	-1.00	-1.00	-1.00	-1.00	-0.79
<i>Dianella sandwicensis</i>	-0.51	-0.41	0.79	0.24	-1.00	-0.35
<i>Cheirodendron trigynum</i>	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
<i>Vaccinium reticulatum</i>	0.27	-0.21	0.62	0.17	-1.00	-0.71
<i>Coprosma</i> sp.	-1.00	-1.00	0.05	-0.32	0.45	-1.00
<i>Peperomia</i> sp.	-0.32	-0.21	0.51	-1.00	-1.00	0.01
<i>Dicranopteris linearis</i>	-1.00	-1.00	-1.00	-1.00	-1.00	0.03
<i>Rubus</i> sp.*	-0.51	-1.00	-1.00	-1.00	-1.00	0.27
<i>Hedychium</i> spp.*	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
<i>Smilax melastomifolia</i>	0.64	0.70	0.93	-1.00	-1.00	0.37

Positive and negative Jacobs' indices indicate that different plants were used more or less frequently, respectively, than expected by chance. Values ≥ 0.20 are in bold.

*Nonnative species.

where D_{ia} is the selectivity index of snail species i for plant type a , r_i is the ratio of plant type a use to all the other plant types used by that species and p_a is the ratio of plant a to all the other plants available for the individual to use within the local area. To calculate p_a , we used percent cover of that species, not number of individuals present since different plant species differed significantly in their size. If a snail species preferentially uses a certain plant the D_{ia} score will be positive. A negative D_{ia} score indicates that a plant was not preferred, i.e. fewer snails on the plant than expected by chance. The range of potential scores is from 1 to -1. We first calculated a global Jacobs' selectivity index for each snail species on each plant species by averaging the percent cover of all plant species in the five plots and using the total number of individuals of each snail species on each plant species in the five plots. We also calculated a separate Jacobs' selectivity index for each snail species in each of the 5 plots when at least 10 individuals were collected in a plot. We did this to make sure that patterns described by the global Jacobs' index were consistent among sites (i.e. that the global Jacobs' index was not dominated by snail activity at one or a few sites).

In total, we recorded 727 snails from the 5 plots. Abundant snails were assigned to six taxonomic groups: one succineid species (*Catinella rotundata* (Gould, 1846)), two helicarionid species (*Philonesia hartmanni* Ancey, 1889 and *P. oahuensis* (Ancey, 1889)) and three achatinellid taxa (*Elasmias* spp., *Tornatellides* sp. and *Auriculella* spp.). There were two morphotypes each in the genera *Elasmias* and *Auriculella*, but they were difficult to tell apart consistently because of the size and age of the snails. The *Elasmias* species are <2 mm in shell height and the majority of the *Auriculella* specimens collected were juveniles (<5 mm in shell height). As such, we lumped the two morphotypes within each genus together for our analyses.

Contrary to our hypothesis, we found that different snail species had similar preferences. Two plant species, *Ilex anomala* and *Broussaisia arguta*, were preferred by all snail species, while several common plant species were not preferred (e.g. *Metrosideros polymorpha*, *Cibotium* spp. and *Styphelia tameiameia*; Table 2). These patterns of selectivity were fairly consistent among sites (Fig. 1) and seem to be consistent with data from other wet forests in Hawaii, where *B. arguta* also seems to be preferred by succineids

