Technical Report HCSU-044

A LANDSCAPE-BASED ASSESSMENT OF CLIMATE CHANGE VULNERABILITY FOR ALL NATIVE HAWAIIAN PLANTS

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Abstract

In Hawai'i and elsewhere, research efforts have focused on two main approaches to determine the potential impacts of climate change on individual species: estimating species vulnerabilities and projecting responses of species to expected changes. We integrated these approaches by defining vulnerability as the inability of species to exhibit any of the responses necessary for persistence under climate change (i.e., tolerate projected changes, endure in microrefugia, or migrate to new climate-compatible areas, but excluding evolutionary adaptation).

To operationalize this response-based definition of species vulnerability within a landscape-based analysis, we used current and future climate envelopes for each species to define zones across the landscape: the toleration zone; the microrefugia zone; and the migration zone. Using these response zones we calculated a diverse set of factors related to habitat area, quality, and distribution for each species, including the amount of habitat protection and fragmentation and areas projected to be lost to sea-level rise. We then calculated the probabilities of each species exhibiting these responses using a Bayesian network model and determined the overall climate change vulnerability of each species by using a vulnerability index. As a first iteration of a response-based species vulnerability assessment (VA), our landscape-based analysis effectively integrates species-distribution models into a Bayesian network-based VA that can be updated with improved models and data for more refined analyses in the future.

Our results show that the species most vulnerable to climate change also tend to be species of conservation concern due to non-climatic threats (e.g., competition and predation from invasive species, land-use change). Also, many of Hawai'i's taxa that are most vulnerable to climate change share characteristics with species that in the past were found to be at risk of extinction due to non-climatic threats (e.g., archipelago endemism, single-island endemism). Of particular concern are the numerous species that have no compatible-climate areas remaining by the year 2100. Species primarily associated with dry forests have higher vulnerability scores than species from any other habitat type. When examined at taxonomic levels above species, low vulnerabilities are concentrated in families and genera of generalists (e.g., ferns or sedges) and typically associated with mid-elevation wet habitats. Our results replicate findings from other regions that link higher species vulnerability with decreasing range size.

This species VA is possibly the largest in scope ever conducted in the United States with over 1000 species considered, 319 of which are listed as endangered or threatened under the U.S. Endangered Species Act, filling a critical knowledge gap for resource managers in the region. The information in this assessment can help prioritize species for special conservation actions, guide the management of conservation areas, inform the selection of research and monitoring priorities, and support adaptive management planning and implementation.

Introduction

The flora of the Hawaiian Islands is unique on a global scale for its high levels of endemism and represents the adaptive radiation of a small number of colonizing species over the past 30 million years (Price and Clague 2002). However, the combined impact of recent human-mediated invasive competitors, predators, and disease along with large-scale land-use change on isolated Hawaiian ecosystems is a well-recognized state of biodiversity crisis (Gemmill *et al.* 1998, Wagner *et al.* 1999, Sakai *et al.* 2002, Wood *et al.* 2007, Pratt and Jacobi 2009). The 109 historical plant extinctions, along with the 319 currently threatened/endangered native plant species in Hawaiʽi (37.4% of all endangered plant species in the U.S.), highlight the extremely challenging environment conservation practitioners face in a place considered by many as idyllic (U.S. Fish and Wildlife Service 2013). Within this context, conservation biologists and resource managers in the region are now concerned that global climate change will further impact the beleaguered Hawaiian biota (Sadler 1999, Pratt and Gon 2002, Ziegler 2002).

Over the next decades the Hawaiian flora is expected to be impacted by changes in temperature, precipitation, and sea level. By 2100 even the United Nations Environment Programme's Intergovernmental Panel on Climate Change (IPCC) mid-range A1B emission scenario is expected to result in a mean annual temperature increase of 2.5°C (Nakicenovic *et al.* 2000, Zhang *et al.* 2012), but with larger temperature increases in higher elevation areas that serve as important refugia from current non-climatic threats for many species (Huber *et al.* 2005, Giambelluca *et al.* 2008). A continuation of an archipelago-wide increase in drought is also projected (Oki 2004, Bassiouni and Oki 2012), especially in drier areas such as the unique alpine and subalpine Hawaiian ecosystems (Cao *et al.* 2007, Timm *et al.* 2013). Additionally, a continuing and accelerating rise in sea level may exceed 1 m by 2100, leading to increased coastal flooding (Church and White 2006, Jevrejeva *et al.* 2008, Fletcher 2009, Church *et al.* 2011).

The implications of these changes to the native Hawaiian flora are already increasingly evident. Recent trends in drought have been implicated in the population declines of the Haleakalā silversword, *Argyroxyphium sandwicense* ssp. *macrocephalum*, on Maui (Krushelnycky *et al.* 2013) and in the decrease of fruit production by *Sophora chrysophylla* trees, further threatening the native endangered bird species *Loxioides bailleui* (Banko *et al.* 2013). In spite of these and other examples, rigorous research detailing the specific impacts of climate change on Hawaiian terrestrial ecosystems is still sparse. In Hawaiʽi, the number of native plant species already under conservation concern, along with the multiple additional species that may be at risk due to climate change effects, is astounding. There are simply not enough research and monitoring resources to substantially advance our understanding of the ecological impacts of climate change without a rigorous concerted effort. To determine the potential impacts of climate change on individual species, research efforts have focused on two main approaches: assessing species vulnerabilities and understanding and projecting species responses to expected changes.

Assessing the Vulnerability of Species to Climate Change

Vulnerability assessments (VAs) are syntheses of available information used to determine the potential impacts of a threat (e.g., climate change) on species of interest (Glick *et al.* 2011). As syntheses, one of the reasons climate change VAs can be useful is that the generation of climate-relevant knowledge in many cases predates recent climate warming trends (e.g., demography from long-term plot data, studies about pollination, etc.). Hence a VA provides the opportunity to reanalyze, translate, and synthesize existing knowledge within the context of climate change. Assessments determine vulnerabilities by integrating diverse types of information by commonly relying on qualitative approaches such as expert ranking exercises or literature reviews, but may also involve more quantitative methods (Dlamini 2011, Giupponi *et al.* 2013).

Understanding Species Responses to Changes in Climate

Several studies attempt to clarify potential impacts of climate change on species by exploring the ways in which species respond to past, ongoing, or projected climate shifts. While species' evolutionary responses to climate change have received much attention, research has generally focused on potential shifts in distributions (e.g., migration into new climate-compatible areas), perhaps due to the relative ease and availability of data needed for addressing basic questions (Elith and Leathwick 2009, Miller 2010). In that regard, a species distribution model (SDM) is a common tool used to evaluate species' responses to change by identifying areas lost, gained, or retained between present and future scenarios or more nuanced shifts in habitat suitability. In this approach, researchers develop predictive models of a species' distribution based on its current habitat requirements and fit them to various projected climate change scenarios.

A Response-based Definition of Species Vulnerability to Climate Change

When the goal of research is to determine the impacts of climate change on species of interest, responses and vulnerabilities are two sides of the same coin, but this relationship has not been fully articulated. Typically, VAs attempt to determine species vulnerability by estimating species exposure to climate change, sensitivity to such changes, and their adaptive capacity to respond to change (Williams *et al.* 2008, Chin *et al.* 2010, Gardali *et al.* 2012, Foden *et al.* 2013). A few VAs rely on a definition of vulnerability that focuses directly on a chosen set of factors that are deemed relevant (Bagne *et al.* 2011). On the other hand, response studies often attempt to reach conclusions about overall species vulnerabilities, but tend to link vulnerability directly only to the responses considered in the research when in fact other species responses to climate are possible. For instance, several studies have commonly focused on the need of species to migrate as the primary determinant of vulnerability (Coops and Waring 2011, Trisurat *et al.* 2011). In order to fully understand the link between responses and vulnerability, a more holistic consideration of multiple responses is necessary (O'Connor *et al.* 2012).

In this assessment we define climate change vulnerability as the relative inability of species to exhibit the possible responses necessary for persistence under climate change. As such, this response-based definition of vulnerability comprehensively integrates previous work that focused on one or more of the responses (Holt 1990, Parmesan 2006, Dawson *et al.* 2011, Hof *et al.* 2011). To do this we have considered the full set of responses of species to climate change:

> **Migration response.** A species (or subset populations) follows its moving climate envelope through dispersal and establishment in new areas that are beyond the current distribution of the species (Huntley and Webb 1989, Parmesan and Yohe 2003, Root *et al.* 2003, Beever *et al.* 2011). For plants, this implies permanent colonization of new *climate-compatible areas* (i.e., areas within the range of climate conditions in which a species is known to occur) by populations rather than individual seasonal movements. For example, Huntley and Webb (1989) showed that the common hazel (*Corylus avellana*) migrated 1500 m/yr from the southwest towards the northeast during the Holocene. Similarly, meta-analysis of range boundaries for 99 species of birds, butterflies, and alpine herbs has shown that the range boundaries shifted toward the poles during the last 100 years at a rate of over 6 km per decade (Parmesan and Yohe 2003).
>
> **Microrefugia response.** Small populations of a species endure within an area that has become unsuitable at the macro-climatic scale (i.e., beyond the species' ability to tolerate) by individuals surviving in microrefugia that retain suitable climate characteristics

(Dobrowski 2011, Keppel *et al.* 2011, McLaughlin and Zavaleta 2011, Ashcroft *et al.* 2012a,b). For example, in response to climatic forcing over the last few decades, California valley oak saplings have been confined to microrefugia around water bodies which provide higher groundwater availability (McLaughlin and Zavaleta 2011). Topographically complex areas that are less exposed (e.g., deep valleys) are more likely to harbor such microrefugia (Daly *et al.* 2010, Dobrowski 2011).

Evolutionary adaptation response. A species (or subset populations) expands or alters its niche to withstand changes in climate by way of natural selection and other evolutionary mechanisms (Thomas *et al.* 2001, Figueirido *et al.* 2011, Hoffmann and Sgro 2011). For example, brown Argus butterflies (*Aricia agestis*) have switched to *Geranium* and *Erodium* host plant species, which had been in habitats too cool to support population growth before the 1980s (Thomas *et al.* 2001). Similarly, it has been shown that bush crickets in the last 20 years have exhibited higher frequencies of extra-long winged individuals that are better able to engage in long-range dispersal and colonization (Thomas *et al.* 2001).

Toleration response. A species (or subset populations) endures climate change with little or no adjustment because the changes are within the current environmental niche based on the magnitude of projected changes, current niche breadth, and plasticity of the species (Stillman 2003; Chown *et al.* 2004, 2007; Thuiller *et al.* 2005a; Calosi *et al.* 2008; Charmantier *et al.* 2008; Nicotra *et al.* 2010). For example, invasive springtail species are often more successful than indigenous counterparts because they are better at tolerating the increased desiccation brought about by warming temperatures (Chown *et al.* 2007). Niche breadth is an important factor in allowing species to tolerate the effects of warming. A study of 1200 European plant species showed that boreo-alpine species, which occupy the cold margin of the temperature gradient and have a narrow niche breadth, are highly sensitive to climate warming (Thuiller *et al.* 2005b). Another factor allowing this response is the phenotypic plasticity of the species (Charmantier *et al.* 2008). A 47-year population study of the great tit (*Parus major*) in the United Kingdom revealed that female birds were able to time their breeding each year to match the timing of a host of different insect prey species and thus tracked a rapidly changing environment closely for nearly fifty years (Charmantier *et al.* 2008). Plants also employ phenotypic plasticity to tolerate climate change. A meta-analysis showed that 87% of plant species show shifts in phenology towards earlier spring times (Nicotra *et al.* 2010).

The integration of species responses and vulnerability addresses common limitations of the two approaches with respect to climate change. First, it allows for a clear integration of research on individual responses into a comprehensive framework, including common species distribution model studies. Second, it allows for the potential validation of vulnerability results since responses are, at least in principle, observable as opposed to vulnerability, sensitivity, and adaptive capacity which are conceptual. Third, a response-based assessment allows for an easier integration of climate change vulnerability with other non-climatic threats as these threats can be directly related to altered species responses to climate (e.g., land cover fragmentation reducing the ability of species to migrate). Lastly, the ability of a species to exhibit any given response has much clearer management implications than differences in sensitivity, exposure, and adaptive capacity.

Scope of Landscape-based Climate Change Vulnerability Assessment

In this assessment, we quantified the vulnerability of each species by estimating the relative ability of species to persist under projected climate change by tolerating expected changes, enduring in microrefugia within areas where compatible climate is lost, and/or migrating to new climate-compatible areas. For this assessment we did not consider the fourth possible response, evolutionary adaptation, since we did not have relevant data that could be analyzed for each species (the subject of future research efforts).

Although VAs and response studies such as SDMs are commonly used to determine the ecological impacts of climate-change, they have largely been used separately (Lloret and González-Mancebo 2011, Rowland *et al.* 2011). As a first attempt to operationalize our response-based definition of species vulnerability, we integrated SDMs into a VA framework using a Bayesian network (BN)-based species vulnerability model. An advantage to the BN model is that it can be updated with improved models and data, setting the groundwork for more refined analyses in the future. More specifically, we used the BN species vulnerability model to estimate the ability of a species to exhibit each of the responses required for it to persist under a changing climate in probabilistic terms. For each of the responses considered, we estimated the relative probability of the species exhibiting the response based on a set of relevant landscape factors related to the amount, quality, and distribution of projected areas lost, gained, and maintained in climate-compatible areas between now and 2100. Lastly, we used these relative response probabilities for each individual species to determine overall climate change vulnerability by using a response-based species vulnerability index.

We have applied this novel methodology to quantify the climate change vulnerability of native Hawaiian plant species to demonstrate patterns of vulnerability with respect to habitat associations, conservation status, and other characteristics. This species vulnerability assessment is possibly the largest in scope ever conducted for the entire country, with over 1000 species considered, 319 of which are listed as either endangered or threatened under the U.S. Endangered Species Act.

METHODS

Estimating the Ability of Species to Respond to Climate Change

Most VAs rely on qualitative approaches, such as expert ranking exercises or literature reviews, to integrate diverse types of information which yield a static picture of the state of knowledge for a given species that cannot be easily updated with improved knowledge (Giupponi *et al.* 2013). For the current assessment we alternatively used a BN model to integrate information related to the responses of species to climate change in a more dynamic approach (Marcot *et al.* 2006, Uusitalo 2007, Catenacci and Giupponi 2010, Aguilera *et al.* 2011). The BN model approach provided a way to integrate a large set of information regarding interacting factors into a set of resulting probabilities that denote the relative ability of species to exhibit each of the responses to climate change considered in the analysis.

Bayesian networks are probabilistic graphical models that represent factors within a system or issue of interest as nodes connected by arrows indicating causal or correlation links. Factors in a BN typically have a set of discrete states; for example, the factor ‘projected change in climate envelope area’ in our model has three states: large decrease, medium decrease, and small decrease or increase. The links between nodes in a graphical model are directional, indicating the flow of causal information through the model. Nodes that are downstream also have states;

in the absence of data on the true state of that node, the value is modeled as a probability of being in each state, conditional upon the states of the immediately 'upstream' nodes (i.e., parent nodes). This structure allows for the propagation of information across the model, whereby the likely state of each node is estimated (Uusitalo 2007, Bensi *et al.* 2013).

BN models approximate the way human reasoning works under uncertainty (Jayasurya *et al.* 2010, Kaedi and Ghasem-Aghaee 2012), and thus have been applied in fields such as medical diagnosis and computer science to replicate or simulate expert judgment (Jayasurya *et al.* 2010, Villordon *et al.* 2010). These BNs simulate complex reasoning by considering the relationships between states of a given factor in the network to all other states of directly related factors through the specification of conditional probabilities (Marcot *et al.* 2006, McNay *et al.* 2006). For example, in a hypothetical BN model, a node 'species dispersal capacity' (with states low and high) is determined by a single upstream node 'seed size' (with states small and large) and a set of conditional probabilities to specify the probability of observing a high-dispersal capacity for a species if we know the species has small seeds. In this way, information about the state of any node in the network can be used to update the probabilities of particular states of all other related nodes in the network.

Response-based Species Vulnerability Indicator

Because these species responses to climate change occur at the population scale, it is possible that a species may exhibit a combination of these responses across multiple populations (e.g., a primary microrefugia response at the trailing edge and a migration response at the leading edge of the distribution of a species). However, with a decreasing ability of species to tolerate projected changes, the combination of the other responses to climate (migrate or endure in microrefugia) become increasingly important for the species to persist. In effect, the combined ability of a species to exhibit any of these responses should be inversely related to its vulnerability to climate change. Hence, to summarize our probability estimates of each of the responses considered in the BN model into a single vulnerability metric, we devised a simple species vulnerability indicator that encapsulates the expected behavior described above:

$$\text{Vulnerability} = [1 - \text{mean}[\text{p}_{\text{microrefugia}} + \text{p}_{\text{migration}}]] \times [1 - \text{p}_{\text{toleration}}] \tag{1}$$

This formulation yields a vulnerability score that is inversely related to the ability of species to exhibit a combination of the responses considered and follows from the rationale that both microrefugia and migration responses are more important for species that are less likely to tolerate expected changes in climate (i.e., whether or not a species has great migration potential is less meaningful if it is very likely to tolerate expected changes within its current range). As the response probabilities ranged from 0 to 1, the vulnerability indicator was similarly scaled, such that a score of 0 meant the species was not vulnerable at all and a score of 1 meant the species was extremely vulnerable to climate change (Table 1). Also note that this indicator can be easily expanded in future assessments to consider an adaptation response.

Linking Species Distribution Models and Species Responses to Climate Change

To define the extent of current and future climate-compatible areas for each plant species, we used a rectilinear surface range envelope (RSRE) approach, using elevation as a surrogate index for mean annual temperature and a moisture index as an indicator of plant available moisture (detailed description of methods below; Nix 1986, Busby 1991, Price *et al.* 2012). The

Table 1. Relationship between species responses to climate change and vulnerability indicator behavior.

		Responses				
Example vulnerability scenarios	Expected vulnerability	Microrefugia	Toleration	Migration	Vulnerability indicator	Transformed vulnerability indicator
No change between baseline and future envelopes; good habitat quality	Very low	0	1	0	0	0
Substantial overlap; good habitat quality	Low	0.25	0.75	0.25	0.188	0.39
Some overlap; good habitat quality	Medium	0.5	0.5	0.5	0.25	0.43
Complete envelope mismatch; good habitat quality	High	0.5	0	0.5	0.5	0.58
No future envelope; bad habitat quality	Extremely high	0.2	0	0	0.9	0.83

resulting set of climate envelopes delineates all areas in current and future climate that fall within the full range of climate conditions under which the species is known to occur. As such, these climate envelopes are simple SDMs that approximate the climate-based fundamental niche of a species. Given the simplicity of the methodology, these models may appear to be 'optimistic' when compared to the actual occurrence of species across the landscape, since they have no model-based omission error but a high commission (i.e., false positive) error.

Using these climate envelopes, for each species we defined the **Toleration zone** as areas of overlap between current and future climate envelopes where individuals or populations may be able to tolerate projected changes in climate (Figure 1). The **Microrefugia zone** included current climate-compatible areas that are projected to become incompatible by 2100, but where the species might persist over the long term in micro-climatic refugia created by structurally complex habitat and related micro-climatic variability (Ashcroft 2010, Dobrowski 2011, Ashcroft *et al.* 2012b, Temunović *et al.* 2013). Lastly, the **Migration zone** included areas beyond a species' current climate envelope but that by 2100 become new climate-compatible areas into which a species must migrate to in order to persist under climate change (Johnstone and Chapin 2003).

Vulnerability Factors Considered in Assessment

We determined the probability that a species will exhibit any of three responses considered (i.e., tolerate, endure in microrefugia, or migrate) by considering zone-specific factors related to habitat area, quality, and distribution. To derive the response probabilities for each species using the species vulnerability model, we considered landscape-based factors related to species habitat area, quality, and distribution in relation to the three response zones considered. First,

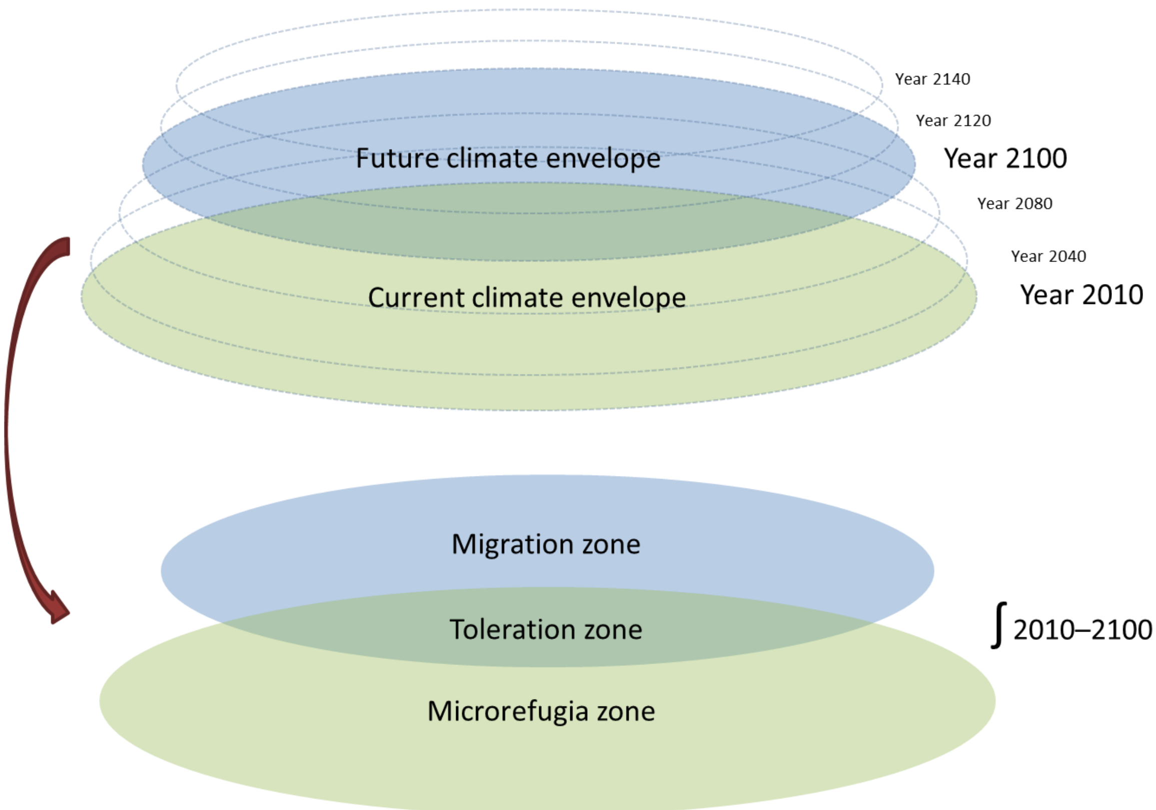

Figure 1. Diagram of the link between species distribution models and species responses to climate change. Dotted lines represent the continuous nature of shifts in climate envelopes, which our analysis represents as two time steps (2010 and 2100). A microrefugia response is mainly expected in areas of lost climate compatibility by 2100; a toleration response is mainly expected in areas of continuous climate suitability between now and 2100; and a migration response is mainly expected in areas that have suitable climate in the future but not in the present.

we evaluated the characteristics that determine its effective habitat area and habitat quality for the three response zones for each species. For this analysis, we estimated **habitat area** as the total zone area minus permanently unsuitable habitat (e.g., urban areas) and **habitat quality** using characteristics that would make the habitat more or less suitable for the individual plant species within each response zone. Second, for each species we also considered **habitat distribution** characteristics that were relevant to all responses considered. Zone habitat area, zone habitat quality, and overall habitat distribution of each species were evaluated by considering a suite of factors described below.

Habitat area factors
For each response zone, the effective habitat area was defined by the total extent of the zone minus factors that make the area unusable by the species in question, either now or in the future at 2100. These factors included distribution of young lava flow areas (for non-pioneer species only; see logical factors below), areas subject to inundation from rising sea level, and heavily modified areas under irreversible land cover change (e.g., urbanization).

Lava flow areas—For non-pioneer species, young lava flows were subtracted from the total response zone, since these areas are unlikely to contribute any substantial amount of habitat for most native species between now and 2100. We considered the distribution of young lava flows based on an analysis by Price *et al.* (2007) that identified substrate ages that generally have poorly developed soil that support few species related to geographical differences in plant available moisture.

Area lost to sea-level rise—Because flooding or erosion from sea-level rise can cause irreversible destruction of habitat for coastal species, areas lost to sea-level rise between now and 2100 were subtracted from the total response zone area. Inundation due to sea-level rise was modeled using the U.S. Geological Survey's 10-m resolution Digital Elevation Model (DEM) coverage to generate a simple 1-m sea-level rise (SLR) 'bathtub' model for the entire archipelago. These flooded areas were then subtracted from the response zones generated for each species. Unfortunately, the lack of bathymetric data for the archipelago precluded the assessment of the compounded impacts of SLR with wave run-up and storm surge (Reynolds *et al.* 2012).

Heavily modified areas—Areas classified as heavily modified (i.e., urban or agricultural lands) were subtracted from the response zones of each species analyzed, based on the assumption that these areas would continue to be utilized in this condition. To define these highly degraded areas, we used a habitat quality map generated by Price *et al.* (2007); this map is based on the Hawaii Gap Analysis Program (HIGAP) land cover classification (Gon 2006) and the Agricultural Land Use Map (ALUM) developed by the Hawai'i Department of Agriculture (http://planning.hawaii.gov/gis/). This habitat quality map classifies all land cover into three categories: native, invasive-dominated, and heavily modified. We use the 2007 estimate of habitat quality as an indicator of habitat quality for the entire period of the assessment, since there are no available land cover future projections for Hawai'i.

Habitat quality factors

For each response zone, habitat quality was defined by several factors, including the percent of the zone in native-dominated cover; the amount of fragmentation within the zone; the invasibility of the zone by highly detrimental non-native species; and the amount of habitat currently designated for conservation protection within the response zone. For each of these habitat quality factors, to reduce correlations among habitat area and quality metrics, we considered effective habitat area versus total habitat area by excluding all areas in heavily modified habitat, projected to be lost to sea-level rise, or in young lava flow areas (for non-pioneer species only).

Area in native cover—Given the importance of native habitat in the conservation of native plant species, the availability of native-dominated areas (as opposed to non-native dominated areas) may be an important factor to determine the overall habitat quality for native species. To define native-dominated areas, we used a map of current habitat quality generated by Price *et al.* (2007, described above) to delineate all native-dominated areas in Hawai'i. We estimated the proportion of each species response zone that overlapped with these native-dominated areas as indicators of habitat quality.

Fragmentation—Fragmented landscapes may make a species more vulnerable to changes in climate by constraining movement, limiting gene flow, or reducing effective population size (Andrén 1994, Opdam and Wascher 2004, Thuiller *et al.* 2005b, Fischer and Lindenmayer 2007, Garcia and Chacoff 2007, Herrera *et al.* 2011). To define a simple fragmentation metric that was not influenced by species-specific differences in climate-envelope size, we calculated the ratio between edge and total effective habitat area available within vegetated portions of a species response zone. This index will be close to 1 for species that have most of their available habitat near edges. Edge areas were defined as areas within 100 m of non-vegetated portions of a species' climate envelope (Lynch and Whigham 1984, Reed *et al.* 1996, Grashof-Bokdam 1997). Non-vegetated areas were excluded from the analysis using the Landfire vegetation classification data (Rollins 2009).

Invasibility—Ziegler (2002) estimated that, of the approximately 10,000 plant taxa introduced to the Hawaiian Islands, only a small subset (around 90) are regarded as extremely harmful due to competitive ability, ecosystem modification, and biogeochemical habitat degradation. Using the additive invasibility index developed by Vorsino *et al.* (in review) we determined the invasibility of each species' response zones by non-native plant species. The additive invasibility index is a geographic index that highlights areas that are highly suitable for 17 invasive habitat-modifying plant species in the present and future. The index is the result of a predictive analysis that uses a compilation of each species' ensemble SDMs projected onto current and future (2100) bioclimatic and topographic variables.

Habitat protection—Protected conservation areas are important reservoirs of local biodiversity (Chape *et al.* 2005, Vellak *et al.* 2009, Mokany *et al.* 2013) where long-term protective designation may safeguard certain species from the combined effects of climate change and other existing threats such as land-cover change, invasive species, etc. (Beier and Brost 2010, Mokany *et al.* 2013). Habitat protection for each response zone was comprised of two underlying factors: total area under protective designation and areas that are intensively managed by fencing out and removing feral ungulate populations.

Despite the claims of reduced relevancy of protected areas for species conservation under climate change (Hannah *et al.* 2002, 2007; Caro *et al.* 2009; Mora and Sale 2011; Wiens *et al.* 2011), species and communities within designated protected areas may be more capable of responding to the shifting threats brought about by climate change than species in unprotected areas (Malhi *et al.* 2008, Hole *et al.* 2009). Even for protected areas that are not managed, research shows protective status may have a general positive impact on local biodiversity (Vellak *et al.* 2009, Mora and Sale 2011, Mokany *et al.* 2013). As such, habitat protection within each species' response zone was estimated by calculating the proportion of the effective habitat within the zone that overlapped with areas under protective designation (e.g., Nature Conservancy lands and other protected land trusts; state natural area reserves, parks, wildlife sanctuaries; national parks; and wildlife refuges).

Because native Hawaiian plants lack common defenses to browsing and trampling, damage from introduced feral or domesticated ungulates is one of their greatest threats (Carlquist 1980, Ziegler 2002). Therefore, the development of large ungulate-free areas may be one of the most valuable conservation management strategies in Hawai‵i. For each species' response zone, we quantified the proportion of the effective habitat area that was protected by ungulate fencing.

Zone habitat quality factors

In addition to the habitat quality factors considered for all response zones, we also considered factors particular to each zone.

Fraction of occurrence points within the toleration zone (toleration zone habitat quality)—The fraction of known current occurrences of a species within the toleration zone was considered indicative of the portion of individuals of a species that could make use of this zone to persist during climate shifts. All of the occurrence points are within the current climate envelope since they were a subset of the data used to define it. To obtain a complete snapshot of known locations for native species across the archipelago, we compiled and merged point-location datasets from all known available sources that had been collected since 1970. This included, but was not limited to, the Hawaiian species database from the Hawaii Biodiversity and Mapping Program (2010); the Hawaiʽi listed species shapefiles from the U.S. Fish and Wildlife Service (2012); the Hawaii Forest Bird Survey plant data (2012); and the Army Propagation database from the Oʽahu Army Natural Resources Program (2011). All data were screened for taxonomic and geopositional errors. After screening the data, we included a total of 48,866 points from 689 species (63.5% of all native plant species). Given that the majority of points collected were related to monitoring of species under conservation concern (i.e., endangered, rare, and vulnerable species), only points for these species can be considered to be nearly complete representations of species occurrences (60% of species in the dataset versus 44% of all native plant species). Despite these limitations, the point data available were still adequate for this coarse geographical analysis for species with at least four location points, because we simply calculated the proportion of points falling within the toleration response zone relative to the total number of points where the species were known to occur.

Topographic and climatic diversity (microrefugia zone habitat quality)—Topographic and climatic variability were considered for the microrefugia zone since areas within steep environmental gradients or with diverse micro-climates may possess microrefugia that may remain suitable for a particular species even when the regional climate does not (Ashcroft *et al.* 2009, 2012b; Dobrowski 2011). Topographic and climatic diversity were measured by considering the steepness of environmental gradients within a species' microrefugia zone and the topographical diversity that may allow for micro-climates to occur within a context of macro-climatic changes. Methods for each of these sub-factors are defined below.

Precipitation gradient (topographic and climatic diversity)—Using a 250-m resolution map of precipitation for Hawaiʽi (Giambelluca *et al.* 2013), we calculated the slope of precipitation as the percent change in millimeters of precipitation by metric distance. An average precipitation gradient value was calculated for the area of each species' microrefugia zone.

Average slope (topographic and climatic diversity)—As a proxy of temperature gradients across the landscape, we computed slope at 10-m spatial resolution for the entire archipelago. Slope is a reasonable measure of temperature gradients since preliminary analyses showed elevation and temperature are highly correlated ($r = -0.987$ at 100 m spatial scale). The average slope value was then calculated for each species' microrefugia zone as a measure of the steepness of the temperature gradient within that zone.

Aspect variability (topographic and climatic diversity)—Aspect diversity has been considered in continental studies of micro-climatic variability and refugia (Ashcroft *et al.* 2009, 2012b; Dobrowski 2011), but in Hawaiʽi the change in aspect is especially relevant because small changes in aspect may lead to large differences in wind, solar radiation, and precipitation patterns. To calculate aspect diversity we calculated the average of the standard deviations of the cosine and sine of aspect within the microrefugia zone for each species using a 10-m resolution DEM.

Slope variability (topographic and climatic diversity)—Topographic complexity may have a role in the formation of a species' microrefugia by affecting the dissipation of temperature and precipitation in a specific locality (Ashcroft *et al.* 2009, 2012b; Dobrowski 2011). As a simple measure of topographic complexity, using a 10-m resolution DEM we calculated the variability in slope as the average of the standard deviation of the slope within the microrefugia zone for each species.

Distance between current and future climate envelopes (migration zone habitat quality)—The greater the distance between current and future climate envelopes, the greater the inaccessibility (and hence utility) will be of the migration zone to current populations. We quantified the distance between envelopes as the average minimum distance between each pixel in the current envelope to the closest pixel in the future envelope. We then divided this distance metric by the square root of the area of the current species' envelope to control for area effects, in which large-ranged species naturally have greater absolute distance between current and future envelopes.

Landscape connectivity (migration zone habitat quality)—Similar to distance between current and future climate envelope, landscape connectivity was considered a determinant of migration zone habitat quality since less accessible future climate-compatible areas are less useful for the persistence of a plant species. Anthropogenic and natural barriers to species movement across the landscape may prevent a species from following its climate envelope (Tyler 2000). However, as the sum effect of landscape connectivity in islands in the context of species invasion and climate change is unknown, we recognized this as a potentially important factor in the vulnerability model but did not measure it. As such, this factor is included simply as an unknown factor contributing to the uncertainty in migration zone quality in the vulnerability model.

Habitat distribution factors

Factors in this group are relevant to the overall climate change vulnerability of a species beyond individual response zones. Landscape-distribution factors include the number of biogeographic regions in which the species is present by 2100, indicating how widespread a species is projected to be; the proximity of a species to the maximum elevation of available habitat, indicating how pressed a species may be against the limits of available habitat; projected change in total climate envelope area between current and future climate envelopes, indicating overall changes in available habitat for individual species; and the pattern of current occupancy of a species within its current climate envelope, indicating how well a species fills its current climate envelope.

Number of future climate-compatible biogeographic regions—The fact that a large portion of native Hawaiian flowering plant species are restricted to single volcanic mountains (Price 2004) suggests these are meaningful biogeographic regions that may separate interacting communities and distinct populations of individual species. Hence, beyond the total extent of areas climatically compatible for a species, it should be important to consider the distribution of these climate-compatible areas across recognized Hawaiian biogeographic regions. Following careful review of all available historical records for species occurrence across distinct biogeographic regions, current and future climate envelopes for all species were constrained to those regions in which the species was known to have occurred in the past (Price *et al.* 2007). Because a species may lose all climate space within a given biogeographic region, we counted the number of these regions that overlap with the future climate envelope of a species as indicative of biogeographic distribution of the species between now and 2100.

Proximity of species to maximum elevation of available habitat
In isolated high islands where latitudinal or longitudinal shifts in species distribution are not possible, the range of possible movement along elevational gradients is a key to understanding the prospects of a species under continuing shifts in climate. This is especially the case for projected increases in global temperature that imply an upward elevational shift for island species. To determine how close species may be edging towards the maximum elevation of available habitat, we compared each species' increase in mean elevation between the current and future climate envelopes to the maximum elevation of vegetated areas within each biogeographic region in which the species was known to occur. We did this by calculating the percentage of the biogeographic regions in which the predicted elevational increase between the present and 2100 is expected to be larger than the suitable elevational range above the 2100 climate envelope mean elevation. To estimate the maximum elevation of vegetated areas within each biogeographic region, we calculated the 95th percentile of the elevation of all areas belonging to forest, shrubland, or grassland cover using Landfire cover classes.

Projected change in total climate envelope area—The overall amount of climate-compatible area that a species can use at any given time has clear implications to its long-term persistence. We calculated the proportional change in climate-envelope area for each species by dividing the area of the future climate envelope by the area of the current climate envelope. Thus, a value of 1 would indicate no change in the total envelope area, but that does not necessarily indicate a complete overlap in envelopes between now and 2100.

Pattern of current occupancy within current climate envelope—Since many factors may lead to a discrepancy between the climate envelope and the actual distribution of a species (e.g., competition), it is crucial to understand the actual occupancy of the species within its climate envelope. Although we had a large number of location points for species that were used to determine the distribution of individuals across broad response zones, the *ad hoc* collection of points precluded us from conducting a refined analysis of geographical distribution of populations within compatible-climate areas. Therefore, this factor was included simply as an unknown factor in the vulnerability model.

Logical factors
To accommodate the complexity of relationships among factors in our model, we included a small number of factors that add simple logical behavior to the vulnerability model. Among these were some species traits that refined the impact of spatial factors used in the analysis.

Species persistence in non-native habitat—The suitability of compatible-climate areas for a species should reflect the fact that many native species have very limited distributions within non-native communities across the archipelago. Experts on native flora were asked to identify all species that appear to persist indefinitely within non-native habitats. Experts categorized all native species independently and then met to discuss their discrepancies. After agreeing on a final list, a wider set of experts reviewed the list but found no objections to the resulting classifications. For species deemed able to persist, weights of relevant factors in the model (i.e., percent of area in native-dominated cover and landscape invasibility) were reduced to reflect the wider niche of these species.

Pioneer species status—Especially on the islands of Hawai'i and Maui, the effective habitat area within compatible climate for a species should account for a species' ability to populate young lava flow areas that few species can inhabit. We used a dataset that classified all species as pioneer or non-pioneer using a binary status for each species. If a species was not identified as a pioneer, young lava flow areas were subtracted from the effective habitat area for the species.

Species with no overlap between current and future climate envelopes—Species with no overlap between current and future climate envelopes are unlikely to easily tolerate expected changes in climate within their current climate envelope. This limitation means they must either endure in suitable microrefugia within their current envelope or move to newly available climate-compatible areas to avoid extinction. Species that were estimated to overlap less than 1% of their current climate envelope with their projected future climate envelope were classified as 'no-overlap' species. For these species, habitat quality within the toleration zone was switched to an unsuitable state in the model as there is effectively no area within that zone for the species to utilize.

Species with no future climate envelope—Species with no future climate envelope represent an extreme case of vulnerability in which no projected suitable climate areas exist for the species to persist in the future. Species that are estimated to have more than 99% of their current climate envelope lost by 2100 were classified as 'wink-out' species. For these species, habitat quality within the toleration and migration zones were switched to an entirely unsuitable state in the model, as there is effectively no area of overlap or expansion in suitable climate between now and 2100 for these species to utilize.

Creation and Parameterization of Bayesian Network Based Species Vulnerability Model

The initial construction (i.e., specification of relevant factors in a system and their relationships) and parameterization (i.e., definition of the conditional probabilities) of a BN model can be done using either data-driven or expert-based approaches (Catenacci and Giupponi 2010, Pitchforth and Mengersen 2013). Given the small number of studies that quantitatively explore the relationship between observed responses of species to climate change and factors thought to contribute to these responses, we used an expert-based approach to construct and parameterize the first iteration of our model. This will serve as a basic structure for future improvements based on the rapidly growing climate-change literature.

To start the species vulnerability model, we constructed an initial model describing the relationships among spatial factors relevant to species' responses to climate change. Factors of interest and their relationships were identified through multiple discussions among authors and other experts in Hawaiian ecology and conservation biology. In these non-structured discussions we considered other species' VAs and relevant primary research that linked vulnerability of species to landscape-related factors within the context of island biology and conservation (Hill *et al.* 2001, Warren *et al.* 2001, Chen *et al.* 2009, Zhu *et al.* 2011, Forero-Medina *et al.* 2011). During this model-building process we first reviewed a large number of relevant SDMs, VAs, and primary research papers to identify the relevant landscape-related factors. We then defined causal or correlative relationships among all factors using directional arrows among *parent* (independent) and *child* (dependent) nodes in the model (e.g., 'slope variability' is one of the parent factors for the 'topographic diversity' factor; the 'topographic diversity' factor is one parent of the 'microrefugia zone habitat quality' factor, etc.).

Once all relevant factors were included in the model and their relationships represented by directional links in the model, we defined a minimum number of states necessary to describe the variability of each factor with respect to all species considered (e.g., the factor 'proximity of species climate envelope to top of available habitat' can either be 'close' or 'far'). These states must be all-inclusive and thus have a cumulative probability of one (i.e., there are no other possible states). Following the guidelines of Marcot *et al.* (2006), we then limited the number of discrete states for each factor in the model to allow for simpler propagation of probabilities across the model.

To reduce the amount of subjectivity used in the assessment, we discretized the continuous values from calculated metrics to factor states based on the distribution of values from all species. In this way, factors with three states (e.g., low, medium, and high) are simply defined by the 33rd and 66th percentiles of the distribution of the species data. So information regarding differences in habitat quality among response zones would not be lost, these thresholds were calculated based on values for the entire current and future range. As parameterized, a species with no known information and uniform priors for all factors in the model would have an even chance of exhibiting any of the three responses considered in the vulnerability model. Thus, we consider resulting response probabilities in the model in a comparative sense (i.e., relative probabilities) to determine which species are more or less vulnerable, and do not take these probabilities as accurate estimates of observing a given response for any given species.

In the absence of the primary research detailing the mechanistic relationships among model factors, we parameterized the model using conditional probabilities devised under a set of simplifying assumptions. Firstly, we assumed that all parent factors had equal importance in determining the state of their common child factor in the model (e.g., the relative importance of all factors determining migration zone habitat quality was weighted equally). However, for the three responses defined by zone habitat area, zone habitat quality, and overall species habitat distribution, species habitat distribution (the common factor among the three) was weighted as one-third of the weight of both zone habitat area and quality to prevent triple-weighting it, which would have given it a disproportionate effect on the model. Since the assumption of equal weights of parent factors was a relatively large assumption, we compared vulnerability results from this equal-weight model with results from an alternative model with factor weights that more closely reflected the relative factor importance ascribed by experts.

We also assumed that the impacts of parent factors on a child factor are independent, meaning that the state of one parent factor does not influence the state of other parents. The exception to this assumption was the use of logical factors that did not directly change the probability of child factor states but altered the relative weights of other parent factors. For example, for species categorized as being able to persist in non-native habitat, the proportion of native cover or the habitat invasibility were not as important in defining habitat quality.

Lastly we assumed that changes in the state of a parent factor resulted in linear and additive impacts on the state of the child factor. As an example, consider a parent factor ‘habitat fragmentation’ with three states (low, average, and high) that determines 25% of the probability that a child factor ‘habitat quality’ will be in a favorable or unfavorable state. Low fragmentation state (the ‘best’ condition) in the parent state will add the full 25% to the probability of a favorable habitat quality state in the child node. Average fragmentation will only add 12.5% to the overall probability of a favorable habitat quality state, and high fragmentation will not contribute at all to the probability of a favorable habitat quality state. In effect, the vulnerability model under these simplifying assumptions can be thought of as a null model that can be compared with subsequent improved or more complex model iterations (e.g., multiplicative, interactive effects).

For a BN model, prior probability distributions are required that specify the background or average state of factors (Marcot *et al.* 2006, Bensi *et al.* 2013). To calculate the priors for each factor, we used the frequency distribution of all species combined. For example, the priors for the factor 'habitat fragmentation' were the percentages of the species that had low, medium, or high fragmentation. Since the thresholds for discretizing continuous landscape factors into states were based on the distribution of the data, in practice these priors approximated uniform distributions across all states for most factors. This uniform prior can be considered to be 'uninformative' in the Bayesian sense, as it represents a neutral starting point as a basis for estimating relative vulnerability of each species. Appendix 1 includes diagrams of the complete BN model of species vulnerability to climate change, including all factors, their relationships, states, and prior probabilities.

From Landscape Metrics to Climate Change Responses

The BN model was implemented in the GeNIe (Graphical Network Interface) Version 2.0 software package, which allows network models to use a graphical user interface (Decision Systems Laboratory 2012). Model files are saved in an extensible markup language (XML) format, which we read into the statistical application R using the XML library (Lang 2012, R core team 2012). The network models were then translated into the format used by an R-language categorical network library (Balov and Salzman 2011). The landscape metrics output from ArcGIS were discretized (as described above) for each model node where the information was available. For each species, the known model nodes were set to their appropriate states, and the three response nodes were used to summarize the species' vulnerability: the probability of favorable vs. unfavorable vulnerability due to tolerating change, enduring in microrefugia, or migrating.