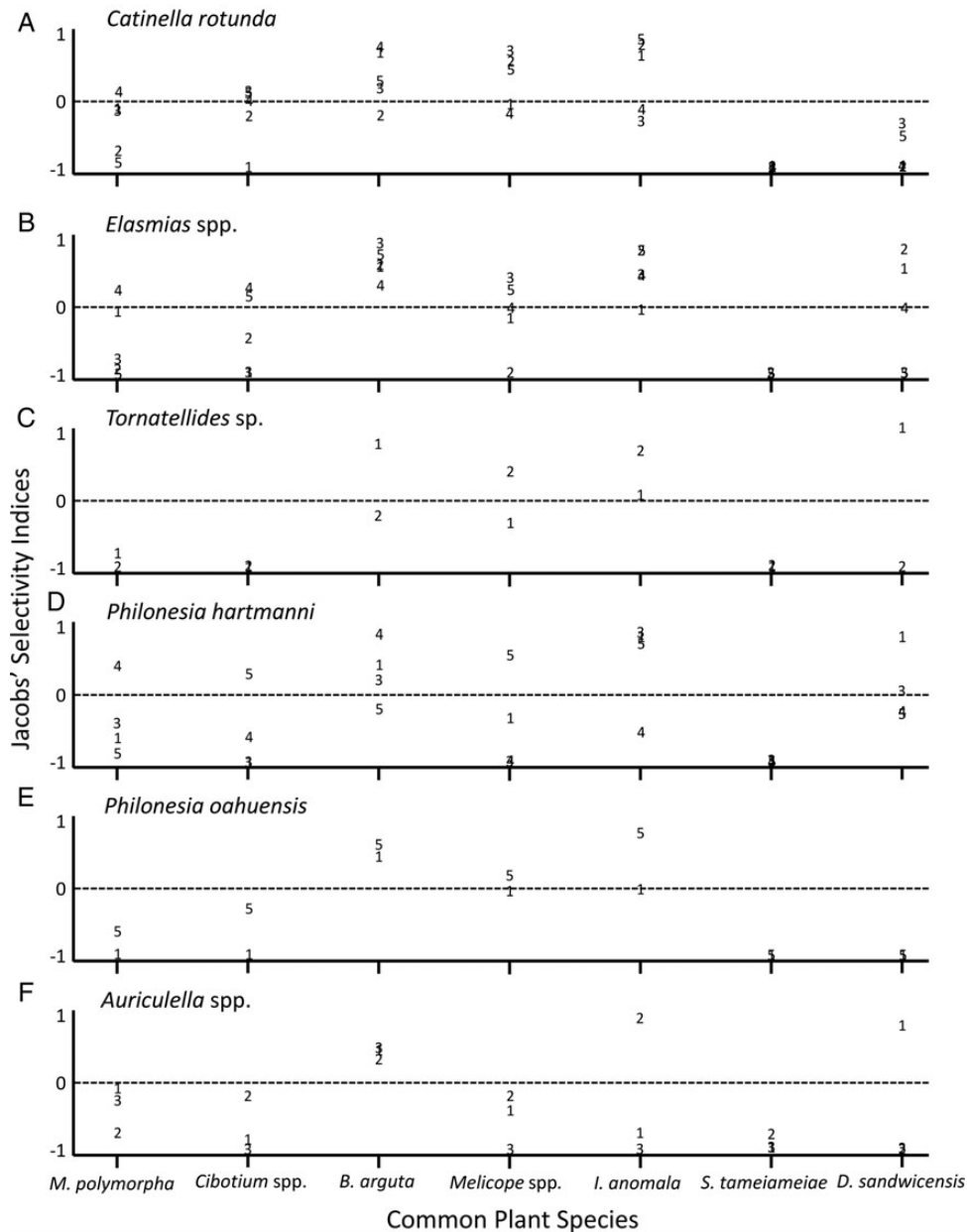


Figure 1. Plant selection by snails at each of the 5 sites (in instances where >10 individuals were collected at a site) in the Mt Kaala NAR. Positive and negative Jacobs' indices indicate that different plants were used more or less frequently, respectively, than expected by chance. Numbers in the figure represent the site. Plant species are listed in full in Table 1.

(Brown, Spain & Crowell, 2003; Brown, Spain & Arizumi, 2006; Meyer, 2012). Preference for plant species that constitute a small percentage of the plant surface area should be interpreted conservatively, since finding just a few individuals on a plant could result in a high preference score. This finding contrasts with studies on arboreal *Partula* species in Moorea, which found differences in plant-host preference among species (Murray, Johnson & Clarke, 1982), with some species showing strong preferences for particular plant species and others being found on a wide range of host plants. Similar to our study, it is not clear what is influencing this preference, as little is known regarding the feeding habits or interspecific interactions among these taxa. Comparisons with other studies on plant preferences are often difficult, as plant preferences may be determined by several factors, including palatability of the plant by snail herbivores

(Mølgaard, 1986; Linhart & Thompson, 1995; Briner & Frank, 1998). Not surprising, most studies of snail plant preferences have focused almost exclusively on the role of plant secondary metabolites or palatability in determining snail preferences. Such studies examine snails that actually feed on the plants, which is in stark contrast to the epiphytic grazing thought to be the primary mode of feeding in Hawaiian land snails. Additional studies examining plant-host preferences of arboreal snails are needed, especially those focused on species of conservation concern, to identify plant species that are critical to the preservation of these species. Too often, only anecdotal observational data are available (Lok & Tan, 2008; Sutcharit, Tongkerd & Panha, 2013), which leads to broad conclusions (e.g. snails require healthy forests) that do not provide specific instructions as to how better to protect these species.

Currently, there is no explanation for why snails prefer *I. anomala* and *B. arguta*, or why fewer snails than expected were found on *M. polymorpha* and *Cibotium* species. We recommend that further studies examine both how fungal communities differ among plant species and how leaf shape (as well as other leaf characteristics) may influence snail preferences. Currently, our knowledge of the diversity and abundance of epiphytic fungus on different Hawaiian plants is extremely limited. Therefore, we are unable to speculate if *I. anomala* and *B. arguta* are good hosts for fungal growth, the presumed food of these arboreal snails, or if these species promote growth of particular types of fungus that are preferred by snails. We have observed high quantities of fungus growing on the undersides of *B. arguta* leaves, especially when snails are absent. Snails in Hawaii may also prefer plants that offer protection from heavy rain, which is common at Mt Kaala. This hypothesis stems from numerous observations that snails prefer plant species with broad leaves and are commonly found on the undersides of these leaves (e.g. *B. arguta* and non-native ginger, *Hedychium* spp.) in wet forests of Hawaii (Brown *et al.*, 2003, 2006; Meyer, 2012; this study), which may protect them from heavy rain. In addition, we found that snails did not prefer plants with small leaves (e.g. *Vaccinium reticulatum* and, to a lesser extent, *Coprosma* sp. and *M. polymorpha*). However, there is nothing to suggest that leaves of *M. polymorpha* confer any less protection than *I. anomala*, since both are robust. Large *Cheirodendron trigynum* leaves are probably avoided because they flap vigorously with minimal wind.

While the mechanisms that underlie the similarities in snail plant preferences still need to be elucidated, the conservation ramifications are clear. First, these results indicate that many snail species may be negatively affected if the forest were to lose even a few species of plants. To test this conclusion further, we recommend that future experiments examine if growth and reproduction rates are higher when snails feed on preferred plants as opposed to those that were not preferred. Second, these results indicate that snail species are able to coexist using similar plant-host resources. Possible explanations include: (1) epiphytic fungal resources are not limiting, (2) different snail species use different resources on a single plant or (3) snail populations are not large enough to limit these resources. It seems that populations of all these land snail species are persisting on Mt Kaala in the absence of biotic mechanisms, such as competitive exclusion, that might limit their coexistence. Finally, most speciation in land snails in Hawaii has resulted from both dispersal (within and among islands) and vicariance driving allopatric diversification (Holland & Cowie, 2009). These findings suggest that preserving native habitats, especially those that have plant species supporting native land snail populations, and dispersal vectors may help to preserve the evolutionary processes that will help allow future diversifications.

ACKNOWLEDGEMENTS

We thank the Division of Forestry and Wildlife and Natural Area Reserve System (Department of Land and Natural Resources) for permits and the Oahu Army Natural Resource Program for access to the study site. All authors were supported by NSF grant DEB 1120906 or NSF DEB 0949061. In addition, we thank Robert H. Cowie and two anonymous reviewers for insightful comments.

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