Vulnerability Indicator Transformation

One drawback of the vulnerability indicator formulation we used is that multiplying two terms between 0 and 1 will naturally yield a distribution of indicator values that is skewed to the right. To eliminate the skew of the resulting vulnerability indicator values, we applied an arcsin transformation, which still preserved the original characteristics of the indicator (i.e., values bounded by 0 and 1) yet allowed for better discrimination among small values:

$$\text{Vulnerability}_{\text{transformed}} = \text{arcsine}(\text{Vulnerability}^{1/3} \times 2/\pi) \qquad (2)$$

Contrary to standard arcsine transformations that use the square root of values, we found that a cube-root transformation yielded a distribution closer to the standard Gaussian distribution. All vulnerability indicator values in this manuscript include this transformation (Table 1).

Vulnerability Contrasts

We compared estimated vulnerability scores from the model across multiple species groupings (e.g., genera, families, conservation status) using ANOVA tests and post-hoc Tukey tests. Only groups with $n \geq 20$ were considered to avoid undue within-group variance. For each comparison, a goodness-of-fit test was made to evaluate within-group normality of data distribution. If the data failed the normality test, we sequentially applied data transformations (ln+1, square root, cube root) until normality was achieved. If transformations failed to yield a normally distributed data set, these data were ranked prior to conducting the ANOVA, making this analysis equivalent to performing nonparametric tests. ANOVA comparisons that resulted in significant differences among groups were subjected to a post-hoc Tukey test to determine which groups were statistically different from each other.

Species Vulnerability Model Evaluation

To evaluate the performance of the BN model, we compared the model vulnerability scores with climate change vulnerability rankings generated by a group of native plant experts. The 32 test species varied widely in distribution, elevation, and moisture regime. Experts were asked to indicate the relative landscape vulnerability for each of the test species with which they were familiar. For each species, experts indicated a vulnerability rank from a five-point scale (very low, low, medium, high, very high) and were asked to note the main factors that contributed to their ranking choice. Experts could also indicate whether a reasonable informed judgment could be made for the species based on what is known about the species.

Species Distribution Model Methods

To define the extent of current and future climate-compatible areas for each plant species, we used a rectilinear surface range envelope (RSRE) approach, using elevation as a surrogate index for mean annual temperature and a moisture index as an indicator of plant available moisture (Nix 1986, Busby 1991, Price *et al.* 2012). This RSRE approach was preferred over other SDM approaches since test runs show its simpler fit produces better results for species where location data are very limited (a substantial portion of the species considered).

Given the limited latitudinal range across the archipelago, the use of elevation as a surrogate measure of temperature is well justified (correlation between the two at a 100-m scale is very high, $r = -0.987$). In this RSRE approach, the extremes of distributions of a species with respect to each environmental variable were calculated based on available location data for the species (i.e., for species 'x', all known records occurred in places with mean annual temperatures between 12 and 19°C). After defining these extremes, we mapped areas that fell within the defined extremes for the two climate indicators using both current and future climate maps. Price *et al.* (2007) provides a comprehensive description of the model methodology. Future climate indices were derived from calculating the change between year 2000 and 2100 climates based on the AR4 SRES A1B emission scenario (Nakicenovic *et al.* 2000) and multi-model mean from CMIP3 global circulation models (Zhang *et al.* 2012). The moisture index was updated by considering changes in precipitation based on statistically downscaled precipitation projections (Timm and Diaz 2009) that show a consistent linear relationship between precipitation change and mean annual temperature. We used a linear fit that represents a 6% decrease in precipitation for the driest areas of the state and no change in the wettest areas to modify current moisture index values. For temperature, we used annual temperature regional projections (Giambelluca *et al.* 2008) that suggest a 1°C increase at sea level and a 3°C increase at 4200 m by 2100 to modify our elevation-based temperature index (J. Price, University of Hawai'i at Hilo, unpublished data). We developed all species maps and subsequent analyses for the main Hawaiian islands (Hawai'i, Maui, Kaho'olawe, Lāna'i, Moloka'i, O'ahu, Kaua'i, and Ni'ihau).

Dynamic Updating of Analysis

We performed all original analyses and modeling under a modeling and programming philosophy that easily allows for inevitable updates and improvements, given the constant expansion of climate-related information and methods. Hence, the entire methodology that calculated the landscape factors considered in the BN vulnerability model used Python scripting with ArcGIS that allows for updates and recalculations with minimal effort. Similarly, steps developed to integrate the spatial results into the BN model and subsequent output generation (graphs, tables, maps) were developed using approaches that can be easily updated with new data.

Assessment Assumptions and Limitations

As with any semi-quantitative vulnerability assessment, there were major assumptions and limitations that underlie the analysis (Appendix 2). In the Guidelines and Recommendations for Use section under Results, we describe best practices for using the assessment information in conservation-related decision making.

RESULTS

We quantified the vulnerability of over 1000 species of Hawaiian plants by determining the amount, quality, and distribution of projected areas lost, gained, and maintained in climate-compatible areas between now and 2100. By determining the probability of each of the three responses considered (i.e., toleration, migration, microrefugia) for each Hawaiian native plant species and, consequently, each individual species' climate change vulnerability ranks (Appendix 3), we can demonstrate the patterns of vulnerability with respect to habitat associations, conservation status, and other species characteristics.

Model vs. Expert Comparison

Comparison of model vs. expert-based vulnerability ranks for the test set of species yielded a clear, positive relationship between the two with no apparent outliers (Figure 2; $r = 0.698$). Species vulnerability scores ranging from 0 to 1 were transformed to a quintile of distribution among all species (i.e., the lowest 20% of vulnerability scores were assigned a value of one, the next 20% a value of two, etc.). However, there was a visibly higher agreement between experts and model ranks for low- and high-vulnerability species, compared to mid-ranked species. Using these data, the average deviation between model and expert ranks for all species was within the range of deviations among experts (average rank distance and standard deviation for model [0.205 ± 0.019] and experts [0.195 ± 0.031]). Once combined with the expert rankings, the same experts could not differentiate the model-based vulnerability rankings from their own. Comparing these results to results based on a model with expert-defined factor weights that emphasized the importance of native cover and protected areas only resulted in a small change in vulnerability rankings among species, indicating vulnerability scores are relatively robust to changes in factor weights.

Summary of Vulnerability Factors Across All Species

The factors considered in the vulnerability model differed substantially among species and response zones (Table 2). With respect to species distribution shifts, on average, only 45.0% of a species' current climate envelope overlapped with their 2100 climate envelope. Considering new compatible-climate areas by 2100, there was an average 39% decrease in area between current and future climate envelopes for all Hawaiian native plant species. Additionally, approximately 15% of species have non-overlapping current and future climate envelopes, implying there is no significant portion of their current range where they will be able to tolerate projected changes in climate (Figure 3; Appendix 4). Approximately 5% of species appear to be at extremely high risk of extinction (i.e., 'wink-out' species) because they are projected to lose more than 99% of their climate envelope area between now and 2100 (Figure 4; Appendix 4).

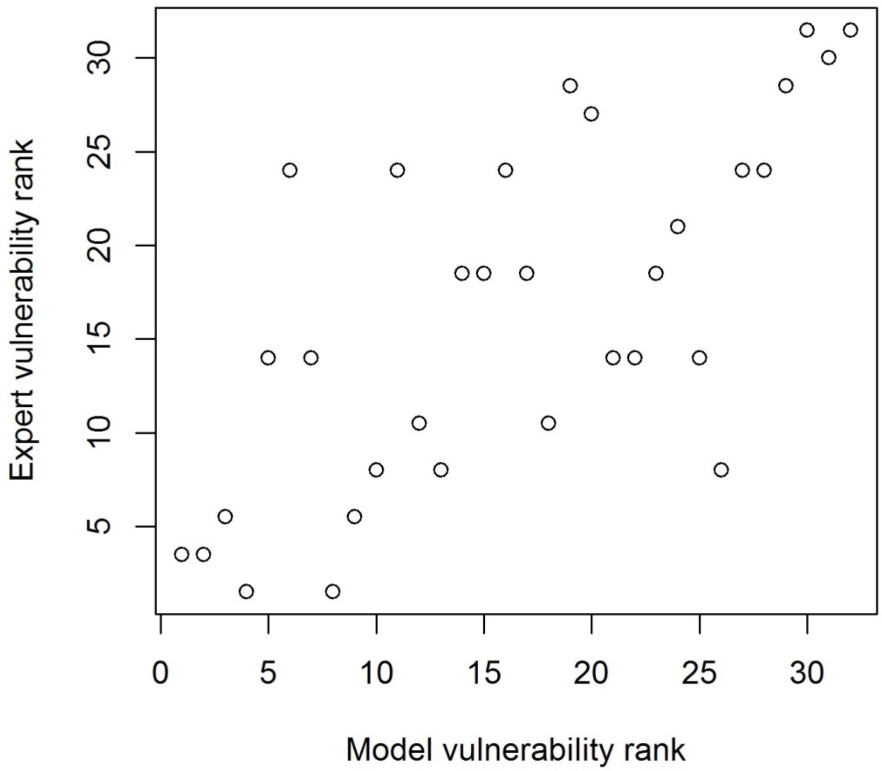

Figure 2. Comparison of ranked vulnerability scores between model results and expert rankings for a subset of native plant species

On a positive note, a comparatively larger proportion of known species' locations were found to occur in the toleration zone of species (66%) as opposed to in areas of lost climate compatibility (i.e., microrefugia zone). Similarly, despite the large projected contractions in climate envelopes for most species, on average, native Hawaiian plant species will still have more than five biogeographic regions where they may find compatible climate space by 2100. Additionally, in only 17.8% of cases was the projected upward elevational shift of a species in individual biogeographic regions greater than the elevation difference between future climate envelope and the top of available habitat.

Beyond these broad species distribution factors, other factors considered in the assessment showed large variation among species and response zones. Among factors with elevation-based patterns, human-modified habitat made up a greater portion of low-elevation microrefugia zones, while lava flows covered a larger portion of higher elevation migration zones. Notably, the portion of areas lost to sea-level rise was minimal, at only 1% of the microrefugia zones for all species, but 9.49% for coastal species (i.e., species with current suitable climate within areas of minimum elevation <10 m and maximum elevation <500 m). Results showed clear decreases in habitat quality for most factors considered in the analyses (e.g., area under protective designation, area under ungulate fencing, native-dominated cover and fragmentation; Table 2, Figure 5). An opposite pattern was observed for landscape invasibility; the only habitat indicator that was projected to 2100. Appendix 5 contains distribution graphs for each factor, as well as

Table 2. Mean (and standard deviation [s.d.]) values for all vulnerability factors for native Hawaiian flora.

	Microrefugia zone		Toleration zone		Migration zone		All zones	
	Mean	S.d.	Mean	S.d.	Mean	S.d.	Mean	S.d.
Area lost to sea-level rise*	0.00695	0.0361						
Lava-flow area*	0.0413	0.0683	0.063	0.102	0.1	0.187		
Heavily modified habitat*	0.12	0.132	0.0352	0.0538	0.0112	0.0326		
Non-pioneer effective area (km^2)	420	464	1060	1660	125	202		
Pioneer effective area (km^2)	466	546	1240	1980	164	256		
Total area (km^2)	600	761	1310	2110	167	262		
Area under protective designation**	0.37	0.196	0.522	0.176	0.598	0.234		
Fragmentation	0.643	0.226	0.46	0.212	0.4	0.251		
Area in native cover**	0.411	0.298	0.617	0.256	0.739	0.268		
Ungulate exclusion area**	0.111	0.196	0.228	0.228	0.397	0.321		
Invasibility	0.214	0.0664	0.197	0.1	0.236	0.0934		
Precipitation gradient	0.0328	0.0203						
Aspect variability	0.652	0.0763						
Average slope	20.4	9.59						
Slope variability	0.761	0.312						
Overlap between current and future climate envelope							0.45	0.282
Projected change in total climate envelope area							0.606	0.361
Proximity to maximum height of available habitat							0.178	0.322
Fraction of occurrence points within the toleration zone							0.671	0.357
Number of future compatible biogeographic regions							5.12	4.74
Distance between current and future climate envelopes							208	1280
Species with overlap between current and future climate envelope							0.85	
Wink-out species							0.0498	
Persistence in non-native habitat							0.211	
Pioneer species							0.0894	

* Proportional area to total zone area; ** proportional area to effective zone habitat area

Figure 3. Species with no overlap between current and future climate envelopes. Current envelopes shown, color ramp shows number of overlapping species.

vertical bars denoting the threshold values used to discretize each factor into distinct factor states. Appendix 6 includes the histograms of the three responses considered in the analysis and the resulting vulnerability scores for all species combined.

Identification of High-vulnerability Species and Taxonomic Groups

In this landscape-based assessment, the vulnerability index was determined by the amount, quality, and distribution of areas lost, gained, and maintained in a species' climate-compatible areas; these landscape changes have strong implications for the likelihood of persistence of these species without conservation action. *Labordia triflora*, *Kanaloa kahoolawensis*, and *Melicope nealae* were identified as the most vulnerable species, while *Isachne distichophylla*, *Cyrtandra paludosa*, and *Hymenophyllum recurvum* were the least vulnerable to climate change impacts (Table 3). Species with no future climate space topped the list of vulnerable species. Of the species that are expected to retain some future climate space by 2100, *Silene alexandri*, *Myrsine mezii*, and *Dubautia herbstobatae* were the most vulnerable (Table 4). For each species considered, we generated a set of maps that contextualized the projected distributional shifts within the set of information considered in the analyses. Appendix 7 has a

Figure 4. Species with no future climate envelopes (wink-out species). Current envelopes shown, color ramp shows number of overlapping species.

single-species example for *Metrosideros polymorpha*; response zone maps for all species can be accessed at https://drive.google.com/folderview?id=0BzZaJl_zsI0vYTA4Nm1URkJTZTg&usp=sharing. High resolution map packages that can be opened on Google Earth are also available for individual species upon request to authors. An example for *Bonamia menziesii* can be downloaded at https://docs.google.com/file/d/0BzZaJl_zsI0vd1dqeV82Ni05RjA/edit?usp=sharing.

Besides vulnerability scores for each species, the BN model succinctly represents the state of factors that contributed to a species' overall vulnerability score and thus can be used to understand the underlying reasons for a particular vulnerability score. A table summarizing the differences among three example species with high, medium, and low vulnerability is presented in Appendix 8.

Results were compiled for all species to assess overall trends in guild and ecosystem vulnerability. Using the overlap of all current climate envelopes for species with vulnerability scores above the median, areas across the islands with the greatest concentration of vulnerable

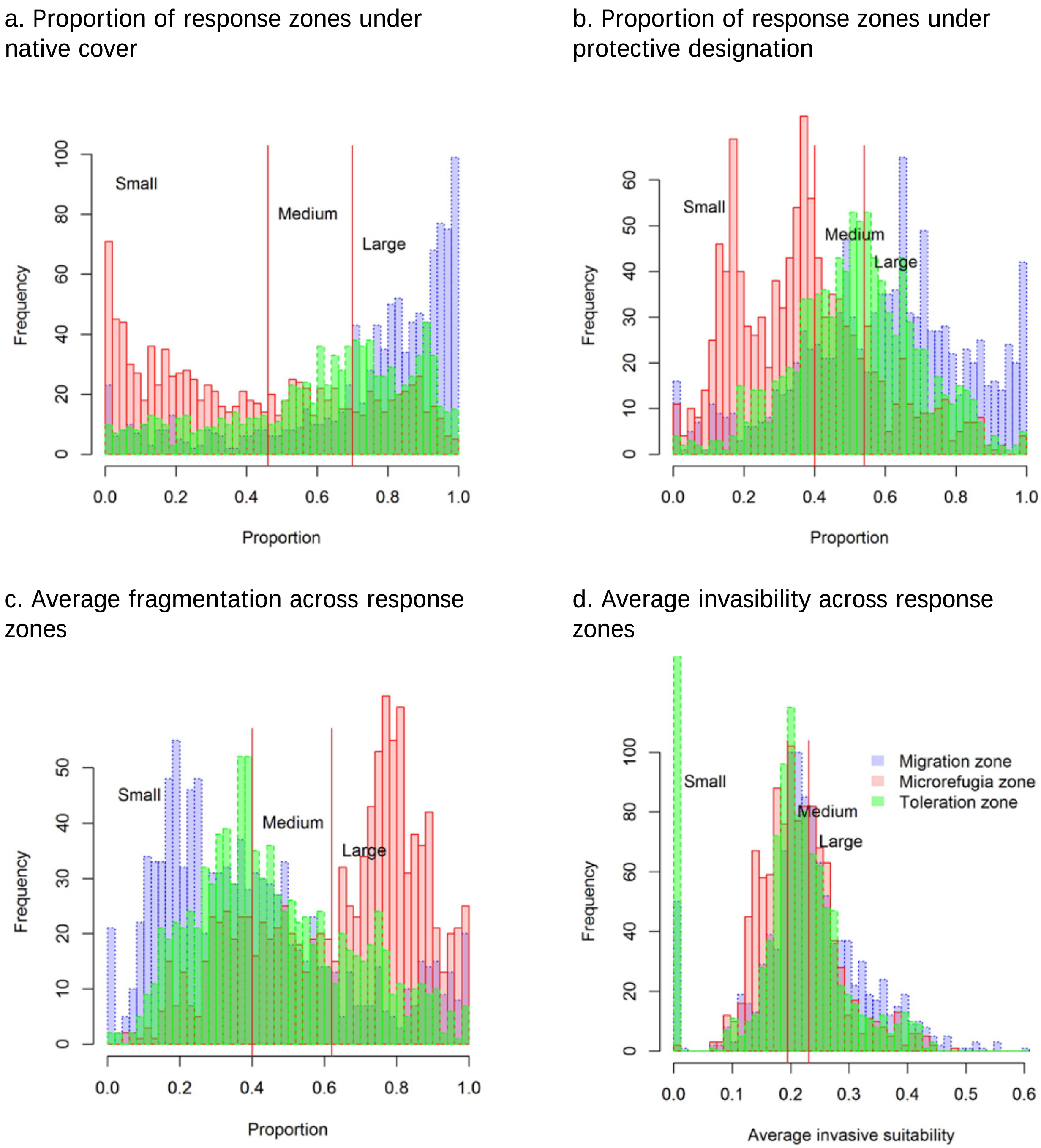

Figure 5. Histogram distributions of example factors considered by the species vulnerability assessment. Vertical red lines denote the threshold values used to discretize each factor into distinct factor states (small, medium, and large).

species due to climate change showed a clear increasing pattern distinctively characterized by age, size, and height of the islands (Figure 6). We also created ensemble maps for each

Table 3. Ten most and least vulnerable native Hawaiian plant species to climate change.

Species	Family	Vulnerability	Conservation status
Labordia triflora	Loganiaceae	0.663	Endangered
Kanaloa kahoolawensis	Fabaceae	0.649	Endangered
Melicope nealae	Rutaceae	0.649	Extinct
Cressa truxillensis	Convolvulaceae	0.644	Apparently secure
Melanthera waimeaensis	Asteraceae	0.643	Endangered
Schiedea helleri	Caryophyllaceae	0.64	Endangered
Hibiscadelphus woodii	Malvaceae	0.636	Extinct
Lipochaeta degeneri	Asteraceae	0.635	Extinct
Silene alexandri	Caryophyllaceae	0.628	Endangered
Xylosma crenatum	Salicaceae	0.62	Endangered
...	...	...	...
Cibotium menziesii	Dicksoniaceae	0.187	Apparently secure
Joinvillea ascendens	Joinvilleaceae	0.185	Rare
Cyrtandra platyphylla	Gesneriaceae	0.184	Apparently secure
Coprosma ernodeoides	Rubiaceae	0.181	Apparently secure
Elaphoglossum pellucidum	Dryopteridaceae	0.179	Apparently secure
Kadua axillaris	Rubiaceae	0.178	Apparently secure
Platydesma spathulata	Rutaceae	0.177	Apparently secure
Hymenophyllum recurvum	Hymenophyllaceae	0.176	Apparently secure
Cyrtandra paludosa	Gesneriaceae	0.174	Apparently secure
Isachne distichophylla	Poaceae	0.158	Apparently secure

response zone for all species combined. These maps depict: regions that by 2100 are likely to be suitable for native species currently not present, based on migration response zones (Figure 7); regions most likely to contain the greatest number of native species confined to microrefugia, based on microrefugia response zones (Figure 8); and regions with the fewest changes in species composition, based on toleration response zones (Figure 9). Lastly, to provide management-specific information, we created an ArcGIS extension that allows the user to determine the set of species that may gain, lose, or maintain climate space within their area of interest, along with their associated vulnerability scores and related habitat quality and area metrics (https://docs.google.com/file/d/0BzZaJl_zsI0vbmNBWmpBaXBnRms/edit?usp=sharing). Appendix 9 provides an example list for the Hanawi Natural Area Reserve in Maui.

Most and Least Vulnerable Genera and Families

Of families containing more than four native species, Caryophyllaceae, Arecaceae, and Violaceae were the most vulnerable (Table 5). At the genus level, *Schiedea*, *Lysimachia*, and *Lipochaeta* had the highest vulnerability scores (Table 6). ANOVA and paired-contrasts tests showed that there were highly significant differences among families (Figure 10) and genera (Figure 11). However, due to the high within-family and within-genus variability in vulnerability

Table 4. Most vulnerable native Hawaiian plant species that have a projected future climate envelope.

Species	Family	Vulnerability	Conservation status
Silene alexandri	Caryophyllaceae	0.628	Endangered
Myrsine mezii	Primulaceae	0.619	Endangered
Dubautia herbstobatae	Asteraceae	0.612	Endangered
Schiedea lydgatei	Caryophyllaceae	0.611	Endangered
Korthalsella degeneri	Viscaceae	0.609	Rare
Phyllostegia waimeae	Lamiaceae	0.601	Extinct
Kadua st.-johnii	Rubiaceae	0.6	Endangered
Schiedea sarmentosa	Caryophyllaceae	0.598	Endangered
Pleomele fernaldii	Asparagaceae	0.596	Endangered
Sanicula mariversa	Apiaceae	0.595	Endangered
Tetramolopium sylvae	Asteraceae	0.595	Rare
Bidens hillebrandiana	Asteraceae	0.59	Apparently secure
Kadua parvula	Rubiaceae	0.589	Endangered
Melicope makahae	Rutaceae	0.589	Endangered
Pritchardia aylmer-robinsonii	Arecaceae	0.584	Endangered
Asplenium dielpallidum	Aspleniaceae	0.583	Endangered
Melanthera kamolensis	Asteraceae	0.582	Endangered
Sicyos maximowiczii	Cucurbitaceae	0.581	Apparently secure
Cyrtandra sessilis	Gesneriaceae	0.58	Endangered
Schiedea apokremnos	Caryophyllaceae	0.579	Endangered

scores, the analyses did not yield clearly separable vulnerability groups. Instead, families and genera located at opposite extremes of the vulnerability values tended to be statistically different from one another, but many families and genera in between had statistically similar vulnerabilities.

Identification of Characteristics Associated with Vulnerable Taxa

Comparison tests indicated several characteristics of species that were generally more vulnerable to climate change. Species under any conservation listing (i.e., rare, vulnerable, endangered, possibly extinct) had vulnerability scores significantly higher than apparently secure species (Figure 12). The median vulnerability score for endangered species was above the median of all other groups except for the group of possibly extinct species. Additionally, endemic species were significantly more vulnerable than indigenous species (i.e., endemic to Hawaiʽi and elsewhere; 0.423 vs. 0.321 median vulnerability respectively; $F = 34.3$, $p(>F) = 6.14^{-09}$), and dicot species were significantly more vulnerable than monocot species, which were in turn more vulnerable than fern species (Figure 13). All combined, dicot endemic species already under conservation listing tended to have higher vulnerability scores than other species (Appendix 10); the 406 species in this group had a median vulnerability of 0.47, as compared to the median vulnerability of 0.36 for the 678 other species. Results also suggest that coastal species (i.e., species with current suitable climate within areas of minimum elevation <10 m

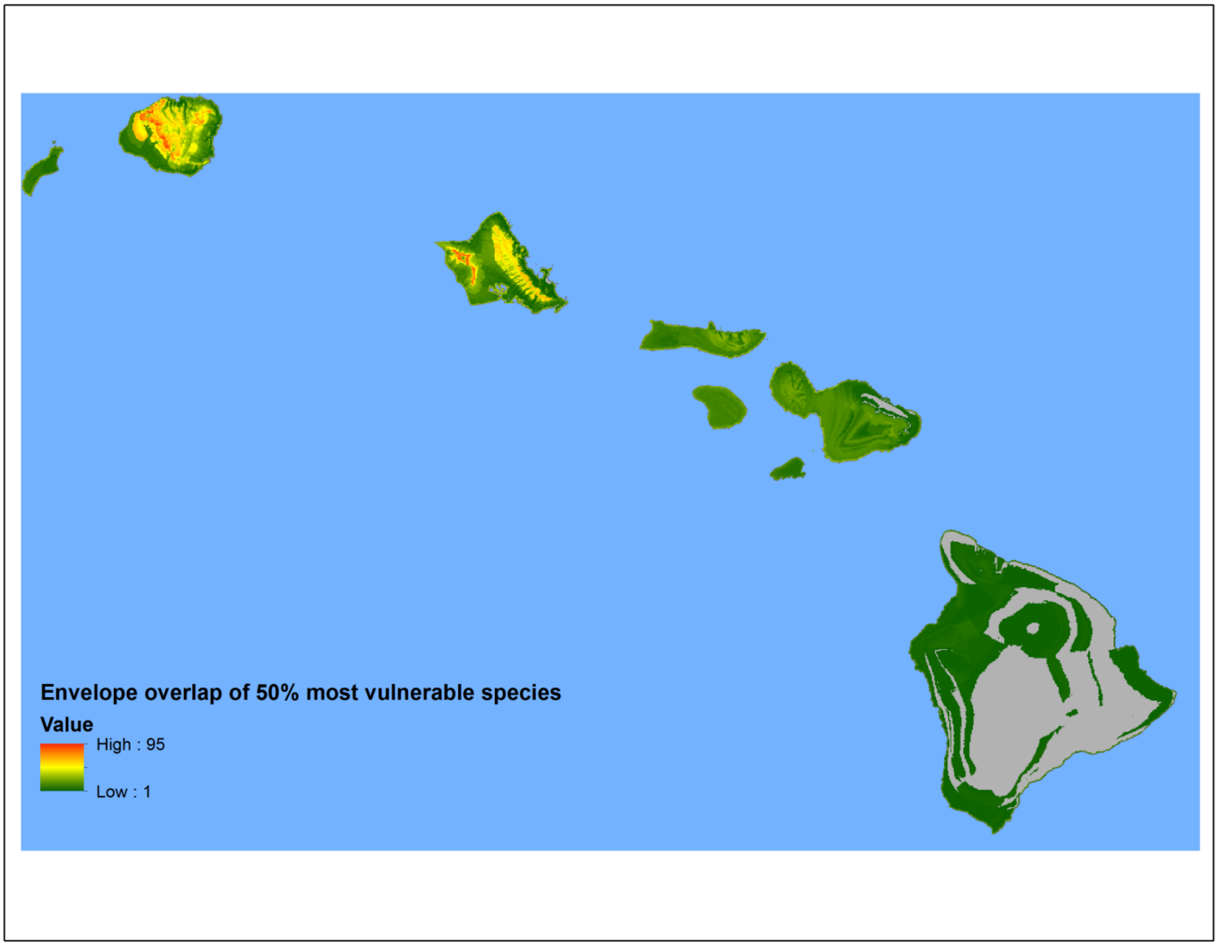

Figure 6. The 50% most vulnerable species across the Hawaiian Islands. Current envelopes shown, color ramp shows number of overlapping species.

and maximum elevation <500 m) also tended to be more vulnerable than non-coastal species, but a climate envelope-independent coastal classification should be used to confirm these results. Non-pioneer species and species dependent on native habitat had higher vulnerability scores than other species, even when removing the impacts of these traits from the model runs (Appendix 10).

Impact of Worst and Best Habitat Quality Scenarios on Species Vulnerabilities

To assess the impact of management-related habitat quality factors on vulnerability scores for all species, we calculated the change in vulnerability scores for all species under worst- and best-case scenarios for these factors. The factors considered in this analysis were fragmentation, area in native cover, area under protective designation, ungulate-free areas, and zone invasibility. Based on the median vulnerability score of 0.411, 542 species had above-median vulnerability based on current habitat conditions. Under a best habitat quality scenario, in which each of the above factors was maximized, the number of species above that median vulnerability score dropped to 233. Conversely, under the worst habitat quality scenario, 760 species had vulnerability scores above the current median vulnerability score. Habitat

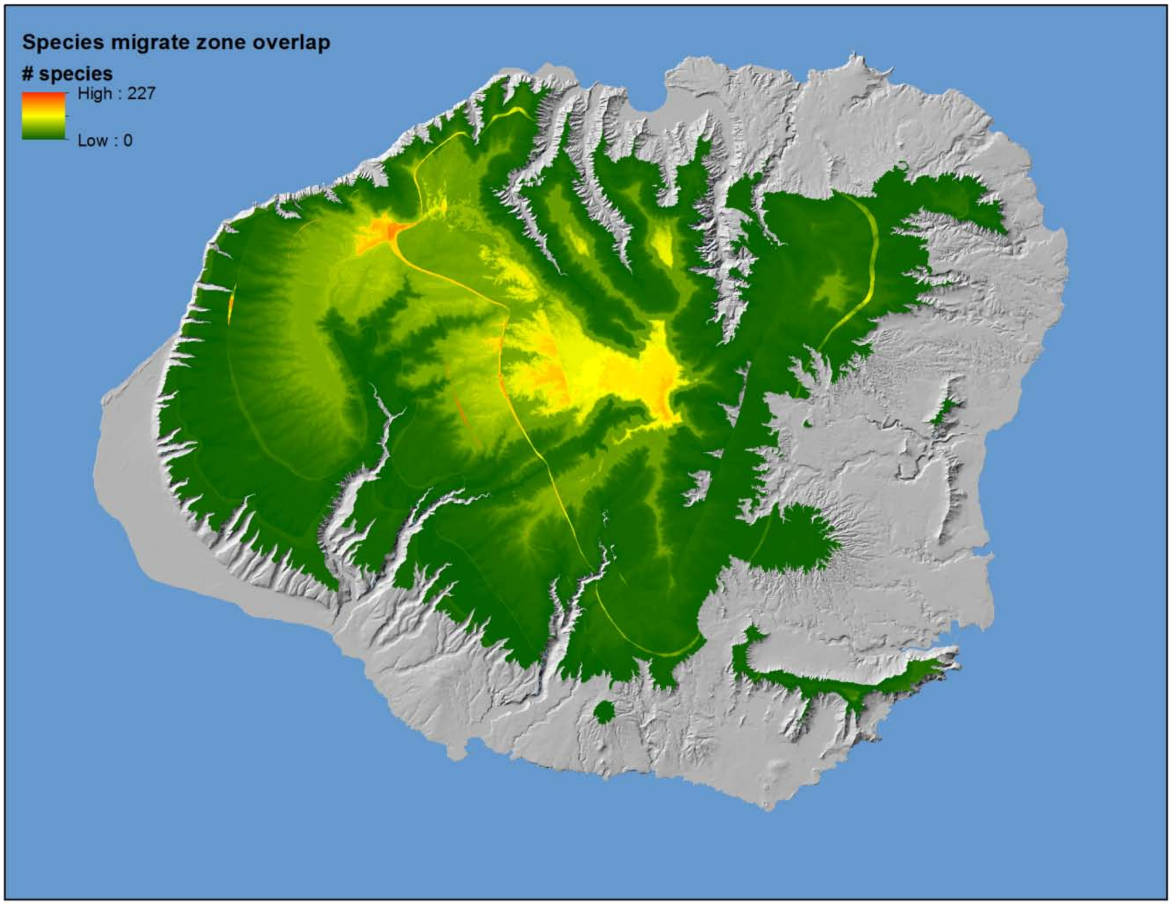

Figure 7. Areas where the greatest number of native plant species have new climate-compatible areas by 2100 for the island of Kaua'i. Map based on the overlap of migration zones for all native Hawaiian plant species. 'Warmer' colored areas are more likely to be suitable for native species not currently present.

improvement (Table 7) or habitat degradation (Table 8) was predicted to affect some genera or families more than others.

Generalizing from Species-specific Results to Regional and Local Management Scale
In addition to the species and zone overlap maps that represent broader vulnerability patterns across the landscape, additional analyses provided information that placed these vulnerability assessment results within a landscape context useful for place-based prioritization of conservation efforts. Given the higher vulnerability of single-island endemics, we compared their vulnerability among islands. Vulnerability scores for O'ahu and Moloka'i single-island endemics were higher than scores for other islands. Hawai'i Island, the youngest, largest, and highest island in the archipelago (Ziegler 2002), had the fewest vulnerable single-island endemics (Figure 14).

We also found that plant 'communities' or vegetation cover types tended to differ in the vulnerability of their associated species. By associating each species to a primary habitat type

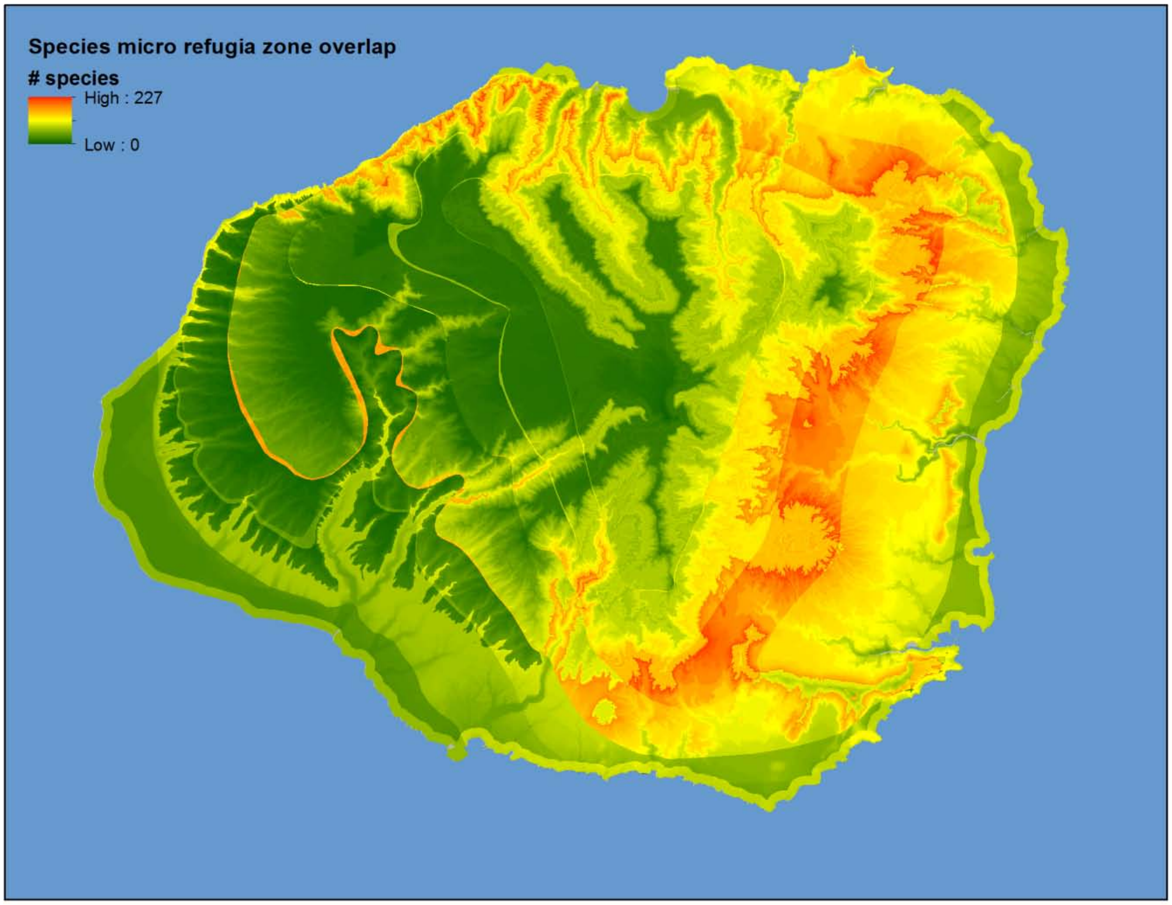

Figure 8. Areas where the greatest number of native plant species may be confined to microrefugia by 2100 for the island of Kauaʽi. 'Warmer' colored areas are likely to contain a greater number of native species confined to microrefugia.

based on the dominant cover within a species' current climate envelope, results showed that species primarily associated with dry forests and deciduous shrublands tended to have higher vulnerabilities than species associated with other habitat types (Figure 15). Conversely, wet forests or perennial grasslands tended to have species with low vulnerabilities. Species associated with mesic forests tended to have mid-range vulnerability scores.

Correlation Analyses

Altogether, correlations show that, considering species distribution and landscape context alone, there is a limited set of ways in which species tend to be vulnerable to climate change. Across species, most correlations for independent factors considered in the model were weak, which indicates a degree of independence among factors considered. However, for most factors calculated for each of the three zones, correlations among zones tended to be high (e.g., amount of native cover in the migration zone was highly correlated with amount of native cover in the toleration zone). This, however, was less true when comparing microrefugia and migration zones, which are spatially disjunct.

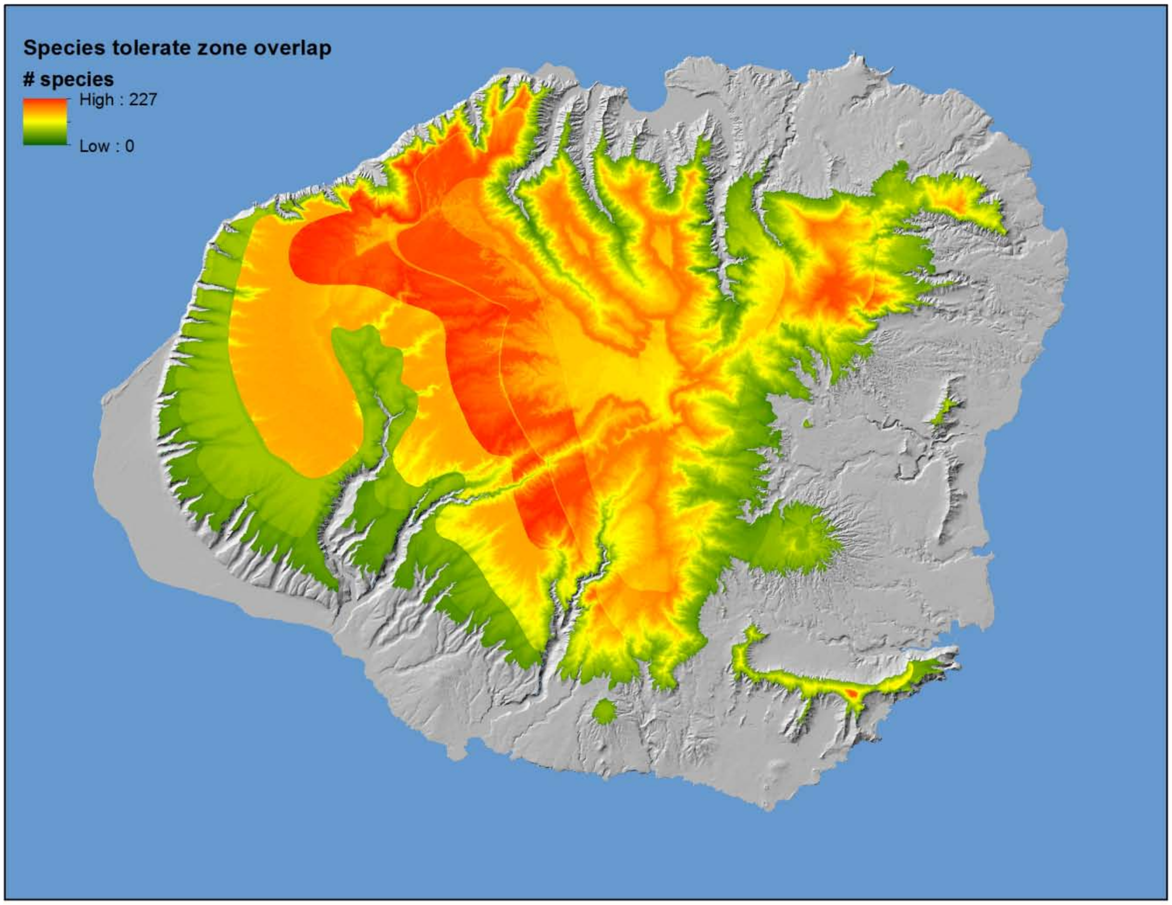

Figure 9. Areas where the greatest number of native plant species may tolerate projected changes in climate by 2100 for the island of Kaua'i. 'Warmer' colored areas are likely to contain a greater number of native species that can persist in place.

There were a few habitat-quality factors with strong correlations across species (Figure 16); native area and fragmentation were strongly negatively correlated, and fraction of area under protective designation and native cover were positively correlated. Topographic and climatic diversity factors were weakly correlated to other habitat-quality factors. Besides the generally low correlation among species for habitat-quality factors, all habitat-quality factors were highly correlated among zones (Figure 16). Factors determining the habitat distribution characteristics of the species did not show a high degree of correlation (Figure 17). Area-based factors yielded a similar pattern of correlations, where correlations across factor types were comparatively weak compared to correlations for factors across zones. The exception was the high correlation among amount of heavily modified area in the microrefugia zone with most other habitat area factors related to that zone—a result not particularly surprising given that for many species heavily modified habitat accounts for a majority of the microrefugia zone (Figure 18).

There were strong correlations among most higher level-dependent factors in the model (i.e., child factors; Figure 19). Given the strong correlation among zones for any particular independent factor in the vulnerability model, it was not surprising that response probabilities

Table 5. Ten most and least vulnerable native Hawaiian plant families to climate change.

Family	*n*	Mean	S.d.
Caryophyllaceae	30	0.5	0.0855
Arecaceae	20	0.469	0.0898
Violaceae	11	0.467	0.0834
Euphorbiaceae	18	0.462	0.0789
Asparagaceae	6	0.462	0.0917
Geraniaceae	6	0.462	0.118
Convolvulaceae	9	0.458	0.118
Primulaceae	33	0.458	0.113
Asteraceae	88	0.455	0.0923
Loganiaceae	16	0.454	0.123
...	...	...	...
Woodsiaceae	9	0.348	0.0801
Viscaceae	6	0.342	0.142
Rosaceae	5	0.341	0.147
Pteridaceae	12	0.341	0.124
Lycopodiaceae	12	0.339	0.0915
Aspleniaceae	26	0.329	0.109
Polypodiaceae	17	0.304	0.0953
Dryopteridaceae	28	0.301	0.0859
Thelypteridaceae	8	0.286	0.0764
Hymenophyllaceae	9	0.278	0.0761

Table 6. Ten most and least vulnerable native Hawaiian plant genera to climate change.

Genus	*n*	Mean	S.d.
Schiedea	26	0.512	0.0696
Lysimachia	12	0.497	0.0929
Lipochaeta	6	0.491	0.0852
Melanthera	11	0.489	0.0884
Lobelia	11	0.48	0.0905
Tetramolopium	9	0.472	0.0984
Ipomoea	5	0.469	0.116
Euphorbia	17	0.469	0.0761
Pritchardia	20	0.469	0.0898
Pleomele	6	0.462	0.0917
...	...	...	...
Huperzia	10	0.351	0.0951
Coprosma	13	0.343	0.136
Korthalsella	6	0.342	0.142
Carex	8	0.341	0.115
Asplenium	26	0.329	0.109
Adenophorus	10	0.306	0.107
Pteris	5	0.302	0.093
Cyclosorus	6	0.295	0.0832
Dryopteris	11	0.294	0.0889
Elaphoglossum	9	0.283	0.0958

and vulnerability scores were strongly correlated with one another. The exception was microrefugia habitat quality that was often weakly negatively correlated with most other dependent factors in the model. These unexpected negative correlations resulted in microrefugia habitat quality not being correlated to overall vulnerability (Figure 19).

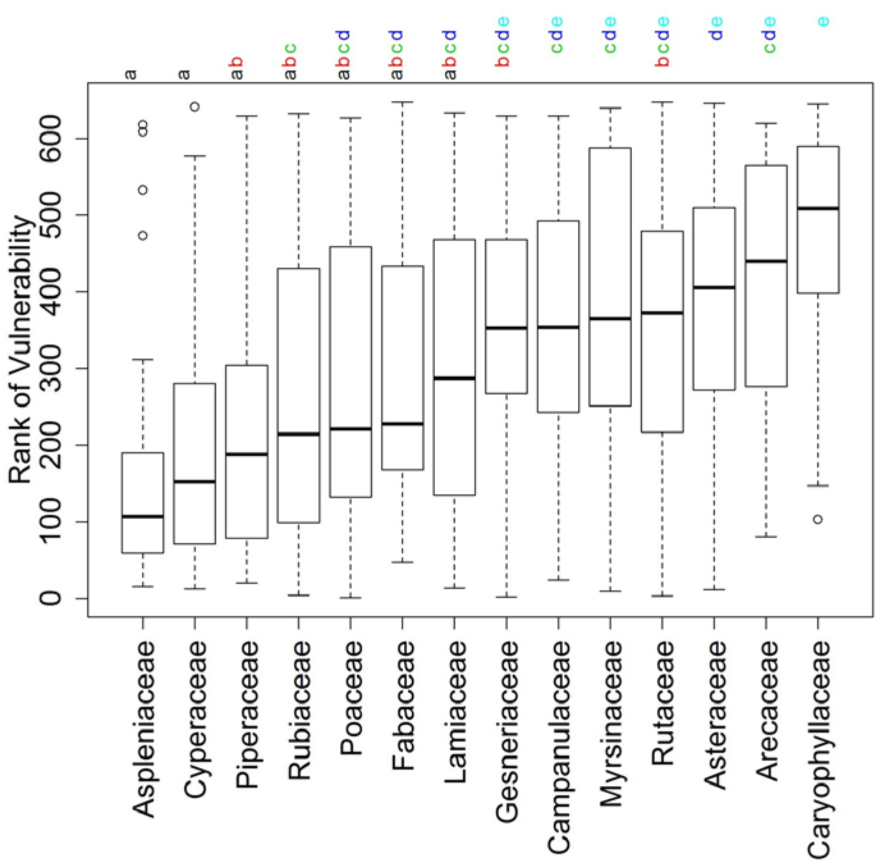

Figure 10. Differences in vulnerability scores by native Hawaiian plant families. Letters on top of the graph denote grouping of families by pair-wise statistical significance; groups that share the same letter are not significantly different. Only families with ≥20 species were included in the comparison.

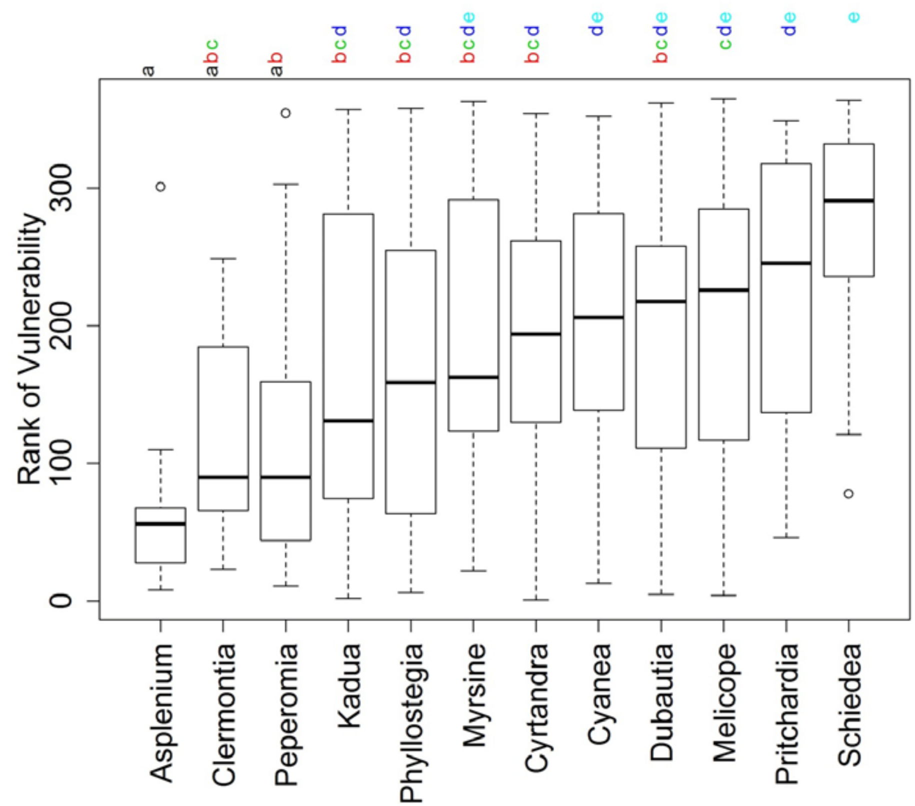

Figure 11. Differences in vulnerability scores by native Hawaiian plant genera. Letters on top of the graph denote grouping of genera by pair-wise statistical significance; groups that share the same letter are not significantly different. Only genera with ≥20 species were included in the comparison.

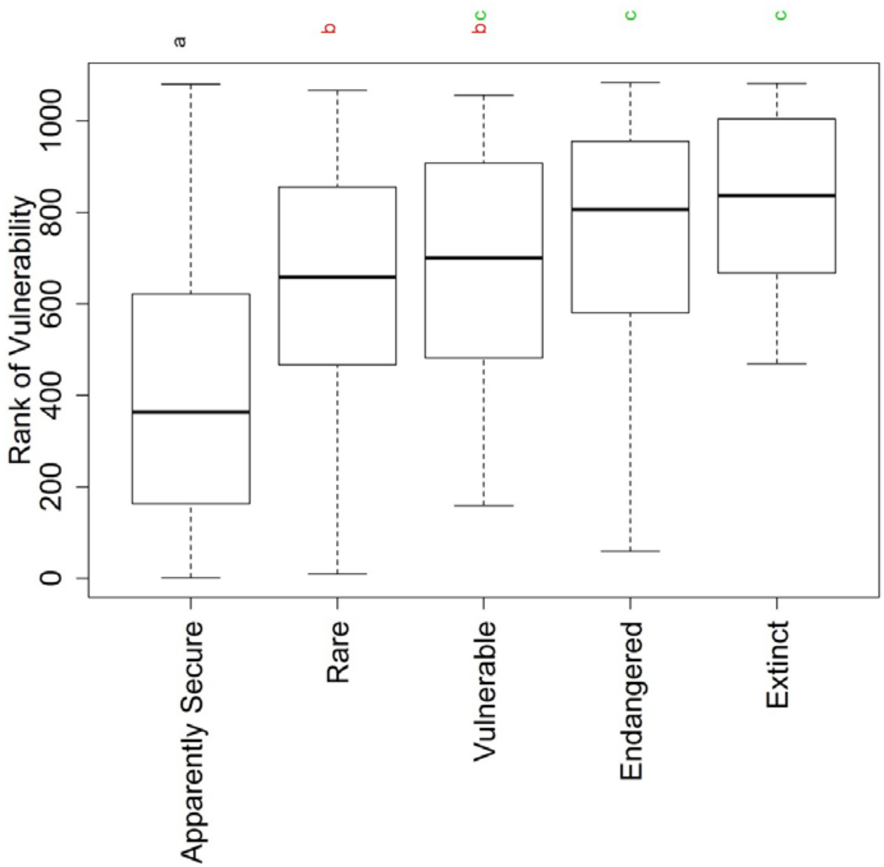

Figure 12. Differences in vulnerability scores by species conservation status. Letters on top of the graph denote grouping of states by pair-wise statistical significance; groups that share the same letter are not significantly different. Only groups with ≥20 species were included in the comparison.

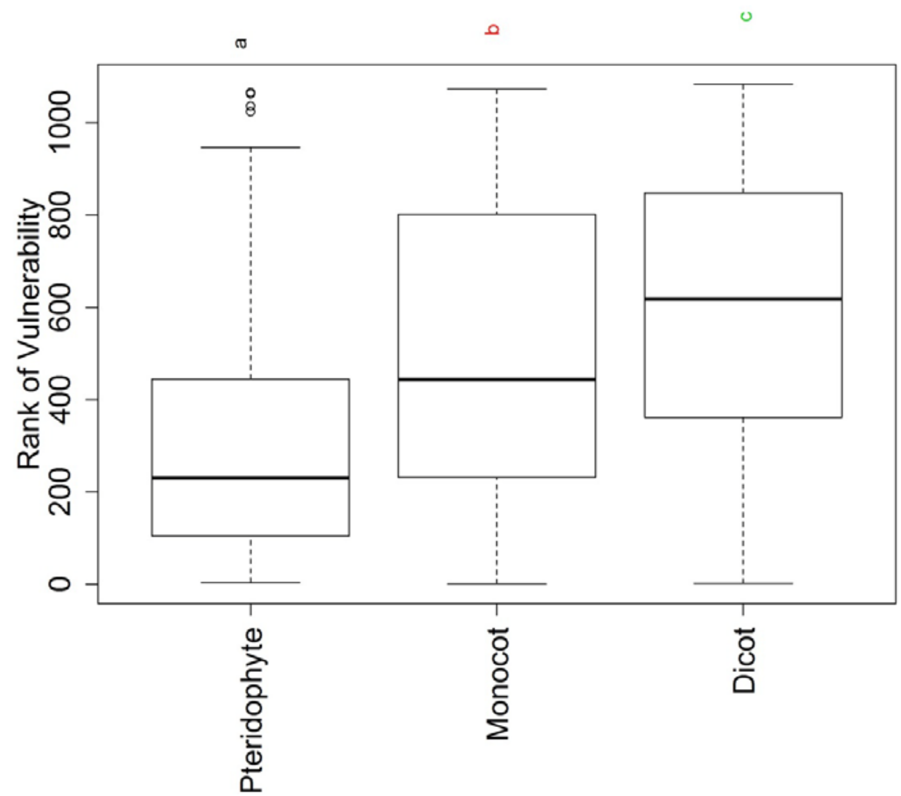

Figure 13. Differences in vulnerability scores by major plant groups. Letters on top of the graph denote grouping by pair-wise statistical significance; groups that share the same letter are not significantly different.

Table 7. Families with biggest reductions in vulnerability due to hypothetical habitat improvement.

Family	*n*	Current mean vulnerability score	% Decrease
Nyctaginaceae	7	0.354	44.9
Thelypteridaceae	8	0.286	42.9
Santalaceae	7	0.356	41.6
Amaranthaceae	10	0.403	40.9
Fabaceae	22	0.404	40.3
Pteridaceae	12	0.341	39.3
Solanaceae	9	0.403	39.2
Convolvulaceae	9	0.458	38.3
Viscaceae	6	0.342	36.8
Poaceae	45	0.396	35.4
Urticaceae	15	0.365	34.6
Malvaceae	19	0.453	34.5
Rhamnaceae	6	0.448	34.5
Woodsiaceae	9	0.348	34.4
Asparagaceae	6	0.462	34.2
Cyperaceae	43	0.353	34.2
Apocynaceae	8	0.414	33.3
Aspleniaceae	26	0.329	32.8
Hymenophyllaceae	9	0.278	32.8
Cucurbitaceae	12	0.408	30.9

Table 8. Families with biggest increases in vulnerability due to hypothetical additional habitat degradation.

Family	*n*	Current mean vulnerability score	% Increase
Hymenophyllaceae	9	0.278	49.3
Polypodiaceae	14	0.317	48.9
Dryopteridaceae	28	0.301	47.0
Lycopodiaceae	12	0.339	42.7
Thelypteridaceae	8	0.286	40.1
Rosaceae	5	0.341	38.5
Aspleniaceae	26	0.329	36.8
Piperaceae	24	0.361	34.3
Lamiaceae	51	0.401	32.8
Viscaceae	6	0.342	31.9
Blechnaceae	8	0.358	30.4
Pteridaceae	12	0.341	29.9
Cyperaceae	43	0.353	29.3
Rubiaceae	54	0.383	29.2
Geraniaceae	6	0.462	28.9
Araliaceae	14	0.392	28.8
Urticaceae	15	0.365	28.8
Rutaceae	52	0.43	27.9
Woodsiaceae	9	0.348	27.8

DISCUSSION

This assessment attempts to evaluate the potential climate change threats to the entire native flora of the main Hawaiian Islands, thus filling a critical knowledge gap for resource managers in the region and starting a concerted effort to address the biological

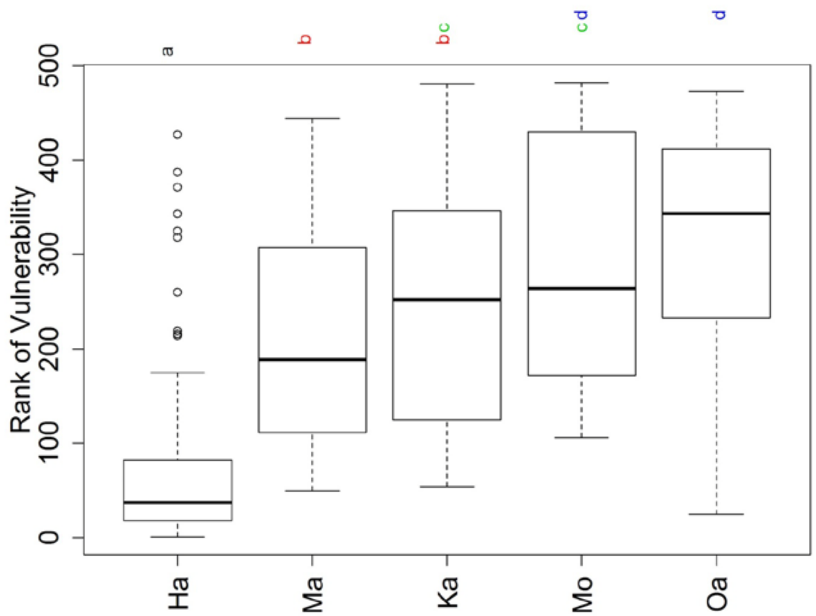

Figure 14. Differences in vulnerability scores among single island endemics by island. Letters on top of the graph denote grouping by pair-wise statistical significance; groups that share the same letter are not significantly different. Only islands with ≥20 species were included in the comparison. Islands are as follows: Ha = Hawai'i, Ma = Maui, Ka = Kaua'i, Mo = Moloka'i, and Oa = O'ahu.

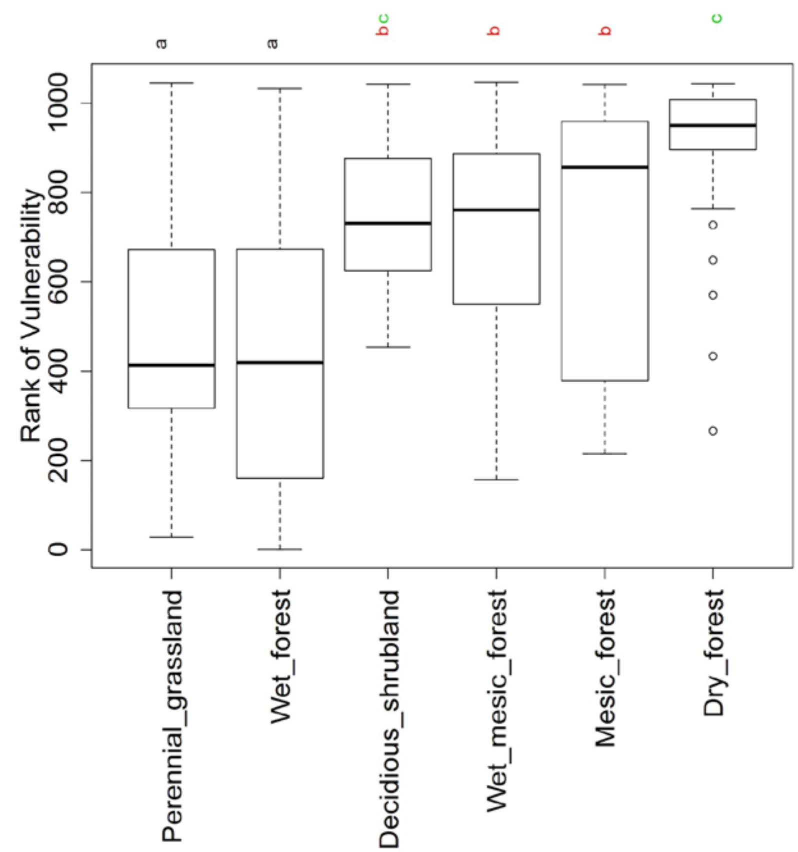

Figure 15. Species vulnerability by primary habitat association. Perennial grasslands and deciduous shrublands are heavily altered, non-native habitats and reflect the underlying cover classes of the underlying Landfire dataset. Letters on top of the graph denote grouping of families by pair-wise statistical significance; groups that share the same letter are not significantly different. Only habitats with ≥20 species were included in the comparison.

	Area under protective designation in Migration zone	Area under Protective designation in Microrefugia zone	Area under Protective designation in Tolerate zone	Invasibility in Migration zone	Invasibility in Microrefugia zone	Invasibility in Tolerate zone	Precipitation gradient in Microrefugia zone	Fragmentation in Migration zone	Fragmentation in Microrefugia zone	Fragmentation in Tolerate zone	Area in native cover in Migration zone	Area in native cover in Microrefugia zone	Area in native cover in Tolerate zone	Ungulate exclusion areas in Migration zone	Ungulate exclusion areas in Microrefugia zone	Ungulate exclusion areas in Tolerate zone	Aspect variability in Microrefugia zone	Average slope in Microrefugia zone	Slope variability in Microrefugia zone	Distance between current and future climate envelopes
Area under Protective designation in Microrefugia zone	0.41																			
Area under Protective designation in Tolerate zone	**0.70**	**0.68**																		
Invasibility in Migration zone	-0.11	-0.04	0.04																	
Invasibility in Microrefugia zone	-0.01	0.09	0.08	0.49																
Invasibility in Tolerate zone	0.11	0.22	0.27	**0.60**	**0.81**															
Precipitation gradient in Microrefugia zone	0.00	0.33	0.07	-0.29	-0.33	-0.25														
Fragmentation in Migration zone	-0.13	-0.20	-0.20	**0.51**	0.46	0.39	-0.42													
Fragmentation in Microrefugia zone	-0.29	**-0.65**	-0.49	0.24	0.16	0.01	-0.41	0.36												
Fragmentation in Tolerate zone	-0.41	-0.42	-0.46	0.42	0.47	0.37	-0.42	**0.59**	**0.73**											
Area in native cover in Migration zone	0.45	0.39	0.46	-0.24	-0.31	-0.20	0.32	**-0.51**	-0.47	**-0.65**										
Area in native cover in Microrefugia zone	0.26	**0.69**	0.47	-0.37	-0.33	-0.18	**0.51**	-0.45	**-0.88**	**-0.75**	**0.59**									
Area in native cover in Tolerate zone	0.38	**0.57**	**0.54**	-0.39	-0.41	-0.30	0.48	**-0.55**	**-0.70**	**-0.84**	**0.83**	**0.85**								
Ungulate exclusion areas in Migration zone	0.26	0.26	0.22	-0.23	-0.37	-0.25	0.41	-0.35	-0.47	**-0.59**	**0.51**	**0.52**	**0.58**							
Ungulate exclusion areas in Microrefugia zone	-0.06	0.33	0.02	-0.11	0.01	0.02	**0.53**	-0.13	**-0.57**	-0.33	0.24	**0.54**	0.38	**0.53**						
Ungulate exclusion areas in Tolerate zone	0.07	0.36	0.15	-0.16	-0.10	-0.05	**0.53**	-0.18	**-0.61**	-0.48	0.39	**0.60**	**0.53**	**0.75**	**0.90**					
Aspect variability in Microrefugia zone	-0.30	0.05	-0.22	0.12	0.21	0.19	0.30	0.05	0.14	0.28	-0.09	-0.10	-0.13	-0.10	0.09	0.05				
Average slope in Microrefugia zone	-0.22	0.27	-0.02	-0.02	0.03	0.16	**0.53**	-0.16	-0.08	0.09	0.14	0.23	0.18	-0.01	0.24	0.16	**0.72**			
Slope variability in Microrefugia zone	0.21	-0.34	-0.01	-0.07	-0.18	-0.26	-0.42	0.07	0.11	-0.16	-0.10	-0.18	-0.13	0.02	-0.29	-0.21	**-0.68**	**-0.85**		
Distance between current and future climate envelopes	-0.20	0.10	-0.07	0.07	0.05	0.03	0.14	-0.04	-0.14	-0.03	0.00	0.15	0.06	-0.01	0.20	0.16	0.08	0.12	-0.11	
Fraction of occurrence points within the tolerate zone	0.20	-0.24	0.04	-0.12	-0.28	-0.20	-0.06	-0.17	0.11	-0.20	0.21	-0.13	0.10	0.21	-0.20	-0.07	-0.14	-0.19	0.28	-0.26

Figure 16. Correlations among habitat quality factors. Bold cells highlight correlations where |r| > 0.5. Green cells denote a positive correlation, and red cells denote a negative correlation.

	Number of future compatible biogeographic regions	Overlap between current and future climate envelope	Projected change in total climate envelope area
Overlap between current and future climate envelope	**0.54**		
Projected change in total climate envelope area	0.28	**0.58**	
Proximity to maximum height of available habitat	0.27	**0.52**	0.41

Figure 17. Correlations among habitat distribution factors. Bold cells highlight correlations where |r| > 0.5. Green cells denote a positive correlation, and red cells denote a negative correlation.

	Area lost to sea level rise in Microrefugia zone	Lava flow area in Toleration zone	Lava flow area in Migration zone	Lava flow area in Microrefugia zone	Heavily modified habitat in Migration zone	Heavily modified habitat in Microrefugia zone	Heavily modified habitat in Toleration zone	Total area in Migration zone	Total area in Microrefugia zone
Lava flow area in Toleration zone	-0.01								
Lava flow area in Migration zone	0.00	**0.86**							
Lava flow area in Microrefugia zone	0.13	**0.80**	**0.67**						
Heavily modified habitat in Migration zone	0.26	-0.05	-0.08	0.10					
Heavily modified habitat in Microrefugia zone	0.30	0.15	0.24	0.26	0.36				
Heavily modified habitat in Toleration zone	0.30	0.09	0.10	0.30	**0.64**	**0.75**			
Total area in Migration zone	0.11	0.40	0.45	0.48	0.11	**0.52**	0.49		
Total area in Microrefugia zone	0.27	0.38	0.50	0.46	0.15	**0.62**	**0.54**	**0.68**	
Total area in Toleration zone	0.03	0.47	**0.66**	0.42	-0.11	**0.53**	0.28	**0.59**	**0.78**

Figure 18. Correlations among habitat area factors. Bold cells highlight correlations where |r| > 0.5. Green cells denote a positive correlation, and red cells denote a negative correlation.

impacts of climate change on Hawaiian ecosystems. While research on climate change impacts has typically focused on uncertainties of climate projections, the uncertainties in the underlying ecological responses to climate shifts also pose significant challenges to climate change adaptation in Hawaiʽi and elsewhere (Littell *et al.* 2011). Given these widespread uncertainties, vulnerability assessments are done when robust mechanistic response models are not available or easily applicable to multiple species. Therefore, a VA always entails some degree of subjectivity as projected climate impacts are not quantitatively measured or modeled (Hameed *et al.* 2013). This subjectivity is often tolerated as it is implicitly understood that there are simply not enough resources or time to rigorously examine all potential impacts of climate shifts on multiple species.

	Habitat quality in Migration zone	Habitat quality in Microrefugia zone	Habitat quality in Toleration zone	Landscape distribution	Effective area in Migration zone	Effective area in Microrefugia zone	Effective area in Toleration zone	Microrefugia response	Migrate response	Toleration response
Habitat quality in Microrefugia zone	0.22									
Habitat quality in Toleration zone	**0.75**	0.39								
Landscape distribution	0.48	-0.26	0.38							
Effective area in Migration zone	0.27	-0.37	0.12	**0.65**						
Effective area in Microrefugia zone	0.34	-0.30	0.33	**0.58**	**0.68**					
Effective area in Toleration zone	**0.56**	-0.22	**0.52**	**0.75**	**0.68**	**0.84**				
Microrefugia response	**0.52**	0.24	**0.59**	**0.58**	**0.53**	**0.84**	**0.77**			
Migrate response	**0.69**	-0.18	0.47	**0.79**	**0.87**	**0.69**	**0.80**	**0.66**		
Toleration response	**0.73**	0.04	**0.83**	**0.73**	**0.52**	**0.70**	**0.91**	**0.79**	**0.78**	
Vulnerability	**-0.69**	-0.06	**-0.69**	**-0.76**	**-0.69**	**-0.82**	**-0.90**	**-0.91**	**-0.87**	**-0.94**

Figure 19. Correlations among dependent vulnerability factors, species responses, and vulnerability. Bold cells highlight correlations where |r| > 0.5. Green cells denote a positive correlation, and red cells denote a negative correlation.

General Patterns of Species Vulnerability to Climate Change

In broad terms, our results show that species already of conservation concern due to the number of current threats (e.g., competition and predation from non-native species and land-use change) tend to be the species most vulnerable to climate change. Characteristics known to be related to endangerment and past extinctions (archipelago endemism, single-island endemism) are therefore common to many of Hawaiʽi's plant species that are most vulnerable to climate change (Sakai *et al.* 2002).

The analysis of climate change vulnerability with respect to habitat association shows an increase in vulnerability from wet to dry habitats (Figure 15), excluding perennial grasslands and deciduous shrublands, as they are heavily altered non-native habitats. Species primarily associated with the dry forest biome had higher vulnerability scores than species primarily associated with any other habitat type, a result that parallels the recognized current threats to these forests (Mehrhoff 2002, Brienen *et al.* 2010, Chimera and Drake 2010). The two results are mainly a function of generally low habitat quality metrics for species primarily associated with dry habitats and conversely larger response zone areas for species primarily associated with wet habitats. While these analyses provide initial insights necessary for habitat prioritization based on climate change vulnerability, future analyses considering habitat association based on original native habitats should yield more refined results. However, these results also highlight the additional challenges of dealing with the higher vulnerabilities for species in dry and mesic habitats as, particularly in lower elevations, these areas have already been heavily damaged and may require substantial restoration of the native plant community matrix in order to reduce species' vulnerabilities.

Differences in vulnerability across genera and families tended to reflect the broad patterns of vulnerability across species groups (Figures 10, 11, and 12) with those families and genera typically associated with mid-elevation wet habitats or fairly generalist groups (e.g., ferns or sedges) showing lower vulnerabilities. However, these characteristics should not be used as overly simplified predictors of vulnerability, since there were large differences in vulnerability within each group. For instance, despite most apparently secure species having lower vulnerabilities than species with a conservation-listing status, several apparently secure species still had among the highest vulnerability scores (Figure 12). This may be partly due to the fact that many species that fit the criteria for listing have not been officially listed, but also due to a combination of factors considered such as very limited distributions, particularly in lowland dry habitats. Table 9 lists the most vulnerable species that are currently classified as apparently secure species.

Table 9. Apparently secure native Hawaiian plant species most vulnerable to climate change.

Species	Family	Vulnerability
Cressa truxillensis	Convolvulaceae	0.644
Bolboschoenus maritimus	Cyperaceae	0.619
Cyperus laevigatus	Cyperaceae	0.619
Sadleria wagneriana	Blechnaceae	0.6
Labordia sessilis	Loganiaceae	0.597
Peperomia ellipticibacca	Piperaceae	0.597
Eragrostis paupera	Poaceae	0.596
Bidens hillebrandiana	Asteraceae	0.59
Myrsine degeneri	Primulaceae	0.59
Ipomoea imperati	Convolvulaceae	0.583
Ipomoea littoralis	Convolvulaceae	0.583
Vitex rotundifolia	Lamiaceae	0.583
Ruppia maritima	Ruppiaceae	0.583
Sicyos maximowiczii	Cucurbitaceae	0.581
Lysimachia glutinosa	Primulaceae	0.571
Coprosma elliptica	Rubiaceae	0.564
Heliotropium anomalum	Boraginaceae	0.558
Lysimachia mauritiana	Primulaceae	0.556
Entada phaseoloides	Fabaceae	0.555
Trisetum inaequale	Poaceae	0.552

While the higher vulnerability of coastal species is generally intuitive for a Pacific island setting, this finding is not directly due to projected impacts of sea-level rise, which tended to be small for most species considered. Instead, in our analysis, the high vulnerability of coastal species was generally due to relatively small remaining habitat area and lower habitat quality in coastal areas, due to massive land-use change across the Hawaiian lowlands (Cuddihy and Stone 1990, Pratt and Jacobi 2009). However, the relatively small importance of sea-level rise to our results may be due in part to the relatively simple "bathtub-model" analysis that ignores dynamic flooding effects that can greatly exacerbate static flooding impacts (Reynolds *et al.* 2012). Given the high human population densities of Hawaiian coastal areas, many upslope areas into which coastal species might be able to retreat in response to rising sea levels have been heavily developed or altered, precluding the possibility of migration for coastal species in these areas. Additionally, future consideration of the human responses to flooding can significantly augment projected natural habitat loss (Wetzel *et al.* 2012). Furthermore, because by 2100 many of the coastal areas across the archipelago will be in climates warmer than any experienced since the preceding interglacial period (Late Pleistocene Eemian Stage, 130–116 ka; Kukla *et al.* 2002), it is particularly challenging to estimate the response of coastal species to these non-analog climates. If anything, we may surmise that endemic Hawaiian species may be more vulnerable to these changes than indigenous or recently introduced tropical species.

In terms of the geographic patterns of vulnerability for single-island endemic species, Oʻahu, Molokaʻi, and Kauaʻi had the highest vulnerability scores. This finding is somewhat surprising, since it does not fit the general patterns of current endangerment for single-island endemics across the islands where Molokaʻi has the largest percentage of species at risk followed by Maui (Sakai *et al.* 2002). However, the spatial distribution of the current climate envelopes of all species with above-median vulnerability scores (Figure 6) resembles current conservation-priority areas on Oʻahu and Kauaʻi (FWS unpublished, DLNR 2011).

It is also worth noting that for several of the most endangered plant species current climate envelopes are extremely small with more than 201 species having fewer than 50 known individuals (Plant Extinction Prevention Program of Hawaiʻi, http://pepphi.org/). For these extremely endangered species, vulnerability scores may understate climate-change threats such that stochastic environmental fluctuations and related extreme events, rather than progressive changes in climate, might easily wipe out remaining populations (Parmesan *et al.* 2000, McLaughlin *et al.* 2002).

Drivers of Climate Change Vulnerability for Hawaiian Plant Species

Beyond identifying the most vulnerable individual species and species groups, the large number of species considered helps us identify the particular ways in which species tend to be vulnerable to climate change. But, because of the strong correlations among dependent factors (Figure 19), there are not many ways in which different species tend to be particularly vulnerable to climate change. In fact, high vulnerability species tended to have unfavorable habitat quality, area, and distribution. In that regard, despite using a large number of factors in this assessment, in the end our results replicate findings from many other regions that link higher species vulnerability with decreasing range size (Schwartz *et al.* 2006).

Results of particular concern in our analyses are the numerous species that by 2100 appear to have no compatible-climate areas left. These species might persist by enduring in microrefugia within their current range or by natural selection processes that rapidly expand their niche within the next decades. Unfortunately neither of these responses seems very likely for these species since their limited distribution and population numbers lessen the probability of natural selection towards more climate-adapted variants and their persistence within microrefugia.

Building a Framework to Assess Climate Change Vulnerability of Native Hawaiian Plant Species

While this assessment offers a first glimpse of the vulnerability of the Hawaiian flora with respect to climate change, perhaps most importantly it creates the foundational framework from which refinements can be pursued in the future. This framework is based on two novel approaches to assess species vulnerabilities that may be useful for other species groups and locations elsewhere.

The Bayesian network model approach

By utilizing a BN model approach, we minimized the subjectivity inherent in these assessments. In conventional assessments, experts are often asked to rank the impact of a vulnerability-relevant factor (e.g., habitat quality) on overall vulnerability based on their own knowledge. While this approach harnesses the knowledge of experts involved in an assessment, results from such expert elicitations are neither transparent nor easily replicable, as the underlying information considered and the relevance ascribed to that information differs from expert to expert. With the use of a BN model, more complex hierarchical representations of the factors that contribute to vulnerability can be created, where objective data are directly linked to a species' vulnerability to climate change (e.g., vulnerability is determined by species responses; species responses are partly determined by habitat quality; habitat quality is partially determined by amount of protection; and protection is related to percent of potential habitat under protective designation or ungulate fencing). This linking of vulnerability to quantitative data confines the impact of subjectivity within the assessment process to model creation and parameterization. Even though expert opinion is used during creation and parameterization of the BN model, the resulting BN model structure and underlying conditional probabilities make it apparent how particular sets of information contribute to resulting vulnerability scores. This permits the assessment to be replicated and updated with new information without the need to frequently reconvene experts, as the BN model essentially replaces the experts in information integration. Lastly, as a Bayesian model, prior distribution of factors offers a robust manner to deal with potential gaps in available data (e.g., species without point data necessary to calculate percent of occupancy within the toleration zone).

Operationalizing vulnerability based on species responses

Many species VAs have tried to quantify differences in vulnerabilities by considering the sensitivity of an individual species to climate change, its exposure to climate change stressors, and its adaptive capacity to handle those stressors (Parry *et al.* 2007, Chin *et al.* 2010, Glick *et al.* 2011). While this definition of vulnerability is enticingly simple, it has received criticism for being based on unmeasurable and unclear concepts (Hinkel 2011). In our species VA, we instead quantify vulnerability based on the suite of responses that allow a species to persist under a shifting climate; this approach circumvents many of the limitations of the standard conceptual definition of vulnerability and offers many additional benefits.

Integration with species distribution models—Assessment and SDM-based approaches to evaluating climate change impacts on species have been developing largely parallel to each other, despite the recognized need for more integration (Pearson and Dawson 2003, Dawson *et al.* 2011, Swab *et al.* 2012). Using a response-based definition of species vulnerability allows this integration by putting SDMs within a comprehensive set of considerations. This is a novel approach that can benefit from refinements (see Future Research and Data Needs below). While the response zone concept downplays the importance of species ecotypes (Davis and Shaw 2001), it yields a useful construct where geographical differentiation can be incorporated into the BN-based species vulnerability model by the planned inclusion of non-spatial information, such as species-inherent biological traits (e.g., dispersal impacts on migration response), within the species VA.

Clarity and observability—In comparison with other common species VA approaches that consider sensitivity, exposure, and adaptive capacity as measures of species vulnerability (Williams *et al.* 2008, Foden *et al.* 2013), a response-based assessment is founded on concepts that are directly observable and measurable, and thus, at least in principle, can be validated with time. Additionally, by focusing on responses required for species to persist under climate change, future iterations of our species vulnerability model can likely be directly related to extinction risk, a metric of clear importance in conservation planning.

Consideration of other threats—Although descriptions of climate change vulnerability commonly mention the interactions among climatic and non-climatic threats (Nobis *et al.* 2009, Clements and Ditommaso 2011, Comarazamy *et al.* 2013), in practice, vulnerability assessments rarely evaluate these interactions. Given the widespread impact of non-climatic stressors (e.g., invasive species, land-cover change) on Pacific islands, past vulnerability approaches are of limited use to conservationists and managers dealing with a suite of interacting and ever changing short- and long-term threats to the resilience of the region's socio-ecological systems. Within a response-based species vulnerability model, the impact of current threats on a species' response to climate can be directly explored.

Greater management relevancy—Using the sensitivity, exposure, and adaptive capacity definition of species vulnerability, management implications of assessment results are not entirely clear. For instance, should conservation actions differ among species with either high sensitivity or low adaptive capacity? Focusing on species' responses instead allows for clearer management strategies. For example, a migration response to climate shifts can be supported through enhanced connectivity, dispersal, and colonization assistance. A microrefugia response can be boosted by the establishment and management of strategic reserves that are likely to retain suitable micro-climates (i.e., valley bottom and northern facing slopes). A toleration response can be assisted by reducing non-climatic stressors in areas where species are expected to retain favorable climate space. And lastly, an evolutionary response can be managed by considering gene flow and diversity and maintaining minimum population sizes.

Guidelines and Recommendations for Use of Vulnerability Assessment Results

Given the complex ongoing and projected changes in Hawaiian climate, the need for local and regional adaptation makes VAs increasingly useful decision-making tools for regional resource managers. Following requests from conservation managers for clear guidance regarding the use of assessment results that are based on a complex mix of information, we provide guidance and several considerations that help determine whether the use of VA information is warranted and give recommendations for its appropriate use.

Where to use vulnerability assessment information?

By identifying which species are most vulnerable to climate change, along with factors that influence species vulnerabilities, a VA can help resource managers prioritize conservation actions and strategically allocate funding (Glick *et al.* 2011). Assessment information can be used hypothetically for conservation-related prioritization decisions including what to conserve (e.g., which species to focus on), where to conserve (e.g., prioritizing new protected areas), and how to conserve (i.e., prioritize management actions and conservation strategies), as well as research and monitoring prioritization decisions. Thus, VAs provide important information that can guide adaptive management planning and implementation. Beyond the use of assessment information in current and future prioritization activities, VAs can be used to evaluate the compatibility of current conservation priorities to climate change.

Consider the uncertainties or limitations of the vulnerability assessment and other climate information

Appendix 2 details the main assumptions and limitations of our current effort, and thus serves as a primary means to understanding the extent of this assessment and the ways it may be improved in the future. However, assessment uncertainties are not equal across species and spatial scales. At fine scales the assessment results are less certain (e.g., the link between species' climate envelopes and actual distributions may be more straightforward at the island or biogeographical region scale, but more tenuous within a small parcel). Therefore, we recommend that the results from this assessment be applied at spatial scales larger than small or medium parcel sizes by focusing on broader landscape-level patterns of the results. Additionally, because some of our assessment analyses are likely to be expanded and improved with time, we also recommend that prioritization using VA information focuses on the very high- and very low-vulnerability species, since the scores for these species are less likely to change drastically with additional data.

Consider the prioritization strategy

In conservation prioritization decisions, climate change information can either be the focus (or top consideration) of decision making (i.e., a climate-centered strategy) or can be an additional filter to further screen multiple viable alternatives (i.e., a climate filter strategy). For many prioritization planning efforts in the Pacific islands there are likely more options than resources available, making the climate filter strategy more appropriate in many cases where current VA information can be considered. Even when factoring in the uncertainties and limitations of this assessment, the use of VA information as an additional filter in conservation prioritization improves the chances that subsequent actions will withstand the long-term impacts of climate change, especially when compared to decisions that ignore climate change considerations. For instance, in prioritization of management of conservation areas, VA information could be used to further filter candidate areas for protection that have already been determined to be roughly equivalent in respect to other considerations (e.g., ungulate pressure, distribution of threatened and endangered populations).

Consider whether the redirection of resources away from other serious threats is likely

In few cases, there may be resources available that are dedicated exclusively for climate change adaptation and mitigation (e.g., funding opportunity specifically targeting climate change adaptation projects). In these cases, an additional consideration should be made in regards to whether such proposed climate-related action is compatible with current actions that address other threats.

Despite the fact that there are multiple recognized threats to island ecosystems that may have greater urgency than climate change, the considerations above should help users of this VA realize that there are potentially several opportunities where acting directly on climate change information is warranted (see box below for U.S. Fish and Wildlife Service example). As the proper use may depend on the understanding of the uncertainties and limitations of the approach, if in doubt, managers can contact the Pacific Island Climate Change Cooperative (www.piccc.net) for guidance on the use of the assessment information to address particular needs.

Vulnerability assessment example used by the U.S. Fish and Wildlife Service

The Pacific Islands office of the U.S. Fish and Wildlife Service and its state and private partners are responsible for the protection and recovery of over 525 endangered or threatened plants and animals that occur in Hawai`i, American Samoa, and the Mariana Islands. Evaluating the effects of climate change on conservation actions directed at these species and their habitats is a critical and pressing issue. The information in this vulnerability assessment will aid the service and its partners define the degree to which climate change will affect the conservation of listed species and critical habitats. The vulnerability rankings of the species will be applied to the following actions:

- Prioritization of species for listing and recovery actions will take into account the vulnerability of those species to climate change
- Species listing actions will include comments on the vulnerability of the species to climate change
- Critical habitat designations will include an assessment of how climate change may affect the long-term viability of the habitat
- Recovery planning will include habitat and species vulnerability to climate change.

Future Research and Data Needs

By devising a novel response-based definition of species vulnerability and its BN-based implementation, we have created a framework to comprehensively consider the diverse set of data relevant to determine the vulnerability of individual species to climate change. In doing so, we have purposely defined the current uncertainties and limitations in the approach (see Guidelines and Recommendations for Use of Vulnerability Assessment Results section and Appendix 2) with the intent to lay the groundwork for substantial future improvements. Below are areas that are particularly suited for future research.

Among the biggest limitations of the current assessment is the lack of consideration of species traits known to contribute to the vulnerability of species to climate change. For instance, while our past assessment identifies areas for each species that by 2100 will contain new climate-compatible habitat and the habitat quality of such areas based on several landscape metrics, information regarding reproduction, dispersal, and growth important to whether or not species may migrate to future suitable areas is currently not considered (Perry *et al.* 2005, Nathan *et al.* 2011, Zhu *et al.* 2011). As evolutionary adaptation is related to changes in species traits and characteristics in the context of a specific habitat, the inclusion of species traits and general species characteristics into the BN model should generate first approximations of the relative probability of evolutionary adaptation of a species (Hoffmann and Sgro 2011).

Along with the update of our effort to consider a more comprehensive view of species vulnerability beyond landscape characteristics, we intend to expand our BN-based vulnerability model to include analyses that rigorously define and dynamically update research and monitoring priorities. In turn the new research would ensure future efforts tackle the most important remaining uncertainties in species responses to climate change. Value-of-information analysis can provide a measure of the expected payoff from proposed research, which can be used to set priorities in research and related monitoring (Runge *et al.* 2011). In a similar manner, influence analyses (Marcot 2012) consider the relative impacts of factors in a model and can help determine which refinements (e.g., adding projections to habitat quality analyses) and research gaps (e.g., impact of habitat connectivity) can have the most impact on species responses to climate change. With the completion of these future improvements we should have a well-documented approach that can be applied to other species groups and other areas across the Pacific islands and beyond.

Additionally, at present, the microrefugia concept seems to be most applicable to abundant or widespread species (e.g., *Acacia koa*, *Sophora chrysophylla*) and needs refinement. Species whose distributions are already highly scattered and idiosyncratic seem highly unlikely to have sufficient populations to endure within microrefugia even if they do exist. For these species, one limitation of the approach that must be addressed is the challenge of discerning current microrefugia from within the current distribution. As the species climate envelopes we employed are based on average macro-climate conditions, the difference between current climate-compatible areas and current microrefugia can lead to overly optimistic climate envelopes for species. However, this potential bias is likely minimized by the relatively stable climate of the last millennia and may be partially balanced by the fact that currently the small realized niches of many native plant species seem mostly constrained by non-climatic factors. Nevertheless, improvements can be made through enhanced knowledge of current occupancy within climate envelopes, incorporation of SDMs that may identify current microrefugia through habitat suitability metrics, and a better understanding of the conditions that lead to a decoupling of macro- and micro-climate that results in local refugia (Ashcroft *et al.* 2012b, Temunović *et al.* 2013). A clear first step is a systematic collection of existing species location data and new field data to better describe the distribution of native plant species, particularly in habitat areas that they currently occupy but are not adequately represented in the species location dataset.

CONCLUSIONS

The prospects for Hawaiian flora under climate change are not encouraging as plants face a reduced potential to persist in microrefugia in low-elevation areas due to habitat degradation and limited opportunities for migration due to reduced areas and faster warming at higher elevations (Giambelluca *et al.* 2008). The long history of multiple interacting threats has seemingly left Hawaiian flora perfectly poised to suffer the full blow of the climate shifts expected by 2100. The same threats that have already resulted in over 100 historical plant extinctions in Hawaiʻi have left many species on the edge of existence (U.S. Fish and Wildlife Service 2013). Within this same historical period, many more species have had their naturally small island ranges drastically reduced (Ziegler 2002), a worrisome trend given the link between range size and climate change vulnerability found in this assessment and elsewhere (Thuiller *et al.* 2005a, Ohlemüller *et al.* 2008). Given the vulnerabilities of so many rare species, the consequences of their loss to ecosystem function must be explored (Mouillot *et al.* 2013). One potential saving grace for native plant species is the extreme environmental gradients on these high islands, which reduce the challenge of tracking climate zones by shortening distances necessary in a migration response. This may partially counterbalance the impossibility of latitudinal movement across a continental landscape, as observed in species elsewhere (Huntley and Webb 1989, Parmesan and Yohe 2003).

Without an increased and concerted “climate-smart” conservation effort, it is reasonable to expect Hawaiʽi to be on the leading edge of climate-induced extinctions globally (Thomas *et al.* 2004, Hannah 2012, Warren *et al.* 2013). Because any species, to persist, will have to survive under a new and different climate, acting on climate change information is warranted despite the fact that other threats to island ecosystems may have greater immediacy than climate change. Using the guidelines provided in this assessment, our results can be used in the critical evaluation of goals and priorities of current conservation efforts. More immediately, given the limited resources for conservation in Hawaiʽi, consideration of our VA results can provide a useful additional filter to choose among conservation options, even when uncertainties are large. At the ground scale, action can be focused on species with very high vulnerabilities (such as wink-out and no-overlap species) that are unlikely to see major changes in vulnerability scores even with more refined and expanded future analyses. The fact that climate change vulnerability at a broad level tends to concentrate on already threatened species and associated habitat reinforces the case for controlling the current limiting factors, restoring habitat, and figuring out how to deal with key ecological processes that for many species are currently disrupted (dispersal, pollination, etc.). Ultimately, however, one of the most important components of a climate-smart conservation strategy is to continue to increase management efforts, particularly controlling ungulate populations, invasive plants, and fire, across large landscape units, especially in dry and mesic habitats. By limiting or reducing the effects of these non-climatic threats, and particularly by increasing the viability of microrefugia, native ecosystems and their species may be more resilient to the impacts of a changing climate.

Lastly, this is our first attempt to operationalize our response-based model of species vulnerability. We have clearly outlined the current uncertainties and limitations in our approach to help guide future improvements and expansions. As this VA framework can be updated with improved models and data, we plan to refine these analyses to provide more species- and habitat-specific recommendations, and therefore improve the suite of options available for the challenging task of plant conservation in Hawaiʽi.

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APPENDIX 1. DIAGRAMS OF COMPLETE BAYESIAN NETWORK MODELS OF SPECIES VULNERABILITY TO CLIMATE CHANGE

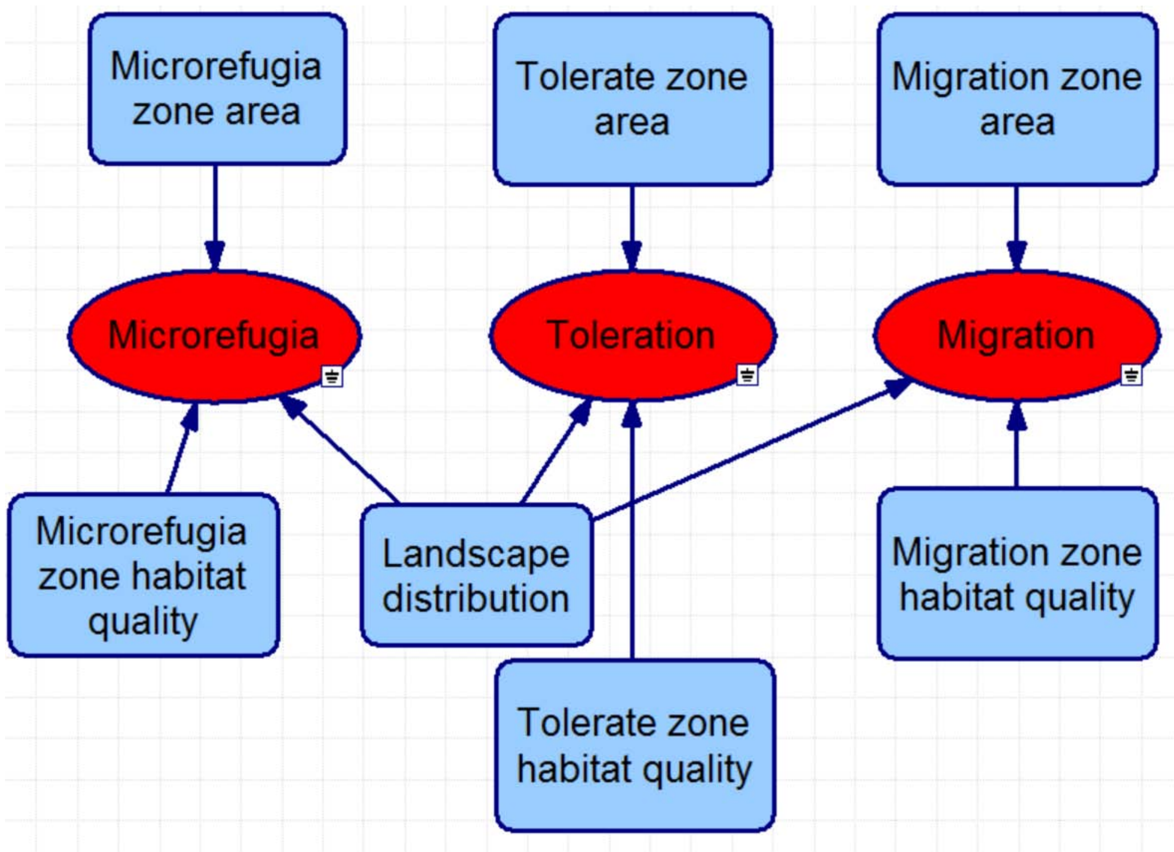


Figure 20. Main model that defines the probability of species responses to climate change (microrefugia, toleration, migration; in red) based on landscape-based factor (in blue). Each of the factors contributing to response probabilities are characterized by individual submodels. The following graphs show each of these submodels along with their factors, states, and priors.

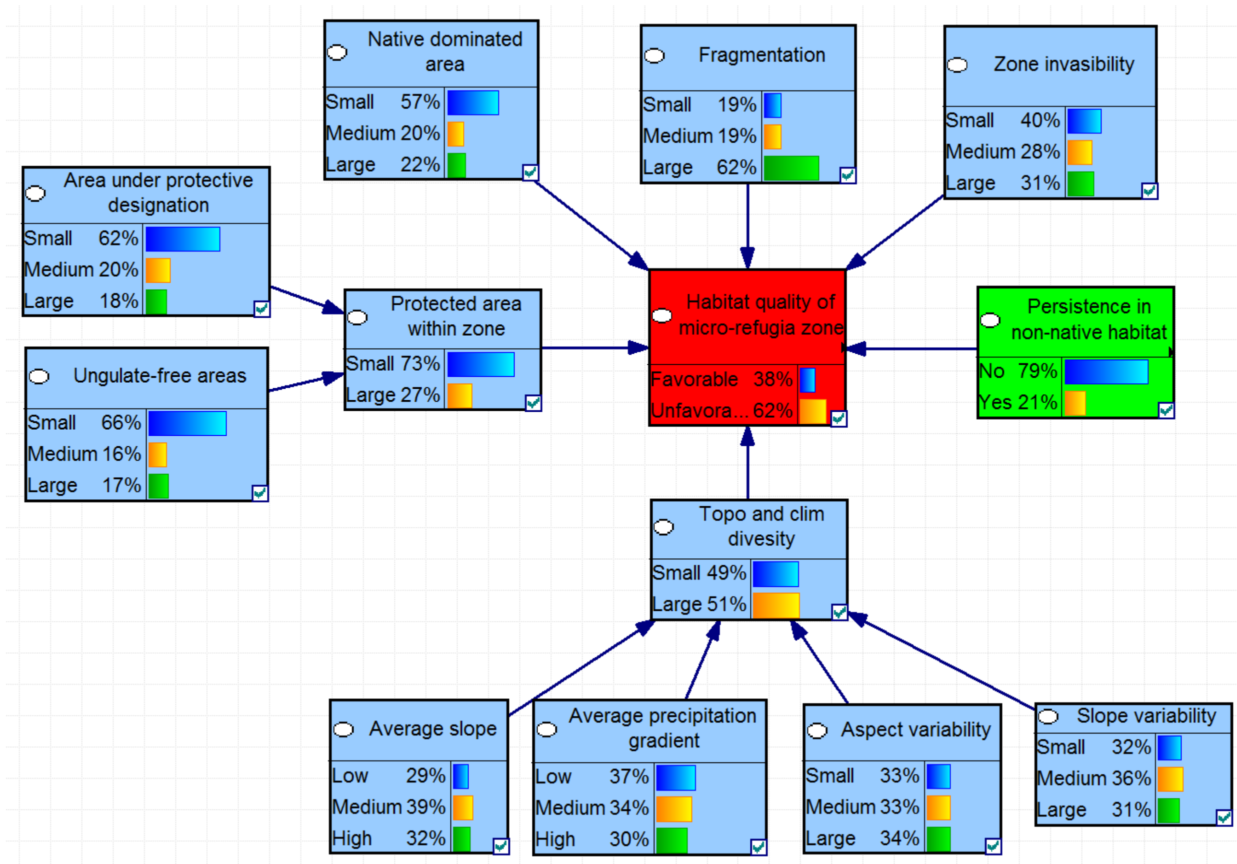


Figure 21. Submodel determining the habitat quality of the microrefugia zone. Green-colored factors are "switch" factors that alter the weight of other factors in the model. In this case, persistence in non-native habitat impacts the importance of native dominated area and zone invasibility on the overall habitat quality of the zone. This habitat quality model varies from similar models for the other zones by also including topographic and climatic diversity (and their subfactors) that are relevant to microrefugia habitat.

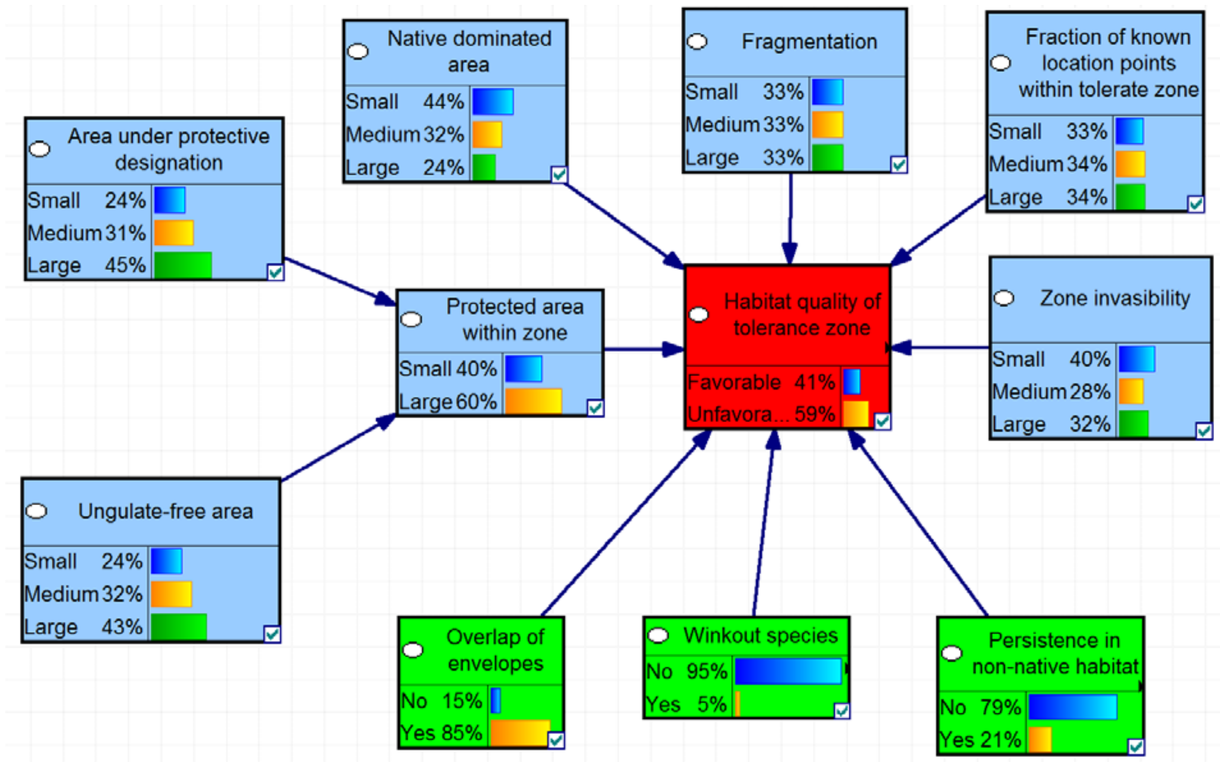


Figure 22. Submodel determining the habitat quality of the toleration zone. In cases where the species does not have any significant effective toleration zone area (due to no overlap between future and current envelopes or no available future envelopes; triggered by the 'winkout species' and 'overlap of envelopes' switch factors), habitat quality for the zone is deemed to be entirely unfavorable. 'Fraction of known location points within the toleration zone' is a specific factor to this submodel that is directly related to the proportion of the individuals/populations of the species that may be in position to make use of this zone.

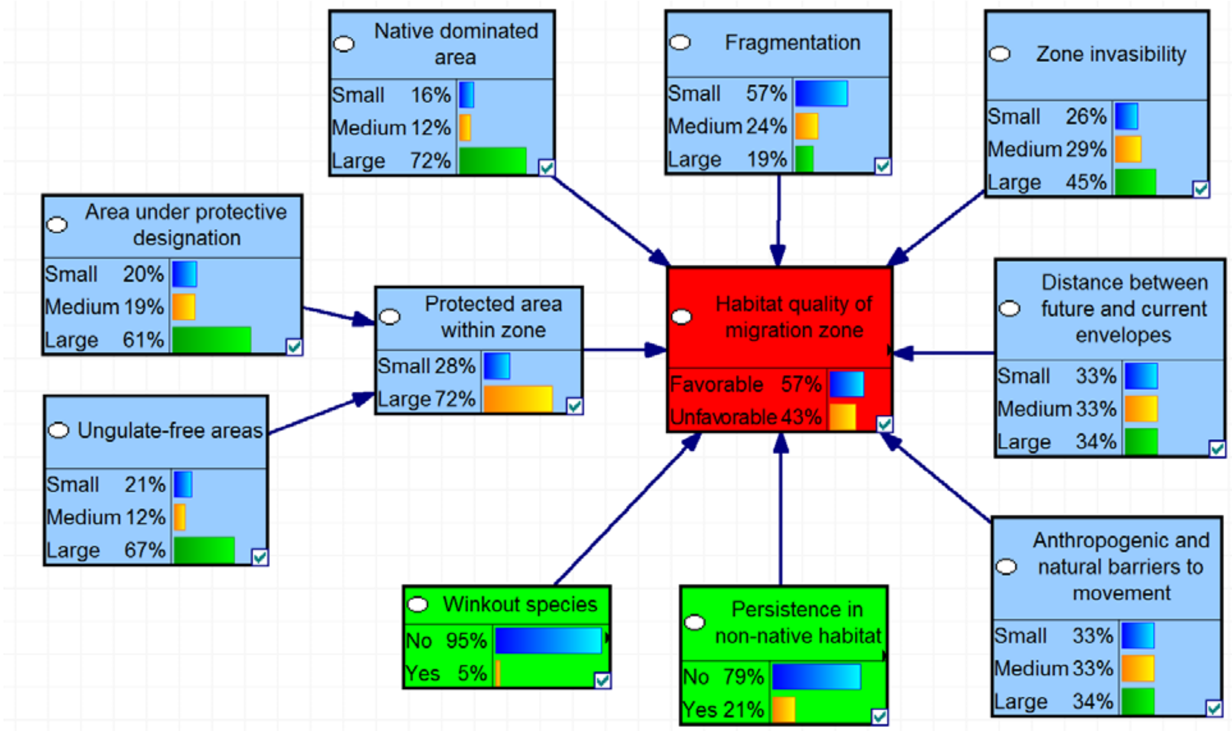


Figure 23. Submodel determining the habitat quality of the migration zone. Distance between current and future climate envelopes and landscape connectivity are specific factors to this submodel since less assessable future climate compatible areas are less useful for the persistence of a plant species.

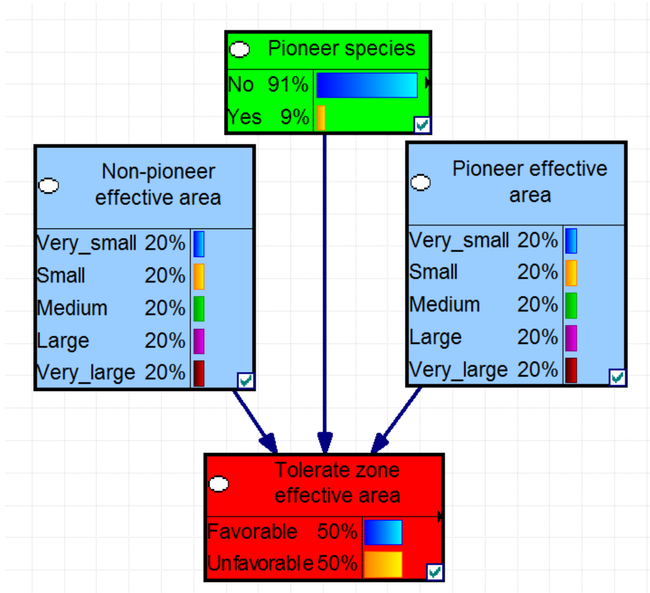


Figure 24. Submodel for determining zone effective area for a species. Pioneer vs non-pioneer effective zone area is chosen by the model based on the 'pioneer species' switch. Pioneer effective area considers area within the zone that overlay with young lava flow substrate as part of its effective area (see Table 1). Both pioneer and non-pioneer effective area subtract projected sea level rise impacted areas and heavily modified areas from total climate compatible area within the zone. All zone effective area submodels are identical.

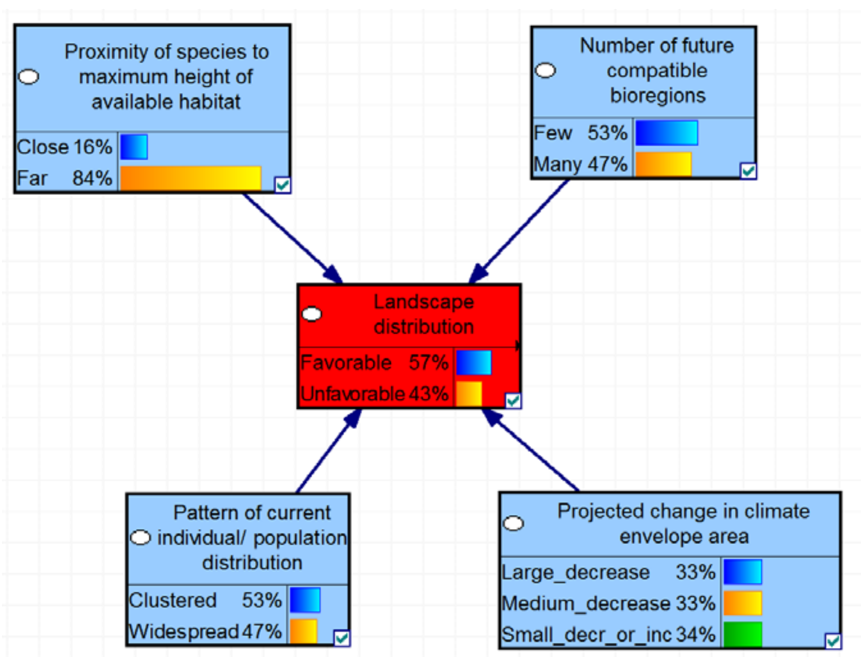


Figure 25. Submodel for determining general (not zone-specific) habitat distribution characteristics of a species that impact the three responses to climate change considered.

APPENDIX 2. MAIN ASSUMPTIONS AND LIMITATIONS OF CURRENT VULNERABILITY ASSESSMENT

Main assumptions:

1. The Bayesian network vulnerability model adequately captures the factors relevant to a species' vulnerability to climate change.

The probabilistic model used to weight available information for each species adequately reflects the relative importance and interactions of factors that define species vulnerability to climate change. As in any vulnerability assessment, many links between species and landscape characteristics to climate change vulnerability are presumed or hypothesized. However, this model offers a baseline model of species vulnerability that can be improved over time with the growing relevant research literature on the subject.

2. The climate projection used is adequate to define vulnerability to climate change.

Despite future climate projections variability and uncertainty, projections used based on the A1B emission scenario (Nakicenovic *et al.* 2000) offer an adequate (if not too optimistic) representation of future climate to define vulnerabilities of species to climate change. Our analysis also assumes that the underlying downscaled climate models provide accurate representations of regional climatic changes by the year 2100. A related strength of our approach is the ability to re-run the analysis with updated climate projections in the future with minimal effort. Because of these climatic uncertainties, it is strongly recommended that these analyses be revised every three to five years to ensure they reflect the best science available.

3. Gaps in species locations records are unrelated to environmental variables.

Species location data represent the full extent of distributions (i.e., no strong bias with respect to environmental variables used in models). Additionally, our models assume that species-climate associations do not vary among islands.

4. Our species climate envelopes approximate the suitable climate space for each species.

While it is widely known that most native species ranges have contracted due to a suite of non-climatic stressors (especially in lowland areas), results from our species distribution models (SDMs) are still useful approximations of suitable climate space for individual species. This is corroborated by several of the non-climatic threats responsible for historical range contractions that seem closely coupled with climate (concurrent forest bird SDMs corroborate that idea).

5. The environmental variables used in the models constrain species' distributions.

In this analysis we assume that environmental variables used to quantify species climate envelopes reflect (directly or indirectly) factors that constrain the distribution of species analyzed, and that annual mean and variability measures are meaningful representations of such variables.

6. There is no change in habitat condition between now and 2100.

Our analyses utilize current habitat condition factors (e.g., current protected area maps, current native/degraded vegetation maps) and do not attempt to project temporal shifts in these conditions between now and 2100. Current habitat quality is likely among the best indicators of habitat quality between now and 2100. As habitat quality has consistently decreased over the history of human occupation of the archipelago, this likely makes our results rather optimistic. Likewise, our analyses do not consider the introduction of new invasive species that deviate strongly from the distribution of current invasives.

7. The impact of interactions among species on individual species vulnerabilities is assumed to be unchanged between now and 2100.

While positive/negative changes in community interactions due to climate and their resulting impact on species vulnerabilities are uncertain and extremely difficult to quantify, these species-centric analyses assume that individual species responses are still a useful indicator of relative vulnerability of species to climate change.

<u>Known limitations:</u>

1. This assessment does not contemplate impacts of climate change beyond 2100.

While the analysis focuses on present climate (defined by 2006 temperature maps and 2011 rainfall maps) and a “middle of the road” future 2100 climate scenario, changes in Hawaiian ecosystems and species distributions due to climate are expected to continue beyond the time range considered in this analysis.

2. Our measure of vulnerability is not an absolute measure that can be directly compared across studies from other regions or different species.

Species vulnerability scores in this assessment are relative scores based on the relative conditions of individual species compared to all other species analyzed (however without considering species interactions as described above). While this makes the individual species scores dependent on the range of species considered in the assessment, this approach reduces the subjectivity in our assessment scores because absolute measures of vulnerability invariably require expert-defined thresholds. A relative measure of vulnerability also arguably better comports the notion that a species’ vulnerability to climate change is dependent on the relative vulnerabilities of co-existing species.

3. This first assessment only considers landscape factors, while leaving out several other factors that may be important to define species vulnerabilities.

This first assessment focuses on landscape factors that partially determine species vulnerability to climate change. An expanded analysis that includes other relevant ecological and demographic traits (e.g., dispersal, reproductive capacity, population density) is planned for the future.

4. This assessment does not consider evolutionary adaptation to climate change or climate-related stressors such as disease.

This limitation is especially relevant to widespread or multi-population species. Natural selection within currently existing variation may lead towards more climate-adapted individuals especially for the more numerous multi-population species that have not suffered past bottlenecks. This omission will likely be addressed in future iterations of the assessment. However, the role of new mutations expanding the climatic range of a species by 2100 is unlikely even for the most short-lived species.

5. Climate envelopes for plants do not imply that the entire area is currently occupied by the species.

The distribution models developed for native plants represent the full extent of compatible climates available for individual species based on known species localities. Hence, while the relative size of these envelopes may be loosely interpreted as differences in niche breadth, they may not be directly related to differences in actual occupancy or habitat suitability.

6. Species climate envelopes used are poorly suited to project distribution of species in novel climates.

The distribution models utilized in this first assessment cannot adequately predict habitat suitability for species in novel climate areas. This limitation is especially relevant to coastal/ lowland species that occur in areas that in the future are warmer than anywhere in Hawaiʽi today.

APPENDIX 3. VULNERABILITY RANKS (IN PERCENT QUANTILES) AND RESPONSE PROBABILITIES TO CLIMATE CHANGE FOR ALL NATIVE HAWAIIAN PLANT SPECIES.

A vulnerability rank of 1 indicate the most vulnerable species, a rank of 0 the least.

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Abutilon eremitopetalum	0.835	0.259	0.24	0.316
Abutilon incanum	0.44	0.341	0.541	0.58
Abutilon menziesii	0.564	0.335	0.516	0.471
Abutilon sandwicense	0.875	0.245	0.32	0.213
Acacia koa	0.0985	0.866	0.847	0.635
Acacia koaia	0.384	0.474	0.659	0.548
Acaena exigua	0.965	0.0169	0.0169	0.263
Achyranthes mutica	0.878	0.146	0.391	0.22
Achyranthes splendens	0.507	0.459	0.51	0.471
Adenophorus abietinus	0.359	0.585	0.606	0.563
Adenophorus epigaeus	0.682	0.467	0.213	0.424
Adenophorus haalilioanus	0.483	0.506	0.606	0.42
Adenophorus hymenophylloides	0.0755	0.963	0.677	0.727
Adenophorus oahuensis	0.669	0.417	0.391	0.374
Adenophorus periens	0.174	0.777	0.748	0.681
Adenophorus pinnatifidus	0.0396	0.959	0.802	0.681
Adenophorus tamariscinus	0.0157	0.895	0.909	0.681
Adenophorus tenellus	0.0184	0.902	0.873	0.71
Adenophorus tripinnatifidus	0.124	0.842	0.677	0.756
Adenostemma viscosum	0.15	0.767	0.838	0.649
Adiantum capillus-veneris	0.263	0.667	0.873	0.495
Agrostis avenacea	0.181	0.81	0.731	0.66
Agrostis sandwicensis	0.18	0.902	0.409	0.774
Alectryon macrococcus	0.623	0.349	0.534	0.381
Alphitonia ponderosa	0.321	0.538	0.748	0.57
Alyxia stellata	0.176	0.774	0.838	0.602
Anoectochilus sandvicensis	0.233	0.792	0.677	0.62
Antidesma platyphyllum	0.0313	0.895	0.909	0.627
Antidesma pulvinatum	0.32	0.513	0.748	0.588
Arachniodes insularis	0.273	0.735	0.57	0.649
Argemone glauca	0.283	0.754	0.646	0.573
Argyroxiphium caliginis	0.931	0.0169	0.231	0.263
Argyroxiphium grayanum	0.601	0.467	0.302	0.467
Argyroxiphium kauense	0.369	0.617	0.445	0.606
Argyroxiphium sandwicense	0.536	0.42	0.427	0.495
Argyroxiphium virescens	0.647	0.417	0.445	0.363
Artemisia australis	0.348	0.582	0.639	0.561

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Artemisia kauaiensis	0.829	0.371	0.284	0.242
Artemisia mauiensis	0.655	0.509	0.469	0.282
Asplenium acuminatum	0.253	0.813	0.606	0.61
Asplenium adiantum-nigrum	0.259	0.938	0.409	0.649
Asplenium aethiopicum	0.0304	0.86	0.873	0.731
Asplenium contiguum	0.226	0.981	0.552	0.585
Asplenium dielerectum	0.309	0.602	0.802	0.517
Asplenium dielfalcatum	0.547	0.41	0.624	0.388
Asplenium dielmannii	0.774	0.367	0.481	0.185
Asplenium dielpallidum	0.954	0.0526	0.338	0.138
Asplenium excisum	0.378	0.706	0.606	0.449
Asplenium haleakalense	0.848	0.0169	0.302	0.37
Asplenium hobdyi	0.434	0.503	0.338	0.599
Asplenium horridum	0.0958	0.8	0.914	0.635
Asplenium insiticium	0.27	0.685	0.677	0.62
Asplenium kaulfussii	0.121	0.767	0.914	0.635
Asplenium lobulatum	0.082	0.81	0.873	0.681
Asplenium macraei	0.156	0.838	0.838	0.56
Asplenium monanthes	0.213	0.706	0.624	0.727
Asplenium nidus	0.192	0.717	0.82	0.647
Asplenium normale	0.22	0.753	0.731	0.635
Asplenium peruvianum	0.0847	0.852	0.838	0.67
Asplenium polyodon	0.07	0.885	0.748	0.745
Asplenium schizophyllum	0.215	0.77	0.641	0.685
Asplenium sphenotomum	0.292	0.61	0.445	0.717
Asplenium trichomanes	0.196	0.852	0.766	0.563
Asplenium unilaterale	0.0331	0.895	0.873	0.681
Asplenium unisorum	0.943	0.0169	0.32	0.188
Astelia argyrocoma	0.495	0.521	0.641	0.37
Astelia menziesiana	0.0994	0.938	0.731	0.681
Astelia waialealae	0.896	0.0169	0.0169	0.392
Athyrium microphyllum	0.165	0.981	0.445	0.745
Bacopa monnieri	0.468	0.26	0.606	0.561
Bidens amplectens	0.883	0.193	0.26	0.254
Bidens asymmetrica	0.841	0.274	0.374	0.231
Bidens campylotheca	0.267	0.767	0.731	0.531
Bidens cervicata	0.804	0.317	0.32	0.285
Bidens conjuncta	0.705	0.46	0.266	0.374
Bidens cosmoides	0.792	0.384	0.365	0.239
Bidens forbesii	0.762	0.585	0.231	0.22
Bidens hawaiensis	0.262	0.774	0.766	0.495
Bidens hillebrandiana	0.964	0.0526	0.177	0.192

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Bidens macrocarpa	0.734	0.417	0.338	0.31
Bidens mauiensis	0.634	0.331	0.338	0.47
Bidens menziesii	0.194	0.783	0.847	0.552
Bidens micrantha	0.45	0.531	0.623	0.435
Bidens molokaiensis	0.882	0.0954	0.266	0.299
Bidens populifolia	0.691	0.396	0.445	0.331
Bidens sandvicensis	0.415	0.549	0.666	0.441
Bidens torta	0.654	0.407	0.28	0.444
Bidens valida	0.658	0.431	0.588	0.249
Bidens wiebkei	0.735	0.281	0.481	0.303
Bobea brevipes	0.396	0.542	0.641	0.499
Bobea elatior	0.0479	0.831	0.909	0.681
Bobea sandwicensis	0.401	0.584	0.588	0.498
Bobea timonioides	0.407	0.449	0.677	0.513
Boehmeria grandis	0.198	0.767	0.873	0.531
Boerhavia acutifolia	0.685	0.0526	0.561	0.448
Boerhavia herbstii	0.581	0.242	0.561	0.473
Boerhavia repens	0.428	0.448	0.521	0.555
Bolboschoenus maritimus	0.988	0.0526	0.0526	0.16
Bonamia menziesii	0.3	0.584	0.722	0.605
Brighamia insignis	0.867	0.124	0.302	0.295
Brighamia rockii	0.838	0.324	0.445	0.163
Broussaisia arguta	0.087	0.874	0.802	0.681
Caesalpinia bonduc	0.425	0.424	0.581	0.543
Caesalpinia kavaiensis	0.421	0.477	0.655	0.489
Calamagrostis expansa	0.239	0.663	0.427	0.77
Calamagrostis hillebrandii	0.712	0.417	0.266	0.385
Callistopteris baldwinii	0.0967	0.917	0.838	0.574
Canavalia galeata	0.757	0.292	0.353	0.337
Canavalia hawaiiensis	0.314	0.553	0.806	0.54
Canavalia kauaiensis	0.716	0.366	0.414	0.329
Canavalia molokaiensis	0.761	0.281	0.588	0.185
Canavalia napaliensis	0.711	0.31	0.481	0.331
Canavalia pubescens	0.596	0.374	0.474	0.436
Capparis sandwichiana	0.442	0.399	0.541	0.555
Carex alligata	0.224	0.915	0.512	0.668
Carex echinata	0.4	0.503	0.302	0.652
Carex kauaiensis	0.891	0.0169	0.374	0.263
Carex macloviana	0.108	0.852	0.695	0.756
Carex meyenii	0.183	0.831	0.731	0.638
Carex montis-eeka	0.214	0.77	0.391	0.781
Carex thunbergii	0.708	0.0169	0.445	0.477

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Carex wahuensis	0.0856	0.89	0.806	0.66
Cassytha filiformis	0.322	0.585	0.713	0.563
Cenchrus agrimonioides	0.409	0.559	0.568	0.51
Centaurium sebaeoides	0.736	0.0526	0.409	0.438
Charpentiera densiflora	0.778	0.224	0.409	0.31
Charpentiera elliptica	0.709	0.413	0.391	0.328
Charpentiera obovata	0.132	0.816	0.84	0.635
Charpentiera ovata	0.115	0.788	0.891	0.649
Charpentiera tomentosa	0.222	0.681	0.873	0.574
Cheirodendron dominii	0.755	0.467	0.266	0.295
Cheirodendron fauriei	0.459	0.521	0.641	0.413
Cheirodendron forbesii	0.625	0.0883	0.534	0.495
Cheirodendron platyphyllum	0.519	0.421	0.57	0.442
Cheirodendron trigynum	0.126	0.895	0.731	0.681
Chenopodium oahuense	0.277	0.622	0.793	0.573
Chrysopogon aciculatus	0.291	0.513	0.82	0.599
Cibotium chamissoi	0.093	0.849	0.914	0.561
Cibotium glaucum	0.0552	0.866	0.887	0.655
Cibotium menziesii	0.00921	0.907	0.94	0.668
Cibotium nealiae	0.495	0.521	0.641	0.37
Cladium jamaicense	0.229	0.693	0.873	0.54
Claoxylon sandwicense	0.34	0.538	0.802	0.495
Clermontia arborescens	0.367	0.627	0.534	0.563
Clermontia calophylla	0.554	0.603	0.588	0.26
Clermontia clermontioides	0.234	0.795	0.766	0.538
Clermontia drepanomorpha	0.551	0.546	0.374	0.449
Clermontia fauriei	0.582	0.531	0.409	0.402
Clermontia grandiflora	0.365	0.628	0.427	0.617
Clermontia hawaiiensis	0.113	0.959	0.802	0.531
Clermontia kakeana	0.315	0.716	0.655	0.53
Clermontia kohalae	0.352	0.688	0.766	0.367
Clermontia lindseyana	0.0727	0.77	0.748	0.802
Clermontia micrantha	0.683	0.485	0.333	0.356
Clermontia montis-loa	0.247	0.852	0.552	0.638
Clermontia oblongifolia	0.329	0.627	0.606	0.585
Clermontia pallida	0.733	0.403	0.302	0.338
Clermontia parviflora	0.164	0.852	0.838	0.531
Clermontia peleana	0.252	0.735	0.641	0.638
Clermontia persicifolia	0.642	0.46	0.391	0.374
Clermontia pyrularia	0.617	0.288	0.266	0.535
Clermontia samuelii	0.444	0.627	0.427	0.499
Clermontia tuberculata	0.651	0.502	0.374	0.353

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Clermontia waimeae	0.488	0.467	0.445	0.52
Cocculus orbiculatus	0.173	0.78	0.851	0.591
Colubrina asiatica	0.892	0.0526	0.275	0.287
Colubrina oppositifolia	0.33	0.584	0.748	0.522
Coniogramme pilosa	0.035	0.885	0.748	0.799
Coprosma cymosa	0.38	0.496	0.784	0.463
Coprosma elliptica	0.926	0.0169	0.0169	0.349
Coprosma ernodeoides	0.00645	0.948	0.806	0.812
Coprosma foliosa	0.394	0.585	0.606	0.499
Coprosma kauensis	0.592	0.563	0.338	0.413
Coprosma longifolia	0.713	0.424	0.266	0.381
Coprosma menziesii	0.139	0.831	0.766	0.681
Coprosma montana	0.0645	0.852	0.873	0.67
Coprosma ochracea	0.0681	0.845	0.673	0.808
Coprosma pubens	0.0138	0.938	0.873	0.67
Coprosma rhynchocarpa	0.0101	0.895	0.838	0.81
Coprosma ternata	0.656	0.446	0.231	0.445
Coprosma waimeae	0.781	0.306	0.391	0.274
Crepidomanes minutum	0.123	0.81	0.909	0.585
Cressa truxillensis	0.995	0.0169	0.0169	0.124
Cryptocarya mannii	0.493	0.424	0.588	0.467
Ctenitis latifrons	0.148	0.831	0.838	0.585
Ctenitis squamigera	0.413	0.449	0.677	0.502
Cuscuta sandwichiana	0.474	0.316	0.548	0.555
Cyanea aculeatiflora	0.461	0.52	0.534	0.477
Cyanea acuminata	0.684	0.46	0.32	0.374
Cyanea angustifolia	0.358	0.675	0.621	0.498
Cyanea arborea	0.866	0.0883	0.552	0.195
Cyanea asarifolia	0.532	0.499	0.552	0.392
Cyanea asplenifolia	0.579	0.0883	0.695	0.485
Cyanea calycina	0.631	0.567	0.32	0.374
Cyanea comata	0.93	0.0883	0.374	0.163
Cyanea copelandii	0.447	0.567	0.409	0.535
Cyanea coriacea	0.539	0.413	0.624	0.392
Cyanea crispa	0.649	0.395	0.445	0.374
Cyanea dunbariae	0.727	0.0705	0.57	0.381
Cyanea elliptica	0.272	0.688	0.731	0.581
Cyanea fauriei	0.799	0.331	0.374	0.256
Cyanea fissa	0.55	0.456	0.659	0.328
Cyanea floribunda	0.134	0.81	0.695	0.745
Cyanea gibsonii	0.914	0.0169	0.0169	0.37
Cyanea giffardii	0.808	0.0883	0.463	0.324

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Cyanea glabra	0.504	0.46	0.481	0.492
Cyanea grimesiana	0.497	0.52	0.606	0.392
Cyanea habenata	0.831	0.0526	0.534	0.278
Cyanea hamatiflora	0.378	0.563	0.641	0.52
Cyanea hardyi	0.752	0.349	0.427	0.274
Cyanea hirtella	0.559	0.563	0.463	0.381
Cyanea horrida	0.506	0.563	0.534	0.402
Cyanea humboldtiana	0.636	0.417	0.374	0.417
Cyanea kahiliensis	0.58	0.392	0.534	0.413
Cyanea kolekoleensis	0.812	0.0526	0.427	0.353
Cyanea koolauensis	0.888	0.0169	0.374	0.274
Cyanea kunthiana	0.594	0.467	0.409	0.424
Cyanea lanceolata	0.697	0.338	0.391	0.381
Cyanea leptostegia	0.924	0.146	0.124	0.263
Cyanea lobata	0.644	0.442	0.57	0.27
Cyanea longiflora	0.687	0.417	0.356	0.374
Cyanea longissima	0.432	0.478	0.606	0.499
Cyanea macrostegia	0.419	0.585	0.427	0.552
Cyanea mannii	0.844	0.31	0.445	0.16
Cyanea marksii	0.56	0.563	0.445	0.392
Cyanea mceldowneyi	0.531	0.328	0.57	0.477
Cyanea membranacea	0.887	0.288	0.356	0.138
Cyanea munroi	0.779	0.0526	0.463	0.363
Cyanea obtusa	0.615	0.431	0.606	0.302
Cyanea pilosa	0.0746	0.856	0.677	0.792
Cyanea pinnatifida	0.913	0.0705	0.302	0.242
Cyanea platyphylla	0.168	0.831	0.856	0.531
Cyanea procera	0.6	0.477	0.463	0.381
Cyanea purpurellifolia	0.866	0.0169	0.374	0.317
Cyanea quercifolia	0.93	0.0883	0.374	0.163
Cyanea recta	0.492	0.606	0.463	0.435
Cyanea remyi	0.574	0.413	0.57	0.392
Cyanea scabra	0.635	0.521	0.32	0.392
Cyanea sessilifolia	0.911	0.0169	0.338	0.253
Cyanea shipmanii	0.8	0.0169	0.0169	0.51
Cyanea solanacea	0.717	0.317	0.445	0.338
Cyanea solenocalyx	0.622	0.563	0.32	0.381
Cyanea spathulata	0.43	0.538	0.624	0.452
Cyanea st.-johnii	0.962	0.0169	0.0169	0.274
Cyanea stictophylla	0.0543	0.813	0.641	0.845
Cyanea superba	0.936	0.0169	0.32	0.21
Cyanea sylvestris	0.544	0.478	0.588	0.37

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Cyanea tritomantha	0.146	0.852	0.838	0.563
Cyanea truncata	0.76	0.0526	0.481	0.374
Cyanea undulata	0.934	0.0705	0.266	0.22
Cyclosorus boydiae	0.431	0.774	0.624	0.238
Cyclosorus cyatheoides	0.0773	0.853	0.873	0.638
Cyclosorus hudsonianus	0.0838	0.81	0.909	0.638
Cyclosorus interruptus	0.149	0.709	0.914	0.635
Cyclosorus sandwicensis	0.0884	0.981	0.695	0.681
Cyclosorus wailele	0.502	0.453	0.641	0.41
Cyperus cyperinus	0.686	0.346	0.481	0.345
Cyperus fauriei	0.289	0.624	0.838	0.506
Cyperus hillebrandii	0.205	0.681	0.873	0.606
Cyperus hypochlorus	0.266	0.685	0.695	0.62
Cyperus javanicus	0.398	0.441	0.619	0.561
Cyperus laevigatus	0.988	0.0526	0.0526	0.16
Cyperus odoratus	0.473	0.299	0.641	0.524
Cyperus pennatiformis	0.31	0.717	0.806	0.388
Cyperus phleoides	0.193	0.688	0.873	0.624
Cyperus polystachyos	0.12	0.813	0.878	0.624
Cyperus sandwicensis	0.319	0.663	0.713	0.513
Cyperus trachysanthos	0.729	0.0526	0.414	0.448
Cyrtandra biserrata	0.476	0.517	0.695	0.356
Cyrtandra calpidicarpa	0.621	0.438	0.516	0.342
Cyrtandra confertiflora	0.516	0.563	0.606	0.328
Cyrtandra cordifolia	0.672	0.456	0.499	0.285
Cyrtandra crenata	0.784	0.0705	0.606	0.285
Cyrtandra cyaneoides	0.454	0.452	0.659	0.452
Cyrtandra dentata	0.693	0.338	0.481	0.338
Cyrtandra ferripilosa	0.773	0.0526	0.374	0.406
Cyrtandra filipes	0.387	0.645	0.749	0.345
Cyrtandra garnotiana	0.659	0.396	0.427	0.374
Cyrtandra giffardii	0.189	0.72	0.677	0.731
Cyrtandra grandiflora	0.634	0.331	0.552	0.374
Cyrtandra grayana	0.553	0.628	0.356	0.413
Cyrtandra grayi	0.517	0.581	0.588	0.324
Cyrtandra halawensis	0.524	0.645	0.588	0.26
Cyrtandra hashimotoi	0.42	0.67	0.499	0.467
Cyrtandra hawaiensis	0.127	0.81	0.909	0.574
Cyrtandra heinrichii	0.773	0.0526	0.552	0.331
Cyrtandra hematos	0.953	0.0169	0.0169	0.295
Cyrtandra kalihii	0.646	0.524	0.32	0.374
Cyrtandra kamooloaensis	0.487	0.521	0.641	0.381

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Cyrtandra kauaiensis	0.459	0.521	0.641	0.413
Cyrtandra kaulantha	0.894	0.0526	0.409	0.224
Cyrtandra kealiae	0.52	0.452	0.606	0.399
Cyrtandra kohalae	0.589	0.474	0.659	0.26
Cyrtandra laxiflora	0.831	0.456	0.177	0.253
Cyrtandra lessoniana	0.737	0.46	0.159	0.374
Cyrtandra longifolia	0.555	0.585	0.463	0.37
Cyrtandra lydgatei	0.464	0.71	0.481	0.388
Cyrtandra lysiosepala	0.0525	0.959	0.909	0.36
Cyrtandra macraei	0.666	0.331	0.481	0.374
Cyrtandra macrocalyx	0.552	0.52	0.516	0.381
Cyrtandra menziesii	0.192	0.795	0.873	0.506
Cyrtandra munroi	0.606	0.495	0.588	0.281
Cyrtandra nanawalensis	0.678	0.0526	0.552	0.46
Cyrtandra oenobarba	0.664	0.0883	0.606	0.431
Cyrtandra oxybapha	0.901	0.0169	0.266	0.295
Cyrtandra paliku	0.857	0.0526	0.356	0.32
Cyrtandra paludosa	0.00184	0.959	0.945	0.574
Cyrtandra pickeringii	0.503	0.477	0.641	0.392
Cyrtandra platyphylla	0.00737	0.981	0.873	0.67
Cyrtandra polyantha	0.945	0.0169	0.266	0.21
Cyrtandra procera	0.728	0.403	0.32	0.338
Cyrtandra propinqua	0.57	0.456	0.534	0.392
Cyrtandra rivularis	0.624	0.374	0.516	0.374
Cyrtandra sandwicensis	0.886	0.0169	0.374	0.274
Cyrtandra sessilis	0.948	0.0169	0.338	0.167
Cyrtandra spathulata	0.392	0.71	0.695	0.324
Cyrtandra subumbellata	0.763	0.274	0.374	0.317
Cyrtandra tintinnabula	0.206	0.731	0.838	0.592
Cyrtandra viridiflora	0.973	0.0169	0.0169	0.253
Cyrtandra waianaeensis	0.817	0.396	0.32	0.224
Cyrtandra wainihaensis	0.599	0.371	0.588	0.37
Cyrtandra waiolani	0.921	0.0169	0.391	0.21
Cyrtandra wawrae	0.602	0.435	0.588	0.328
Cyrtomium caryotideum	0.282	0.651	0.806	0.528
Cystopteris douglasii	0.368	0.681	0.641	0.456
Cystopteris sandwicensis	0.665	0.481	0.266	0.406
Delissea niihauensis	0.877	0.324	0.374	0.131
Delissea rhytidosperma	0.607	0.413	0.606	0.328
Delissea subcordata	0.692	0.352	0.463	0.342
Delissea undulata	0.593	0.496	0.606	0.281
Deparia fenzliana	0.583	0.371	0.624	0.37

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Deparia marginalis	0.169	0.745	0.909	0.574
Deparia prolifera	0.261	0.642	0.695	0.652
Deschampsia nubigena	0.0599	0.938	0.802	0.66
Dianella sandwicensis	0.0829	0.866	0.847	0.647
Dichanthelium cynodon	0.332	0.663	0.427	0.642
Dichanthelium hillebrandianum	0.227	0.735	0.606	0.702
Dichanthelium isachnoides	0.701	0.467	0.374	0.317
Dichanthelium koolauense	0.64	0.467	0.338	0.402
Dicranopteris linearis	0.0907	0.898	0.806	0.647
Digitaria setigera	0.274	0.628	0.766	0.595
Diospyros hillebrandii	0.638	0.341	0.454	0.411
Diospyros sandwicensis	0.185	0.684	0.847	0.66
Diplazium arnottii	0.457	0.578	0.463	0.492
Diplazium molokaiense	0.426	0.521	0.641	0.456
Diplazium sandwichianum	0.105	0.866	0.806	0.668
Diplopterygium pinnatum	0.0239	0.902	0.909	0.635
Dissochondrus biflorus	0.618	0.367	0.57	0.367
Dodonaea viscosa	0.2	0.805	0.771	0.591
Doodia kunthiana	0.351	0.584	0.715	0.51
Doodia lyonii	0.268	0.645	0.838	0.538
Doryopteris angelica	0.825	0.22	0.391	0.274
Doryopteris decipiens	0.366	0.466	0.706	0.561
Doryopteris decora	0.235	0.674	0.831	0.591
Doryopteris takeuchii	0.982	0.0169	0.0169	0.224
Drosera anglica	0.614	0.627	0.374	0.327
Dryopteris crinalis	0.275	0.813	0.57	0.599
Dryopteris fusco-atra	0.0387	0.902	0.766	0.774
Dryopteris glabra	0.175	0.927	0.499	0.735
Dryopteris hawaiiensis	0.138	0.902	0.766	0.613
Dryopteris mauiensis	0.293	0.653	0.552	0.663
Dryopteris rubiginosum	0.13	0.777	0.499	0.831
Dryopteris sandwicensis	0.117	0.81	0.873	0.638
Dryopteris subbipinnata	0.762	0.0169	0.409	0.413
Dryopteris tetrapinnata	0.48	0.563	0.499	0.456
Dryopteris unidentata	0.0221	0.86	0.838	0.774
Dryopteris wallichiana	0.106	0.83	0.572	0.817
Dubautia arborea	0.436	0.463	0.57	0.517
Dubautia ciliolata	0.0654	0.817	0.659	0.827
Dubautia herbstobatae	0.986	0.117	0.124	0.117
Dubautia imbricata	0.541	0.521	0.356	0.477
Dubautia knudsenii	0.511	0.563	0.534	0.392

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Dubautia laevigata	0.723	0.431	0.516	0.206
Dubautia latifolia	0.807	0.267	0.338	0.299
Dubautia laxa	0.298	0.735	0.534	0.627
Dubautia linearis	0.0249	0.86	0.802	0.795
Dubautia menziesii	0.732	0.542	0.427	0.178
Dubautia microcephala	0.657	0.456	0.499	0.295
Dubautia paleata	0.755	0.467	0.266	0.295
Dubautia pauciflorula	0.823	0.0526	0.391	0.353
Dubautia plantaginea	0.17	0.856	0.713	0.652
Dubautia platyphylla	0.71	0.381	0.32	0.381
Dubautia raillardioides	0.522	0.499	0.499	0.435
Dubautia reticulata	0.652	0.374	0.481	0.363
Dubautia scabra	0.0589	0.948	0.847	0.573
Dubautia sherffiana	0.919	0.253	0.249	0.167
Dubautia syndetica	0.753	0.0705	0.516	0.37
Dubautia waialealae	0.811	0.295	0.195	0.349
Dubautia waianapanapaensis	0.604	0.563	0.391	0.37
Elaeocarpus bifidus	0.465	0.585	0.641	0.36
Elaphoglossum aemulum	0.199	0.788	0.802	0.585
Elaphoglossum alatum	0.182	0.752	0.873	0.581
Elaphoglossum crassicaule	0.549	0.573	0.472	0.379
Elaphoglossum crassifolium	0.0764	0.8	0.914	0.655
Elaphoglossum fauriei	0.657	0.51	0.302	0.381
Elaphoglossum paleaceum	0.047	0.894	0.78	0.746
Elaphoglossum parvisquameum	0.116	0.903	0.766	0.656
Elaphoglossum pellucidum	0.00552	0.917	0.945	0.681
Elaphoglossum wawrae	0.0737	0.842	0.748	0.767
Eleocharis calva	0.785	0.165	0.366	0.355
Eleocharis obtusa	0.118	0.923	0.806	0.573
Embelia pacifica	0.0147	0.895	0.909	0.681
Entada phaseoloides	0.912	0.0526	0.445	0.181
Eragrostis atropioides	0.303	0.624	0.695	0.592
Eragrostis deflexa	0.411	0.51	0.713	0.445
Eragrostis fosbergii	0.849	0.31	0.284	0.245
Eragrostis grandis	0.137	0.81	0.838	0.638
Eragrostis leptophylla	0.357	0.624	0.695	0.485
Eragrostis monticola	0.528	0.443	0.623	0.385
Eragrostis paupera	0.97	0.0526	0.0526	0.227
Eragrostis variabilis	0.225	0.713	0.833	0.573
Erythrina sandwicensis	0.364	0.466	0.686	0.573
Eugenia koolauensis	0.714	0.0526	0.445	0.46

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Eugenia reinwardtiana	0.449	0.492	0.606	0.47
Euphorbia arnottiana	0.874	0.274	0.231	0.253
Euphorbia atrococca	0.718	0.371	0.499	0.274
Euphorbia celastroides	0.258	0.631	0.833	0.573
Euphorbia clusiifolia	0.694	0.374	0.374	0.374
Euphorbia degeneri	0.859	0.0526	0.22	0.374
Euphorbia deppeana	0.84	0.306	0.463	0.156
Euphorbia eleanoriae	0.783	0.306	0.463	0.231
Euphorbia haeleeleana	0.661	0.328	0.534	0.349
Euphorbia halemanui	0.703	0.37	0.499	0.295
Euphorbia herbstii	0.837	0.306	0.409	0.199
Euphorbia kuwaleana	0.818	0.246	0.213	0.352
Euphorbia multiformis	0.264	0.635	0.873	0.528
Euphorbia olowaluana	0.439	0.574	0.695	0.36
Euphorbia remyi	0.498	0.52	0.606	0.392
Euphorbia rockii	0.973	0.0169	0.0169	0.253
Euphorbia skottsbergii	0.641	0.288	0.409	0.449
Euphorbia sparsiflora	0.744	0.0705	0.534	0.37
Eurya sandwicensis	0.011	0.902	0.873	0.752
Exocarpos gaudichaudii	0.255	0.777	0.659	0.595
Exocarpos luteolus	0.496	0.477	0.606	0.424
Exocarpos menziesii	0.356	0.638	0.731	0.445
Festuca hawaiiensis	0.47	0.453	0.713	0.399
Fimbristylis cymosa	0.345	0.491	0.713	0.573
Fimbristylis dichotoma	0.19	0.841	0.699	0.647
Fimbristylis hawaiiensis	0.355	0.599	0.713	0.492
Flueggea neowawraea	0.37	0.51	0.748	0.499
Fragaria chiloensis	0.231	0.706	0.677	0.674
Freycinetia arborea	0.023	0.895	0.909	0.649
Gahnia aspera	0.791	0.249	0.427	0.281
Gahnia beecheyi	0.414	0.727	0.391	0.502
Gahnia lanaiensis	0.903	0.0169	0.0169	0.381
Gahnia vitiensis	0.529	0.628	0.356	0.435
Gardenia brighamii	0.576	0.41	0.409	0.471
Gardenia mannii	0.648	0.456	0.588	0.242
Gardenia remyi	0.21	0.693	0.887	0.573
Geranium arboreum	0.633	0.46	0.445	0.363
Geranium cuneatum	0.133	0.649	0.606	0.831
Geranium hanaense	0.942	0.0169	0.0169	0.317
Geranium hillebrandii	0.795	0.274	0.28	0.338
Geranium kauaiense	0.926	0.0169	0.0169	0.349
Geranium multiflorum	0.533	0.477	0.534	0.413

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Gossypium tomentosum	0.721	0.0526	0.454	0.448
Gouania hillebrandii	0.67	0.288	0.356	0.449
Gouania meyenii	0.916	0.0348	0.356	0.228
Gouania vitifolia	0.577	0.392	0.592	0.384
Grammitis baldwinii	0.688	0.431	0.481	0.292
Grammitis forbesiana	0.301	0.663	0.57	0.642
Grammitis hookeri	0.212	0.885	0.427	0.735
Gunnera kauaiensis	0.739	0.467	0.338	0.274
Gunnera petaloïdea	0.353	0.628	0.356	0.66
Haplopteris elongata	0.115	0.788	0.891	0.649
Haplostachys haplostachya	0.32	0.643	0.847	0.4
Haplostachys linearifolia	0.797	0.317	0.106	0.392
Heliotropium anomalum	0.918	0.0526	0.0526	0.341
Heliotropium curassavicum	0.851	0.0526	0.24	0.374
Hesperocnide sandwicensis	0.25	0.667	0.731	0.635
Hesperomannia arborescens	0.397	0.465	0.675	0.522
Hesperomannia arbuscula	0.63	0.416	0.592	0.297
Hesperomannia lydgatei	0.561	0.456	0.552	0.392
Heteropogon contortus	0.331	0.582	0.666	0.573
Hibiscadelphus distans	0.879	0.0705	0.356	0.274
Hibiscadelphus hualalaiensis	0.932	0.0705	0.338	0.188
Hibiscadelphus woodii	0.993	0.0169	0.0169	0.145
Hibiscus arnottianus	0.514	0.384	0.586	0.462
Hibiscus brackenridgei	0.382	0.441	0.619	0.585
Hibiscus clayi	0.91	0.102	0.367	0.197
Hibiscus furcellatus	0.376	0.436	0.715	0.555
Hibiscus kokio	0.228	0.584	0.896	0.617
Hibiscus waimeae	0.597	0.413	0.57	0.36
Hillebrandia sandwicensis	0.453	0.52	0.57	0.467
Huperzia erosa	0.244	0.778	0.356	0.756
Huperzia erubescens	0.159	0.77	0.606	0.77
Huperzia filiformis	0.178	0.932	0.699	0.581
Huperzia haleakalae	0.699	0.467	0.302	0.36
Huperzia mannii	0.337	0.37	0.695	0.649
Huperzia nutans	0.789	0.0169	0.499	0.36
Huperzia phyllantha	0.0405	0.852	0.909	0.681
Huperzia serrata	0.286	0.813	0.427	0.652
Huperzia stemmermanniae	0.578	0.0883	0.695	0.485
Huperzia subintegra	0.405	0.628	0.356	0.585
Hymenophyllum lanceolatum	0.191	0.778	0.784	0.627
Hymenophyllum obtusum	0.154	0.774	0.873	0.602
Hymenophyllum recurvum	0.00276	0.938	0.909	0.724

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Hypolepis hawaiiensis	0.25	0.735	0.427	0.735
Ilex anomala	0.1	0.898	0.806	0.635
Ipomoea imperati	0.957	0.0526	0.0526	0.267
Ipomoea indica	0.316	0.582	0.726	0.573
Ipomoea littoralis	0.955	0.0883	0.0883	0.238
Ipomoea pes-caprae	0.707	0.259	0.199	0.481
Ipomoea tuboides	0.379	0.441	0.659	0.573
Isachne distichophylla	0.000921	0.959	0.945	0.681
Isachne pallens	0.486	0.542	0.606	0.392
Ischaemum byrone	0.852	0.0883	0.302	0.335
Isodendrion hosakae	0.827	0.0883	0.338	0.356
Isodendrion laurifolium	0.843	0.185	0.463	0.228
Isodendrion longifolium	0.49	0.477	0.659	0.392
Isodendrion pyrifolium	0.726	0.106	0.534	0.382
Isoetes hawaiiensis	0.584	0.438	0.409	0.449
Jacquemontia ovalifolia	0.462	0.448	0.44	0.555
Joinvillea ascendens	0.00829	0.907	0.914	0.725
Kadua acuminata	0.143	0.81	0.909	0.531
Kadua affinis	0.0801	0.89	0.806	0.668
Kadua axillaris	0.0046	0.895	0.909	0.777
Kadua centranthoides	0.0562	0.902	0.766	0.742
Kadua cookiana	0.869	0.221	0.356	0.22
Kadua cordata	0.287	0.813	0.606	0.545
Kadua coriacea	0.611	0.524	0.588	0.245
Kadua degeneri	0.815	0.349	0.409	0.199
Kadua elatior	0.288	0.685	0.784	0.502
Kadua fluviatilis	0.506	0.563	0.641	0.317
Kadua flynnii	0.643	0.367	0.552	0.335
Kadua foggiana	0.459	0.521	0.641	0.413
Kadua formosa	0.408	0.624	0.784	0.281
Kadua fosbergii	0.802	0.36	0.302	0.274
Kadua knudsenii	0.781	0.306	0.391	0.274
Kadua laxiflora	0.395	0.645	0.641	0.431
Kadua littoralis	0.936	0.0883	0.195	0.238
Kadua parvula	0.96	0.0169	0.231	0.188
Kadua st.-johnii	0.978	0.0526	0.124	0.185
Kadua tryblium	0.417	0.538	0.659	0.452
Kanaloa kahoolawensis	0.997	0.0169	0.0169	0.113
Keysseria erici	0.819	0.274	0.213	0.338
Keysseria helenae	0.926	0.0169	0.0169	0.349
Keysseria maviensis	0.512	0.51	0.481	0.456
Kokia drynarioides	0.73	0.324	0.481	0.292

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Kokia kauaiensis	0.758	0.238	0.481	0.292
Korthalsella complanata	0.0709	0.831	0.873	0.681
Korthalsella cylindrica	0.157	0.795	0.802	0.645
Korthalsella degeneri	0.983	0.0526	0.231	0.106
Korthalsella latissima	0.141	0.67	0.82	0.745
Korthalsella platycaula	0.433	0.456	0.606	0.51
Korthalsella remyana	0.248	0.749	0.695	0.61
Labordia cyrtandrae	0.698	0.46	0.284	0.374
Labordia degeneri	0.68	0.438	0.445	0.32
Labordia fagraeoidea	0.768	0.338	0.302	0.317
Labordia hedyosmifolia	0.0783	0.945	0.766	0.656
Labordia helleri	0.535	0.456	0.606	0.381
Labordia hirtella	0.144	0.853	0.731	0.681
Labordia hosakana	0.952	0.0169	0.0169	0.295
Labordia kaalae	0.881	0.352	0.284	0.16
Labordia lydgatei	0.668	0.0883	0.552	0.452
Labordia pumila	0.786	0.317	0.249	0.338
Labordia sessilis	0.973	0.0169	0.0169	0.253
Labordia tinifolia	0.107	0.745	0.909	0.681
Labordia triflora	0.998	0.0169	0.0169	0.0812
Labordia venosa	0.565	0.503	0.374	0.46
Labordia waialealae	0.613	0.503	0.302	0.438
Labordia waiolani	0.603	0.588	0.284	0.417
Lellingeria saffordii	0.245	0.735	0.391	0.756
Lepechinia hastata	0.801	0.388	0.481	0.142
Lepidium arbuscula	0.843	0.224	0.391	0.245
Lepidium bidentatum	0.477	0.428	0.507	0.522
Lepidium serra	0.769	0.352	0.302	0.31
Lepisorus thunbergianus	0.0433	0.89	0.887	0.647
Leptecophylla tameiameiae	0.14	0.866	0.755	0.66
Lindsaea repens	0.158	0.745	0.927	0.563
Liparis hawaiensis	0.0193	0.86	0.873	0.752
Lipochaeta connata	0.471	0.485	0.677	0.399
Lipochaeta degeneri	0.992	0.0169	0.0169	0.149
Lipochaeta heterophylla	0.588	0.417	0.463	0.427
Lipochaeta lobata	0.653	0.31	0.284	0.481
Lipochaeta rockii	0.676	0.331	0.302	0.449
Lipochaeta succulenta	0.898	0.0526	0.266	0.287
Lobelia dunbariae	0.87	0.0169	0.302	0.338
Lobelia gaudichaudii	0.973	0.0169	0.0169	0.253
Lobelia gloria-montis	0.645	0.424	0.32	0.424
Lobelia grayana	0.595	0.435	0.499	0.392

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Lobelia hillebrandii	0.343	0.538	0.677	0.57
Lobelia hypoleuca	0.273	0.721	0.646	0.614
Lobelia kauaensis	0.627	0.521	0.374	0.37
Lobelia niihauensis	0.741	0.292	0.463	0.303
Lobelia oahuensis	0.973	0.0169	0.0169	0.253
Lobelia villosa	0.896	0.0169	0.0169	0.392
Lobelia yuccoides	0.79	0.298	0.449	0.241
Luzula hawaiiensis	0.0258	0.879	0.719	0.826
Lycium sandwicense	0.859	0.0526	0.22	0.374
Lycopodiella cernua	0.241	0.956	0.552	0.573
Lycopodium venustulum	0.13	0.777	0.499	0.831
Lysimachia daphnoides	0.546	0.67	0.284	0.435
Lysimachia filifolia	0.443	0.499	0.695	0.413
Lysimachia forbesii	0.985	0.0169	0.0169	0.21
Lysimachia glutinosa	0.938	0.0169	0.0169	0.328
Lysimachia hillebrandii	0.299	0.628	0.713	0.585
Lysimachia kalalauensis	0.853	0.331	0.231	0.256
Lysimachia lydgatei	0.765	0.31	0.302	0.331
Lysimachia mauritiana	0.915	0.0526	0.24	0.275
Lysimachia maxima	0.876	0.0169	0.302	0.328
Lysimachia remyi	0.383	0.628	0.499	0.552
Lysimachia scopulensis	0.941	0.0526	0.338	0.17
Lysimachia venosa	0.926	0.0169	0.0169	0.349
Machaerina angustifolia	0.0907	0.898	0.806	0.647
Machaerina mariscoides	0.0511	0.849	0.914	0.647
Marattia douglasii	0.0488	0.938	0.802	0.681
Marsilea villosa	0.872	0.0169	0.298	0.338
Melanthera fauriei	0.82	0.263	0.356	0.274
Melanthera integrifolia	0.61	0.316	0.414	0.473
Melanthera kamolensis	0.95	0.0957	0.338	0.117
Melanthera lavarum	0.381	0.499	0.57	0.585
Melanthera micrantha	0.798	0.238	0.481	0.249
Melanthera remyi	0.82	0.263	0.356	0.274
Melanthera subcordata	0.297	0.681	0.766	0.51
Melanthera tenuifolia	0.816	0.288	0.391	0.245
Melanthera tenuis	0.809	0.31	0.391	0.245
Melanthera venosa	0.671	0.431	0.481	0.313
Melanthera waimeaensis	0.994	0.0169	0.0169	0.127
Melicope adscendens	0.88	0.26	0.374	0.163
Melicope anisata	0.51	0.563	0.534	0.392
Melicope balloui	0.418	0.478	0.606	0.52
Melicope barbigera	0.832	0.288	0.338	0.256

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Melicope christophersenii	0.901	0.296	0.213	0.188
Melicope cinerea	0.669	0.417	0.391	0.374
Melicope clusiifolia	0.0672	0.915	0.806	0.668
Melicope cruciata	0.775	0.467	0.195	0.295
Melicope degeneri	0.824	0.0169	0.409	0.36
Melicope elliptica	0.402	0.556	0.606	0.502
Melicope feddei	0.632	0.563	0.249	0.413
Melicope haleakalae	0.531	0.328	0.57	0.477
Melicope haupuensis	0.772	0.238	0.445	0.292
Melicope hawaiensis	0.278	0.645	0.838	0.517
Melicope hiiakae	0.834	0.231	0.356	0.274
Melicope hosakae	0.747	0.403	0.302	0.317
Melicope kaalaensis	0.864	0.203	0.391	0.224
Melicope kavaiensis	0.696	0.317	0.266	0.445
Melicope knudsenii	0.722	0.306	0.391	0.36
Melicope lydgatei	0.873	0.0169	0.445	0.274
Melicope macropus	0.515	0.496	0.624	0.367
Melicope makahae	0.96	0.0169	0.231	0.188
Melicope molokaiensis	0.325	0.628	0.641	0.574
Melicope mucronulata	0.913	0.163	0.32	0.185
Melicope munroi	0.777	0.317	0.302	0.317
Melicope nealae	0.997	0.0169	0.0169	0.113
Melicope oahuensis	0.719	0.424	0.249	0.381
Melicope orbicularis	0.424	0.477	0.463	0.574
Melicope ovalis	0.568	0.46	0.409	0.46
Melicope ovata	0.518	0.442	0.57	0.431
Melicope pallida	0.785	0.353	0.391	0.245
Melicope paniculata	0.609	0.413	0.534	0.37
Melicope peduncularis	0.238	0.724	0.802	0.563
Melicope pseudoanisata	0.167	0.77	0.713	0.717
Melicope puberula	0.452	0.496	0.624	0.452
Melicope quadrangularis	0.744	0.0705	0.534	0.37
Melicope radiata	0.0175	0.917	0.909	0.638
Melicope reflexa	0.679	0.417	0.356	0.385
Melicope rotundifolia	0.689	0.381	0.374	0.381
Melicope saint-johnii	0.814	0.36	0.213	0.306
Melicope sandwicensis	0.847	0.231	0.356	0.253
Melicope sessilis	0.386	0.485	0.57	0.581
Melicope volcanica	0.0424	0.842	0.748	0.81
Melicope waialealae	0.628	0.52	0.374	0.37
Melicope wawraeana	0.472	0.506	0.624	0.42
Metrosideros macropus	0.646	0.524	0.32	0.374

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Metrosideros polymorpha	0.122	0.841	0.847	0.627
Metrosideros rugosa	0.855	0.274	0.249	0.274
Metrosideros tremuloides	0.72	0.433	0.492	0.235
Metrosideros waialealae	0.403	0.585	0.356	0.606
Microlepia speluncae	0.41	0.585	0.499	0.531
Microlepia strigosa	0.0792	0.866	0.84	0.66
Microsorum spectrum	0.218	0.745	0.856	0.531
Morelotia gahniiformis	0.0276	0.912	0.771	0.776
Morinda trimera	0.338	0.628	0.713	0.499
Mucuna gigantea	0.339	0.436	0.668	0.629
Mucuna sloanei	0.334	0.638	0.891	0.306
Myoporum sandwicense	0.2	0.805	0.771	0.591
Myrsine alyxifolia	0.846	0.367	0.338	0.185
Myrsine degeneri	0.962	0.0169	0.0169	0.274
Myrsine denticulata	0.703	0.424	0.195	0.424
Myrsine emarginata	0.499	0.631	0.516	0.374
Myrsine fernseei	0.543	0.499	0.534	0.392
Myrsine fosbergii	0.456	0.438	0.624	0.481
Myrsine helleri	0.62	0.521	0.391	0.37
Myrsine juddii	0.985	0.0169	0.0169	0.21
Myrsine kauaiensis	0.715	0.413	0.463	0.274
Myrsine knudsenii	0.981	0.0169	0.0169	0.231
Myrsine lanaiensis	0.221	0.71	0.802	0.613
Myrsine lessertiana	0.188	0.923	0.619	0.647
Myrsine linearifolia	0.467	0.477	0.641	0.435
Myrsine mezii	0.987	0.0169	0.124	0.145
Myrsine petiolata	0.542	0.563	0.534	0.349
Myrsine pukooensis	0.422	0.667	0.481	0.474
Myrsine punctata	0.521	0.485	0.606	0.377
Myrsine sandwicensis	0.0718	0.902	0.838	0.635
Myrsine vaccinioides	0.813	0.274	0.302	0.306
Myrsine wawraea	0.54	0.499	0.463	0.435
Nama sandwicensis	0.663	0.242	0.414	0.448
Nephrolepis cordifolia	0.0129	0.912	0.878	0.727
Nephrolepis exaltata	0.151	0.764	0.878	0.611
Neraudia angulata	0.854	0.267	0.391	0.203
Neraudia kauaiensis	0.781	0.306	0.391	0.274
Neraudia melastomifolia	0.313	0.62	0.748	0.535
Neraudia ovata	0.285	0.681	0.784	0.51
Neraudia sericea	0.751	0.331	0.32	0.342
Nertera granadensis	0.29	0.735	0.427	0.681
Nestegis sandwicensis	0.209	0.709	0.84	0.602

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Nothocestrum breviflorum	0.203	0.702	0.909	0.552
Nothocestrum latifolium	0.354	0.535	0.624	0.588
Nothocestrum longifolium	0.0635	0.895	0.856	0.638
Nothocestrum peltatum	0.917	0.188	0.124	0.263
Nototrichium divaricatum	0.846	0.367	0.338	0.185
Nototrichium humile	0.675	0.327	0.481	0.37
Nototrichium sandwicense	0.297	0.631	0.733	0.573
Ochrosia compta	0.667	0.353	0.516	0.342
Ochrosia haleakalae	0.363	0.581	0.784	0.431
Ochrosia kauaiensis	0.937	0.0526	0.249	0.224
Ochrosia kilaueaensis	0.59	0.431	0.588	0.345
Ophioderma pendulum	0.0534	0.852	0.945	0.585
Ophioglossum petiolatum	0.494	0.471	0.534	0.47
Ophioglossum polyphyllum	0.485	0.288	0.516	0.567
Oreobolus furcatus	0.195	0.777	0.57	0.745
Osteomeles anthyllidifolia	0.184	0.772	0.838	0.591
Pandanus tectorius	0.296	0.525	0.757	0.624
Panicum beecheyi	0.598	0.413	0.57	0.36
Panicum fauriei	0.435	0.399	0.554	0.555
Panicum konaense	0.371	0.488	0.748	0.51
Panicum lineale	0.767	0.353	0.302	0.31
Panicum longivaginatum	0.863	0.0169	0.0169	0.445
Panicum nephelophilum	0.416	0.499	0.677	0.467
Panicum niihauense	0.842	0.0526	0.295	0.37
Panicum pellitum	0.317	0.624	0.659	0.581
Panicum ramosius	0.821	0.0348	0.427	0.345
Panicum tenuifolium	0.237	0.667	0.802	0.613
Panicum torridum	0.475	0.448	0.414	0.555
Panicum xerophilum	0.39	0.478	0.606	0.563
Paspalum scrobiculatum	0.11	0.81	0.873	0.649
Pellaea ternifolia	0.177	0.774	0.838	0.602
Peperomia alternifolia	0.523	0.596	0.624	0.274
Peperomia blanda	0.172	0.781	0.851	0.591
Peperomia cookiana	0.0571	0.831	0.909	0.67
Peperomia eekana	0.389	0.521	0.606	0.542
Peperomia ellipticibacca	0.973	0.0169	0.0169	0.253
Peperomia expallescens	0.548	0.467	0.445	0.456
Peperomia globulanthera	0.526	0.503	0.374	0.492
Peperomia hesperomannii	0.455	0.606	0.463	0.477
Peperomia hirtipetiola	0.318	0.628	0.606	0.606
Peperomia hypoleuca	0.046	0.917	0.909	0.531
Peperomia kipahuluensis	0.463	0.585	0.427	0.499

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Peperomia kokeana	0.861	0.331	0.302	0.203
Peperomia latifolia	0.18	0.853	0.659	0.681
Peperomia ligustrina	0.0608	0.81	0.909	0.681
Peperomia macraeana	0.16	0.853	0.802	0.585
Peperomia mauiensis	0.571	0.56	0.695	0.174
Peperomia membranacea	0.251	0.874	0.588	0.585
Peperomia oahuensis	0.438	0.499	0.624	0.467
Peperomia obovatilimba	0.35	0.735	0.499	0.552
Peperomia remyi	0.119	0.816	0.867	0.635
Peperomia rockii	0.612	0.502	0.445	0.363
Peperomia sandwicensis	0.336	0.663	0.677	0.502
Peperomia subpetiolata	0.803	0.0883	0.516	0.303
Peperomia tetraphylla	0.136	0.816	0.847	0.622
Perrottetia sandwicensis	0.0368	0.89	0.887	0.668
Peucedanum sandwicense	0.413	0.51	0.659	0.477
Phyllanthus distichus	0.366	0.578	0.677	0.513
Phyllostegia ambigua	0.0285	0.813	0.784	0.824
Phyllostegia bracteata	0.361	0.67	0.534	0.552
Phyllostegia brevidens	0.157	0.813	0.641	0.738
Phyllostegia electra	0.576	0.585	0.391	0.392
Phyllostegia floribunda	0.0626	0.788	0.909	0.702
Phyllostegia glabra	0.284	0.77	0.677	0.535
Phyllostegia grandiflora	0.737	0.46	0.159	0.374
Phyllostegia haliakalae	0.517	0.521	0.427	0.467
Phyllostegia helleri	0.569	0.585	0.409	0.392
Phyllostegia hirsuta	0.68	0.502	0.284	0.374
Phyllostegia hispida	0.586	0.502	0.463	0.385
Phyllostegia kaalaensis	0.946	0.0526	0.32	0.16
Phyllostegia kahiliensis	0.871	0.0526	0.284	0.331
Phyllostegia knudsenii	0.941	0.0526	0.338	0.17
Phyllostegia lantanoides	0.794	0.296	0.213	0.36
Phyllostegia macrophylla	0.152	0.735	0.606	0.788
Phyllostegia mannii	0.616	0.424	0.409	0.424
Phyllostegia mollis	0.899	0.124	0.356	0.21
Phyllostegia parviflora	0.208	0.71	0.784	0.645
Phyllostegia racemosa	0.281	0.795	0.641	0.549
Phyllostegia renovans	0.404	0.517	0.713	0.452
Phyllostegia rockii	0.759	0.0883	0.516	0.345
Phyllostegia stachyoides	0.393	0.585	0.534	0.542
Phyllostegia velutina	0.153	0.602	0.588	0.827
Phyllostegia vestita	0.0295	0.852	0.909	0.702
Phyllostegia waimeae	0.98	0.0169	0.302	0.113

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Phyllostegia warshaueri	0.328	0.452	0.677	0.635
Phyllostegia wawrana	0.556	0.431	0.588	0.388
Phytolacca sandwicensis	0.087	0.874	0.802	0.681
Pilea peploides	0.271	0.799	0.568	0.617
Pipturus albidus	0.0203	0.898	0.914	0.647
Pipturus forbesii	0.48	0.563	0.499	0.456
Pipturus kauaiensis	0.5	0.563	0.641	0.328
Pipturus ruber	0.534	0.563	0.499	0.381
Pisonia brunoniana	0.0921	0.849	0.914	0.561
Pisonia sandwicensis	0.179	0.709	0.867	0.635
Pisonia umbellifera	0.081	0.8	0.914	0.647
Pisonia wagneriana	0.599	0.441	0.579	0.334
Pittosporum argentifolium	0.441	0.563	0.57	0.456
Pittosporum confertiflorum	0.26	0.899	0.592	0.548
Pittosporum flocculosum	0.75	0.308	0.353	0.337
Pittosporum gayanum	0.557	0.563	0.374	0.435
Pittosporum glabrum	0.327	0.663	0.641	0.545
Pittosporum halophilum	0.947	0.0526	0.159	0.235
Pittosporum hawaiiense	0.187	0.831	0.802	0.563
Pittosporum hosmeri	0.162	0.81	0.909	0.488
Pittosporum kauaiense	0.808	0.371	0.356	0.231
Pittosporum napaliense	0.906	0.224	0.249	0.203
Pittosporum terminalioides	0.103	0.895	0.838	0.595
Planchonella sandwicensis	0.128	0.767	0.856	0.681
Plantago hawaiensis	0.466	0.51	0.231	0.606
Plantago pachyphylla	0.219	0.77	0.374	0.781
Plantago princeps	0.28	0.706	0.606	0.631
Platanthera holochila	0.377	0.627	0.463	0.585
Platydesma cornuta	0.692	0.467	0.356	0.338
Platydesma remyi	0.343	0.345	0.677	0.656
Platydesma rostrata	0.448	0.538	0.624	0.431
Platydesma spathulata	0.00368	0.924	0.909	0.742
Plectranthus parviflorus	0.227	0.674	0.851	0.591
Pleomele aurea	0.767	0.353	0.302	0.31
Pleomele auwahiensis	0.484	0.517	0.641	0.388
Pleomele fernaldii	0.969	0.0169	0.374	0.0919
Pleomele forbesii	0.796	0.224	0.32	0.342
Pleomele halapepe	0.575	0.396	0.481	0.449
Pleomele hawaiiensis	0.305	0.61	0.76	0.552
Plumbago zeylanica	0.424	0.417	0.588	0.545
Poa mannii	0.756	0.306	0.499	0.253
Poa sandvicensis	0.928	0.0169	0.0169	0.349

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Poa siphonoglossa	0.904	0.188	0.159	0.263
Polypodium pellucidum	0.0497	0.938	0.802	0.681
Polyscias flynnii	0.962	0.0169	0.0169	0.274
Polyscias gymnocarpa	0.695	0.374	0.374	0.374
Polyscias hawaiensis	0.161	0.745	0.909	0.585
Polyscias kavaiensis	0.0414	0.895	0.873	0.67
Polyscias oahuensis	0.0893	0.866	0.86	0.622
Polyscias racemosa	0.727	0.263	0.463	0.338
Polyscias sandwicensis	0.323	0.548	0.726	0.573
Polyscias waialealae	0.489	0.628	0.369	0.477
Polyscias waimeae	0.674	0.431	0.624	0.206
Polystichum bonseyi	0.545	0.485	0.499	0.42
Polystichum haleakalense	0.508	0.331	0.677	0.449
Polystichum hillebrandii	0.223	0.646	0.802	0.656
Portulaca lutea	0.856	0.0883	0.0883	0.41
Portulaca molokiniensis	0.826	0.0169	0.418	0.355
Portulaca sclerocarpa	0.236	0.724	0.82	0.552
Portulaca villosa	0.471	0.395	0.499	0.545
Potamogeton foliosus	0.373	0.467	0.713	0.542
Pritchardia affinis	0.437	0.404	0.753	0.445
Pritchardia arecina	0.448	0.478	0.57	0.499
Pritchardia aylmer-robinsonii	0.959	0.0169	0.273	0.186
Pritchardia beccariana	0.24	0.764	0.757	0.562
Pritchardia forbesiana	0.562	0.52	0.606	0.306
Pritchardia glabrata	0.806	0.0883	0.552	0.281
Pritchardia hardyi	0.527	0.456	0.57	0.413
Pritchardia hillebrandii	0.885	0.224	0.302	0.213
Pritchardia kaalae	0.905	0.267	0.284	0.16
Pritchardia lanaiensis	0.907	0.0169	0.302	0.274
Pritchardia lanigera	0.171	0.645	0.873	0.688
Pritchardia lowreyana	0.566	0.496	0.659	0.281
Pritchardia martii	0.738	0.433	0.385	0.268
Pritchardia minor	0.715	0.349	0.499	0.295
Pritchardia munroi	0.935	0.0883	0.409	0.131
Pritchardia napaliensis	0.89	0.267	0.249	0.203
Pritchardia perlmanii	0.491	0.499	0.57	0.435
Pritchardia schattaueri	0.884	0.0526	0.467	0.217
Pritchardia viscosa	0.89	0.0526	0.356	0.256
Pritchardia waialealeana	0.509	0.499	0.534	0.435
Pseudognaphalium sandwicensium	0.308	0.688	0.646	0.573
Pseudophegopteris keraudreniana	0.0322	0.895	0.873	0.681

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Psilotum complanatum	0.0166	0.898	0.914	0.668
Psilotum nudum	0.186	0.731	0.878	0.591
Psychotria fauriei	0.747	0.403	0.302	0.317
Psychotria grandiflora	0.909	0.267	0.159	0.224
Psychotria greenwelliae	0.445	0.521	0.641	0.435
Psychotria hathewayi	0.793	0.31	0.427	0.245
Psychotria hawaiiensis	0.11	0.853	0.873	0.595
Psychotria hexandra	0.538	0.467	0.588	0.381
Psychotria hobdyi	0.85	0.0883	0.409	0.292
Psychotria kaduana	0.331	0.66	0.713	0.488
Psychotria mariniana	0.326	0.642	0.715	0.51
Psychotria mauiensis	0.129	0.81	0.856	0.638
Psychotria wawrae	0.505	0.521	0.624	0.37
Psydrax odorata	0.256	0.666	0.768	0.596
Pteralyxia kauaiensis	0.558	0.41	0.588	0.399
Pteralyxia macrocarpa	0.552	0.46	0.391	0.481
Pteridium aquilinum	0.166	0.745	0.838	0.649
Pteris cretica	0.0212	0.948	0.847	0.668
Pteris excelsa	0.125	0.915	0.726	0.668
Pteris hillebrandii	0.344	0.531	0.731	0.542
Pteris irregularis	0.163	0.735	0.809	0.682
Pteris lidgatei	0.591	0.424	0.499	0.402
Ranunculus hawaiensis	0.232	0.752	0.624	0.677
Ranunculus mauiensis	0.399	0.477	0.499	0.595
Rauvolfia sandwicensis	0.341	0.466	0.793	0.548
Remya kauaiensis	0.764	0.309	0.391	0.289
Remya mauiensis	0.889	0.0526	0.338	0.267
Remya montgomeryi	0.725	0.367	0.516	0.249
Rhus sandwicensis	0.169	0.75	0.847	0.635
Rhynchospora chinensis	0.109	0.938	0.802	0.574
Rhynchospora rugosa	0.0948	0.917	0.838	0.574
Rhynchospora sclerioides	0.0451	0.874	0.94	0.561
Rubus hawaiensis	0.0359	0.912	0.664	0.826
Rubus macraei	0.304	0.53	0.574	0.687
Rumex albescens	0.5	0.563	0.641	0.328
Rumex giganteus	0.197	0.899	0.699	0.585
Rumex skottsbergii	0.142	0.767	0.873	0.638
Ruppia maritima	0.956	0.0526	0.0526	0.267
Sadleria cyatheoides	0.0691	0.89	0.847	0.647
Sadleria pallida	0.243	0.981	0.525	0.573
Sadleria souleyetiana	0.204	0.878	0.432	0.746
Sadleria squarrosa	0.342	0.738	0.418	0.602

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Sadleria unisora	0.573	0.606	0.405	0.375
Sadleria wagneriana	0.979	0.0169	0.0169	0.243
Sanicula kauaiensis	0.74	0.317	0.28	0.381
Sanicula mariversa	0.968	0.0169	0.231	0.167
Sanicula purpurea	0.705	0.46	0.266	0.374
Sanicula sandwicensis	0.294	0.606	0.606	0.66
Santalum ellipticum	0.39	0.441	0.619	0.573
Santalum freycinetianum	0.311	0.601	0.695	0.584
Santalum haleakalae	0.66	0.392	0.374	0.402
Santalum paniculatum	0.111	0.866	0.806	0.66
Sapindus oahuensis	0.567	0.448	0.494	0.423
Sapindus saponaria	0.355	0.56	0.802	0.452
Scaevola chamissoniana	0.147	0.938	0.695	0.627
Scaevola coriacea	0.939	0.0883	0.0883	0.27
Scaevola gaudichaudiana	0.423	0.549	0.646	0.441
Scaevola gaudichaudii	0.385	0.477	0.548	0.596
Scaevola glabra	0.401	0.67	0.499	0.499
Scaevola kilaueae	0.23	0.838	0.766	0.495
Scaevola mollis	0.372	0.675	0.548	0.518
Scaevola procera	0.629	0.499	0.356	0.392
Scaevola sericea	0.7	0.234	0.24	0.481
Sceptridium subbifoliatum	0.587	0.288	0.544	0.454
Schiedea apokremnos	0.948	0.0954	0.316	0.138
Schiedea diffusa	0.302	0.663	0.427	0.695
Schiedea globosa	0.788	0.121	0.302	0.397
Schiedea haleakalensis	0.605	0.442	0.463	0.399
Schiedea helleri	0.994	0.0169	0.0169	0.135
Schiedea hookeri	0.662	0.359	0.492	0.355
Schiedea kaalae	0.797	0.36	0.32	0.274
Schiedea kauaiensis	0.742	0.281	0.481	0.292
Schiedea kealiae	0.933	0.168	0.253	0.18
Schiedea ligustrina	0.836	0.245	0.391	0.245
Schiedea lychnoides	0.724	0.274	0.374	0.381
Schiedea lydgatei	0.983	0.0954	0.195	0.0955
Schiedea mannii	0.822	0.31	0.356	0.245
Schiedea membranacea	0.458	0.456	0.695	0.424
Schiedea menziesii	0.69	0.413	0.338	0.381
Schiedea nuttallii	0.833	0.345	0.463	0.142
Schiedea obovata	0.944	0.124	0.213	0.188
Schiedea pentandra	0.895	0.21	0.356	0.167
Schiedea perlmanii	0.92	0.0883	0.374	0.185
Schiedea pubescens	0.478	0.456	0.57	0.477

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Schiedea salicaria	0.908	0.245	0.302	0.16
Schiedea sarmentosa	0.977	0.138	0.231	0.0955
Schiedea spergulina	0.702	0.366	0.454	0.329
Schiedea stellarioides	0.878	0.349	0.356	0.124
Schiedea trinervis	0.81	0.374	0.249	0.288
Schiedea viscosa	0.839	0.324	0.409	0.185
Schizaea robusta	0.254	0.778	0.534	0.67
Schoenoplectus juncoides	0.36	0.682	0.771	0.352
Schoenoplectus tabernaemontani	0.324	0.632	0.818	0.434
Scleria testacea	0.469	0.367	0.641	0.495
Selaginella arbuscula	0.0511	0.849	0.914	0.647
Selaginella deflexa	0.513	0.503	0.409	0.492
Senna gaudichaudii	0.436	0.424	0.554	0.543
Sesbania tomentosa	0.451	0.399	0.521	0.555
Sesuvium portulacastrum	0.749	0.0526	0.24	0.481
Sicyos alba	0.307	0.617	0.552	0.66
Sicyos anunu	0.349	0.581	0.838	0.41
Sicyos cucumerinus	0.215	0.774	0.661	0.675
Sicyos erostratus	0.608	0.435	0.374	0.445
Sicyos herbstii	0.805	0.203	0.338	0.331
Sicyos hispidus	0.525	0.496	0.445	0.463
Sicyos lanceoloidea	0.746	0.413	0.427	0.242
Sicyos lasiocephalus	0.537	0.496	0.641	0.324
Sicyos macrophyllus	0.012	0.706	0.878	0.863
Sicyos maximowiczii	0.949	0.0169	0.11	0.264
Sicyos pachycarpus	0.446	0.424	0.534	0.543
Sicyos waimanaloensis	0.681	0.346	0.266	0.452
Sida fallax	0.242	0.713	0.793	0.573
Sideroxylon polynesicum	0.347	0.492	0.677	0.588
Silene alexandri	0.991	0.0526	0.159	0.0847
Silene hawaiiensis	0.216	0.752	0.802	0.581
Silene lanceolata	0.406	0.602	0.624	0.452
Silene struthioloides	0.427	0.542	0.463	0.542
Sisyrinchium acre	0.145	0.692	0.606	0.81
Smilax melastomifolia	0.135	0.874	0.731	0.681
Solanum americanum	0.285	0.738	0.646	0.573
Solanum incompletum	0.308	0.64	0.811	0.484
Solanum nelsonii	0.966	0.0526	0.0526	0.234
Solanum sandwicense	0.563	0.46	0.588	0.363
Sophora chrysophylla	0.101	0.808	0.887	0.647
Spermolepis hawaiiensis	0.346	0.492	0.677	0.588

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Sphenomeris chinensis	0.0442	0.852	0.909	0.66
Sporobolus virginicus	0.859	0.0526	0.22	0.374
Stenogyne angustifolia	0.306	0.617	0.873	0.445
Stenogyne bifida	0.564	0.52	0.499	0.381
Stenogyne calaminthoides	0.207	0.82	0.606	0.692
Stenogyne calycosa	0.626	0.413	0.552	0.328
Stenogyne campanulata	0.83	0.324	0.374	0.217
Stenogyne cranwelliae	0.673	0.36	0.338	0.424
Stenogyne haliakalae	0.776	0.367	0.534	0.142
Stenogyne kaalae	0.855	0.253	0.249	0.285
Stenogyne kamehamehae	0.374	0.628	0.391	0.617
Stenogyne kanehoana	0.864	0.203	0.391	0.224
Stenogyne kealiae	0.43	0.538	0.624	0.452
Stenogyne macrantha	0.0341	0.788	0.909	0.756
Stenogyne microphylla	0.333	0.681	0.695	0.477
Stenogyne purpurea	0.479	0.563	0.534	0.435
Stenogyne rotundifolia	0.619	0.438	0.338	0.449
Stenogyne rugosa	0.279	0.745	0.766	0.488
Stenogyne scrophularioides	0.155	0.706	0.677	0.77
Stenogyne sessilis	0.104	0.86	0.766	0.71
Sticherus owhyhensis	0.203	0.735	0.606	0.735
Streblus pendulinus	0.312	0.581	0.838	0.495
Strongylodon ruber	0.217	0.693	0.893	0.548
Syzygium sandwicensis	0.262	0.717	0.806	0.515
Tectaria gaudichaudii	0.0617	0.81	0.909	0.681
Tetramolopium arenarium	0.388	0.574	0.748	0.413
Tetramolopium capillare	0.61	0.477	0.463	0.37
Tetramolopium consanguineum	0.412	0.553	0.695	0.424
Tetramolopium filiforme	0.923	0.224	0.124	0.235
Tetramolopium humile	0.265	0.81	0.766	0.445
Tetramolopium lepidotum	0.77	0.331	0.32	0.31
Tetramolopium remyi	0.868	0.0705	0.356	0.295
Tetramolopium rockii	0.893	0.0169	0.316	0.285
Tetramolopium sylvae	0.967	0.0526	0.213	0.16
Thelypteris globulifera	0.249	0.938	0.552	0.574
Thespesia populnea	0.731	0.127	0.24	0.481
Touchardia latifolia	0.0267	0.898	0.94	0.561
Trematolobelia grandifolia	0.587	0.288	0.544	0.454
Trematolobelia kauaiensis	0.529	0.628	0.356	0.435
Trematolobelia macrostachys	0.362	0.631	0.498	0.59
Trematolobelia singularis	0.951	0.0169	0.0169	0.295

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Tribulus cistoides	0.9	0.0526	0.0526	0.366
Trisetum glomeratum	0.102	0.835	0.356	0.867
Trisetum inaequale	0.902	0.0526	0.338	0.245
Uncinia brevicaulis	0.65	0.417	0.338	0.417
Uncinia uncinata	0.0939	0.738	0.485	0.866
Urera glabra	0.0378	0.917	0.909	0.574
Urera kaalae	0.862	0.374	0.391	0.117
Vaccinium calycinum	0.202	0.878	0.498	0.721
Vaccinium dentatum	0.058	0.863	0.771	0.764
Vaccinium reticulatum	0.112	0.863	0.664	0.764
Vandenboschia cyrtotheca	0.123	0.81	0.909	0.585
Vandenboschia davallioides	0.211	0.874	0.699	0.573
Vandenboschia draytoniana	0.269	0.681	0.909	0.413
Vandenboschia tubiflora	0.637	0.456	0.57	0.274
Vicia menziesii	0.295	0.381	0.516	0.756
Vigna marina	0.787	0.0883	0.302	0.41
Vigna owahuensis	0.391	0.477	0.623	0.552
Viola chamissoniana	0.375	0.627	0.57	0.531
Viola helenae	0.744	0.0705	0.534	0.37
Viola kauaensis	0.622	0.463	0.391	0.399
Viola lanaiensis	0.922	0.0169	0.0169	0.36
Viola maviensis	0.276	0.546	0.374	0.77
Viola oahuensis	0.973	0.0169	0.0169	0.253
Viola wailenalenae	0.54	0.499	0.463	0.435
Vitex rotundifolia	0.957	0.0526	0.0526	0.267
Waltheria indica	0.238	0.68	0.833	0.573
Wikstroemia bicornuta	0.705	0.46	0.266	0.374
Wikstroemia forbesii	0.585	0.503	0.463	0.385
Wikstroemia furcata	0.572	0.478	0.606	0.328
Wikstroemia hanalei	0.771	0.0705	0.499	0.349
Wikstroemia monticola	0.828	0.346	0.409	0.185
Wikstroemia oahuensis	0.257	0.716	0.735	0.584
Wikstroemia phillyreifolia	0.134	0.788	0.873	0.627
Wikstroemia pulcherrima	0.335	0.531	0.802	0.51
Wikstroemia sandwicensis	0.0663	0.849	0.914	0.618
Wikstroemia uva-ursi	0.482	0.459	0.51	0.504
Wikstroemia villosa	0.639	0.51	0.302	0.402
Wilkesia gymnoxiphium	0.677	0.384	0.498	0.326
Wilkesia hobdyi	0.75	0.184	0.494	0.329
Xylosma crenatum	0.99	0.0169	0.0169	0.188
Xylosma hawaiiense	0.0976	0.81	0.909	0.627
Zanthoxylum dipetalum	0.246	0.663	0.856	0.556

Species	Vulnerability	Tolerate	Migrate	Micro-refugia
Zanthoxylum hawaiiense	0.483	0.538	0.677	0.345
Zanthoxylum kauaense	0.145	0.863	0.771	0.632

APPENDIX 4. LIST OF ALL SPECIES WITH NO FUTURE CLIMATE ENVELOPES (I.E., WINK-OUTS) AND/OR NO OVERLAP BETWEEN CURRENT AND FUTURE CLIMATE ENVELOPE

Wink-out species

Species	Family	Vulnerability	Conservation status
Acaena exigua	Rosaceae	0.593	Extinct
Astelia waialealae	Asteliaceae	0.549	Endangered
Bolboschoenus maritimus	Cyperaceae	0.619	Apparently secure
Coprosma elliptica	Rubiaceae	0.564	Apparently secure
Cressa truxillensis	Convolvulaceae	0.644	Apparently secure
Cyanea gibsonii	Campanulaceae	0.556	Endangered
Cyanea shipmanii	Campanulaceae	0.506	Endangered
Cyanea st.-johnii	Campanulaceae	0.59	Endangered
Cyperus laevigatus	Cyperaceae	0.619	Apparently secure
Cyrtandra hematos	Gesneriaceae	0.582	Rare
Cyrtandra viridiflora	Gesneriaceae	0.597	Endangered
Doryopteris takeuchii	Pteridaceae	0.607	Rare
Eragrostis paupera	Poaceae	0.596	Apparently secure
Euphorbia rockii	Euphorbiaceae	0.597	Endangered
Gahnia lanaiensis	Cyperaceae	0.553	Endangered
Geranium hanaense	Geraniaceae	0.575	Endangered
Geranium kauaiense	Geraniaceae	0.564	Endangered
Heliotropium anomalum	Boraginaceae	0.558	Apparently secure
Hibiscadelphus woodii	Malvaceae	0.636	Extinct
Ipomoea imperati	Convolvulaceae	0.583	Apparently secure
Ipomoea littoralis	Convolvulaceae	0.583	Apparently secure
Kanaloa kahoolawensis	Fabaceae	0.649	Endangered
Keysseria helenae	Asteraceae	0.564	Endangered
Labordia hosakana	Loganiaceae	0.582	Rare
Labordia sessilis	Loganiaceae	0.597	Apparently secure
Labordia triflora	Loganiaceae	0.663	Endangered
Lipochaeta degeneri	Asteraceae	0.635	Extinct
Lobelia gaudichaudii	Campanulaceae	0.597	Vulnerable
Lobelia oahuensis	Campanulaceae	0.597	Endangered
Lobelia villosa	Campanulaceae	0.549	Rare
Lysimachia forbesii	Primulaceae	0.612	Extinct
Lysimachia glutinosa	Primulaceae	0.571	Apparently secure
Lysimachia venosa	Primulaceae	0.564	Endangered
Melanthera waimeaensis	Asteraceae	0.643	Endangered
Melicope nealae	Rutaceae	0.649	Extinct
Myrsine degeneri	Primulaceae	0.59	Apparently secure
Myrsine juddii	Primulaceae	0.612	Endangered
Myrsine knudsenii	Primulaceae	0.605	Endangered

Species	Family	Vulnerability	Conservation status
Panicum longivaginatum	Poaceae	0.53	Rare
Peperomia ellipticibacca	Piperaceae	0.597	Apparently secure
Poa sandvicensis	Poaceae	0.564	Endangered
Polyscias flynnii	Araliaceae	0.59	Endangered
Portulaca lutea	Portulacaceae	0.527	Apparently secure
Ruppia maritima	Ruppiaceae	0.583	Apparently secure
Sadleria wagneriana	Blechnaceae	0.6	Apparently secure
Scaevola coriacea	Goodeniaceae	0.573	Endangered
Schiedea helleri	Caryophyllaceae	0.64	Endangered
Solanum nelsonii	Solanaceae	0.594	Vulnerable
Trematolobelia singularis	Campanulaceae	0.582	Endangered
Tribulus cistoides	Zygophyllaceae	0.55	Apparently secure
Viola lanaiensis	Violaceae	0.56	Endangered
Viola oahuensis	Violaceae	0.597	Endangered
Vitex rotundifolia	Lamiaceae	0.583	Apparently secure
Xylosma crenatum	Salicaceae	0.62	Endangered

No overlap species

Species	Family	Vulnerability	Conservation status
Argyroxiphium caliginis	Asteraceae	0.566	Rare
Asplenium dielpallidum	Aspleniaceae	0.583	Endangered
Asplenium haleakalense	Aspleniaceae	0.524	Apparently secure
Asplenium unisorum	Aspleniaceae	0.576	Endangered
Bidens hillebrandiana	Asteraceae	0.59	Rare
Boerhavia acutifolia	Nyctaginaceae	0.466	Apparently secure
Carex kauaiensis	Cyperaceae	0.547	Apparently secure
Carex thunbergii	Cyperaceae	0.474	Apparently secure
Centaurium sebaeoides	Gentianaceae	0.487	Endangered
Cheirodendron forbesii	Araliaceae	0.451	Apparently secure
Colubrina asiatica	Rhamnaceae	0.548	Apparently secure
Cyanea arborea	Campanulaceae	0.531	Extinct
Cyanea asplenifolia	Campanulaceae	0.435	Endangered
Cyanea comata	Campanulaceae	0.565	Extinct
Cyanea dunbariae	Campanulaceae	0.482	Endangered
Cyanea giffardii	Campanulaceae	0.509	Extinct
Cyanea habenata	Campanulaceae	0.517	Rare
Cyanea kolekoleensis	Campanulaceae	0.51	Endangered
Cyanea koolauensis	Campanulaceae	0.544	Endangered
Cyanea munroi	Campanulaceae	0.503	Endangered
Cyanea pinnatifida	Campanulaceae	0.556	Endangered
Cyanea purpurellifolia	Campanulaceae	0.532	Endangered

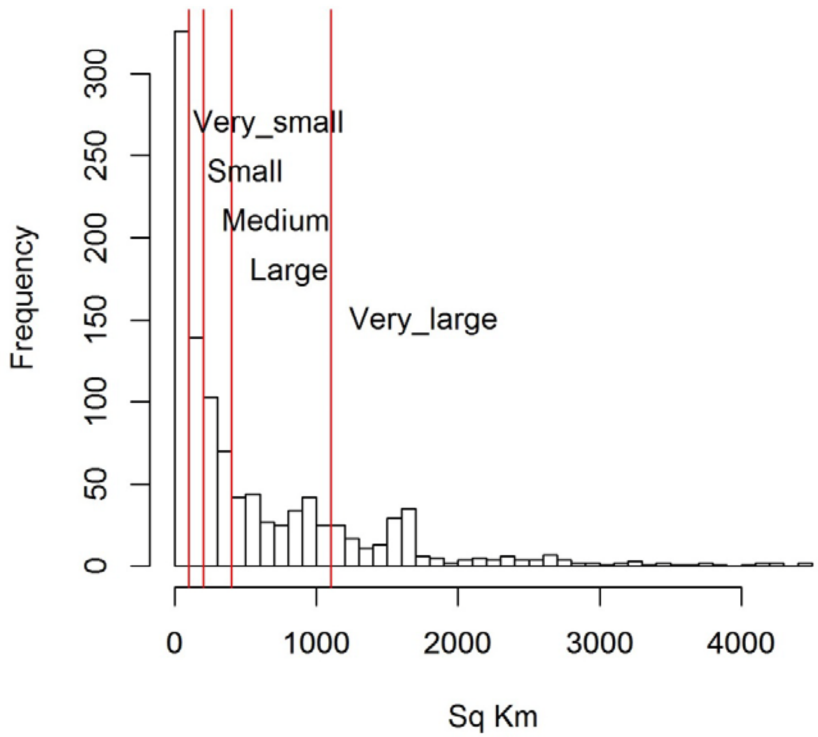
Species	Family	Vulnerability	Conservation status
Cyanea quercifolia	Campanulaceae	0.565	Extinct
Cyanea sessilifolia	Campanulaceae	0.555	Endangered
Cyanea superba	Campanulaceae	0.57	Endangered
Cyanea truncata	Campanulaceae	0.497	Extinct
Cyanea undulata	Campanulaceae	0.567	Endangered
Cyperus trachysanthos	Cyperaceae	0.483	Endangered
Cyrtandra crenata	Gesneriaceae	0.503	Extinct
Cyrtandra ferripilosa	Gesneriaceae	0.501	Endangered
Cyrtandra heinrichii	Gesneriaceae	0.5	Rare
Cyrtandra kaulantha	Gesneriaceae	0.548	Vulnerable
Cyrtandra nanawalensis	Gesneriaceae	0.464	Rare
Cyrtandra oenobarba	Gesneriaceae	0.461	Endangered
Cyrtandra oxybapha	Gesneriaceae	0.551	Endangered
Cyrtandra paliku	Gesneriaceae	0.528	Endangered
Cyrtandra polyantha	Gesneriaceae	0.577	Endangered
Cyrtandra sandwicensis	Gesneriaceae	0.544	Vulnerable
Cyrtandra sessilis	Gesneriaceae	0.58	Endangered
Cyrtandra waiolani	Gesneriaceae	0.56	Extinct
Dryopteris subbipinnata	Dryopteridaceae	0.498	Apparently secure
Dubautia pauciflorula	Asteraceae	0.515	Endangered
Dubautia syndetica	Asteraceae	0.492	Rare
Entada phaseoloides	Fabaceae	0.555	Apparently secure
Eugenia koolauensis	Myrtaceae	0.476	Endangered
Euphorbia degeneri	Euphorbiaceae	0.528	Apparently secure
Euphorbia sparsiflora	Euphorbiaceae	0.49	Rare
Gossypium tomentosum	Malvaceae	0.479	Vulnerable
Gouania meyenii	Rhamnaceae	0.557	Endangered
Heliotropium curassavicum	Boraginaceae	0.526	Apparently secure
Hibiscadelphus distans	Malvaceae	0.539	Endangered
Hibiscadelphus hualalaiensis	Malvaceae	0.566	Extinct
Huperzia nutans	Lycopodiaceae	0.504	Endangered
Huperzia stemmermanniae	Lycopodiaceae	0.435	Endangered
Ischaemum byrone	Poaceae	0.526	Endangered
Isodendrion hosakae	Violaceae	0.516	Endangered
Isodendrion pyrifolium	Violaceae	0.482	Endangered
Kadua littoralis	Rubiaceae	0.569	Vulnerable
Kadua parvula	Rubiaceae	0.589	Endangered
Kadua st.-johnii	Rubiaceae	0.6	Endangered
Korthalsella degeneri	Viscaceae	0.609	Rare
Labordia lydgatei	Loganiaceae	0.462	Endangered

Species	Family	Vulnerability	Conservation status
Lipochaeta succulenta	Asteraceae	0.549	Apparently secure
Lobelia dunbariae	Campanulaceae	0.534	Rare
Lycium sandwicense	Solanaceae	0.528	Apparently secure
Lysimachia mauritiana	Primulaceae	0.556	Apparently secure
Lysimachia maxima	Primulaceae	0.537	Endangered
Lysimachia scopulensis	Primulaceae	0.573	Endangered
Marsilea villosa	Marsileaceae	0.534	Endangered
Melicope degeneri	Rutaceae	0.515	Endangered
Melicope lydgatei	Rutaceae	0.535	Endangered
Melicope makahae	Rutaceae	0.589	Endangered
Melicope quadrangularis	Rutaceae	0.49	Endangered
Myrsine mezii	Primulaceae	0.619	Endangered
Ochrosia kauaiensis	Apocynaceae	0.571	Rare
Panicum niihauense	Poaceae	0.521	Endangered
Panicum ramosius	Poaceae	0.514	Rare
Peperomia subpetiolata	Piperaceae	0.508	Extinct
Phyllostegia kaalaensis	Lamiaceae	0.579	Endangered
Phyllostegia kahiliensis	Lamiaceae	0.534	Rare
Phyllostegia knudsenii	Lamiaceae	0.573	Extinct
Phyllostegia rockii	Lamiaceae	0.496	Extinct
Phyllostegia waimeae	Lamiaceae	0.601	Extinct
Pittosporum halophilum	Pittosporaceae	0.579	Endangered
Pleomele fernaldii	Asparagaceae	0.596	Endangered
Portulaca molokiniensis	Portulacaceae	0.515	Rare
Pritchardia aylmer-robinsonii	Arecaceae	0.584	Endangered
Pritchardia glabrata	Arecaceae	0.509	Vulnerable
Pritchardia lanaiensis	Arecaceae	0.553	Vulnerable
Pritchardia munroi	Arecaceae	0.568	Endangered
Pritchardia schattaueri	Arecaceae	0.542	Endangered
Pritchardia viscosa	Arecaceae	0.547	Endangered
Psychotria hobdyi	Rubiaceae	0.525	Endangered
Remya mauiensis	Asteraceae	0.546	Endangered
Sanicula mariversa	Apiaceae	0.595	Endangered
Sceptridium subbifoliatum	Ophioglossaceae	0.437	Extinct
Schiedea perlmanii	Caryophyllaceae	0.559	Endangered
Sesuvium portulacastrum	Aizoaceae	0.491	Apparently secure
Sicyos maximowiczii	Cucurbitaceae	0.581	Apparently secure
Silene alexandri	Caryophyllaceae	0.628	Endangered
Sporobolus virginicus	Poaceae	0.528	Apparently secure
Tetramolopium remyi	Asteraceae	0.533	Endangered

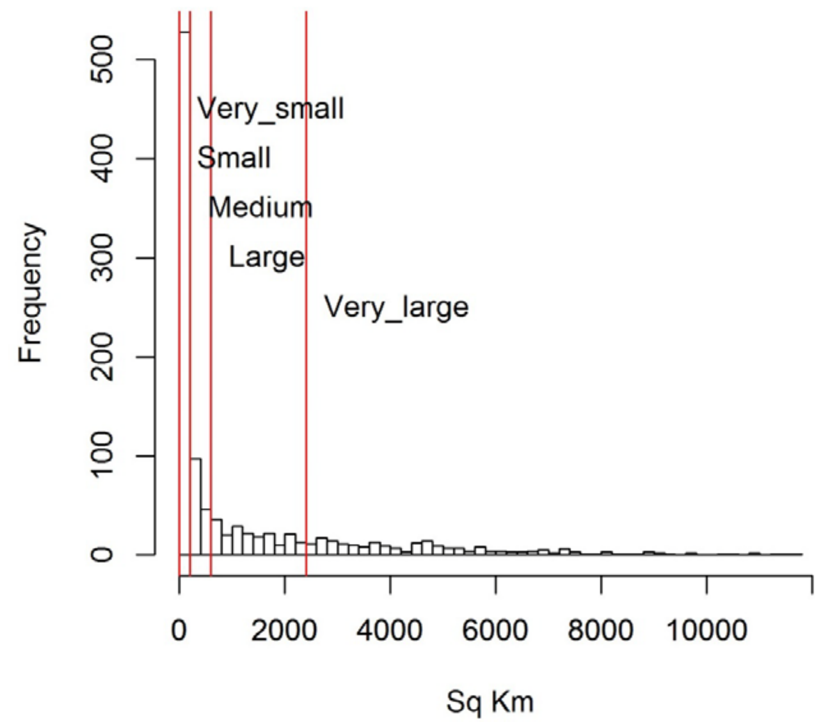
Species	Family	Vulnerability	Conservation status
Tetramolopium rockii	Asteraceae	0.548	Vulnerable
Tetramolopium sylvae	Asteraceae	0.595	Rare
Trematolobelia grandifolia	Campanulaceae	0.437	Rare
Trisetum inaequale	Poaceae	0.552	Apparently secure
Vigna marina	Fabaceae	0.504	Apparently secure
Viola helenae	Violaceae	0.49	Endangered
Wikstroemia hanalei	Thymelaeaceae	0.5	Extinct

APPENDIX 5. DISTRIBUTIONS OF FACTORS CONSIDERED IN VULNERABILITY MODEL

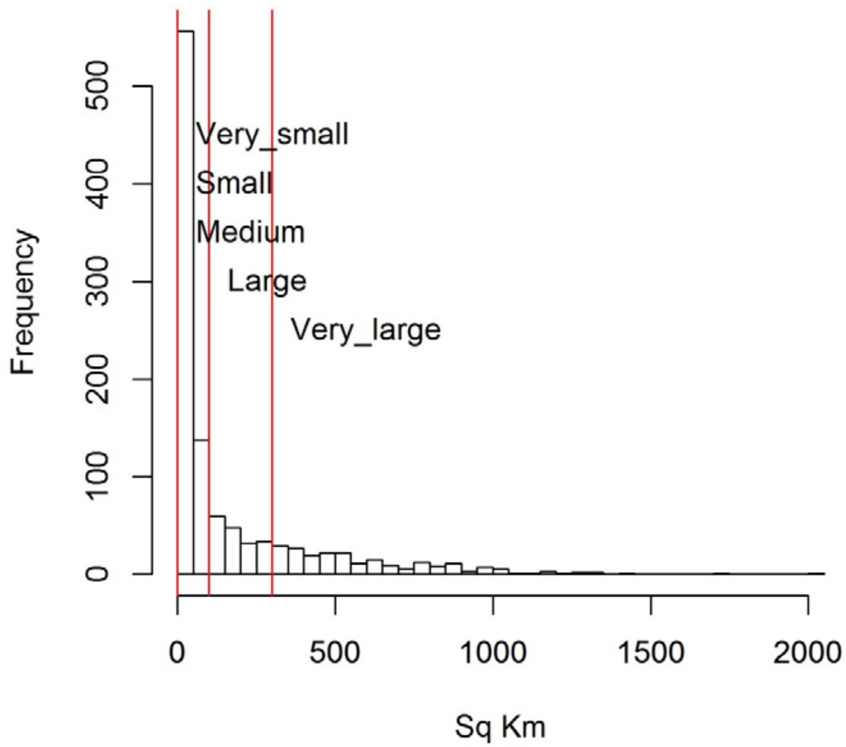
a) Total microrefugia zone area



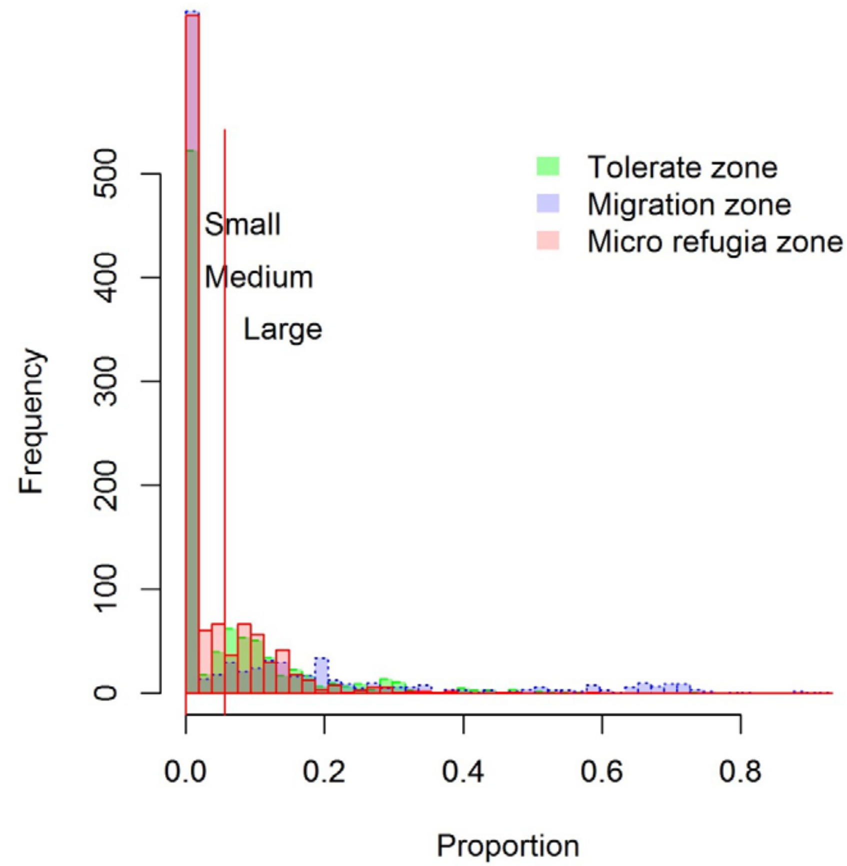
b) Total toleration zone area



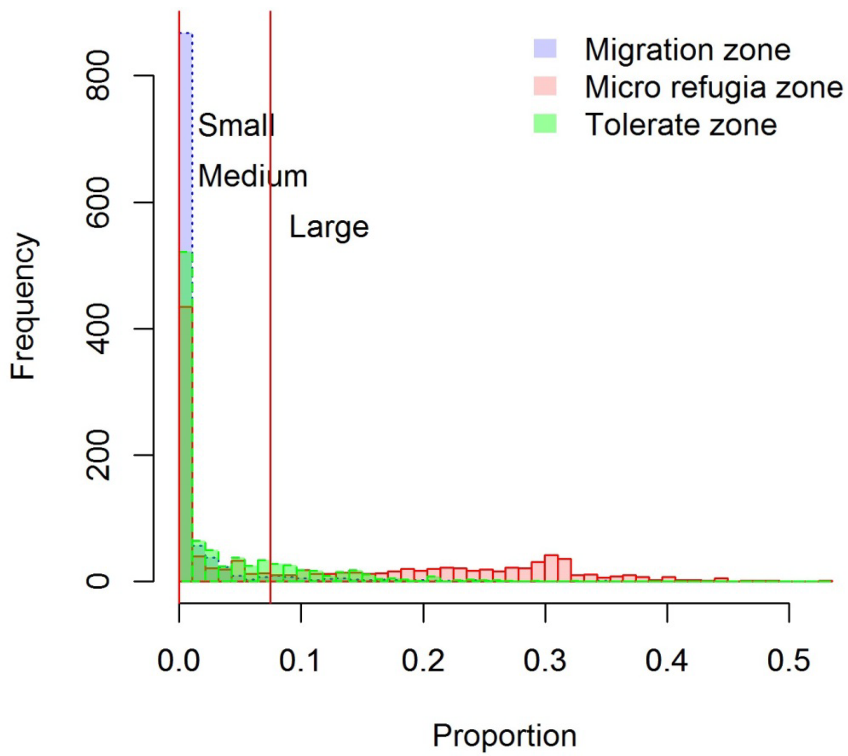
c) Total migration zone area



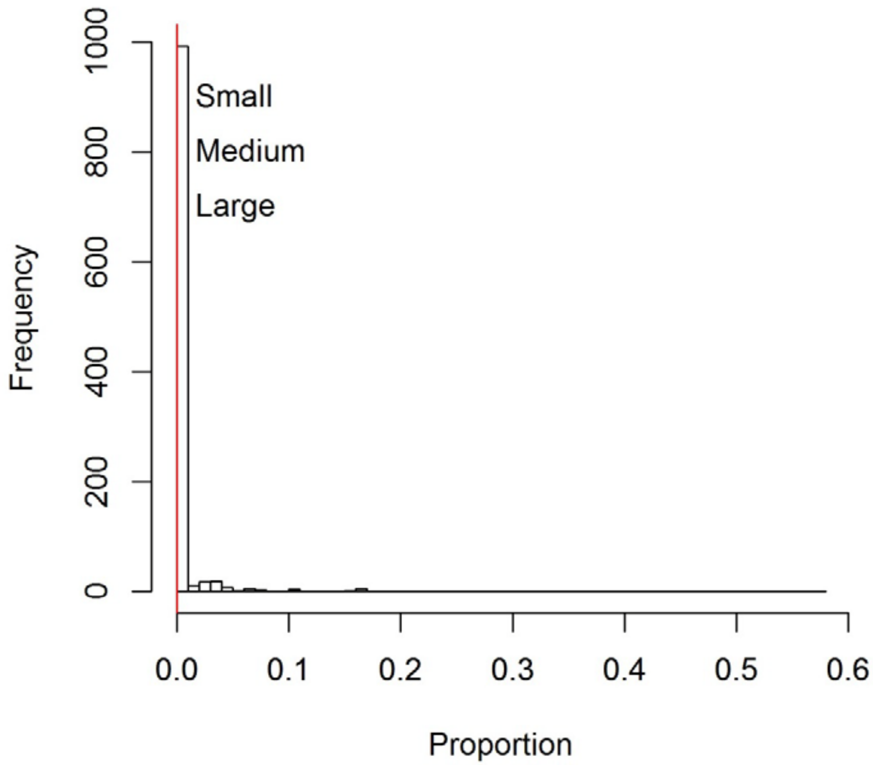
d) Lava flow area across response zones



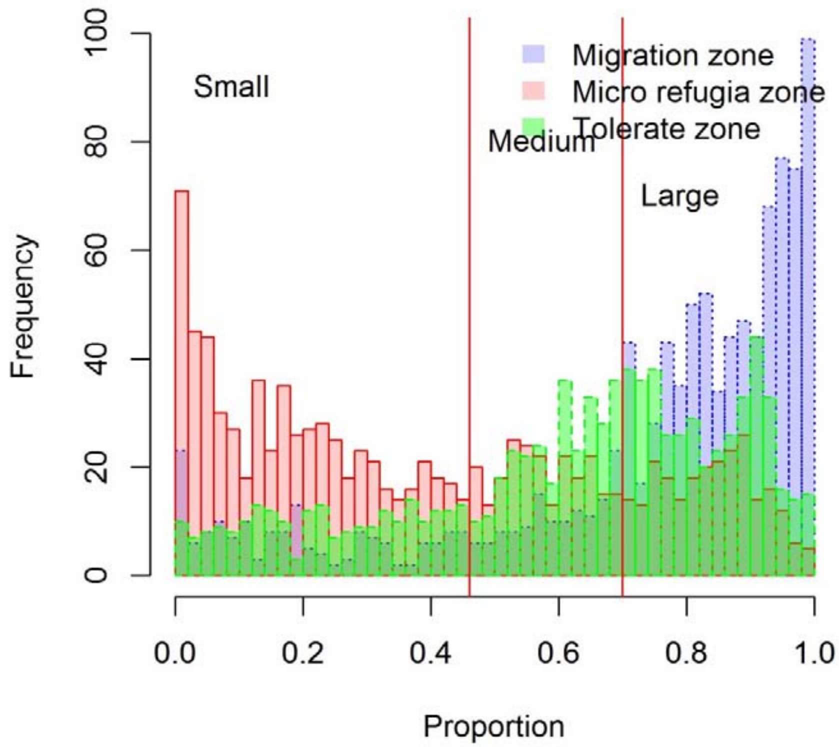
e) Heavily modified habitat across response zones



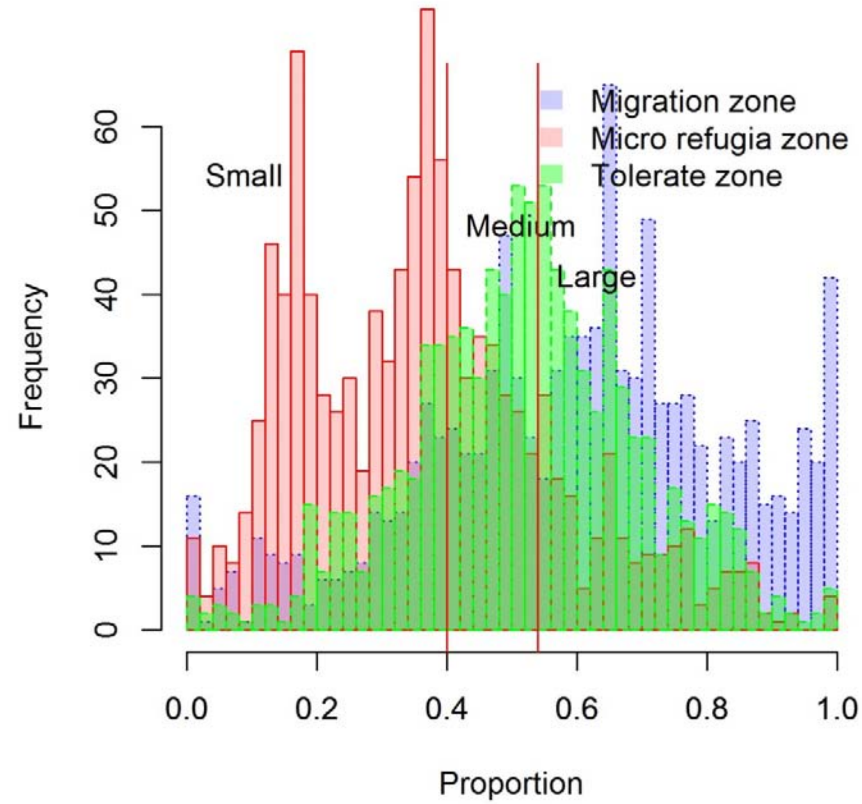
f) Area lost to sea-level rise in microrefugia zone



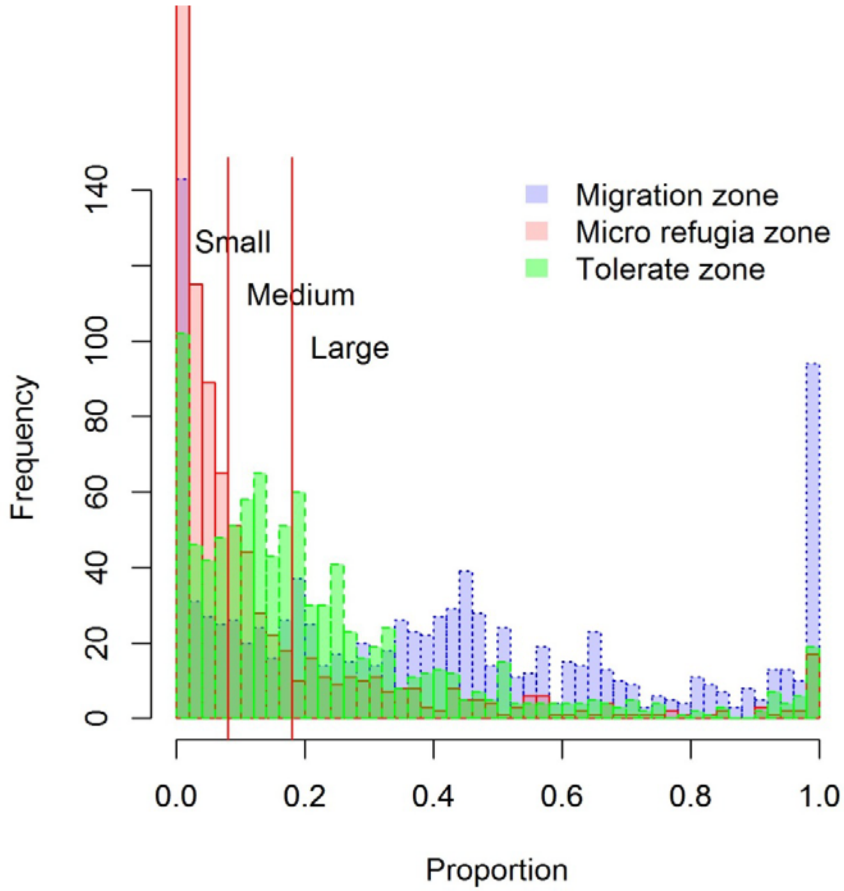
g) Native cover across response zones



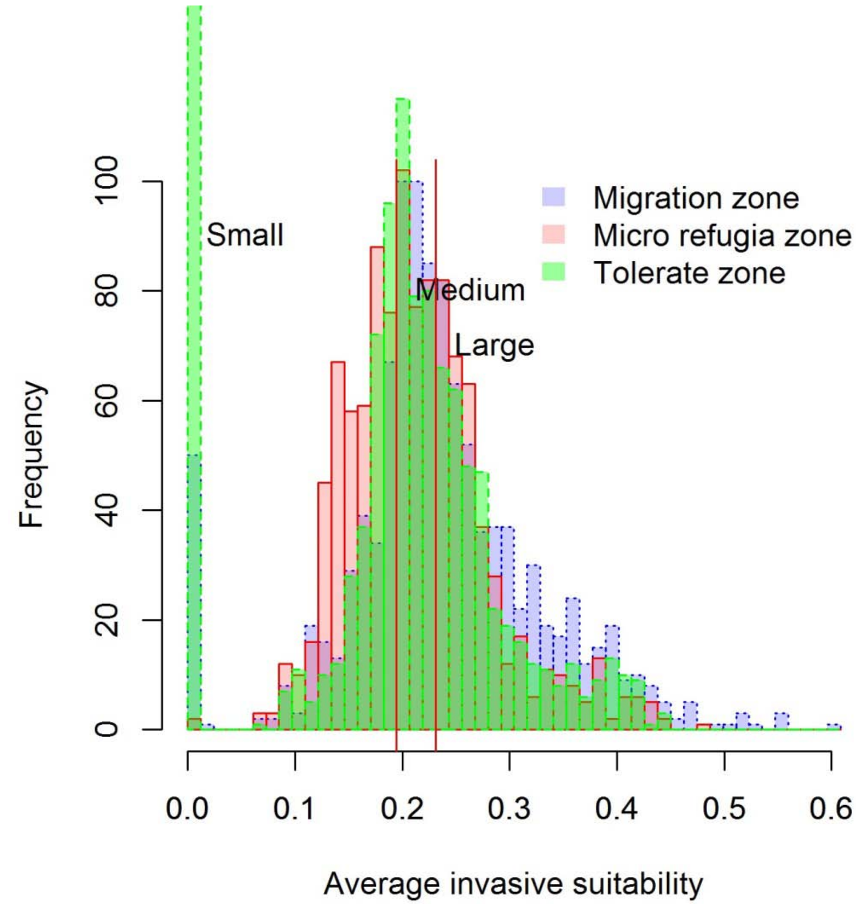
h) Area under protective designation across response zones



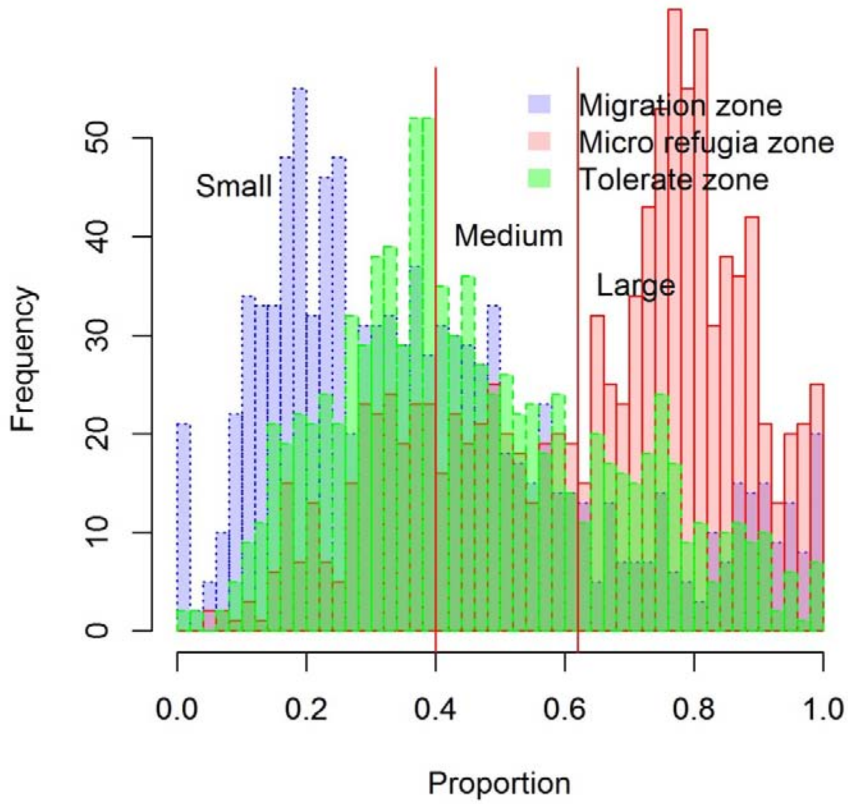
i) Ungulate exclusion areas across response zones



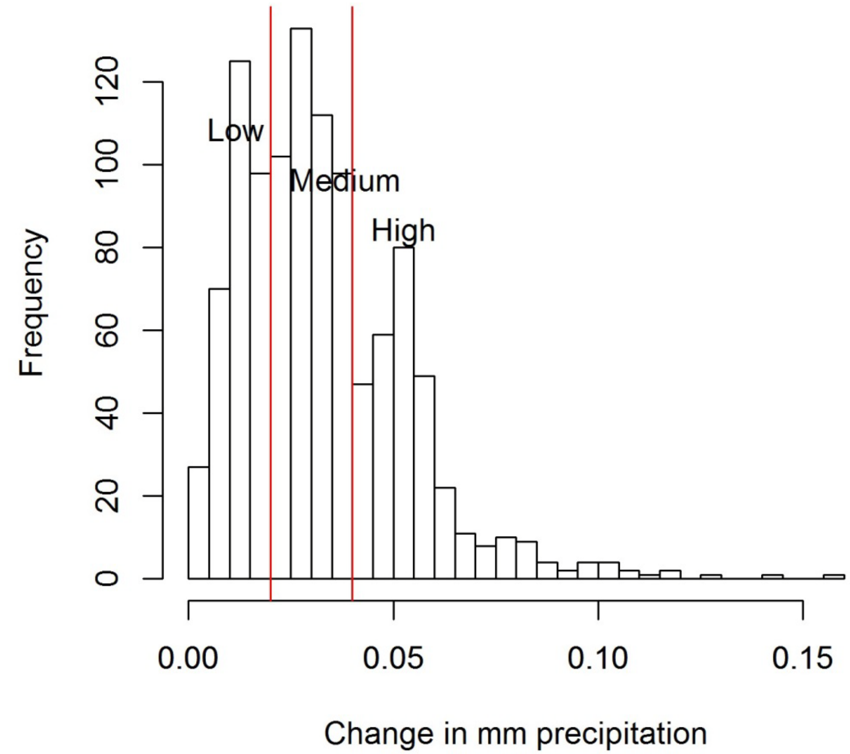
j) Invasibility across response zones



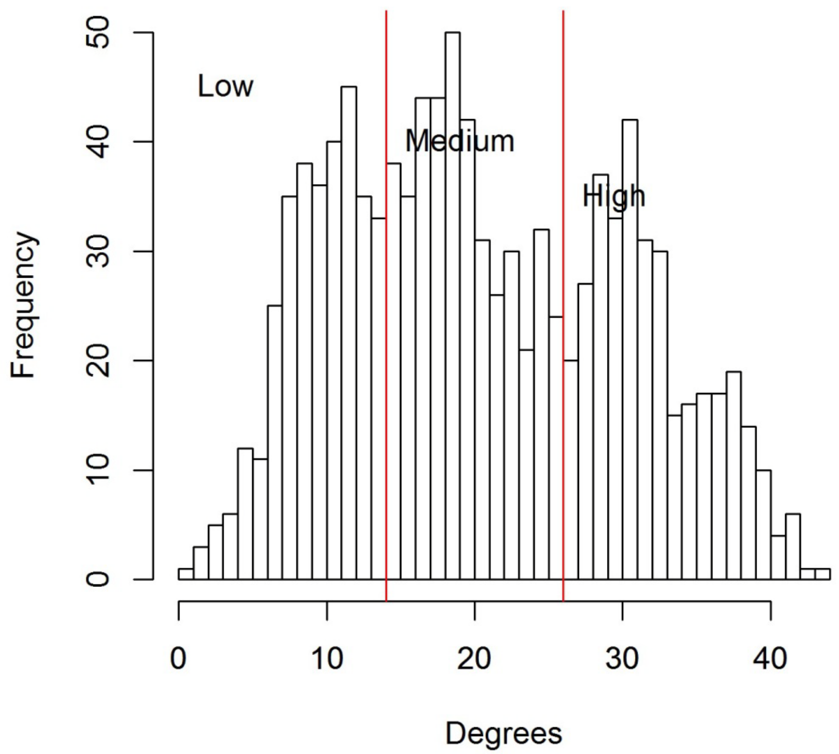
k) Fragmentation across response zones



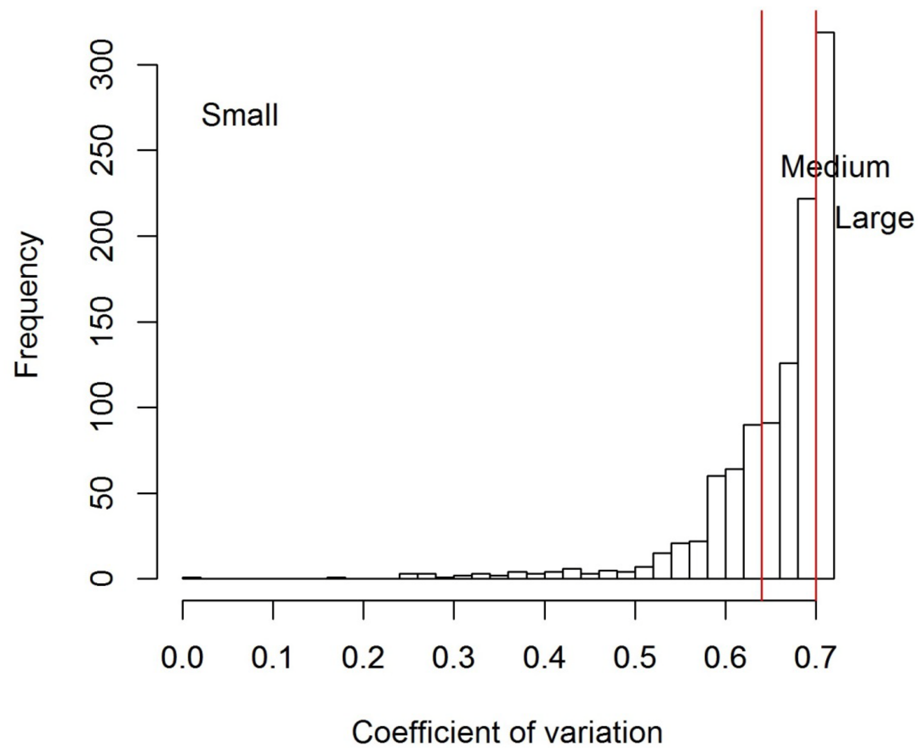
l) Precipitation gradient in microrefugia zone



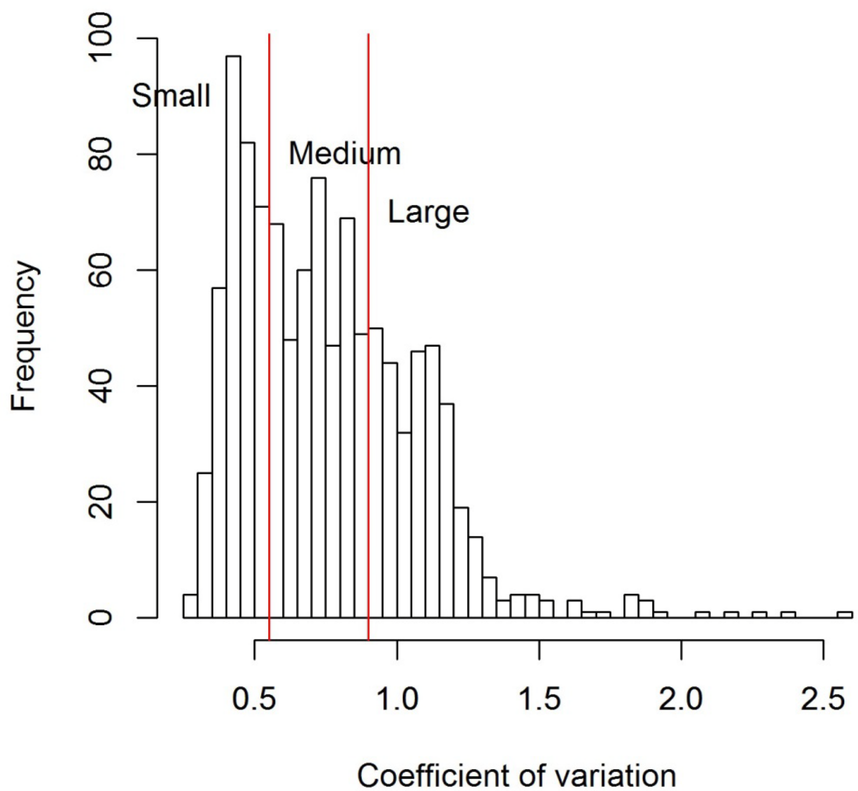
m) Average slope in microrefugia zone



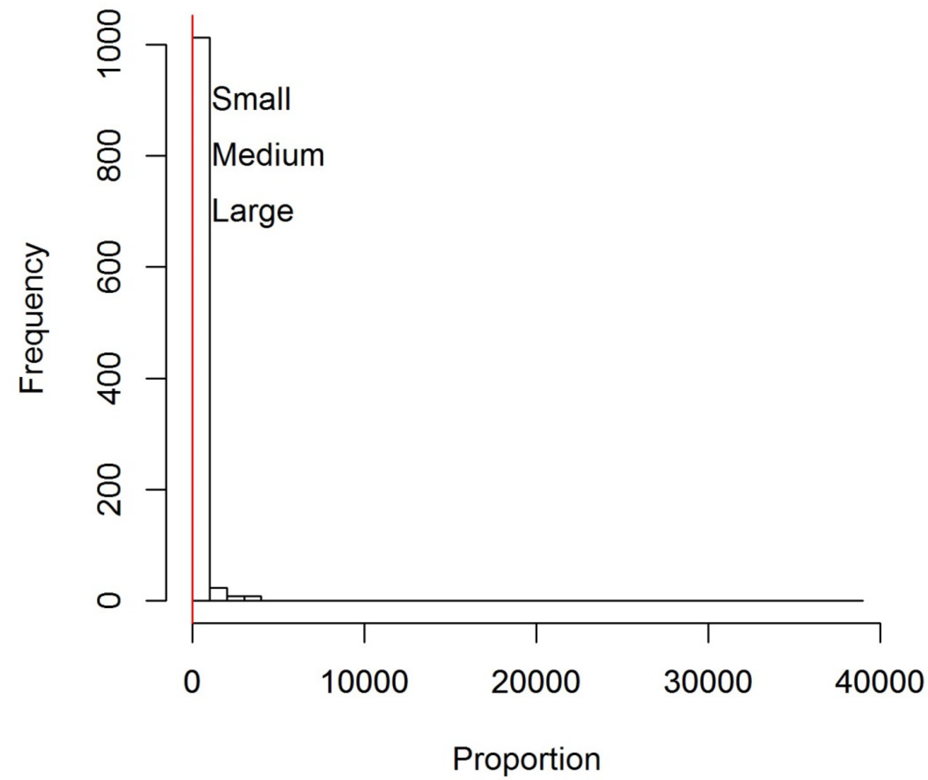
n) Aspect variability in microrefugia zone



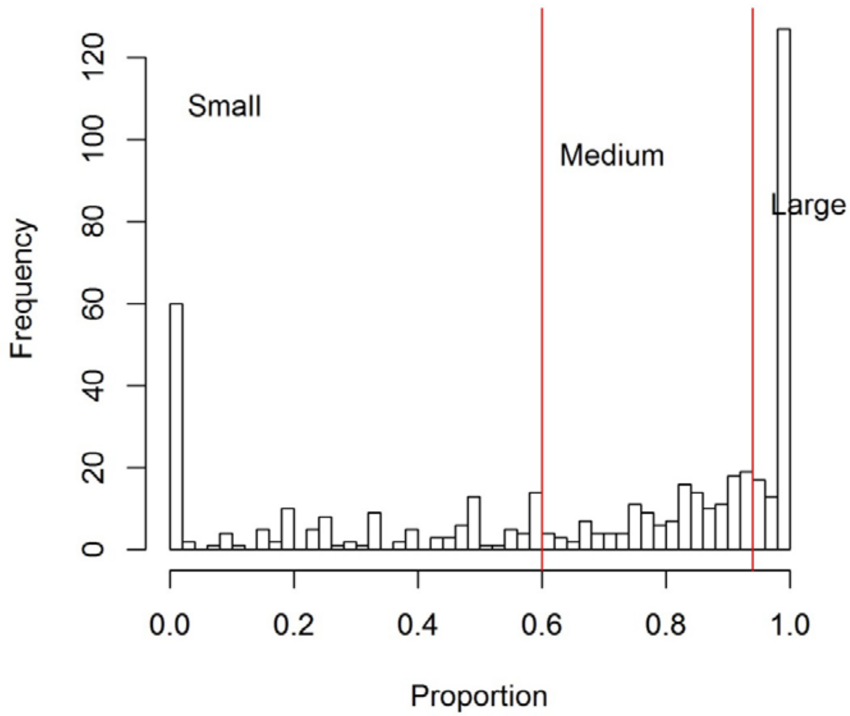
o) Slope variability in microrefugia zone



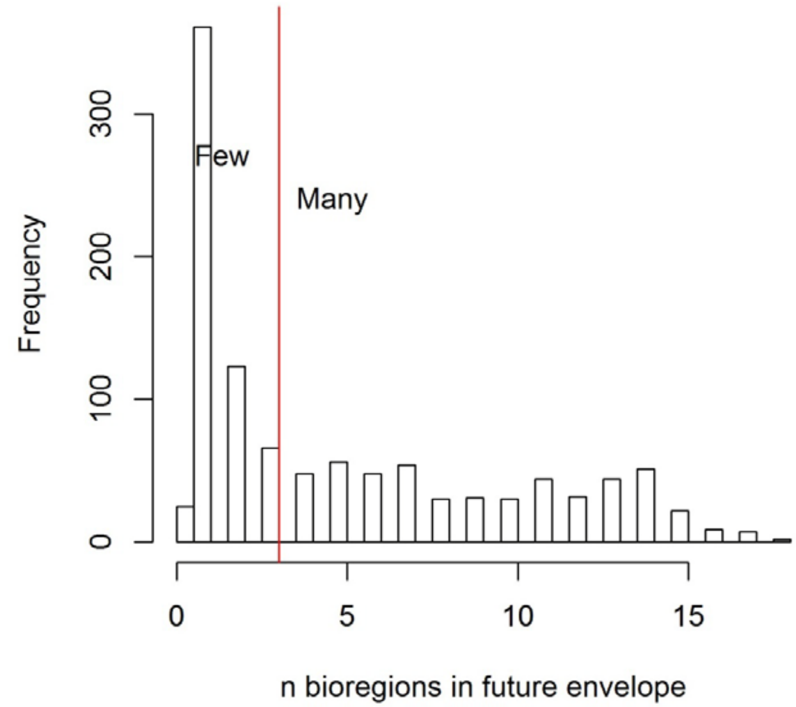
p) Distance between current and future climate envelopes



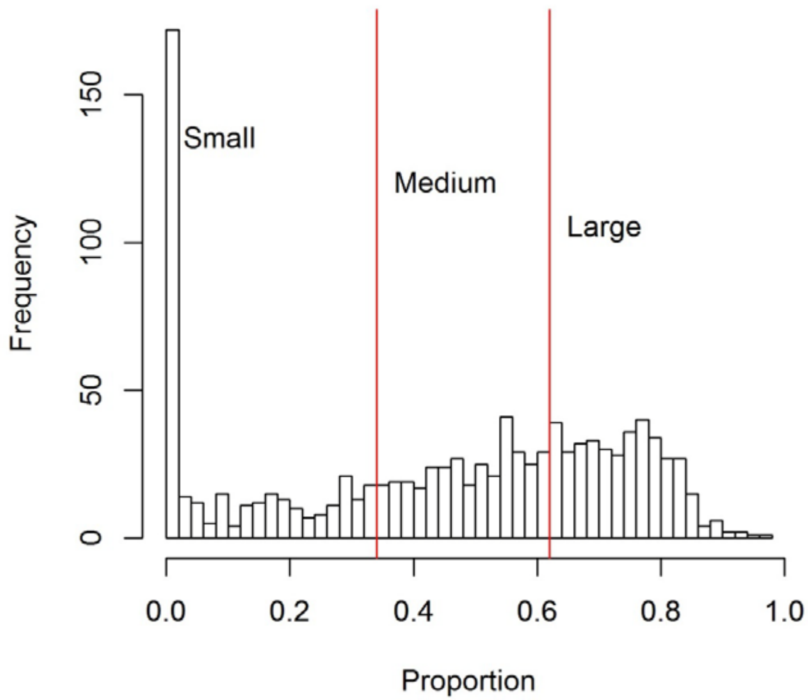
q) Fraction of occurrence points within the toleration zone



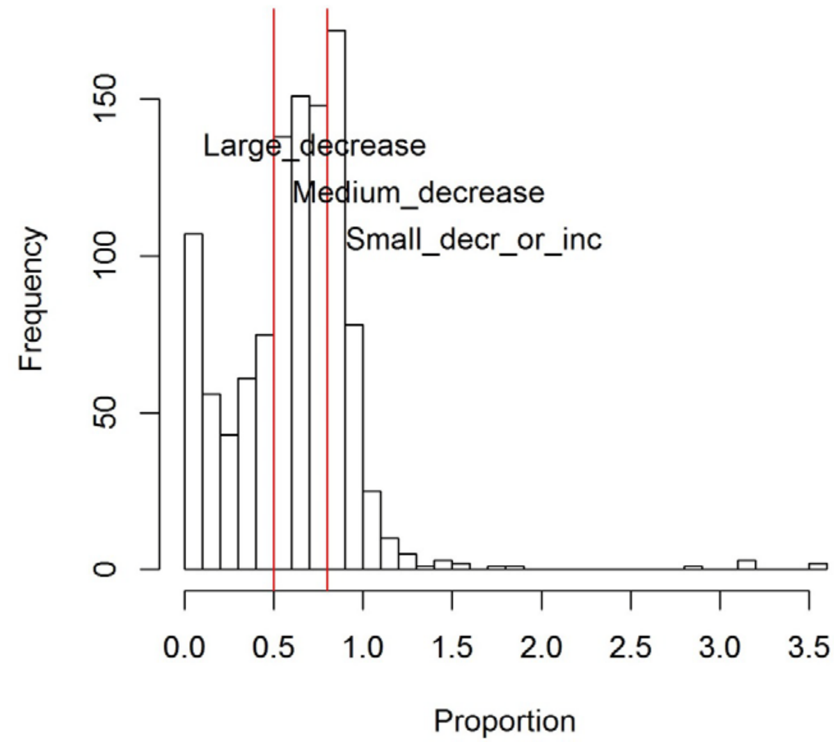
r) Number of future compatible biogeographic regions



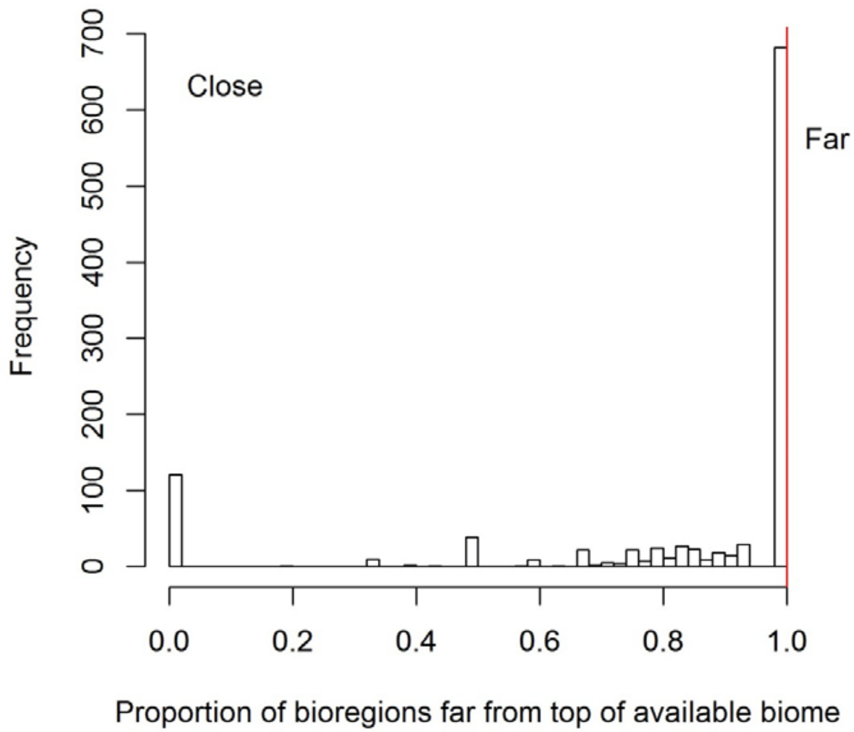
s) Overlap between current and future climate envelopes



t) Projected change in climate envelope area

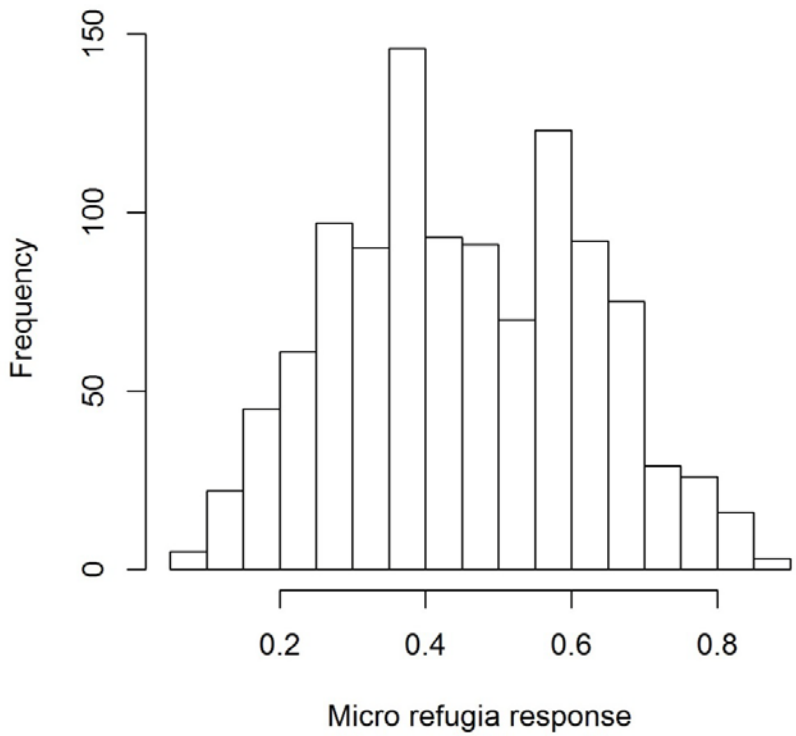


u) Proximity to maximum height of available habitat

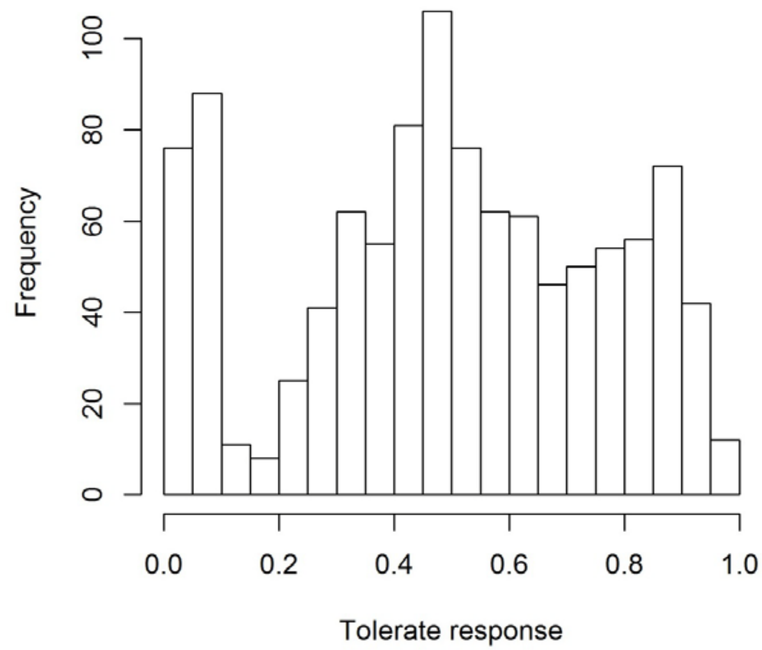


APPENDIX 6. HISTOGRAM DISTRIBUTION OF THE THREE RESPONSES CONSIDERED IN THE ANALYSIS AND THE RESULTING VULNERABILITY SCORES FOR ALL SPECIES COMBINED

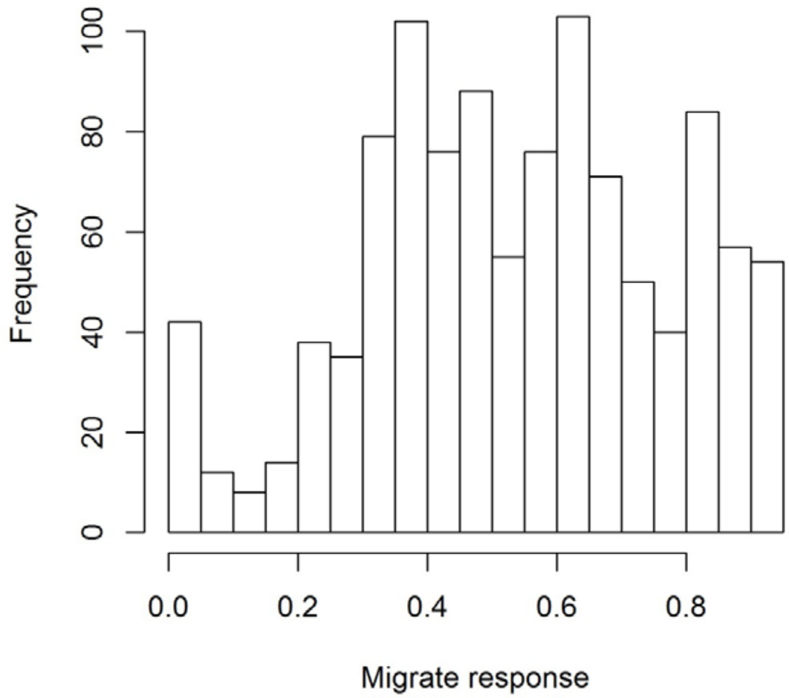
a. Histogram distribution of the probability of microrefugia response across all native Hawaiian plant species



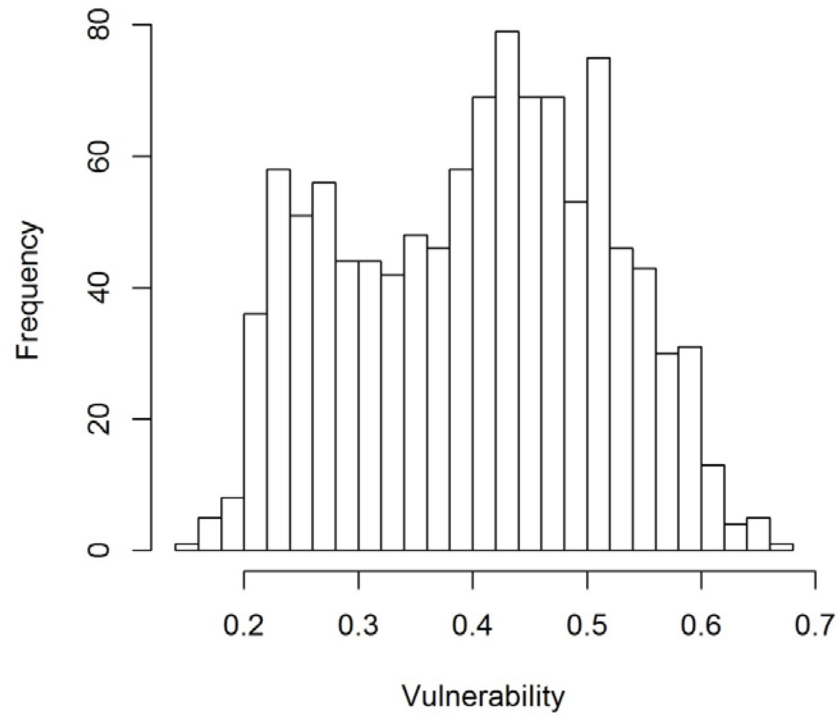
b. Histogram distribution of the probability of toleration response across all native Hawaiian plant species



c. Histogram distribution of the probability of migration response across all native Hawaiian plant species

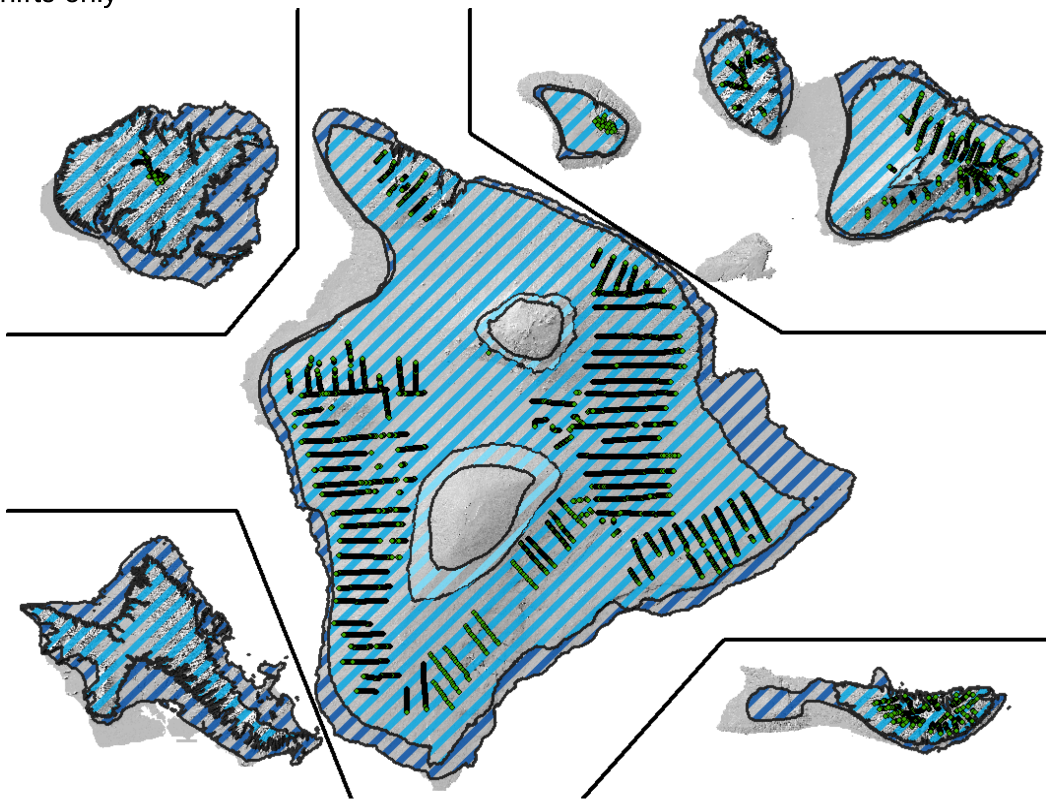


d. Histogram distribution of climate change vulnerability scores across all native Hawaiian plant species



APPENDIX 7. EXAMPLE VULNERABILITY MAPS FOR *METROSIDEROS POLYMORPHA*

a) Climate envelope shifts only



Species climate envelope shifts

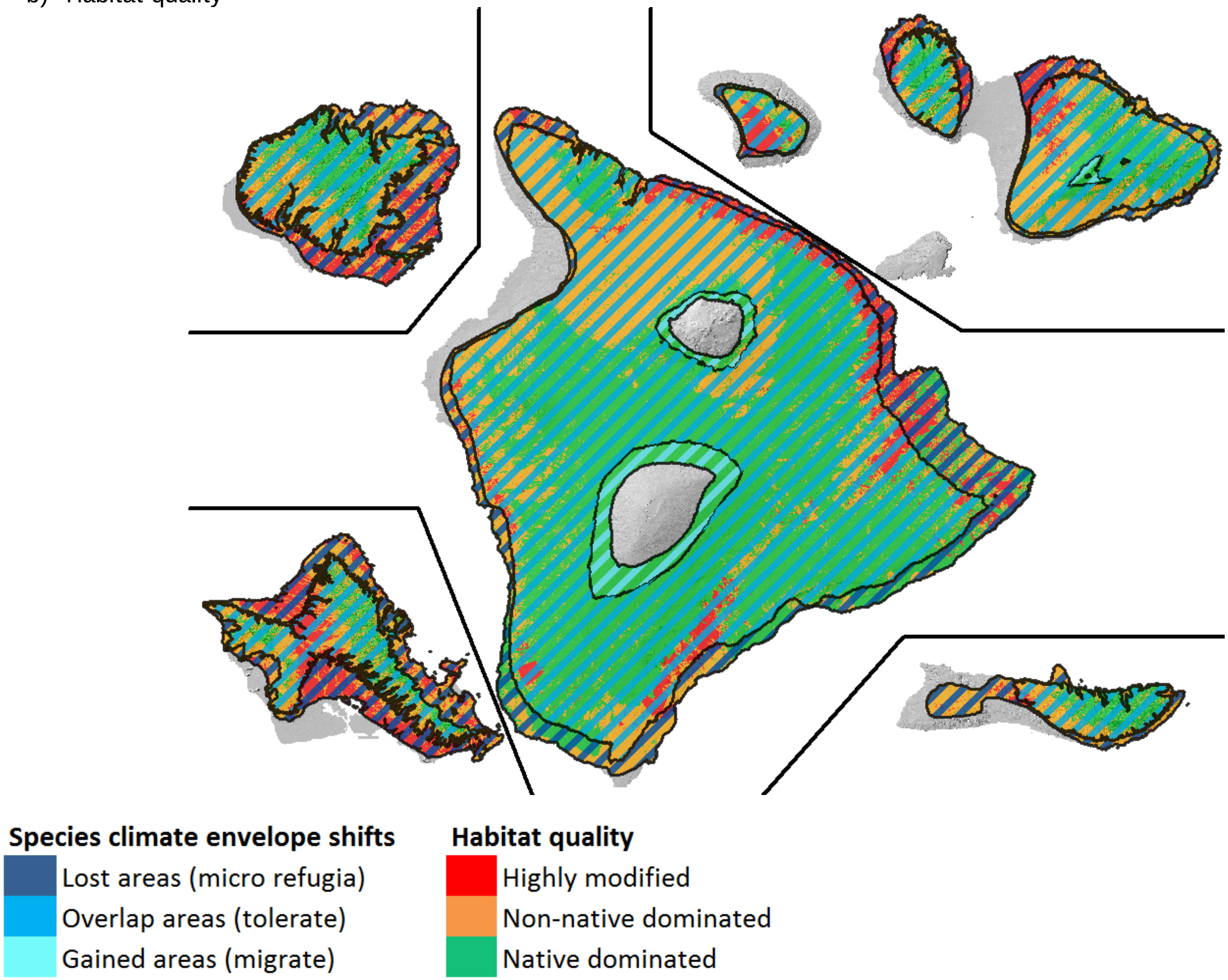
Lost areas (micro refugia)

Overlap areas (tolerate)

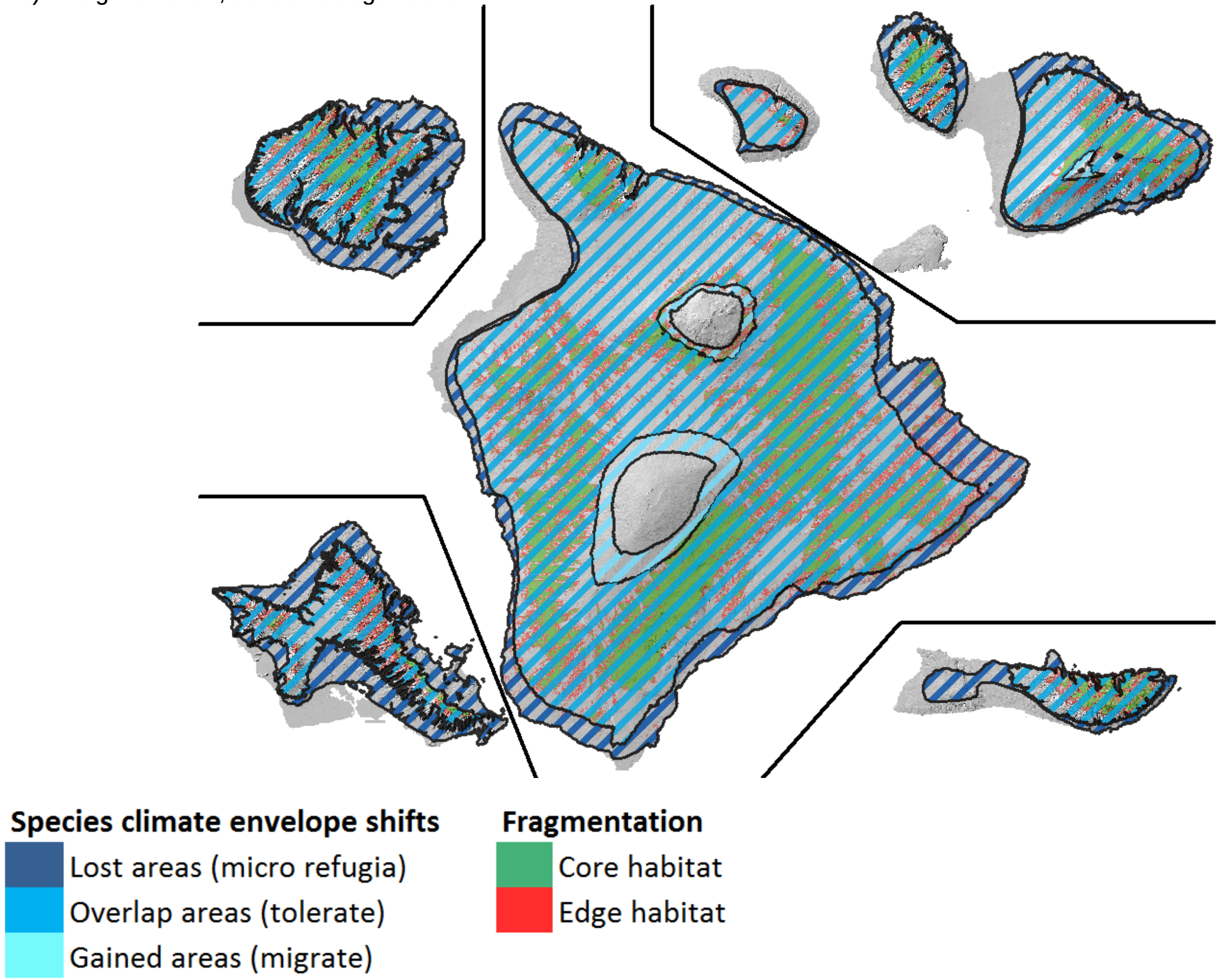
Gained areas (migrate)

Current occurrence

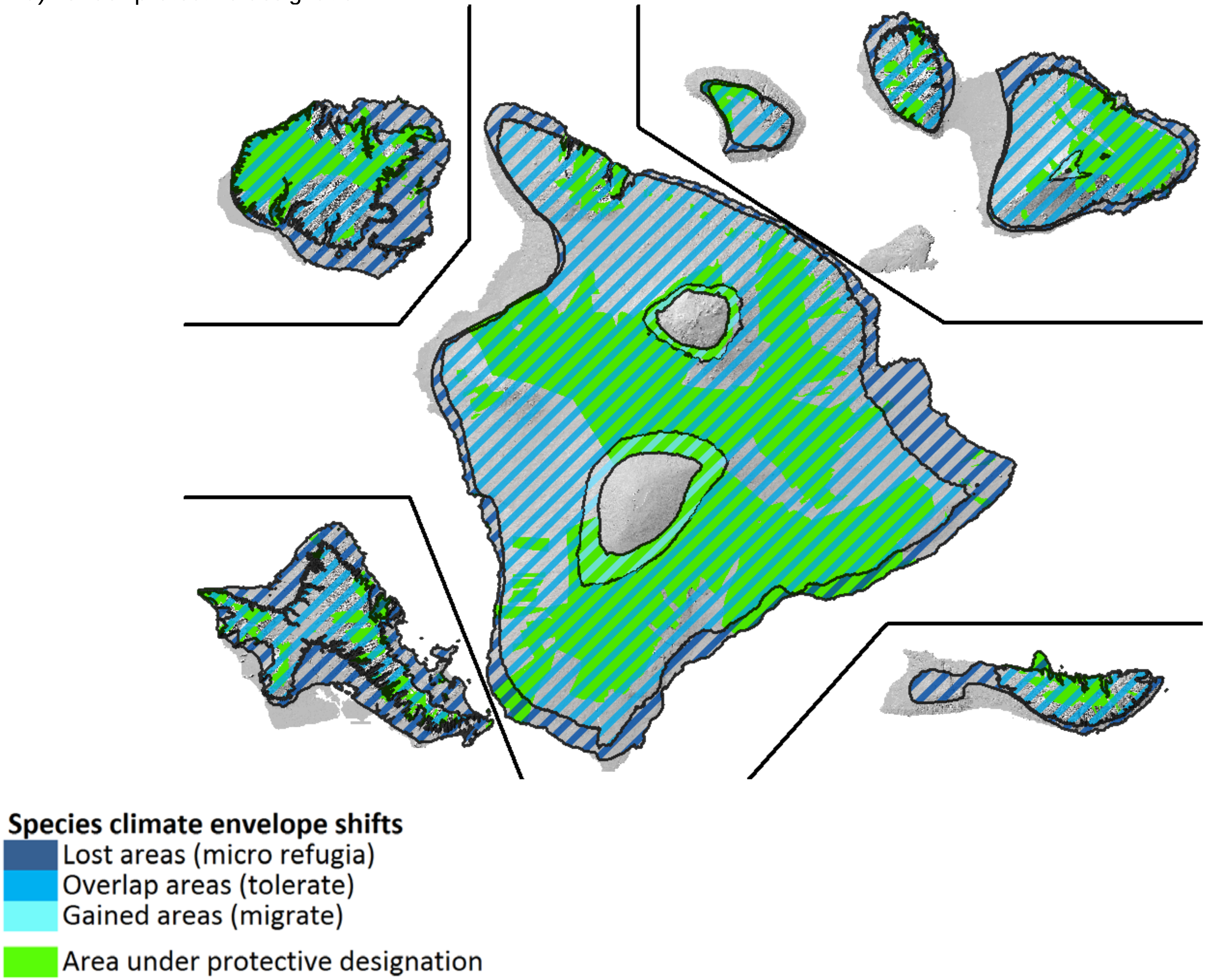
b) Habitat quality



c) Fragmentation, core and edge habitat



d) Under protective designation



APPENDIX 8. VULNERABILITY FACTORS AND THEIR CATEGORIZED STATES FOR HIGH / MEDIUM / LOW VULNERABILITY EXAMPLE SPECIES

Factor	Zone	Category	Type	*Euphorbia rockii*	*Hibiscus kokio*	*Metrosideros polymorpha*
Family				Euphorbiaceae	Malvaceae	Myrtaceae
Vulnerability				0.597	0.295	0.247
Microrefugia				0.253	0.617	0.627
Toleration				0.0169	0.584	0.841
Migration				0.0169	0.896	0.847
Total area	Microrefugia	Habitat area	Value	54.3	1160	3150
Total area	Microrefugia	Habitat area	State	Very_small	Very_large	Very_large
Total area	Toleration	Habitat area	Value	0	1680	10900
Total area	Toleration	Habitat area	State	Very_small	Large	Very_large
Total area	Migration	Habitat area	Value	0.306	214	526
Total area	Migration	Habitat area	State	Very_small	Large	Very_large
Lava flow area	Microrefugia	Habitat area	Value	0	0	0.138
Lava flow area	Microrefugia	Habitat area	State	Small	Small	Large
Lava flow area	Toleration	Habitat area	Value	NA	0	0.17
Lava flow area	Toleration	Habitat area	State	none	Small	Large
Lava flow area	Migration	Habitat area	Value	0	0	0.718
Lava flow area	Migration	Habitat area	State	Small	Small	Large
Heavily modified habitat	Microrefugia	Habitat area	Value	0.000166	0.26	0.303
Heavily modified habitat	Microrefugia	Habitat area	State	Small	Large	Large
Heavily modified habitat	Toleration	Habitat area	Value	NA	0.0267	0.0717
Heavily modified habitat	Toleration	Habitat area	State	none	Medium	Medium
Heavily modified habitat	Migration	Habitat area	Value	0	0.00199	0
Heavily modified habitat	Migration	Habitat area	State	Small	Small	Small
Area lost to sea level rise	Microrefugia	Habitat area	Value	0	0	0.0179
Area lost to sea level rise	Microrefugia	Habitat area	State	Small	Small	Large

Factor	Zone	Category	Type	*Euphorbia rockii*	*Hibiscus kokio*	*Metrosideros polymorpha*
Area in native cover	Microrefugia	Habitat quality	Value	0.813	0.056	0.218
Area in native cover	Microrefugia	Habitat quality	State	Large	Small	Small
Area in native cover	Toleration	Habitat quality	Value	NA	0.418	0.608
Area in native cover	Toleration	Habitat quality	State	none	Small	Medium
Area in native cover	Migration	Habitat quality	Value	0.815	0.804	0.979
Area in native cover	Migration	Habitat quality	State	Large	Large	Large
Area under Protective designation	Microrefugia	Habitat quality	Value	0.37	0.21	0.178
Area under Protective designation	Microrefugia	Habitat quality	State	Small	Small	Small
Area under Protective designation	Toleration	Habitat quality	Value	NA	0.394	0.512
Area under Protective designation	Toleration	Habitat quality	State	none	Small	Medium
Area under protective designation	Migration	Habitat quality	Value	0.571	0.652	0.847
Area under protective designation	Migration	Habitat quality	State	Large	Large	Large
Ungulate exclusion areas	Microrefugia	Habitat quality	Value	0.0283	0.00642	0.0079
Ungulate exclusion areas	Microrefugia	Habitat quality	State	Small	Small	Small
Ungulate exclusion areas	Toleration	Habitat quality	Value	NA	0.117	0.188
Ungulate exclusion areas	Toleration	Habitat quality	State	none	Medium	Large
Ungulate exclusion areas	Migration	Habitat quality	Value	0.0912	0.284	0.459
Ungulate exclusion areas	Migration	Habitat quality	State	Medium	Large	Large
Invasibility	Microrefugia	Habitat quality	Value	0.106	0.235	0.239
Invasibility	Microrefugia	Habitat quality	State	Small	Medium	Large

Factor	Zone	Category	Type	*Euphorbia rockii*	*Hibiscus kokio*	*Metrosideros polymorpha*
Invasibility	Toleration	Habitat quality	Value	0	0.199	0.214
Invasibility	Toleration	Habitat quality	State	Small	Medium	Medium
Invasibility	Migration	Habitat quality	Value	0.072	0.206	0.25
Invasibility	Migration	Habitat quality	State	Small	Medium	Large
Fragmentation	Microrefugia	Habitat quality	Value	0.567	0.858	0.79
Fragmentation	Microrefugia	Habitat quality	State	Medium	Large	Large
Fragmentation	Toleration	Habitat quality	Value	NA	0.538	0.394
Fragmentation	Toleration	Habitat quality	State	none	Medium	Medium
Fragmentation	Migration	Habitat quality	Value	0.254	0.244	0.578
Fragmentation	Migration	Habitat quality	State	Small	Small	Medium
Precipitation gradient	Microrefugia	Habitat quality	Value	0.0554	0.0289	0.0167
Average slope	Microrefugia	Habitat quality	Value	32.7	20	9.98
Precipitation gradient	Microrefugia	Habitat quality	State	High	Medium	Low
Average slope	Microrefugia	Habitat quality	State	High	Medium	Low
Aspect variability	Microrefugia	Habitat quality	Value	0.705	0.688	0.599
Aspect variability	Microrefugia	Habitat quality	State	Large	Medium	Small
Slope variability	Microrefugia	Habitat quality	Value	0.385	0.719	1.16
Slope variability	Microrefugia	Habitat quality	State	Small	Medium	Large
Distance between current and future climate envelopes		Habitat quality	Value	395	9.78	4.14
Distance between current and future climate envelopes		Habitat quality	State	Large	Small	Small
Fraction of occurrence points within the toleration zone		Habitat quality	Value	0	0.706	1
Fraction of occurrence points within the toleration zone		Habitat quality	State	Small	Medium	Large
Number of future compatible biogeographic regions		Habitat distribution	Value	1	6	15
Number of future compatible biogeographic regions		Habitat distribution	State	Few	Many	Many

Factor	Zone	Category	Type	*Euphorbia rockii*	*Hibiscus kokio*	*Metrosideros polymorpha*
Overlap between current and future climate envelope		Habitat distribution	Value	0	0.591	0.775
Overlap between current and future climate envelope		Habitat distribution	State	Small	Medium	Large
Projected change in total climate envelope area		Habitat distribution	Value	0.00564	0.667	0.813
Projected change in total climate envelope area		Habitat distribution	State	Large_decrease	Medium_decrease	Small_decr_or_inc
Proximity to maximum height of available habitat		Habitat distribution	Value	0	1	1
Proximity to maximum height of available habitat		Habitat distribution	State	Close	Far	Far
Winkout species		Switches	State	Yes	No	No
Species with overlap between current and future climate envelope		Switches	State	No	Yes	Yes
Persistence in non-native habitat		Switches	State	No	Yes	Yes
Pioneer species		Switches	State	No	No	Yes

APPENDIX 9. LIST OF SPECIES WITH LOST, GAINED, AND MAINTAINED CLIMATE SPACE BETWEEN CURRENT AND 2100 CLIMATE FOR HANAWI NATURAL AREA RESERVE, MAUI, AND THEIR RELATED CLIMATE CHANGE VULNERABILITY SCORES

			% overlap of area with species climate envelopes	
Species	Vulnerability	Current/ future compatibility	Current	Future
Geranium hanaense	0.58	CURRENT	0.01	0.00
Asplenium haleakalense	0.54	BOTH	0.10	0.01
Dryopteris subbipinnata	0.52	BOTH	0.10	0.04
Carex thunbergii	0.50	BOTH	0.11	0.04
Dubautia platyphylla	0.50	BOTH	0.02	0.00
Huperzia haleakalae	0.50	BOTH	0.29	0.13
Cyrtandra ferripilosa	0.50	BOTH	0.12	0.03
Lobelia gloria-montis	0.49	BOTH	0.38	0.15
Wikstroemia villosa	0.49	BOTH	0.14	0.14
Phyllostegia mannii	0.48	BOTH	0.45	0.31
Argyroxiphium grayanum	0.48	BOTH	0.38	0.20
Cyanea kunthiana	0.48	BOTH	0.49	0.31
Dubautia menziesii	0.47	BOTH	0.00	0.00
Peperomia expallescens	0.47	BOTH	0.52	0.37
Schiedea haleakalensis	0.46	BOTH	0.00	0.00
Dubautia reticulata	0.46	BOTH	0.02	0.03
Clermontia tuberculata	0.46	BOTH	0.42	0.25
Uncinia brevicaulis	0.46	BOTH	0.16	0.03
Argyroxiphium virescens	0.46	BOTH	0.02	0.02
Keysseria maviensis	0.46	BOTH	0.60	0.40
Geranium arboreum	0.46	BOTH	0.01	0.03
Stenogyne rotundifolia	0.45	BOTH	0.17	0.04
Polystichum bonseyi	0.45	BOTH	0.20	0.12
Argyroxiphium sandwicense	0.45	CURRENT	0.00	0.00
Santalum haleakalae	0.45	BOTH	0.02	0.02
Melicope ovalis	0.44	BOTH	0.42	0.23
Labordia venosa	0.44	BOTH	0.60	0.37
Dubautia waianapanapaensis	0.43	BOTH	0.49	0.28
Artemisia mauiensis	0.43	BOTH	0.02	0.03
Peperomia globulanthera	0.43	BOTH	0.61	0.36
Lobelia grayana	0.43	BOTH	0.21	0.15
Cyanea glabra	0.43	BOTH	0.57	0.40
Geranium multiflorum	0.42	BOTH	0.18	0.08

Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Melicope haleakalae	0.42	BOTH	0.29	0.21
Cyanea mceldowneyi	0.42	BOTH	0.28	0.20
Cyanea asplenifolia	0.41	BOTH	0.21	0.24
Huperzia stemmermanniae	0.41	BOTH	0.17	0.13
Cyanea copelandii	0.41	BOTH	0.70	0.41
Cyanea horrida	0.41	BOTH	0.48	0.30
Asplenium hobdyi	0.41	BOTH	0.42	0.22
Dryopteris tetrapinnata	0.41	BOTH	0.10	0.15
Pipturus forbesii	0.41	BOTH	0.11	0.14
Peperomia kipahuluensis	0.40	BOTH	0.91	0.61
Cyanea aculeatiflora	0.40	BOTH	0.55	0.37
Cyrtandra grayi	0.40	BOTH	0.12	0.21
Carex echinata	0.40	BOTH	0.29	0.12
Pritchardia arecina	0.40	BOTH	0.59	0.43
Clermontia samuelii	0.40	BOTH	0.96	0.65
Pittosporum argentifolium	0.40	BOTH	0.19	0.21
Cyanea longissima	0.39	BOTH	0.70	0.54
Diplazium molokaiense	0.39	BOTH	0.08	0.19
Melicope orbicularis	0.39	BOTH	0.97	0.67
Cyrtandra hashimotoi	0.39	BOTH	0.96	0.77
Cyrtandra biserrata	0.39	BOTH	0.08	0.19
Cyanea macrostegia	0.39	BOTH	0.81	0.52
Melicope balloui	0.39	BOTH	0.59	0.44
Selaginella deflexa	0.38	BOTH	0.43	0.19
Cyclosorus boydiae	0.38	BOTH	0.66	0.77
Peperomia eekana	0.38	BOTH	0.89	0.76
Myrsine emarginata	0.38	BOTH	0.13	0.21
Lysimachia remyi	0.38	BOTH	0.99	0.90
Cyanea hamatiflora	0.38	BOTH	0.69	0.50
Stenogyne kamehamehae	0.38	BOTH	0.97	0.65
Trematolobelia macrostachys	0.37	BOTH	0.91	0.72
Phyllostegia haliakalae	0.37	BOTH	0.19	0.21
Phyllostegia bracteata	0.37	BOTH	0.69	0.49
Cyrtandra spathulata	0.37	BOTH	0.79	0.94
Peperomia obovatilimba	0.37	BOTH	0.85	0.64
Melicope sessilis	0.36	BOTH	0.52	0.39
Huperzia mannii	0.36	BOTH	0.22	0.17
Asplenium sphenotomum	0.36	BOTH	0.40	0.26
Melicope molokaiensis	0.36	BOTH	0.76	0.79

Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Hillebrandia sandwicensis	0.35	BOTH	0.11	0.21
Bidens micrantha	0.35	BOTH	0.21	0.21
Lobelia hillebrandii	0.35	BOTH	0.75	0.80
Korthalsella platycaula	0.35	BOTH	0.00	0.06
Sanicula sandwicensis	0.34	BOTH	0.17	0.07
Asplenium excisum	0.34	BOTH	0.11	0.21
Huperzia subintegra	0.34	BOTH	0.96	0.65
Ranunculus mauiensis	0.34	BOTH	0.14	0.20
Coprosma foliosa	0.33	BOTH	0.89	1.00
Clermontia peleana	0.33	BOTH	0.81	0.72
Dichanthelium cynodon	0.33	BOTH	0.78	0.47
Platanthera holochila	0.33	BOTH	0.90	0.66
Psychotria mariniana	0.33	BOTH	0.59	0.79
Viola chamissoniana	0.33	BOTH	0.13	0.21
Pittosporum glabrum	0.33	BOTH	0.94	1.00
Cystopteris douglasii	0.32	BOTH	0.02	0.03
Clermontia arborescens	0.32	BOTH	0.97	0.78
Cyperus sandwicensis	0.32	BOTH	0.84	0.97
Clermontia grandiflora	0.32	BOTH	0.94	0.74
Clermontia kakeana	0.32	BOTH	0.89	1.00
Adenophorus abietinus	0.32	BOTH	0.65	0.67
Gunnera petaloïdea	0.32	BOTH	0.84	0.55
Rubus macraei	0.32	BOTH	0.02	0.02
Sadleria squarrosa	0.32	BOTH	0.99	0.95
Schiedea diffusa	0.32	BOTH	0.83	0.52
Mucuna sloanei	0.32	BOTH	0.09	0.42
Morinda trimera	0.31	BOTH	0.31	0.58
Grammitis forbesiana	0.31	BOTH	0.82	0.77
Stenogyne microphylla	0.31	BOTH	0.00	0.00
Kadua elatior	0.31	BOTH	0.55	0.75
Dryopteris mauiensis	0.31	BOTH	0.46	0.34
Psychotria kaduana	0.31	BOTH	0.67	0.84
Kadua cordata	0.31	BOTH	0.89	1.00
Clermontia oblongifolia	0.31	BOTH	0.63	0.76
Phyllostegia glabra	0.31	BOTH	0.62	0.81
Viola maviensis	0.31	BOTH	0.37	0.20
Plantago princeps	0.31	BOTH	0.97	1.00
Peperomia hirtipetiola	0.31	BOTH	0.68	0.67
Dryopteris crinalis	0.30	BOTH	0.91	0.97

Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Cyperus pennatiformis	0.30	BOTH	0.58	0.78
Pilea peploides	0.30	BOTH	0.98	1.00
Asplenium insiticium	0.30	BOTH	0.00	0.07
Eragrostis leptophylla	0.30	BOTH	0.00	0.00
Cyperus hypochlorus	0.30	BOTH	0.00	0.06
Pseudognaphalium sandwicensium	0.30	BOTH	1.00	1.00
Deparia prolifera	0.30	BOTH	0.63	0.81
Wikstroemia oahuensis	0.30	BOTH	0.83	0.97
Asplenium acuminatum	0.30	BOTH	0.89	1.00
Lysimachia hillebrandii	0.30	BOTH	0.86	0.93
Sisyrinchium acre	0.30	BOTH	0.18	0.08
Dubautia laxa	0.30	BOTH	0.84	0.95
Korthalsella remyana	0.29	BOTH	0.78	0.94
Nertera granadensis	0.29	BOTH	0.96	0.80
Solanum americanum	0.29	BOTH	0.21	0.21
Calamagrostis expansa	0.29	BOTH	0.62	0.37
Cyrtomium caryotideum	0.29	BOTH	0.01	0.03
Argemone glauca	0.29	BOTH	0.00	0.00
Stenogyne rugosa	0.29	BOTH	0.02	0.03
Anoectochilus sandvicensis	0.29	BOTH	0.84	0.96
Chenopodium oahuense	0.29	BOTH	0.02	0.03
Fragaria chiloensis	0.29	BOTH	0.02	0.03
Panicum pellitum	0.29	BOTH	0.00	0.00
Vandenboschia draytoniana	0.29	BOTH	0.51	0.72
Lobelia hypoleuca	0.29	BOTH	0.83	0.84
Arachniodes insularis	0.29	BOTH	0.95	0.74
Tetramolopium humile	0.28	BOTH	0.00	0.00
Plantago pachyphylla	0.28	BOTH	0.89	0.55
Bidens campylotheca	0.28	BOTH	0.98	1.00
Carex montis-eeka	0.28	BOTH	0.95	0.61
Syzygium sandwicensis	0.28	BOTH	0.61	0.80
Pittosporum confertiflorum	0.28	BOTH	1.00	1.00
Asplenium schizophyllum	0.28	BOTH	0.78	0.53
Chamaesyce celastroides	0.28	BOTH	0.00	0.03
Sicyos cucumerinus	0.28	BOTH	0.92	0.81
Asplenium adiantum-nigrum	0.28	BOTH	0.21	0.21
Asplenium monanthes	0.28	BOTH	0.17	0.21
Exocarpos gaudichaudii	0.28	BOTH	1.00	1.00

Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Eragrostis atropioides	0.28	BOTH	0.00	0.00
Schizaea robusta	0.28	BOTH	0.86	0.77
Peperomia membranacea	0.28	BOTH	0.97	1.00
Hypolepis hawaiiensis	0.28	BOTH	0.94	0.66
Thelypteris globulifera	0.28	BOTH	0.99	1.00
Lellingeria saffordii	0.28	BOTH	0.97	0.65
Sadleria pallida	0.27	BOTH	0.99	1.00
Sida fallax	0.27	BOTH	0.20	0.21
Lycopodiella cernua	0.27	BOTH	0.98	1.00
Waltheria indica	0.27	BOTH	0.04	0.13
Melicope peduncularis	0.27	BOTH	0.59	0.79
Cladium jamaicense	0.27	BOTH	0.62	0.80
Dichanthelium hillebrandianum	0.27	BOTH	0.68	0.49
Cyanea elliptica	0.27	BOTH	0.46	0.53
Asplenium contiguum	0.27	BOTH	0.98	1.00
Eragrostis variabilis	0.27	BOTH	0.04	0.15
Dubautia plantaginea	0.27	BOTH	1.00	1.00
Doodia lyonii	0.27	BOTH	0.34	0.60
Charpentiera tomentosa	0.27	BOTH	0.24	0.53
Microsorum spectrum	0.27	BOTH	0.47	0.69
Carex alligata	0.27	BOTH	1.00	1.00
Strongylodon ruber	0.27	BOTH	0.34	0.60
Melicope pseudoanisata	0.26	BOTH	0.89	0.71
Adiantum capillus-veneris	0.26	BOTH	0.64	0.82
Huperzia erubescens	0.26	BOTH	0.69	0.50
Vandenboschia davallioides	0.26	BOTH	0.95	1.00
Phyllostegia brevidens	0.26	BOTH	0.82	0.55
Grammitis hookeri	0.26	BOTH	1.00	0.88
Gardenia remyi	0.26	BOTH	0.37	0.63
Cyperus hillebrandii	0.26	BOTH	0.01	0.03
Sadleria souleyetiana	0.26	BOTH	0.97	0.92
Sticherus owhyhensis	0.26	BOTH	0.85	0.64
Vaccinium calycinum	0.26	BOTH	0.99	0.88
Boehmeria grandis	0.26	BOTH	0.55	0.75
Elaphoglossum aemulum	0.26	BOTH	0.70	0.87
Asplenium trichomanes	0.26	BOTH	0.02	0.03
Rumex giganteus	0.26	BOTH	1.00	1.00
Oreobolus furcatus	0.26	BOTH	0.97	0.64
Sphaerocionium lanceolatum	0.25	BOTH	0.78	0.91

Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Asplenium nidus	0.25	BOTH	0.25	0.53
Fimbristylis dichotoma	0.25	BOTH	1.00	1.00
Myrsine lessertiana	0.25	BOTH	1.00	1.00
Panicum tenuifolium	0.25	BOTH	0.02	0.03
Carex meyenii	0.25	BOTH	0.21	0.21
Ranunculus hawaiensis	0.25	BOTH	0.02	0.03
Huperzia filiformis	0.25	BOTH	0.92	1.00
Agrostis avenacea	0.25	BOTH	1.00	1.00
Peperomia latifolia	0.25	BOTH	0.90	1.00
Trisetum glomeratum	0.25	BOTH	0.20	0.13
Dryopteris glabra	0.25	BOTH	0.99	0.88
Adenophorus periens	0.25	BOTH	0.64	0.73
Deparia marginalis	0.25	BOTH	0.63	0.81
Rhus sandwicensis	0.25	BOTH	0.21	0.51
Polystichum hillebrandii	0.25	BOTH	0.00	0.03
Myrsine lanaiensis	0.25	BOTH	0.02	0.03
Pteridium aquilinum	0.25	BOTH	0.02	0.03
Asplenium normale	0.25	BOTH	0.86	0.96
Lindsaea repens	0.25	BOTH	0.17	0.48
Polyscias hawaiensis	0.25	BOTH	0.34	0.60
Peperomia macraeana	0.25	BOTH	0.96	1.00
Athyrium microphyllum	0.25	BOTH	1.00	1.00
Ctenitis latifrons	0.24	BOTH	0.75	0.91
Phyllostegia macrophylla	0.24	BOTH	0.86	0.61
Adenostemma viscosum	0.24	BOTH	0.11	0.44
Cyclosorus interruptus	0.24	BOTH	0.48	0.70
Scaevola chamissoniana	0.24	BOTH	0.91	1.00
Kadua acuminata	0.24	BOTH	0.64	0.82
Dodonaea viscosa	0.24	BOTH	1.00	1.00
Myoporum sandwicense	0.24	BOTH	1.00	1.00
Labordia hirtella	0.24	BOTH	0.89	1.00
Adenophorus hymenophylloides	0.24	BOTH	0.92	1.00
Leptecophylla tameiameiae	0.24	BOTH	1.00	1.00
Peperomia tetraphylla	0.24	BOTH	1.00	1.00
Eragrostis grandis	0.24	BOTH	1.00	1.00
Clermontia lindseyana	0.24	BOTH	0.19	0.17
Geranium cuneatum	0.24	BOTH	0.19	0.10
Charpentiera obovata	0.24	BOTH	0.08	0.19
Smilax melastomifolia	0.24	BOTH	1.00	1.00

Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Cyperus phleoides	0.24	BOTH	0.59	0.79
Cyrtandra hawaiensis	0.23	BOTH	0.68	0.85
Lycopodium venustulum	0.23	BOTH	0.73	0.47
Dryopteris rubiginosum	0.23	BOTH	0.67	0.42
Psychotria mauiensis	0.23	BOTH	0.80	0.95
Psilotum nudum	0.23	BOTH	0.65	0.83
Osteomeles anthyllidifolia	0.23	BOTH	0.02	0.03
Planchonella sandwicensis	0.23	BOTH	0.78	0.93
Vandenboschia cyrtotheca	0.23	BOTH	0.61	0.80
Crepidomanes minutum	0.23	BOTH	0.63	0.81
Pteris excelsa	0.23	BOTH	1.00	1.00
Eleocharis obtusa	0.23	BOTH	0.91	1.00
Cheirodendron trigynum	0.23	BOTH	0.99	1.00
Metrosideros polymorpha	0.23	BOTH	1.00	1.00
Asplenium kaulfussii	0.23	BOTH	0.65	0.83
Peperomia remyi	0.23	BOTH	0.79	0.94
Agrostis sandwicensis	0.23	BOTH	1.00	0.74
Pellaea ternifolia	0.23	BOTH	0.02	0.03
Adenophorus tripinnatifidus	0.23	BOTH	0.95	0.80
Alyxia stellata	0.23	BOTH	0.95	1.00
Dryopteris sandwicensis	0.23	BOTH	0.89	1.00
Rhynchospora chinensis	0.23	BOTH	0.86	0.99
Psychotria hawaiiensis	0.23	BOTH	0.85	0.98
Charpentiera ovata	0.23	BOTH	0.01	0.09
Haplopteris elongata	0.23	BOTH	0.34	0.60
Cocculus orbiculatus	0.23	BOTH	0.82	0.96
Peperomia blanda	0.23	BOTH	0.93	1.00
Paspalum scrobiculatum	0.23	BOTH	0.48	0.70
Pittosporum terminalioides	0.23	BOTH	0.21	0.21
Labordia tinifolia	0.23	BOTH	0.63	0.81
Ilex anomala	0.23	BOTH	0.96	1.00
Diplazium sandwichianum	0.23	BOTH	0.98	1.00
Cibotium chamissoi	0.23	BOTH	0.63	0.81
Pisonia brunoniana	0.23	BOTH	0.04	0.13
Callistopteris baldwinii	0.23	BOTH	0.80	0.94
Rhynchospora rugosa	0.23	BOTH	0.80	0.95
Carex macloviana	0.23	BOTH	0.21	0.21
Sophora chrysophylla	0.23	BOTH	0.02	0.03
Pteris irregularis	0.23	BOTH	0.14	0.21

Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Uncinia uncinata	0.23	BOTH	0.84	0.54
Xylosma hawaiiense	0.23	BOTH	0.73	0.90
Acacia koa	0.23	BOTH	0.99	1.00
Asplenium horridum	0.23	BOTH	0.53	0.73
Polyscias oahuensis	0.22	BOTH	0.89	1.00
Asplenium macraei	0.22	BOTH	0.11	0.21
Astelia menziesiana	0.22	BOTH	0.99	1.00
Korthalsella cylindrica	0.22	BOTH	0.98	1.00
Machaerina angustifolia	0.22	BOTH	0.96	1.00
Dicranopteris linearis	0.22	BOTH	0.95	1.00
Carex wahuensis	0.22	BOTH	1.00	1.00
Pneumatopteris sandwicensis	0.22	BOTH	0.95	1.00
Phytolacca sandwicensis	0.22	BOTH	0.16	0.21
Broussaisia arguta	0.22	BOTH	0.96	1.00
Hymenophyllum obtusum	0.22	BOTH	0.64	0.82
Dianella sandwicensis	0.22	BOTH	0.98	1.00
Asplenium peruvianum	0.22	BOTH	0.02	0.03
Pisonia umbellifera	0.22	BOTH	0.46	0.68
Nephrolepis exaltata	0.22	BOTH	0.70	0.87
Kadua affinis	0.22	BOTH	0.96	1.00
Asplenium lobulatum	0.22	BOTH	0.83	0.97
Microlepia strigosa	0.22	BOTH	0.86	0.99
Cyclosorus cyatheoides	0.22	BOTH	0.92	1.00
Elaphoglossum crassifolium	0.22	BOTH	0.64	0.82
Phyllostegia ambigua	0.22	BOTH	0.62	0.40
Zanthoxylum kauaense	0.22	BOTH	0.94	1.00
Korthalsella complanata	0.22	BOTH	0.98	1.00
Sadleria cyatheoides	0.22	BOTH	1.00	1.00
Elaphoglossum wawrae	0.22	BOTH	0.76	0.49
Melicope clusiifolia	0.22	BOTH	0.97	1.00
Dubautia scabra	0.22	BOTH	1.00	1.00
Dryopteris hawaiiensis	0.22	BOTH	0.17	0.21
Nothocestrum longifolium	0.22	BOTH	0.80	0.95
Asplenium polyodon	0.22	BOTH	0.98	0.71
Coprosma montana	0.22	BOTH	0.02	0.03
Coprosma ochracea	0.22	BOTH	0.97	0.64
Tectaria gaudichaudii	0.22	BOTH	0.61	0.80
Peperomia ligustrina	0.22	BOTH	0.69	0.78
Deschampsia nubigena	0.21	BOTH	1.00	1.00

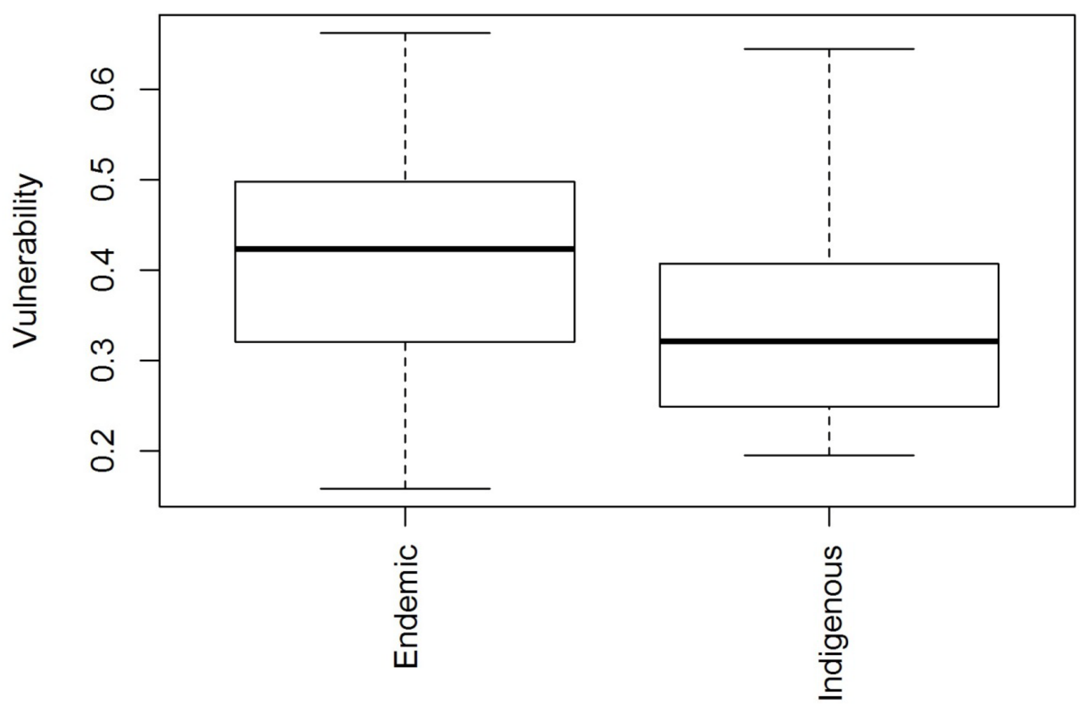
Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Ophioderma pendulum	0.21	BOTH	0.61	0.80
Rhynchospora sclerioides	0.21	BOTH	0.59	0.79
Cibotium glaucum	0.21	BOTH	0.91	1.00
Peperomia cookiana	0.21	BOTH	0.94	1.00
Selaginella arbuscula	0.21	BOTH	0.68	0.85
Machaerina mariscoides	0.21	BOTH	0.59	0.79
Polypodium pellucidum	0.21	BOTH	1.00	1.00
Marattia douglasii	0.21	BOTH	0.96	1.00
Bobea elatior	0.21	BOTH	0.51	0.72
Sphenomeris chinensis	0.21	BOTH	0.75	0.91
Cyperus polystachyos	0.21	BOTH	0.72	0.89
Elaphoglossum paleaceum	0.21	BOTH	0.98	0.76
Lepisorus thunbergianus	0.21	BOTH	0.98	1.00
Elaphoglossum parvisquameum	0.21	BOTH	0.88	0.88
Urera glabra	0.21	BOTH	0.84	0.97
Vaccinium reticulatum	0.21	BOTH	1.00	0.81
Touchardia latifolia	0.21	BOTH	0.76	0.92
Polyscias kavaiensis	0.21	BOTH	0.86	0.98
Huperzia phyllantha	0.21	BOTH	0.45	0.68
Adenophorus pinnatifidus	0.21	BOTH	0.83	0.97
Antidesma platyphyllum	0.21	BOTH	0.76	0.92
Dryopteris wallichiana	0.21	BOTH	0.72	0.44
Melicope volcanica	0.21	BOTH	0.96	0.67
Perrottetia sandwicensis	0.21	BOTH	0.90	1.00
Asplenium unilaterale	0.20	BOTH	0.89	1.00
Pseudophegopteris keraudreniana	0.20	BOTH	0.88	0.99
Coniogramme pilosa	0.20	BOTH	0.97	0.67
Freycinetia arborea	0.20	BOTH	0.75	0.91
Pteris cretica	0.20	BOTH	1.00	1.00
Pipturus albidus	0.20	BOTH	0.90	1.00
Labordia hedyosmifolia	0.20	BOTH	0.90	0.86
Psilotum complanatum	0.20	BOTH	0.70	0.87
Myrsine sandwicensis	0.20	BOTH	0.88	0.99
Coprosma pubens	0.20	BOTH	0.91	0.98
Adenophorus tamariscinus	0.20	BOTH	0.93	1.00
Embelia pacifica	0.20	BOTH	0.82	0.96
Vaccinium dentatum	0.19	BOTH	0.96	0.91
Kadua centranthoides	0.19	BOTH	0.96	0.97

Species	Vulnerability	Current/ future compatibility	% overlap of area with species climate envelopes	
			Current	Future
Cibotium menziesii	0.19	BOTH	0.76	0.92
Cyrtandra platyphylla	0.19	BOTH	0.87	0.96
Joinvillea ascendens	0.18	BOTH	0.63	0.81
Cyrtandra paludosa	0.18	BOTH	0.72	0.88
Coprosma rhynchocarpa	0.18	BOTH	1.00	0.83
Dryopteris fusco-atra	0.18	BOTH	0.96	0.81
Elaphoglossum pellucidum	0.18	BOTH	0.63	0.81
Rubus hawaiensis	0.18	BOTH	0.95	0.62
Asplenium aethiopicum	0.18	BOTH	0.15	0.21
Coprosma ernodeoides	0.18	BOTH	1.00	0.81
Morelotia gahniiformis	0.18	BOTH	1.00	0.78
Hymenophyllum recurvum	0.18	BOTH	0.81	0.95
Luzula hawaiiensis	0.18	BOTH	0.98	0.66
Dubautia linearis	0.18	BOTH	0.21	0.21
Diplopterygium pinnatum	0.18	BOTH	0.76	0.90
Kadua axillaris	0.18	BOTH	0.94	0.95
Dryopteris unidentata	0.18	BOTH	0.86	0.86
Liparis hawaiensis	0.17	BOTH	0.95	0.95
Adenophorus tenellus	0.17	BOTH	0.83	0.97
Isachne distichophylla	0.17	BOTH	0.75	0.91
Nephrolepis cordifolia	0.17	BOTH	0.76	0.90
Eurya sandwicensis	0.16	BOTH	0.84	0.87
Platydesma spathulata	0.15	BOTH	0.73	0.84

APPENDIX 10. CHARACTERISTICS ASSOCIATED WITH DIFFERENCES IN VULNERABILITY SCORES AMONG SPECIES

Letters above the graphs indicate grouping by pair-wise statistical significance. Groups that share the same letter are not significantly different.

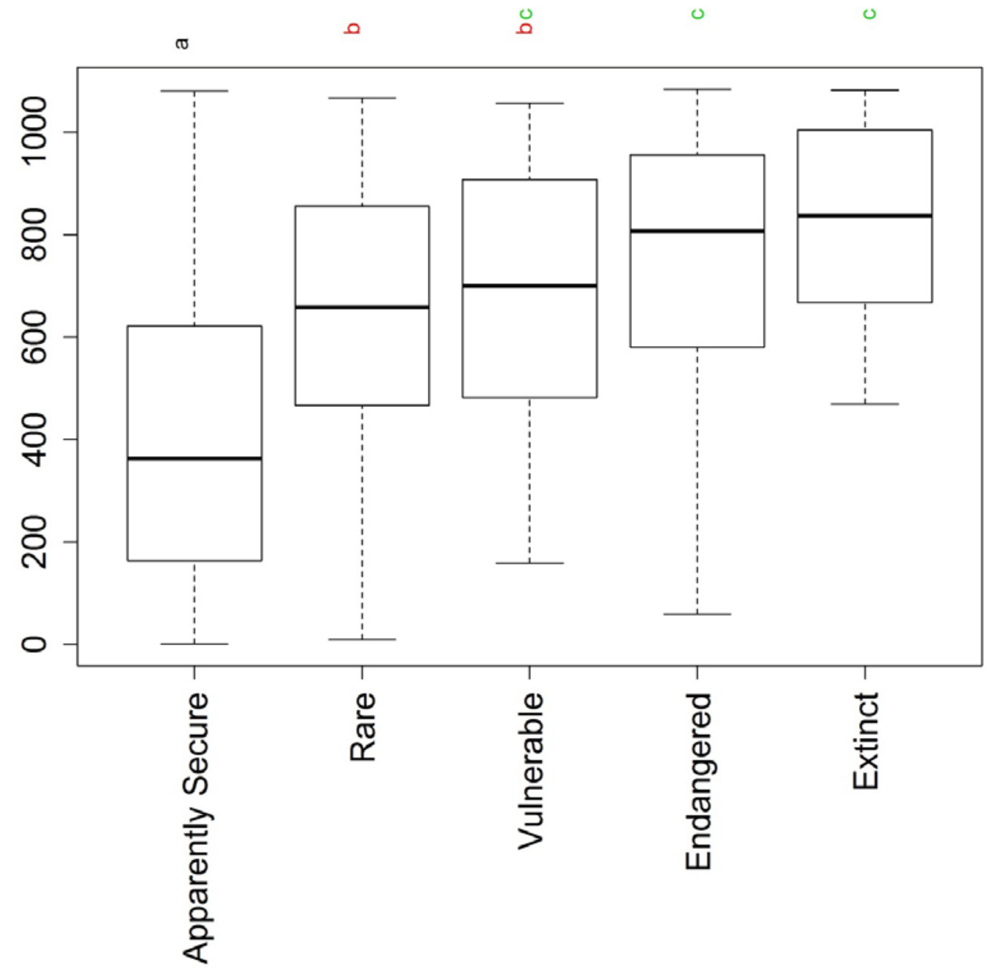
a) Differences in vulnerability between endemic and indigenous species



	Mean	Count	Standard deviation	Median
Endemic	0.409055	949	0.11054	0.423409
Indigenous	0.350166	137	0.117175	0.321159

F value	Pr(>F)
34.33791	6.14E-09

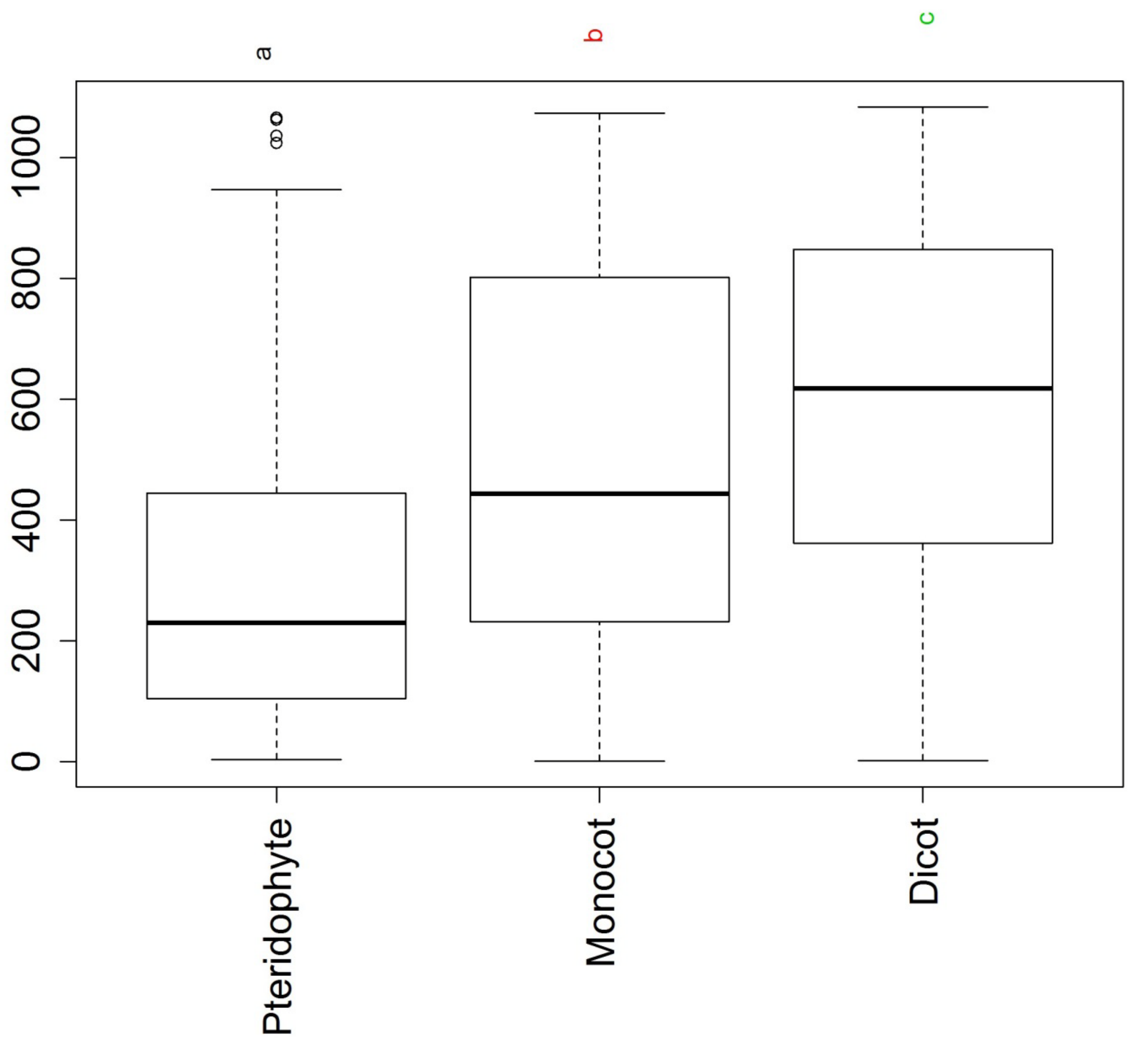
b) Differences in vulnerability among species under different conservation status



	Mean	Count	Standard deviation	Median
Extinct	0.502659	33	0.088905	0.502215
Endangered	0.475776	261	0.090884	0.489565
Vulnerable	0.449942	52	0.084314	0.450778
Rare	0.429616	133	0.094279	0.439795
Apparently Secure	0.353795	605	0.103927	0.348425

F value	Pr(>F)
87.785	1.30E-64

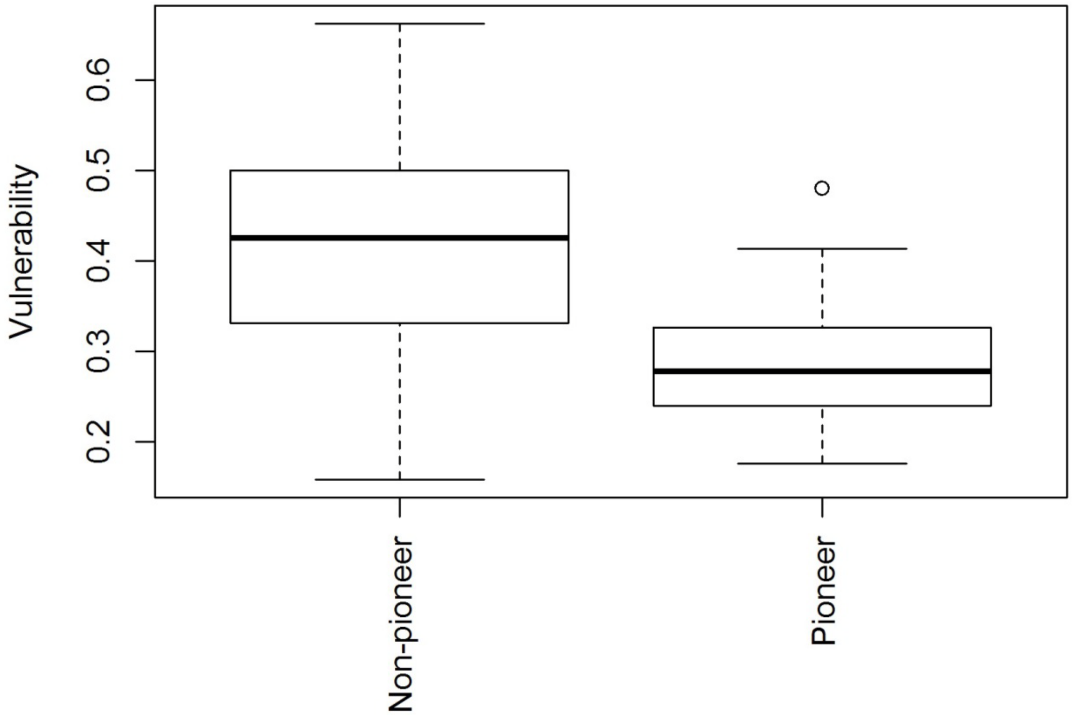
c) Differences in vulnerability among major plant groups



	Mean	Count	Standard deviation	Median
Dicot	0.421319	800	0.10682	0.431551
Monocot	0.386137	129	0.116981	0.381736
Pteridophyte	0.314161	157	0.096555	0.286862

F value	Pr(>F)
65.94351	9.50E-28

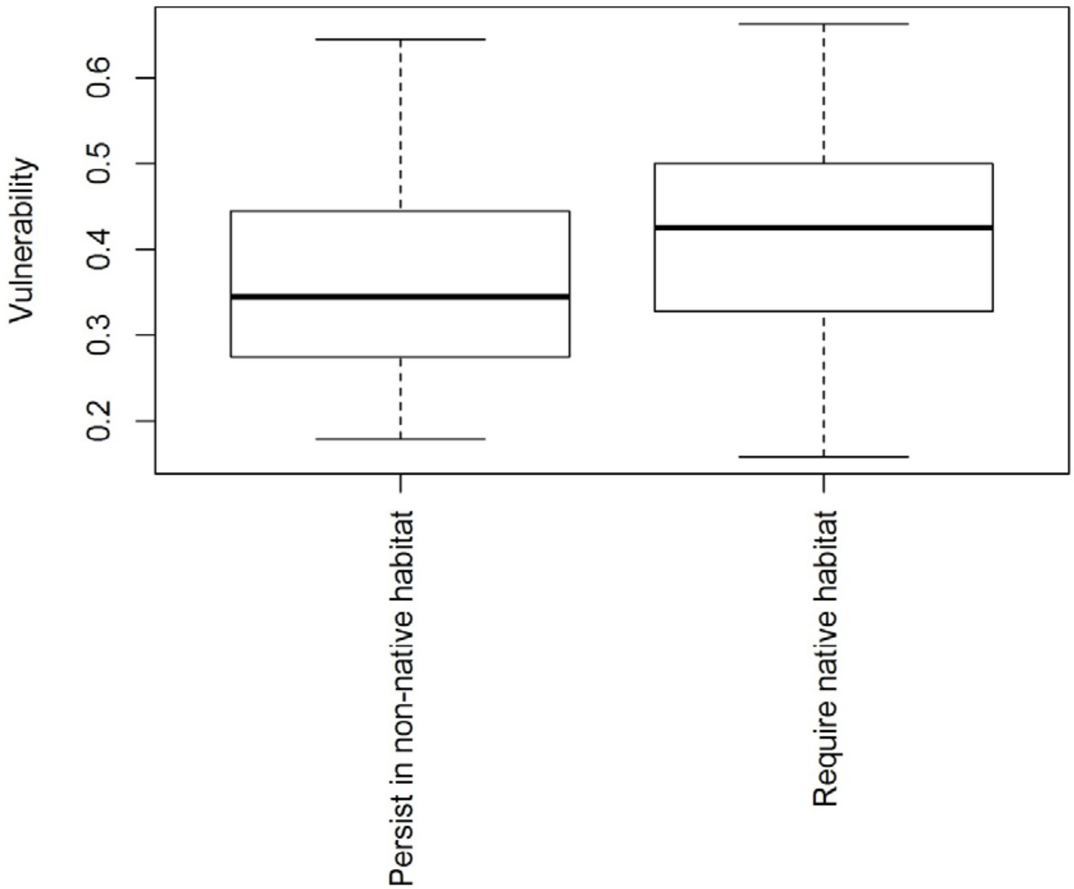
d) Differences in vulnerability between pioneer and non-pioneer species



	Mean	Count	Standard deviation	Median
Non-pioneer	0.414386	989	0.109465	0.425408
Pioneer	0.285629	97	0.057392	0.277669

F value	Pr(>F)
129.7934	1.77E-28

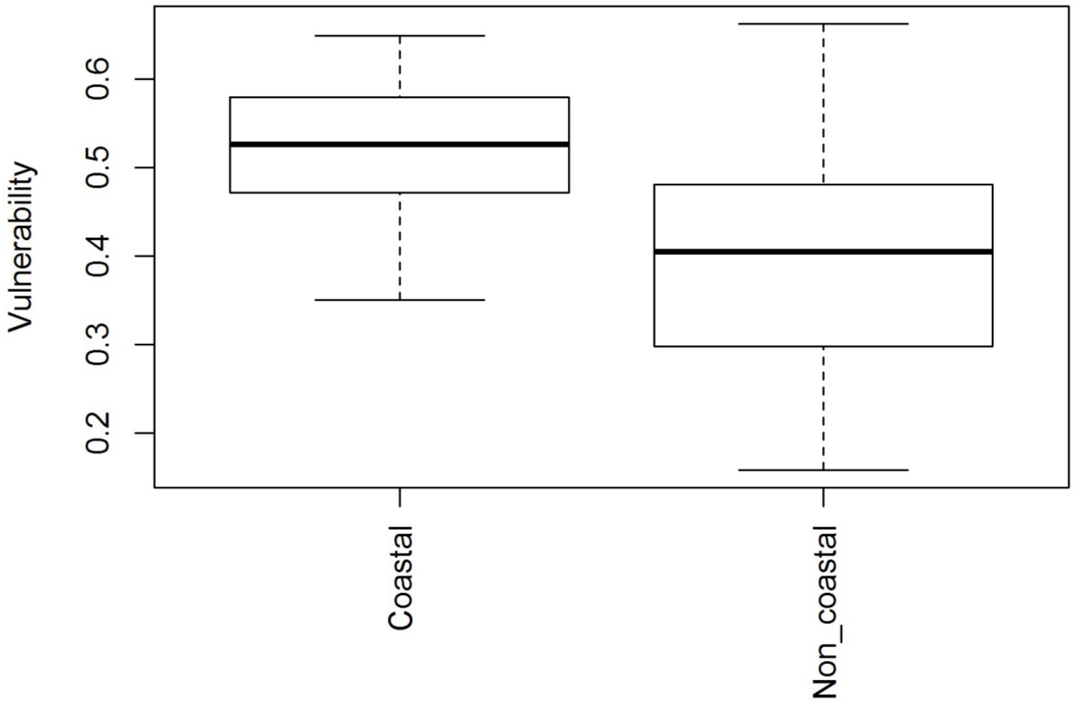
e) Differences in vulnerability between species that require native habitat or persist in non-native habitat



	Mean	Count	Standard deviation	Median
Require native habitat	0.413922	856	0.109914	0.425523
Persist in non-native habitat	0.36158	230	0.110483	0.344281

F value	Pr(>F)
41.34489	1.91E-10

f) Differences in vulnerability between coastal and non-coastal species



	Mean	Count	Standard deviation	Median
Coastal	0.514586	61	0.075076	0.52608
Non_coastal	0.394876	1025	0.11138	0.405275

F value	Pr(>F)
67.29158	6.59E-16